Fact Sheet 1.3: Drainage and Culverts

The mitigation objective of this Fact Sheet is to reduce roadway flooding and erosion that occur when the capacity, alignment or operation of roadway drainage structures become overwhelmed or fail.

Choosing a solution for drainage issues requires that you determine the cause of the damage since different causes require different mitigation solutions. Studies, such as hydrologic and hydraulic (H&H) analyses, help determine the scale of the solution and the upstream and downstream effects of the solution. The most common drainage issues for roadways include:

- **Insufficient capacity**. High water levels from storm surge or heavy rains may exceed the capacity of ditches or culverts. Roadway flooding may cause the road shoulder to be damaged or the embankment through which the culvert passes to be damaged.
- **High-velocity flows**. Turbulence at the culvert inlet and outlet can cause scour and erosion. Floodwaters or storm surge action also can scour roadway ditches and drainage structures.
- **Debris impact and plugging**. Floodwater often carries debris, which can become caught or wedged in ditches and culverts as the water rises or recedes. Sediment and debris in culverts and drainage structures will reduce flow. Lodged debris can interfere with the flow of water, and floating debris also can cause damage to road and highway structures.

Table 1.3.1 summarizes some common mitigation strategies to reduce the likelihood of damage to roadway drainage structures caused by floods and hurricanes. While these strategies generally are stand-alone, they may be combined with methods from other fact sheets to reach a desired result.

Table 1.3.1. Road Culvert and Drainage Mitigation Solutions

Solutions and Options	***Erosion and Scour***	***Inundation and Washout***	***Debris Impacts and Plugging***
Mitigation Solution: Increase Design Capacity			
Option 1: Increase Ditch Capacity	✓	✓	✓
Option 2: Replace a Culvert with a Box or Arch Culvert	✓	✓	✓
Option 3: Replace a Culvert with a Bridge	✓	✓	✓
Option 4: Add Pipe Culverts	✓	✓	✓
Mitigation Solution: Reduce Embankment Erosion			
Option 1: Shape Culvert Entrance	✓	✓	
Option 2: Construct a Cutoff Wall	✓	✓	
Option 3: Install Appropriate Culvert End Sections	✓	✓	
Option 4: Install Lining in the Ditch	✓	✓	
Option 5: Install Check Dams	✓	✓	
Option 6: Construct an Energy Dissipater	✓	✓	
Mitigation Solution: Improve Alignment			
Option 1: Realign Culvert	✓	✓	✓
Option 2: Install Approach Berms	✓	✓	
Option 3: Install Flow Diverters	✓	✓	
Option 4: Install Additional Culverts	✓	✓	
Option 5: Realign the Stream Channel	✓	✓	
Mitigation Solution: Reduce Obstructions			
Option 1: Install an Entrance Debris Barrier	✓		✓
Option 2: Install a Sediment Catch Basin Upstream			✓
Option 3: Install a Relief Culvert	✓	✓	✓
Mitigation Solution: Relocate or Replace with Water Crossing			
Option 1: Relocate Culvert	✓	✓	
Option 2: Add a Low Water Crossing	✓		
Option 3: Add a High-Water Overflow Crossing	✓		

Refer to the culvert diagram, below, for an illustration of components of the system (Figure 1.3.1).

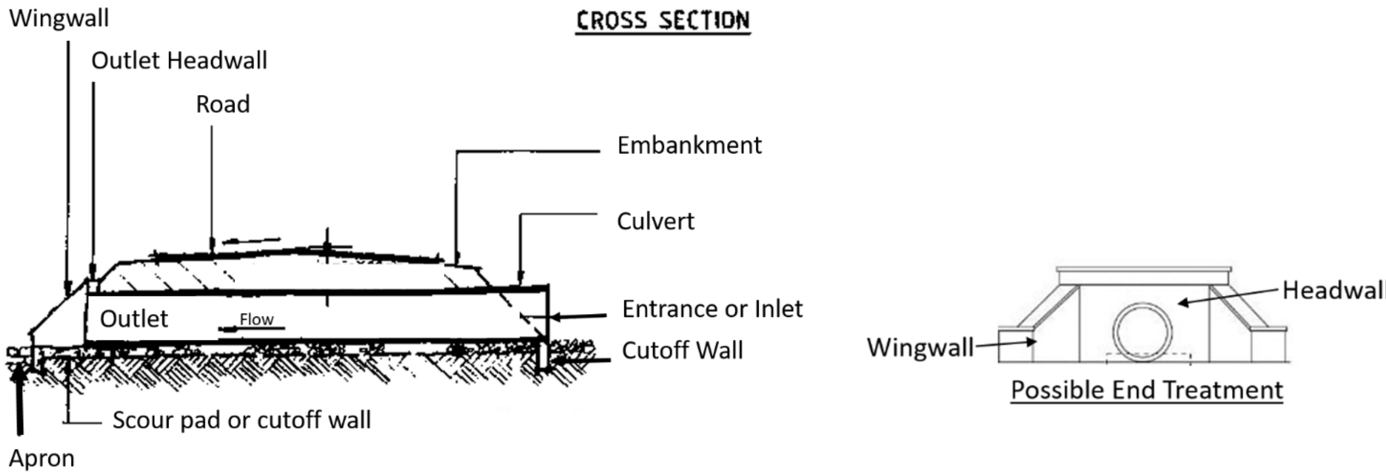


Figure 1.3.1. Components of a culvert.

Mitigation Solution: Increase Design Capacity

Damage to or failure of drainage structures can occur from flooding across the roadway caused by inadequate culvert capacity or ineffective end sections, which leads to embankment erosion. Figure 1.3.2 shows example cross-sections for different types of drainage structures.

