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# Summary of Trenchless Technology for Use With USDA Forest Service Culverts





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## Table of Contents

INTRODUCTION .....	1
TRENCHLESS TECHNOLOGY VERSUS OPEN-CUT EXCAVATION.....	1
PIPE INSPECTION.....	2
Cleaning.....	2
Inspection of Pipe Interior .....	2
Inspection-Void Assessment.....	3
PIPE MAINTENANCE .....	3
Spot repair .....	3
Grouting .....	3
PIPE REHABILITATION.....	4
Sliplining .....	4
Spiral-wound Pipe.....	5
Cured-in Place Pipe (CIPP) .....	6
Fold-and-Form Pipe.....	6
Spray-On-lining .....	7
Swagelining and Roll-down.....	7
PIPE REPLACEMENT.....	7
Pipe Bursting .....	7
Pipe Splitting.....	9
NEW PIPE CONSTRUCTIONS.....	9
Pipe Ramming .....	10
Horizontal-Auger Boring .....	11
Pipe Jacking .....	12
Horizontal-Directional Drilling .....	12
Microtunneling and Conventional Tunneling.....	12
CONCLUSIONS .....	13
APPENDIX A.....	15





## INTRODUCTION

Trenchless technology consists of the methods, materials, and equipment used for replacing, rehabilitating, or installing pipes with little or no excavation of the ground above. Closely associated with this technology are various techniques for investigating, locating, inspecting, and assessing conduits and the surrounding earth materials.

This report, which summarizes the trenchless technologies most appropriate for U.S. Department of Agriculture (USDA) Forest Service roadway culvert applications, can help USDA Forest Service engineers best determine where and when to use this rapidly evolving technology. Techniques for replacing or rehabilitating corrugated metal pipe (CMP) culverts, 18 inches or greater in diameter, are emphasized because they are commonly used for USDA Forest Service culverts. The discussion of trenchless technology that benefits other, smaller nonculvert pipes, such as small utility lines, is incidental to this report.

Trenchless technology can enhance forest roadway culvert applications by minimizing excavation and may be less costly than conventional open-cut excavation. The demand for rehabilitating or replacing these culverts is driven by the following factors:

- Many thousands of culverts installed in the 1950s and 1960s on USDA Forest Service lands are now reaching or exceeding their functional lives. Many culverts are deteriorating because of corrosion, scour, erosion, separation, or other damage.
- Some culverts lack sufficient hydraulic capacity to handle large storm events as mandated in new standards.
- Traffic disruption or restriction is more difficult or undesirable because of the increased public use of national forest lands for recreation and other purposes.
- Escalating environmental constraints require shorter construction timeframes and minimal disturbance to soil and streams.
- Culverts now must have larger conduits to enhance the passage of aquatic organisms, other animals, and large woody debris.

## TRENCHLESS TECHNOLOGY VERSUS OPEN-CUT EXCAVATION

Engineers need to assess the advantages and disadvantages of trenchless versus open-cut methods when planning culvert rehabilitation or replacement. Trenchless technology has the following advantages:

- **Cost:** Substantial cost savings are possible. However, even when trenchless methods are more expensive, such technology may be the best alternative because of other considerations discussed below.
- **Environmental effects:** Less soil is disturbed so impacts on adjacent organisms and water bodies can be reduced significantly.
- **Disruption:** Traffic delays are reduced or eliminated, as is heavy truck traffic associated with culvert excavation deep below the roadway.
- **Speed of installation:** Construction often takes less time, regardless of the road fill depth.
- **Safety:** Many safety concerns associated with steep-excitation slopes, work inside trench boxes, and worker exposure to traffic may be eliminated or reduced.
- **Less engineering:** Less surveying, fewer design calculations, and fewer drawings and specifications may be required.
- **Fewer unknowns:** Minimal ground disturbance results in fewer contingencies associated with subsurface conditions with pipe lining options.

Trenchless technology has the following disadvantages:

- **Cost:** Where placement is shallow and traffic is not a major constraint, excavation is usually more cost effective.
- **Level of engineering difficulty:** Specialized expertise in related technologies and the impact on subsurface site conditions is required.
- **Decreased flow capacity:** Practices such as lining pipes with thick structural sections reduce pipe openings, decreasing the pipe's flow capacity.
- **Grade or alignment corrections:** Effecting necessary changes to the existing grade and alignment are not always possible.



- Shorter design life: Rehabilitation techniques such as spot repair or grouting have a shorter design life than new pipe installation.
- Susceptible to fire damage: Forest engineers found that culverts lined with plastic or replaced with corrugated polyethylene pipe were damaged severely when subjected to wildfires. Fire caused the plastic to burn or melt from one-half to the complete culvert length. Engineers should be aware of this potential for fire damage.

#### **A Special Note about Costs**

Costs provided are installation estimates based on municipal applications. Do not use these costs for comparison without considering site circumstances and characteristics. For example, the values may not include the high costs of transporting workers and equipment to distant locations or of undertaking new construction to overcome access difficulties at culvert ends. Moreover, costs can vary significantly because of market conditions, contractor availability, or economy of scale.

### **PIPE INSPECTION**

Before deciding on rehabilitation and replacement options, evaluate the condition of the existing culvert and the cause of the failure. Choosing the method that best meets the objectives requires understanding the exact nature and cause of distress to the pipe.

#### **Cleaning**

Workers should clean the culvert before inspection occurs. Appropriate cleaning procedures include excavating soil and debris jams by hand or with a backhoe or by water jetting and probing. The crew can use pigging (pushing or pulling a cylindrical tool to dislodge material inside). Specialized machines operate with a collapsible bucket and a back-and-forth action to dislodge the material inside. A hydrovac (a powerful vacuum machine having hose reels with high-pressure nozzles) may be used if common cleaning methods cause unacceptable sediment pollution.

