

Stream Simulation

Major Steps in the Stream-simulation Construction

Let contract

Inspect and control all aspects of crossing construction

Document the installation as-built

RESULTS

The completed stream simulation crossing

Baseline for monitoring

Figure 8.1—Major steps in the stream-simulation construction.

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This chapter focuses on contract administration, addressing itself primarily to the contracting officer (CO), the contracting officer's representative (COR), and the inspectors. The chapter is not intended to stand alone. It builds on material presented earlier in this guide, because it is essential that people involved in construction have a good understanding of project design elements and objectives. Ideally, the COR who takes primary responsibility at this stage was also involved in the design phase, at least in a consulting role, and is already familiar with the design of the project.



Figure 8.2—Open-bottom arch stream-simulation culvert on Wilson Creek, Boise National Forest, Idaho.

This chapter describes how to administer construction of the complete project, paying particular attention to unique and special emphasis elements that make stream-simulation projects different. Although many aspects of these projects are identical to other road-construction and stream-crossing projects, stream-simulation projects are often large structures, and they require streambed construction (figure 8.2). These considerations, along with more rigid survey and construction tolerances, add significantly to the complexity of construction. Proper attention to detail, continual indepth assessment of site details as the project progresses, good communication, and careful, informed decisionmaking are equally important for the construction phase.

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This chapter emphasizes factors critical to the performance of stream-simulation structures, including:

- Construction survey.
- Structure grade control.
- Structure alignment.
- Structure foundation and backfilling.
- Stream-simulation bed construction.

8.1 BRIEF INTRODUCTION TO STREAM-SIMULATION CONSTRUCTION

The following subsections highlight areas where contract administration for stream-simulation projects differs somewhat from traditional stream-crossing projects. None of this is intended to replace policy and direction in the Forest Service Manual and Handbook, it merely emphasizes topics that are either unique to stream simulation, or that sometimes cause problems in construction.

For policy and direction for contract administration on Forest Service contracts, go to Forest Service Handbook (FSH) 6309.11 Contract Administration. The Road Construction Handbook is FSH 7709.57, and FSH 7709.56b contains guidance for Transportation Structures including major and minor culverts. For policy and direction for the Forest Service Engineering Construction Certification Program, go to FSH 7109.17 Engineering Certification. For the entire self-study Engineering Construction Certification program, go to the Engineering Manual 7115 series of manuals. You can download these documents from the Forest Service internal Web site. (Other public lands agencies may have similar programs and policy.)

8.1.1 Roles

For a stream-simulation project, the project team includes individuals not always found on construction projects. The experience of hydrologists, geomorphologists, and fisheries biologists is essential to the success of aquatic organism passage projects. In some cases, these specialists may be participating in the engineering project development process for the first time. The key personnel working on most stream-simulation projects are listed below. Depending on the complexity of the project and the availability of personnel, some of those listed may or may not be members of a specific project team.

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- Land manager (district ranger or forest supervisor).
- Contracting officer (CO).
- Contracting officer's representative (COR).
- Inspector(s).
- Project team— subject matter specialists.
 - ▲ Designer.
 - ▲ Geotechnical or structural engineer.
 - ▲ Hydrologist/geomorphologist.
 - ▲ Fisheries biologist.
- Contractor.

8.1.2 Communications

Because good communication is critical for construction projects, we reemphasize it here. All communications must be complete, accurate, and honest. During the final design process, the design engineer must determine the needs of the land manager, the project team, and the permitting agencies, and convert those requirements into accurate drawings, specifications, and other contract requirements. Otherwise, intelligent communication with the contractor becomes impossible. The contractor, in turn, must construct the project precisely to the contract drawings and specifications. Many of the concepts involved in stream-simulation projects may be new to many contractors; for example, the tight tolerance for elevation control is not widely known in the low-volume road construction industry, and in many cases, the work requires hand labor. The entire process, therefore, requires a great deal of time, commitment, and communication among all the members of the project team including contractors and contract administrators.

Contract administrators may not completely understand all the performance details of the structure or its stream-simulation design features. Therefore, when unexpected problems arise on a project, contract administrators should immediately contact the designer for input leading to solutions that preserve design performance.

Similarly, the project team and design engineer should involve contract administrators early in the planning process. The separation in many organizations between planning/design and contract administration

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imposes artificial barriers and decreases the level of communication. Both the COR and the inspector can provide good information on project constructability, and valuable advice on the types of hazards that exist at particular construction sites. Their knowledge of the capabilities and limitations of various types of equipment is extremely valuable to project teams choosing site location or considering construction access. CORs and inspectors may be able to solve problems that are difficult to solve without firsthand field experience; they may be able to offer solutions that are simpler and less costly, while providing the same level of effectiveness. Therefore, contract administration personnel should be involved early in the project-development process.

8.1.3 Contact Administration Meetings

This section discusses meetings that are particularly important to stream-simulation projects. For successful stream-simulation projects, formal contract administration meetings include the following:

8.1.3.1 Prebid tour

This meeting is particularly important for stream-simulation projects, which may be unfamiliar to some potential bidders. The prebid tour is an onsite meeting during solicitation, allowing the offering agency and prospective bidders to view the project together to clarify the project drawings, specifications, and contract requirements before bidding. Generally attending are the CO, designers, COR, inspectors, and prospective bidders. Having the project team at this meeting is often useful, as they can explain the rationale behind any special construction features in the design. If stream simulation is relatively new in an area, it may be desirable to begin with an office slide show illustrating the different aspects of an installation.

Often, during the prebid tour and other reviews, questions will arise regarding the project that cannot be answered through the solicitation. In this case, the CO will issue an amendment to the solicitation. The amendment provides the necessary clarification and provides identical information to all bidders to ensure fair and equal competition.

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8.1.3.2 Pework meeting

This is the first meeting after the contract has been awarded. It is generally an office meeting for reviewing the contract, including contract clauses, special contract requirements, drawings, specifications, and any final clarifications with the successful bidder. This meeting gives everyone a chance to discuss and reinforce any special or unusual contract requirements, such as permit requirements or special construction requirements.

Generally attending are the CO, COR, inspector(s), a district or program representative, the design engineer, and the contractor. Having the project team present is useful, as they can explain why special construction requirements for stream-simulation construction are important to the success of the project. The CO or the COR should brief the team members beforehand on contract authority, to avoid potentially embarrassing breaches during the meeting (project team members do not ordinarily have contract authority). The Notice to Proceed is usually issued at this meeting.

8.1.3.3 Pework field meeting

This is the first field meeting between the contract administration personnel and the contractor. Additional attendees might include a district representative and possibly a representative from the permitting agency. On complex projects, the designer should be present, to provide any necessary clarification of the drawings and specifications. Again, members of the project team should be present to explain the importance of special construction requirements unique to stream-simulation construction. The meeting will cover the overall project, with an emphasis on such initial items as surveying, clearing, dewatering, traffic bypass (if appropriate), project limits, temporary erosion control, storage and stockpile areas, camping, and general land use, as well as any permit requirements. At this meeting, contract administration personnel should establish day-to-day working relationships, communications channels, and ground rules.

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8.1.3.4 Final inspection/post-construction meeting

The final formal onsite construction meeting reveals to all team members the results of their collective efforts in designing and constructing a stream-simulation project. At this point, work on the project is essentially complete, and the project is ready for use, except for a few small “clean up” items. The project is inspected in its entirety, and the final punch list of items needing completion is finalized. Ideally, all project team members and contract administrators should participate in this meeting, and all parties should express, objectively, what went right or wrong with the project. Lessons learned should be well documented with suggestions for future projects. When the punch-list items are completed, the project is formally accepted, and final payment is processed.

8.1.4 Construction and Inspection

In many respects, stream-simulation projects are no different than other stream-crossing projects. However, some features make stream-simulation projects different and more complex. The way the streambed is treated inside the structure as well as up and downstream of the crossing generally differs from past construction of stream crossings. The structure infill is the most unique feature of any stream-simulation project; its proper construction is vital to its performance. Upstream and downstream controls also play critical roles in the way that the infill of the structure performs. All of these features need your extra attention, because of the strict tolerances required for proper performance and because of the relative newness of these features to the construction industry. In addition, much of this work must be performed by hand, particularly in small structures.

8.1.5 Construction BMPs

BMPs for construction are in section 7.1, in the Construction BMP checklist. All of the items in the BMP list are discussed in detail in either this chapter, chapter 7, or appendix G. The list provides an excellent “watch list” for protecting the construction site, the stream and aquatic organisms during construction, as well as for proper construction of the stream-simulation channel inside the culvert.

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8.1.6 Construction Survey and Tolerances

Surveying for a stream-simulation project requires more time and attention than normal (section 8.2.2). For stream-simulation projects, both the construction survey and the original site survey require great accuracy and attention to detail. Construction tolerances on stream-simulation projects are likewise critical. Small changes in gradient, location, or bed material can profoundly affect the structure's performance.

For example, if the gradient in the structure is steeper than designed, the resulting increase in stream velocity can cause the infill to wash out of the structure. If the gradient is shallower than designed, the resulting decrease in stream velocity can cause the stream to deposit material in the structure. In either case, the structure will not match the stream long profile and may cause an aquatic passage barrier to form at the inlet or outlet. If the structure is placed with a change in alignment, similar consequences could occur, with poor inlet or outlet performance or unanticipated bank erosion. If the bed material does not include enough fine material, the infill may be permeable enough to allow the stream to travel below the surface. If this happens, low flow may not be deep enough to provide for aquatic organism passage, or the channel may become completely dry.

8.1.7 Permits and Permit Requirements

Generally, stream-simulation projects are constructed under permit from State and Federal agencies. Permits may include strict requirements on protection of aquatic species, levels of suspended sediment, and construction pollutants. Often a seasonal restriction on the construction timeframe (often called the “construction window”) defines when construction can actually occur on the site during a normal year. Along with these restrictions, permits will include requirements for site closure, including seasonal closures (if the construction will take more than one season to complete).