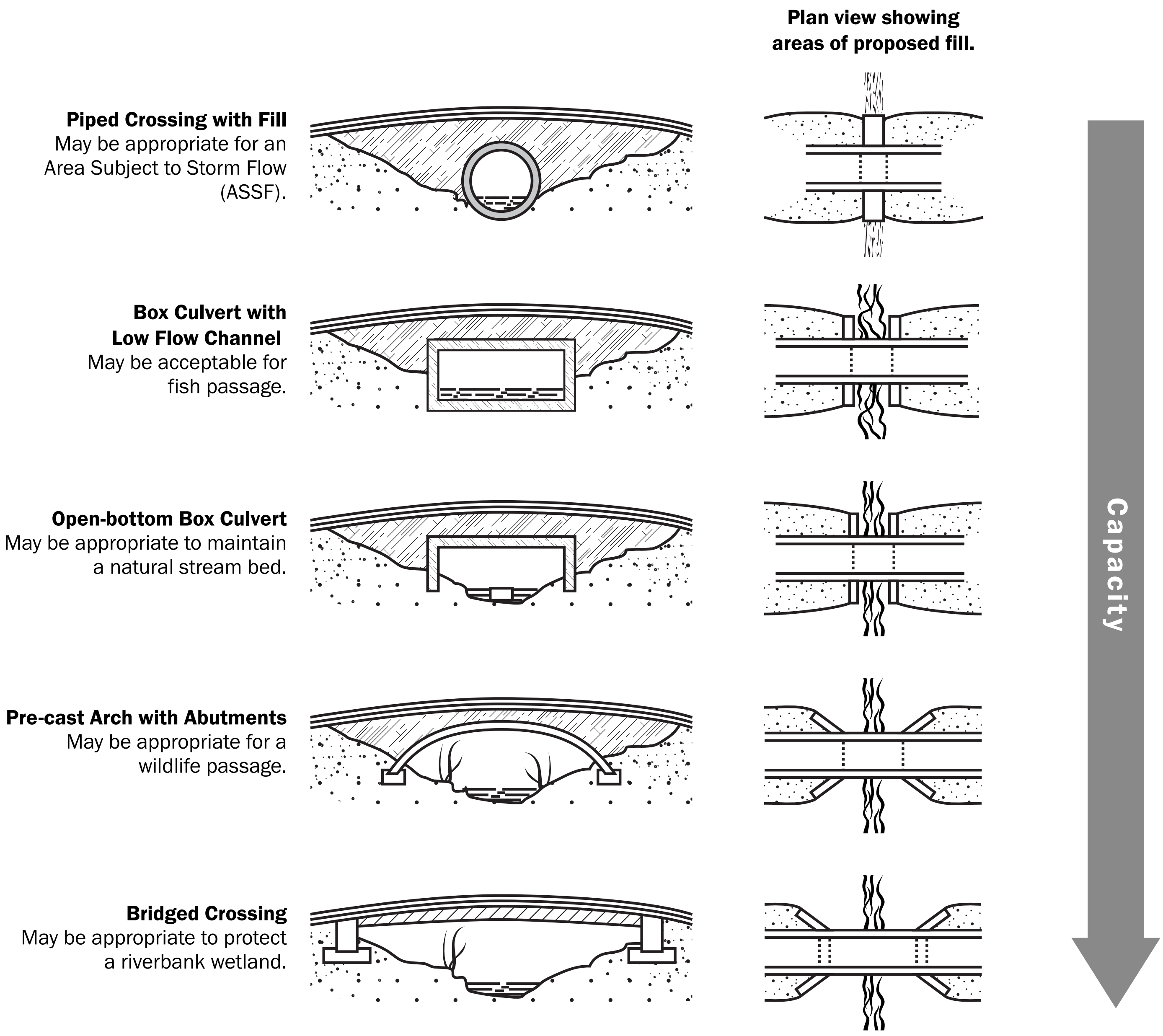


Figure 1.3.2. Alternative stream crossing designs.

The following considerations apply to all the options that follow:

- The capacity of a culvert, channel or stream is a function of the cross-sectional area and the water velocity.
- Erosion and scour are a function of the water velocity and soil characteristics.
- Enlarging the cross-sectional area can decrease water velocities and reduce erosion and scour. Still, it may mean more structural support is necessary.
- Many states have adopted stream crossing standards to balance ecological and wildlife habitat needs in and around the stream with the needs of road users. Always consult state standards for specific requirements.

Option 1: Increase Ditch Capacity

Reducing overflow and overland flooding increases the ditch capacity by increasing the ditch depth or width (Figure 1.3.3).

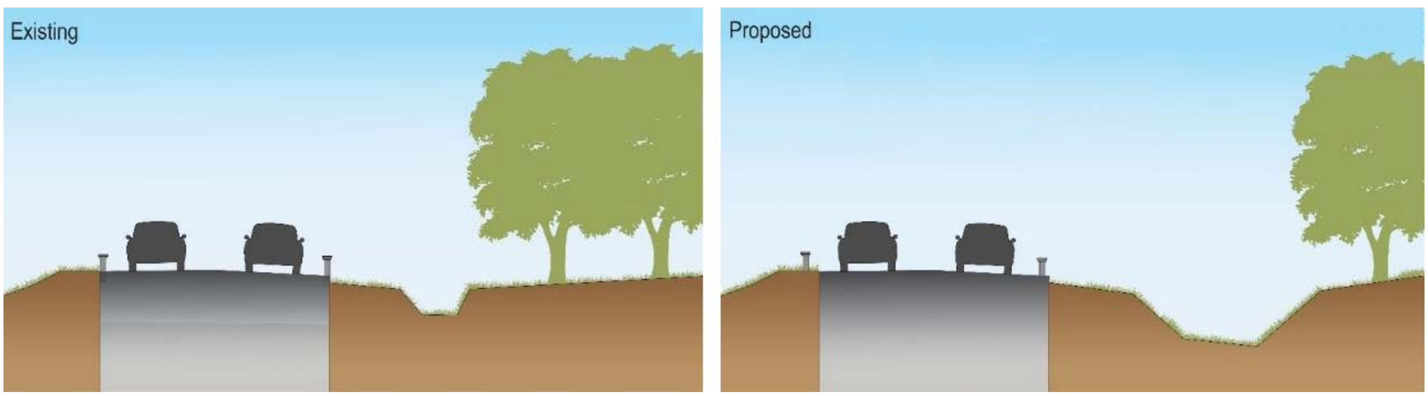
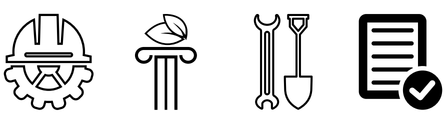


Figure 1.3.3. Increasing ditch capacity can help protect against overland flooding.

CONSIDERATIONS:



Option 2: Replace a Culvert with a Box or Arch Culvert

A box or arch culvert provides additional capacity in low fill situations. A box or arch culvert can be designed for very minimal fill height (Figure 1.3.4).

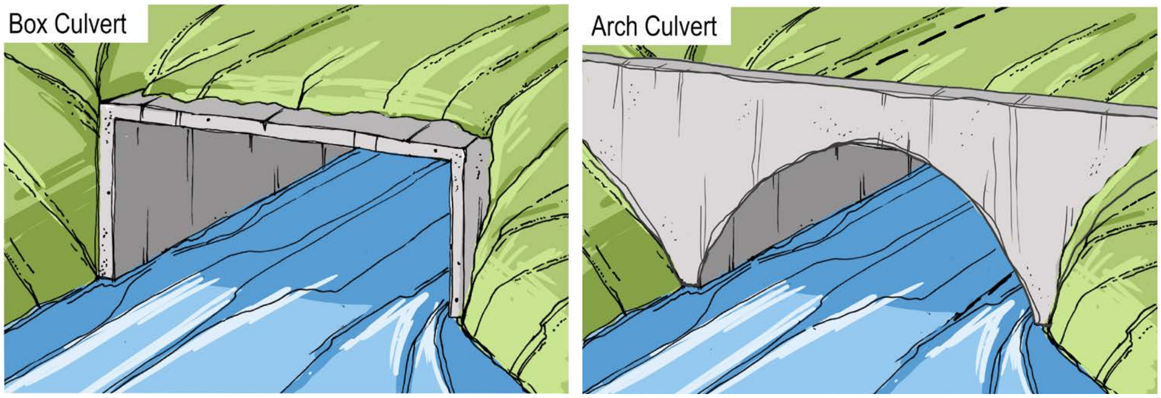
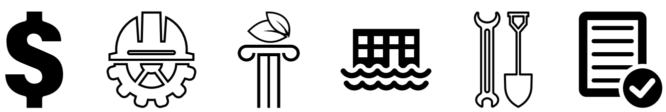


Figure 1.3.4. An arch culvert or a box culvert can provide increased flow capacity.

