FLOOD HAZARD MITIGATION HANDBOOK

FOR

PUBLIC FACILITIES

Produced By:
FEMA Region 10
Response & Recovery Division
Infrastructure Section

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HANDBOOK

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Federal Emergency Management Agency
Region 10

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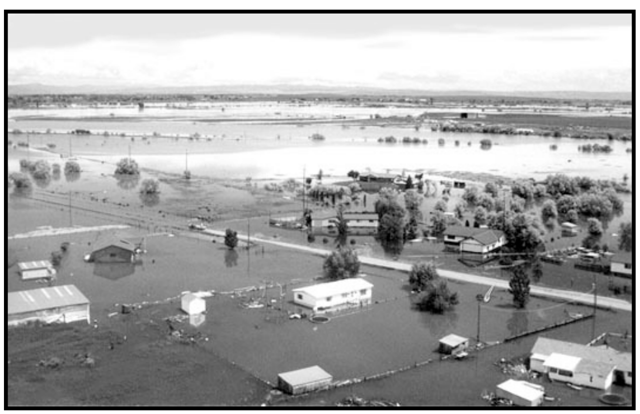
INTRODUCTION

The Federal Emergency Management Agency (FEMA) continuously strives to improve the delivery of disaster assistance to states and local governments. This *Flood Hazard Mitigation Handbook for Public Facilities* (Handbook) assists those entities directly affected by natural catastrophic events and Presidentially-declared disasters by providing various ideas for mitigation measures. These measures are intended to help identify options and mitigation ideas for local jurisdictions that can be used at any time, not only after a disaster.

FEMA is charged to provide the focal point of disaster response at the Federal level. FEMA's mission to reduce loss of life and property caused by natural disasters is accomplished through a comprehensive emergency management program.

Before a disaster strikes, FEMA provides funding and technical assistance for a range of preparedness and mitigation activities. One example is floodplain management, of which FEMA has several programs that provide incentives for communities to reduce future flood risks.



During the disaster, FEMA works with governmental and volunteer agencies, such as the Red Cross, to meet the immediate needs of disaster victims by providing food, shelter, and medical care. Through the Federal Response Plan, FEMA coordinates the resources of other Federal agencies to respond to emergency situations that are beyond the capabilities of State and local resources.

After a disaster, FEMA coordinates long-term recovery efforts through a number of mitigation programs. The Public Assistance Program provides funding opportunities for implementing mitigation measures during the rebuilding of disaster-damaged public infrastructure. The Hazard Mitigation Program supports a number of mitigation programs that help protect communities by working to reduce or eliminate future disaster damage.

The Problem: As disasters have grown in frequency and severity, the costs of response and recovery have escalated to unsustainable levels. In the Pacific Northwest, between 1996 and 1998 alone, FEMA provided over $535 million in disaster assistance. This figure does not include assistance paid by other Federal agencies, costs to State and local governments, or direct individual or business losses. Nationwide, natural disasters cost over $50 billion each year.

The Solution: The most effective way to reduce these excessive losses is through disaster preparedness and mitigation. To best achieve this goal, we as a society need to vigorously pursue three objectives:

OBJECTIVE 1: To break the disaster–rebuild–disaster cycle. This cycle of repetitive loss is the historical mode of disaster recovery. But merely repairing substandard facilities to their pre-disaster condition does not protect the community from future disaster damages or reduce long-term costs. Mitigation betterments should always be considered in the rebuilding process, utilizing a multi-hazard approach whenever possible.

OBJECTIVE 2: To strengthen existing infrastructure and facilities to more effectively withstand the next disaster.

OBJECTIVE 3: To ensure that communities address natural hazards. Comprehensive plans should acknowledge all hazards that pose a risk and take steps to avoid these hazards altogether, or incrementally reduce the community's exposure to its hazards.

The Savings: The outcome of achieving these objectives will be more resilient and economically sustainable communities. An analysis of FEMA-funded mitigation measures in the Pacific Northwest has established that for every dollar spent in damage prevention, two to three dollars are saved in future repairs.

PURPOSE OF HANDBOOK

The *Flood Hazard Mitigation Handbook for Public Facilities* (Handbook) is intended to aid local jurisdictions in identifying a variety of feasible mitigation ideas that can be implemented during the rebuilding process. It focuses on projects commonly eligible for hazard mitigation funding under the Public Assistance Program. Frequently, due to the urgency to repair the facility, long-term mitigation opportunities are not fully explored. As a result, hazard mitigation funding opportunities through FEMA's Public Assistance program are not fully utilized.

This Handbook provides local jurisdictions with mitigation ideas that have demonstrated success and can be timely implemented. These mitigation measures relate to the most common damages sustained by severe flood events. This Handbook can be a useful mitigation tool regardless whether a specific project is proposed for FEMA funding under either the Public Assistance or Mitigation programs.

Mitigation measures in the Handbook are presented as helpful ideas. To learn of other mitigation measures, see FEMA's Mitigation Policy No. 9526.1. This Policy includes an appendix of measures already determined by FEMA to be cost-effective when certain conditions are met, such as when the cost of the listed mitigation measure does not exceed 100 percent of the project cost. None of the mitigation measures in this Handbook, however, should be considered 'pre-approved' or otherwise automatically eligible for FEMA funding. Only FEMA staff can determine eligibility, once they have reviewed a project proposal.

MITIGATION ALTERNATIVES FOR FLOOD DAMAGED PUBLIC FACILITIES

Organization of mitigation measures in this Handbook:
Damages to public facilities from a disaster can vary greatly, dependent upon site and facility condition. This Handbook is organized first by type of facility, then by failures or damages that are commonly sustained by that facility due to a flood. Each category of failure or damage lists a selection of mitigation ideas to consider. The effectiveness, limitations, and considerations for each mitigation measure are also identified.

Engineering, design, and permitting requirements:
The Handbook does not detail site-specific requirements, as the engineering analysis, design, and permitting of each project will vary widely. In many instances, the applicant is well qualified to conduct the engineering and design, as well as construction specifications, in-house. In other cases, it will be necessary to contract with outside sources.

Public Assistance eligibility:
As with all agencies that provide federal funding, FEMA requires specific criteria be met regarding eligibility before it approves proposed projects. *ONLY FEMA CAN DETERMINE AN APPLICANT'S ELIGIBILITY.* Eligibility criteria are detailed in the *Public Assistance Guide*, FEMA Publication 322. Additional information can also be obtained through FEMA's website at www.fema.gov or the FEMA Regional Office.

Regulations and Considerations:
The following considerations may be referenced in each mitigation measure. Definitions are in Appendix A, "Regulations and Considerations."

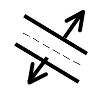
National Environmental Policy Act


Endangered Species Act


National Historic Preservation Act


US Army Corps of Engineers / Clean Water Act


Floodplain / Wetlands


Right of Way Constraints


Maintenance Required to Maintain Effectiveness

$ Project May be Cost-Prohibitive


Downstream or Upstream Effects


Engineer Needed

Mitigation Keywords:
The "Glossary and Keyword Index," found at Appendix B, provides a glossary of terms and identifies keywords which are italicized and bolded in the text. A keyword is a mitigation element used in two or more mitigation measures in the Handbook, and is intended to help the reader become familiar with the mitigation element by understanding its use in a different measure.

FLOOD DAMAGE INTRODUCTION

Since 1994, each state within Region 10 has incurred at least three Presidentially-declared disasters for flood events. Between 1994 and 2000, Region 10's Public Assistance program provided $397.5 million to municipalities, counties, and other eligible applicants for the repair and restoration of flood damaged public facilities.

Northwest flood damages are most commonly caused by excessively heavy rains, successive rainstorm events, or rapid melting of heavy snow accumulations. With these events, peak flood levels are reached and recede relatively rapidly.

Assessing the Cause of Damage

Mitigation measures are designed to reduce or eliminate future damage to facilities. Determination of the appropriate mitigation measure depends, in part, on an assessment of the cause of damage. A proper assessment is critical, as mitigation applied inappropriately could actually *increase* risk to the facility or other structures in the floodplain. Assessments should:

- be made as soon as possible after the flood event;
- be based on technically sound field observations;
- include discussions with maintenance personnel, local citizens, and other persons who observed when and how damage occurred; and
- be verified, when possible, by records of past damages such as photographs.

Details on assessing the causes of damage are discussed at the "Introductions" for each facility where appropriate.

The following sections identify the types of flood damage most typically sustained by public facilities. Various mitigation measures are then provided which respond to the specific damages to each facility. Mitigation measures have been identified for common flood damages to the following facilities:

Flood Damage Introduction

ROADS

Roads are the most commonly damaged facility in a flood event. Damage to roads may be caused by floodwaters overtopping and eroding road surfaces, shoulders, and embankment slopes, and by washing out roadway prisms. Mitigation measures identified may also be applicable to railroads or other embankment facilities damaged by flood events. Damages to roads and other embankment facilities can be mitigated by:

- Protecting ditches from erosion and increasing the capacity for ditches to carry side flow;
- Constructing protection from embankment slope erosion; and
- Protecting road surfaces and shoulders from erosion.

Assessing the Causes of Road Damage

Selection of appropriate mitigation measures for damaged road facilities depends upon the flow conditions that caused the damage. Some observations of these flow conditions can be made during or immediately after the damage occurrence.

If the elevations of the upstream and downstream high water marks are nearly the same, the flow conditions across the road were tranquil or streaming, and scour of the entire road surface

and shoulders will be evident. Erosion of the upstream embankment may have also occurred and there may be deposition of gravel across the road surface. Appropriate mitigation for this flow condition includes:

- Hardening the entire road surface and shoulders in the road overflow section, and
- Armoring the top of the upstream embankment.

If the upstream and downstream high water marks are significantly different, the flood flow was likely in a ‘supercritical’ state (rapid and turbulent flow) at the downstream side of the road, and scour of the downstream road shoulder and embankment will be evident. Appropriate mitigation for this flow condition includes:

- Hardening the downstream road shoulder, and
- Armoring the entire downstream face of the embankment.

If the road prism was washed out, a determination of the flow conditions will be critical in order to appropriately design the restoration and mitigation. To identify the flow conditions that caused damage to roads and their embankments, determine:

- The upstream and downstream water surface elevations, and
- The scour and erosion features on the remaining road surfaces, shoulders, and embankments.

This section discusses mitigation measures for common flood damages to roads, which are caused by:

A. Ditch Erosion

Introduction

Problem: Severe roadway and ditch erosion due to water velocities eroding the ditch and overflow areas.

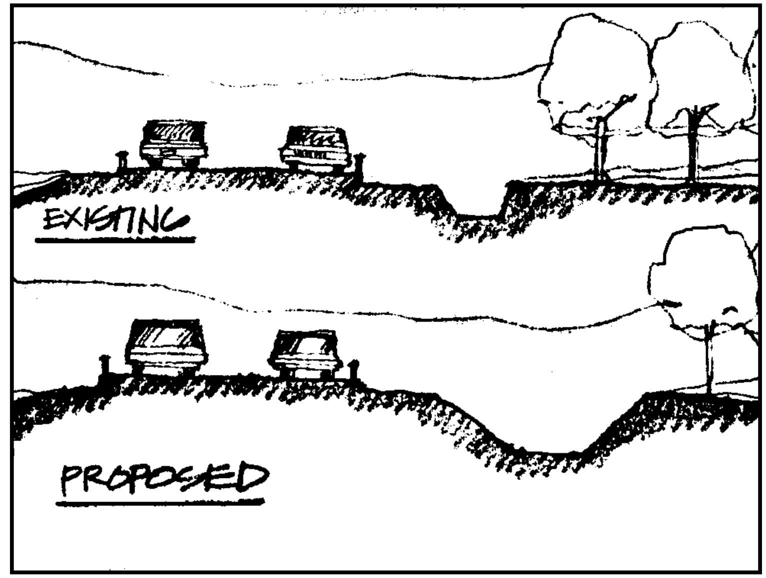
Mitigation Objective: To strengthen eroded areas and/or redirect floodwaters away from ditch areas vulnerable to erosion.

Mitigation measures to protect roads from flood damage caused by ditch erosion include:

ROADS

A.1 Increase Ditch Capacity

Increase the capacity of the roadway ditch by increasing its depth and/or width.



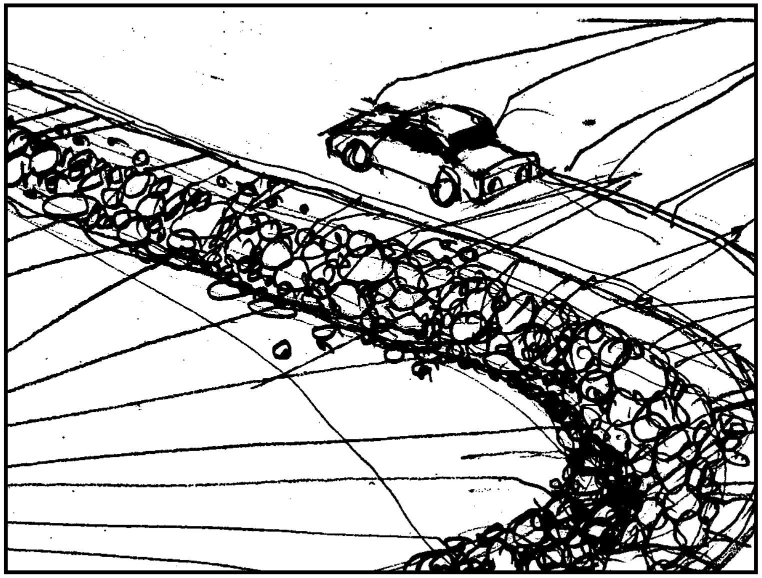
Effectiveness:
- Very effective in areas of low to moderate flow velocity where overtopping of the roadway ditch causes the damage.
- Effectiveness in high flows can be increased by ***lining*** the ditch, ***embankment slope protection***, or installing ***check dams***.

Limitations:
- In areas of high velocity flows, or if ditch is constructed from fine, highly erodeable materials, additional measures may be needed.
- May require increased slope angles on either side of ditch.

Considerations:

A.2 Install Lining in the Ditch

Line the ditch with rock, concrete, asphalt, or vegetation to prevent ditch erosion. Use larger and coarse-grained materials to protect against high velocity flows.



Effectiveness:
- Very effective.
- Suitable for high-flow velocity, and high-flow condition.
- Grass lined ditches provide bio-filtration and sediment reduction.

Limitations:
- Grass lining requires time for the grass to become established prior to use.
- Concrete lined ditches increase run-off and decrease time of floodwaters concentration.

Considerations:

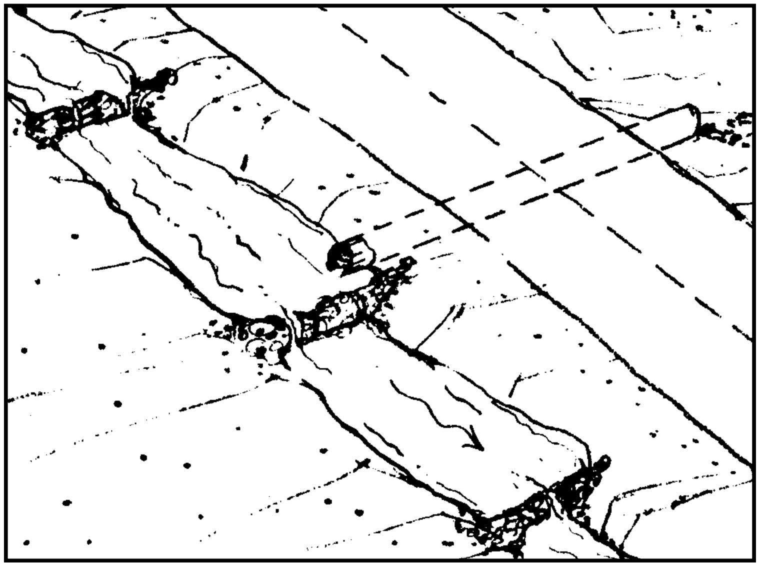
A.3 Install Additional Cross Culverts

Install ***additional*** roadway cross ***culverts*** to cut off the flow so as not to exceed the capacity of the roadway ditch. This measure will address the problem of ditch erosion when excessive flow in the ditch is either overtopping the road or is causing erosion of the road prism. Cross culverts are usually small-sized, ranging from 18 to 24 inches in diameter.

Effectiveness:
- Very effective in reducing the volume of runoff in the ditch line.

A.4 Install Check Dams

Install low-height barriers (***check dams***), usually made of loose rock, to slow the velocity of the storm water and reduce the scouring action of the flow.



Effectiveness:
- Very effective in reducing flow velocity and erosion.

Limitations:
- Difficult to maintain.
- May be more appropriate for temporary erosion and silt control.

Considerations:

B. Embankment Erosion

Introduction

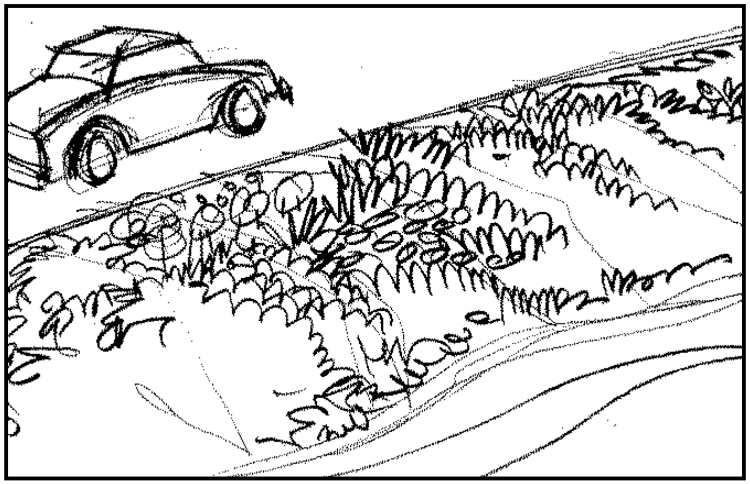
Problem: Damage caused by erosion of inadequately protected slopes.

Mitigation Objective: Harden the damaged embankment slope or redirect flows to avoid higher velocities.

Mitigation measures to protect roads from flood damage caused by embankment erosion include:

B.1 Bio-Engineered Embankment Slope Protection

Provide bio-engineered ***embankment slope protection*** by covering the slope with deep rooting vegetation and where it is adjacent to and in contact with a live stream, strategically anchor large woody debris (i.e. root wads) that will hold the soil in place and protect it from erosion.



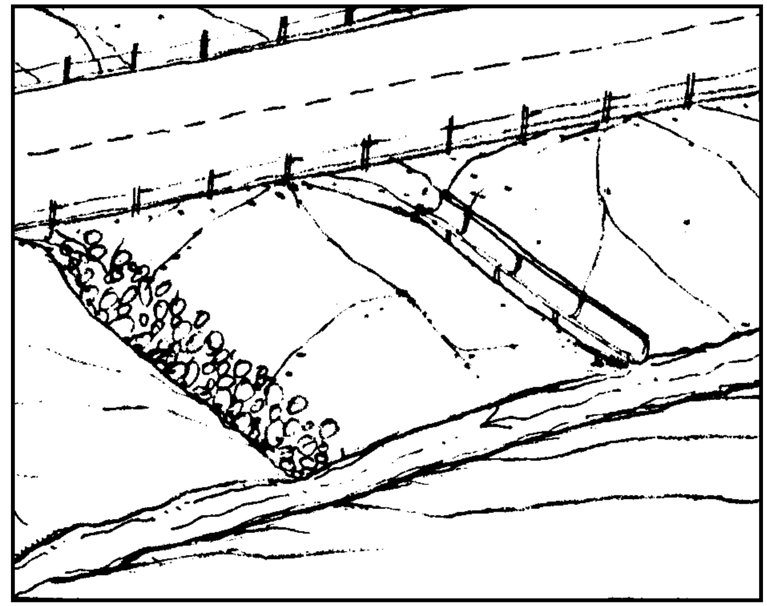
Effectiveness:
- Very effective in areas of low flow velocity.
- Environmentally friendly.
- Contributes to settling of particulate matter.

Limitations:
- Vegetation must have sufficient time to become established prior to being exposed to floodwaters.
- Generally not suitable for areas of sustained high velocity flows.

Considerations:

B.2 Install Half-Round or Spillway Pipes, or Rock Channels

Concentrate flows in a collection structure and install half-round or spillway pipes, or rock channels down steep slopes to eliminate erosion.