#### **Inspection of Pipe Interior**

Culvert inspection is most effective during the lowest streamflow. Use the following equipment:

- Field book and digital camera (to document the inspection).
- Rock hammer or similar probing tool (to test the culvert material integrity).
- Powerful lamp, 1 million candlepower or more (having a light at the opposite end of the culvert is helpful to determine pipe deformation).

- Binoculars (to view the culvert's interior when entry is unsafe or impossible).
- Metal rods of various lengths (to probe through culvert walls and holes to determine the culvert-wall thickness and the size of any voids around the culvert).

When the culvert diameter is too small for safe entry, visually inspect the pipe's interior from both ends using a powerful light. If the pipe is safe and at least 36 inches in diameter, inspect the entire length by crawling through the pipe. (Update your job hazard analysis form to include this type of work.) Evaluate the safety issues for each site and follow the requirements for confined-space entry.

Use a closed-circuit television (CCTV) camera mounted on a small tractor to view the pipe's interior condition where manual methods are unacceptable. CCTV-camera inspections are common for sewers and water lines and cost about \$150 to \$170 per hour, including travel time.

When pipe corrosion is significant, evaluate the surrounding soils and/or water for potential corrosion of the pipe replacement or repair material. Factor in corrosion rates, particularly in areas where the soils are chemically aggressive to metal or where the water contains corrosive chemicals (for example, acidic drainage from mines).



Figure 1—Inspection. Unreinforced concrete pipe (circa 1930) filled with soil and rock fragments shows cracked and broken barrels and separated joints. This pipe is plugged, and the stream has formed a pond upstream of the embankment, causing dangerous settlement, erosion, and sinkholes. Careful inspection of the pipe's interior revealed the cause of the problem. (USDA Forest Service photo.)



## Inspection-Void Assessment

When voids are noted or suspected (such as, where the ground has subsided above the pipe) around the exterior of a buried pipe, or when infiltration is observed inside the pipe, carefully determine the size and extent of the voids and their potential danger to public safety. Useful manual techniques include the following:

- Probing with steel rods from within the culvert, when safe to do so.
- Drive-probing with steel rods powered by a hammer from the surface.
- Augering from the ground surface, either by hand or by power.
- Employing test pits (potholing) from the ground surface, if the pipe is not too deep.

When one cannot directly assess the pipe exterior, consider remote methods:

- Use ground-penetrating radar and thermography to determine the shape and extent of void(s) that may exist around the pipe.
- Use sonar for flooded pipes.

## PIPE MAINTENANCE

Spot repair and grouting to fix defective pipes have many applications and are particularly cost-effective in treating small pipe segments. Spot repair and grouting may be necessary before using rehabilitation techniques such as pipe lining.

### Spot Repair

Spot repair pipes for limited distressed areas, ensuring that both the defect and the cause are fixed. Making a small repair may be the simplest, most cost-effective way to handle pipe defects and degradation.

Spot repair techniques include the following:

- Use bladders or the inversion method (see page 6, cured-in-place pipe) to place relatively short cured-in-place (CIPP) sleeves. Ensure that the host pipe is in good condition. (This technique may fail where joints have separated and adjacent pipe sections are offset.) These cases may require bypass pumping. Sleeve installation costs \$2,000 to \$5,000 for each 18-inch-diameter pipe repair.

- Use specialized joint packers equipped with grout injection lines to pump grout under pressure to fill voids and seal joints. These packers may allow stream flow through the device during repair. The cost of grouting with packers varies widely, so assess each site individually.
- Grout by hand, possibly with force account crews. Although this method is relatively simple, confined space, toxicity, and flow bypass must be considered. Assess costs separately for each site.
- When the pipe is large enough for entry, mechanical seals suitable for CMP are available. Use of mechanical seals may require void remediation through grouting. Mechanical seals may work poorly with helical pipes or small-diameter CMP. Assess costs separately for each site.

### Grouting

Grouting is used to seal open joints, fill voids around pipes, and stabilize the surrounding ground. Several types of grout (for example, cementitious, urethane, and acrylamide) can be designed to meet installation and performance criteria. The complexity and cost of grouting vary greatly, depending on the type of grout and equipment needed. Jobs can range from simple hand placement of grout in joints to a complex process involving specialized experience, equipment, and procedures.

Factors in selecting the type of grout include:

- Viscosity and penetration (consistency varying from water to paste).
- Time-set control.
- Environmental factors (for example, soil type or chemistry, temperature, soil moisture, and ground water).
- Additives for changing consistency, gel time, or strength.
- Toxicity of the grouting materials and its potential effects on surrounding plant and animal life.

When workers can enter pipes safely, they can pump low-density cementitious grout into voids with relative ease. To fill voids around the pipe's exterior, inject grout either from within the pipe or from the ground surface. When using packers on small-diameter pipes, use a low-shear resin gel grout or other suitable chemical grout.



Workers can use either cementitious grout or resins in spot repairs. Sometimes multiple grouts work well together to meet variable site conditions or lower project costs.

Although grout is commonly used in sliplining (to fill the annular space between the old and new pipes), ensure that the external grout pressure does not collapse the new lining. For this application use cellular low-density cement grout under low pressure.

Grouting costs vary from \$10 per linear foot for small annular spaces to several hundred dollars per linear foot for large annular spaces (\$100 to \$150 per cubic yard of grout).

## PIPE REHABILITATION

Pipe rehabilitation refers to renewing a culvert's interior. An existing pipe may have leaks, corrosion, minor damage, or misalignment due to differential settlement at a broken joint. Engineers may need to include earth pressures in the design to ensure that culverts retain structural competency. Pipe rehabilitation methods with potential USDA Forest Service culvert applications include sliplining, spiral wound, cured-in-place-pipe, fold and form, spray-on-lining, and swagelining and rolldown.