CONSIDERATIONS:



Option 3: Replace a Culvert with a Bridge

Whether the land upstream of the culvert has significant development or there are habitat reasons to protect the stream bed, replacing a culvert with a bridge may be appropriate (Figure 1.3.5).

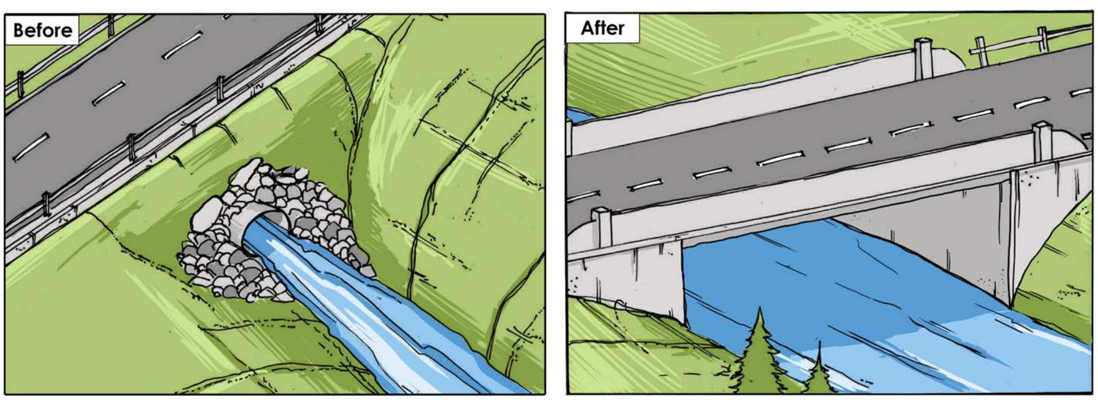


Figure 1.3.5. Replacing a culvert with a bridge can protect the stream bed and the road.

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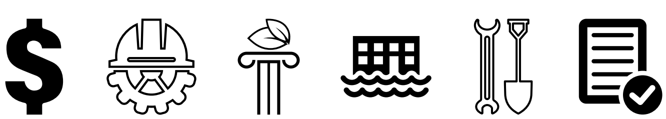


Option 4: Add Pipe Culverts

Multiple culverts may be the best choice when using a single, larger pipe is too costly or when site constraints, such as how deep the pipe must be covered, require a smaller pipe size. Multiple culverts also may be more suitable than a single, large-diameter culvert pipe for low fill areas.

Install additional culverts, along with the existing culvert, at either the same level or—to minimize sediment buildup—at differing elevations (Figure 1.3.6).

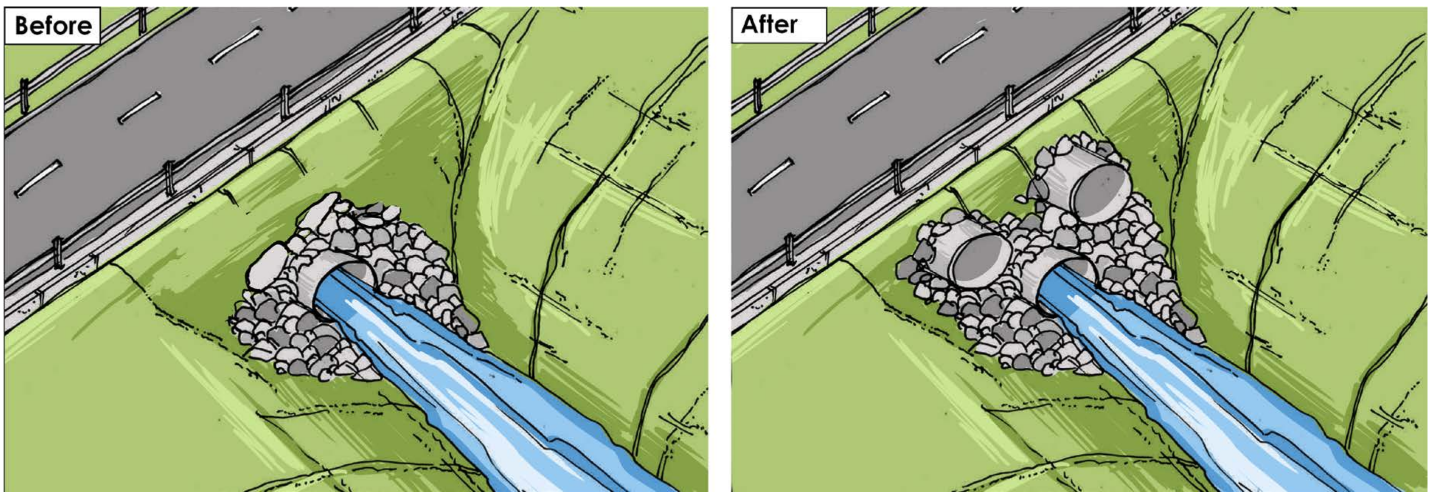
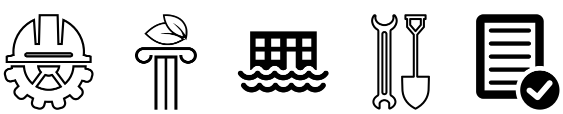


Figure 1.3.6. Installing multiple culverts can increase flow capacity.

CONSIDERATIONS:



Mitigation Solution: Reduce Embankment Erosion

Embankment erosion may be a result of inadequate culvert end sections.

Option 1: Shape Culvert Entrance

Shaping the culvert entrance is most effective for large culverts and moderately effective for small culverts. It is crucial to prevent undermining at the culvert entrance. To do this, shape the culvert entrance to match the embankment slope or stream path by beveling or skewing the entrance (Figure 1.3.7). Turbulence at the entrance and through the culvert will be lessened, which reduces bank erosion, and culvert efficiency will increase.