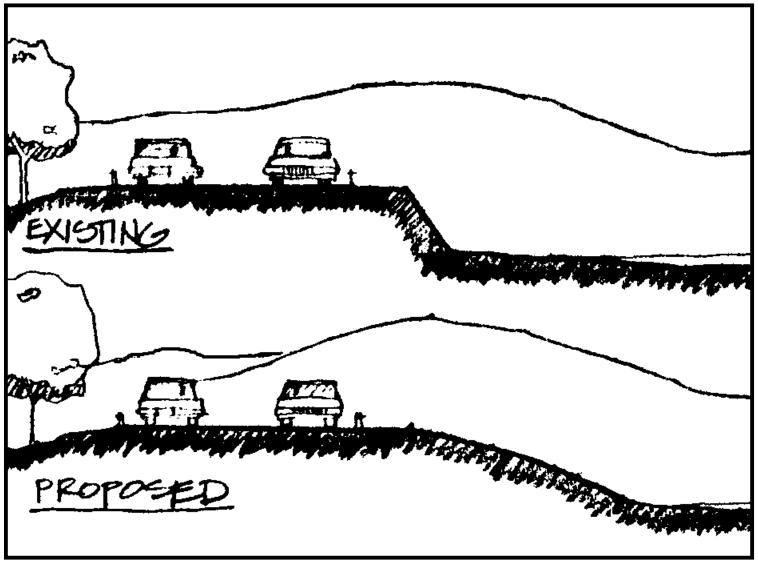


Effectiveness:
- Most effective for intermittent streams or surface water collection.
- Pipes very effective when properly connected to drainage collection structures or roadway ditches.

Limitations:
- Requires good anchors to eliminate failure by slippage of the pipes on the steep slope.
- Consider constructing an ***energy dissipater*** at bottom of slope.

B.3 Change Geometry of Roadway Section

Alter the angle of an embankment slope through shoulder rounding and slope reduction to reduce erosion. Reducing the angle of slope generally reduces the velocity of the water running across it.



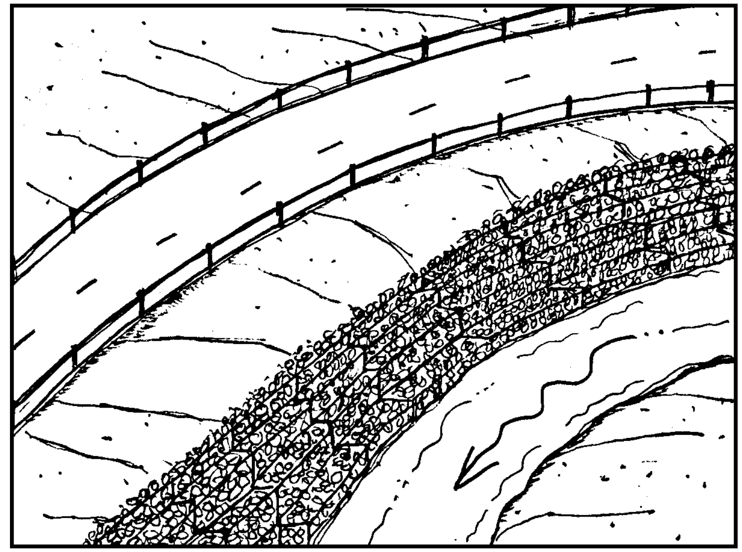
Effectiveness:
- Very effective in areas of roadway overtopping with low velocity flows.
- Particularly effective if combined with armoring of the downstream embankment slope and road shoulder.

Limitations:
- May reduce carrying capacity of ditch or stream.

Considerations:

B.4 Construct a Wall

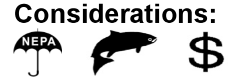
Construct a wall to protect the slope from erosion and consequent sloughing and slumping. Walls can be constructed of various materials including rock, gabions, sheet pile, concrete, etc.



Effectiveness:
- Very effective.
- Suitable for high velocity, high volume flood events.
- May be designed to accommodate replanting of a damaged riparian area.

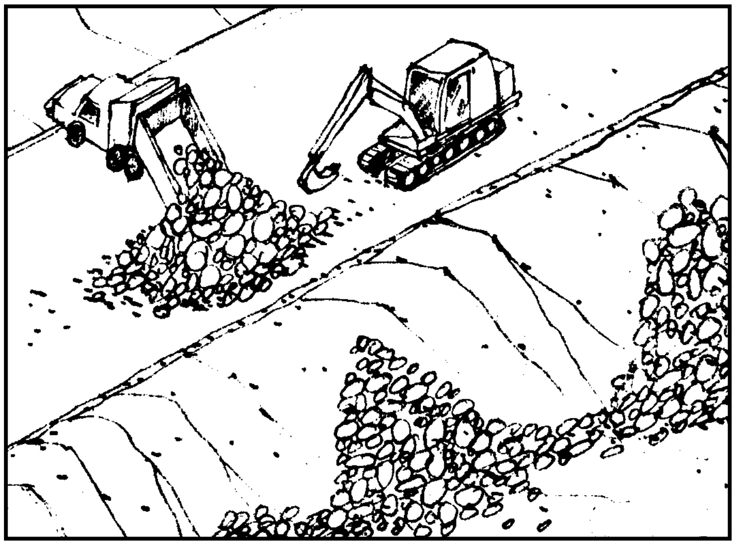
Limitations:
- May preclude regrowth of riparian areas.

Considerations:



B.5 Place Riprap Along Eroded Slope

Place appropriately sized ***riprap*** along the eroded embankment slope in sufficient quantities to resist scouring effects of higher velocity flows and protect the embankment slope from future flood damage.



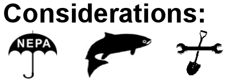
Effectiveness:

- Very effective in areas of moderate flow velocity and volume when appropriately graded material is placed in sufficient quantity and layered so fines are not eroded.
- Water velocity will determine size and volume of riprap.

Limitations:

- Extensive use of riprap may preclude re-growth of riparian areas.
- Access may limit where riprap can be placed.

Considerations:



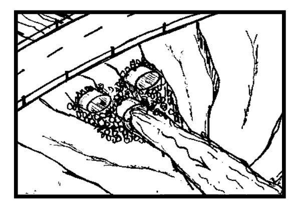
C. Surface and Shoulder Erosion

Introduction

Problem: Road surface and shoulder erosion caused by water flowing over the top of the roadway, due to low roadway elevation or inadequate drainage structure capacity.

Mitigation Objective: Harden the top of the roadway or divert floodwater from the top of the roadway to prevent erosion of the road surface and shoulder.

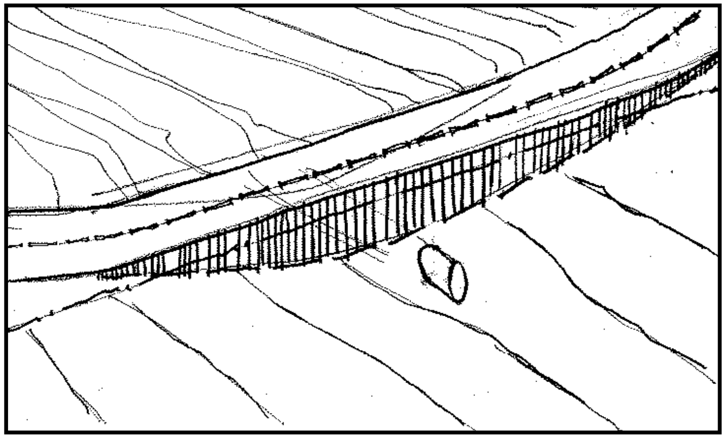
Mitigation measures to protect roads from flood damage caused by surface and shoulder erosion include:



3. Add Multiple Pipe Culverts
(p. 24)

C.1 Increase Roadway Elevation

Increase the roadway elevation by adding suitable fill material to raise the roadway surface above the design flood elevation.



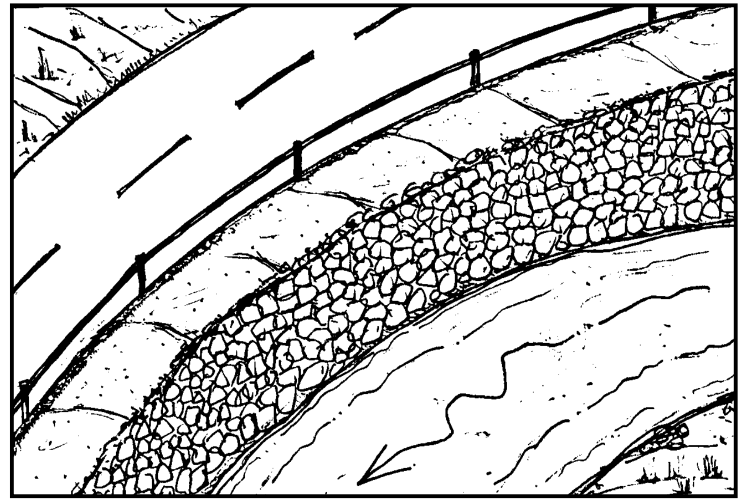
Effectiveness:
- Very effective in areas where the flood elevations are above the roadway surface for a short distance.
- Prevents future damage and keeps the roadway in service during flood events.

Limitations:
- May not be justified if frequent flood elevations are too high above the roadway.
- May increase upstream flood elevation and create a damming effect.
- Should be used in conjunction with ***embankment slope protection*** measures.

Considerations:

C.2 Construct Shoulder Protection

To protect the road shoulder from erosion, pave downstream shoulder with asphalt concrete pavement, concrete, ***riprap***, or other appropriate revetments.



Effectiveness:
- Very effective when drainage structure capacity cannot be increased to prevent overtopping.

Limitations:
- The treatment must be compatible with the soil type and roadway conditions.
- Asphalt concrete may have a limited life on slopes.
- May have adverse impacts on riparian areas. Willows and other plantings can be staked within the shoulder protection.

Considerations:

CULVERTS

Damage to culverts is caused primarily by floodwaters eroding culvert entrances or outlets and road embankments, and usually results in a full or partial washout or misalignment of the culvert. These damages may be due to insufficient design capacity or end treatments, inadequate slope protection, or inadequate protection from floating debris. Careful determination of the cause for the damage is necessary, as different causes require different mitigation.

Assessing the Causes of Culvert Damage

Selection of appropriate mitigation depends upon the culvert flow conditions at the time of damage. Surveys of high water marks located upstream and downstream from the culvert, and surveys of the inlet and outlet elevations are necessary to identify the flow conditions.

Flow through a culvert may be controlled by its entrance or outlet conditions, or by downstream channel features. A culvert will flow full if its outlet is submerged or if the depth of water above the top of its entrance is greater than 1.5 times its diameter. Damage to a culvert *flowing full* usually occurs when the road embankment is overtopped and is fully or partially washed out. Appropriate mitigation measures include:

- Increasing culvert size;
- Increasing efficiency of the entrance; and/or
- Raising the culvert.

If raising the culvert causes it to flow partially full, adjust the slope to return it to full flow conditions.

A culvert may flow partially full when the water depth is above the top of the culvert's entrance and below the top of the outlet, or when the water surface is below the top of the culvert at both entrance and outlet. Damage to a culvert flowing *partially full* usually occurs when embankment erosion has occurred. Appropriate mitigation for these conditions include:

- Increasing culvert entrance efficiency, and/or
- Decreasing the slope of the culvert.

If the culvert was flowing *partially full* and the flow at the outlet was in a *subcritical* or *tranquil state*, the damage will likely be confined to its entrance. In this case, appropriate mitigation includes:

- Increasing the efficiency of the entrance, and
- Armoring the entrance embankment.

If the culvert was flowing *partially full* and the flow at the outlet was in a *supercritical* or *turbulent state*, damage may have occurred to either the entrance or outlet or both. Appropriate mitigation would then include:

- Increasing efficiency of entrance and outlet conditions, and
- Armoring the entrance and outlet embankments.

If, as a result of these conditions, *erosion of the streambed* with subsequent head cutting and embankment erosion occur, appropriate mitigation would be:

- Installation of a stilling basin, and/or
- Armoring of the stream channel and road embankment.

To identify the flow conditions that caused the damage, determine:

- Water surface elevations upstream and downstream from the culvert at the time of damage;
- Elevations of the culvert entrances and outlets;
- Whether downstream channel erosion and head cutting occurred; and
- Evidence of road embankment erosion.

Floodwaters frequently carry debris both as the flows rise or recede. Debris carried by rising flood flows may become caught or wedged in culverts, plugging the flow. Culverts can then be washed out or damaged due to increased surface flow elevations. Mitigation measures should be designed to protect against debris impact and accumulation, and to assist in passing debris through the structure openings. Debris carried by receding flood flows will generally be deposited on the stream overbanks and draped over culvert entrances. Damage to culverts will most likely occur due to factors other than floating debris, and mitigation should be developed based upon the most probable cause of damage.

This section discusses mitigation measures for common flood damages to culverts, which are caused by:

CULVERTS

A. Insufficient Capacity and/or Inefficient End Sections

Introduction

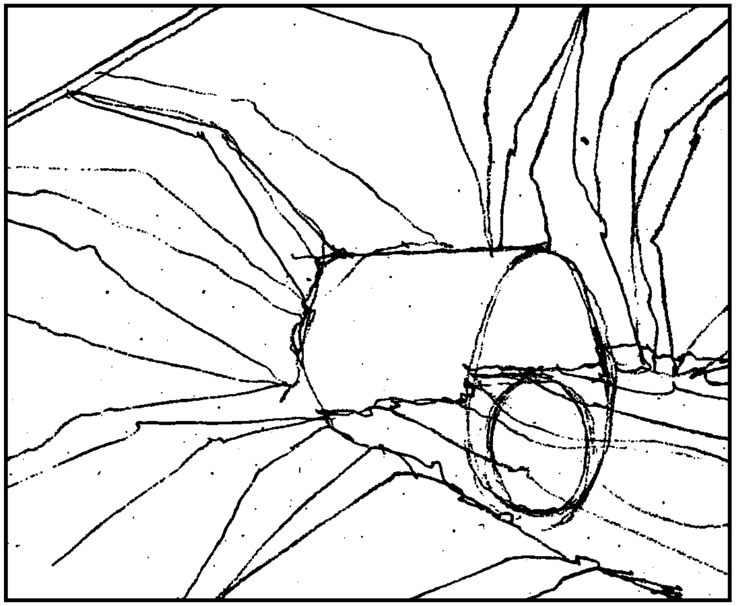
Problem: Damage or failure of a culvert resulting from overtopping and/or erosion of embankments due to insufficient culvert capacity and/or inefficient end sections. The inadequate capacity may be a result of inappropriate hydrologic analysis of flood peaks and volumes, and/or application of inappropriate culvert design criteria.

Mitigation Objective: To prevent future damage to a pipe culvert by increasing the design capacity and adding effective end sections; redesigning the culvert installation; replacing the culvert with an alternate drainage structure(s); and/or adding an overflow channel.

Mitigation measures to protect culverts from flood damage due to insufficient capacity or inefficient end sections include:

A.1 Replace With Larger Pipe Culvert

A larger culvert allows for the passage of a greater volume of water.



Effectiveness:
- Very effective if, at the time of failure the culvert was flowing full. (See “Assessing Culvert Damage,” pp. 17-19)

Limitations:
- Ineffective if damage was due to original culvert’s inefficient end sections rather than inadequate capacity.
- Consider culvert ***endwalls, wingwalls***, ***energy dissipaters***, ***debris barriers***, ***embankment slope protection***, and a ***high water overflow crossing*** for maximum effectiveness.

Considerations:

CULVERTS

A.2 Increase Efficiency of Entrance &/or Outlet Design

Culvert entrance rounding, entrance bevel rings, ***wingwalls***, ***flared end sections, paving the culvert entrance bottom***, and/or “U” shaped ***endwalls*** may increase the efficiency of a pipe culvert.

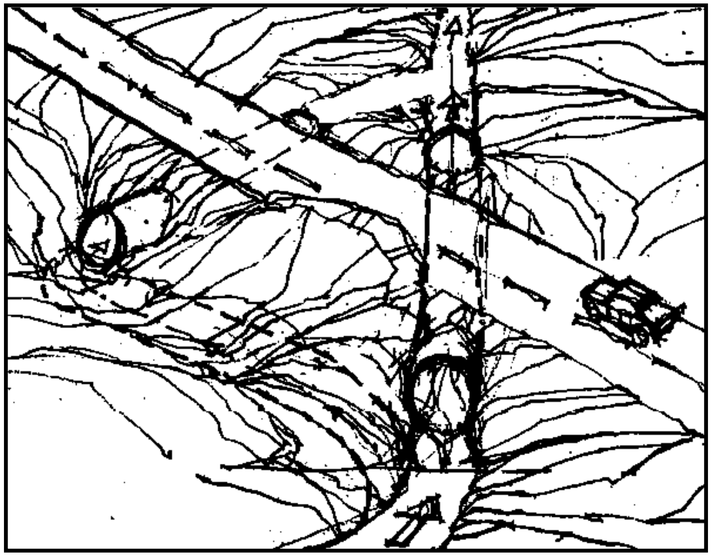
Effectiveness:
- Very effective.
- Treatments can increase efficiency up to 20 percent.
- Consider ***embankment slope protection***, ***energy dissipaters***, and entrance ***debris barriers*** for maximum effectiveness.

Limitations:
- The least effective of these treatments are entrance wingwalls and flared entrance end sections.
- Effectiveness is less for endwalls and wingwalls when centerline of culvert is at an angle to that of the stream.

Considerations:

A.3 Change Culvert Alignment

Change culvert horizontal and vertical alignment to match centerline and slope of stream. Direct entrance and exit alignment to maximize culvert efficiency. (See also "Culverts-Misalignment," pp. 40-45)



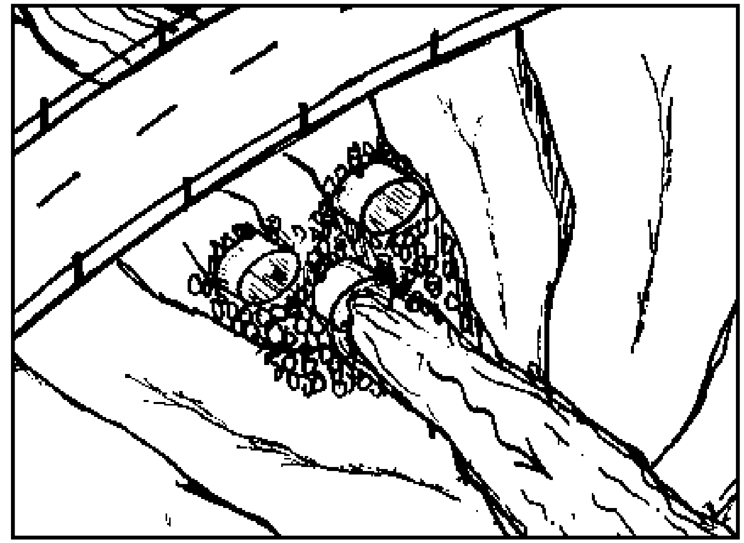
Effectiveness:
- Very effective.
- Consider culvert ***entrance and outlet treatments, energy dissipaters*** and ***debris barriers, embankment slope protection***, ***low water crossing***, or ***high water overflow crossing*** for maximum effectiveness.

Limitations:
- A culvert bottom slope less than that of the stream may cause backwater conditions with decreased efficiency and potential siltation.
- A culvert bottom slope greater than that of the stream may cause scour of the streambed at the outlet and erosion downstream.

Considerations:

A.4 Add Multiple Pipe Culverts

Multiple culverts may be installed with an existing culvert at a single crossing site at either the same or at differing elevations. The culverts should be placed at different elevations in the embankment and should be separated by more than one-tenth the diameter of the individual culverts to minimize the potential for sedimentation build-up.



Effectiveness:
- Generally very effective.
- Particularly effective when combined with culvert ***entrance and outlet treatments*** and ***embankment slope protection***.
- May be more suitable than a single, large diameter culvert pipe for low fill areas.
- Sedimentation can be minimized by use of the scour effect from higher velocity flows.

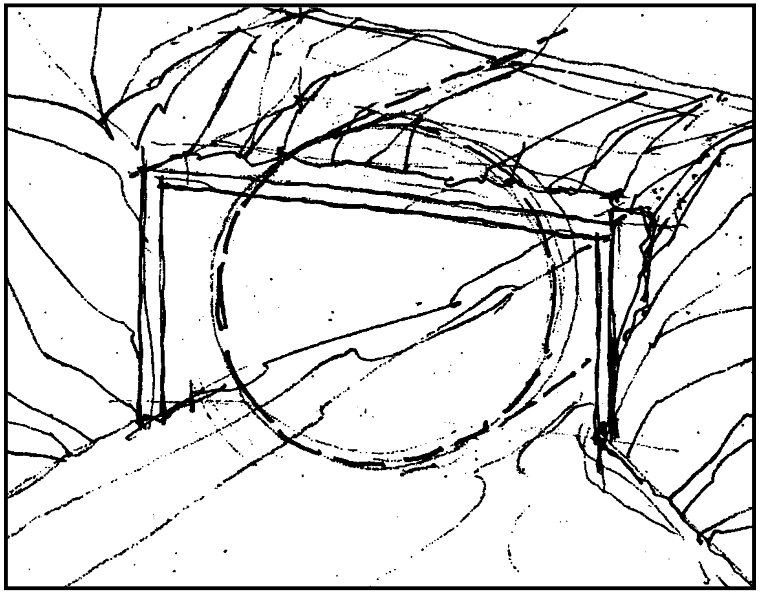
Limitations:
- Smaller pipe culverts will restrict debris passage.

Considerations:

NEPA

A.5 Replace With a Box or Arch Culvert

A box or arch culvert provides additional capacity in low fill situations. Can be designed for very minimal fill height.