### Flow capacity vs. friction

Lining a rough pipe with a smooth material decreases friction within the pipe, but when an inlet control hydraulic condition exists it does not increase the flow capacity of the pipe. The condition where reduced friction increases flow is common in sewers and water distribution lines, but is encountered only occasionally with the USDA Forest Service culverts.

## Sliplining

Description: For sliplining, workers push and/or pull new pipe into the existing pipe and grout the annular space. The new pipe may be either a fusion-welded high density polyethylene (HDPE) plastic continuous pipe or segmental pipe (a string of discrete pipe barrels connected by threaded, snap-together, welded, or similar joints).

**Size/Length:** Use sliplining on culverts up to 63 inches in diameter for continuous pipe and 158 inches in diameter for segmental pipe. The allowable maximum length of either type far exceeds that of a typical culvert. Distortions in the existing pipe (caused by differential settlement at joints, pipe ovality, or cracked or crushed pipe barrels) may limit the sleeve diameter.

**Access:** Logistics and terrain determine excavation requirements for pipe access. Shorter discrete pipes may solve space limitations. Sometimes workers can place pipes without diverting streamflow.

**Cost:** Costs vary from \$50 per linear foot for 18-inch-diameter pipe to \$400 to \$500 per linear foot for 60-inch-diameter pipe. As culverts over 60 inches in diameter can vary substantially in cost, estimate costs according to local conditions.

**USDA Forest Service opportunities:** Relatively straight pipes that can accommodate a small-to-moderate decrease in diameter may be good candidates for sliplining. Pipes may be corroded, deformed, badly damaged, or near collapse, but greater distortions may require smaller-diameter liners. The old pipe must have sufficient clearance to pull a new pipe through the opening and allow proper grouting. For some culverts with segmental pipe, a force account crew can perform the simple technique.



Figure 2—A fusion-welded HDPE pipe is ready to pull into an existing pipe. The leading end of the pipe has been cut with a chain saw and drilled for attaching a cable that pulls the new pipe into place with a backhoe.

(Photo used with permission of Oregon DOT.)



Figure 3—New HDPE pipe that has been pulled inside the old pipe with a badly corroded invert. The end will be trimmed, grout tubes placed, and the annular space between the old and new pipes filled with low-density cellular grout. Although the grout is not structural, it fills the voids in the embankment around the old pipe and seals off waterflow to stem further soil erosion around the pipe.  
(Photo used with permission of Clackamas County, OR.)

### Spiral-wound Pipe

**Description:** Spiral-wound pipe lining of an existing pipe with a profiled strip, spirally wound to form a continuous pipe after installation. After installing the strip, workers fill the annulus (ring) with high-strength flowable grout. One size strip can line many sizes of culverts.

**Size/Length:** The size can be 8 to 120 inches in diameter, with an unlimited length.

**Access:** Depending on the manufacturer, workers may not have to enter the pipe to place the strips. The need for stream bypass depends on flow.

**Cost:** Costs vary from \$100 per linear foot for 18-inch-diameter pipe (remote methods) to \$750 per linear foot for hand-placed large diameters.

**USDA Forest Service opportunities:** Properly grouted spiral-wound pipe provides structural rehabilitation of pipes that do not need upsizing.



Figure 4—A nearly finished spiral-wound lining of an old corrugated metal pipe. This project involved two pipes, one 84 inches in diameter and one 72 inches in diameter, about 4 miles upstream. Danby spiral-wound stripping was hand-placed 1.5 inches deep (1 inch for the smaller pipe). The worker is packing the ends of the annular space between the old pipe and the lining, forming a dam for the high strength (10,000- to 15,000-pounds-per-square-inch) structural grout that the contractor will pump through the small tubes to fill the annular space behind the lining. After grouting, the worker uses a hammer to test for voids in the annular space and repaired deficiencies. A welded-wire truss holds the lining the specified distance from the old pipe. When the work is complete, the composite materials form a structural solution for the corroded and failing pipes. Steel weirs were installed later to provide fish passage. The cost was \$125,000 for 220 feet of pipe. (Photo used with permission of Oregon DOT.)



### **Cured-in-Place Pipe (CIPP)**

**Description:** Cured-in-place pipe involves installing a tight-fitting sleeve inside an existing pipe. Workers invert or drag a watertight needle-punched felt-fabric tube saturated with catalyzed polyester, vinylester, or epoxy resin into the pipe. With the inversion method, workers affix one end of the fabric tube on the end of the culvert, while water pressure is used to invert the tube, thereby inserting the tube into the culvert and pressing it against the inside. Curing takes place by heating and recirculating the water. The pipe also can be cured with ultraviolet light, air, or steam. CIPP liners can be structural or nonstructural, depending on the thickness of the liner.

**Size/Length:** CIPP liners can be up to 108 inches in diameter for the inverted-in-place method described above with a maximum length that far exceeds the length of a typical culvert. Liner wall thickness can be up to 2 inches and may be a structural solution. However, choosing a wall thickness may need special design and installation expertise, particularly with thicker linings.

**Access:** Entry is through the ends of the existing pipe or from a manhole. A stream bypass may be necessary.

**Cost:** Costs range from \$100 per linear foot (perhaps less for large quantities) for 18-inch diameter pipe to \$800 or more per linear foot for large-diameter pipe.

**USDA Forest Service opportunities:** CIPP can provide structural (or nonstructural) rehabilitation of existing pipes that can accommodate a small-to-moderate decrease in diameter. The styrene monomer-based resins (polyester and vinylester) in the liner are potentially toxic before they are cured. Nontoxic epoxy resins may better suit sensitive environments.