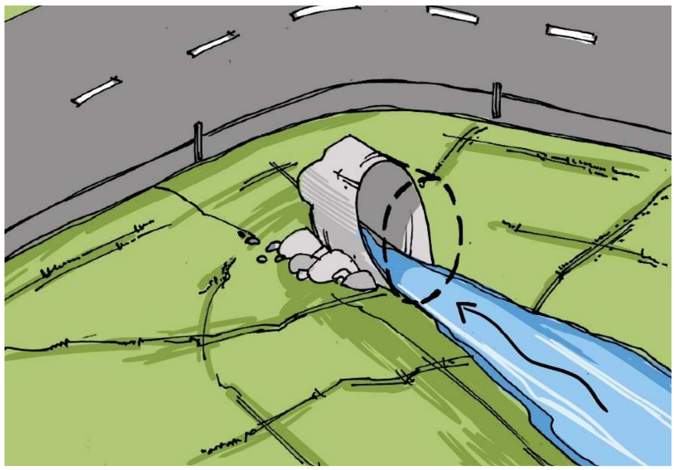
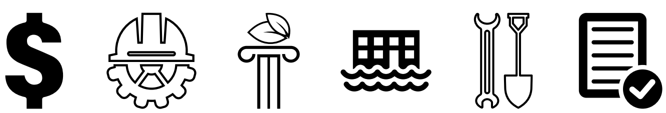


Figure 1.3.7. Shaping the culvert entrance can reduce erosion at the intake.

CONSIDERATIONS:



Option 2: Construct a Cutoff Wall

This mitigation measure is most effective for large culverts. Install a low-height steel sheet pile or concrete cutoff wall to reduce undermining or erosion at the culvert entrance (Figure 1.3.8). Cutoff walls should extend below the culvert entrance to at least one and a half times the culvert diameter.

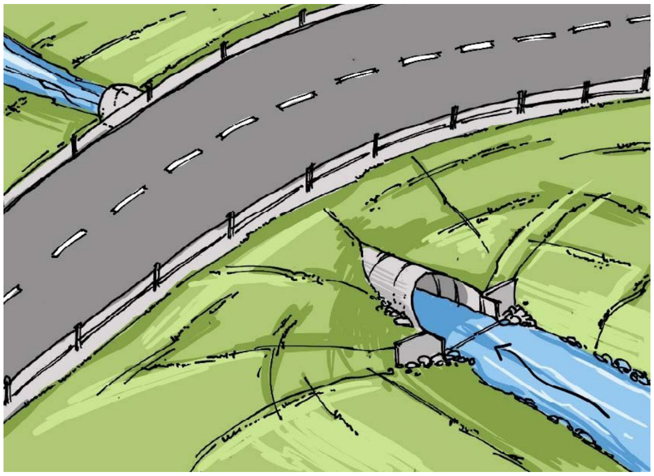
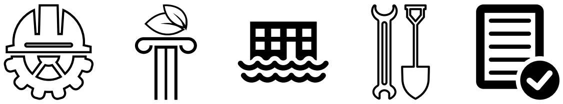


Figure 1.3.8. A cutoff wall can reduce undermining.

CONSIDERATIONS:



Option 3: Install Appropriate Culvert End Sections

To direct flow into and out of the culvert and protect embankment slopes at the culvert entrance and exit, install endwalls, wingwalls or flared end sections (Figure 1.3.9).

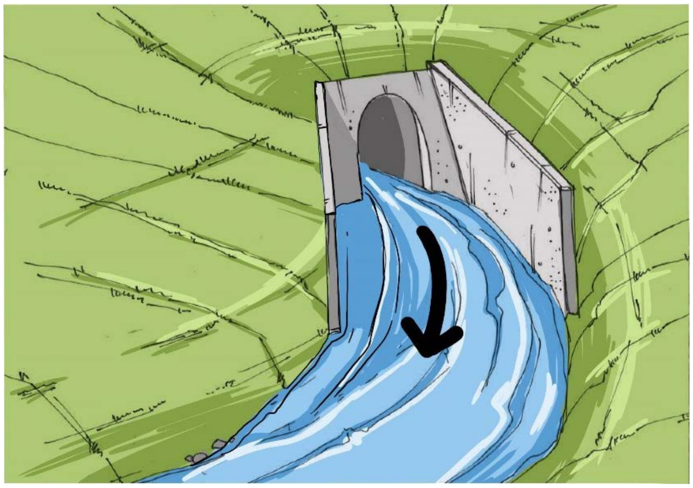
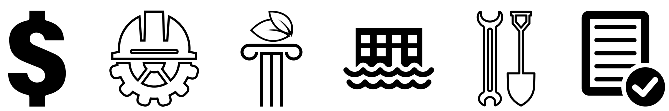


Figure 1.3.9. Wingwalls, headwalls and endwalls can protect embankment slopes.

When evaluating this option, keep these considerations in mind:

- Use straight or "U"-shaped endwalls, headwalls or flared wingwalls when the centerline of the stream aligns with the culvert.
- Use "U"-shaped endwalls, headwalls or wingwalls when an abrupt change in flow direction is necessary.
- Construct an "L"-shaped headwall to redirect the flow to the angle of the culvert.
- Wingwalls are preferred when flow volumes and velocities are high and for culvert pipes that are 36 inches or larger.
- Straight headwalls may decrease culvert capacities but rounding the entrance corners may offset any capacity decrease.
- If stream velocities are high, scour of embankment sides may result from eddies at the culvert end sections.
- Attaching fabricated flared end sections to culvert entrances and outlets may cause the culvert joints to separate if the culvert cannot support additional weight.

CONSIDERATIONS:



Option 4: Install Lining in the Ditch

Lining the ditch with rock, matting, asphalt or vegetation can help to reduce ditch erosion from high-velocity and high-volume flood flows (Figure 1.3.10).

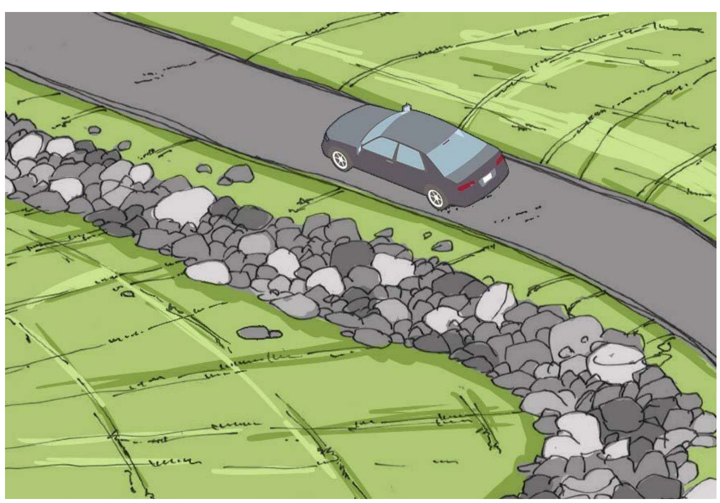
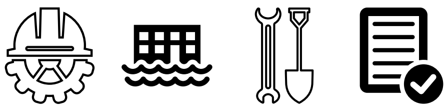


Figure 1.3.10. Ditch lining can reduce erosion and improve flow capacity.