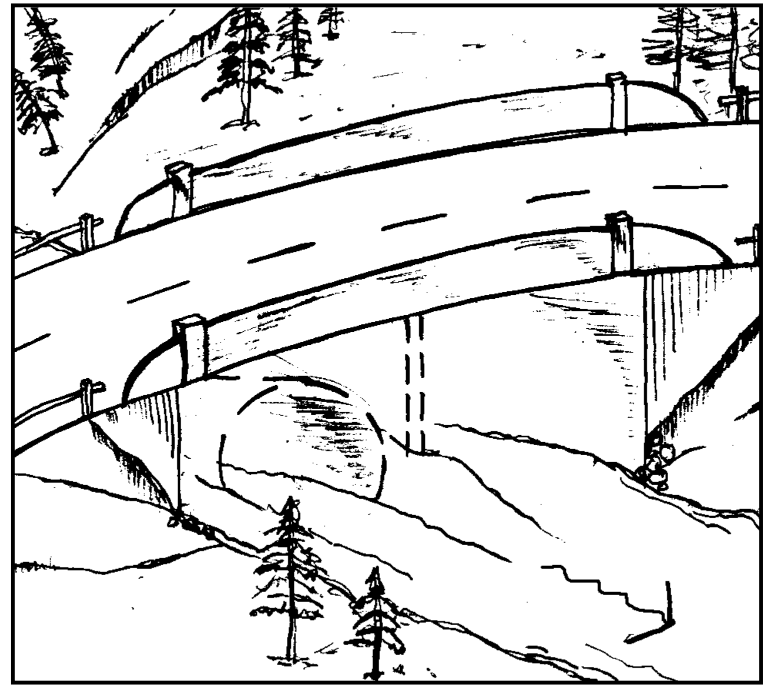
Effectiveness:
- Generally very effective.
- ***Rounding culvert entrances***, installing ***wingwalls***, ***paving culvert entrance bottoms***, and/or installing ***flared outlets*** may also increase culvert capacity.

Considerations:

CULVERTS

A.6 Replace With a Bridge

Replace culvert with a bridge.



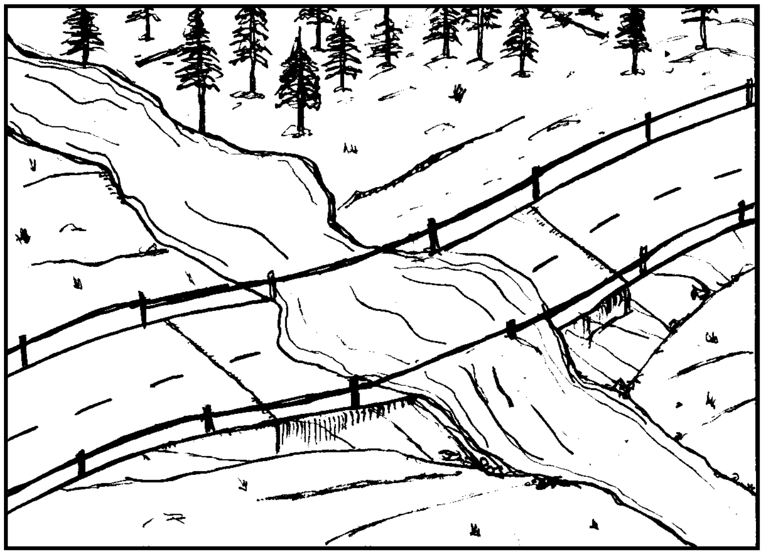
Effectiveness:
- Very effective in increasing flow capacity through embankment.

Limitations:
- May require engineering analysis and design.

Considerations:

A.7 Replace With or Add a Low Water Crossing

Replace culvert with a depression in the roadway that will accommodate the anticipated flows (***low water crossing***), or add a roadway depression over a culvert.



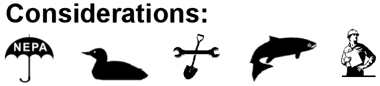
Effectiveness:

- Generally very effective in seasonal intermittent drainages and as an emergency spillway.

Limitations:

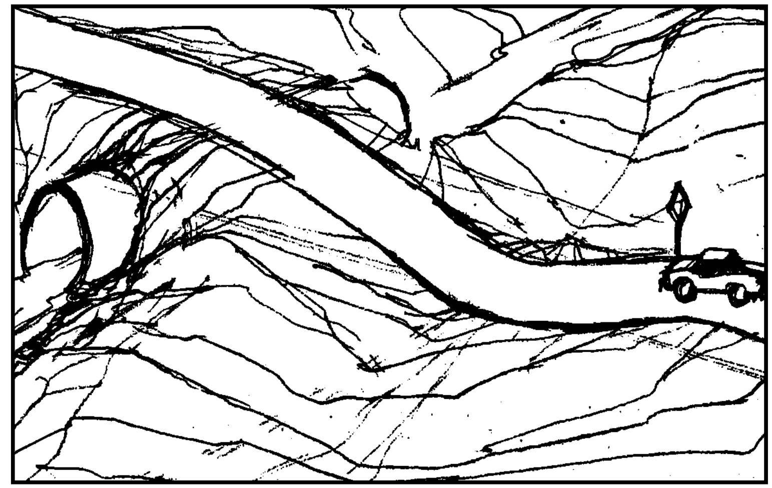
- Not appropriate if roadway provides access to a critical facility.
- Road impassable during flooding events.
- Adequate signage and barricades are necessary when water depth exceeds a safe level for vehicles.
- Roadway and embankments should be designed and constructed to withstand anticipated flows.
- The profile of the crossing should match the shape of the stream crossing as close as possible.

Considerations:



A.8. Install a High Water Overflow Crossing

Install overflow section (***high water overflow crossing***) in the roadway that will accommodate flows from the overbank areas of the stream. This effectively reduces and provides an emergency spillway. High water overflow crossings should be located at natural side channels and/or in line with heavy flow areas located on the stream overbanks.



Effectiveness:

- Generally very effective, and particularly when the road must remain passable during normal flows and topography makes a ***low water crossing*** infeasible.

Limitations:

- Not appropriate if roadway provides access to a critical facility.
- Road impassable during flooding events.
- Adequate signage and barricades are necessary when water depth exceeds a safe level for vehicles.
- Roadway and embankments should be designed and constructed to withstand anticipated flows.

Considerations:

B. Plugging

Introduction

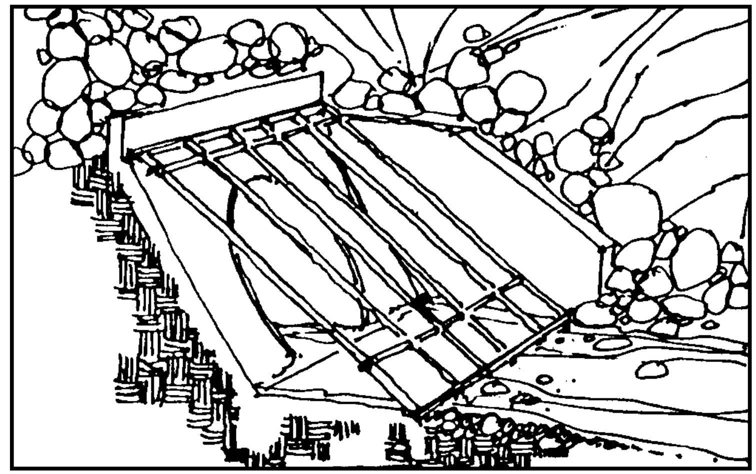
Problem: Damage or failure of a culvert caused by overtopping and erosion of the embankment due to plugging of the culvert with debris and/or silt. Debris deposition across the culvert entrance, or debris caught or wedged in the culvert, restricts the water flow. A culvert can then be washed out or damaged due to increased water surface elevations upstream.

Mitigation Objective: To prevent future damage to a culvert by preventing it from becoming plugged.

Mitigation measures to protect culverts from flood damage caused by plugging include:

B.1 Install an Entrance Debris Barrier

Install an entrance ***debris barrier (debris deflector*** **or** debris crib) to prevent blockage of the culvert or ***debris fins*** designed to orient the floating debris for easy passage through the culvert. Install a “V” shaped or semi-circular rack at the culvert entrance or a straight rack at the end of ***wingwalls*** to allow for overtopping of rack by the flow when debris accumulates around the rack. Install debris deflector or debris fins at upstream entrance to the culvert and install a debris crib over the entrance with a drop inlet.



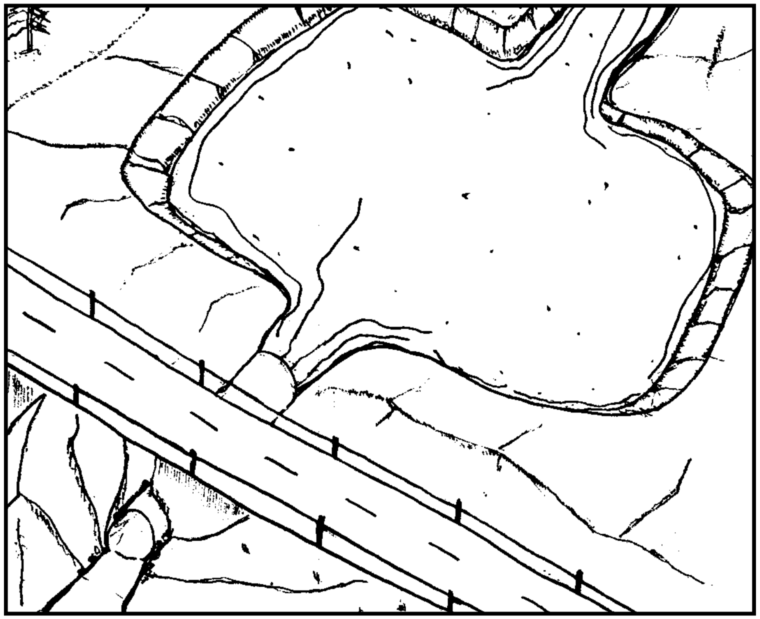
Effectiveness:
- Generally very effective in areas that have significant debris loading in the upstream drainage.
- Consider ***embankment slope protection,*** culvert ***entrance and outlet treatments***, and ***energy dissipaters*** where appropriate for maximum effectiveness.

Limitations:
- Adequate stream channel storage for debris accumulation must be available.

Considerations:

B.2 Install a Sediment Catch Basin

Install a sediment catch basin upstream of the culvert. The basin should be located far enough upstream and the openings should be sized to allow the suspended sediment sufficient time to settle out prior to entering the culvert.



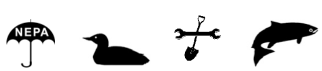
Effectiveness:

- Generally very effective.
- Particularly effective in areas where heavy silt and/or sand loading occurs during flood events and velocity levels do not provide for scouring of the streambed and culvert.

Limitations:

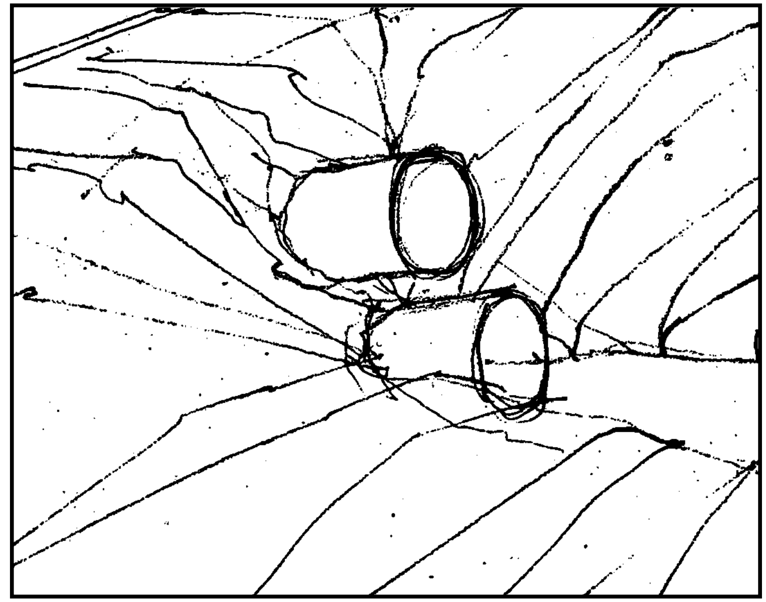
- Requires adequate storage in basin.
- Must be easily accessible for sediment clean out.

Considerations:



B.3 Install a Relief Culvert

Relief culvert(s) should be located at the crossing site and in the embankment above the flow line of the primary culvert. This configuration provides an alternate route for the flow, if the main culvert gets plugged, and prevents sedimentation through the high flow scouring action.



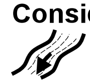
Effectiveness:

- Generally very effective.
- Design of relief culvert(s) should include appropriate ***entrance and/or outlet treatment(s)*** and ***embankment slope protection***.

Limitations:

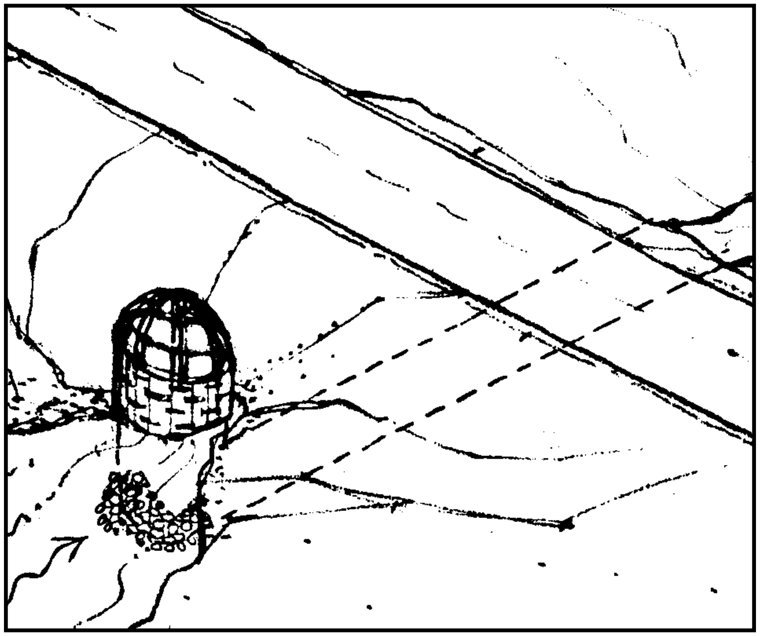
- Embankment geometry may limit ability to locate culvert(s) above flow line of primary culvert.

Considerations:



B.4 Install a Perforated Standpipe

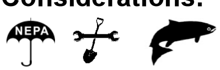
Install a perforated standpipe in lieu of the traditional culvert entrance. The standpipe allows debris to float up with the rising floodwaters without impacting flow into the culvert. The standpipe should be armored at its base by constructing a cone of free draining gravel around it. The area upstream of the entrance should be suitable for storing floodwaters.



Effectiveness:
- Generally very effective.

Limitations:
- Standpipe may be vulnerable to damage from high velocity flows.

Considerations:



C. Embankment Erosion

Introduction

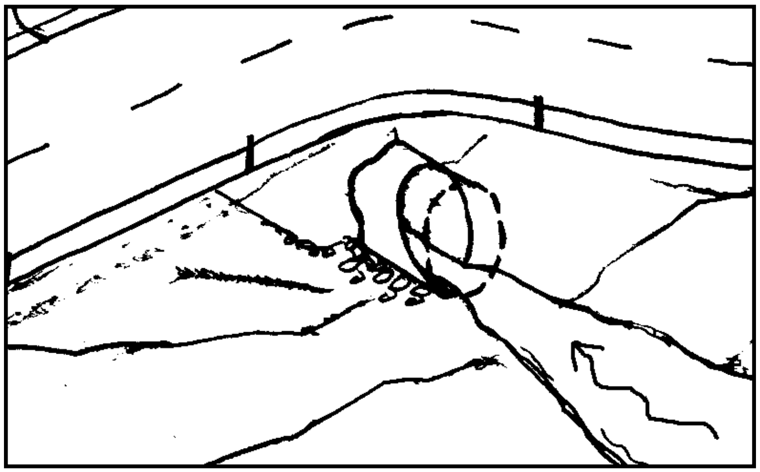
Problem: Damage or failure of a culvert caused by erosion of the embankment at its entrance and/or outlet, or around the outside of the culvert. The embankment erosion and subsequent culvert damage or failure may be a result of inadequate culvert end sections.

Mitigation Objective: To prevent future damage to a pipe culvert by adding appropriate end sections.

Mitigation measures to protect culverts from flood damage caused by embankment erosion include:

C.1 Shape Culvert Entrance

Shape (bevel/skew) ***culvert entrance*** to match the embankment slope or stream alignment. Culvert efficiency will be increased, and turbulence at the entrance and through the culvert will be decreased, reducing erosion of the bank.



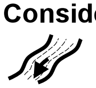
Effectiveness:

- Very effective with large culverts.
- Moderately effective for smaller culverts.
- A ***cutoff wall*** and/or ***paved culvert entrance bottom*** should be considered to prevent undermining of the entrance.
- Consider culvert ***endwalls, wingwalls***, ***debris barriers***, and/or ***embankment slope protection*** to maximize effectiveness.

Limitations:

- Cutting a culvert to bevel or skew its entrance may weaken a large diameter culvert's ability to resist ring compression; flanges may be required to stiffen it.

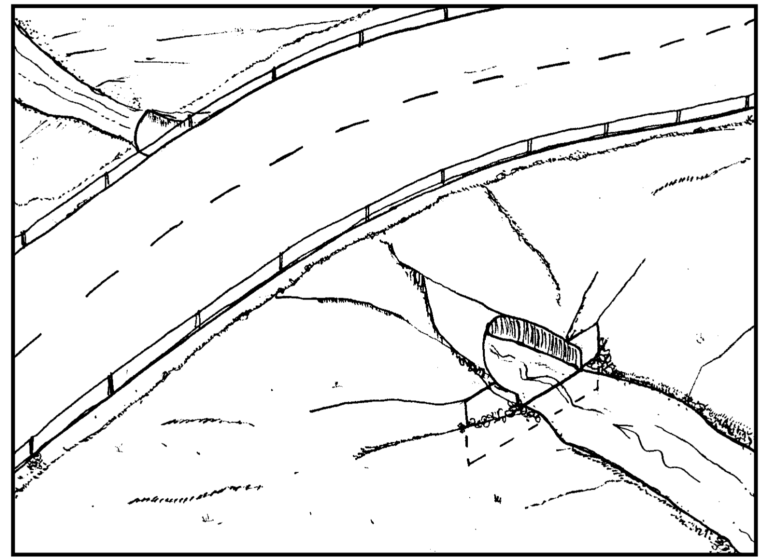
Considerations:



CULVERTS

C.2 Construct a Cutoff Wall

Construct sheet steel, low height, ***cutoff wall*** to prevent undermining of culvert entrance. The sheeting should extend below the culvert entrance to at least one half times the culvert diameter and above the culvert entrance to a point where it meets the junction of the embankment with other end treatments.



Effectiveness:

- Very effective, particularly for large culverts and when used with a ***shaped culvert entrance*** and/or ***paved culvert entrance bottom***.
- Effectiveness increases if combined with culvert ***endwalls, wingwalls***, ***debris barriers***, and/or ***embankment slope protection***.

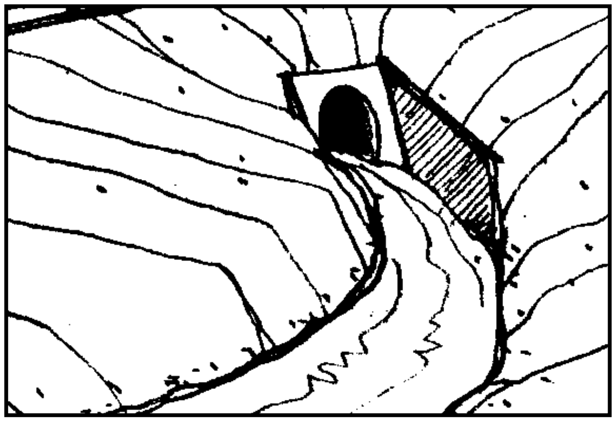
Limitations:

- Streambed geology may prohibit installation of cutoff wall.

Considerations:

C.3 Install Appropriate Culvert End Sections

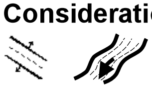
Construct an ***endwall***, ***wingwalls***, and/or ***flared end section*** to direct flow into and out of the culvert and protect embankment slopes. Straight or “U” shaped endwalls or flared wingwalls may be used when the centerline of the stream is aligned with the culvert. A “U” shaped endwall or wingwall may be used when an abrupt change in the flow direction is necessary. An “L” shaped endwall may be constructed to redirect the flow to the angle of the culvert.



Effectiveness:
- Very effective. Generally suitable for high velocities.
- Wingwalls are preferred when both flow volumes and velocities are high.
- Consider culvert ***energy dissipaters***, ***debris barriers*** and ***embankment slope protection***.

Limitations:
- Straight endwalls may decrease culvert capacities, but ***rounding of the entrance*** corners may offset it.
- If stream velocities are high, lateral scour of embankments may result from eddies at the culvert end sections.
- Attaching fabricated flared end sections to culvert entrances and outlets may cause separation of culvert joints if the culvert cannot support additional weight.

