

Stream Simulation

Steps and Considerations in Final Design

Select structure type

- Project objectives and stream-simulation sustainability
- Fill height
- Construction issues
- Costs

Design the crossing installation

- Foundations or bedding
- Structure
- Mitigate failure potential

Specify streambed materials and placement

- Gradation
- Key features, bedforms, banks, grade controls
- Bed elevation
- Auxiliary grade-control structures up- and/or downstream of crossing structure

Specify dewatering and water quality protection requirements

- Diversion system
- Animal protection and removal
- Sediment treatment system
- Rewatering

Provide for short-term pollution control

Provide for long-term stabilization (revegetation)

RESULTS

Contract solicitation package

Figure 7.1—Steps and considerations in final design.

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7.1 PHASE OVERVIEW

The previous chapters presented the tools needed for designing the stream-simulation channel, including size and orientation, streambed characteristics, and restoration needs outside the culvert. The next task is to finalize the design for the installation as a whole: to verify the engineering plans for both the crossing structure and the roadway, and to prepare the documents necessary for soliciting bids for construction.

At this point in the project the focus shifts to completing important design details, and project responsibility passes from the project team to the design engineer. The design details discussed in this chapter are either unique to stream-simulation projects or require more emphasis because the projects are generally bigger and take longer to construct than traditional culverts.

This phase of project design can be accomplished either with in-house resources or by contracting (or a combination of the two methods.) The assumption that Architectural and Engineering contractors require only minimal oversight can lead to poor results. As a minimum, the agency must have a staff with a level of technical expertise that allows them to recognize poor or inaccurate work, as well as enough skilled people to provide prompt and proper technical oversight for the contracted work. The design engineer is responsible for recognizing and correcting situations where expertise is not represented adequately within the team. Whether the final design is done in-house or by contract, the final product must be the same quality.

Develop construction drawings from the site plan produced during the site assessment (see section 5.1.2). Along with the original topography, the new plan includes profile and cross-section drawings of the new structure and its related channel features, details of the roadway, and other project details. This development process may take a few days to several weeks (depending on the complexity of the site,) and is often the most time-consuming part of design and contract development.

As you develop the detailed contract drawings of the stream-simulation design, numerous questions may arise that require consultation with the project team. This need for consultation, along with possibly short deadlines, will always add pressure and confusion to a project. Nevertheless, you should be proactive, communicating regularly with other members of the project team to solve design issues. Both the inspector

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and the contracting officer's representative (COR) can offer valuable information and assistance, particularly about construction techniques for difficult sites. Integrate these experts into your design team as the design progresses and include them in all pertinent communications. Definitely involve the COR in decisions about what aspects of the dewatering and erosion and pollution control plans must be performed inhouse.

Finally, assemble all elements of the project into a package that includes drawings, specifications, supplemental specifications, special contract requirements, and the contract boilerplate. The contracting officer then offers the contract package to the public for construction bids. The specifications and special contract requirements cover elements of the design that the detailed drawings cannot adequately describe. When the standard specifications do not adequately describe the work, write supplemental specifications to modify them. The Forest Service uses *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects* (FP-03: FHA, 2003b) for standard specifications. See appendix H for sample supplemental specifications. Special contract requirements (Federal Acquisition Regulations Section H—part of the contract boilerplate) cover other aspects of the project, such as water quality and environmental protection. Appendix H also includes examples of special contract requirements.

Construction BMP Checklist

While completing the final design, consider the following list of BMPs that will help minimize sediment in the stream. These BMPs should be in the back of your mind as you make decisions on the project. Even as early in the final design as structure selection, **BMPs** can influence your decisions. Different types of structures involve different levels of site disturbance and different lengths of time for construction. All of the items on the BMP list are discussed in detail in either this chapter, chapter 8, or appendix G. Where ever appropriate, include these items in the contract to provide proper control during construction. To include them, place them in the specifications, the special contract requirements, or on the drawings.

BMPs are usually required in construction permits

Federal, State, and county permits often include required BMPs and performance standards (e.g., turbidity requirements). Apply for permits early, because these requirements must be in the special contract requirements, the erosion control plan, and may need notes and details in the drawings.

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Stormwater Management, Erosion, and Sediment Control

- Minimize bare ground.
- Minimize impact to **riparian vegetation**.
- Prevent excavated material from running into water bodies and other sensitive areas.
- Use appropriate erosion barriers (silt fence, hay bales, mats, coir logs).
- Dewater before excavation.
- Manage sediment-laden water encountered during excavation.
 - ▲ Sediment basins.
 - ▲ Fabric, biobag, or hay-bale corrals.
 - ▲ Sand filter.
 - ▲ Geotextile filter bags.

As a quick check (not to replace required monitoring,) be sure that the turbidity of water 100 to 200 feet downstream of the site is not visibly greater than turbidity upstream of the project site.

Dewatering

- Minimize the extent and duration of the hydrological disruption.
- Consider using bypass channels for maintaining some river and stream continuity during construction.
- Develop a storm management plan.
- Use dams to prevent **backwatering** of construction areas.
- Gradually dewater and rewater river and stream segments to avoid abrupt changes in streamflow and water temperature.
- If fish are present, prevent them from entering the construction site by placing block nets at the upstream and downstream ends of the dewatered section.
- Salvage aquatic organisms (fish, salamanders, crayfish, mussels) stranded during dewatering.
- Segregate clean bypass water from sediment-laden runoff or seepage water.
- Use antiseep collars.
- Use upstream sumps to collect ground water and prevent it from entering the construction site.
- Collect construction drainage from ground water, storms, and leaks, and treat it to remove sediment.
- Use a downstream sediment control sump to collect water seeping out of the construction area.
- Use fish screens around the bypass pipe intake.
- Use appropriate energy dissipators and erosion control at the outlet.
- Make sure to have adequate pumping capacity for handling storm flows.

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Pollution Control

- Wash equipment to remove leaked petroleum products and avoid introduction of invasive species.
- Repair equipment before construction to minimize leaks.
- Be prepared to use petroleum-absorbing “diapers” if necessary.
- Locate refueling areas and hazardous material containment areas away from streams and other sensitive areas.
- Establish appropriate areas for washing concrete mixers, and prevent concrete wash water from entering rivers and streams.
- Take steps to prevent leakage of stockpiled materials into streams or other sensitive areas (i.e., locate the stockpiles away from water bodies and other sensitive areas, use sediment traps, cover during heavy rains).

Streambed and Banks Within Structures

- Check construction surveys to ensure appropriate slopes and elevations.
- Use appropriately graded material that has been properly mixed before placing it inside the structure.
- Avoid segregation of bed materials.
- Compact the bed material.
- Wash in fines to ensure that fine materials fill gaps and voids.
- Construct an appropriate low-flow channel and **thalweg**.
- Carefully construct any designed bed forms to ensure functionality and stability.
- Where included in the design, construct well-graded banks for roughness, passage by small wildlife, and instream bank-edge habitat.
- Tie constructed banks into upstream and downstream banks.

Soil Stabilization and Revegetation

- Ensure soil surface is rough enough to collect seeds and moisture.
- Implement seeding and planting plan for both short-term stabilization and long-term restoration of riparian vegetation.
- Water the vegetation to ensure adequate survival.
- Use seed, mulch and/or erosion control fabrics on steep slopes and other vulnerable areas.
- Avoid jute netting (which has been known to trap and kill fish and wildlife) near streams or rivers.
- Avoid placing gabions in contact with the stream (for the same reason as above.)

Timing of Construction

- Generally, time construction for periods of low flow, observing any required work windows.
- Ensure all lifestages of resident aquatic species are protected adequately during construction.
- Consider whether construction should be limited during periods of high flows.

7.2 CROSSING STRUCTURE SELECTION

Search for specific products that will meet the stream, roadway, traffic, and construction needs according to earlier design decisions (see chapter 6.) A wide variety of structures may fit the site criteria, such as circular pipes, pipe arches, concrete or metal boxes, open-bottom concrete or metal arches, and many bridge types. All have their specific advantages and disadvantages. Use the structure type that best fits the specific needs and objectives of each crossing.

Developing a pool of local knowledge by gaining experience with various stream types and roadways is important. Study and compare options, and monitor projects objectively after construction. The goal is to learn which structures best meet project objectives by comparing their total costs (for example, planning, design, administration, contract, maintenance, replacement, and salvage) to the benefits they offer (for example, aquatic species passage, and long-term maintenance of channel form and function).

Stream-simulation sustainability influences structure type selection because the structure must accommodate the potential variation in channel alignment and bed elevation (section 6.1.) over its lifetime. Structure width and embedment depth were determined in chapter 6 and usually by now the project team has identified a tentative structure type. However, as you draw the structure and fit it into the site, better ways to meet project objectives may become evident. Construction objectives, such as the duration of construction, also may be important. With input from the project team, develop structure alternatives and identify costs, risks, site impacts, and effectiveness in meeting site objectives. The project team should review the alternatives and make a final decision on the structure choice before you proceed to the remaining design details.

One-piece embedded metal pipes are usually used on small streams because of their low cost and generally simple installation. Actual width is limited to what can be legally hauled to the site. Larger road-stream crossings may be constructed with a wide variety of structure types (see figures 7.2 through 7.6).

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Figure 7.2—1-piece corrugated metal pipe (embedded).



Figure 7.3—1-piece corrugated metal pipe arch (embedded).



Figure 7.4—1-piece open-bottom arch.



Figure 7.5—Multiplate open-bottom pipe arch.



Figure 7.6—Multiplate open-bottom box.

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While the design of a stream-simulation structure is based primarily on accommodating natural stream function, the roadway also influences the selection of the structure type, height, and length. Road-design (as opposed to stream-simulation design) features that will influence structure selection include:

- Rights-of-way limits.
- Road and site geometry.
- Traffic handling during construction.
- Initial and lifecycle costs.
- Lifespan.
- Risk.
- Environmental impacts caused by the construction.

Where more than one alternative satisfies the design criteria, consider designing several alternative crossings for the contract and advertise them as separate alternative bid items, so that the final design structure is based on cost. You can also define specific design criteria and request that a design firm analyze possible alternatives. Using more than one alternative is particularly useful when analysis of the alternatives requires design skills that are not readily available.