When evaluating this option, keep these considerations in mind:

- Larger and coarser-grained materials will protect against high-velocity flows.
- Grass-lined ditches provide bio infiltration and sediment reduction. However, grass linings require time to become established before they are fully effective.
- Concrete-lined ditches increase the velocity of runoff flows. Asphalt and concrete with high lime contents may not be appropriate because the water may leach the lime from the liner, which can cause water quality issues.

CONSIDERATIONS:



Option 5: Install Check Dams

Install low-height barriers (check dams) to slow stormwater flow and reduce scouring and erosion from the flow (Figure 1.3.11).

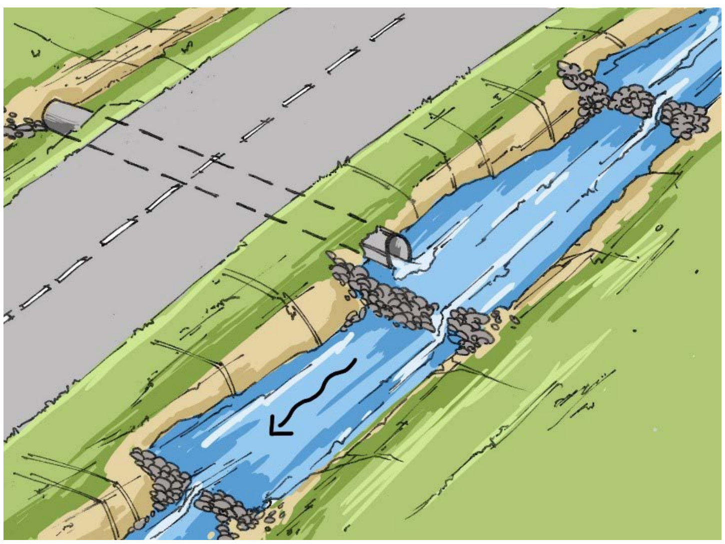


Figure 1.3.11. Check dams help slow water and decrease scouring.

When evaluating this option, keep these considerations in mind:

- Properly installed check dams will slow the water flow, trap a portion of the bed load, and allow the settling of a portion of the suspended sediments. Each of these impacts can reduce potential downstream erosion.
- Check dams, usually made of quarried stone, are suitable for small streams and artificial drainage channels.
- This measure may work best for temporary erosion and silt control. Check dams in locations not easily accessed by equipment may be difficult to maintain.

CONSIDERATIONS:

Option 6: Construct an Energy Dissipater

Mitigate erosion and scour at the culvert exit with energy dissipation, which uses structures placed in the stream or waterway to reduce the velocity of the flow (Figure 1.3.12). General types of energy dissipation measures include:

- An apron, which is a hardened surface such as concrete or grouted riprap, at the culvert exit, which reduces turbulent flow that can scour the toe of the embankment or undermine the culvert;
- Baffle structures, which are used to shift the zone of high-velocity flow from the culvert downstream so that it does not pose a risk to the embankment; and
- Increasing tailwater depth by digging a discharge pool or stilling basin to control turbulent flow at the culvert exit.

Energy dissipater designs may include concrete or rock sloping aprons, “bucket” outlets that divert the flow downstream, stilling basins, or other elaborate structures.

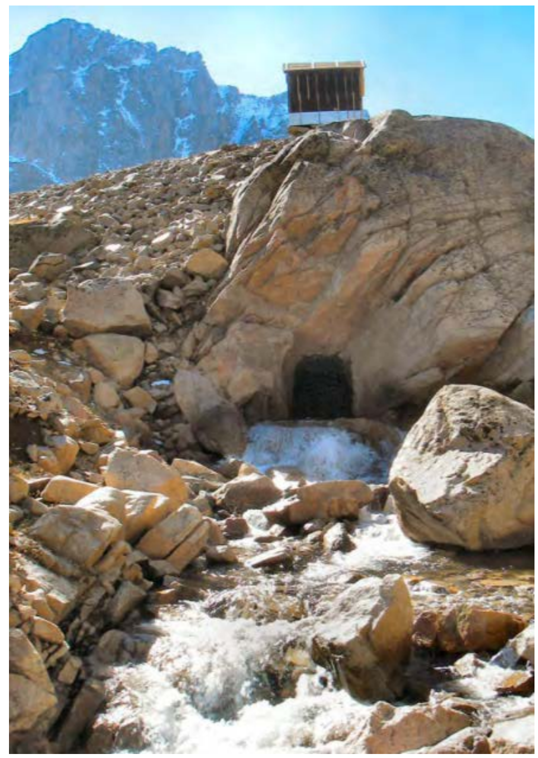


Figure 1.3.12. Energy dissipaters can be installed at culvert discharges to decrease erosion and scour.

CONSIDERATIONS:

Mitigation Solution: Improve Alignment

Changing the culvert's horizontal (side to side) and vertical (up and down) alignment to match the centerline and slope of the stream can reduce erosion caused by misalignment. Aligning the culvert inlet and outlet along the axis of the stream can maximize culvert efficiency.

Option 1: Realign Culvert

To reduce or eliminate erosion along the embankment, which can damage the culvert, realign the culvert (either vertically or horizontally) to match the centerline of the stream (Figure 1.3.13).

- All realignments should take into consideration the whole drainage system.
- Realignment also may require moving the culvert to match the current stream location.
- Stream or road geometry and permit conditions may prevent changing the culvert alignment.

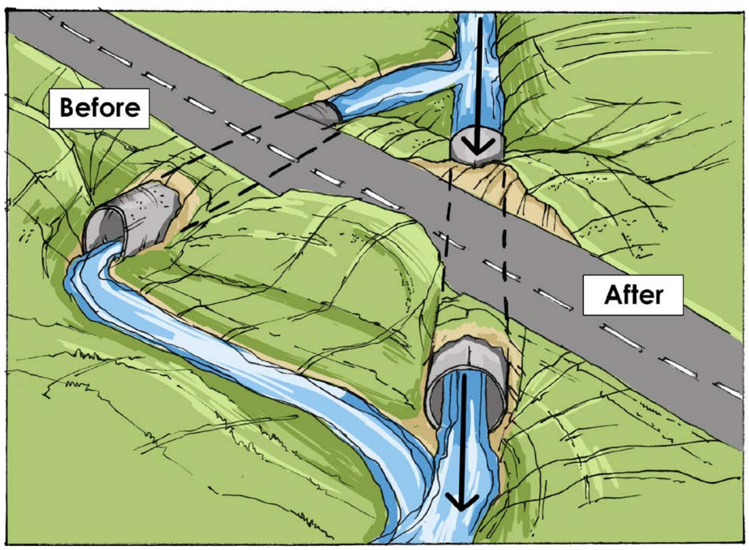
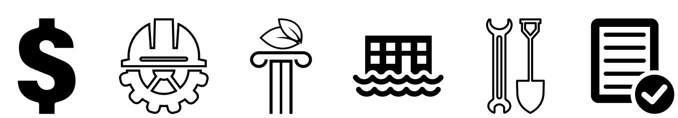


Figure 1.3.13. Realigning the culvert to the stream centerline can reduce damage to the culvert.