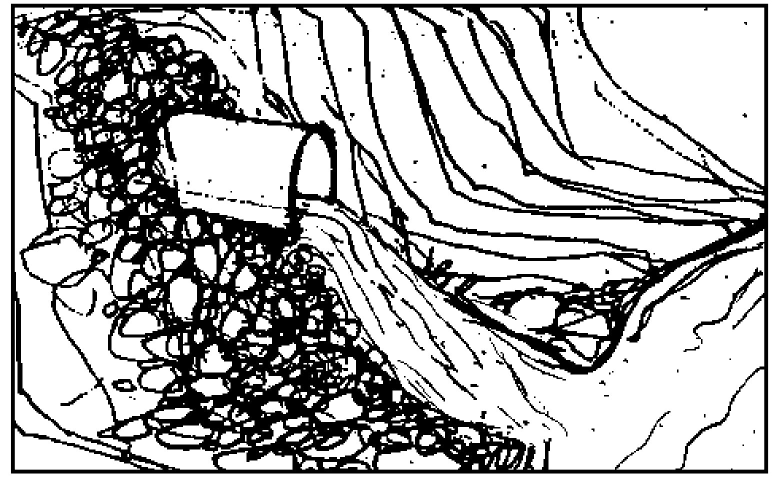
Considerations:



CULVERTS

C.4 Construct an Energy Dissipater

Construct an ***energy dissipater*** to minimize scouring at the culvert outlet. Energy dissipater designs may include concrete or rock sloping aprons, “bucket” outlets that throw the jet downstream, stilling basins, or other more elaborate structures.



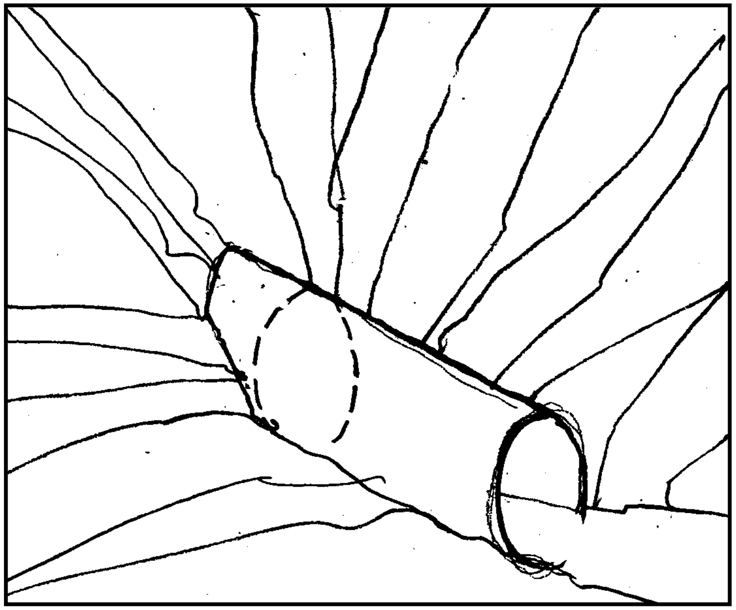
Effectiveness:
- Very effective. Especially effective when there is a significant drop from the bottom of the outflow end of the culvert to the drainage flow line, or when the gradient of the culvert is steep.
- If stream velocities are high, may be needed to eliminate lateral scour.

Limitations:
- Stream channel geometry may dictate the design of energy dissipaters.
- Depending on existing conditions, stream velocity, and depth of pool, measure may have considerable impacts on fish.

Considerations:

C.5 Extend Culvert Inlet or Outlet

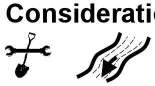
Extend culvert entrance and/or outlet past the embankment face.



Effectiveness:
- Moderately effective in reducing turbulence at culvert entrance.
- Moderately effective in reducing erosion of the downstream embankment, but can cause erosion to upstream embankment due to eddies.
- Consider ***energy dissipaters***, ***embankment slope protection***, and ***debris barriers*** to maximize effectiveness.

Limitations:
- Extensions can cause scour of the streambed downstream.
- Extensions are vulnerable to flow and debris impacts.

Considerations:



CULVERTS

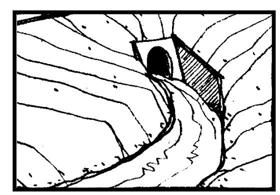
D. Misalignment

Introduction

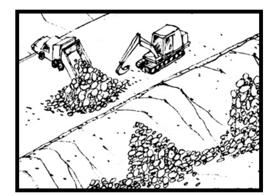
Problem: Damage to a culvert caused by its horizontal and/or vertical misalignment with the stream channel and subsequent erosion of the embankment. The misalignment may be a result of original design miscalculations and/or subsequent stream migration.

Mitigation Objective: To prevent future damage to a culvert by aligning the culvert to the axis of the stream; to prevent future migration of the stream away from the culvert; and to design supplementary drainage structures to accommodate future migration of the stream channel.

Mitigation measures to protect culverts from flood damage caused by their misalignment include:



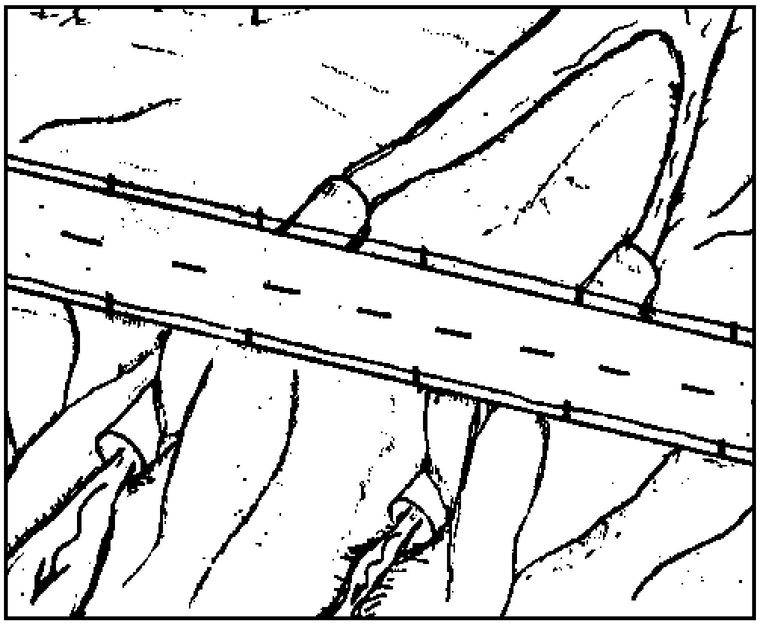
6. Install Appropriate Culvert End Sections (p. 37)



7. Place Riprap (p. 13)

D.1 Install Additional Culverts

Locate ***additional culverts*** at previous and/or potential stream alignments at road crossing site. The additional culverts should be located some distance from the mainstream culvert.



Effectiveness:
- Very effective.
- Consider ***embankment slope protection*** and culvert ***energy dissipaters***, ***endwalls, wingwalls***, and ***debris barriers*** for maximum effectiveness.

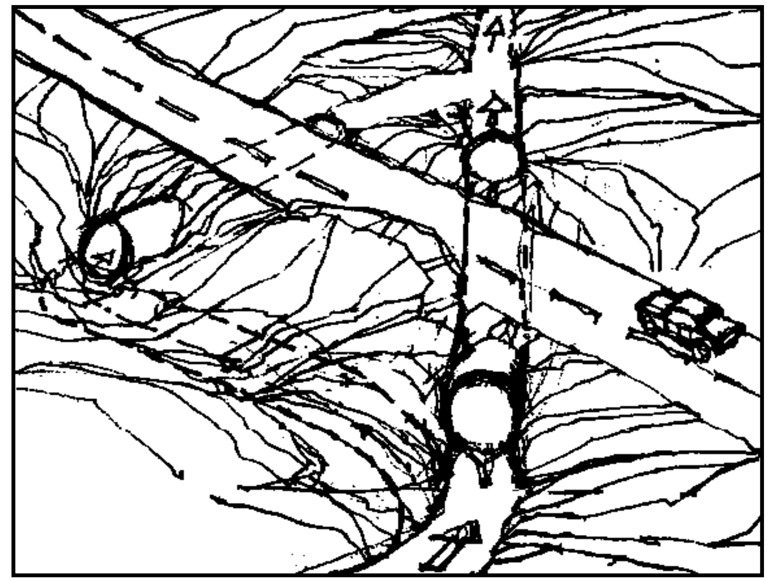
Limitations:
- Potential for sedimentation of culverts that are not carrying higher floodwater velocities.
- Consider varying the culverts' elevations.

Considerations:

CULVERTS

D.2 Realign Culvert

Align centerline of the culvert (either vertically or horizontally) to the centerline of the stream to eliminate erosion along the embankment and subsequent damage to the culvert. Alignment may require relocating culvert to present location of stream channel.

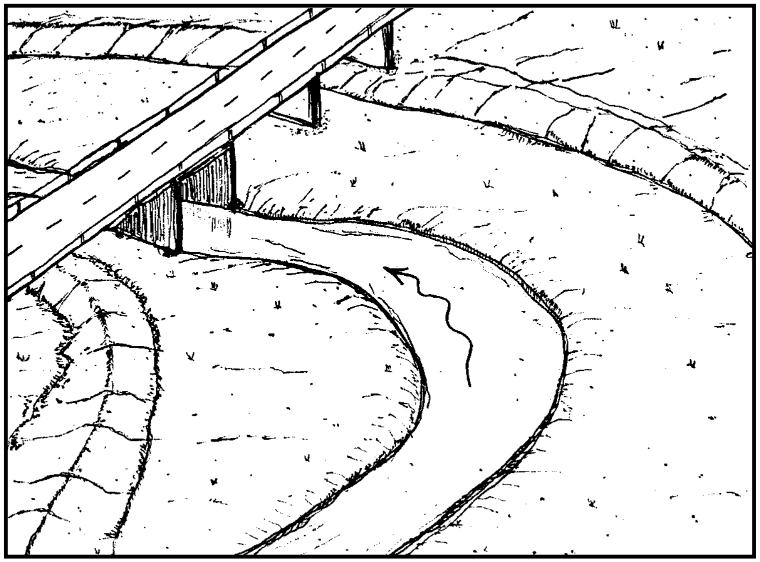


Effectiveness:
- Very effective.
- Consider ***embankment slope protection***, culvert ***endwalls, wingwalls***, ***energy dissipaters,*** and ***debris barriers*** for maximum effectiveness.
- Stream and/or road geology may preclude alteration of culvert alignment.

Considerations:

D.3 Install Approach Berms

Install approach ***berms*** on the stream overbanks. Berms should be aligned so that flow is directed into and at the same angle as the culvert and away from the embankment.



Effectiveness:

- Effective at high flows, but no effect at low flows.
- Consider ***embankment slope protection***, culvert ***endwalls***, ***wingwalls***, ***energy dissipaters***, and ***debris barriers*** for maximum effectiveness.

Limitations:

- Overbank geometry may preclude this option.
- Berms need to be placed on the stream overbanks near or at the edge of the floodway so that water-surface elevations are not significantly increased at the culvert or upstream.

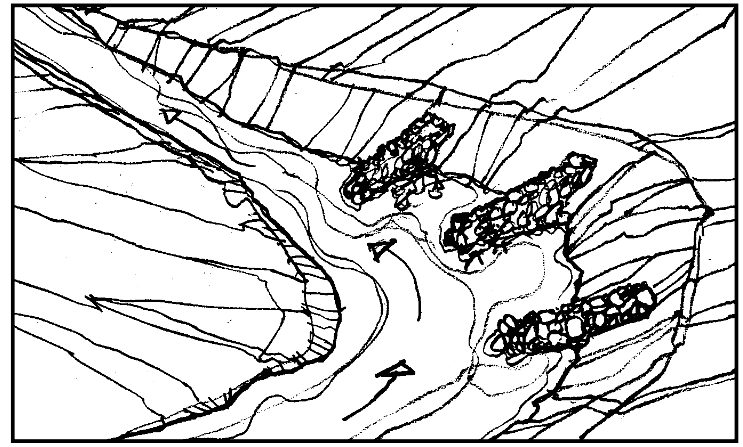
Considerations:

NEPA

CULVERTS

D.4 Install Flow Diverters

Install flow diverters (barbs) in the stream. Design barbs to redirect the flow away from the embankment and into the culvert.



Effectiveness:

- Particularly effective during relatively low flows.
- May not be effective at high flows.
- May help prevent channel migration at all flow levels.
- Consider culvert ***endwalls***, ***wingwalls***, ***debris barriers***, and ***energy dissipaters*** for maximum effectiveness.
- Consider using natural materials such as root balls or anchored logs.

Limitations:

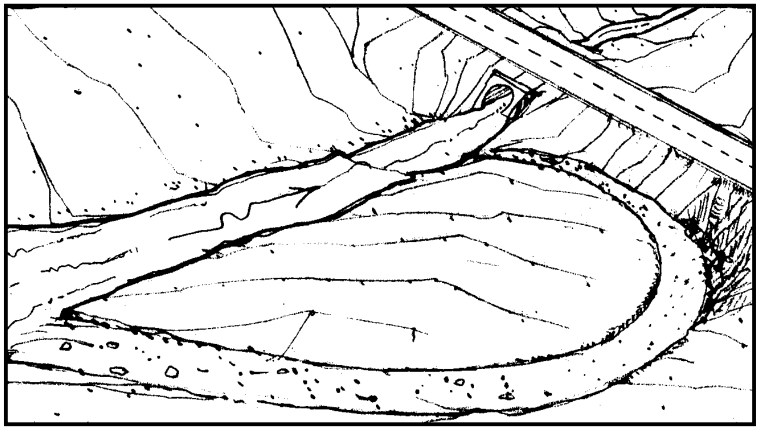
- Requires additional stream ***embankment slope protection*** for high flows.
- Design should include measures, such as sheet steel piling, to eliminate wash-out of landward end of barbs.
- Height of barbs should not cause significant increase in water-surface elevations for high flows at or upstream of the culvert.

Considerations:

NEPA

D.5 Realign the Stream Channel

Channel flow should be directed into and at same angle as the culvert and away from the embankment to reduce erosion along the embankment and consequent damage to the culvert.



Effectiveness:
- Very effective.
- Consider ***embankment slope protection***, culvert ***endwalls***, ***wingwalls***, ***energy dissipaters***, and ***debris barriers*** for maximum effectiveness.

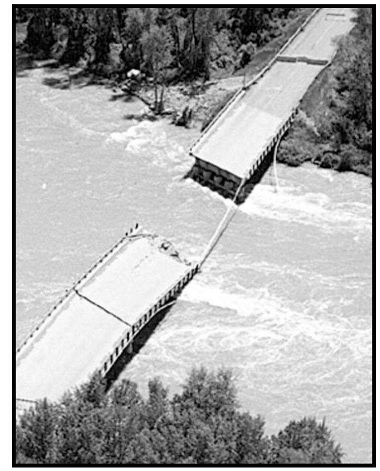
Limitations:
- Stream may reclaim original channel over time due to natural meandering.

Considerations:

BRIDGES

BRIDGES

Flood damage to bridges are typically caused by water overtopping decks, erosion of the streambed under piers and abutment footings, erosion of the embankments, and impact and accumulation of floating debris on the decks, piers, and abutments. These damages may be related to the inadequate hydraulic capacity of the bridge, misaligned piers and/or abutments, or accumulation of debris.



Assessing the Causes of Bridge Damage

Inadequate hydraulic capacity of a bridge may result in streambed scour on both sides of the piers and abutment. Misalignment of the piers and/or abutments may result in streambed scour on the exposed side of the piers, and deposition of streambed materials on the lee sides. To help identify excessive flood flow velocities that caused undermining and subsequent damage to bridge piers and abutments, determine:

- The location of streambed scour, and
- Deposition of streambed materials.

Debris can threaten bridge facilities, whether it is carried in flood flows that are rising or receding. In rising waters, debris may become caught on bridge piers and abutments, which decreases the size of the bridge opening. The bridge can then become damaged by flow impacting the decks, piers, and abutments, and by washouts of piers and abutments due to streambed scour.

Damage caused by debris impact and accumulation is verified by observing debris jammed into bridge members, debris piles deposited around the upstream side of piers and abutments, and streambed scour below and adjacent to debris piles. If debris was carried through receding flood flows, the debris will be deposited on the stream overbanks or around the base of piers and abutments, but are usually not the cause of damage.

This section discusses mitigation measures for common flood damages to bridge facilities, which are caused by:

BRIDGES

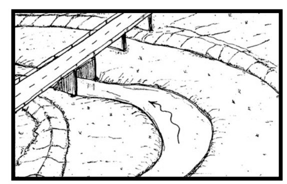
A. Misalignment

Introduction

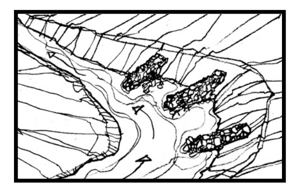
Problem: Damage to a bridge caused by its misalignment with the stream channel. The misalignment may be a result of original design miscalculations and/or subsequent stream migration. (See “Culverts-Misalignment,” pp. 40-45)

Mitigation Objective: To prevent future damage to a bridge by aligning its abutments and piers to the centerline of the stream, by preventing future migration of the stream away from the bridge, and/or by installing additional bridge openings to accommodate future migration of the stream channel.

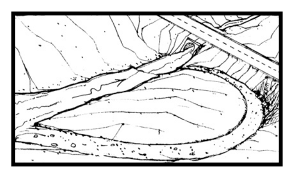
Mitigation measures to protect bridges from flood damage caused by misalignment include:



5. Install Approach Berms (p. 43)



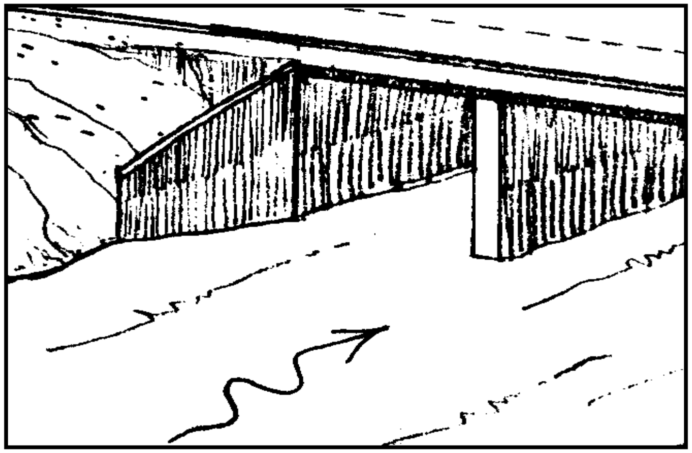
6. Install Flow Diverters (p. 44)



7. Realign the Stream Channel (p. 45)

A.1 Construct Bridge Wingwalls

Install bridge entrance and outlet ***wingwalls***. Design wingwalls to redirect the flow into the bridge opening and eliminate erosion under the bridge piers, abutments and embankment. Use flared wingwalls angled to coincide with the stream. (See “Culverts-Embankment Erosion,” pp. 34-39)



Effectiveness:
- Very effective.
- Flow volumes may be increased up to 30 percent depending on angle of wingwalls.
- Rounding or beveling of abutment corners may increase flow volumes by 20 percent.
- Consider ***debris deflectors*** and ***embankment slope protection*** for maximum effectiveness.

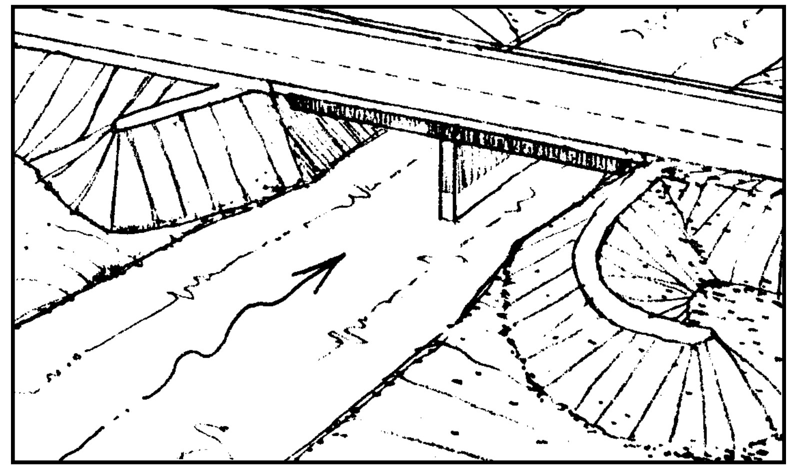
Limitations:
- If stream velocities are high, lateral scour of embankments may result from eddies at the ends of wingwalls. Design wingwall shapes and their angles to the stream to minimize the development of eddies.
- Design of debris deflectors needs to account for effect of stream and bridge pier and abutment alignment.