7.2.1 Site Geometry

Nearly all parameters of the site geometry influence structure design and selection. To ensure that all traffic can pass safely over the site, base the road width, horizontal and vertical alignment, and curve widening on standard geometric design methods. The following checklist indicates important roadway factors that affect the position, length, and shape of the structure:

- Horizontal and vertical alignment.
- Skew of structure to road centerline.
- Adequate curve widening.
- Adequate sight distance.
- Road intersections.
- Adequate fill cover over the crossing structure for the life of the structure.

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- Vertical curves and road surface.
- Type and thickness of roadway surface, shoulders, and slough widening.
- Widening for curbs and guardrail, where required.
- Proximity to existing utilities, both buried and overhead.

7.2.1.1. Dipping the road profile to prevent stream diversion

Where a risk of **debris** plugging and embankment overtopping exists, the stream-simulation design will call for a dip over the crossing structure or adjacent to it, down grade. This dip will prevent the stream from running down the road if the culvert overtops. Check the remaining fill height to see which structures will fit under the road grade with sufficient cover. On relatively low fills, a dip may mean that a low-profile structure is needed (see table 7.1). Consider how normal erosion and road grading will affect cover over the structure during its life. To maintain adequate cover to protect the structure, it may be necessary to add measures such as informative signs for maintenance crews or paving/hardening the dip.

7.2.1.2. Low embankment options

When the height of the road embankment is low compared to stream width, consider using a low-profile structure. Each culvert has a unique range of cover heights—that is, where the culvert will support the design load without failure. For circular pipe, pipe arch, and open-bottom arch structures, cover height becomes an issue when the fill height is less than about one-half the structure width plus the required cover. Cover height is important for metal culverts because they require the structural backfill to help support the load. Check the manufacturer’s literature for the allowable cover height range for the highest expected loads during the structure’s lifetime. Increasing pipe thickness may reduce the required cover. Although the cost will be higher, the structure’s lifespan will increase. Alternatively, investigate the feasibility of raising the road profile to gain proper cover over the structure. If neither of these alternatives is feasible, various structure types are available in low-profile shapes. Low-profile shapes tend to be more expensive than standard shapes.

Concrete boxes, vaults with lids, and precast bridges are often used at low-clearance crossings. The lid or roof can be structurally designed to act as the driving surface.

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Table 7.1 displays the variety of shapes available and height-to-width ratio (i.e., how “short” they are). Use this table to help choose a structure to fit beneath a low embankment.

Table 7.1—Structures suitable for low-embankment sites, with approximate height-to-width values (will vary with manufacturer and material type)

EMBEDDED PIPE TYPE	Height-to-width ratio
Pipe arch— single piece and multiplate	76-86% (subtract embedded depth)
Low-profile horizontal ellipse—multiplate	75% (subtract embedded depth)
Low-profile metal arch— steel or aluminum	32-50%
Low-profile concrete box culvert	3'—varies
BOTTOMLESS PIPE TYPE	Height-to-width ratio
Low-profile concrete arches (BEBO E-series)	30-36%
Bottomless box culvert, 5.5" x 15" corrugation—steel	22-42%
Bottomless box culvert, 2" x 6" corrugations— steel or aluminum	18-50%
BRIDGE TYPE	Minimum clearance
Various bridge options	~3'—varies

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7.2.2. Construction Considerations

Refer to section 6.5.1 and table 6.7. The table lists potential risks to long-term sustainability of the stream-simulation channel, along with design features that can reduce these risks. Several of the design strategies listed in table 6.7 affect the choice of structure size and type.

Table 7.2 highlights some of the construction issues that may affect structure selection and dimensions.

Table 7.2—Construction issues that may affect choice of structure

CONSTRUCTION RELATED PROBLEMS	SOLUTIONS
Pipe too small to construct stream-simulation bed.	● Provide a minimum pipe height (diameter) of 6' to allow most workers to stand upright while constructing the streambed. Pipes as small as 5' have been used successfully. Smaller diameters can be used if they are constructed in half diameter sections, sections, but smaller pipes may not have enough embedment depth to accommodate natural fluctuations in streambed elevation. ● Top-load an open-bottom or lidded culvert.
Lengthy dewatering time (1-10 days) (Structures with poured concrete footings may take 1-4 weeks).	● Use one-piece embedded pipe. ● Use precast or metal footings for open-bottom arch. ● Use a bridge with precast spread-footings.
Excessive construction noise.	● Avoid blasting, use nonexplosive methods. ● Avoid pile driving.
Lengthy construction time.	● Use simple designs: CMPs, or prefabricated box culverts, or bridges where possible instead of complex, labor intensive structures.
Near-surface bedrock	● Use open-bottom culvert with concrete stemwalls formed to bedrock.
Limited in-channel access	● Use open-bottom or top-loaded culvert
Poor foundation material	● Use full-bottom pipe. ● Lower the road if possible to reduce total dead load on the foundation soils. ● Use a geotechnically designed foundation (geotextile, geogrids, etc.)

7.2.3. Cost Considerations

Cost considerations related to the design, material and labor, expected life, and ultimate replacement of the structure often influence structure selection (table 7.3). Changes in the structure's size may have an influence on the project cost but not proportionally; for example, a structure twice as large does not cost twice as much (see sample cost estimates in appendix G.3). Manufacturers will often help find the most economical structure shape for the design criteria. Structure types and sizes also influence maintenance and replacement costs; for instance, large structures, while initially more costly, also are less prone to flood damage and debris plugging.

Table 7.3 lists factors that affect total project costs (e.g., initial costs and projected lifetime and replacement costs).

Table 7.3— Cost factors that affect choice of structure

COST FACTOR	CONTROLLING FACTORS
Initial costs	● Structure type (one piece is less expensive than multiplate). ● Structure type (one piece embedded is less expensive than open-bottom arch in small sizes). ● Special shapes (squashed, low-profile, box). ● Special features (collars, thrust beams, special backfill, headwalls). ● Delivery. ● Shape control engineering (super-span culverts). ● Construction duration.
Durability and replacement cost	● Resistance to corrosion and abrasion (see table 7.4). ● Ability to salvage existing foundations and streambed (open-bottom arches and bridges) when replacing structure in the future. ● Vulnerability to flood damage.
Maintenance costs	● Debris removal. Structure type and size will influence debris-removal costs. ● Repairing flood-related damage to eroded streambanks, stream-simulation bed, grade-control structures.

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Table 7.4 lists the durability of different structure material types from the most durable to the least. To help weigh cost and durability, use tables 7.4 and 7.5 in conjunction with each other.

Table 7.4—Durability factors that affect choice of structure

DURABILITY FACTOR	STRUCTURE MATERIAL (listed in order of longest to shortest design life)
Corrosion or deterioration rate. Soil pH and conductivity influence corrosion and deterioration rate in metal culverts. Increasing metal thickness, concrete strength, or adding special coatings will enhance longevity. See table 7.5.	● Prestressed concrete. ● Reinforced concrete bridges and culverts. ● Steel bridges — weathering steel or if maintained with paint. ● Aluminum culverts. ● Aluminized steel culverts. ● Galvanized steel culverts. ● Treated timber bridges (durability varies with treatment and climate). ● Untreated timber bridges.
Abrasion rate. Size, shape, and flow rate of sediments influence abrasion rate. See Ault and Ellor 2000.	● Concrete. ● Aluminum culverts (more vulnerable to abrasion in sandy sediment). ● Aluminized steel culverts (more vulnerable to abrasion in cobble sediment). ● Galvanized steel culverts (more vulnerable to abrasion in cobble sediment).

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This table, from the Oregon Department of Transportation's Hydraulics Manual (ODOT 2005), is an example of the type of information that may be available and helpful in choosing a structure material appropriate for the site.

Table 7.5—Pipe material service life for Oregon (ODOT 2005) PIPE MATERIAL SERVICE LIFE: Average Years to Maintenance, Repair or Replacement Due to Corrosion (includes effects of scour as well)

Material	Location East or West of Cascades	Water & Soil pH	Soil Resistivity (ohm-cm)	Service Life (Years)
Galvanized Steel	East	4.5 – 6.0	1,500 – 2,000	30
	East	>6 – 7	1,500 – 2,000	35
	East	>7 – 10	1,500 – 2,000	40
	West	4.5 – 6.0	1,500 – 2,000	15
	West	>6 – 7	1,500 – 2,000	20
	West	>7 – 10	1,500 – 2,000	25
Aluminum	East or West	4.5 – 10	>1,500	75
Aluminized Steel	East	5 – 9	>1,500	65
	West	5 – 9	>1,500	50
Concrete	All Locations	4.5 – 10	>1,500	75+
Polyethylene	All Locations	4.5 – 10	>1,500	75

For galvanized steel, the service life increases for soil resistivity as follows:

Resistivity (ohm-cm)	Factor
2,000 – < 3,000	1.2
3,000 – < 4,000	1.4
4,000 – < 5,000	1.6
5,000 – < 7,000	1.8
> 7,000	2.0

The service life indicated is for 16-gauge metal pipes. Multiply the service life by the appropriate factor for different thickness:

Gauge	14	12	10	8
Factor	1.3	1.7	2.2	2.9

Bituminous-coated (AASHTO M190) metal pipe adds 10 years to the service life in all locations. Apply the factors from the previous two items to the total service life. (Many regions do not permit bituminous-coated pipes because of water quality issues.)

Soil resistivity or pH readings outside the indicated limits will require special design considerations.

7.2.4 Tips for Choosing Structures

The following tips may be helpful when choosing between different structure types:

- Embedded pipes are most economical of all the structures and quick to construct, at least up to sizes where they become multiplate structures (12 to 15 feet, depending on the manufacturer); however, except for box culverts, these structures require large excavations.
- When fill heights are relatively low (one-half to two-thirds of design width), round and pipe-arch culverts may not fit under the embankment with sufficient cover. Consider using low profile and box structures, raising the fill height, or using a bridge. Fill is relatively inexpensive if raising the grade over the structure does not affect the road grade or alignment for a long distance. However, if the grade is raised over a long distance to accommodate a large pipe, fill costs may become excessive and there may be significant wetland impacts with large increases in the embankment height.
- In bottomless structures, and box culverts with lids, the streambed can be constructed from the top, reducing the need for equipment to operate in the channel.
- Embedded pipes more than 25 feet in diameter may have to be buried over 10 feet deep for filling to design width. These pipes therefore may not be practical if dewatering is either difficult or impossible, or if bedrock is too close to the surface.
- Compared to culverts, channel-spanning bridges tend to have lower risks and higher longevity, and provide better passage for aquatic, semiaquatic, and terrestrial animals. When they are close in cost to other structures, they are generally preferable.
- Bridges are worth considering for active **flood-plain** locations and debris-flow or landslide-prone areas where high clearance is necessary.