8.1.8 Contract Modifications/Design Changes

Given so many variables, projects seldom flow from beginning to end without a contract modification (i.e., a change order). With such complex projects, anticipating every site problem during the final design is difficult, if not impossible. In addition, once onsite, the contractor, inspector, or COR may find a simpler, more effective, or more economical way of accomplishing the intent of the design and may initiate a proposal for a modification. (In this document, the terms “change order” and “contract modification” are interchangeable.)

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Whatever the need is for the modification, the process for solving the problem is the same. Whoever identifies a problem proposes a solution (along with team help, if necessary), and the COR estimates the cost. Depending on the complexity of the problem, all members of the project team may need to review the proposed solution. The contractor's input to the solution of any design change can be invaluable, particularly in the area of construction methods and constructability. The designer will provide the engineering solution, with input from contract administration personnel and the remainder of the project team and the contractor.

8.1.9 As-built Drawings and Final Construction Report

As-built drawings begin with the contract drawings for the project. All change orders, including minor deviations, are clearly marked and the drawings modified, so that they accurately depict the structure as it was finally constructed. While time-consuming, this process is key to the success of future projects. Being able to study the current generation of projects—through the “as-built” drawings and the final construction report—gives future designers a better understanding of similar projects.

For Forest Service projects, FSM 7721.36 requires a final construction report. Specific requirements for the document are included in FSH 7709.57, Chapter 7. Contract-administration personnel prepare the final construction report. Its purpose is to provide background for future similar projects, and it should thoroughly and objectively document “lessons learned” (both good and bad).

8.2 STREAM-SIMULATION CONSTRUCTION TOPICS

The remainder of this chapter emphasizes areas of work that require special attention in stream simulation. It provides lists of items to be routinely checked and lists of common problems, with possible solutions and helpful hints. This section will follow the work progress of a typical project, beginning with Section H “Special Contract Requirements” and ending with the final cleanup and post-construction monitoring.

The first item on the construction project is planning. The contractor is required to submit a project schedule. The purpose of the schedule is not only to track the contractor's work progress, but also to give you—the COR—a useful tool for work planning. When the contractor submits the

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schedule, be sure that it provides realistic information that will benefit the contract-administration process. Obviously, the contractor must update the schedule periodically to reflect current progress of the project (see figure G-1 for a sample project schedule.) A project schedule can take many forms, ranging from showing proposed work progress on a calendar to using detailed Gantt or Critical Path Charts. At the very least, the schedule should identify project start and completion dates and proposed timeframes for important work items such as:

- Construction survey.
- Mobilization.
- Stream diversion and dewatering.
- Aquatic organism capture and transport (timeframe for others to perform work).
- Existing structure removal when applicable.
- Clearing.
- Structure excavation.
- Structure installation.
- Structure backfill.
- Road reconstruction.
- Site cleanup and demobilization.
- Seasonal site closure for projects spanning more than one construction season.

8.2.1 Safety

Inspect the contractor's operations to ensure that all work is accomplished safely. (An inspector who witnesses unsafe acts that lead to an accident and does not intervene can be held personally liable.) Most safety issues are standard ones for a variety of construction projects, including operations for excavation, confined spaces, concrete placement, heavy lifting, underground utilities, power equipment, potential fire hazards, and machinery. Be familiar with FSH 7709.57 section 2.5 and Occupational Safety and Health Administration (OSHA) regulations that apply to the particular project. Safety is a personal responsibility, as well as the contractor's responsibility. (For OSHA regulations, go to http://www.osha.gov/dts/osta/otm/otm_v/otm_v_2.html.)

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Follow OSHA regulations when working with power equipment in a confined space. When installing streambed material inside the culvert with power equipment, or working in the narrow spaces between footings and excavated slopes, consider:

- Replacing some power equipment work with hand labor.
- Providing large fans to exhaust air from confined spaces.
- Other placement methods.

In addition to OSHA regulations governing construction, you should emphasize safety for both contract administration personnel and anyone visiting the job site. (See Forest Service Health and Safety Code Handbook, FSH 6709.11.)

Perform a job hazard analysis. Identify job tasks, their known hazards, and abatement actions for each hazard. For each project, fill out a FS-6700-7 job hazard analysis (JHA), and file it in the project folder. Review the JHA before going to project sites.

8.2.2 Construction Survey

This phase of the project requires more attention to detail than ordinary stream-crossing projects. The COR, the inspector, the project team, and the contractor should visit the site together to create a thorough understanding of the site, design objectives, and details. Visually examine the site to make sure that it looks like the drawings. Spot check elevations to find obvious discrepancies in the survey or design. Because streams change occasionally between site surveys and construction, design changes may be necessary. Always contact the project team with any questions about the location of project features when the drawings differ from actual site conditions.

Protect control points that were established during original topographic survey. They are important references that are necessary to establish construction stakes for the project, for monitoring the construction, for developing as-built drawings, and for monitoring the project in the future. Control points may consist of a reference point on any permanent structure. One simple control point is a 24- to 48-inch reinforcing bar, driven into soil by hand a safe distance away from the maintained roadway and stream in a stable location. Locate offset reference stakes in the area of the culvert inlet and/or outlet in locations where they will not be disturbed by construction or potential stormflows but where they can be easily checked during the project.

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An error in placing the foundation or bedding can badly affect the outcome of the entire project (figure 8.3), and may result in the eventual failure of the stream-simulation bed or the culvert structure.



Figure 8.3—Results of a survey error. Footings were constructed 2 feet higher than the designed location because of a construction survey error. Always doublecheck surveys!

In figure 8.3, the footings were constructed approximately 2 feet higher than designed, due to a contractor survey error that the inspector did not catch. The stream-simulation bed still had to be constructed to match the stream profile, so that the footings were not embedded as deeply as designed.

This error resulted in:

- An increased risk of the foundation being undermined by scour.
- Less fill (on the inside of the footings) for resisting the overturning forces (on the outside) thereby reducing the safety factor for overturning and bearing capacity.
- Insufficient cover height over the pipe, which was designed for minimum cover. To compensate, the contractor had to raise road grade 2 feet, creating an obvious hump in the road profile and limiting some truck traffic.

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Inspectors should verify contractor surveys by checking—and rechecking—the work. Mistakes in the survey and construction staking will affect the entire project. Your job is to insist on accuracy at all stages.

Survey Inspection Checklist

Take care of the following items before beginning any work on the site:

- ✓ Verify control points, which are typically established during the original topographic survey (section 5.1.2).
- ✓ Reestablish any missing control points and, if necessary, establish additional control points to aid construction of the stream channel and any channel restoration work.
- ✓ Resolve discrepancies with the surveyor and design engineer before construction begins.
- ✓ Clearly mark all clearing and construction limits, especially near the stream channel, with stakes and flagging.
- ✓ Clearly mark stockpile-storage areas, waste areas, and borrow-source areas with stakes or flagging.
- ✓ Review and establish any proposed construction access with the contractor.
- ✓ Document agreements on a work order.
- ✓ Ensure accurate placement of slope stakes and references for the road travel way, embankment limits, and all excavation slopes.
- ✓ Check that erosion and sediment control and dewatering/sediment removal features are properly located.
- ✓ Check construction stakes to ensure accurate location of the structure, especially the elevation, position, grade, alignment, excavation slopes, and width.

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8.2.3 Special Contract Requirements (H Clauses)

Review the contract for any special contract requirements in section H or in other sections of the contract. Review Section H requirements, Standard Specifications and Supplemental Specifications, not only for special requirements but also for any potential conflicts between them. If conflicts exist, notify the CO and design engineer to resolve them. See appendix H for sample H clauses, and section 7.9 for a summary of the clauses.

8.2.4 Signs and Traffic Control Plans

The contract may require a traffic-control plan. Options usually include: a traffic detour onto other roads, a traffic bypass over the site or adjacent to it, or a traffic barrier.

If a change in public traffic access is necessary, be aware that it can affect other aspects of the project. For example, a change may require constructing a temporary road, lengthening the culvert, or moving the dewatering dam and bypass pipe. It may cause additional resource damage, and in some cases, may even increase the cost enough to make a bridge more practical and economical.

8.2.5 Erosion, Sediment, and Pollution Control

Maintaining water quality throughout the project (by preventing erosion, and preventing sediment and pollutants from entering streams) should be a major focus for contract administration. Most sediment is generated during embankment and foundation excavation, and by erosion of freshly disturbed slopes, constructed embankments, stockpiles, and road surfaces. (See section 8.2.6 for dewatering. Check section H, Special Contract Requirements, for turbidity requirements.)

Erosion control means that the soil remains in place, either undisturbed or protected with a protective covering such as mulch, rock, or a membrane.

Sediment control means that soil already eroded is captured and prevented from harming the stream or sensitive riparian areas. Sediment control includes dewatering the site to prevent sediment transport downstream and capturing the sediment with sediment-trapping mats, dams, or silt fences. See appendix G figures G.8 and 9 for example drawings of temporary erosion and sediment control features.

8.2.5.1 Reviewing erosion- and sediment-control plans

If the guidelines in chapter 7 were followed, the contract does not specify specific methods of erosion and sediment control. Instead, it makes the contractor responsible for the end result of meeting the requirements spelled out in the supplemental specifications and section H. For ease of contract administration, if any changes in the contractor's plan are required, write them in terms of "end results" or performance rather than specifying specific methods.

The contract may have specific sections relating to erosion and pollution control, such as a Supplemental Specification 157, or a special contract requirement similar to H3 (appendix H). If not, make sure that the specifications and drawings adequately cover any erosion and sediment control requirements in the National Environmental Policy Act document (including BMPs) and in the water quality permit.

Normally, the contractor is required to submit a plan for erosion, sediment, and pollution control (H.3, appendix H). The erosion-control plan can consist of a variety of erosion-prevention and sediment-trapping methods. These methods and details can be obtained from a variety of sources, including instream work permit requirements (BMPs), standard engineering practices, and standard OSHA requirements for excavations and preventing slope failures.

Review the erosion and sediment plan with the project team and ensure it protects the site as required in the contract. Much more detail on erosion and sediment control is in sections 7.7 and 7.8, but some common methods are:

- Erosion control
 - ▲ Minimize cleared and disturbed area.
 - ▲ Dewater the construction area (section 8.2.7).
 - ▲ Use slope treatments, such as seed, mulch, erosion-control fabrics, geotextile fabrics, and membrane, during and after construction.
 - ▲ Maintain temporary erosion and sediment control measures.
 - ▲ Provide armor and/or ditch dam energy dissipators for newly constructed or maintained road drainage ditches.