Considerations:

BRIDGES

A.2 Construct Spur Dikes

Spur dikes are embankments designed to direct flood flows into a bridge opening. They are ‘tied into’ the road embankment at an appropriate point landward from the bridge opening and then extend upstream. The usual shape of a spur dike is either straight or elliptical. Spur dikes should be installed at an angle to redirect the flow into the bridge opening, thereby eliminating the potential for erosion along and under the bridge piers and abutments and along the bridge embankment.



Effectiveness:
- Very effective. Consider ***debris deflectors*** and ***embankment slope protection*** for maximum effectiveness.

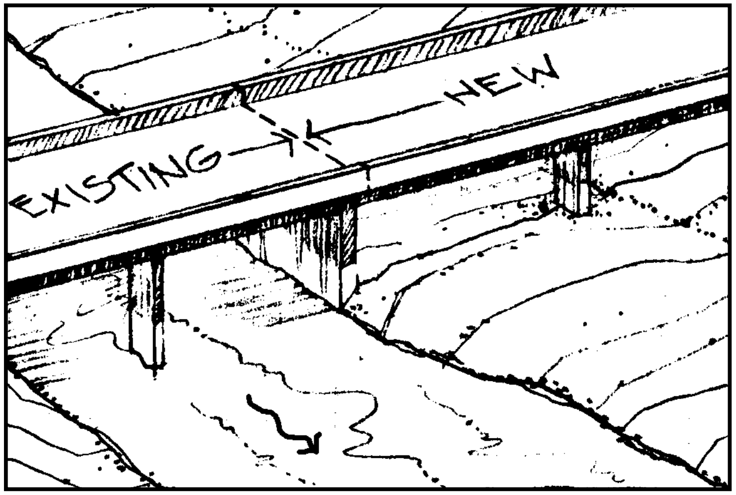
Limitations:
- Spur dikes should be placed on the stream overbanks so water-surface elevations are not increased significantly.
- If stream velocities are high, scour of spur dike embankments may result from eddies at their upstream ends and along their sides. Design spur dike shapes and angles to the stream to minimize development of eddies.

Considerations:

NEPA $

A.3 Install Additional Bridge Openings or Spans

Install additional bridge openings or bridge spans. These additional openings or spans should be located at historical and/or potential stream alignments at a crossing site. This measure can be employed to mitigate for the effects of a braiding streambed, or a widening streambed.



Effectiveness:
- Very effective.
- Consider bridge entrance and outlet ***wingwalls***, ***debris deflectors***, and ***embankment slope protection*** for maximum effectiveness.

Limitations:
- Crossing geometry may preclude this option.

Considerations:

$

A.4 Realign Piers and Abutments

Realign the bridge ***piers and abutments*** to be parallel to the centerline of the stream, thereby eliminating the potential for erosion along and under the bridge piers and abutments and along the embankment. Realignment of the bridge may include ***relocating*** it to the vicinity of the present stream channel and/or aligning the bridge opening to the centerline of the stream.

Effectiveness:
- Very effective.
- Flow volumes may be increased up to 30 percent when piers are aligned.
- Consider bridge entrance and outlet ***wingwalls***, **debris deflectors,** and ***embankment slope protection*** for maximum effectiveness.

Considerations:

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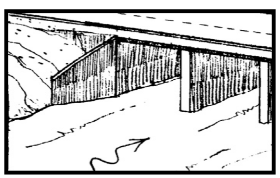
B. Insufficient Capacity (Decks)

Introduction

Problem: Damage to bridge decks and associated superstructures (railings and truss) as a result of overtopping due to insufficient capacity for flow through the bridge opening.

Mitigation Objective: To prevent damage to bridge decks and associated superstructures by increasing the design capacity for the bridge opening, and/or modifying the bridge deck design to allow for controlled overflow.

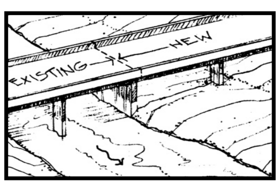
Mitigation measures to protect bridge decks from flood damage caused by insufficient capacity include:



6. Construct Bridge Wingwalls (p. 49)

7. Install High Water Overflow Crossing (p. 28)

8. Realign Piers and Abutments (p. 52)

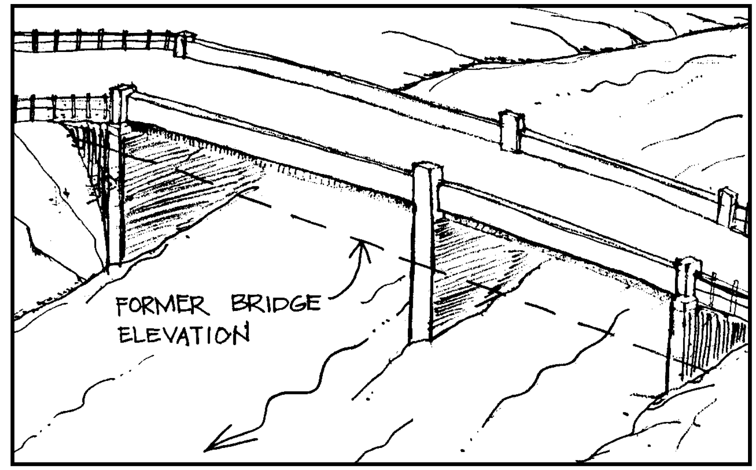


9. Install Additional Bridge Openings or Spans (p. 51)

BRIDGES

B.1 Elevate the Bridge Deck

The bridge deck and associated superstructure should be ***elevated*** to a level sufficient to pass anticipated flood flows. Approach sections to the bridge may likewise need to be raised.



Effectiveness:
- Most effective mitigation for passing flood flows.

Limitations:
- The pier and abutment supports may need to be redesigned to accommodate and support the elevated bridge deck and associated superstructure.

Considerations:

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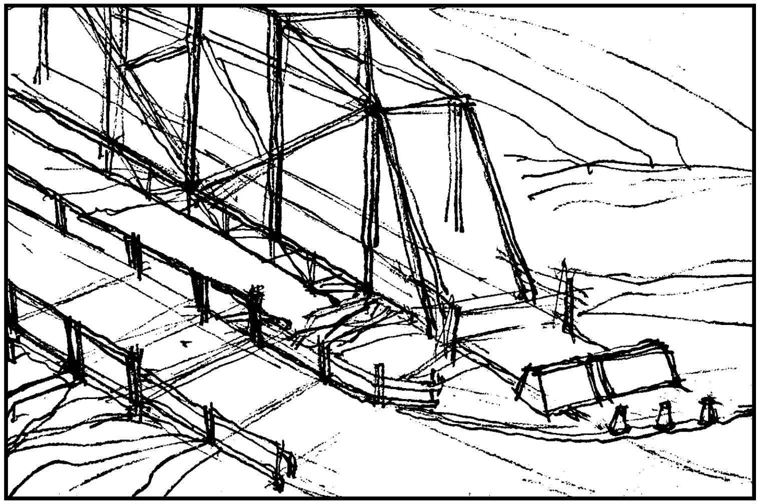
B.2 Replace a Steel Truss Bridge With an Open Deck Bridge

Replacing a steel truss bridge with an open deck bridge will reduce the backwater conditions upstream, and eliminate the accumulation of debris should the bridge become over-topped during flood events.



Effectiveness:
- Generally very effective.
- An open deck bridge does not trap floating debris to the same extent that a steel truss bridge will when overtopped.
- Effectiveness is increased if open deck bridge is ***elevated.***

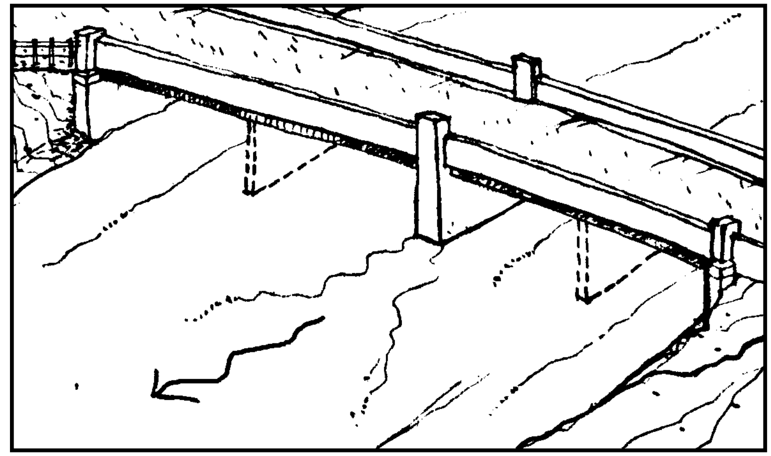
Limitations:
- Bridge piers and abutments may require extensive redesign to accommodate open deck bridge.

Considerations:

BRIDGES

B.3 Replace Multi-Spans With a Single Span Bridge

Replace the multiple spans of a bridge with a single clear-span to eliminate the need for piers. This will increase the flow through the bridge and reduce upstream backwater conditions.



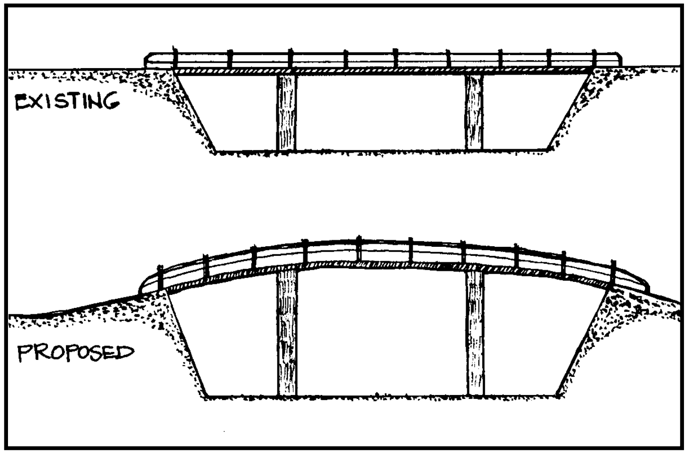
Effectiveness:
- Very effective.
- Increases the effective size of the bridge opening and flow capacity.
- Reduces debris accumulation.
- Decreases the backwater conditions upstream from the bridge and the effects of drawdown through it.
- Consider ***relief openings***, ***wingwalls***, ***realignment of piers and abutments***, ***embankment slope protection***, and abutment ***debris deflectors*** for maximum effectiveness.

Limitations:
- Length of span may be limited by strength of materials.

Considerations:

B.4 Increase Bridge Opening Size

Increase the size of the bridge opening(s) by lengthening the opening or raising the bridge deck. Increasing bridge opening size will decrease any backwater conditions upstream from the bridge and reduce the effects of drawdown through the bridge.



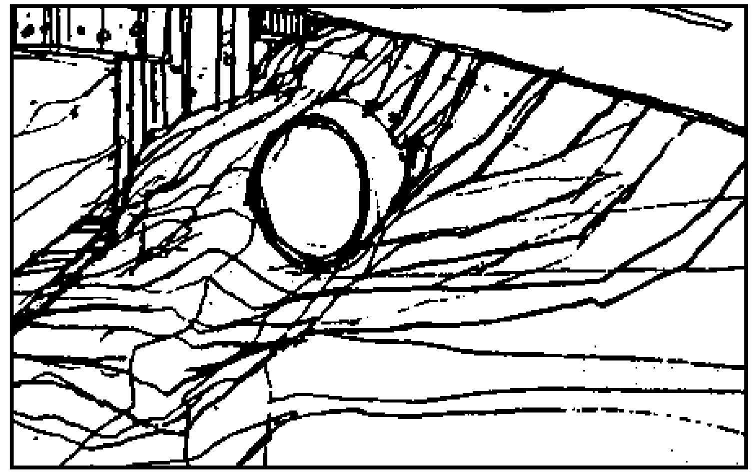
Effectiveness:
- Very effective. Particularly effective where damage was caused by overtopping of the bridge due to excessively high water surface elevations upstream or by excessively high water velocities eroding the pier and abutment foundations.
- Degree of effectiveness varies with the difference of the water surfaces upstream and downstream from the bridge, and with the water velocities through the bridge.
- Consider ***relief openings***, ***wingwalls***, ***realignment of piers and abutments***, ***embankment slope protection***, and ***debris deflectors*** for maximum effectiveness.

Limitations:
- Crossing and stream channel geometry may preclude this option.

Considerations:

B.5 Construct a Relief Opening

Construct one or more ***relief openings*** through the road prism at a location that will carry excess floodwaters. The relief opening may be a culvert or bridge, or multiple culverts or bridges. The openings should be located at natural side channels and in line with heavy flow areas located on the stream overbanks. (See “Culverts-Plugging,” pp. 29-33)



Effectiveness:
- Generally very effective, particularly if combined with appropriate culvert and/or bridge ***entrance and outlet treatments***.
- Consider ***wingwalls***, ***embankment slope protection***, and ***debris deflectors*** for maximum effectiveness.

Limitations:
- Geometry of drainage area may preclude this option.

Considerations:

NEPA

C. Erosion (Approaches)

Introduction

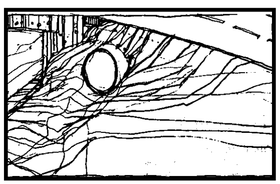
Problem: Damage to bridge approaches resulting from overtopping with subsequent erosion of the road surface, shoulder and embankment, and from impact of flood flows and debris with subsequent erosion of the embankment.

Mitigation Objective: To prevent future damage to bridge approaches (embankments, road shoulder, and road surface) by eliminating overtopping and erosion.

Mitigation measures detailed in other sections, such as "Culverts" and "Roads," that can be employed to protect bridge approaches from flood damage include:

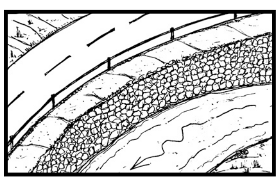
BRIDGES

1. Install a High Water Overflow Crossing (p. 28)

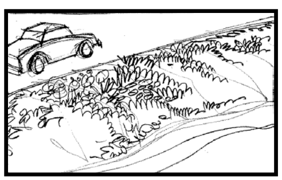


2. Construct a Relief Opening (p. 58)

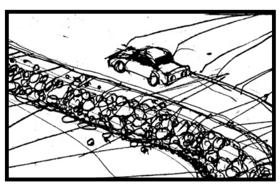
3. Realign the Stream Channel (p. 45)



4. Construct Shoulder Protection (p. 16)



6. Bio-Engineered Embankment Slope Protection (p. 9)



5. Install Lining in the Ditch (p. 5)

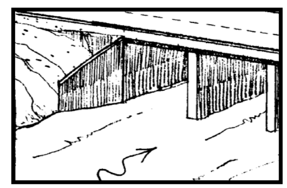
D. Scour (Piers & Abutments)

Introduction

Problem: Damage to bridge piers and abutments resulting from scouring of the streambed along and under their footings.

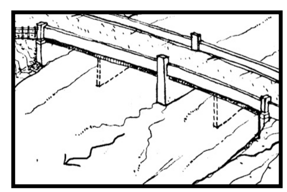
Mitigation Objective: Reduce flood flow velocities along bridge piers and abutments, thereby eliminating scouring of the streambed along and under their footings.

Mitigation measures to protect bridge piers and abutments from flood damage due to scour include:

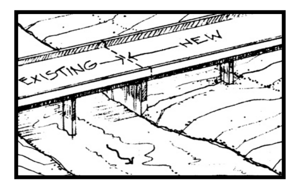


4. Construct Bridge Wingwalls (p. 49)

5. Realign Piers and Abutments (p. 52)



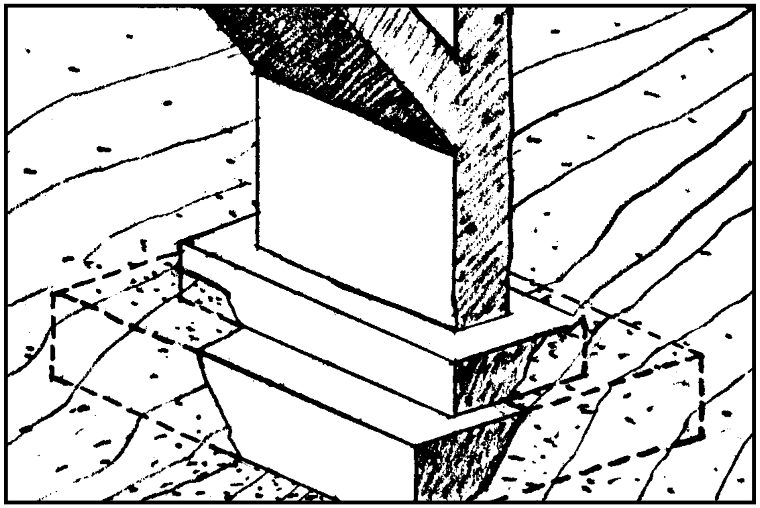
6. Replace Multi-Spans With Single Span Bridge (p. 56)



7. Install Additional Bridge Openings or Spans (p. 51)

D.1 Increase Footing Depth

The depth of pier and abutment footings should be extended below the expected depth of streambed scour or to bedrock. The expected depth of scour depends on the flood flow velocities along the footing and the nature of the streambed materials.



Effectiveness:

- Very effective, particularly when flood flow velocities are relatively high.
- Consider ***flow deflectors***, ***debris deflectors***, or ***replacing multi-spans with a single span*** for maximum effectiveness.

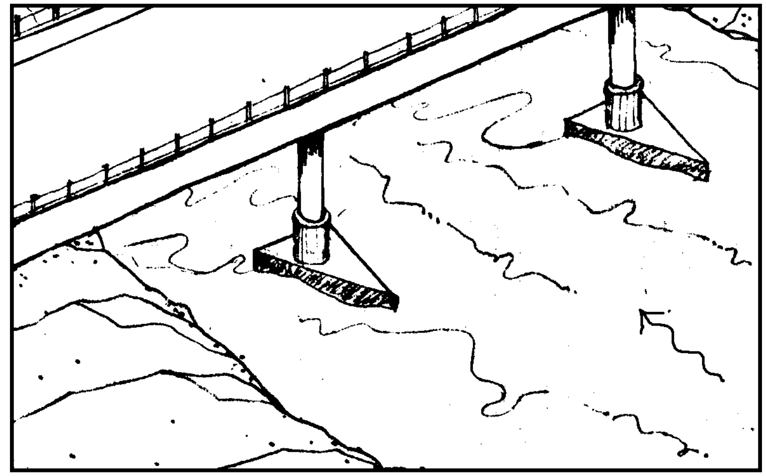
Limitations:

- The depth of pier and abutment footings may be limited by streambed characteristics.
- Footings should be inspected periodically after floods for streambed erosion.

Considerations:

D.2 Install Flow Deflectors

Install "V" shaped ***flow deflectors*** on or immediately upstream from the upstream sections of piers and abutments to reduce flow velocities and protect footings from scouring. Install a concrete collar on lower section of piers immediately above the footing. Also extend lower sections of abutments and the ***wingwalls***, if present. This will assist in deflecting flood flows away from the piers and abutments, and will eliminate streambed scour along and under them.



Effectiveness:

- Flow deflectors are very effective, particularly for flood flows with high velocities.
- Pier collars and abutment sub-walls are moderately effective.
- Pier collars and extended abutment and wingwalls may provide additional protection from impact of rocks and debris.

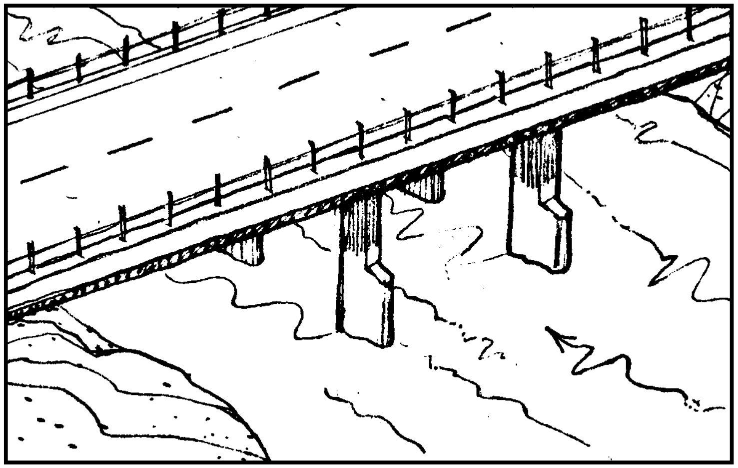
Limitations:

- Flow deflectors should be inspected periodically after floods for impact damage and for streambed erosion.

Considerations:

D.3 Install Semicircular or Triangular Endnoses

Semicircular or triangular ***endnoses*** may be installed on the upstream ends of the piers to redirect flood flow velocities. Pier endnoses are a protection measure, such as sheet metal attached to the pier to redirect flow. Endnoses should also be designed to both prevent debris accumulation and to protect the piers and abutments from floating debris impact.



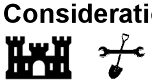
Effectiveness:

- Moderately effective where flood flow velocities are relatively high.
- Less effective when flood flow velocities are relatively low.

Limitations:

- Piers should be inspected periodically after floods for impact damage and for streambed erosion.
- Bridge decks need to be high enough to pass floating debris.
- Any debris that accumulates in the bridge opening needs to be removed during the flood or immediately after the flood peak has passed.