7.3 STRUCTURAL DESIGN

Design elements of the crossing structure include:

- Crossing structure.
- Foundation.
- Structural backfill.

7.3.1 The Crossing Structure

Pipe, pipe arch, and bottomless structures are constructed of either corrugated metal or reinforced concrete. Structural design is not necessary, because manufacturers supply this information in brochures and for individual projects to ensure correct use of their products. Culvert brochures usually have tables giving design solutions for various culvert dimensions, corrugation types, thickness, traffic loads, and range of fill heights. You can get this information directly from the manufacturer for specific designs. To do so, have the following minimum site information available before contacting them:

- Maximum traffic load.
- Fill height range.
- Soil weight.
- Soil type.
- Foundation bearing capacity.
- Structure dimensions.

Bridges are constructed of a variety of modular and individually engineered materials with steel, concrete, and wood as the common building materials. Structural bridge design or review is beyond the scope of this document. Whenever a bridge may be a suitable option, a bridge engineer should be part of the design team.

Standards for designing bridges, culverts, foundations, and backfill are in Standard Specifications for Highway Bridges, 17th edition (AASHTO 2002). Another good resource for all pipes is the installation manual for corrugated steel pipe, pipe arches, structural plate (NCSPA undated).

7.3.2 Footing Design

You must be able to recognize foundation situations that are risky or complex enough to require expert assistance for design of an open-bottom structure—or even to preclude such a structure. The geotechnical investigation conducted during the site assessment (section 5.1.7) should yield enough information for you to determine the degree of complexity and risk. Unsuitable soils or foundation conditions that will require further expert analysis include:

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- Silts and clays.
- Soils with high organic content.
- Unconsolidated soils.
- Bed rock.

If these materials are present, particularly if the site is geologically complex, a detailed site investigation is needed.

Footing design requires the following analyses:

- Structural analysis: quantifying and analyzing stresses on the footing, and adjusting footing dimensions until the load distributes evenly on the footing.
- Bearing capacity analysis: analyzing the soil bearing capacity for various footing depths and widths.
- Scour scenario analysis: ensuring that the worst-case scour condition leaves enough embedment depth to develop sufficient bearing capacity to support the foundation loads.
- Foundation design: designing the footing details, including reinforcement, culvert attachment, shape, and constructability aspects.
- Settlement estimation: estimating the amount of settlement expected to occur.

The above analyses are within the skills of most bridge, structural, foundation, geotechnical, and geological engineers. Ensure that the required expertise is available if you do not have all the skills necessary for designing bottomless arch or box-culvert footings. For more detailed discussion regarding footing design and foundations, see appendix G.4.2

The following example illustrates inadequate footing design methods. One type of open-bottom arch—a half-round corrugated metal pipe (CMP) with flat lengths of corrugated sheet metal welded on each edge of the arch to function as a footing (figure 7.7)—has been used in a number of locations to provide continuity in small streams. Some of these structures have failed because they were not adequately embedded and scour occurred under the corrugated sheet metal footings. Therefore, when considering using these less-expensive structures, use the same design procedures as you would use on larger more complex open-bottom arches. Ignoring proper design procedure makes failure likely.



Figure 7.7—Open-bottom pipe arch with metal footings.

7.3.3 Structure Backfill

Backfill material in the special backfill zone (figure 7.8) interacts with the structure to provide more strength than either material could provide by itself. Backfill requirements vary for different types and sizes of structures and are usually specified by the manufacturer. Backfill and compaction specifications for culverts are covered in FP-03, Section 209 under:

- Backfill material (for general backfilling of culverts).
- Lean concrete (for both bedding and partial backfill material).
- Bedding material (for placing beneath pipe structures as a leveling and piping prevention layer (figure 7.9).
- Foundation fill (for replacing unsuitable material and for long-span structures).

Choose foundation fill gradation A-1-a from FP-03, Section 705 for long-span (greater than 25 feet) structures, because you can easily place it and compact it to high strength without overstressing or distorting corrugated steel structures. Consult the structure manufacturer for specific recommendations.

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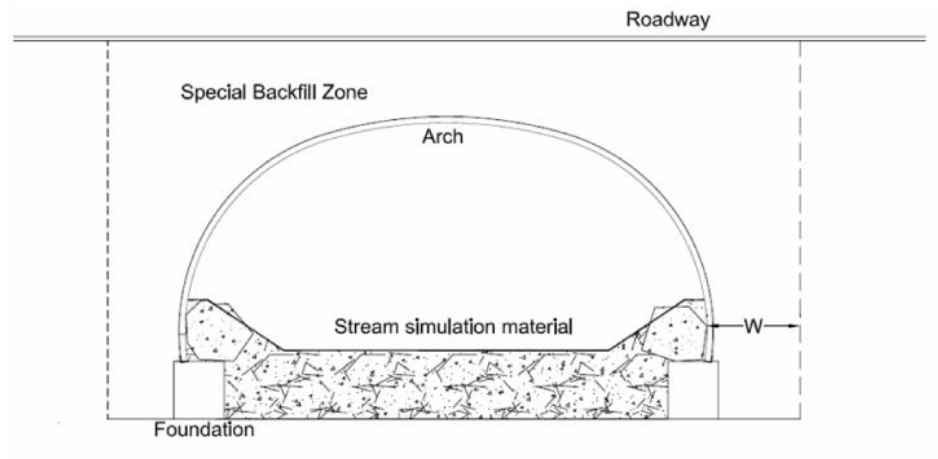


Figure 7.8—Special backfill zone for an open-bottom arch.



Figure 7.9—Shaping culvert bedding.

7.3.4 Existing Site Materials

The crossing design may be able to use several types of materials available on site; for example:

- Large boulders.
- Large **woody debris**.
- Bedding material from the old culvert.
- Streambed materials in areas that will be disturbed.
- Clearing debris.

These materials may be suitable for constructing streambed features such as steps, banks, or other **key features**. The old bedding (figure 7.10) may be useful in the stream-simulation bed material recipe (section 7.5.2.2), and clearing debris can be used for erosion control (figure 7.11).



Figure 7.10—Old culvert bedding may be used in the stream-simulation bed mix.

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Figure 7.11—Clearing debris scattered for erosion control.

Also evaluate the existing embankment to determine if the soil meets structural and general backfill requirements. Estimate whether additional backfill will be required or if a surplus exists. Old embankments sometimes have large trees and other surprises buried in them. These “surprises” are normally handled during construction under the changes clause. Trees and other native materials may be suitable for placement as instream structures upstream or downstream of the structure. The site assessment documentation should contain recommendations on how to use these materials on the project. You may place them in disturbed areas to control erosion, in riparian zones for habitat, or in the stream for additional aquatic habitat or **grade control**. Depending on long-term goals, trees and other native material may or may not be anchored to the bank; consult with the project team.

7.4 HANDLING TRAFFIC DURING CONSTRUCTION

Four options are generally available for accommodating or controlling traffic during the project.

- (1) Redirecting traffic to alternate routes.
- (2) Closing the road briefly (3 days to 1 week).
- (3) Providing an adjacent temporary road-stream crossing (often over the dewatering dam). Either ensure that the roadway has sufficient width, slope, traction, and geometric alignment to allow all expected traffic to use the bypass, or provide signs indicating vehicle limitations. Keep in mind that this option affects the dewatering system, clearing limits, excavation volumes, and traffic management efforts. Figure 7.12 illustrates this option but does not use the dewatering dam.
- (4) Passing traffic over the construction site while constructing the structure in two stages.
 - (a) Allow enough road-surface width for building more than half the new structure at one time. Sometimes, you can achieve the needed width by lowering the road surface temporarily.
 - (b) Construct a stable roadway to support traffic safely (according to Occupational Safety and Health Administration standards.) To support the excavation side of the embankment, you may need some form of retaining wall. (Because of the need to construct the road fill in two stages, this option may require a longer structure.)

Traffic bypasses can account for anywhere from 10 percent to as much as 50 percent of the total project cost, depending on the size of the project and the complexity of the bypass. The total cost of a traffic bypass includes the combined increased costs of slowing the construction work and adding traffic control personnel, signs, traffic control lights, and other project details. Figures H.4 and H.5 show examples of a sign plan and a gate plan.

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Figure 7.12—Typical construction site traffic bypass.

7.5 DEVELOPING SPECIFICATIONS

Chapter 6 covered design of particle-size gradations and other features of the simulated streambed using data from the reference reach. This section develops contract specifications based on the stream-simulation design. Stream-simulation construction contracts require modifying standard specifications to describe their specialized construction. The Forest Service uses Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (Federal Highways publication FP-03) for standard specifications. Use Specifications 151-Erosion Control, 251-Riprap, and 705-Materials for the parent specifications to describe dewatering, streambed construction, and streambed materials in stream-simulation projects. Appendix H provides examples of supplemental specifications.

All construction specifications that describe work to be done—specifications in FP-03 Divisions 200 through 600—consist of three parts:

- **Description:** This part describes the scope of work covered in the specification.
- **Materials:** This part nearly always refers to a materials specification. In the case of stream simulation, Supplemental Specification 705 covers rock and filler material.
- **Construction methods:** This part describes all features and how to construct them. Often, to clarify features difficult to describe in words, the specification refers to drawings.

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Some aspects and requirements of stream-simulation construction will be unfamiliar to contractors, even those with instream experience. Well-written notes and specifications for aspects outside the normal practice will allow bidding that is more accurate and minimizes expensive change orders.

7.5.1 Submittals

You may often use specifications to require the contractor to design and submit a plan for portions of the project work for approval. When using this method, expected results should normally be specified—not methods for performing the work. For some work, contractor design is more appropriate, allowing the contractor to perform the work in a manner that best fits his or her work methods and, most important, making the contractor responsible for the end result. Allow reasonable time for a submittals process, i.e., adequate time for the contractor to design and submit the proposal for the specified work and adequate time for a thorough but timely agency review of the proposal. Work items often specified in the contract and designed or performed by the contractor through a submittals process are:

- Quality control.
- Construction surveying.
- Temporary erosion and pollution control.
- Dewatering and water treatment.
- Storm management plan.
- Structural backfill materials.
- Concrete mix designs.
- Stream-simulation bed mixture.
- Revegetation.