### **Fold-and-Form Pipe**

**Description:** Fold-and-form technology uses HDPE or polyvinyl chloride (PVC) plastic pipe materials with properties that allow pipe deformation. The pipe lining is folded into a C-, U-, or H-shape that reduces its cross sectional area before insertion into the existing pipe. The liner reverts to its original round shape when subjected to pressure and/or heat. The annular space between the old pipe and the liner may require grouting, unless the old pipe and the new pipe fit closely together. The method may be structural or nonstructural, depending on the flexural modulus (stiffness) of the material after curing and the structural-dimension ratio of the pipe.

**Size/Length:** With PVC, the fold-and-form method typically is limited to 24-inch-diameter pipe. Use HDPE with folded pipe technology up to 36 inches in diameter. Length can easily exceed that of a typical culvert.

**Access requirements:** You may need stream bypass.

**Cost:** Costs range from \$100 to \$300 per linear foot.

**USDA Forest Service opportunities:** This method may be useful when hydraulic conditions allow a small decrease in the size of the pipe's upstream opening. Pipes with an abrupt bend, such as those with differential settlement problems, may restrict use. Grouting of the annular space may or may not be necessary, depending on how close the liner fits the old pipe.

Figures 5 through 8. Fold-and-form lining. This photo sequence shows a U-liner rehabilitation of 18-inch-diameter CMP. (Photos used with permission of Rinker Pipeline Systems.)



Figure 5—An 18-inch folded U-liner being pulled into place through a drop inlet from the coil trailer.



Figure 6—The U-liner after it has been pulled into place and cut off the coil. Although this is not a typical culvert inlet condition, this photo illustrates that a folded HDPE pipe can bend through a tight corner.



Figure 7—After heating the end of the pipe, the contractor puts a plug in place that restrains the pipe to handle the processing pressure. The contractor then sandwiches off the liner on the other end and adds steam generated by a boiler truck.



Figure 8—A completed installation, showing a new HDPE liner (U-liner) within the old CMP. The tight fit makes grouting unnecessary.

### Spray-On-Lining

Description: Workers pull a machine through a culvert at a constant rate, spraying a lining material radially onto the interior wall. Cement mortar and resinous materials such as epoxy are common lining materials. Culverts that are 36 inches and larger can accommodate a reinforced cement mortar lining with welded-wire mesh. The method results in lining thickness of 1/4 to 2 inches for epoxy or resinous linings and 2 to 4 inches for mortar linings.

Size/Length: Maximum diameter and length exceed that of a typical culvert.

Access: Spray-on-lining requires only small amounts of additional space at each end of the pipe. At the launch end, there must be enough space to set up the equipment. At the exit end, either a winch setup or a block is required to change the direction of the pulling cable leading to the winch. A backhoe or excavator can support the block temporarily. Normally, streamflow will need to be diverted through the culvert.

Cost: Spray-on-lining costs depend on the lining material, structural reinforcement required, the site location and access, and the availability of specialty contractors. Spray-on-mortar lining varies from \$100 to \$150 per linear foot for 24-inch-diameter pipe to \$250 to \$350 per linear foot for 60-inch-diameter pipe. Resinous linings are more expensive.

USDA Forest Service opportunities: Spray-on-lining provides a structural (or nonstructural) rehabilitation of pipes that can accommodate a small-to-moderate reduction in diameter.

### Swagelining and Rolldown

Description: These methods use HDPE- or PVC-plastic pipe with properties that allow pipe deformation. Consider swagelining with close-fit pipes where the user temporarily reduces the diameter by pulling the pipe string through one or more dies, which may be heated. For the rolldown technique, similar to swagelining, the user temporarily reduces pipe diameter by mechanical rolling. Both variations may require grouting of the annular space between the old pipe and the liner, unless the old pipe and the new pipe fit snugly. Both methods may be structural or nonstructural, depending on the flexural modulus of the material and the structural dimension ratio of the pipe.

Size/Length: Swagelining and rolldown currently is limited to 48-inch-diameter pipe.

Access requirements: Stream bypass may be necessary.



Cost: No cost information is available for the swagelining or rolldown methods in sizes that would be useful in USDA Forest Service culvert applications.

USDA Forest Service opportunities: These two methods may work well where hydraulic conditions allow a small decrease in the size of the pipe's upstream opening. Pipes with an abrupt bend, such as with differential settlement problems, may not be suitable for swagelining and rolldown methods. The added expense and lack of availability for the swagelining and rolldown methods may not overcome the slight sizing advantage over sliplining or fold-and-form pipes.

## PIPE REPLACEMENT

Pipe bursting and pipe splitting are trenchless methods used to replace a culvert at its exact location and alignment. In both cases, the contractor uses tools to break or cut the old pipe and force the fragments out into the surrounding soils. Simultaneously, the tools draw the new pipe into the resulting void. A larger new pipe is possible with these methods.

### Pipe Bursting

Description: Pipe bursting is used to break brittle pipe, such as concrete, through a mechanically-applied force from within the pipe. This process forces pipe fragments outward into the surrounding ground while simultaneously drawing in a new pipe, of the same or larger diameter, behind the bursting tool. The force may be a steady, statically applied pushing or pulling force.

In one variation, a wedge-shaped pneumatic impact tool may power the pipe-bursting device and convert the pipe's forward thrust into a radial bursting force. In a second variation, a hydraulic device is inserted into the front end of the new pipe and expanded to produce the radial force. A third variation employs a horizontal directional drill with a rotating bursting or grinding head to disintegrate the old pipe casing and to draw in the new pipe.