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- ▲ Control erosion at lead-out ditches and pipe outlets.
- ▲ Prevent road surface runoff from entering the excavation by using surface dips, berms, or outsloping the road.
- ▲ Maintain road surfaces and drainage systems during the contract.
- ▲ For disturbed areas, stockpile sites, and waste areas, scatter clearing slash and debris, seed and mulch, and slope to drain. (Long slopes over about 50 feet are broken by water collection ditches or berms to dissipate energy and control runoff.)
- ▲ Cover temporary stockpiles with an impermeable membrane to prevent erosion and control moisture.
- Sediment control
 - ▲ Place silt fences, straw bales, or other sediment trapping systems at the bottom of excavated slopes, and temporary drainages.
 - ▲ Use sumps for collecting sediment-laden water upstream and downstream of construction, and in bypass pipe ditches.
 - ▲ Locate the area for the water treatment/sediment removal system and verify the system will function as intended at that location.
 - ▲ Use pumps (or gravity when possible) for transporting water to treatment areas.
 - ▲ Monitor and maintain pumping equipment during dewatering operations.
 - ▲ Install erosion controls in the treated water release area if not being released directly into the stream.
 - ▲ Ensure prescribed method for removing sediment functions as intended. Identify alternative methods if more treatment is necessary.
 - ▲ Wash paved road surfaces at the end of the project to prevent sediment from entering the stream, and to restore safe traffic conditions.

The Storm Action Plan should require monitoring and maintaining erosion and sediment control measures and immediate repair or replacement in the case of damage.

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Temporary Erosion and Sedimentation Control Inspection Checklist

For maximum effectiveness, make certain that appropriate erosion-control measures are in place at the beginning of site-disturbance activities. (Refer to sections 7.7 and 7.8.) Tips on handling common problems that arise with erosion and sediment controls are in appendix G.4.3.6.

Inspect and monitor the following activities during each site visit throughout construction, and make changes as necessary to control sediment production. Verify that:

- ✓ The dewatering system is installed according to the approved dewatering plan and is functioning properly.
- ✓ Sediment collection systems are installed according to the approved erosion-control plan and are functioning properly.
- ✓ Excavation and waste stockpiles are protected from rainfall and are located where they will not fail or erode directly into the stream. In locations where protection is not practical, be sure sediment-control measures are in effect.
- ✓ Drainage from open excavations, fresh cut banks, and embankments is captured and treated.
- ✓ Water treated and discharged back to the stream meets contract requirements. (Ground water intrusion will increase sediment production. Despite the best dewatering efforts, ground water seepage occurs at many sites. Drainage may come from many different places and increase substantially during storm events.)
- ✓ The contractor takes measures to reduce sediment production, such as by minimizing bucket spill into construction area drainage and by avoiding slope failures in over-steepened excavations. (Because all water discharged back to the stream requires treatment to remove sediments, remind the contractor that it may be more cost effective to reduce sediment production during excavation in order to reduce the amount of water treatment necessary—especially in silt-clay rich soils.)
- ✓ No excavated slopes remain vulnerable to erosion or failure. (If left for long periods (days) these slopes may benefit from using a membrane cover. Assess the slope condition frequently. While membrane covers can be helpful, covering slopes will also slow drying the soil in embankments and in turn cause sloughing. Keep in mind that excavated slope erosion is often the largest source of sediments on the project.)
- ✓ The contractor is careful when loading and hauling wet materials, especially near the site. Be sure that the contractor either avoids spilling excess soil onto the road during haul or provides a means of preventing this sediment from entering the stream. (Sediments around loading areas can be trapped with berms or sand bags. Existing roadside vegetation may provide sufficient trapping elsewhere.)
- ✓ All sediment- and erosion-control methods function as intended. (Silt fences filling with soil and/or water will fail, either by structure failure or by overflowing, unless the soil is removed before the sediment traps fill.)
- ✓ For multiple-year projects, the contract should contain adequate site protection provisions covering conditions peculiar to the site at the end of each work season. (If additional protection is necessary because of expected storm events, snowmelt, frost heave, ravel, wind, etc., the inspector and the project team should initiate a change order to encompass the necessary work. If the area has a history of vandalism, for example, vehicle barriers may be necessary to close the site to traffic, especially during hunting season or other high-use in recreation periods.)

8.2.5.2 Pollution control and prevention plans

The primary sources of pollution on a project are vehicle fuels, hydraulic fluids, lubricants, invasive plants and animals carried in on equipment, and human waste. Special contract requirements specify methods, procedures, and rules to follow to reduce the risk of pollution. Depending on the contract, the contractor may be required to submit a pollution-control plan.

Be proactive in ensuring that the contract meets water-quality and soil-protection goals. Items such as hydraulic oil or other fluid leaks can cause serious damage in a very short time. To meet project and environmental requirements, deal with spills immediately and firmly. Review plans and operations to ensure that construction activities comply at all times with specified pollution control objectives. Make sure that protections are in place or are ready to deploy immediately when necessary.

Special contract requirements generally include all or some of the following. See also sections 7.8.11 and 7.9, and H-clause 3 in appendix H.

- Landscape Preservation and Hazardous Materials
 - ▲ Written approval required for operating equipment in live streams.
 - ▲ Service equipment only in approved areas.
 - ▲ Transport waste offsite.
 - ▲ Treatment for general construction debris. (Usually, the contract will require that construction debris be removed to an off-forest site according to local, State, and Federal regulations.)
- Hazardous Materials
 - ▲ Spill plan submittal.
 - Specifies hazardous material cleanup kit.
 - Specifies which materials must be on hand to contain spills.
 - Specifies that required spill containment devices, pads, and booms are onsite and ready to deploy immediately.
 - ▲ Review the spill plan and require modifications as necessary to meet project objectives and goals.
- Industrial Camps
 - ▲ Self-contained toilet facilities onsite.

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- Equipment Cleaning
 - ▲ Pressure-wash equipment to remove foreign terrestrial, aquatic weed, and animal species.
 - ▲ Repair fuel, lubricant, and hydraulic leaks.
 - ▲ Inspect daily (depending on activity).

8.2.6 Dewatering and Sediment Removal

A dewatering system bypasses the streamflow around the site and removes most of the water from the excavation area of the project (figure 8.4). (See appendix H for a sample dewatering supplemental specification, and figures H.6, 7, 8, and 13 for sample dewatering system drawings.) Water that escapes the bypass system—by flowing around or beneath the dam or seeping into the excavation—must be captured and treated to remove the sediments before returning it to the stream. In areas prone to seasonal storms during the construction season, even channels with dry stream beds may require dewatering plans. A simpler system than that shown in figure 8.4 may be suitable in such areas.



Figure 8.4. Diversion dam and gravity pipe bypass system. Bypass road is visible in the background, and excavation in main road is just beyond it.

Excavation activities produce most of the sediments on a project. As part of the dewatering, encourage the contractor to avoid inadvertently mixing excavated soil and water. Not mixing soil and water will reduce the amount of water needing treatment and reduce the risk of exceeding turbidity levels in the stream. The contractor will also find this practice advantageous because it reduces water-treatment costs.

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8.2.6.1 Protection of aquatic organisms when dewatering

To maximize protection of aquatic organisms, review the dewatering plan and the species-removal plan with the biologist and contractor in the field before beginning construction. When endangered and threatened species are present, dewatering may take on critical importance, and regulatory agency personnel may review it in the field. See appendix G.4.4 for case examples of dewatering and species protection for a stream crossing and a stream-restoration project.

Dewatering often traps aquatic animals, and construction activities in the dewatered stream channel frequently kill organisms that have retreated into moist gravels. To avoid stranding, stressing, or killing aquatic organisms: dewater gradually, capture the organisms, and transport them to the best available stream habitat above or below the construction site.

No standard method exists for capturing and handling aquatic organisms. The biological opinion from the regulatory agency should cover the methods for endangered species act-listed species. State fish and game agencies are a good source for guidelines for handling captured aquatic organisms. Generally, placing captured fish in a bucket of water kept at ambient stream temperature is best. The exact methods for capture and transport will depend on channel features such as dimensions, shape, substrate size, and location of hiding places. Choose trap and transport techniques that reduce stress on individuals selected for protection.

To determine a practical and reliable way to dewater, collect and transport aquatic organisms, and rewater the site in a controlled and staged manner, the contractor, inspector, and project biologist should coordinate their timing and work together. The construction contractor generally does not perform aquatic organism removal, but the contract should provide a stop-work requirement that allows time for that work (section 7.8). It is important to ensure that when dewatering begins enough qualified personnel are present to collect and move species safely and efficiently. The contractor and inspector may also be able to help with species transport under the guidance of the fish biologist. For example, if aquatic organisms will be transported over rough ground to an upstream or downstream habitat, the contractor's assistance in clearing a pathway for this effort may be extremely helpful.

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Protecting aquatic organisms also includes:

- Minimizing damage to aquatic habitat by limiting turbidity and sedimentation of the streambed.
- Minimizing water temperature increases by avoiding vegetation removal and retaining shade. Before implementing any proposed changes to clearing limits, review them with the project biologist.
- Preventing the spread of invasive species such as zebra mussels, snail species, and weeds. Be sure that all tools and equipment are thoroughly cleaned before they are brought to the construction site.
- Avoiding chemical contamination and rapid changes in water temperature.
- Adhering to the instream construction window, which is usually determined by the permit. The timing is set to avoid critical aquatic organism life cycle periods such as migration and spawning.

8.2.6.2 Dewatering plan review

If the contract does not contain a dewatering and water-treatment plan but instead requires the contractor to submit one, review the contractor's submittal carefully. Be sure it includes the elements described in section 7.8. Review Supplemental Specification 157 and the sample dewatering plan drawings in appendix H for features that may be used on the project. A successful dewatering plan includes the following:

- A diversion dam to direct water into a bypass pipe or pump system to capture the majority of stream flow. About 90- to 95-percent capture is considered successful. The dam must have sufficient height and width for stability.
- A method for temporarily pumping or diverting water around the bypass dam area during its construction.
- Screens on pump intakes to prevent leaves and other debris and aquatic organisms from entering the pumps.
- A hydraulically designed water bypass system (leak-proof pipe, lined-ditch, or pump system) capable of handling construction-season flow conditions, including possible storm flows.