CONSIDERATIONS:



Option 2: Install Approach Berms

On the stream overbanks, which are formed when streams overflow their banks and deposit sediment on the floodplain, install approach berms to direct the flow into and at the same angle as the culvert, away from the embankment (Figure 1.3.14). Berms need to be placed on stream overbanks near or at the edge of the flood channel so that water surface elevations are not significantly increased at the culvert or upstream.

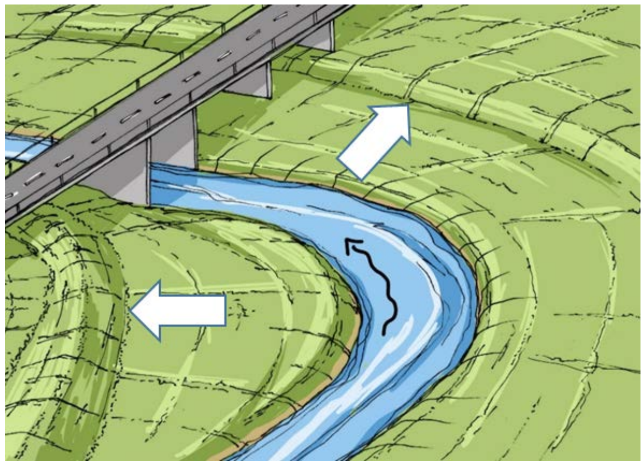
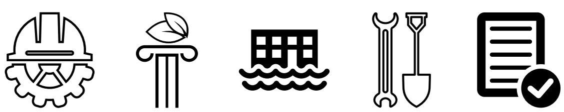


Figure 1.3.14. Approach berms can direct flow away from embankments.

CONSIDERATIONS:



Option 3: Install Flow Diverters

Flow diverters (barbs) in the stream can redirect streamflow away from the stream bank into the culvert (Figure 1.3.15). Natural materials, such as root balls or anchored logs, can be effective, habitat-friendly flow diverters and reduce channel movement. The size of diverters should not increase water surface elevation for high flows either at or upstream of the culvert.

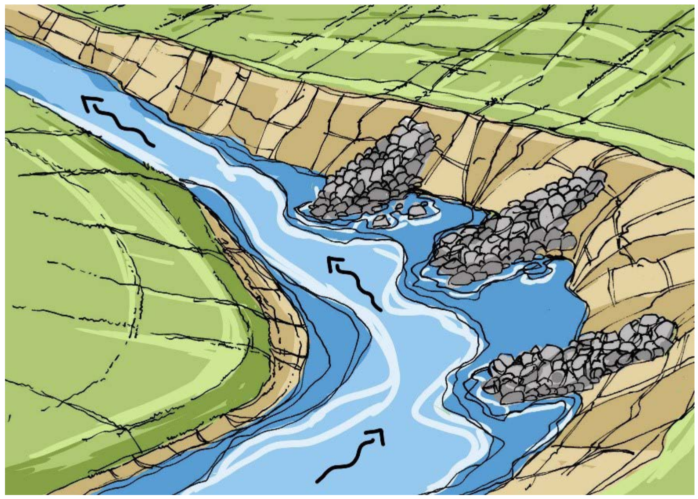
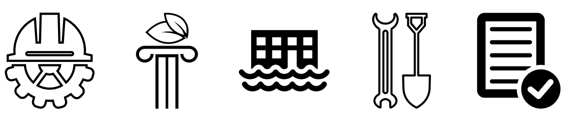


Figure 1.3.15. Flow diverters can realign the stream channel.

CONSIDERATIONS:



Option 4: Install Additional Culverts

Install additional culverts at the road crossing site (Figure 1.3.16). Elevating additional culverts so that they are only used during flood events can reduce clogging to the original culvert at the lower elevation. This measure can be useful when height limits exist.

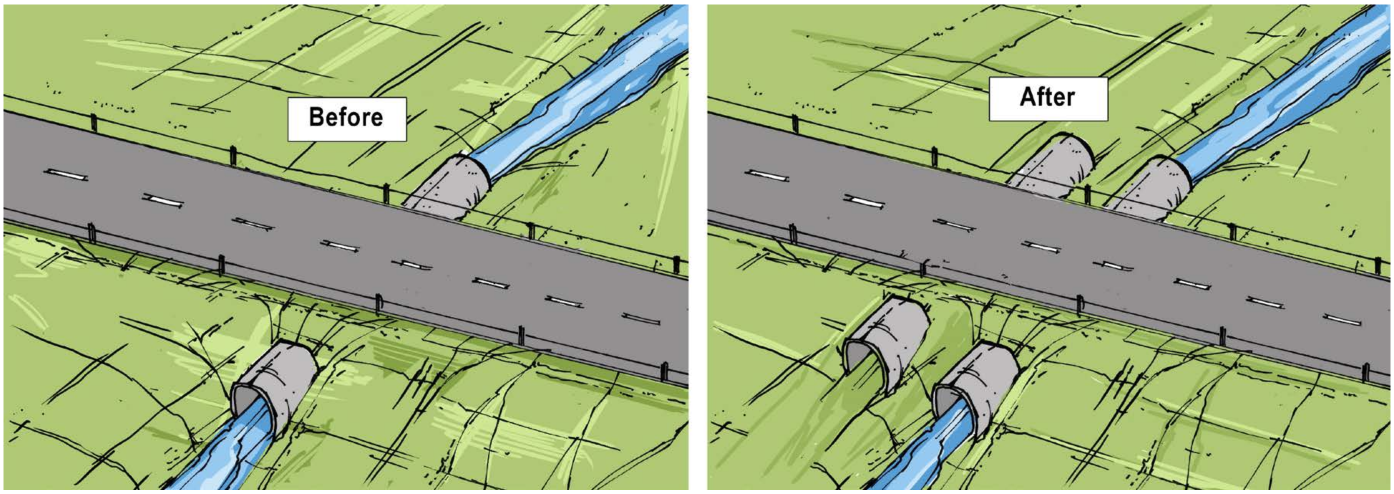
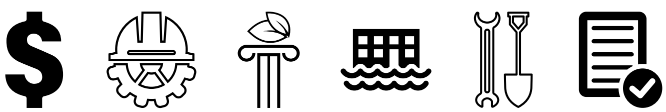


Figure 1.3.16. Installing additional culverts can reduce velocity and clogging.