Pipe bursting commonly is used for replacing water lines and gravity sewers where the pipe materials (for example, reinforced concrete, cast iron, vitrified clay, or wood stave pipes) can shatter or stretch, and historically has been limited to those materials.

Size/Length: Bursting of pipes up to 24 inches in diameter is common in sewer rehabilitation. Large-diameter bursting tools up to 48 inches in diameter are available. Upsizing pipes to 30 percent is common, and larger upsizing is possible, with the current upper limit being 100 percent (uncommon). Pipe-bursting project lengths range to about 500 feet.

Access: An access pit may be needed, depending on the site geometry and what methods the contractor uses to power the operation. A stream bypass may be necessary.

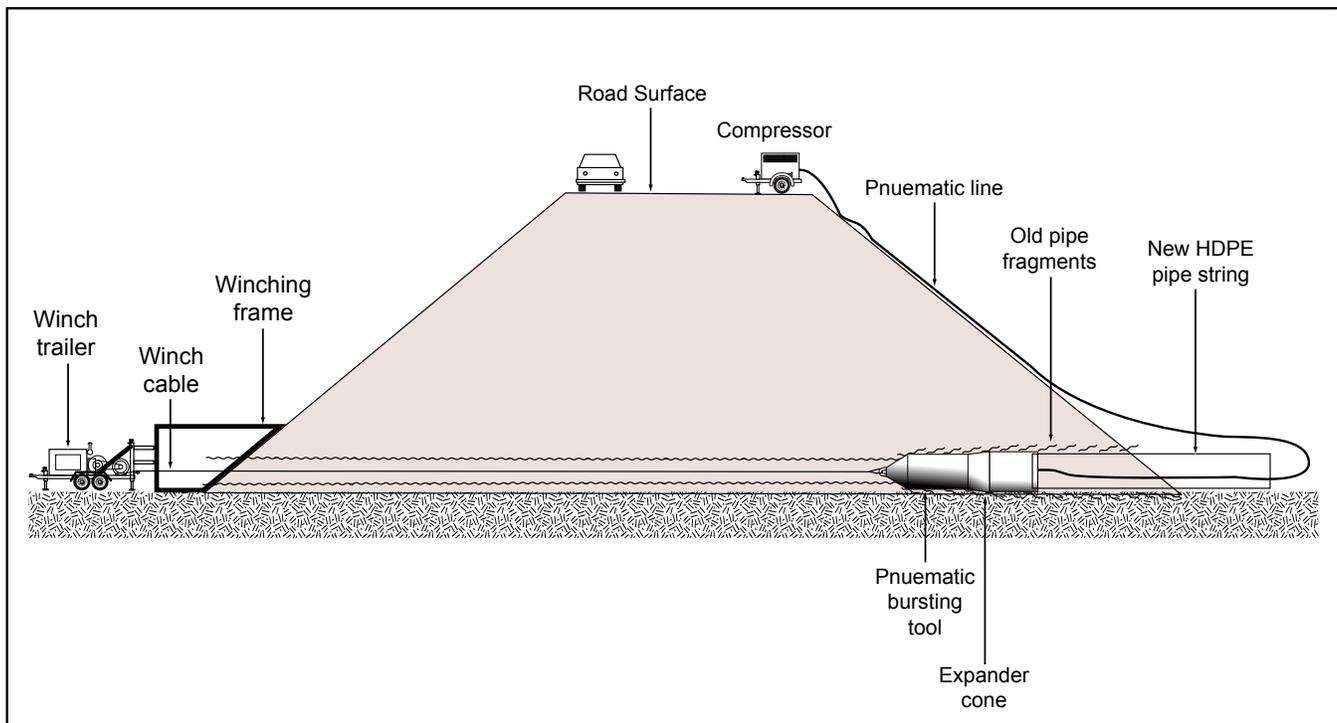


Figure 9—Typical pipe bursting.



**Cost:** Costs vary from \$100 to \$200 per linear foot for 18-inch-diameter pipes and \$850 per linear foot for the 48-inch-diameter pipes. Cost per foot is greatly influenced by the total footage installed.

**USDA Forest Service opportunities:** The pipe-bursting technique is suitable for pipes of most materials except for the corrugated metal traditionally used in most USDA Forest Service culverts. Attempts to pull, push, or pound the typical conical-shaped pipe-bursting tool through a CMP causes the corrugations to bend; the pipe to buckle, bunch up, and the tool to jam in the hole. New pipe-bursting technology may overcome this difficulty. Pipe splitting allows the user to advance the bursting tool by first splitting open the pipe.



Figure 10—This pneumatic pipe-bursting tool (painted red) is welded to the leading edge of the expander cone, which has four fixed knives. The trailing HDPE-pipe string has been fusion-welded to form the entire length required and attached with bolts to the bursting cone. A cable is attached to the forward tip of the bursting tool, and the assembly is hammered through the old brittle pipe with the constant force of a winch on the receiving end of the embankment. (Photo used with permission of TT Technologies, Inc.)

### Pipe Splitting

**Description:** Pipe splitting is a variation of pipe bursting that involves breaking an existing CMP (or solid-wall steel, ductile iron, or cast iron pipe) by longitudinal splitting. Workers force the old pipe into the surrounding ground while drawing in a new pipe of the same or larger diameter. The cutting device may consist of fixed blades or a “schnoz” welded on the bursting cone, the hydraulically expanding blades of the “Epandit” system, or the rolling cutting wheels of the “Grundoburst” system.

**Size/Length:** Up to 14-inch-diameter pipe is becoming common in water line applications. You also can use up to a 48-inch-diameter pipe, in excess of 500-feet long with a higher degree of difficulty.

**Access:** See pipe bursting.

**Cost:** Comparable to pipe bursting, but probably more expensive, given the higher risk associated with this rapidly developing technology.