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- A sump above the excavation to collect water seeping past the diversion dam; and a pump, bypass ditch, or other means for transporting the water to the treatment system (figure 8.5). (If the water is clean, it can be pumped back upstream to the bypass system to reduce the load on the water treatment system.)
- A sump immediately downstream from the excavation to collect sediment-laden seepage water, and a means to transport it to a treatment system (figure 8.6).
- Sump pumps that are capable of handling expected flows.
- A specific sediment-removal method, including backup if the preferred method fails.
- A storm action plan that includes both Government and contractor contacts along with specific action items for avoiding a catastrophic failure.



Figure 8.5—Upper sump collects water that bypasses or seeps through the diversion dam.

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Figure 8.6—Lower sump collects water bypassing the construction. The hose on the right is discharge from the upper sump. The water is pumped from the sump to a treatment area where the water is dispersed in the vegetation.

The design engineer, COR, and inspector should all review the dewatering and sediment-removal plan carefully to ensure that the objectives are understood, and that the plan is effective at collecting and treating dirty water, meets hydraulic needs, and allows for project limitations such as rights-of-way and instream work permit requirements.

8.2.6.3 Dewatering inspection recommendations

Because the amount of ground water can vary significantly and is difficult to predict before construction begins, the dewatering plan should allow for necessary adjustments. If the dewatering plan was written as an end-result or performance-based specification, the contractor must be prepared to make appropriate changes to the dewatering system to eliminate sedimentation. Either the COR or the inspector must be quick to recognize any potential failure of the dewatering system and require any necessary changes.

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Above all, all sites must have a method of capturing and treating sediment and drainage downstream of the project (sections 7.8.3 and 7.8.4). The method usually consists of a sump and pump system that feeds the dirty water to a treatment system. This system is the project's final opportunity to keep sediment out the stream.

Follow the approved diversion plan exactly, adjusting it only to fit the site. Contact the design engineer if changes are necessary. If something is not working correctly, have the contractor repair it immediately, because the integrity of the individual design elements is key to preventing leaks from reaching the stream.

Dewatering System Inspection Checklist

Check the following items to ensure that the dewatering system protects aquatic species and functions properly:

Bypass dams and downstream backwater dams.

- ✓ Dam materials are tightly packed.
- ✓ Dam elevation is correct (provides for flood capacity).
- ✓ Dam length and width is correct. (Even though the dam is small, it is still a dam and must be stable and safe.)
- ✓ Membrane is properly installed, embedded into banks and stream bottom to the dimensions specified (or as necessary to intercept both surface and subsurface water).
- ✓ The dam has a reasonably good seal against the streambed, bank, and bypass pipe. (Expect some seepage to get past the dam; collecting 100 percent of the water is nearly impossible.)

Stream bypass by pumping

- ✓ Screens are on all pump intakes.
- ✓ Pump intake is placed deep enough that the entire screen is submerged, providing enough head for the pump to operate efficiently.
- ✓ Pump capacity is sufficient to pump entire stream around construction area. Multiple or unusually large pumps are required in larger stream flows. Pumps and stream flows are measured differently. One cubic foot per second (typical streamflow unit) equals 448 gallons per minute (typical pump measurement).
- ✓ During excavation activities, check all pumps until the excavation water clears. (Pumps may have to run constantly, and you may need one or more backup pumps.)

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Stream bypass by gravity through pipe.

- ✓ Pipe capacity is adequate to pass required streamflow for the construction season and any anticipated extensions. Pipe capacity can be determined with either pipe-flow nomographs or software such as HY-8.
- ✓ The pipe is effectively sealed to the dam according to specification (section 7.8.1).
- ✓ Pipe diameter, material type, joint type, and sealer or gasket must be as specified.
- ✓ Pipe joints are straight, unstressed, and leakproof.
- ✓ Pipe is placed at the designed grade and elevation.
- ✓ The pipe outlet area is scour resistant. If downstream fish passage is allowed, outlet is placed in a pool or other suitable release area.
- ✓ Any seepage from the diversion dam that flows into the bypass pipe ditch is collected in a sump before it enters the stream. (If it is very clean [test it to be sure] it can be pumped back into the stream).

Stream bypass by gravity into existing side or constructed channel.

- ✓ The diversion channel slope, width, and bank slopes are constructed as designed. These characteristics ensure stability and keep the channel scour-resistant. Supplemental erosion control measures may consist of: rock lining, a membrane, straw, check dams, geotextiles, etc.
- ✓ The area between the channel and the construction area must be sufficiently stable to prevent an accidental diversion into the construction area, and to prevent channel seepage from reaching the excavation area. (Reinforce the channel, if necessary.)

Stream bypass and water treatment system—general.

- ✓ Check the pipe diversion inlet daily. Make sure that any debris such as leaves and twigs are removed periodically. If screens are required on the pipe or on pumps and hose inlets, cleaning may be required daily, especially in areas of significant leaf fall during construction.
- ✓ Enough fuel is available to keep pumps running up to 24 hours a day, when required, to prevent stream sedimentation during storm events.
- ✓ System includes automatic pump control floats to conserve fuel and maintain pool elevation within an acceptable range (figure 8.7)
- ✓ Backup pumps and extra pump capacity (including fuel) are onsite to accommodate increased stream flows during storm events.
- ✓ Where storms, vandalism, or other events could cause a system malfunction, check the system daily—including weekends.



Figure 8.7—Pump controls: float switches are attached to stake in sump.

Dewatering and aquatic-organism removal.

- ✓ The project team biologist is kept informed of the contract schedule, so that he or she can be present for species removal during dewatering.
- ✓ A staged (slow, controlled) dewatering procedure is clearly understood and agreed to by the contractor.
- ✓ Necessary equipment such as buckets, nets, shock equipment, and dip nets are onsite before dewatering begins.
- ✓ Equipment necessary for special-capture methods is on hand if needed for listed species.
- ✓ All equipment is cleaned before it is brought to the site as well as when it leaves the site, to protect against introducing invasive species.
- ✓ The release area is located and a safe pathway from the dewatering area to the release area has been cleared.
- ✓ Before dewatering begins, enough people for the capture/removal job are in place.
- ✓ Dewatering begins gradually so that aquatic organisms are not stranded in the dry streambed.

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8.2.6.4 Tips for collecting and treating sediment-laden water

Upstream sump

- Maintain sump pool volume with enough capacity to prevent flooding the excavation.
- Capture the seepage and pump it to the treatment system. The water may eventually clear enough for pumping back into the stream.
- For both convenience and reliability, run all sumps from a central electric generator.

Water collection within the excavation area

- Collect as much water as possible within the excavation area. Then concentrate and divert the water away from loose soil to reduce sedimentation.
- Maintain the drainage area between the foundations and excavation edge by removing accumulated soil deposits and debris.

Downstream sump

- This sump is important, as it offers the last chance for collecting and diverting dirty water for treatment (figure 8.6).
- Use the downstream sump at all times to capture and divert dirty water to the treatment system.
- Be sure that the sump-pool capacity is sufficient for stormflows, especially if sedimentation rate is high.
- Have enough pumps to handle seepage during storm events, and keep pumps in good working order.
- Keep transport hoses for sediment removal stable and leak-free to avoid causing erosion or allowing sediment to enter live streams.
- Use a downstream backup instream filter in case the downstream sump capacity is exceeded. The filter may be geotextile wrapped straw bale or other sediment filter.
- Ensure that the backup sediment filter is constructed and positioned properly, and sealed against the streambed.
- Monitor the filter to ensure that it remains effective but do not expect it to completely eliminate turbidity in the stream.

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Downstream dam

- On flat sites or in deep water, you may need a downstream dam to prevent backwatering of the excavation and sump.
- Construct the dam the same way as the upstream bypass dam and size it according to the downstream need.

Water treatment methods

- Follow contract drawings and specifications. If the system is not working, follow normal contract protocol and modify the contract. (Again, performance-based specifications will make the specified end result the contractor's responsibility.) Be sure that water released into the forest for natural filtering (figure 8.8) does not “short circuit” back to the stream untreated. (See various filtration and water treatment methods in sections 7.8.4 and appendix G.4.1.3.)
- Untreated or inadequately treated water will yield high turbidity levels in the stream below the construction site. To enforce turbidity requirements in the contract, know how to check stream turbidity levels during construction, or know who can. If necessary, ask the project team for help with this item.



Figure 8.8—Natural filtration on the forest floor isolated from the stream channel is one means of treating sediment-laden water.

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Dewatering and water treatment—what can go wrong?

- Unanticipated floods and thunderstorms (see figure 8.9) exceeding normal conditions can overwhelm dewatering systems sending flow through excavation areas, causing soil erosion, structure damage, and stream turbidity and sedimentation.
- Hydraulic failure of dewatering dams or pipes can occur.
- Poorly designed or constructed systems may fail during normal summer storms, creating damage similar to that of an unanticipated large flood event. (This scenario is preventable.)
- Stockpiles located close to the stream may not be covered in time to prevent saturation or erosion. The material may become unusable long enough to cause a delay in the project.
- Sediment capture and treatment systems may not provide adequate treatment, allowing dirty water to reenter the stream and calling for additional methods to prevent harm to aquatic organisms from sediment, turbidity levels, or toxicity.
- Equipment such as pumps and generators can break down.
- Equipment breakdowns can leak petroleum products into the project site, requiring an expensive hazmat-treatment action.
- Generators or pumps can run out of fuel when no one is onsite.
- Sumps and pumps can be too small to keep water from exceeding sump capacity.
- Bypass pipes or channels can leak drainage into excavation or embankment areas.
- Early freezing, wet weather, fires, or other unanticipated emergencies can set back the entire project.

Figure 8.9 shows what happened when a flood—300 percent of normal high summer flow volume—exceeded the capacity of the bypass dam. The bypass structure was overtopped, and water diverted through the construction area, causing erosion, high turbidity in the stream, and partial infilling of concrete forms with fine sediments.