7.5.2 Supplemental Specification 251: Streambed Construction

7.5.2.1 Description

The description is an introduction to the specification. Briefly describe the features— especially unique features—that you want to construct under this specification. (See appendix H for an example of Supplemental Specification 251.)

Stream Simulation

7.5.2.2 Materials

The Materials section of Supplemental Specification 251 should refer to material specification Supplemental Specification 705 (section 7.5.3). Supplemental Specification 251 includes a description of work required to achieve the gradations specified in Supplemental Specification 705.

The streambed may contain material that you can salvage from the excavation and use for at least a portion of the stream-simulation bed mix. Excavated material that appears too dirty to use may simply be the natural subsurface layer, which is often much richer in fines than the surface of an **armored streambed**. At some culvert-replacement sites, natural streambed materials may be covered by the old culvert bedding material (figure 7.10). Bedding depths can vary, depending on the roughness of the underlying channel surface or whether the channel is incised or not.

Consider making provisions in the contract for using the native streambed material if it meets gradation requirements. Alternatively, native material can be part of the recipe for the streambed-simulation bed mix. If the material cannot be used for the streambed-simulation bed, it can be used elsewhere on the project as common excavation for other backfill. Provide locations for stockpiling, mixing, and disposing of the material depending on the final determination for the use of the onsite materials.

The drawback to using onsite materials in the bed mix recipe is that you will not know the mix proportions when the project is advertised. It may be far more expedient and economical for the project not to depend on onsite materials. If, during construction, you determine the onsite materials are useable, the government can take a deduction for using the onsite material in lieu of purchased or hauled material through a change order.

If you are going to include onsite materials in your bed mix, you must sample the onsite materials and determine their gradation. The best time to sample is during excavation of the existing structure. Two sampling methods can be used: the pebble count method (section 5.1.6.1), or bulk sampling. Keep in mind that representative samples of material for bulk sampling where the largest particles are over 4 to 5 inches must be several hundred pounds (reference American Society for Testing and Materials standard C136-06). If sampling and gradation testing of onsite materials is performed after the contract is awarded, contract administrators will use a change order to incorporate the onsite materials.

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Once the gradations of all the materials (both onsite and commercial) have been determined, determine the proportions of each material that will be needed to produce the stream-simulation bed mix (the gradation specified in Section 705, see figure 7.17). The process of developing a stream-simulation bed mix recipe is identical to developing a mix design for Portland cement or asphalt concrete from several differently graded stockpiles.

Sampling can be done in-house or by the contractor. Specify either option in the materials section of Supplemental Specification 251.

Sampling by the contractor

Specify a submittal for the bed-mix recipe (the proportions of the different aggregate stockpiles to be used in the bed mix) based on the gradations determined during the stream-simulation design (see section 6.2.1.1.) The contractor will develop the mix recipe as a submittal using materials recovered from the site excavation, from commercially available materials, or from a mix of both.

Sampling by contract administrators

Specify in the contract that the engineer will perform sampling and testing during structure excavation and that the bed-mix recipe will be designed “in-house.” Be sure to include a provision that (a) states that the contractor cannot proceed with any streambed construction until the analysis and streambed-simulation recipe are complete and, (b) provides a reasonable length of time for the sampling, testing, and analysis.

7.5.2.3 Construction methods

To develop the Construction Methods section of Supplemental Specification 251, use or modify the example in appendix H to describe features such as:

- Stream-simulation bed cross section and profile.
- Low-water thalweg.
- Steps, constructed riffle crests.
- Banks, edge features.
- Rock clusters.
- Grade-control structures.

Stream Simulation

- Handling of known or discovered natural key features (for example, bedrock, natural rock steps that are part of the stream-simulation design).

Describe the streambed features designed in chapter 6 in detail in the contract and show them on the contract drawings. (See figure H.9 and H.14, and section 6.2.) Determine which onsite materials, if any, can be used for constructing these features, and incorporate those materials and features into the specification. If possible, use detail drawings and refer to them with the specification. Include language in the specification or special contract requirements that provides protection for the structure against damage while streambed materials are placed.

Constructing streambeds and other features inside very small culverts usually involves hand labor (figure 7.13). Hand labor will be required to help seal streambeds and for compaction close to the structure where compaction by equipment is impossible. (See also figure 8.16.)



Figure 7.13—Hand labor walk-behind equipment.

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Stream-Simulation Bed Details

Supplemental Specification 251 (appendix H) covers placing streambed material. It specifies the size, depth, surface profile, and compaction of the bed material, as well as layer placement when needed.

You may need fine-grained filler material (referred to as “select borrow” in the sample specification) to fill in voids between larger rocks and against the sides of the culvert. As discussed in chapter 6, the filler material is washed into the voids in the streambed (figure 7.14), reducing streambed permeability and helping to keep the streamflow on the surface during low-flow periods. This practice also reduces the loss of fines and thus decreases turbidity during the initial rewatering.



Figure 7.14—Washing filler material into the voids in the stream-simulation bed.

Stream Simulation

When using footings in high-risk scour areas, specify placing a layer of larger more stable streambed material against the footings to prevent scour of the footings (figure 7.15). Provide for protecting the stemwalls and the structure during construction.



Figure 7.15—Footing armor.

Channel Margins

Continuous channel banklines or other margin features, such as rock clusters, are part of the stream-simulation design (section 6.2.1.3). The margins may be a single row of rocks, or they may be wide enough to simulate a flood plain in the culvert (figure 6.22). Banks should be constructed carefully to limit void space between the large rocks. Voids should be filled by jetting or flooding in filler material.



Figure 7.16—Newly constructed (2006) stream-simulation channel and banks, Surveyor Creek, Lolo National Forest, ID. The top of the bank is at bankfull elevation, indicated by the painted line. Note the transition between natural banks outside and constructed banks inside the culvert.

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Key Features

Key features are grade-control or diversity-enhancing structures consisting of rock or wood, placed to mimic natural conditions where they are called for in stream-simulation design plans. Ensure rock is carefully placed to produce the desired degree of stability. Individual rocks and rock clusters should be embedded a minimum of one-third of their size.

The stream-simulation plans may also call for steps, bands of riffle-sized rock, and rock clusters (figures 6.23, and 6.25). In steep step-pool channels where steps must be as stable as natural steps, the rocks must be carefully placed, bearing against—and interlocked with—other step rocks (section 6.2.2.4). Steps generally have two tiers, an upper tier of rocks immediately upstream and a lower tier of footer rocks below and immediately downstream of the upper tier, to prevent scour and undermining (figure H.9).

In pool-riffle channels, the stream-simulation design may call for constructed riffle crests to simulate intermediate mobility key features like pool tailouts, and promote natural development of diverse bed structures over time. Construct these by placing streambed material to full depth for a distance along the length of the culvert, then switching to coarser material for the width of the band, alternating this pattern through the length of the culvert (section 6.2.2.2). Both bands and the rest of the channel are shaped with a low-flow thalweg, so that the cross section dips in the middle and rises toward the walls of the structure (figure H.15).

Where bank stability and/or habitat requires placing wood outside the structure, place it with about two-thirds of the tree's length on the bank, with the remainder lying in or over the water and pointing upstream at a sharp angle. The wood must be well buried, anchored, or large enough to remain immobile. To ensure these features will be stable for the life of the structure, work with an experienced biologist or hydrologist. Where possible, develop site-specific designs to use available local materials.

7.5.3 Developing SPS 705: Specifying Rock Sizes

Section 705 specifies characteristics of aggregates, including the gradation of the materials used for various purposes. To modify Section 705 for stream simulation, we need to specify the gradations of all the materials needed for the features discussed in the Supplemental Specification 251, Construction Methods. The project team has already developed a gradation curve for the bed mix (section 6.2.1.1), with units of millimeters, the most common units used for pebble counts. The bed-gradation specification must be in a format that material suppliers understand. Generally, this format is a table of sieve sizes, with percent-finer values (the percentage of aggregate by weight passing the particular sieve) accompanied by a percentage range of tolerances (for example, 50-percent passing through the sieve, plus or minus 5 percent, expressed “45% - 55%”).

If using bulk sampling, simply insert the values determined from the laboratory analysis of the sample into table 705-7 (figure 7.18), and use the table in Supplemental Specification 705.

If using the particle-size distribution curve from chapter 6, do the following:

- Determine the closest sieve sizes (the next largest) to the D_{95} , D_{84} , D_{50} , D_{30} , and D_{10} values (or other key values) on the particle-size distribution curve, and insert those values in table 705-7 (figure 7.18).
- Verify that the sieve size is no more than 5-percent greater than the desired particle size. If the size is greater, choose another point on the distribution curve, close to the desired size, that better coincides with a standard sieve.
- Using the particle-size distribution curve, find for each sieve size the percent-finer value on the vertical axis (figure 7.17). Insert those values in table 705-7. (These are the values for the stream-simulation bed gradation, expressed as “percent finer values.”)
- To provide flexibility, use a tolerance range of 10 percent (plus or minus 5 percent) for each sieve size. Generally, no less than 5-percent fines (finer than number 8 sieve) are allowed in the manufactured streambed-simulation rock. The stream-simulation bed mix design (6.2.1.1) may specify a different fines content based on the reference reach. Similarly, 90 to 100 percent of the material should pass the D_{95} size.
- For the filler material, use 1-inch minus or D_{16} , whichever is smaller. (A minimum of 50 percent of the filler material should pass the sieve representing the D_5 value of the streambed-simulation bed.)