**USDA Forest Service opportunities:** This technology has potential for increased use and may solve the problem of conventional pipe bursting in CMP. However, this method may collapse an existing CMP, posing a risk of jamming the tool in the hole. Currently, the method has limited use. Engineers can expect improvements.



Figure 11—“Grundoburst” pipe-splitting tools with rolling cutters. This tool is winched ahead of an expander cone with a constant-force winch system. This pipe-splitting approach is promising for USDA Forest Service applications but needs further development.

(Photo used with permission of TT Technologies, Inc.)

### NEW PIPE CONSTRUCTION

If a new pipe is required away from an existing culvert, the contractor can install a steel conduit through an existing fill. Pipe ramming is the most promising trenchless method for USDA Forest Service applications. Other potentially useful trenchless methods are horizontal auger boring and horizontal directional drilling. Microtunneling and conventional tunneling methods are mentioned briefly, but currently lack feasible applications to culverts.

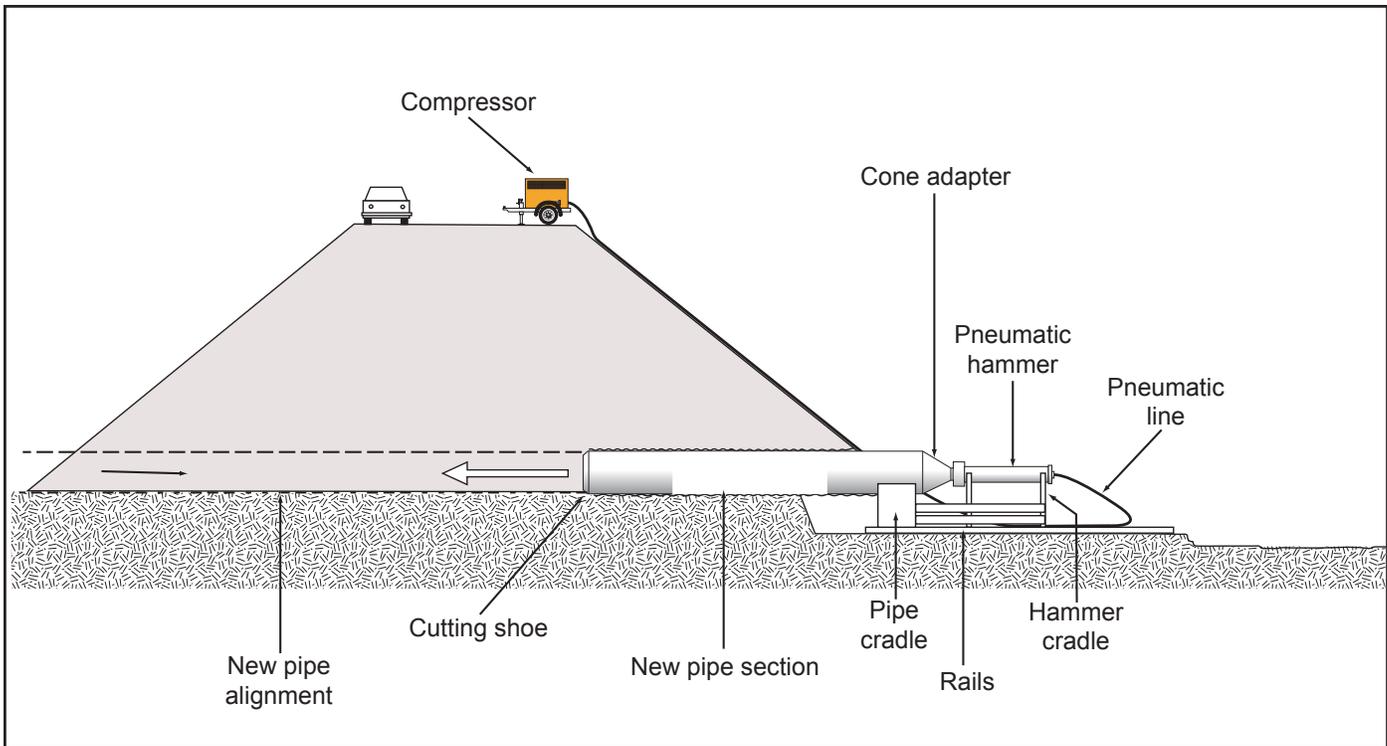


Figure 12—Typical pipe ramming.

### Pipe Ramming

**Description:** Pipe ramming is a nonsteerable method of installing a culvert by driving an open-ended steel casing with a percussive hammer from a drive pit. The contractor may use auguring, jetting, or compressed air to remove soil, or small machines such as a Bobcat in large-diameter pipe. Although similar to a steel-pipe piledriver, pipe ramming works horizontally. The hammer can be a piledriver modified for horizontal use. Pipe ramming is a relatively new to the United States, but rapid advances in this technology are expected.

**Size/Length:** Ramming steel pipe to 144 inches in diameter has been successful for lengths up to a 285 feet. Smaller-diameter pipe has been rammed up to 350 feet in length.

**Access:** An access area at the invert elevation is necessary to accommodate the hammer and length of each pipe segment. This may require excavating a pit. Additional room may be needed for a backstop and jacking frame, particularly with large-diameter pipe. The minimum dimension longitudinal to the pipe varies from 30 to 70 feet. A stream bypass may be necessary.

**Cost:** The cost can be as low as \$260 per linear foot for 24-inch-diameter pipe to \$6,000 per linear foot for the largest pipe.