Figure 8.9—Unusual summer storm overwhelms bypass system. (a) Looking downstream at bypass pipe, now in mid-channel. (b) Looking downstream through the open excavation.

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8.2.7 Excavation

In this document, excavation refers to all excavation (including removal of the road embankment surrounding an existing pipe structure) except structural excavation. Section 8.2.10 covers structural excavation which is defined as the part of the excavation necessary to install the new structure, including its footings.

Check the contract for specific requirements and encourage the contractor to minimize the length of dewatering time. If erosion protection measures, such as silt fences at the base of embankments, are in place and working well, delaying dewatering until excavation is close to stream channel level may be suitable. If possible use the existing culvert while excavating the existing road embankment to place the bypass. Otherwise, temporary dewatering with pumps will be necessary before the bypass can be constructed.

8.2.7.1 OSHA and excavation safety

Maintain safe, stable slopes during excavation, and be aware of conditions that indicate slope instability. The slope ratio either is stated on the contract drawings or is governed by OSHA regulations. OSHA guidelines regulate maximum slopes and configurations for trenches and excavations up to 20 feet deep. A registered professional engineer must design excavations deeper than 20 feet. OSHA recognizes that excavating is one of the most hazardous construction operations. Therefore, it revised OSHA Part 1926, Subpart P, Excavations, of 29 CFR 1926.650, .651, and .652 to make the standard easier to understand, to permit the use of performance criteria where possible, and to provide construction employers with options when classifying soil and selecting employee protection methods. Contract administrators must thoroughly understand this document!

The common hazards for embankment excavation (table 8.1) may be encountered at stream crossings. A number of stresses and deformations can occur in an open cut or trench. For example, increases or decreases in moisture content can adversely affect the stability of a trench or excavation. OSHA classifies soil into five categories and recommends maximum excavation slope angles for various benching and trenching options.

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Table 8.1—Slope failure mechanisms (OSHA 1999)

TENSION CRACKS. Tension cracks usually form at a horizontal distance of 0.5 to 0.75 times the depth of the trench, measured from the top of the vertical face of the trench.

SLIDING. Sliding or sluffing may occur as a result of tension cracks.

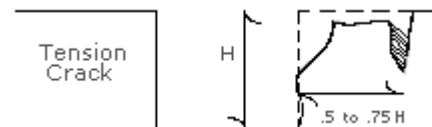
TOPPLING. In addition to sliding, tension cracks can cause toppling. Toppling occurs when the trench's vertical face shears along the tension crack line and topples into the excavation.

SUBSIDENCE AND BULGING. An unsupported excavation can create an unbalanced stress in the soil, which, in turn, causes subsidence at the surface and bulging of the vertical face of the trench. If uncorrected, this condition can cause face failure and entrapment of workers in the trench.

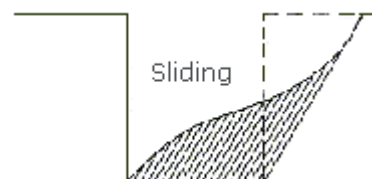
HEAVING OR SQUEEZING. Bottom heaving or squeezing is caused by the downward pressure created by the weight of adjoining soil. This pressure causes a bulge in the bottom of the cut, as illustrated in the drawing above. Heaving and squeezing can occur even when shoring or shielding has been properly installed.

BOILING. Boiling is evidenced by an upward water flow into the bottom of the cut. A high water table is one of the causes of boiling. Boiling produces a "quick" condition in the bottom of the cut, and can occur even when shoring or trench boxes are used.

TENSION CRACK



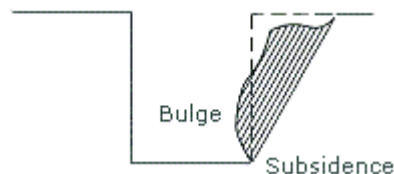
SLIDING



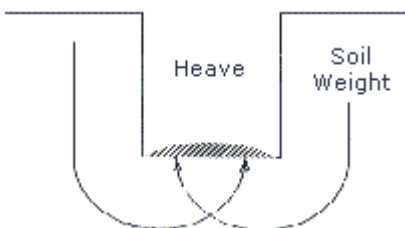
TOPPLING



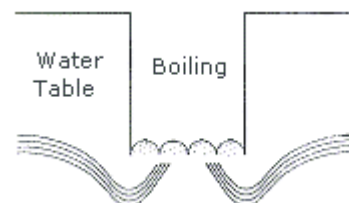
SUBSIDENCE & BULGING



HEAVING OR SQUEEZING



BOILING



8.2.7.2 Excavation—what can go wrong?

- Inaccurate construction survey (double-check the stakes for location and elevation before beginning excavation).
- Excavation slope failure.
- Intense rainstorms, erosion.
- Dewatering system failure during flood event.
- Springs within excavation area causing slope instability or generating large amounts of sediment.
- Very weak subsurface. (Contact the design engineer to determine a suitable solution, such as subgrade reinforcement or a foundations design change.)
- Bedrock is unexpectedly encountered, making redesign of footings or structure necessary.

8.2.8 Structural Excavation

The final embankment excavation, structural excavation, and removal of existing structures create the most sediment and turbidity. To capture and treat the construction water as this work proceeds, the dewatering system must be functioning properly.

To verify that the final depth and location of the excavation are correct, make an accurate survey check as the bottom of the excavation approaches the design depth. You can use a rebar or pipe probe to locate the bedrock depth.

As the excavation approaches the final depth, the design engineer should review the foundation materials to verify soil-bearing capacity, verify that conditions match design assumptions, and approve the foundation conditions. Be prepared to have the contractor reinforce soft areas with subgrade reinforcement material, such as free draining crushed rock. A geotextile may be useful as a filter and reinforcement.

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If appropriate under the contract (section 7.5.2.2), examine the material beneath the culvert and determine if any material can be salvaged. Such material may include:

- Gravel bedding for the existing pipe: This bedding may be usable for part of new culvert bedding.
- Streambed materials: The project team may decide to either keep them in place or remove them for processing with other streambed materials. Streambed materials must meet specification requirements.
 - ▲ The material may appear “dirtier” than other streambed surface materials. (This “dirt” is often only natural subsurface fines.)
 - ▲ If streambed material is removed during construction, it is often too wet and its moisture content may need to be reduced before replacement into the structure. Place it in a separate stockpile and protect from contamination from other materials.
- Soil embankment and backfill: These may meet backfill requirements for the new structure.
- All materials: Must meet contract specifications and must be tested for gradation and other engineering properties.

Keep the foundation area relatively dry. To facilitate subsurface drainage away from the work area and avoid pooling, you may find it helpful to start the excavation downstream of the structure and extend it upstream. This approach also improves the work area and reduces erosion and turbidity. Concentrate seepage into one or more flow paths; ensure that the downstream sump is deep enough and that the pump has enough capacity to keep water levels below the bottom of the excavation.

8.2.8.1 Bedrock and blasting

If the excavation encounters bedrock (or other unsuitable material) that was not detected earlier and that interferes with the foundation, contact the design engineer to identify an appropriate solution. Changes made in culvert alignment or elevation without consultation can seriously affect stream-simulation stability.

Blasting may be necessary when bedrock is encountered. Contact the project biologist before proceeding for help with developing a blasting plan. Blasting may be prohibited during certain time periods to protect

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species, such as nesting birds or listed fish. Such time periods and concerns should be listed in project National Environmental Policy Act documents. Fish near blast sites may suffer swim bladder rupture, tissue and organ damage, or internal bleeding. The damage to fish depends on the size of the charge, distance to the fish, depth of water, substrate type, and the size and species of fish (Keevin 1997).

If the design engineer anticipated blasting on the project, the contract will include FP03 section 205. If blasting is added to the contract because of a design change, include FP03 section 205 and require an approved blasting plan. The contractor must submit the plan and obtain approval in writing before doing any preparatory work (i.e., drilling) for blasting. Obtain the help of a blasting expert to review the blasting plan.

8.2.8.2 Settlement beneath foundations and pipes

Settlement should be limited to avoid adversely affecting alignment, grade, and structural shape. The amount of settlement depends on soil properties and compaction. Contact the design engineer to verify that soil conditions meet design values. If very soft materials (such as wet clay, silt, or other soft plastic fine-grained soils) are unexpectedly present, foundation soils may need reinforcement or replacement or the footings may need redesigning. Differential settlement—caused by the footing’s settling more over the soil region than the bedrock region of the foundation—will create undue stress on the structure.

Recommendations for Structural Excavation Inspection

Verify that :

- ✓ Foundation soils have been tested for shear strength and results meet design assumptions.
- ✓ Foundation excavation elevation and location are correct.
- ✓ Either the design engineer or the geotechnical engineer approved the foundation conditions.
- ✓ The contractor has completed the required compaction testing and compaction meets contract requirements.
- ✓ There is plenty of operating space for equipment for structure assembly and placement of footings, forms, steel, and concrete.

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8.2.9. Constructed Concrete Features



Figure 8.10—Concrete forms and reinforcing during concrete pour.

8.2.9.1 Concrete form inspection

When inspecting concrete forms, verify that:

- Shop drawings and contract drawings agree with each other. Resolve any discrepancies. Send a copy of the drawings to—and discuss any potential changes with—the design engineer.

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- ▲ Note that a change in arch shape may result in a change in the foundation design shape or position.
- Forms match design drawings and that dimensions are correct.
- Forms are stable and well braced to withstand the hydraulic stresses of the fresh concrete. Forms for deep footings and stem walls may require design by a licensed engineer.
- Embedded bolts and fixtures are installed in the formwork.
 - ▲ Anchor positions and angles are correct for open bottom arch location.
 - ▲ For multiplate pipes, hardware for collars and haunch beams is installed according to manufacturer's instructions. (For large complex structures, manufacturers often provide their own inspector for forms and hardware.)
 - ▲ Channels are installed correctly per the manufacturer's instructions.
- Reinforcing bars match design drawings for bar sizes, spacing, and position.
- Bars are tied down to prevent movement during concrete pour.
- Bottoms of footings are flush with excavation or plugged, to prevent concrete leaks into stream water.
- Water is diverted away from forms, if possible, to prevent diluting concrete.
 - ▲ Seal concrete is used if water is present in forms.
- The work site is safe and workers have a safe place to stand during concrete pour.