DEVELOPING THE GRADATION TABLE FROM THE PARTICLE SIZE DISTRIBUTION CURVE

1. Particle size distribution curve from the pebble count
2. Add US standard sieve sizes to the horizontal axis of the distribution curve
3. Lines from sieve sizes to intersect the distribution curve
4. Lines from the intersections on the distribution curve to the vertical axis (% finer)
5. Values intersected on the vertical axis of the distribution curve are values for the gradation table

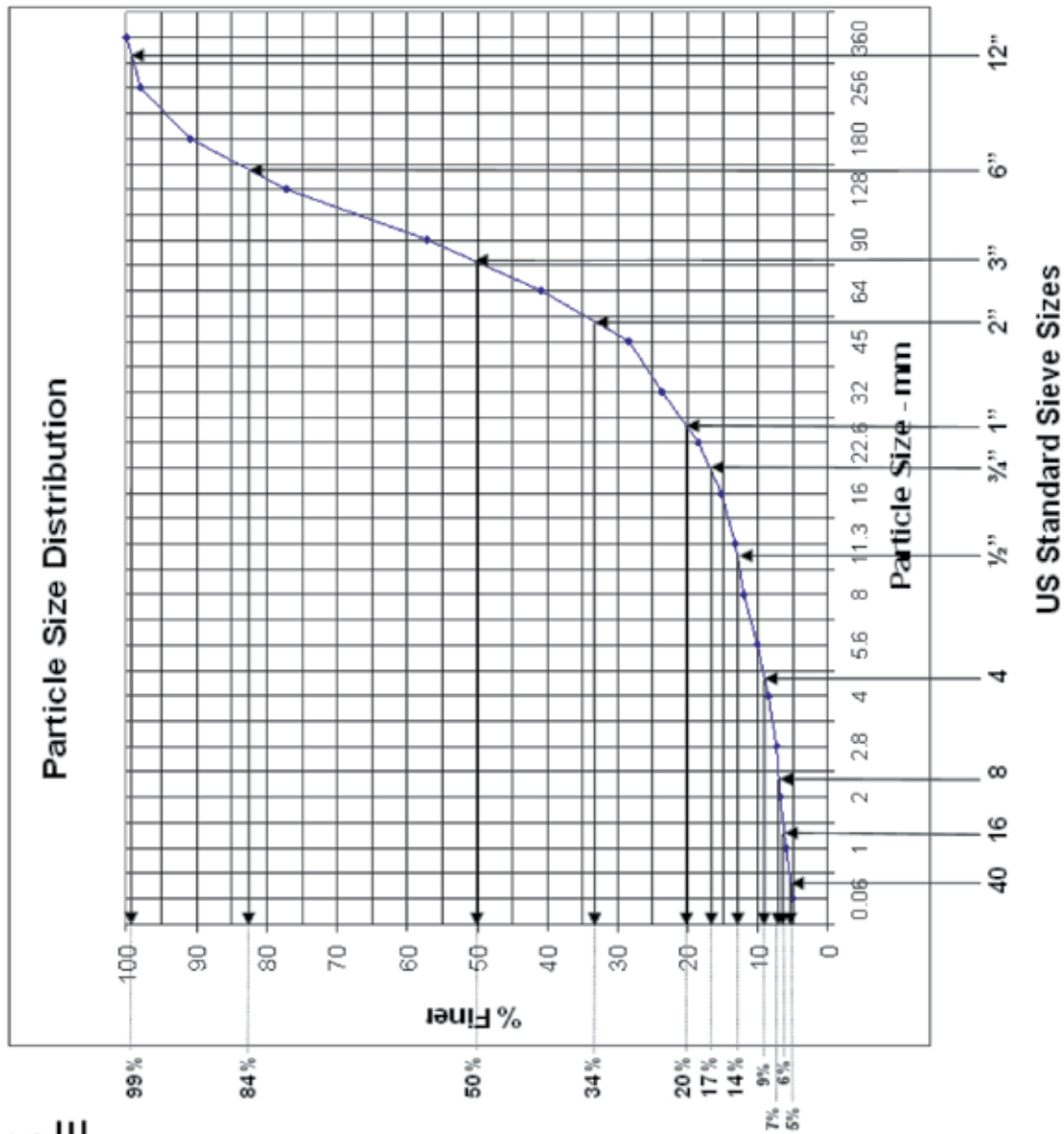


Figure 7.17—Developing a gradation table from a particle-size distribution curve.

Stream Simulation

Using the values determined from the curve in figure 7.17, fill in the values in the table in figure 7.18.

Standard sieve	Stream simulation bed material (percent finer)	Filler material (percent finer)
12"	90-100	
6"	79-89	
3"	45-55	
2"	29-39	
#4	4-14	
3/4"		100
#40		≥ 50

- (1) U.S. Standard Sieve size closest to D_{100} , D_{84} , D_{50} , D_{30} , D_{10} , are:
12", 6", 3", 2", #4
- (2) Filling in the corresponding % finer values allowing $\pm 5\%$ of the value from the distribution curve:
 $12" = 99\% \pm 5\% = 94-104$
 (use 90-100)
 $6" = 84\% \pm 5\% = 79-89$
 $3" = 50\% \pm 5\% = 45-55$
 $2" = 34\% \pm 5\% = 29-39$
 $\#4 = 9\% \pm 5\% = 4-14$
- (3) Finally, filling in the values for filler material: Sieve sizes closest to D_{16} and D_5 are 3/4" and #40.

Figure 7.18—Example of table 705-7, Project Requirements for Stream-Simulation Bed Material.

Channel Rocks

For the purpose of definition in the construction contract, “**channel rocks**” are rock materials needed for constructing key features, such as steps, constructed riffle crests, banks, and clusters. Specify them separately from the stream-simulation material, using sizes already determined for key features in section 6.2.1.3 and 6.2.1.4. Not only diameter but also shape characteristics are important. For example, elongated rocks interlock better and can form a more stable feature in the simulated streambed.

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Table 705-4 (figure 7.19) defines the channel rock size classes and lists approximate weights and acceptable range of rock diameters for each class. Size classes are shown on the drawings for each key feature in the design.

Table 705-4 Size Requirement for Channel Rocks

Channel Rock Class (diameter, inches)	Approximate Weight (pounds)	Median Axis Dimension & Variation in inches
Rock-4	3	4 +/- 1
Rock-6	10	6 +/- 1
Rock-9	33	9 +/- 2
Rock-12	80	12 +/- 2
Rock-16	185	16 +/- 2
Rock-20	365	20 +/- 2
Rock-24	630	24 +/- 3
Rock-30	1,230	30 +/- 3
Rock-36	2,120	36 +/- 4
Rock-42	3,370	42 +/- 4
Rock-48	5,030	48 +/- 5
Rock-54	7,160	54 +/- 5
Rock-60	9,820	60 +/- 6

Figure 7.19—Table 705-4 defines channel rock-size classes.

An example of Supplemental Specification 705 for stream simulation is in appendix H. Tables 705-4 (size requirement for channel rocks) and 705-7 (gradation requirements for stream simulation bed material) are added to the standard specification. In the example in appendix H, channel rocks are required to have a long axis at least 33-percent longer than the median axis. The 133-percent elongation should be field verified for each site. In places where you are constructing permanent features from the channel rocks, you may wish to specify that the rocks are to be fractured and angular.

7.6 DESIGNING FOR FLOOD AND DEBRIS FAILURE PREVENTION

See table 6.7 and section 6.5.2 for discussion of risks caused by high flows, woody debris, and sediment, along with methods of minimizing those risks. Additional information is available in Furniss et al. 1997.

7.7 PLANNING FOR EROSION AND POLLUTION CONTROL

An erosion and sedimentation-control plan details the suite of methods and tools that will be used to minimize sediment delivery to the stream channel during and after construction. The plan contains actions and practices that occur before, during, and after construction, including long-term stabilization elements, such as the revegetation plan. Depending on the site and conditions, the plan may include the following elements:

Before-construction actions

- Planning for water quality monitoring during and after construction.
- Salvaging and storing topsoil.
- Salvaging plants or cuttings.

During-construction actions

- Construction timing and sequencing.
- Site dewatering and rewatering.
- Treating water.
- Providing short-term erosion control on disturbed areas and storage piles.
- Preventing and controlling pollution from equipment and facilities.
- Methods of stabilizing disturbed areas, such as placing rocks and logs for long-term bank stabilization.
- Special treatment of imported or excavated streambed material, such as segregating stockpiles to prevent contamination or covering them to prevent loss.

Post-construction actions

- Removing temporary erosion- and sediment-control measures.
- Revegetating the site.
- Maintaining the site.

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Federal, State, and county permits often include BMPs and performance standards (for example, turbidity requirements) that apply directly to the erosion-control plan. Be sure to include these requirements in the special contract requirements and the erosion-control plan as well as any notes and detail drawings that you may need. You may need to create detailed drawings, applying the BMPs to specific site features and paying for them directly via pay items in the contract.

Including the major features of erosion control in the design gives the project team maximum input into long- and short-term erosion control. Including major features of the dewatering system, long-term revegetation, and site-stabilization plans in the design will also provide greater overall project efficiency. For example, you can clean and retain sediment-retention basins (constructed to control storm flows in the contributing road ditches during construction) as long-term ditch sediment-control measures.

7.7.1 General Erosion Control During Construction

The most important rule for erosion control is to minimize site disturbance within the limits of project goals. First, mark clearing and disturbance limits, and reduce the disturbed area as much as possible. Second, control potential erosion by covering disturbed surfaces (for example, storage piles), or by routing water away from them (for example, using stormwater controls). Third, capture and treat sediment-laden water before releasing it to the stream. Fourth, provide for long-term stabilization of the site through revegetation and other permanent measures.

Standard specifications and contract clauses allow you to (a) specify erosion-control measures, (b) specify outcomes and require the contractor to submit an erosion-control plan to meet them, or (c) combine the two methods. Risk to the owner (the government in this case) is greater when methods and measures are specified, because the responsibility for any failure then remains with the owner. Performance-based specifications are generally encouraged for this reason.

Erosion control can be paid directly as a separate pay item, or made incidental to other work such as installation of the culvert and paid under that pay item. A successful result with either method depends primarily on diligent and consistent enforcement of the requirements. Be sure to include contract language requiring the contractor to maintain all erosion control and prevention features.

Stream Simulation

Consider the following items for the temporary erosion prevention, control, and treatment plan:

- Construction site layout with clearing limits.
- Work schedule, including timing of erosion-control items.
- Dewatering and sediment treatment plan (see section 7.8).
- Storm management plan.
- Sediment-trapping silt fences or straw bales.
- Drainage-control plans directing water away from disturbed areas.
- Ditches and check dams.
- Road drainage details.
- Ditch relief culvert details.