USDA Forest Service opportunities: Ramming of pipes can provide solutions for the following USDA Forest Service applications:

- Large-diameter pipes rammed around or beside existing pipes to increase flow capacity.
- Additional pipes for use as overflow when pipe capacity is exceeded or animal passage is necessary.
- Partially buried pipes for fish passage. (Smooth-walled steel pipes tend to cause high-water velocities and may require special adaptations to accommodate aquatic organisms, such as structures to retain streambed materials in the pipe.)

The contractor may ram a thick-walled pipe through or around some obstructions; however, large boulders, large stumps, or trees may block this approach. Unforeseen subsurface conditions also can pose serious difficulties. Sometimes the contractor has difficulty achieving precise alignment. (See comparison with horizontal auger boring under “opportunities” below.)



Figure 13—Pipe ramming (large scale). This nitrogen-powered pipe-ramming hammer (white) is set on a cradle that slides on rails set for the desired alignment and grade. The hammer is welded to a steel plate (red), which distributes the dynamic force to a cast iron adapter cone (blue) that abuts the new steel pipe string; the block-and-tackle keeps the hammer assembly snug against the pipe during the driving operation. The operator rams a section of pipe, retracts the hammer, and sets the next section of pipe into place. The operator repeats this ramming sequence until the entire pipe is in place, then removes the soil from the pipe's interior. This project consisted of a 10-foot-diameter steel pipe (1.25-inch wall thickness), 200 feet in length, cost \$1 million. Costly complications can occur during a project of this magnitude. (USDA Forest Service photo.)



Figure 14—Pipe ramming (small scale). This pneumatic hammer is welded to the new 24-inch-diameter steel pipe. The entire assembly is suspended from the boom of a track-hoe, which adjusts the alignment and grade as the first section of pipe is driven. (This approach works when alignment and grade are not critical.) Then 70 feet of pipe were driven in two sections at a rate of about 2 inches per blow. Cutting, welding, and driving took about 4 hours. Soil in the pipe was removed with an auger boring machine (see next section), followed by final grading and seeding. Total construction time was 12 hours. The original estimate for

open-trench construction of this 15-foot-high embankment on a busy county road was \$43,000. Cost for the rammed pipe was \$18,000. (Photo used with permission of Clackamas County, OR.)

### Horizontal-Auger Boring

**Description:** During horizontal-auger boring a rotating cutting head forms a cylindrical bore hole, often from a drive pit. Helicallly-wound auger-flights, rotating in a steel casing, remove spoil back to the drive pit. As the auger drills through the soil, the machine pushes the casing ahead. The equipment may have limited steering capability.

**Size/length:** Up to 72-inch-diameter pipes with lengths up to several hundred feet.

**Access:** An access pit for the boring machine and pipe string are necessary, similar to the pipe-ramming application. A backstop is required to provide the reaction force to advance the pipe.

**Cost:** About \$200 per linear foot for a pipe 18 inches in diameter to \$1,000 per linear foot for a pipe 60 inches in diameter.

**USDA Forest Service opportunities:** Auger boring may have higher risks than pipe ramming. An auger's greater sensitivity to boulders and other large obstructions may cause larger deviations from the desired alignment than rammed pipe. Also, an auger may not be able to extract rocks larger than about 40 percent of the auger diameter, whereas a rammed pipe has greater ability to drive through or "swallow" a boulder. Auger boring also involves greater risks, because the auger creates an unsupported open face, particularly when groundwater, weak soil layers, or cohesionless soil is present. An auger sometimes can remove soil with no forward advancement, thereby forming a void or resulting in caving to the surface. Auger boring may be the best option when the soil is cohesive (for example, high clay content) and has few obstructions such as boulders.



Figure 15—Horizontal auger boring. A 24-inch-diameter 0.250-inch steel casing is placed with an auger-boring machine in uniform, drained, stiff clayey soil (a good subsurface condition for this method). Two hydraulic jacks (at the lower rear of the machine) apply forward pressure on the auger and pipe. The reaction force for the jacking system is at the back of the launching pit (not shown). Although the subcontractor was paid \$160 per linear foot for supplying and installing the casing, this price did not include access construction, excavation of the launching and exit pits, or other related costs. (USDA Forest Service photo.)

### Pipe Jacking

**Description:** The term pipe jacking is defined in the tunneling industry as installing pipes behind a shield tunneling machine, by jacking pipe sections from a drive shaft to form a continuous string in the ground. The principal of pipe jacking involves the use of a jacking system to push a pipe. This principal can apply to several techniques, including auger boring and pipe ramming.

**Size/length:** Refer to pipe ramming and horizontal-auger boring.

**Access:** Extra space for the access pit to accommodate the jacking frame and backstop may be required. A stream bypass may be necessary.

**USDA Forest Service opportunities:** The pipe-jacking method is an alternative to pipe ramming. However, the soil in the pipe is incrementally excavated near the forward end of the pipe, which increases the risk of excessive settlement and of a flowing soil condition that may increase contingency costs. The pipe-jacking method alone probably is not feasible for USDA Forest Service culvert applications. However, the principal of pipe jacking can be used in conjunction with pipe ramming and auger boring.

### Horizontal-Directional Drilling

**Description:** Horizontal-directional drilling (HDD) is a steerable method for the installation of pipe, conduit, and cable in a shallow arc, with a surface-launched drilling rig. Contractors drill a fluid-lubricated pilot bore and enlarge it with one or more back reamers to achieve the required pipe size. The positioning of a bent sub or the drill head bias provides the required deviation during the pilot bore.

**Size/length:** Up to 48-inch-diameter pipe (pulled or pushed into place with a back reamer). (However, the 48-inch drill weighs over 1-million pounds and requires several large trucks to deliver.)