8.2.9.2 Pouring concrete

Discuss common problems and contingency plans with the contractor in advance; for example, pump trucks can plug, concrete can spill, forms can be damaged, concrete can arrive early or late, and mistakes or poor planning may cause cold joints. Concrete should be tested for quality to ensure it meets specifications.

Do not spill concrete, cement, or concrete additives into the stream. Concrete and related products that mix with water and enter live streams can kill fish very quickly because high pH levels (cement contains lye) are corrosive to fish gills.

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Special concrete placement methods may be necessary when standing or running water is present in or adjacent to forms. To avoid mixing with standing or flowing water, seal concrete (normal concrete with an extra sack of cement) may provide a more stable mass. The pump hose should touch existing wet concrete when the hose is near any water to prevent mixing the concrete with water. Ensure that water does not pond on the excavation side of forms, where it can be forced through concrete joints and wash away concrete and expose reinforcing steel.

When standing water cannot be pumped from the form, it can be displaced with the fresh concrete. Placing the concrete involves putting the concrete pump hose on the footing bottom in the lowest elevation of the ponded water. Keep the pump hose at the foundation bottom. As concrete is pumped in, the water is displaced. Avoid movement that would agitate the concrete mass and mix the cement with water, such mixing would dilute and weaken the concrete, as well as risk getting cement in the stream water.

When running water is present, place the pump hose at the source of entry to quickly form a plug. The plug seals the leak during the concrete pour and leaves the hose submerged in the concrete. As you encounter other leaks, plug them in the same manner.

8.2.9.3 Inspection recommendations for concrete placement

Before the pour, verify that:

- ✓ The concrete design mix was approved including admixtures.
- ✓ The foundation forms have been approved.
- ✓ Test equipment and test cylinders are onsite before the first concrete truck arrives.
- ✓ The contractor's equipment is checked and operable (pump if applicable, vibrator and a spare).
- ✓ There is adequate access for equipment and personnel before concrete is ordered.
- ✓ A safe and appropriate place to dump excess or reject concrete has been designated.
- ✓ A safe and appropriate place to wash out the interior of the concrete mixer has been designated.

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During the pour, check that:

- ✓ Concrete is not outside the allowed time, and slump or percent air is correct. (Otherwise, reject the concrete.)
- ✓ Forms do not shift and fail. If this occurs, stop the concrete pour and repair forms. Concrete delivery may have to be delayed and concrete already onsite may have to be dumped.

Most things that go wrong on a concrete pour—if not solved immediately—lead to a cold joint. If necessary, prepare the joint before the concrete hardens with a rough unfinished surface to develop effective friction. When lateral forces are high, form keyways to increase the shear strength of the joint.

Contact the design engineer for advice on correcting mistakes on any concrete pour.

8.2.10 Culvert Installation

8.2.10.1 Closed-bottom culvert bedding

Closed-bottom culverts require bedding material to be placed and shaped to match the bottom of the structure. The top of the bedding should conform to the design elevation, slope, and alignment of the pipe. Have the contractor place the soil tight against the structure to prevent subsurface stream flow and to develop soil-structure stress interaction.

Verify the following for the culvert bedding:

- ✓ Bedding material is the correct gradation and thickness.
- ✓ Bedding elevation and alignment match the design elevation for the structure inverts.
- ✓ Bedding shape reasonably matches pipe shape in approximately the center third of the pipe before placing pipe. (See figure 7.9.) A plywood form may be useful for shaping the bedding.
- ✓ Bedding is sufficiently compacted to prevent culvert distortion during bedding and backfill operations. The following two methods are typically used to avoid leaving voids in the culvert bedding:

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- ▲ Voids beneath the culvert are filled by pushing and tamping bedding material into place.
- ▲ Voids are filled with low-strength, high-slump (flowable) concrete called “controlled low strength material.” This material is used in place of shaped and tamped bedding.

With controlled low-strength material (CLSM), ensure that the contractor secures the pipe by placing some of the stream-simulation bed material inside, or by weighting the top of the pipe with soil (to keep it from floating as the heavy CLSM flows under the pipe). To avoid distortion, check that the pipe is fully assembled before contractor places backfill material or CLSM.

8.2.10.2 Open-bottom culvert attachment

Open-bottom structures have footings usually made of concrete, steel, or aluminum. Open-bottom culverts come in a variety of shapes, including metal half-circle arches, low-profile arches, and boxes; high-profile arches, pear shapes, and ellipses, as well as concrete boxes. These structures attach to footings with bolted connections or grouted slots. Be aware of the manufacturer’s requirements, including any certifications required to install their products.

For attachments, verify that embedded bolts and fixtures, and grouted slot-type culvert attachments, meet contract requirements and, if applicable, shop drawings. See figure H.11.

When metal footings are used for open-bottom arches, placing some stream-simulation material between the footings before full pipe assembly is possible, as long as backfill on the outside of the footing is brought up in equal lifts. This method is risky, however, because the footings can shift, making the remaining arch assembly difficult or impossible without resetting the footings.

8.2.10.3 Pipe assembly

All pipe segments require careful handling and alignment to maintain their shape, so they can be properly joined to form a watertight seal. Pipe transporting and handling must be according to manufacturer’s recommendations to prevent damage and assure proper fit. Concrete box culverts are rigid and easily aligned for a tight fit. Metal pipes are flexible,

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depending on their material, thickness, corrugation depth, and dimensions. To slide into proper position, they often need small adjustments during placement.

Leaks can lead to loss of water from the stream-simulation bed or piping of backfill outside the culvert, leading to eventual structure failure. Metal pipe joints are very susceptible to differential movement and shape change during the backfill operation. Deflection and variations in shape of the pipe on either side of the joint can result in joint leaks. Careful assembly is critical to making a leak-proof joint. The joints are either grouted or sealed with waterproof joint wrap, according to the manufacturer's recommendations. For information on pipe couplings for metal pipes, see National Corrugated Steel Pipe Association Installation Manual.

Pipe Assembly Inspection Checklist

- ✓ Check for careful handling of pipes upon delivery, transport to location, and assembly to ensure that they are within shape tolerance and that watertight joints are constructible. Reject materials that do not meet specification (reference AASHTO Standard Specification M36-01 for corrugated steel pipe manufacturing tolerances, zinc coating, etc.)
- ✓ Verify that culvert materials match those specified in the contract.
- ✓ Review coupling materials and installation instructions to ensure that the couplings are properly fitted around the entire pipe joint.
- ✓ Reject leaking joints. (The manufacturers and the design engineer can help solve joint problems.)

8.2.10.4 Multiplate pipes

Multiplate pipes are manufactured in a wide variety of shapes. They consist of multiple corrugated metal plates assembled with bolts and tightened to a specific torque. Because the weakest places in a multiplate pipe are the joints, make sure that all required bolts are installed and tightened to specifications.

Small multiplate pipes may be assembled offsite and placed in one piece. They are not designed to be coupled together in segments like one-piece

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pipes. Instead, they can be partially assembled, placed, and the remaining plates can be bolted on later one at a time. Large multiplate pipes are usually assembled in place. Wide-span multiplate structures sometimes have special assembly requirements. The manufacturer may either send its own inspector or provide guidelines for monitoring shape during assembly and backfill operations. Obtain details covering structural plate installations from the pipe manufacturer, particularly on large structures.

8.2.10.5 Backfill and embankments

For embedded pipes, begin backfilling as soon as bedding is completed and the structure is in place. For open-bottom arches with footings poured in place, backfilling can begin as soon as the concrete has cured long enough (i.e., usually 80 percent of full specified strength) to withstand backfill forces up to the top of the footings. After the arch or box is in place, place the remaining backfill. Leave the dewatering system in place until the backfill is high enough to prevent the stream from flowing along and outside the structure in the event of a sudden storm. The inspector should monitor the shape of metal culverts during backfill and compaction. Many structures require a specific width of special structural backfill on either side of the structure.

Backfilling Tips

- Place backfill at the proper moisture content in thin lifts, according to the specifications on both sides of the footing or culvert.
- Ensure that all backfill material meets the project specifications, especially within special backfill zone areas next to the structure. (Controlled compaction is required on most culvert installations. Check the specifications; the contractor is usually required to provide quality control testing.)
- To prevent damage to the structure, use hand-operated compaction equipment near the structure (e.g., hand-operated in confined areas and machine-compacted in broad areas).
- To prevent damage to the structure, provide a fully compacted, minimum cover height above the pipe before allowing construction equipment or other traffic to cross the structure. Construction equipment may require more cover than design traffic; check fill height tables for the structure or check with the manufacturer.

See National Corrugated Steel Pipe Association Installation Manual for additional information on installing culverts.



Figure 8.11—Example of uneven backfill and compaction. The right side was backfilled before the left side instead of even lifts on both sides, causing the distortion visible in this photo. The distortion induces eccentric loadings on the footings, as well as bending stresses at the anchor bolts on both footings.

8.2.11 Stream-simulation Bed Material Placement

The most important detail of a stream-simulation project is the streambed which, when constructed properly, will enable a variety of aquatic organisms in the stream to travel up and down through the structure at will. Large flood events are likely to occur during the life of the structure. Therefore, the quality of construction is critical to developing the design channel form with the energy-dissipating structures (inside the stream-crossing structure) that ensure sustainability over time.

Contract drawings will show, at a minimum, a shaped streambed in the structure, usually sloping downward toward the center to form a low-water channel. Other features common to many sites include cross-channel steps formed with large rocks, raised stream banks along the interior culvert edges, and fields or clusters of large rocks (figure 8.12). Sills (see section 6.2.2.4) are occasionally attached to the culvert before bed placement, to help support rock steps in the culvert. Their design is unique to each project.

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Figure 8.12—Newly constructed (2007) step-pool channel inside culvert on Eustache Creek, Lolo National Forest, Idaho. Two visible rock weirs (steps) have their lowest points offset to provide some sinuosity at low flow. The top of the sloped banks is bankfull elevation.