Considerations:



BRIDGES

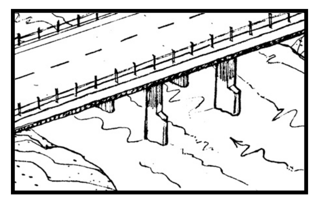
E. Debris Impact (Piers & Abutments)

Introduction

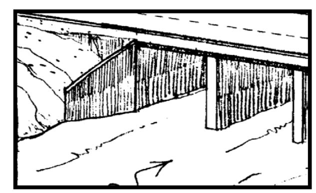
Problem: Damage to bridge piers and abutments resulting from the impact and accumulation of debris.

Mitigation Objective: To prevent future debris damage to bridge piers and abutments by directing debris around and away from them, by providing clear passage of debris through the bridge opening, and by minimizing amount of debris catching on the structural elements of the bridge.

Mitigation measures to protect bridge piers and abutments from flood damage caused by debris impact include:

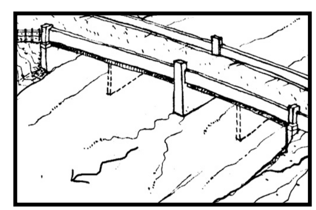


5. Install Endnoses (p. 63)



6. Construct Bridge Wingwalls (p. 49)

7. Realign Piers and Abutments (p. 52)

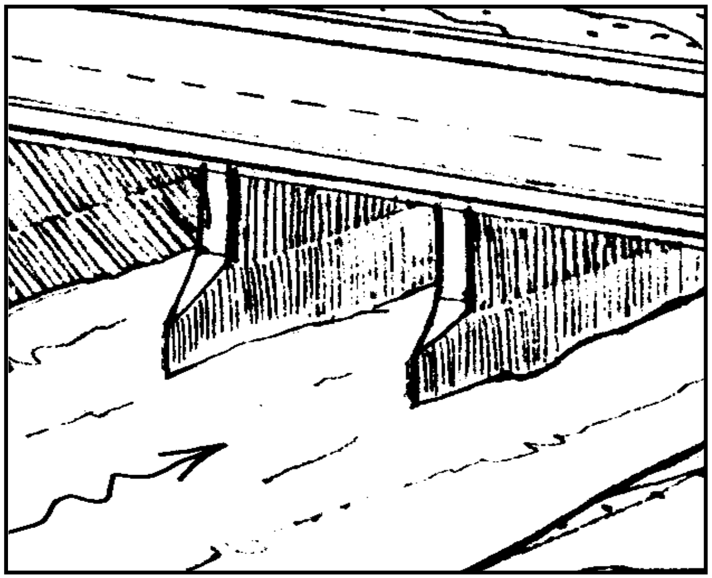


8. Replace Multi-Spans With Single Span Bridge (p. 56)

BRIDGES

E.1 Install Debris Deflectors

Debris deflectors or ***debris fins*** should be installed on the upstream ends of piers and abutments and angled so as to direct floating debris into areas of high flood flow velocities. The debris deflectors and fins should be "V" shaped and extend upstream a sufficient distance to orient the floating debris for easy passage through the bridge. Debris deflectors or fins should be designed to both prevent debris accumulation and to protect the piers and abutments from floating debris impact.



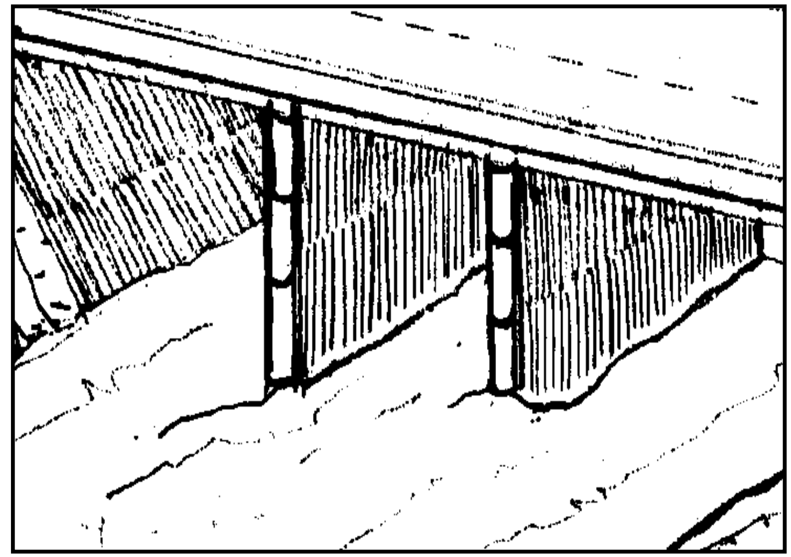
Effectiveness:
- Very effective in areas that have significant debris loading in the upstream drainage and flood flow velocities are high.
- Less effective when flood flow velocities are low.

Limitations:
- Bridge decks need to be high enough to pass floating debris.

Considerations:

E.2 Install Batters

Install ***batters*** (steel plates) on the upstream ends of concrete piers with semicircular or "V" shaped ***endnoses***, or on ***wingwall*** ends and wingwall/abutment junctions to protect them from the impact of floating debris.

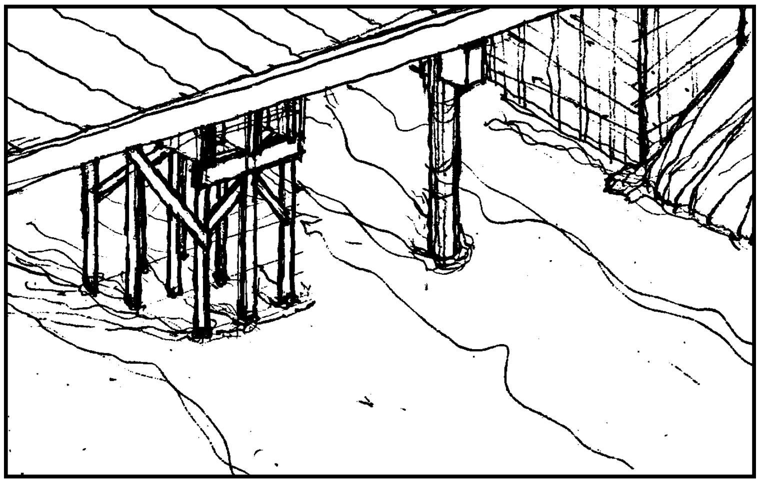


Effectiveness:
- Very effective in protecting piers from debris impact damage.

Considerations:

E.3 Replace Wood Pile Bent Pier Structure With Solid Concrete Column Pier

Replace a pier constructed with wooden piling with a solid concrete column pier. This measure will prevent debris from becoming caught and accumulating in the pile bent pier configuration, and will protect the pier from debris impact.



Effectiveness:

- Very effective in areas that have significant debris loading in the upstream drainage.
- Effectiveness increases with ***debris deflectors*** or ***debris fins***, semicircular or "V" shaped ***endnoses***, and/or ***batters***.

Considerations:

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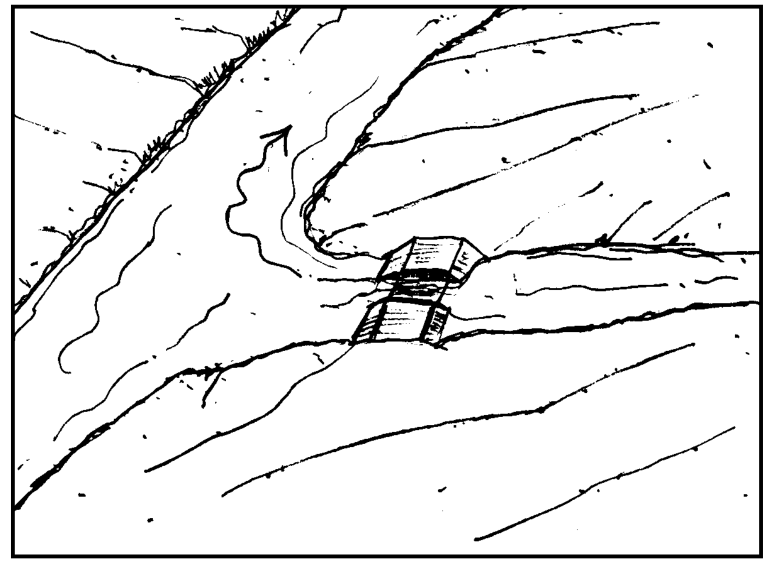
BRIDGES

E.4 Construct Debris Catchments

Debris catchment structures, such as ***debris barriers*** (trash racks) or low height dams, may be constructed on small tributary streams upstream from the bridge. The catchment structures should be designed to trap debris while passing the stream flow. If a debris catchment dam is constructed, it must include an emergency spillway.



Effectiveness:

- Effective where the source of debris is from highly vegetated drainage areas upstream from the bridge and where there are adequate storage areas upstream from the catchment structures.
- Less effective on larger tributary streams.

Limitations:

- Any debris that accumulates upstream from the catchment structures needs to be removed during the flood or immediately after the flood peak has passed.

Considerations:

NEPA $

BUILDINGS

Damage to buildings from flooding is caused by three factors: saturation, velocity, and hydrostatic forces. All retrofits of building structures must allow the accommodation of hydrostatic forces.

Actions taken during restoration can help buildings to resist flotation, collapse, and lateral movement during a flood event. The use of sealants to reduce seepage, installation of pumps and/or check valves to reduce interior water levels, and the elevation of building components can all protect buildings and their contents to varying degrees.

Assessing the Causes of Building Damage

Water *saturation* damage can include:
- Inundation of buildings and their contents, or
- Slope failures and instability.

Damage from *high velocity flows* might include:
- Destruction of buildings and other structures;
- Erosion/scouring of embankments, slopes, levees, and foundations; or

BUILDINGS

- Drainage facility damage (i.e., dislodged or moved culverts).

Damage due to *hydrostatic forces* might include:
- Destruction of buildings, foundations, and other structures, or
- Soil erosion and/or subsoil movement.

In addition to direct damage, *collateral damage* might include:
- Contamination of wells and other facilities inundated by sewage, hazardous materials, and other contaminants in the floodwater;
- Debris from damaged homes, vegetation, orphaned drums, etc., causing debris dams or exacerbating velocity damage as projectiles impact structures; or
- Siltation of ditches, roadways, drainage facilities, etc.

This section discusses mitigation measures for common flood damages to buildings, which are caused by:

A. Inundation

Introduction

Problem: Damage to buildings, equipment, and other components are most commonly caused by floodwater inundation. Floodwater inundates the building, saturating the building materials and its contents. The floodwater is usually contaminated by a number of substances, such as sewage and other hazardous materials.

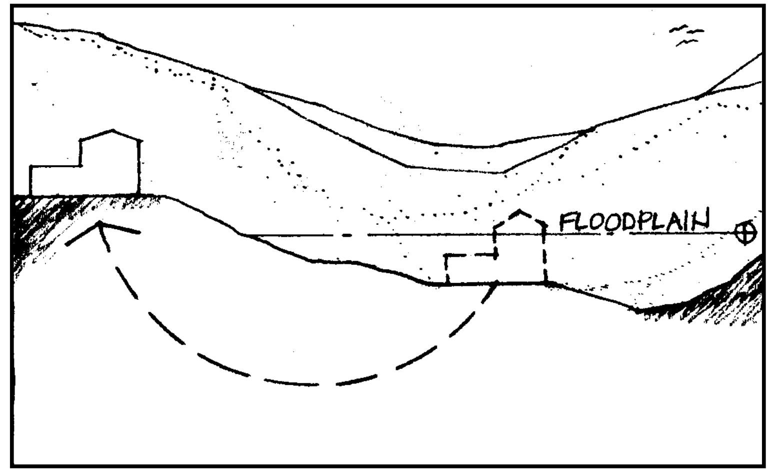
Mitigation Objective: The most effective mitigation is fully protecting the building facility from floodwaters, such as through relocating or elevating the building.

Mitigation measures to protect buildings from flood damage caused by floodwater inundation include:

BUILDINGS

A.1 Relocate Building

Relocate the entire building out of the area subject to flooding and to a safe area, outside the 100-year floodplain or a 500-year floodplain if a critical facility.



Effectiveness:
- The most effective mitigation possible, as the structure will no longer be subject to flooding.

Limitations:
- Appropriate receiving site must be obtained.

Considerations:

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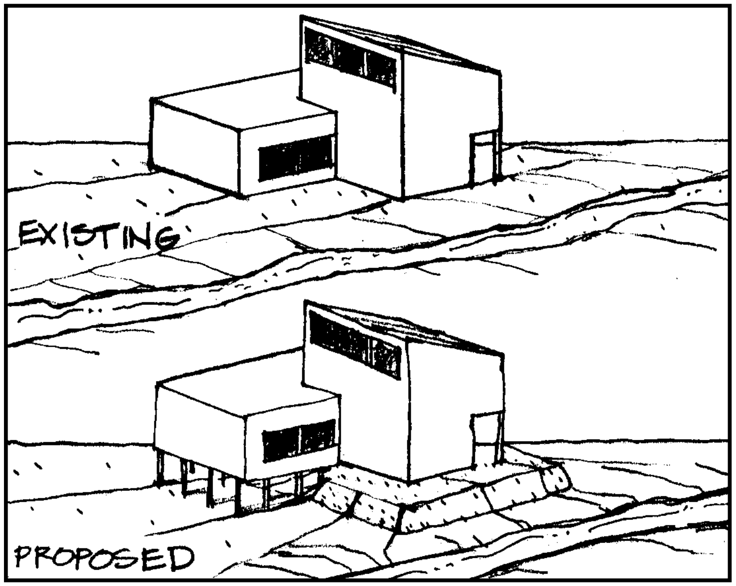
A.2 Elevate Building

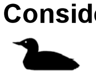
Elevate the building facility on fill or a structure above the design flood elevation or above the 100-year flood. Buildings can be elevated on perimeter walls, piers, piles, or fill. If walls are used to elevate, they must be vented to accommodate hydrostatic forces.



Effectiveness:
- Very effective.
- Area under the building (if built on piers) may be used for storage, parking, or access.

Limitations:
- Building access will be impeded during flood events.
- Fill should be compacted and protected from erosion.
- May require additional mitigation considerations for areas of heavy debris loading.

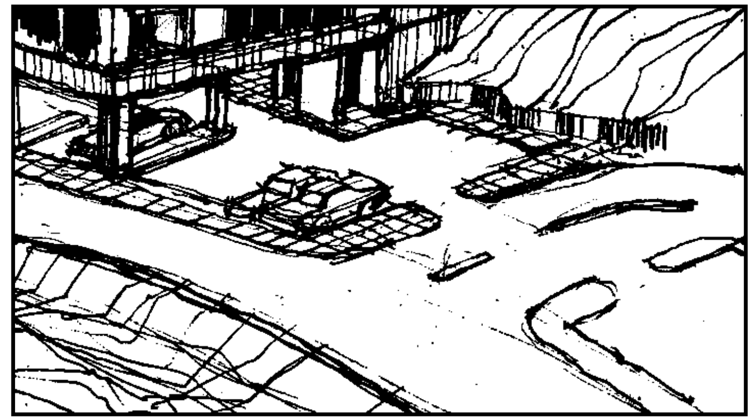
Considerations:

 $

BUILDINGS

A.3 Wet Flood-Proof Building

Allow floodwater to inundate selected portions of the facility in areas that are not vulnerable to damage from floodwater saturation by using water-resistant construction methods, designing openings for flood water passage, and ***elevating*** vulnerable systems, such as electrical equipment above the design flood elevation. Design should include the construction of openings to equalize hydrostatic pressure, and construction of the walls to resist hydrostatic pressure.



Effectiveness:
- Very Effective.

Limitations:
- Portions of building vulnerable to floodwater will be inaccessible during flood event.
- Not practical in areas of high velocity or debris impact.
- Advance warning needed so that stored materials can be removed.

Considerations:

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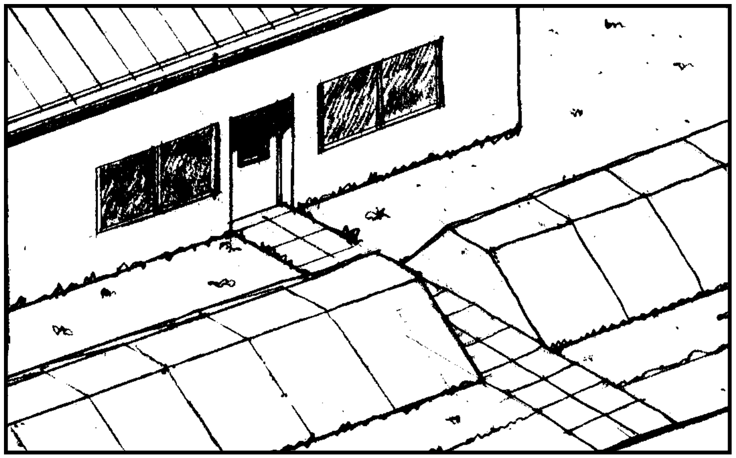
A.4 Dry Flood-Proof Building

Seal the building so that floodwater does not enter. Components of dry flood proofing may include: 1) Constructing exterior floodwalls; 2) Constructing an impermeable ***berm*** around the facility; and/or 3) Sealing the building with water-proof material.

The buoyancy of the building must be considered. Hydrostatic and hydrodynamic forces must be taken into account.



Effectiveness:
- Very effective in preventing damage to building contents.
- Berms and floodwalls can be integrated into landscaping.

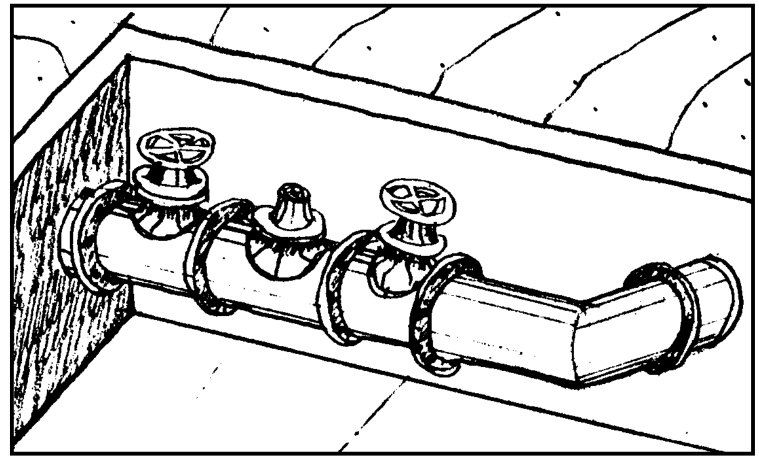
Limitations:
- May not be practical in areas of high velocity flows or heavy debris loading.
- May require access gates be maintained and closed prior to floodwaters reaching structure.
- Site should be designed to resist the forces of floodwaters and accommodate on-site drainage needs.
- Slopes exposed to moderate or high velocity flows should be armored.

Considerations:

NEPA

A.5 Install Backflow Devices on Sewer Drains

Install backflow devices, including one-way and ordinary valves, on sewer lines and floor drains. These devices prevent sewage and/or stormwater from being forced back into the facility.



Effectiveness:
- Very effective, particularly for buildings outside of the floodplain.

Limitations:
- One-way valves may become blocked by debris and fail to close.
- Gate valves require that the valve be manually closed prior to inundation.

Considerations:

B. High Velocity Flows

Introduction

Problem: High velocity flows can scour the soil from under and around footings, threaten the building's structural integrity, and even knock buildings off of their foundations.

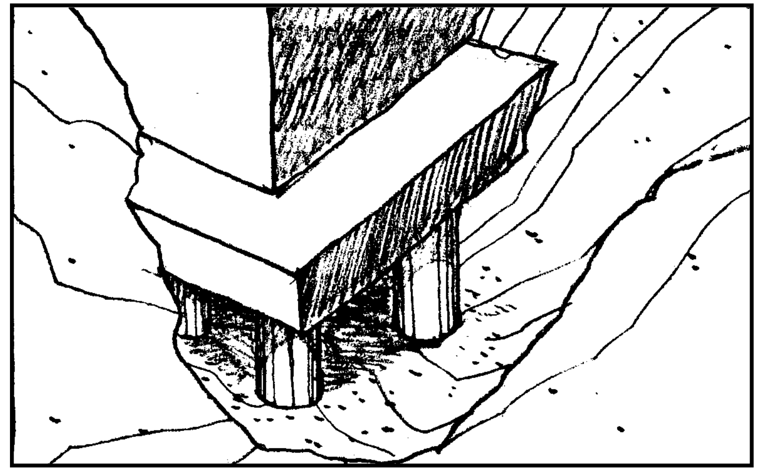
Mitigation Objective: Protect building facilities from damage due to erosion caused by high velocity flood flows.

Mitigation measures to protect buildings from flood damage caused by high velocity flows include:

BUILDINGS

B.1 Construct Piling or New Spread Footing

Building foundations can be undermined due to high velocity flows that scour away the soils supporting the foundation. By constructing a piling or new spread footing, the foundation is supported, thereby preventing failure in subsequent flooding.



Effectiveness:
- Very effective.

Limitations:
- Spread footings should not be used in a coastal environment.
- Area may be inaccessible to pile driving equipment.
- Pile driving may cause damage to adjacent facilities.