CONSIDERATIONS:



Option 5: Realign the Stream Channel

Streamflow should be directed at the same angle as the culvert and away from the embankment to reduce erosion along the embankment and subsequent damage to the culvert (Figure 1.3.17). Embankment slope protection and other mitigation measures may be necessary to achieve maximum effectiveness.

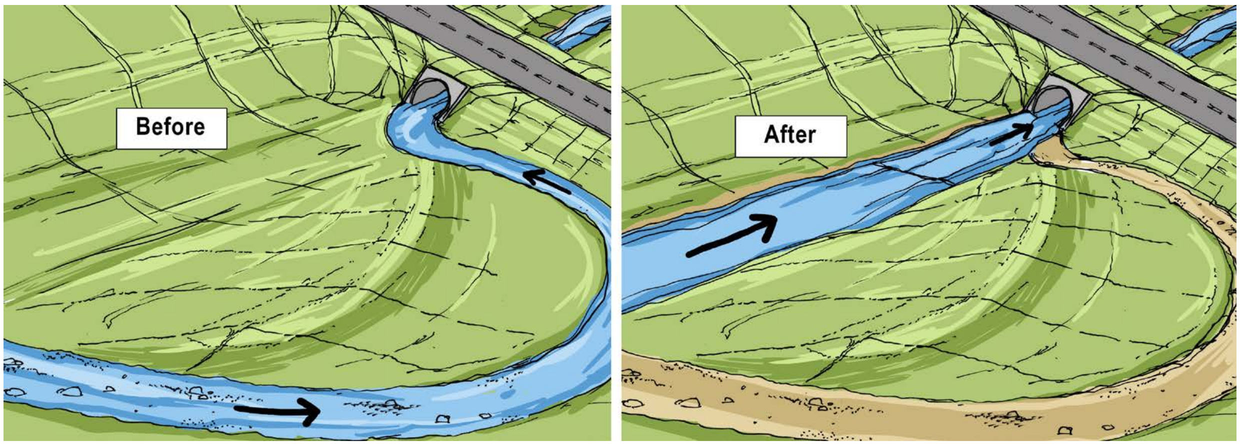
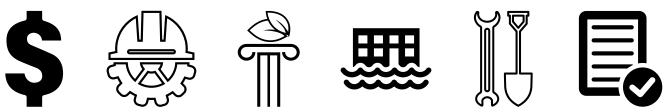


Figure 1.3.17. Realigning the stream can protect embankments.

CONSIDERATIONS:



Mitigation Solution: Reduce Obstructions

A culvert blocked with debris and silt may be damaged or even fail during flooding, causing embankment erosion. Debris at the culvert entrance or caught inside the culvert restricts water flow, raising the upstream water surface elevation, leading to culvert damage or even washout. Protect the culvert entrance from debris to prevent damage.

Option 1: Install an Entrance Debris Barrier

Manage debris flow through a culvert by installing an entrance debris barrier (debris deflector or debris crib) or debris fins to redirect floating debris for easy passage through the culvert (Figure 1.3.18).

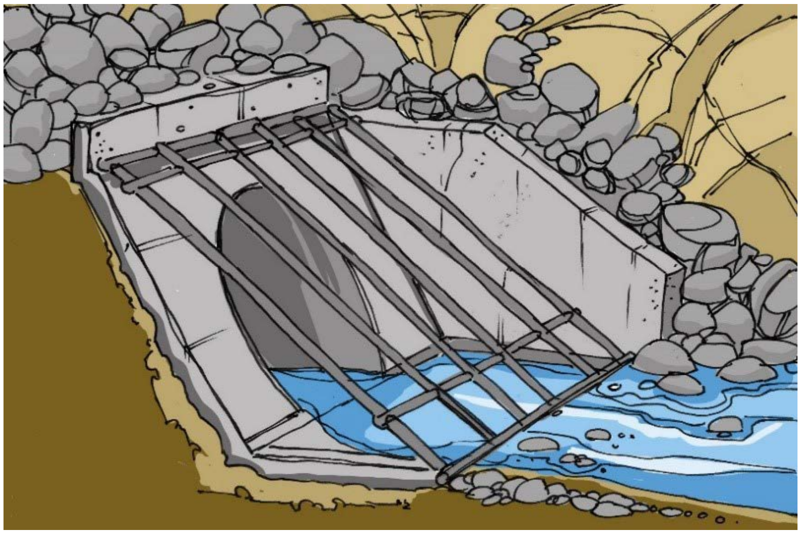
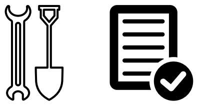


Figure 1.3.18. A debris barrier can protect a culvert from damage.

When evaluating this option, keep these considerations in mind:

- A debris barrier may be a "V"-shaped or semicircular rack at the culvert entrance or a straight rack at the end of wingwalls. A debris crib with a drop inlet also may be used to prevent debris from blocking culverts.
- When debris builds up around the barrier, it can block the culvert and flooding can occur during high flows. Maintenance is an important component.
- There must be adequate stream channel storage available for debris accumulation.

CONSIDERATIONS:



Option 2: Install a Sediment Catch Basin Upstream

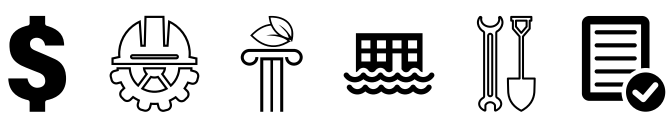
Build a sediment basin or pond upstream from a culvert to allow floating sediment time to settle into the basin before entering the culvert (Figure 1.3.19).

Figure 1.3.19. A sediment basin can help settle suspended sediment and decrease culvert clogging potential.

When evaluating this option, keep these considerations in mind:

- Basins and ponds should be located to be accessible for maintenance and sized to provide enough storage.
- This measure is most effective where heavy silt or sand is transported during floods, causing streambed to scour.

CONSIDERATIONS:



Option 3: Install a Relief Culvert

Installing one or more relief culverts can provide another route for floodwaters if the main culvert gets plugged (Figure 1.3.20). Place the relief culvert at the crossing site and in the embankment above the flow line of the main culvert.