Review the stream-simulation design and the natural streambed with the design engineer, and examine local features and discuss placement details with the contractor. If the streambed design needs modifying for any reason, contact the design engineer immediately to fix the problem before making any changes. Failure to understand all of the stream-simulation parameters can easily lead to error during construction and result in failure of the stream-simulation bed.

8.2.11.1 Size of streambed materials

The gradations, depth, configuration, and extent of the streambed materials are provided in the contract (section 7.5.3, figure 7.18). Review the contract specifications and drawing details, especially the streambed rock gradation, to determine the size and gradation of the mix. To ensure that the correct materials are obtained and that they are correctly placed inside the structure, discuss these details with the design engineer and contractor in advance. The gradation of the streambed materials is critical to the performance of the streambed simulation.

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Table 8.2—Example of a stream-simulation bed material recipe

% Passing	Sieve Size	% Volume	Volume	Material Source Identified
100	12 in	16% of volume is 6 to 12 in	1cy	Boulders borrowed from: glacial outwash borrow source
84	6 in	34% of volume is 1.5 to 6 in	2cy	Unwashed river dredging from McKenzie River
50	1.5 in	34% of volume is 0.5 to 1.5 in	2cy	same
16	0.5 in	16% of volume is 1/8 to 0.5 in	1cy	same
5	0.125 in	5% of volume is smaller than 0.125 in	0.3cy	Excess excavation from coarse sand-silt road embankment soil

The contract should specify streambed material sources. Sources may include onsite material, borrow sites, quarry sites, road maintenance rock fall debris piles, and commercial quarries. Material produced in a quarry can be crushed and screened to the proper gradation. Very large boulders may be hard to obtain from some quarries, but are sometimes available on site in the form of old riprap or colluvium. The design engineer should have identified such material in the contract.

If the material comes from different sources, gradations and quantities of the individual materials will have to be determined to establish a recipe for the mixture. The mix recipe states the proportions of each material type in the mix, and the mixed material requires testing to ensure the proper gradation is being supplied. When reviewing stockpiles of materials for suitability, familiarity with and use of the pebble-count method—for estimating the volumetric or weight-based material gradation—is useful. Channel rocks are generally large and easy to measure. Samples of smaller bed material (see section 7.5.2.2) can be taken to a laboratory for sieve analysis. Use standard submittal procedures for the stream-simulation bed mix recipe (table 8.2) if the contractor is responsible for it. Have the design engineer review the mix design (recipe) before allowing delivery of the materials to the site.

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Regardless of the source(s), make sure that the materials from different sources are well mixed. If materials are mixed onsite, be sure the mixing area is large enough to accommodate all the stockpiles and equipment. If the mixing is done elsewhere, be aware that transport can cause mixed materials to segregate somewhat. Do not attempt to mix the material inside the structure.

8.2.11.2 Constructing the simulated streambed

This is a critical step in the project construction. The inspector and a project team member should be on site to review the constructed bed and ensure that the final shape, slope and details are correct before rerouting water through the structure.

Final bed height should be measured at the center of the surface pieces, not at the top of the largest rocks.

If necessary, wash the surface to force fines deeper into the bed to reduce the permeability of the bed (figure 7.14). The sump pump may be used for washing the bed material in with water from the sump. The downstream sump will capture sediment generated during the washing.

General Inspection Checklist for Placing Streambed Materials (all structures)

Verify that:

- Gradation of stream-simulation bed materials meets specifications.
- Specified compaction methods are followed for every lift.
- Material is carefully tamped around large rock features, to provide good interlocking and low permeability.
- Voids in stream-simulation bed material are filled after each lift by washing filler material into the voids and tamping by hand.
- Elevations are correct during placement to ensure the bed surface is shaped correctly.
- Fill elevation line is painted accurately on the inside of the pipe for the contractor and for monitoring after construction.
- Grade stakes for the bed are accurately placed, especially where the bed extends outside the structure.

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- Large channel rocks are incorporated into the first or second upper lifts and placed as shown in the drawings (this step is important as the channel rocks are embedded in the stream-simulation bed material—not placed on top of it).
- Proper equipment is used for more delicate work.
- The stream-simulation bed is the proper shape according to the drawings.

8.2.11.2.1 Recommendations for placing material in open-bottom arches

Constructing a streambed in an open-bottom arch is relatively easy, because the material can be placed before the arch is set in place (figure 8.13). Headroom does not limit the size of the equipment as in closed structures. An excavator is usually used for placing bed materials, and tracked or rubber-tired equipment can be used for compacting the bed.

- Place the bed, compacted in layers, at the same time that the backfill outside of the footing is being compacted (figure 8.14). This should prevent the footing from moving, and avoids excessive horizontal loading on the stem walls.
- Use proper compaction equipment to ensure there is no damage to the structure as well as to provide proper compaction.



Figure 8.13—Machine placing stream-simulation material. It took 4 days to place 600-cubic yards.

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Figure 8.14—Newly constructed stream-simulation bed for a bottomless arch. The stream-simulation bed material is manufactured rock from a commercial source. Footing backfill and stream-simulation bed material were backfilled and compacted at the same time. Placing the stream-simulation bed is much easier before the structure is in place.

8.2.11.2.2 Recommendations for placing material in embedded pipes

Since embedded pipes are closed structures filled nearly half-full with streambed material (figure 8.15), installing the streambed usually requires hand labor or small equipment (e.g., rubber-tired loaders, garden-sized tractors and trailers, small dozers that can run on a cushion of previously placed bed material).

- Take precautions to avoid damage to the galvanized coating in steel pipes during bed placement.
 - ▲ Do not push material along the culvert bottom; pushing removes galvanizing, speeding up corrosion of the culvert and shortening the life of the structure.
 - ▲ End-dump streambed materials.

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- Use rubber-tired equipment whenever possible, to avoid accidental steel-track damage to the structure.
 - ▲ If the contractor must use a tracked vehicle, place a cushion of fine streambed material in front of the vehicle, deep enough to spread the load and protect the culvert invert from the track grousers.
- Avoid overfilling buckets, and remove spilled material from the travel path.
- The contractor may use hand labor to place streambed materials. With smaller structures, hand placement is often the only option (figure 8.16).

Once material is dumped, it can be spread by hand (or by machine, if clearance allows). A good way to place the bed material is working up from the downstream end, and placing lifts on an angle sloping down in the upstream direction. This technique allows dumping, spreading, and compacting subsequent loads on this slope while maintaining maximum headroom for the remaining length of the culvert for transporting material. It is also a good way of meeting placement and compaction requirements, and it facilitates placing larger channel rocks in the culvert. In small culverts, it is easiest to place lifts full length in the culvert.



Figure 8.15—Bobcat placing bed material to marked elevation.

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Figure 8.16—Assuring proper cross-section shape, rock-band spacing and placement of channel rocks and footers often require hand work.

8.2.11.2.3 Placing channel rocks

Placing channel rocks is a somewhat subjective aspect of construction, calling for careful observation of the existing channel. Depending on the project, some features will need well-interlocked rocks in some places and individual or clusters of rocks elsewhere. Because the placement process is very difficult to specify precisely, it is a difficult procedure to enforce. To make the job more difficult, since the channel rocks are embedded, they must be placed during the construction of the stream-simulation bed and the bed material must be compacted around the channel rocks.

- Check the contract for sizes and any shape requirements of channel rocks.
- Check the contract for details for the locations and placement of channel rocks (figure 8.17).
- When constructing steps with footers, footers should extend deeper than the projected depth of pools that will form in the future.
- Because machinery is necessary for moving large rocks, use care to avoid damaging the structure.

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- Positioning large rocks often requires fitting them together so that they interlock for stability. This often requires several attempts to obtain an acceptable fit.
- Pack with finer material by hand, or place by machine and wash fines in for a tight, stable fit.

Figure 8.18 illustrates the difference between loosely and tightly packed rock structures—both scenarios are important in stream simulation. With few exceptions the rocks in figure 8.18(a) are not well interlocked. In most cases, individual rocks can move independently. The step in figure 18(b) is tightly packed and the rocks are well interlocked. Moving any piece requires moving adjacent pieces as well. Well-interlocked rock is much more stable in a stream channel.

8.2.12 Permanent Erosion Control Measures

Permanent erosion control measures may include conserving and replacing topsoil; planting erosion-control grasses, ground covers, and larger plants; and placing individual rocks, riprap, logs, reinforced slopes, or retaining walls for bank stabilization. Although most of these are outside the scope of this document, they may be included in the contract.

The project should have provisions for stabilizing banks disturbed by construction, and may include provisions to mitigate some anticipated post-construction stream-channel changes. These provisions may include large wood, root wads, biotechnical plantings, plant cuttings, large rock placements, or special stream structures. As these features or structures may be unfamiliar to the contractor and the inspector, contact the design engineer for assistance for placing these structures. Pay special attention to the quality of work on these structures. To withstand multiple flood events during the life of the structure, they will need solid construction.

8.2.12.1 Revegetation

The planned vegetation may have specific planting requirements, and it may require water or mulch during dry spells. Some projects may require an irrigation system to adequately water the plants. Erosion control fabrics or mulch may be placed to stabilize soil while vegetation becomes established. For a discussion of common problems with revegetation and erosion control, and their solutions, see appendix G.4.3.