Considerations:

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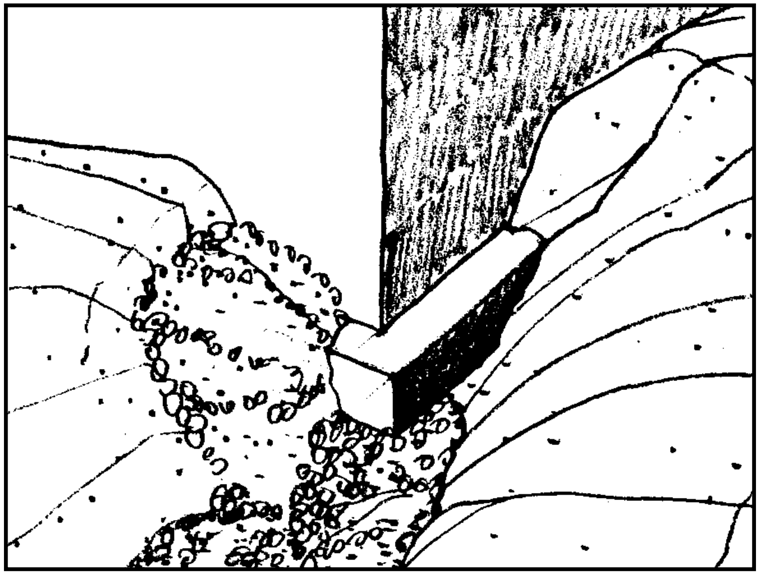
B.2 Replace Footing Materials

To better secure footings and the surrounding material, replace lost footing material of soil or gravel with concrete or grouted granular fill. Soil consolidation and settling caused by inundation, or erosion of the soil due to flow past the footing, can often undermine the soil beneath the footing, which creates a space between the bottom of the footing and the top of the soil beneath the footing.



Effectiveness:
- Very effective.

Limitations:
- May not be effective if future erosion cannot be controlled, or, if in the case of inundation, soil consolidation is not complete.

UTILITIES

Utilities which are frequently damaged in flood events include electrical power, water, sewer and gas distribution, collection and transmission systems (i.e., distribution lines), as well as housing for utility operations or components (electrical substations). Flood damage to these utilities is caused by high velocity flows that cause soil erosion, as well as consolidation and settling of soils or slides. The most appropriate mitigation measure is dependent upon the type of flood damage incurred by each utility system.

This section discusses mitigation measures to protect various utilities from common flood damages that are caused by:

A. High Velocity Flows

Introduction

Problem: High velocity flows can scour and erode soils, which undermine a utility's support.

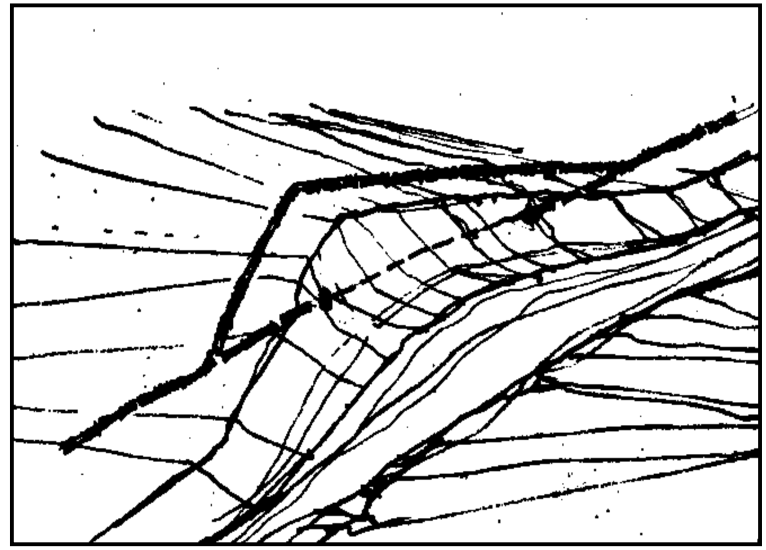
Mitigation Objective: Protect the utility facility from high velocity flows that can erode soils away from the utility, leaving it vulnerable to flood damage.

Mitigation measures to protect utilities from flood damage caused by high velocity flows include:

UTILITIES

A.1 Relocate Utility

Relocate the utility to a safe location away from the hazard. Also consider burying the utility.



Effectiveness:
- Very effective.

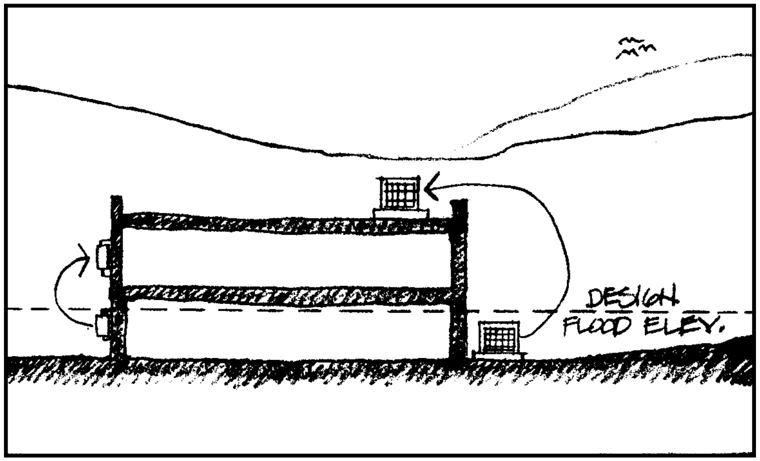
Limitations:
- New location should be free of other hazards, such as exposure to high winds and unstable slopes.

Considerations:

NEPA $

A.2 Elevate Utility

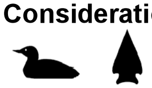
Elevate and/or seal vulnerable components of the utility system, including electrical components and access points, above the design flood elevation.



Effectiveness:
- Very effective in preventing floodwaters from entering the systems, such as: electrical control panels, transformers and switches, and utility access points.

Limitations:
- May require shutdown of the facility.
- May inhibit maintenance access.
- May not be feasible in areas of deep flooding or in urbanized areas.

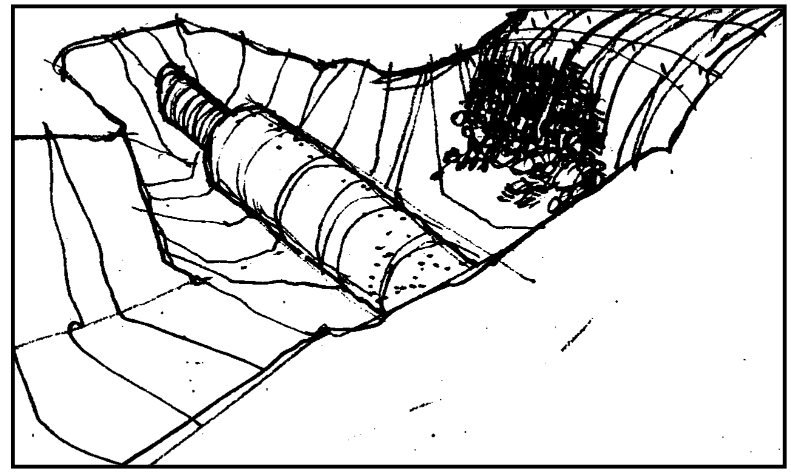
Considerations:



UTILITIES

A.3 Encase the Utility

Encase utility lines, such as electrical, communication, gas and water transmission and distribution lines in concrete and/or conduit to protect them from the damaging effects of floodwaters, including scouring.



Effectiveness:
- Very effective.

Limitations:
- May not be feasible in areas with fine soils subject to high velocity flows, or where extensive erosion is common.
- Maintenance access may be significantly restricted.
- Utility lines could be vulnerable to earthquakes, slides, or other earth movement events.

Considerations:

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B. Soil Settlement

Introduction

Problem: Consolidation and settlement of soils that damage a utility facility during a flood event.

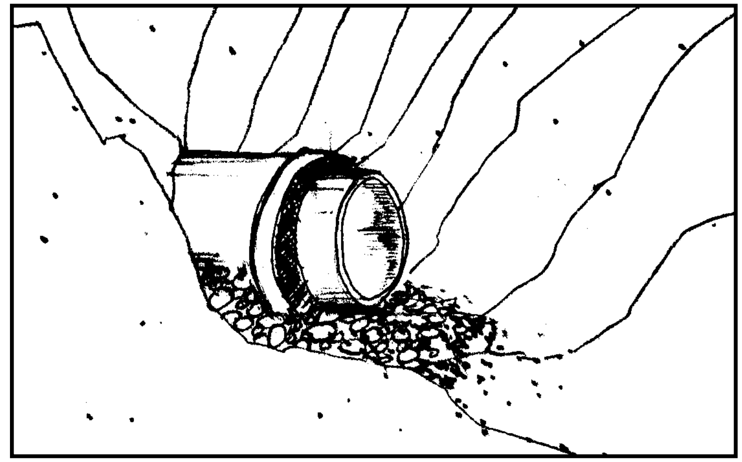
Mitigation Objective: Protect the utility from soil settlement, including slides, from future damage.

Mitigation measures to protect utilities from flood damage caused by soil settlement include:

UTILITIES

B.1 Line Damaged Pipes

Provide a ***lining*** inside damaged storm and sanitary sewer lines to prevent infiltration and/or exfiltration and associated erosion and settlement. Lining will also prevent increased flows due to infiltration of excessive groundwater that could overwhelm treatment plants or other facilities during periods of wet weather. Several lining techniques are available. The most common techniques are slip lining and inversion lining.



Effectiveness:
- Very effective.
- Will prevent infiltration/exfiltration of floodwaters.

Limitations:
- Lining may not be useful if system components are too far out of alignment.
- May not be feasible for small diameter pipes.

Considerations:

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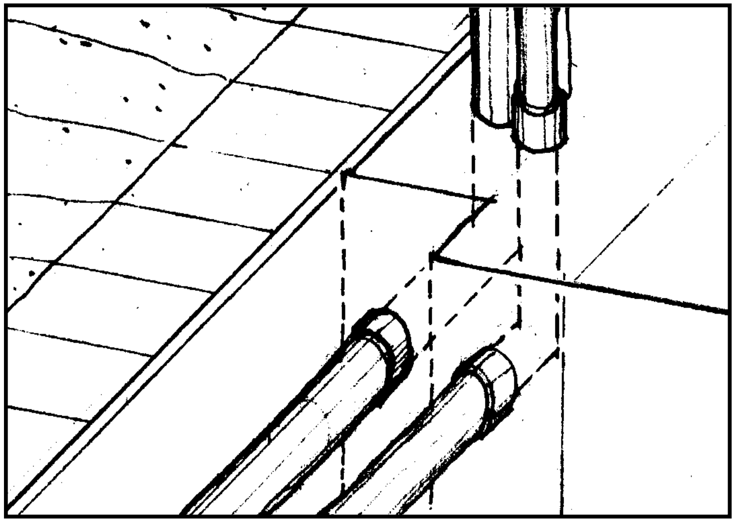
B.2 Bury the Utility

Place above ground utilities, such as transmission and distribution lines for electricity and communication lines, underground to avoid damage from floodwaters, debris, and from soil settlement.



Effectiveness:
- Very effective.

Limitations:
- Maintenance access may be restricted.
- Buried utility lines could be vulnerable to earthquakes, slides, or other earth movement events.

Considerations:

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IRRIGATION FACILITIES

Typically, irrigation systems are made up of several components, including: intake, conveyance, and distribution systems. Due to the nature and general location of these facilities, all may be at risk to damage from flooding. Irrigation facilities are most vulnerable to high velocity flows.

This section discusses mitigation measures for common flood damages to irrigation facilities, which are caused by:

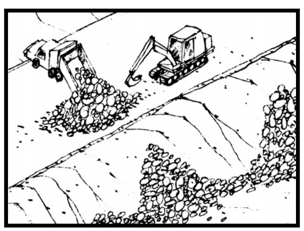
A. High Velocity Flows

Introduction

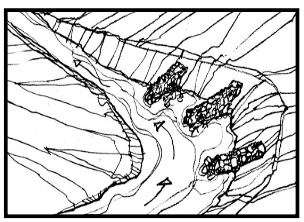
Problem: High velocity flows impact an irrigation facility causing erosion that either undermines support or directly damages the facility.

Mitigation Objective: To prevent damage by reducing high velocity flows that will reduce erosion.

Mitigation measures for common flood damages to irrigation facilities caused by high velocity flood flows include:



3. Place Riprap (p. 13)



4. Install Flow Diverters (p. 44)

A.1 Install an Inverted Siphon

Construct an inverted siphon to transport irrigation water under a stream or canal in order to prevent floodwaters and debris from damaging the at-grade flume or culvert crossing.

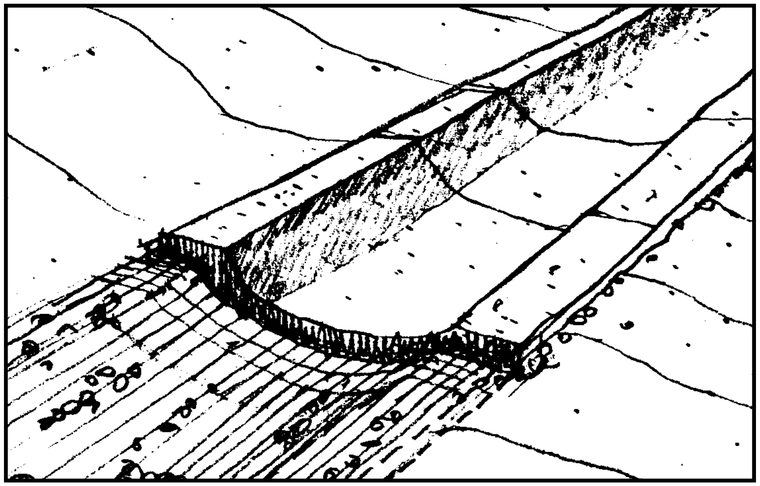
Effectiveness:
- Very effective in preventing debris impact damage and floodwater causing overfill to irrigation facilities.

Limitations:
- Depth of stream and geology may preclude this option.

Considerations:

A.2 Line Earthen Canals

After repairing erosion-damaged irrigation earthen canals, apply cement concrete to the canal walls. ***Lining*** is accomplished by pumping and spraying the mixture over reinforcing wire in areas that are exposed to highly erosive flows. (Shotcrete and Gunite are examples). The concrete and reinforcing wire should be applied from concrete structure to concrete structure, or from an upstream cut-off wall installed to prevent flows from scouring under the upstream edge of the installation.



Effectiveness:
- Very effective.
- Lining limits scour damage to canal walls.
- Lining also limits canal water loss from percolation through canal soils.

Limitations:
- Aquifers or wetlands may be impacted due to loss of groundwater percolation.

Considerations:

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MISCELLANEOUS FACILITIES

There are a number of miscellaneous facilities, such as fences, buoyant fixtures, and boat ramps, which sustain flood damage due to inundation or erosion caused from high velocity flood flows. This section will discuss mitigation measures designed to protect these miscellaneous facilities during flood events that will reduce or prevent future damage.

This section discusses mitigation measures for common flood damages to by various facilities, which are caused by:

A. Inundation

Introduction

Problem: Damage to miscellaneous facilities, such as fences and buoyant fixtures are commonly caused by floodwater inundation. In addition to saturation damage, the facility can be damaged or destroyed by debris that is carried through the floodwaters.

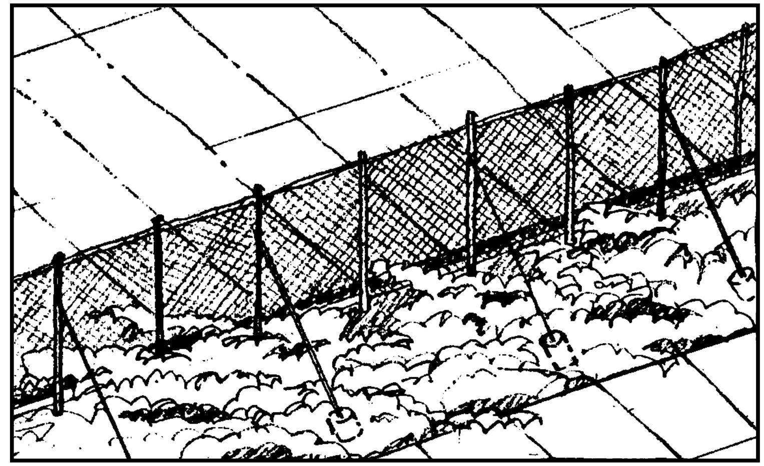
Mitigation Objective: To protect miscellaneous facilities from damage due to floodwater inundation.

Mitigation measures to protect various facilities from flood damage caused by floodwater inundation include:

MISCELLANEOUS FACILITIES

A.1 Strengthen Fencing

Strengthen fences damaged by low to moderate velocity flows by: 1) Using heavier gauge materials; 2) Adding back bracing to the line posts; and/or 3) Installing intermediate line posts.



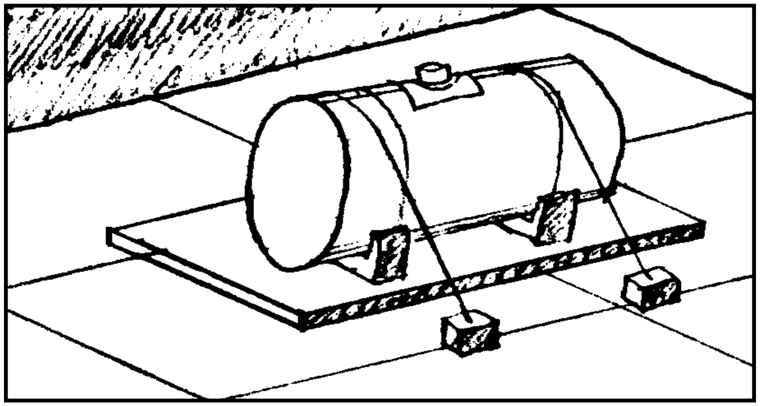
Effectiveness:
- Fence strengthening is generally effective in areas that are flooded by low velocity flows with minimal debris loading.
- Additional measures, such as providing sacrificial fence sections to allow floodwaters to pass, may be required to increase the effectiveness during times of moderate flow.

Limitations:
- Fence strengthening has limited effectiveness in areas of moderate to heavy velocity and debris loading.
- Fence strengthening could, in some extreme cases, cause a damming effect, raising upstream water levels.

Considerations:

A.2 Anchor & Tie-Down Buoyant Facilities

Provide anchors and tie-downs for fuel tanks and other buoyant facilities, such as mobile offices, storage buildings, and playground equipment to keep them from being washed away during flood events.



Effectiveness:

- Anchors and tie-downs are very effective in keeping small, buoyant facilities from being washed away.
- Also prevents object from becoming a debris projectile or a source of contamination.

Limitations:

- May not be effective in areas of moderate to high velocity flows with moderate to heavy debris loading. In these instances, ***relocation***, ***elevation***, or other mitigation alternatives should be considered.

MISCELLANEOUS FACILITIES

B. High Velocity Flows

Introduction

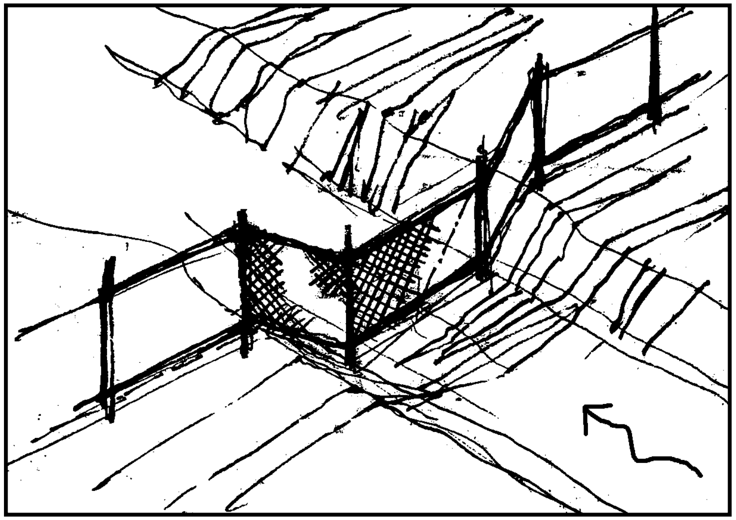
Problem: Damage to miscellaneous facilities, such as fences and boat ramps, can be due to high velocity flows that erode supporting materials, or carry debris that impacts and then damages the facility.

Mitigation Objective: To protect miscellaneous facilities from future damage due to high velocity flows.

Mitigation measures to protect various facilities such as boat ramps from flood damage caused by high velocity flows include:

B.1 Install Sacrificial Fence Sections

Install sacrificial (break-away) fence sections in boundary or other fences (i.e. fence sections designed to fail at strategic locations) to allow floodwaters to pass, relieving pressure on adjacent fence sections, preventing major damage to the fence. Sacrificial sections should be designed so that the failed sections do not become loose in the floodwaters and create additional debris or cause collateral damage.