You may need to include the following in your special contract requirements to cover temporary erosion and sediment control:

- Cover aggregate stockpiles to prevent wind and rainfall erosion.
- Cover excavated slopes to reduce surface erosion.
- Sweep and clean off road surfaces.
- Submit a storm management plan, including the following as a minimum:
 - ▲ List of contacts including contract administration and contractor personnel.
 - ▲ Site specific list of action items, for example:
 - Maintain erosion control measures including ditches, barriers, silt fences, etc.
 - Maintain the construction bypass system and any components, such as trash screens.
 - Have extra pumping capacity onsite ready to use in emergency.
 - Block traffic or provide traffic control if necessary.

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- If the project is longer than one construction season:
 - ▲ Be prepared for an early winter storm and construct over-winter erosion-control measures early.
 - ▲ Provide for periodic maintenance checks during winter and during spring runoff.
 - ▲ Inspect and maintain all erosion-control measures before spring restart of construction.
 - ▲ Remove and dispose of temporary erosion-control measures and accumulated sediment after construction and after the site has stabilized.

For projects that could extend over more than one construction season, see appendix G.4.3.7.

7.7.2 Permanent Erosion Control Measures

Specifications that have an end result are much easier to administer than process-oriented specifications.

Develop necessary drawing details and special-project specifications for permanent erosion control on roads, road embankments, streambanks, and other disturbed areas.

Many long-term stabilization measures, such as in-channel wood, streambank rocks, and engineered slope-stabilization measures, are design features included in Supplemental Specification 251. Where vegetation may be difficult to establish in a mat thick enough to provide erosion control, combine vegetation with other measures such as riprap, root wads or logs, or erosion-control matting.

Typical components of a long-term stabilization plan include:

- Seeding, mulching, and planting of exposed soils.
- Scattering construction slash on exposed soil areas for erosion control.
- Ditches, relief culverts, and dips that drain to natural sediment-filtering vegetation and stable landforms where runoff can infiltrate, rather than running directly into the stream.
- Erosion protection for road cut-and-fill embankments.

Stream Simulation

- Integrated streambank protection:

- ▲ Although riprap is generally very successful and stable, it is sometimes not aesthetically desirable on some visually sensitive sites and may not be desirable due to habitat loss.
- ▲ For vegetation, use native plant species such as willows, groundcovers, and other native species.
- ▲ Other bioengineering methods (WDFW 2003).

For detailed discussion on revegetation, see appendix G.4.3.

7.7.2.1 Diversion-prevention dips

In many cases, a diversion-prevention dip will be an essential part of the permanent erosion control system (section 6.5.2.3). Diversion-prevention dips provide a drainage pathway across the road to avoid stream diversion down the road (figure 7.20). Design the dip without severe grade changes that exceed the design standard for the road and could pose a traffic hazard. Make sure the dip will capture all the overtopping water and carry it in a controlled way to the intended relief drainage pathway. Plan to plug any continuous road ditches on the downgrade side of the stream crossing to prevent them from diverting ponded water down the road.



Figure 7.20—Diversion-prevention dip on the Plumas National Forest, California. The diversion dip is located just down the road from the stream crossing because the crossing is on a tight curve.

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When a culvert plugs and sends water over the road through the relief dip, the water tends to pool relatively gently on the upstream side. However, once through the relief dip and over the road, the water rushes down the much steeper embankment slope and can cause considerable erosion. Make sure the downstream slope of the relief dip is well protected with vegetation and or riprap.

A relief dip also may be used to provide stormflow relief by means of a controlled failure. In such a scenario, the dip is protected from erosion in the same way as other fillslope areas. If the stream-simulation structure plugs, the stormflow causes failure at the relief dip location, preventing the stormwater from running down the road and thereby limiting overall damage.

A good diversion-prevention dip has the following characteristics:

- Accommodates the critical vehicle at the design speed.
- Cross section is adequate to contain the design stormflow volume.
- Outsloped at less than 5 percent.
- Incorporates embankment erosion-control measures.
- Associated ditches are plugged to prevent floodwater escape down the ditch.

7.8 DEWATERING, BYPASS, AND WATER TREATMENT DURING CONSTRUCTION

Live streams require dewatering to prevent mixing soil with streamwater during construction. Unless subsurface water exists, a dry streambed may not require dewatering. However, if water quality is an issue, create and implement a reliable bypass plan for handling stormflows. Summer storm events may be the most intense storms during the year in some areas, and unusual events can happen at any time.

Often, engineers do not take dewatering seriously enough. Although the dewatering system does not have to be elaborate, it needs to work effectively. The bypass dam is the first line of defense on the project, and the downstream sediment collection point—whether an excavated pool, an existing scour pool, or a dammed pool—is the last. These components of the dewatering system must work well and reliably. The failure of a dewatering system can cause serious damage to the stream habitat, delay the project, and result in cost overruns.

Stream Simulation

Only a gross estimate of the amount of surface and subsurface water and sediment that need capturing and treating can be made until the site is actually excavated. We recommend that the engineer and a hydrologist work together on the dewatering-system design, and take into account historical flows during the construction season. Be sure to require that the contractor provide adequate pumping ability, regardless of project conditions, and to have a backup pump always available for handling stormflows and taking over if the primary pump malfunctions.

A successful dewatering and bypass system does all of the following:

- Captures streamflow and successfully diverts it around the project.
- Handles stormflows without failure, with backup pumps readily available onsite.
- Captures water that seeps around the bypass before it reaches the excavation, and reroutes and treats it (if necessary) before releasing it back to the stream.
- Captures and removes sediments from water that seeps into the excavation from its edges or from springs, mixes with soil and becomes turbid.
- Does not **backwater** the site.
- Captures water that seeps into the excavation from downstream and either treats it or—if it is kept clean—releases it back into the stream.
- Protects fish and other species of concern by providing suitable screens on all pump intakes in areas containing aquatic organisms.
- Accomplishes dewatering in a controlled manner, slowly and in stages, allowing capture and transport of aquatic organisms out of the construction area.
- Accomplishes rewatering by releasing any large pools of water dammed during construction in a slow, controlled manner avoiding downstream water heating during rewatering.
- Provides for fish passage around the construction site where necessary.

Supplemental Specification 157 (example in appendix H) requires the contractor to take the measures necessary for dewatering and treating sediment to meet turbidity requirements. Figure 7.21 shows a generic dewatering plan demonstrating key components of a complete plan, including a stop-work requirement to permit relocating aquatic species

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before the dewatering takes place. An actual dewatering plan, however, is site-specific; details, configuration, and components of the plan will vary by site. Appendix G.4.1 includes more detailed information on elements of the bypass and dewatering system.

The length of time the bypass and dewatering system must be in place varies with each project. Small embedded pipes or precast structures may only require a site to be dewatered for a few days or less. Projects with cast-in-place concrete usually need at least 2 weeks. Sites requiring a bypass road may require continuous dewatering until the bypass road is removed. Complex projects may require more than one construction season, along with bypasses capable of handling high-flow events throughout the year.

7.8.1 Bypass Dams

As long as the existing culvert is still in place, you can direct water through it and use it for the bypass. Once the culvert is removed, however, you will need a bypass dam or convenient natural pool to gather water, direct it into a transport structure, and divert it around the project site. This bypass dam or pond location is important. By locating it close to the excavation, you create the best chance of capturing most of the water entering the construction site. Using a natural pool, when one is conveniently available, will reduce the height of the bypass dam. When doing extensive upstream channel work, use more than one bypass dam to capture the flow from springs and side drainages. Do not locate bypass dams on any stream features that control the channel gradient (e.g., steps, or pool tail-outs). Those features tend to allow more seepage beneath a dam built on top of them than other more well-graded and smoother channel areas. If constructing the dam in those locations is the only option, preserve stream stability by reconstructing those features as close as possible to the original features.

Three different methods for diverting water are in common use:

- **Pumping and transport hoses:** A gas, diesel, or electric pump pumps from a stream pool or an excavated sump during the entire dewatering period, diverting the water around the site and back into the stream. Float switches control the pumps as water levels fluctuate to save energy and keep the pumps from running dry. Screens must be used to protect organisms (figure G.5) and must be maintained—if screens plug, pumps lose efficiency or can run dry. See the biologist on the project team for help in sizing this screen.