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COOK CREEK STREAM CROSSING STEP-POOL STEP DETAILS

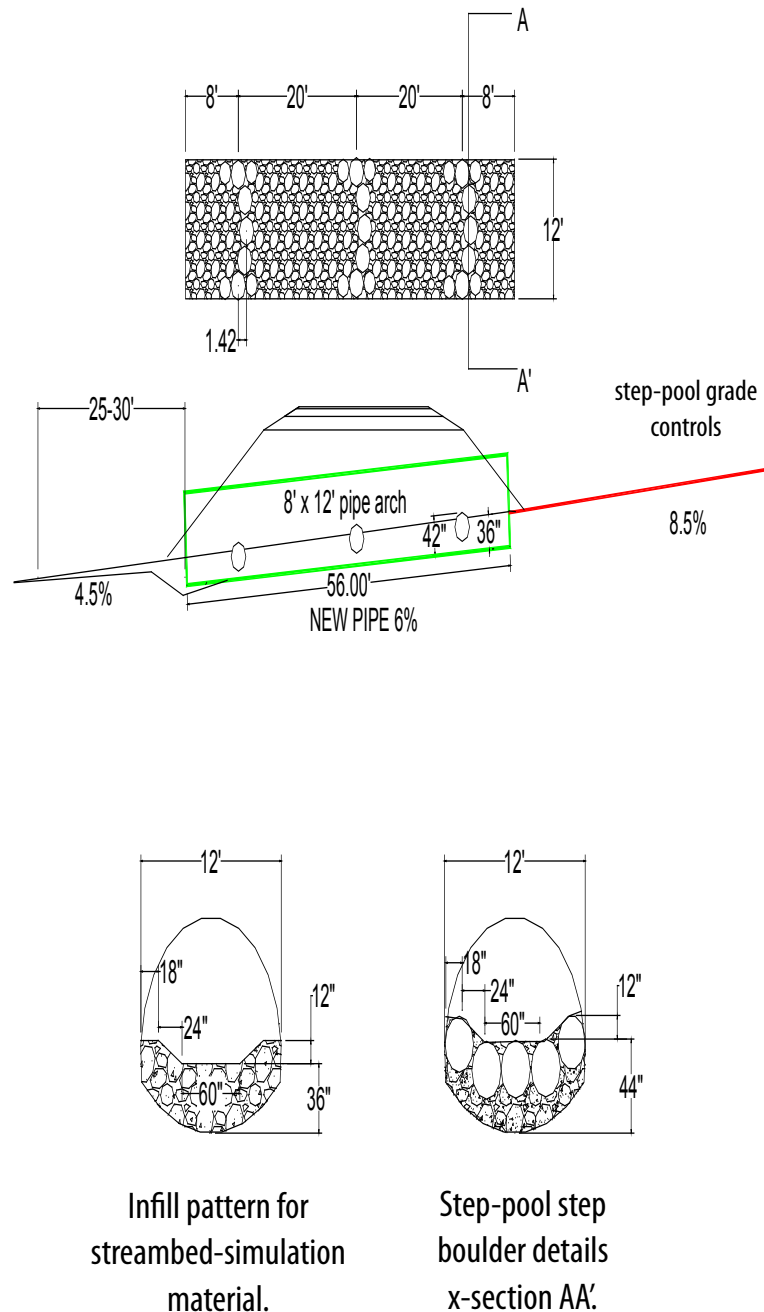


Figure 8.17—Stream-simulation bed details.

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Figure 8.18—Streambed features such as steps must be well interlocked to withstand large flood events.
(a) Poorly interlocked rock; (b) a tightly interlocked rock step.

8.2.12.2 Riprap inspection

Riprap commonly is used for stabilizing streambanks at culvert entrances, channel edges, embankments, and steep slopes. Over-steepened slopes can be stabilized with a thin layer (rockery) or thick layer (buttress).

Riprap is designed to be a well-graded but free-draining material because it lacks fine aggregates. Riprap is much more stable when well graded; a cluster of large rocks does not have the same interlocking forces as well graded riprap material. To be stable in a stream setting when covering a streambank, either the riprap must sit on a stable surface such as bedrock, or a foundation of riprap must be constructed below the possible scour zone to support the mass.

Riprap design generally includes:

- Enough thickness (twice $D_{\max}$) to provide good interlocking with other riprap materials.
- A maximum slope limit of 1:1 (1½:1 is preferable).
- Geotextile behind and beneath to prevent piping of soil through the riprap (piping can eventually undermine the riprap's stability).

Inspectors should check:

- ✓ Riprap gradation by measuring individual pieces. Adjust riprap gradation as necessary to obtain specified gradation.
- ✓ The staking for the riprap limits.
- ✓ The specified placement method.
- ✓ The final product for thickness, interlocking, slope, height, and width.
- ✓ Riprap is placed flush with the existing channel edge to avoid restricting the stream channel (requires excavating the streambank).

8.2.13 General Road Construction

- Ensure that road construction does not damage the structure.
- Ensure loose soil is not spilt where it will erode directly into the stream without being treated.
- Make sure that survey-control points are protected. If control points are disturbed or destroyed by construction, the contractor may have to provide additional surveying or even roadway design.
- Check the embankment slope, width, and height during construction. Correcting an error in the embankment after construction is complete is both difficult and costly.

8.2.13.1 Roadway drainage structures

- Make sure that road surface runoff drains into areas that can filter the water before it enters the stream directly.
- Configure road dips or surface-shape changes to divert road-surface runoff before the stream crossing. Make sure that outsloped roadways drain onto stable landforms.
- Ensure that culverts draining onto disturbed areas have downpipes or other means to carry water beyond vulnerable areas.
- In erosion-prone areas, spread slash, straw, or other erosion-control materials to stabilize bare soil.

For diversion prevention dips (see 7.7.2.1)

- Make sure that longer tapers and gentler rate of grade change are provided where lowboys must be accommodated (figure 8.19).
- Verify that downslope erosion protections are in place.
- Plug any downgrade ditches or other escape routes to prevent downgrade flooding of the roadway.
- Ensure that aggregate surfacing is spread evenly throughout the dip. A very common mistake is to grade the aggregate surfacing thin at the high part of the dip and thick at the low part of the dip, thereby seriously reducing the capacity of the dip.

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Figure 8.19—The grade change at this dip is too severe to accommodate a lowboy, which has high-centered on top of the dip..

8.2.14 Demobilization/Cleanup

Check the contract and specifications for any special requirements. Always ensure that the following items have been taken care of:

- ✓ All construction debris cleaned up, hauled off, and disposed of according to specifications, special contract requirements, and local regulations.
- ✓ Campsites cleaned up according to specifications and special contract requirements.
- ✓ Hazmat items removed and cleaned up according to specifications, special contract requirements, and local regulations.
- ✓ Sediments cleaned or washed from roadways according to specifications and special contract requirements to prevent washing directly into the stream.
- ✓ Stockpile areas, waste areas, and aggregate pits treated and cleaned up according to specifications and special contract requirements.
- ✓ Temporary erosion and sediment controls removed and cleaned up. Trapped sediments removed and properly disposed of.
- ✓ Drainage and final erosion control measures in place and functional.

8.3 POST CONSTRUCTION

8.3.1 Post-construction Project Review

After construction is complete, an extremely important step—and the final item on the project timeline—is the post-construction project review. Even though this review process is time-consuming, review the project from beginning to end—and beyond. Your review observations on this project will contribute invaluable insight for the success of future projects. Include answers to the following questions:

- Overall thoughts and impressions
 - ▲ Was the project a success?
 - ▲ What went well with the construction?
 - ▲ What problems were encountered?
 - ▲ How were these problems solved?
- Project development and design process
 - ▲ How well did communications work?
 - ▲ Did you have the proper mix of project team members?
 - ▲ How would you assess the available skills?
 - ▲ Is the proper skill mix available within the organization?
 - ▲ Should the agency solicit more specialized help for the next project?
- Advertisement and solicitation for bids/proposals
 - ▲ Was the prebid meeting helpful? Could it be improved? Did it answer all questions? If not:
 - ▲ Did the amendment process answer all questions?
- Construction
 - ▲ Was the contract adequate?
 - ▲ Were specifications clear and sufficient?
 - ▲ Did you have special contract requirements?
 - ▲ Were the drawings accurate and clear?
 - ▲ Were the supplemental specifications clear?
 - ▲ Were design and project team personnel available for promptly solving unforeseen issues?
 - ▲ How would you rate the contractor's performance (necessary for best value contracting)?

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Reviewing and discussing the development of the project—and the time and people involved—is extremely beneficial to all team members and the organization as a whole. The discussion should lead to the following questions (and probably more):

- How would you go about project planning and development for future projects to improve the overall process efficiency, communications, design quality, and project overhead costs?
- What worked well on this project? What did not work well? How would you avoid those issues on the next project?

8.3.2 Post-construction Monitoring

Post-construction monitoring provides invaluable information, not only about the design and construction of the particular project, but also about how to improve aquatic organism passage design in general. Detailed review and analysis of project features, such as the structure, stream simulation bed, any stream restoration, and erosion control features, will provide very useful information. These lessons learned add to the knowledge base for developing informed decisions on future projects.

8.3.2.1 Physical monitoring of structure performance

A convenient method for physically monitoring the structure is the bridge inventory. The method uses a standard form listing physical features and conditions of bridges and major culverts, and it adds physical information into the INFRA database and the Federal Highways National Bridge Inventory. Major culverts—which many stream-simulation projects are—are included in the inventory.

Monitoring to date shows that most stream-simulation structural failures are due to poor bedding material placement, poor backfill compaction, unstable footing design, and flood damage where pipes or bed material were undersized.

8.3.2.2 Physical monitoring of streambed performance

The Forest Service culvert-assessment procedure (Clarkin et al. 2005) includes observations of streambed depth and continuity through the structure, as well as basic culvert details. Many recently inventoried culverts have this information and it should be kept up to date as culverts are replaced. The assessment procedure has been modified and expanded

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for use as a monitoring tool on some forests. Forms modified for monitoring include observations and measurements of general channel changes both in the stream and in the structure.

Here are some simple observations for monitoring the success of a stream-simulation project:

- Overall examination: Is there a continuous channel through the culvert, without excessive jumps or velocity barriers?
- Photos taken from the same points year after year, with the same camera or lens.
 - ▲ Inlet upstream and downstream.
 - ▲ Outlet upstream and downstream.
 - ▲ Bed details.
 - ▲ From the road upstream, downstream, and along road both directions.
 - ▲ Other strategic points: Specific stream features or areas expected to undergo changes such as scour and deposition.
- Presence of bed material in the pipe: What has changed?
- Stability of constructed bed forms: What has changed?
- Bed material depth measurement from the top of the culvert, and references painted on the culvert wall.
- Long-profile survey for comparing channel adjustment over time.
- Either channel cross sections near the culvert and in strategic spots, or a complete site plan (which is sometimes quicker and more informative) for monitoring channel alignment changes.

The amount of data you collect will depend on your monitoring objectives, and your ability to analyze and keep track of the data. Commonly cited problems in both embedded pipes and open-bottom arches involve bed material scour.