**Access:** Space is required for the drilling machine at one end and for the product pipe string on the other.

**Cost:** About \$100 to \$300 per linear foot for 18-inch-diameter pipe and \$300 to \$900 per linear foot for 36-inch-diameter pipe. The higher end of these cost ranges will apply to USDA Forest Service applications, as the cost per foot depends on the total footage installed. This process is best suited for long installations (1 mile of pipe). USDA Forest Service culverts are relatively short in comparison.

**USDA Forest Service opportunities:** HDD could be an alternative to pipe ramming (such as for pipes longer than 300 linear feet). However, HDD may not be cost effective for placing culverts, except under extraordinary circumstances. Use of HDD machines for 18- to 24-inch-diameter pipe may be especially useful (in localized areas of the country where contractors are highly competitive). HDD could be used in conjunction with other methods.

### Microtunneling and Conventional Tunneling

**Microtunneling** is a precise, guided remote-controlled method of jacking pipe behind a microtunnel boring machine, where the earth is continuously supported at the face. This method is used to install pipes of all sizes, typically in long runs that far exceed the length of a typical USDA Forest Service culvert.

**Conventional tunnel construction** ranges from manual excavation to the use of self-propelled tunnel-boring machines. Manual access to the tunnel face is generally necessary. Where a lining is required, contractors frequently use bolted segmental rings (multiplates) to support the ground. A tunnel-boring machine is a machine that excavates a tunnel by drilling out the face to full size in one operation. Operators may control it from within the shield or by remote control.



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Because of high cost and complexity, USDA Forest Service engineers are unlikely to design microtunneling or conventional tunneling projects to replace culverts. Such techniques would be cost effective only in rare circumstances where the required length is great. These methods are mentioned as trenchless technologies, but are outside the scope and intent of this report.

## **CONCLUSIONS**

It is imperative the USDA Forest Service engineers evaluate all of the alternatives to service the many thousands of culverts reaching or exceeding their functional lives. This report has presented basic information on trenchless technology that provide viable alternatives to conventional open-cut excavation for USDA Forest Service applications. Currently, the technologies with most direct application to culverts are some of the various lining techniques such as sliplining for rehabilitation and pipe ramming for installing new pipes, as well as inspection, spot repair, and grouting techniques.

Effectively using trenchless technology demands specialized knowledge and experience. Because new variations to the trenchless technologies summarized in this report are being developed at a rapid rate, engineers will find it challenging to stay abreast of the latest information. The additional resources provided in the appendix provide a good starting point.





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# **APPENDIX A**

# **SUGGESTED RESOURCES**





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## APPENDIX A—SUGGESTED RESOURCES

Trenchless technology resources for use with USDA Forest Service culverts

### PUBLICATIONS

Trenchless Technology, No-Dig Engineering, and Directional Drilling

All three magazines are available free from:

Trenchless Technology, Inc.

P.O. Box 190

Peninsula, OH 44264

[www.trenchlessonline.com](http://www.trenchlessonline.com)

Underground Construction

Oildom Publishing Company of Texas, Inc.

14515 Brairhills Parkway, Suite 208

Houston, TX 77077

[www.oildompublishing.com](http://www.oildompublishing.com)

No-Dig International

c/o C&C Mailers International, Inc.

900 Lincoln Boulevard

Middlesex, NJ 08846

### Directory

Directory of the North American Trenchless Technology Industry

Listings of contractors, manufacturers/suppliers, and professional services in the trenchless industry.

Published each May by Trenchless Technology, Inc.

(latest version 2005/2006)

[www.trenchlessonline.com](http://www.trenchlessonline.com)

### Text

Najaf, Mohammad. 2005. Trenchless Technology. McGraw-Hill Professional.

### ORGANIZATIONS

Center for Underground Infrastructure Research and Education (CUIRE)

Michigan State University

517-432-2096

[www.cuire.org](http://www.cuire.org)

Centre for Advancement of Trenchless Technologies (CATT)

University of Waterloo

Ontario, Canada

[www.civil.uwaterloo.ca/catt/](http://www.civil.uwaterloo.ca/catt/)

Trenchless Technology Center

Louisiana Tech University

800-626-8659

[www.latech.edu/tech/engr/ttc](http://www.latech.edu/tech/engr/ttc)

Trenchless Information Center

Northeast Consulting, Inc.

Webster, NY

585-787-1519

[www.no-dig.com](http://www.no-dig.com)

North American Society for Trenchless Technology (NASTT)

Arlington, VA

703-351-5252

[www.nastt.org](http://www.nastt.org)

International Society for Trenchless Technology (ISTT)

London, UK

+44 (0)20 7259 6755

[www.istt.com](http://www.istt.com)

American Public Works Association (APWA)

[www.apwa.net](http://www.apwa.net)

National Utility Contractors Association (NUCA)

[www.nuca.com](http://www.nuca.com)

Plastic Pipe Institute (PPI)

[www.plasticpipe.org](http://www.plasticpipe.org)

Pipe Rehabilitation Council

[www.piperehab.org](http://www.piperehab.org)

### RELATED WEB SITES

No Dig Engineering, Trenchless Technology, Inc.

[www.nodigengineering.com](http://www.nodigengineering.com)

Trenchless Technology, Inc.

[www.ttmag.com](http://www.ttmag.com)

Trenchless Technology, Inc

[www.directionaldrilling.com](http://www.directionaldrilling.com)

Trenchless Technology, Inc

[www.rehabshowcase.com](http://www.rehabshowcase.com)

Trenchless Technology, Inc.

[www.rehabroadshow.com](http://www.rehabroadshow.com)



## **About the Author**

**Rob Piehl** is a geotechnical engineer on the Willamette, Siuslaw, and Mt. Hood National Forests. He has been with the USDA Forest Service since 1980 and has been practicing trenchless technologies for the last 5 years.

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