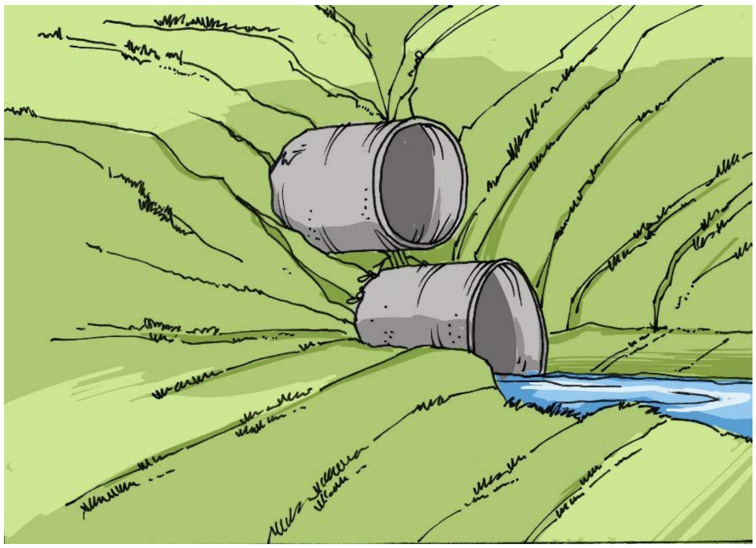
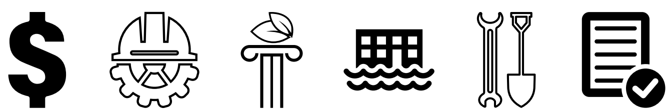


Figure 1.3.20. Install a relief culvert as a second route for floodwaters if the main culvert gets clogged.

CONSIDERATIONS:



Mitigation Solution: Relocate or Replace with Water Crossing

Culverts may need to be relocated to accommodate a migrating stream or an area likely to have high-velocity flooding and bank erosion. Additionally, a culvert is replaceable with another water crossing that allows the roadway to handle the estimated flows.

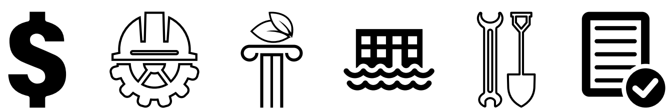
Option 1: Relocate Culvert

Relocate culverts to sites that are less likely to be affected by high-velocity water flows.

When evaluating this option, keep these considerations in mind:

- Move the crossing outside of an area affected by riverine flooding, storm surge or coastal wave action.
- Avoid moving the crossing to a location that will direct flow toward downstream properties, where flooding could happen, or streambeds or stream banks could be damaged.

CONSIDERATIONS:



Option 2: Add a Low-Water Crossing

Replace a culvert with a dip in the roadway to accommodate the anticipated flows (low-water crossing during emergency events) or add a roadway depression over a culvert (Figure 1.3.21).

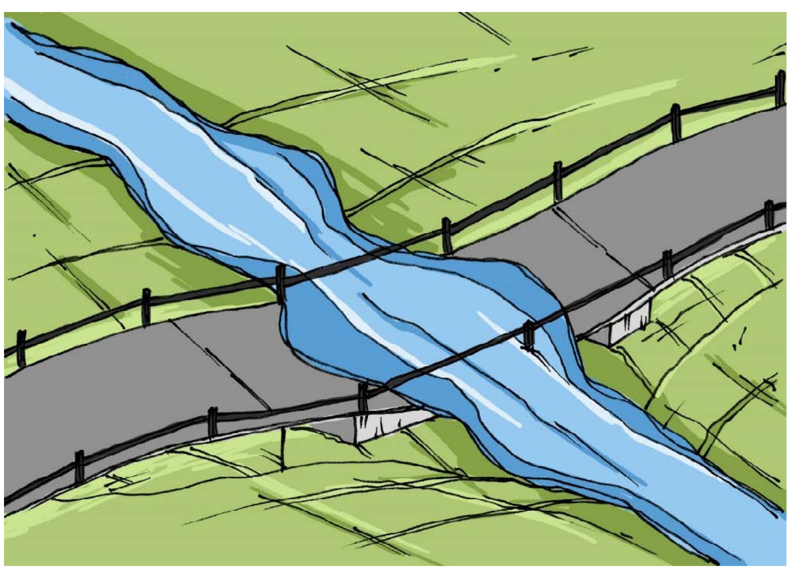
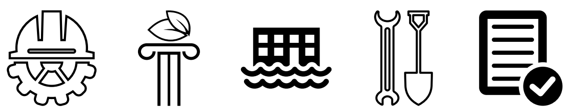


Figure 1.3.21. A low-water crossing in place of a culvert will accommodate flows during emergency events.

When evaluating this option, keep these considerations in mind:

- This option should not be considered if the roadway connects to a critical facility.
- This measure works best in areas where flooding is seasonal.
- It is appropriate only for corridors with low traffic counts.
- Signs and barricades are necessary when water exceeds a depth that is safe for vehicles to pass.
- Design and construct roadway embankments to withstand anticipated water flows.
- The profile of the crossing should match the shape of the stream crossing as closely as possible.

CONSIDERATIONS:



Option 3: Add a High-Water Overflow Crossing

Install an overflow section (high-water overflow crossing) in the roadway to accommodate stream overflowing (Figure 1.3.22).

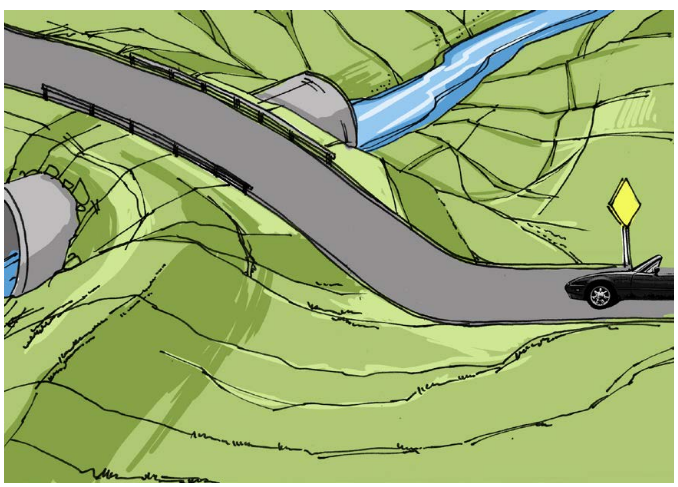
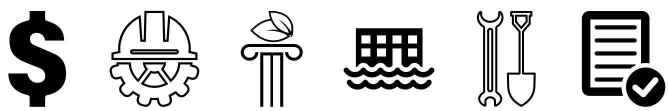


Figure 1.3.22. Installing an overflow section in the roadway can accommodate stream overflows.

When evaluating this option, keep these considerations in mind:

- Locate high-water overflow crossings at natural side channels or in line with heavy flow areas located on stream banks.
- Design the overflow section to limit overflow depth.
- Select a road surface material that protects the road base from saturation.
- Protect the downstream side of the embankment from scouring by the overflowing water by using a toe apron, stilling basin, downstream pool or riprap.
- This measure reduces road or culvert damage by providing an overflow spillway. Still, in a flood event, the road could be impassible.

CONSIDERATIONS:



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Detailed technical information on culvert and drainage methods, considerations, and general design practices can be found in these publications:

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