Stream Simulation

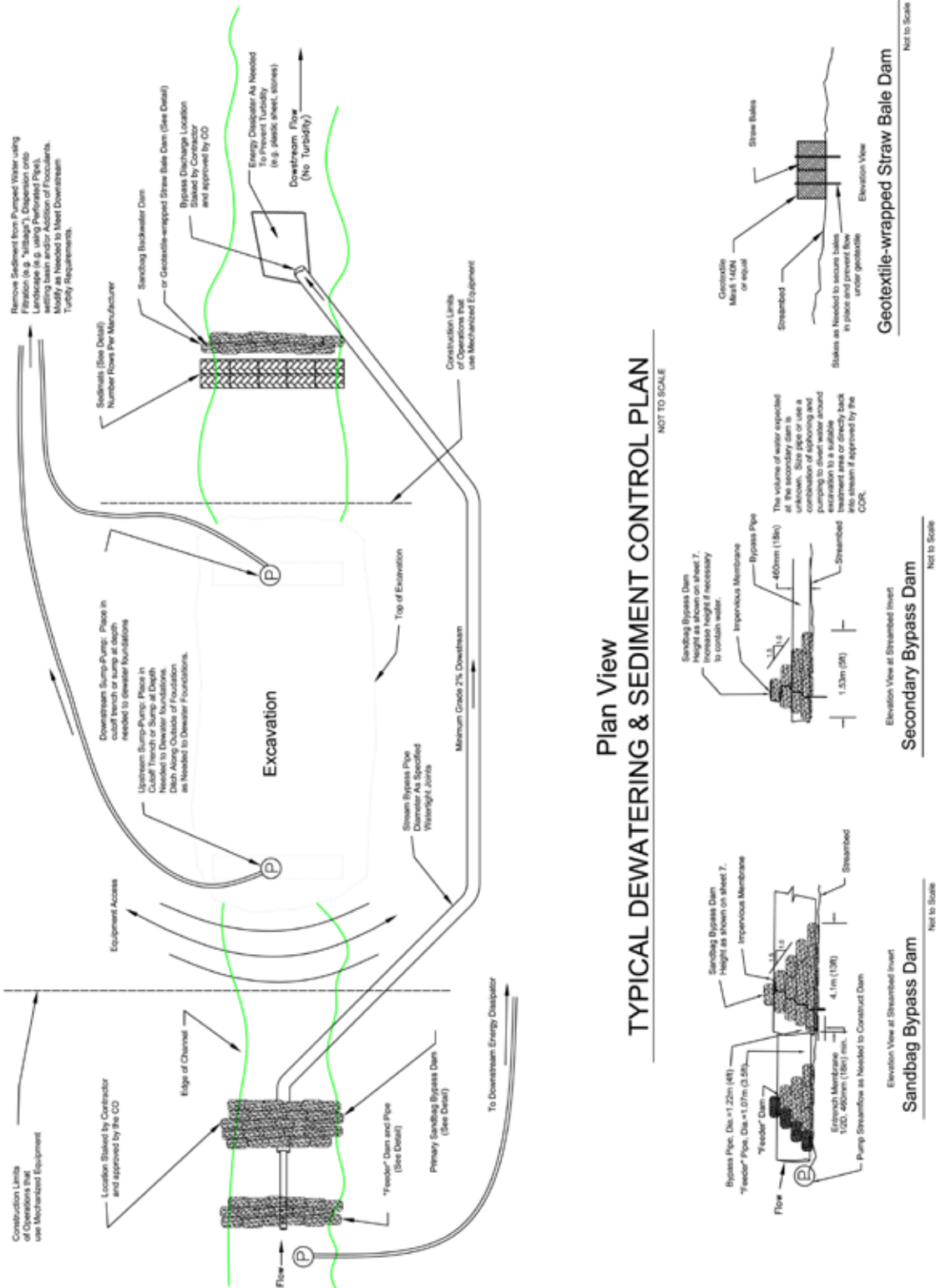


Figure 7.21—Dewatering system details—generic drawing.

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Pumping systems that will reliably convey the bypass design flow can be complicated to design where water must be pumped up, or far away. You may want to contact the pump manufacturer to verify system design is adequate.

- **Bypass dam and pipe:** This method uses a single dam and bypass pipe to dewater the site. Construct the bypass dam from an impermeable membrane and a support structure. The dam can be made of excavated streambed materials, small or very large sandbags, waterbags, or other materials (section G.4.1.1). Since the bypass dam impounds water, it must be stable (e.g., if using streambed materials, you need minimum slopes of 1:1 upstream and 1:1.5 downstream). Place a membrane upstream of the dam, embedded 2 to 4 feet into the stream bottom and sides, to intercept subsurface flow and prevent seepage through bank materials when the dam pools water. If possible, construct the dam adjacent to a pool or excavation, where the membrane can line the entire dam and pool edge to the bottom to maximize capture of subsurface flow. Weigh down the membrane to keep it from floating. Cut a hole in the membrane smaller than the bypass pipe, stretching it around the pipe and binding it to the pipe to make an impermeable seal. The trench for the bypass pipe often collects some of the leakage from the bypass dam. If the water is clean, you can pump it upstream to eventually flow through the bypass pipe. If it is not clean, you can allow it to flow downstream to the sumps or to flow in an erosion-protected ditch alongside the bypass pipe, where it can be captured and treated. Leaves and woody debris can plug the diversion inlet and quickly cause overtopping of the diversion dam; consider placing a coarse mesh screen or fence upstream of the pipe inlet a few feet and tying it back into the diversion dam to catch debris before it can plug the inlet.
- **Feeder dam, bypass dam, and pipe:** This method uses an additional dam to pool and divert water with pumps during the construction of the main bypass dam. This method allows easier construction of the main dam and is more suitable in larger streambeds where dewatering is difficult due to subsurface flows and permeable bank materials. Any water that seeps by the feeder dam collects between the two dams and enters the annular area created by placing the smaller bypass pipe in the feeder dam into the larger bypass-dam pipe. In practice, the two-dam system will make the bypass much more efficient and reduce the amount of seepage that reaches the excavation (see figure 7.21). However, this system is more costly and is only necessary when subsurface flows make construction of the bypass dam difficult.

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Creating a good seal of the bypass dam can be difficult. Expect about 95-percent capture in a good system. If the amount of seepage is a problem, consider deepening or lengthening the membrane to decrease seepage.

7.8.2 Bypass Design

Size the bypass pipe to carry the highest flow reasonably expected to occur during construction, including surface and subsurface flows. The project team should determine the design flow for the bypass system after assessing risks and consequences of exceeding the design flow. Note that some State permits set a minimum return frequency for the design storm for bypass systems.

We recommend that a hydrologist estimate surface flow rates, and that either a hydrologist or a geologist help estimate subsurface flow volumes. (See appendix D for a brief discussion of methods for estimating streamflow.) Once you have estimated the design-flow volume for the bypass, design the pipe to carry the flow at an inlet depth of one pipe diameter or less. You can examine various pipe sizes and inlet-flow depths to find a pipe size and dam height capable of carrying the peak flow without overtopping the bypass dam or plugging the pipe with leaves or woody debris. To determine flow depth at the inlet and water velocity at the pipe gradient, use culvert-design charts or software such as FishXing or HY-8. (You can find FishXing and HY-8, as well as other useful hydraulic software downloads, at the Federal Highway Administration's Hydraulic Engineering Web site: <http://www.fhwa.dot.gov/engineering/hydraulics/software.cfm>.) Be sure that the bypass dam is at least as high as the calculated backwater at the pipe inlet, preferably higher by at least 6 inches to 2 feet, depending on the stream size, slope, and risk. Costs for the pipe and bypass dam are significant. Evaluate various scenarios to determine the least expensive reliable combination.

The bypass pipe requires protection from the considerable thrust that occurs at elbows and bends (both horizontal and vertical.) Weigh down or bury bypass pipes at elbows, bends, and vertical curves to prevent the pipes from moving or coming apart at the couplings.

To prevent seepage into the excavation, the pipe should have sealed joints. Given specifications, manufacturers can provide a pipe with a reliable seal. The pipe usually goes in a trench adjacent to the excavation. Use the calculated pipe velocity to design appropriate outlet erosion-control

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measures or a suitable pool to dissipate energy and reduce damage to organisms that may be transported downstream through the bypass pipe (for gravity bypass systems).

On some relatively flat sites, you can divert water into a natural or constructed channel around the project. The channel can be a lined ditch, raised sandbag, or other type of channel structure. Design the channel to carry the high flow expected either during the construction season, or, for multiseason projects, the expected annual high flow.

Other bypass options that you can design or allow in the contract include:

- (1) A constructed erosion-resistant transport ditch lined with rock or a membrane.
- (2) An existing flood-plain channel.
- (3) Isolated footing areas, with sandbags maintaining streamflow through the center of the project.
- (4) Pumping or siphoning the water through hoses 100 percent of the dewatering time.

Of these four, either you or your hydrologist can design the first three or check them for capacity. For pumping and siphoning systems, because of the difficulty in estimating flows, your best bet is to estimate the needed capacity, then plan on adjusting the capacity in the field.

7.8.3 Sump Design

Use sumps to collect ground water or seepage that escapes capture by the bypass dam (figure 7.21). Locate one or more at low points at the upstream and downstream ends of the excavation area. The upstream sump captures any ground water or seepage that gets past the bypass dam. If this water contains sediment, collect the water for further treatment before it reenters the stream channel (see figures 8.5 and 8.6). The downstream sump collects any sediment and drainage seeping through the area from any source and is the final insurance against sediment entering the stream. If a scour pool already exists at the culvert outlet, the downstream sump may not need to be excavated. If no scour pool exists, construct a waterproof downstream dam to create a sump below the excavation.

To help determine the correct pump size for the estimated seepage into the sump, pump manufacturers provide pump-performance curves (volume versus head). Depending on the application, pumps range from relatively small electric sump pumps to large gasoline- or diesel-powered

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pumps. Automatic float switches for controlling the pumps are available (see figure 8.7). Electric sump pumps are lower in capacity than engine-powered trash pumps (see appendix G.4.1.2).

One way to estimate seepage rates to determine pump capacity needed is to do a pump test near the channel. The pump test is normally done during a geotechnical investigation. It consists of determining how long it takes for seepage to refill a pit of known volume that has been pumped dry.

Estimate the sump collection areas and draw them on the site plan. Because seepage volumes and pumping requirements are only estimates, the design should be conservative. The sump must be large enough to capture all seepage and deep enough so the pump always has enough head to work properly. The contract can also state a requirement that “all sump water must be captured and treated before being released back into the live stream.”

The upstream sump may contain clean water that can be pumped directly back into the stream. If the water does not need treatment, pumping it either into the live-stream channel above the bypass dam or directly into the bypass system to avoid unnecessary treatment is often a convenient tactic. The downstream sump is the main collection point for sediment-laden water from excavation and other site disturbances, and it will always require treatment.

7.8.4. Sediment Treatment Methods

Using soil information and/or onsite drilling records, you can predict the type of sediment likely to be trapped in the sump. Due to the presence of suspended silt and clay, all projects will generate some turbidity. While sand-sized sediments settle quickly, silt and clay take much longer to settle; this water must be treated before being released into the stream channel.

A common and often suitable method of treating sediment-laden water is by natural filtration through soil and vegetation adjacent to the stream. Forest soils with thick layers of organic material, dense ground covers, and soils with at least moderate permeabilities at least 100 feet from a streambed can provide good filtering media for sediments (figure 8.8). You can use a perforated-pipe drainfield, or even irrigation sprinklers to disperse water over a broad area. Be aware that highly permeable riparian areas close to the stream may be ineffective for filtration.

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The project team may have located suitable filtration areas during the site assessment. If none are in the immediate vicinity, you can transport water further away in roadside ditches, swales, excavated ditches, or piping systems to more suitable treatment areas.

A variety of alternative sediment-treatment methods exist (also see appendix G.4.1.3):

- Use a subsurface drain in low-permeability material. Construct it by excavating a hole and filling it with drain rock to increase the absorption area and head.
- Pump sediment into small constructed pools to remove coarse sediment before treating for silt and clay. The ground disturbance associated with large settling ponds may be excessive on most sites.
- In treatment pools, ponds, or containers, include chemical polymers or natural-based flocculants such as:
 - ▲ Polyacrylamide (PAM), such as Chemco 9107GD and 9836A (Tobiason et al. 2001).
 - ▲ Chitosan-based water clarifier, such as Storm-Klear Liqui-Floc (For more information on polymer use for water treatment, see “Conclusions” in the following article:
http://www.forester.net/ec_0101_polymer.html.)
- Filter sump water, using sediment-filter bags similar to those from JMD Company (see http://www.jmdcompany.com/Enviro-Protection_bag.cfm).