Effectiveness:
- Allows the passage of high velocity flows as well as debris in restricted drainages.

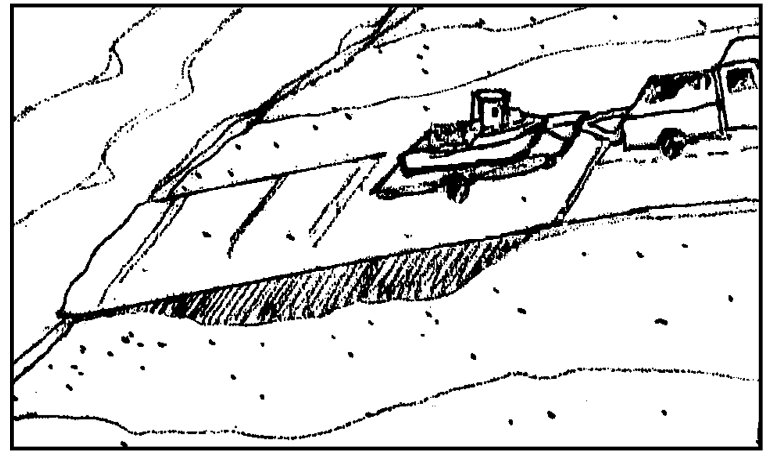
Limitations:
- Sacrificial fence sections may require repairs after flood events.
- May not be effective in preventing damage in situations where floodwater velocities cover a larger area than within the traditional flood channel.

Considerations:

MISCELLANEOUS FACILITIES

B.2 Replace Boat Ramp Material With Concrete

When boat ramps are damaged by erosion, replace the eroded gravel boat ramp or the foundation material eroded from under a concrete boat ramp with concrete.



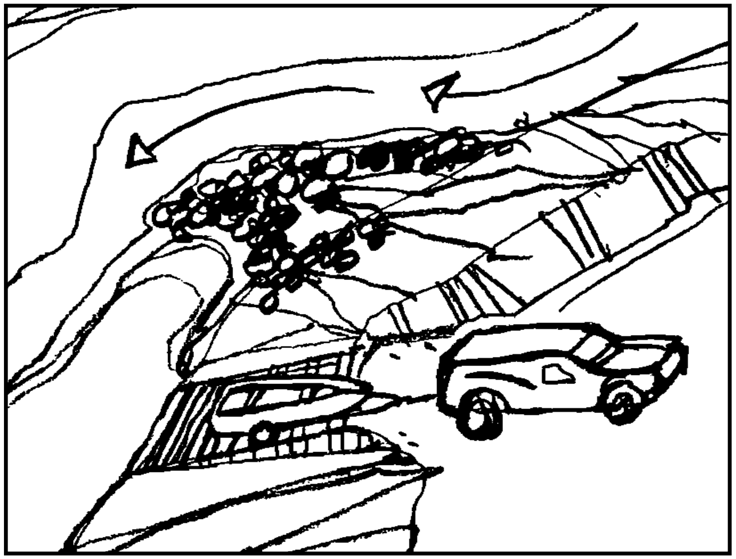
Effectiveness:
- Replacement of eroded material with concrete may be very effective in areas of infrequent, minor erosion damage.
- Other measures, such as ***riprap*** or other slope protection techniques applied to the downstream side of the ramp, may increase the effectiveness of this mitigation alternative.

Limitations:
- May not be effective in situations where the boat ramp is frequently inundated and damaged by high velocity flows.
- Relocation of the ramp, if possible, or other alternatives such as construction of a jetty to protect the ramp should be considered in these instances.

Considerations:

B.3 Construct a Jetty to Protect Boat Ramp

Construct a jetty upstream from the boat ramp to protect it from high velocity flows.



Effectiveness:

- Construction of a jetty upstream from the boat ramp may be very effective in areas of moderate to high velocity flows.
- Other measures, such as ***riprap*** or other slope protection techniques, applied to the downstream side of the ramp may increase the effectiveness of this mitigation alternative.

Limitations:

- Consider ***relocating*** the ramp to the slackwater bay.

Considerations:

NEPA $

APPENDIX A

REGULATIONS AND CONSIDERATIONS

This Appendix briefly discusses significant regulations and issues that should be considered when developing one of the projects identified in this handbook. To streamline the use of the Handbook, these cautions are represented by symbols. The most applicable symbols accompany each mitigation measure in the Handbook. It is solely the project proponent's responsibility to ensure that all applicable codes and standards are met, regardless if they are identified in this Handbook.

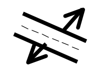
National Environmental Policy Act (NEPA)
All federal agencies must consider the effects of federally-funded projects upon the environment as required by NEPA. Actions identified by this symbol may have an impact on the environment and may require further investigation to determine the extent of any impacts.

Endangered Species Act (ESA)
The ESA protects animals and plants that are federally listed as threatened or endangered (as well as their habitat). Actions identified by this symbol may have an affect on endangered species or their habitat. Consultation and approval by the National Marine Fisheries Service and/or the U.S. Fish and Wildlife Service may be necessary when either agency has jurisdiction.

National Historic Preservation Act (NHPA)
NHPA strives to protect our nation's heritage, and requires the review of any project that affects a structure 50 years or older that may be on (or eligible for) the Federal Register of Historic Places, or that affects a site which may contain artifacts of archaeological or cultural significance. For any action identified by this symbol, FEMA may need to consult with the State or Tribal Historic Preservation Office to determine whether any additional action or mitigation is necessary.

Clean Water Act (CWA)
The U.S. Army Corps of Engineers (Corps) is responsible for ensuring that projects in 'the waters of the United States' do not adversely affect such waters. Actions identified by this symbol may require a permit by the Corps.

Floodplain / Wetlands
Actions identified by this symbol are subject to Executive Order 11988 on Floodplain Management and/or Executive Order 11990 on Wetlands. The Executive Orders on Floodplains and Wetlands are intended to ensure that federally-funded projects avoid long and short term impacts associated with the modification of floodplains or wetlands.



Right of Way Constraints
Mitigation measures identified by this symbol may be limited by required right of way widths, clear zone constraints, and/or geometry of embankment constraints.

Downstream or Upstream Effects
Actions identified by this symbol indicate that the action may impact downstream flow volumes or may create backwater effects upstream of the measure.

Cost
The cost of actions identified by this symbol may be prohibitively expensive.

Maintenance
Actions identified by this symbol may require significant and/or continuous maintenance.

Engineer
Actions identified by this symbol require that an engineer be consulted or hired to develop and/or approve the retrofit.

APPENDIX B

GLOSSARY & INDEX OF FLOOD DAMAGE KEYWORDS

[Keywords are underlined]

Armoring. Placing materials, such as riprap, to protect an embankment or a stream bank.

Backwater. The rise in a stream's water surface elevation caused by an obstruction or constriction to the flow, such as by a dam, bridge, culvert, or a temporary obstruction.

Bank. The lateral boundaries of a stream confining all flow levels that do not rise above them and flow out onto the floodplain. The bank on the left side of a channel looking downstream is the left bank.

Bank protection. Rock, concrete, asphalt, vegetation, or other armor protecting a bank of a stream from erosion. Includes devices used to deflect the forces of erosion away from the bank. See **Embankment Slope Protection.**

Barbs. See **Flow diverters.**

Base flood elevation. See **Design flood elevation.**

Batters. Steel plates attached to the upstream faces of bridge piers to protect them from damage due to the impact of floating debris. pp. 66 and 67.

Berms. Earth-filled structures placed on a floodplain to divert flood flows, most commonly into bridge or culvert openings. The earth fill should be erosion-resistant and the berms should be covered with erosion-resistant vegetation. Berms should be located to ensure no significant increase in water surface elevations. pp. 43 and 75.

Bevel ring, Entrance. A round collar placed on a culvert entrance to divert the flow into the culvert. The collar is beveled from its outer surface inward to the culvert entrance.

Bio-engineering. Use of plant materials to stabilize hill slopes or stream banks. It often involves fascine and bundles in conjunction with other 'hard' structures such as logs, root wads, rock toes, or wooden crib structures.

Bio-filtration. The aerobic and anaerobic processes used to break down wastes, as is typically implemented at a waste water or sewage treatment plant.

Bucket outlet. A concrete or rock structure placed at a culvert outlet to dissipate the energy of the flow as it exits the culvert. The structure is curved upward to throw the water jet downstream.

Capacity. The effective carrying ability of a drainage structure.

Catch basin. A structure that collects water.

Check dams. A small rock or concrete structure generally placed laterally across steep ditches for the purpose of reducing the velocity in the ditch. pp. 4 and 7.

Critical facility. Critical facilities provide essential services to a community, like a fire station, hospital, or nursing home. When relocated or reconstructed, the critical facility must not be located within the 500-year floodplain. The distinction of these facilities is that even a small flood can have life-threatening risks, such as due to access and/or operations issues. See also 44 CFR Chapter 9.4 for a list of critical actions.

Culvert. A closed conduit, other than a bridge, which allows water to pass through a roadway prism.

Culvert, Additional. Intended to mitigate culvert misalignment. Additional culverts are designed to stand alone. Individual design capacities are determined based on the amount of anticipated flow through separate stream channels that have migrated (or are expected to migrate) away from the main stream. pp. 6 and 41.

Culvert entrance bottoms, Paving. pp. 22, 25, and 35-36.

Culvert entrance, Rounding. pp. 22, 25, and 37.

Culvert entrance, Shape. pp. 35 and 36.

Culverts, Multiple. Intended to mitigate insufficient capacity. Multiple culverts are designed as part of the main stream culvert system. They are located at the main stream culvert site and should be at different elevations in the embankment. (i.e., Separated by 0.1 times the diameter of the culvert.)

Cutoff wall. A wall at the end of a drainage structure, the top of which is an integral part of the drainage structure. This wall is usually buried and its function is to prevent undermining of the drainage structure if the natural material at the outlet of the structure is eroded by the water discharging from the end of the structure. Cutoff walls are sometimes used at the upstream end of a structure when there is a possibility of erosion. pp. 35 and 36

Debris barrier (trash rack). A deflector placed at the entrance of a culvert upstream, which tends to deflect heavy floating debris or boulders away from the culvert entrance during high velocity flow. pp. 21-23, 30, 35-37, 39, 41-45, and 68.

Debris basin. Any area upstream from a drainage structure utilized for the purpose of retaining debris in order to prevent clogging of drainage structures downstream.

Debris crib. Open crib-type structure placed vertically over the culvert inlet in log-cabin fashion to prevent inflow of coarse bedload and light floating debris.

Debris deflector. Structure placed at the culvert inlet to deflect the major portion of the debris away from the culvert entrance. They are normally "V" shaped in plane with the apex upstream. pp. 30, 49-52, 56-58, 61, 65, and 67.

Debris fins. Walls built in the stream channel upstream of the culvert. Their purpose is to align debris, such as logs, with the axis of the culvert so that the debris will pass through the culvert barrel without clogging the inlet. They are sometimes used on the bridge piers to deflect drift. pp. 30, 66, and 67.

Design flood elevation. Unless the community has designated a higher elevation, the 100-year floodplain for bridges, buildings and other important facilities, the 500-year floodplain for critical facilities, and the maximum flood that frequently occurs for all other facilities.

Detention storage. Surface water moving over the land is in detention storage. Surface water allowed to temporarily accumulate in ponds, basins, reservoirs, or other types of holding facility, and which is ultimately returned to a watercourse or other drainage system as runoff is in detention storage.

Drawdown. A lowering of the surface water elevation of a stream as it approaches and flows through a bridge or culvert. It is a measure of the difference of the water surface elevation upstream from the bridge or culvert and a short distance downstream from their enrances.

Eddies. Currents of water moving in circular (whirlpool) patterns contrary to the main direction of flood flows. The eddies may move laterally to the downstream direction of flow or at various angles upstream and downstream.

Elevate. pp. 54, 55, 73, 74, 83, and 95.

Embankment slope protection. pp. 4, 9, 15, 21-24, 30, 32, 35-37, 39, 41-45, 49-52, and 56-58.

Emergency spillway. A constructed channel at a dam or other structure designed to pass flood flows that exceed the design capacity of the flow through structures.

Endnoses. Triangular or curved structures added to the upstream side of piers to deflect floating debris and high stream velocities. pp. 63, 66, and 67.

Endwall (treatment/design). A wall at the end of a drainage structure designed to prevent erosion of the embankment at its entrance or outlet. pp. 21, 22, 35-37, and 41-45.

<u>Energy dissipater</u>. A rock or concrete structure designed to reduce the velocity of the flow exiting a culvert to prevent erosion of the streambed and banks. pp. 10, 21-23, 30, 37-39, and 41-45.

<u>Entrance & outlet treatments/design</u>. pp. 23-24, 30, 32, and 58.

<u>Flared outlets/end sections</u>. Manufactured end sections for culvert entrances and outlets. The end sections expand in width outward from the culvert end, are beveled to match the embankment slope, and have rounded corners at their outer ends. pp. 22, 25, and 37.

Floodwaters. Stream flows that have risen above the stream bank, and flow or stand over adjoining lands.

Floodwalls. Walls constructed of water-resistant material around the perimeter of a facility and extending above the design flood elevation to keep floodwaters away from the facility.

<u>Flow deflectors</u>. Triangular or circular structures installed on or immediately upstream from the footings of bridge piers to deflect the flow thereby reducing the flow velocities and preventing scour of the pier footings. pp. 61 and 62.

Flow diverters. Rock structures placed in a stream to divert the flow away from embankments. Usually designed to extend a short distance into the stream, flow diverters or barbs are higher at the edge of the embankment, and are tied into the bank to protect from erosion at their ends.

Flow full. The flow condition of a culvert when all of its cross-sectional area is carrying flow. In general, a culvert will flow full when its outlet is submerged (water surface is above the tope of the culvert outlet) or the depth of water above the top of its entrance is 1.5 times its diameter.

Flow partially full. A flow condition of a culvert when all of its cross-sectional area is not carrying flow. In general, a culvert will flow partially full when the water depth is above (or below)

APPENDICES

the top of its entrance and the water depth is below the top of its outlet.

Gabions. Wire baskets filled with rock and placed along embankments to prevent erosion.

Graded stream. A condition when a stream's bed is neither aggrading (sediment and/or gravel deposition is raising the bed) nor degrading (sediment and/or gravel erosion is lowering the bed). The stream is considered to be in equilibrium.

Head cutting. A condition when a stream's bed is progressively eroding (lowering) in the upstream direction.

'High head' conditions. Once a culvert is flowing full, an increase in the water surface elevation upstream from the culvert has a relatively small effect on the increase of flow through the culvert. The flow through the culvert is then described as being under "high head conditions."

High water marks. Lines found on trees and structures marking the highest elevation (peak) of the water surface for a flood event, created by foam, seed, or other debris.

<u>High water overflow crossing</u>. A depression in a road prism designed to carry flood flows from overbank areas. pp. 21, 23, and 28.

Hydrodynamic forces. Forces imposed on structures by floodwaters due to impacts of moving water on the upstream side of the structure, drag along its sides, and eddies or negative pressures on its downstream side.

Hydrostatic pressure. The pressure exerted in all directions by a given point in a body of water, usually caused by the weight of water overlying it.

Intermittent drainages. Streams that do not flow continuously.

<u>Lining</u>. Protective cover of the perimeter of a channel or the inside of a pipe. pp. 4, 5, 86, and 91.

Low water crossing. A depression in a road prism designed to carry flood flows from an intermittent drainage. pp. 23, 27, and 28.

Meander. In connection with streams, a winding channel usually in an erodible, alluvial valley. A reverse or S-shaped curve or series of curves formed by erosion of the concave bank, especially at the downstream end, shoals and bank erosions. Meandering is a stage in the migratory movement of the channel, as a whole, down the valley.

Overbank. The portion of the bank where the floodwaters flow above the historical confines of the bank.

Permeability. The ability of a material (generally an earth material) to transmit water through its pores when subjected to a pressure or a difference in head.

Realign piers & abutments. pp. 52, 56, and 57.

Relief culvert. Installed to mitigate debris plugging of culverts and bridges. Relief culverts may be installed at the culvert site at a higher elevation or at some distance from bridge openings.

Relief opening. This opening can be a culvert or bridge, or multiple culverts; normally located at natural side channels. pp. 56-58.

Replace multi-span bridge with single span. pp. 56 and 61.

Relocate. pp. 52, 72, 82, 95, and 99.

Revetment. Bank protection to prevent erosion.

Ring compression. Flattening of a circular culvert resulting from beveling its end to match the angle of the embankment. Flanges may be required to stiffen the beveled section of the culvert.

Riparian. Riparian areas occur next to the banks of streams, lakes, and wetlands, and include both the area dominated by continuous high moisture content and the adjacent upland vegetation that exerts an influence on it.

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Riprap. Rock placed on embankment slopes to prevent erosion. pp. 13, 16, 98, and 99.

Roadway prism. The road embankment, shoulder, and surface.

Rounded inlet. The edges of a culvert entrance that are rounded for smooth transition, which reduces turbulence and increases capacity.

Scour. The result of an erosive action of flowing water, primarily in streams, excavating and carrying away material from the bed and banks. Wearing away by abrasive action.

Sediment. Road, gravel, or cobbles that originate from weathering of rocks and is transported by, suspended in, or deposited by water.

Spur dikes. Embankments that are designed to direct flood flows into a bridge opening.

Subcritical flow (tranquil and streaming). Low velocity stream flow. The flow appears to flow in tubes with uniform velocity.

Submerged. Covered with water. Here used as surface water elevations above the top of culvert entrances and outlets.

Supercritical flow (rapid and turbulent). High velocity stream flow. The flow appears to be shooting with varying velocity.

Wingwalls (treatment/design). Concrete walls constructed at culvert and bridge entrances and outlets to direct flows into their openings. Wingwalls may be constructed at angles up to 60 degrees from the culvert and bridge openings. pp. 21, 22, 25, 30, 35-37, 41-45, 49, 51, 52, 56-58, 62, and 66.

APPENDIX C

ACRONYMS

CFR	Code of Federal Regulations
CWA	Clean Water Act
EO	Executive Orders
ESA	Endangered Species Act
FEMA	Federal Emergency Management Agency
HAZMIT	Hazard Mitigation
HMGP	Hazard Mitigation Grant Program
MIT	Mitigation
NEPA	National Environmental Policy Act
NFIP	National Flood Insurance Program
NHPA	National Historic Preservation Act
PA	Public Assistance
PL	Public Law
PL 93-288	Robert T. Stafford Disaster Relief and Emergency Assistance Act
USACE	US Army Corps of Engineers

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REFERENCES

Computation of Peak Discharge at Contractions, by Kindsvater, C.E.; Carter, R.W.; and Tracy, H.J. US Geological Survey Circular #284. Published by US Geological Survey, Washington, DC (1953).

Computation of Peak Discharge at Culverts, by Carter, R.W. US Geological Survey Circular #376. Published by US Geological Survey, Washington, DC (1957).

Design Guidelines for Flood Damage Reduction. Prepared by AIA Research Corp., Washington, D.C., for the Federal Emergency Management Agency. FEMA Publication No. 15, December 1981.

Floodproofing Non-Residential Structures. Prepared by Booker Associates for the Federal Emergency Management Agency. FEMA Publication No. 102, May 1986.

Handbook of Steel Drainage and Highway Construction Products, Second Edition. Published by American Iron & Steel Institute, Washington, DC (1971).

Homeowner's Guide to Retrofitting: Six Ways to Protect Your House From Flooding. FEMA Publication No. 312, June 1998. Published by FEMA, Washington, DC (1998).

Protecting Building Utilities From Flood Damage: Principles & Practices for the Design & Construction of Flood Resistant Building Utility Systems. FEMA Publication No. 348, November 1999. Published by FEMA, Jessup, MD (1999).

Public Assistance Guide. FEMA Publication No. 322, October 1999. Supercedes FEMA 286, issued in September 1996. Published by Response and Recovery Directorate, FEMA, Washington, DC (1999).

"Stormwater Management Practices in Tennessee." Stormwater Management for Public Officials and Planners: Development of an Educational Manual and Workshop Project, Contract Agreement No. 48226. Published by the University of Tennessee Civil & Environmental Engineering Department and the Tennessee Water Resources Research Center (December 1997). Internet: http://www.engr.utk.edu/research/water.

Water-Resources Engineering, by Linsley, R.K. & Franzini, J.B. Published by McGraw-Hill Series in Sanitary Science and Water Resources Engineering, New York (1964).

APPENDIX E

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Dennis Burton – Public Assistance

Stan Chun – Public Assistance

Ron Hormann – Public Assistance

Tom Morello – Public Assistance

JoAnn Oram – Public Assistance

Susan Slate – Public Assistance

Richal Smith – Public Assistance

Phil Carpenter – Hazard Mitigation

Bruce Knipe – Hazard Mitigation

Terry Scanland – Hazard Mitigation

Mark Eberlein – Regional Environmental Officer

Doak Mahlik – External Affairs

Eric Peebles – Outreach

Dayna Bailey – Technical Assistance Contractor

Jay Concepcion – Technical Assistance Contractor

Anahid Kristina Tokes – Technical Assistance Contractor