Figure 7.22—Typical silt-fence installation.

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Silt fences are typically capable of trapping only small quantities of liquid, sand, and coarse silts, down to about 125 microns. They effectively can control overland sediment transport, but are not useful in deeper water, which overtops the silt fence as it becomes plugged with sediment. Include requirements to maintain silt fences when they are used; once the silt fence is filled, it is useless until maintained.

7.8.5 Backwatered Sites

Where the stream is not entrenched and is relatively flat, the excavation may be backwatered easily. Any excavation done in a backwatered site will produce a large volume of dirty water that may require extensive, high-volume treatment methods. Study the long profile to determine the backwatering potential and need for a downstream dam (in addition to the upstream bypass dam). Backwater dams are similar to bypass dams and use the same construction methods. If the backwater is deep, hydrostatic forces on the dam can be substantial, and the dam may require an engineering design. If little water is present, straw bales and plastic sheeting may be all you need for a backwater dam. Another possible solution when there is sufficient grade is lengthening the bypass pipe and outletting water further from the excavation.

Some backwatered sites, especially those adjacent to pools or reservoirs, cannot be dewatered effectively. In those cases, consider different structure types and construction methods that will reduce water quality impacts. For instance, a precast structure may be better suited to this kind of site than a cast-in-place structure. Bridges with driven-pile foundations or spread-footings near the ground surface will cause little impact to the site. Embedded pipes that can be placed quickly may also be suitable, especially if they do not require significant excavation because they are located in a backwatered “pool” location.

7.8.6 Deep Fills

At crossings with deep fills, carefully consider where to locate the bypass pipe to minimize the amount of excavation required for its placement. An open-bottom arch may be more desirable at this kind of site, because the existing pipe can be left in place to act as the dewatering pipe while the arch is constructed around it. Using an open-bottom arch may require a wider structure than selected in chapter 6. You will need to use sandbags or other damming materials to direct the water into the culvert while keeping it out of the excavation. When the existing pipe must finally be removed, you will need to either pump the water or route it through a bypass pipe while the streambed is prepared.

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If constructing an embedded pipe, consider construction methods that require the least time, because you will have to divert the stream during the entire construction. To avoid future leaks in the fill, remove the bypass pipe as the embankment is constructed.

7.8.7 Large Streams

Large streams may require the full suite of dewatering techniques described so far. The key to determining when to cut back or increase dewatering details is to evaluate the risks of failure. For example, when stream sediments contain large quantities of fines, more stringent measures to recover the fine material may be required to meet turbidity requirements. Although collecting all the water on a project before it reaches the excavation is often difficult, providing a conservative sediment-control system is better than causing stream turbidity problems, especially in sensitive habitat.

7.8.8 Small Streams

Although the dewatering system does not have to be elaborate, it does need to work effectively. The failure of a dewatering system on a small stream can sometimes cause just as much damage as a failure on a larger project.

7.8.9 Bedrock Channels

Sediment control is relatively easy in bedrock channels. The key is to create a well-sealed dewatering dam at the upstream end. Once the bedrock is cleaned off and dried, little sediment will be generated. Nonetheless, expect seepage from banks and through the dewatering dam. Because the water that has seeped in will almost never be clean, especially during excavation, construct a downstream sediment trap.

7.8.10 Field Modifications

Because streamflow and seepage volumes are hard to predict and can be highly variable, expect some modification of the dewatering plan in the field by contract administrators working in conjunction with you, the project team, and the contractor. Some modifications may also be necessary for optimizing the system for site conditions that become evident only during excavation.

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7.8.11 Pollution Control

Use special contract requirements, Federal Acquisition Regulations (FAR) Section H, to include pollution controls on a project. (See section 7.9.)

Typically, pollution controls include:

- Equipment washing—to prevent bringing in invasive plant species or petroleum-product pollution.
- Equipment repair—to prevent hydraulic leaks before beginning work.
- Petroleum-absorbing “diapers”—to be on hand and close by.
- Specially constructed fueling areas to contain spills.
- Limitations on camping and control of garbage and litter.
- Onsite toilets.

For jobs involving placing concrete in forms, locate suitable waste areas for dumping bad concrete and for washing mixers before concrete work begins. Never allow concrete washwater and fresh concrete to enter live streams, because the cement in the concrete is deleterious (due to the lye content) to all aquatic species.

Controlling invasive species and disease is a very important part of pollution control. Invasive plants may be accidentally imported into the project area from remote sources of soil, rock, plant, and seed materials. Ensure that the erosion- and pollution-control plan includes provisions against contaminating the project with invasive species (either plants or animals). Provide for washing equipment before bringing it to the project and when using vehicles to haul materials to or from contaminated areas. In addition, to ensure that soil and aggregate sources do not contain invasive plant species, provide for surveying the aggregate sources before using them. Do not use any aggregate source that has invasive plants.

7.9 SPECIAL CONTRACT REQUIREMENTS

Special contract requirements or “H-clauses” modify the main contract clauses or FAR. Following is a summary of the content of H-clauses typically used with aquatic organism passage contracts (see appendix H). These clauses often cover items also specified on the drawings, specifications, and supplemental specifications. Note: In this section, clauses are numbered as a typical contract for reference between chapter 7, chapter 8, and appendix H. Some of these clauses may or may not apply to your contract and thus your numbering may be different.

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Clauses related to species protection

- H.1—Seasonal Restrictions: H.1 specifies the overall dates for the work period, site disturbance, and in-water work. If extensions for site disturbance and in-water work periods are necessary, contact the project team biologist.
- H.13—Protection of Habitat of Endangered, Threatened, and Sensitive Species: H.13 specifies measures to protect plants or animals listed as threatened or endangered. If measures are inadequate or new species are found, the Government may unilaterally modify or cancel the contract. Discovery of threatened, endangered, or sensitive species requires notifying the contracting officer. Site dewatering methods fall under this clause.

Clauses related to water quality

- H.3—Landscape Preservation: H.3 replaces FAR clause 52.236, Control of Erosion, Sedimentation, and Pollution, and specifies requirements for:
 - ▲ Protecting vegetation outside clearing limits.
 - ▲ Preventing fuel and oil pollution.
 - ▲ Preventing or removing objectionable materials deposited in water bodies.
 - ▲ Specifying erosion- and pollution-control measures that must be available onsite.
 - ▲ Specifying turbidity limits and monitoring frequency.
 - ▲ Submitting contractor's plans and obtaining approval—before construction—for the following work items (all which have the potential for causing sedimentation and pollution of the stream and work area):
 - Clearing and grubbing.
 - Removing existing pipe.
 - Dewatering and water treatment.
 - Erosion control.
 - Excavating.
 - Placing channel rock, streambed simulation rock, and select borrow.
 - Placing structural concrete.

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- H.4—Moisture Sensitive Soils: H.4 requires the contractor to design bypass and temporary roads to support highway-legal loads during construction. It also requires the contractor to repair any damage associated with unsuitable material (such as saturated backfill), that would result in silt deposits in streams.
- H.16—Final Cleanup: H.16 requires removing trash and unused material, and requires sweeping and washing the road surface to remove sediment.

Clauses related to pollution control:

- H.14—Sanitation and Servicing Requirements: H.14 requires approval for camping, as well as the placing of oil-absorbing mats under stationary landing equipment and during equipment servicing.

Clauses related to structure or material changes:

- H.5—Value Engineering (VE): H.5 requires that the project team review VE proposals and it limits the use of VE proposals that change the functional service of a facility. (Typically, a change in structure type will not be suitable unless it is an upgrade, such as a sufficiently wide and durable bridge for a culvert structure.)
- H.6—Product Substitution: H.6 requires that the substitution meet the “or equal” clause in all respects, along with written documentation and testing information verifying that the substituted material meets specification requirements. The contractor is responsible for any other modification that the substitution causes. The project team must review any substitution of materials.
- H.10—Control of Material: H.10 specifies the type of excavation expected on the project, along with earthwork tolerances. It requires testing and written documentation of onsite materials to meet project specifications. (Although stream-simulation material is not earthwork, that material still must be placed accurately.) H.10 also specifies requirements for treating borrow, storage, stockpile, and disposal areas.

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Clauses related to traffic:

- H.7—Road Use and Maintenance: H.7 specifies requirements for road closures, traffic controls, and permits. Traffic-control plans are often subject to change after contract award. Contact the project team if a proposed change would affect either the project timeline or any physical site detail.
- H.9—Prosecution of Work: H.9 specifies requirements for providing for public safety throughout the construction (including traffic controls), and notifying the public when the construction work, e.g., road closures or blasting, will affect the public.
- H.11—State Permits: H.11 requires the contractor to obtain and follow State permits.
- H.17—Protection of Improvements: H.17 requires the contractor to protect improvements at the site throughout the construction. The contractor must replace signs, and other site features disturbed by construction, unless the contract specifically says otherwise.

Clauses related to safety:

- H.15—Potential Safety Hazards: H.15 requires the contractor to provide safe working conditions. Occupational Safety and Health Administration (OSHA) regulations apply for working in excavations and for working in confined areas. (For example, using power equipment to place stream materials inside a culvert is covered by OSHA clauses covering working in trenches, working in the vicinity of operating equipment, and working in the vicinity of excavated slopes.)

Miscellaneous clauses:

- H.2—Physical Data (FAR 52.236-4): H.2 states that physical conditions indicated on the drawings and in the specifications are the result of site investigations by the Government and that the Government is not responsible for the contractor's use of the site. H.2 also describes the normal fire season. (Many forests and regions have a fire plan describing the contractor's fire-related responsibilities, including types of equipment that must be kept onsite, hours that may be worked during high fire danger, people to contact in case of fire, preventive measures, and fire weather updates.)
- H.8—Construction Stakes, Lines, and Grades: H.8 specifies requirements for contractor surveys and for protecting survey control points.
- H.12—Protection of Cultural Resources: H.12 requires protecting and reporting any cultural resources discovered during the project (stream settings are often cultural-resource sites). The Government may unilaterally modify or cancel the contract under this clause.