Hazard Mitigation Field Book

Roadways

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FEMA

Foreword

The Federal Emergency Management Agency (FEMA) continually strives to improve the delivery of disaster assistance to states and local governments. This *Hazard Mitigation Field Book (HMFB) for Roadways* assists entities directly affected by catastrophic events and disasters by suggesting mitigation measures. These mitigation measures are intended to help in identifying mitigation options and solutions for local jurisdictions and can be used at any time, and not just after a disaster.

As disasters have grown in frequency and severity[1], the costs of response and recovery have escalated to unsustainable levels. Obligations through the Federal Disaster Relief Fund ballooned from $2.8 billion in 1992 to $34.4 billion in 2005 due to damages associated with the 2004 and 2005 hurricane seasons.[2] The most effective way to reduce these excessive losses is through disaster preparedness and mitigation. To best achieve this goal, we need to pursue two objectives:

- Break the disaster-rebuild-disaster cycle. Merely repairing substandard infrastructure and elements to their pre-disaster condition does not protect the community from future disaster damages or reduce long-term costs. Mitigation improvements should always be considered in the rebuilding process, utilizing a multi-hazard approach whenever possible.
- Ensure that communities address natural hazards. Comprehensive plans should acknowledge all hazards that pose a risk and identify steps to avoid these hazards altogether or incrementally reduce a community's exposure to its hazards.

The outcome of achieving these objectives will be more resilient and economically sustainable communities. Although following and implementing the solutions in the HMFB does not guarantee FEMA funding, an analysis by the National Institute of Building Sciences' Multihazard Mitigation Council established that every dollar spent in damage prevention saves four dollars in future repairs.

1 http://maps.grida.no/go/graphic/trends-in-natural-disasters

2 *Mitigating Misery: Land Use and Protection of Property Rights before the Next Big Flood* by Edward A. Thomas & Sam Riley Medlock (2008). http://www.floods/org/PDF/ASFPM_Thomas&Medlock.pdf

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Safety

You are responsible for your personal safety at all times. Teams or individuals performing inspections may be exposed to hazards, especially following a disaster. Work areas may be isolated, extreme weather conditions may still exist, and heavy equipment may already be operating at the work site. In addition, state and local jurisdictions may be focusing on saving lives and response issues; other issues related to building science or recovery might not be immediately addressed.

Be aware of new safety risks created by an event. These may include washed out roads, downed power lines, non-functioning traffic signals, eroded road surfaces, washed out culverts and roads, high flood levels, etc.

At all times be careful of other motorists on the road.

Ensure that you have taken necessary precautions. Wear appropriate personal protective equipment such as high-visibility protective vests, eye protection, hard hats, leather boots with slip resistant soles, hearing protection, insect repellent, and gloves. Make sure you have a map and a way to call for help if needed.

Remember: Nothing is more important than your personal safety and your ability to safely carry out your task!

Purpose

The FEMA *Hazard Mitigation Field Book (HMFB) for Roadways*[3] helps local government entities choose the best hazard mitigation (HM) solution(s) given their operational constraints and design considerations. By offering the user a quick selection tool, based on broad characteristics, the HMFB reduces a wide array of technical solutions to a few practical options. Although there are many causes of damage to roadways, this Field Book focuses primarily on flood-related causes of damage.

Methodology

The HMFB uses a two-step selection process that includes 1.) a *Project Identification Diagram* that quickly outlines the specific hazard and presents the relevant mitigation solutions to be considered and 2.) a *Selection Matrix* that introduces HM solutions with their principal considerations and respective weights.

Step One – Project Identification Diagram

The Project Identification Diagram is a linear decision tool that screens possible HM options for practical solutions based on clearly identified criteria and a qualitative weighing process.

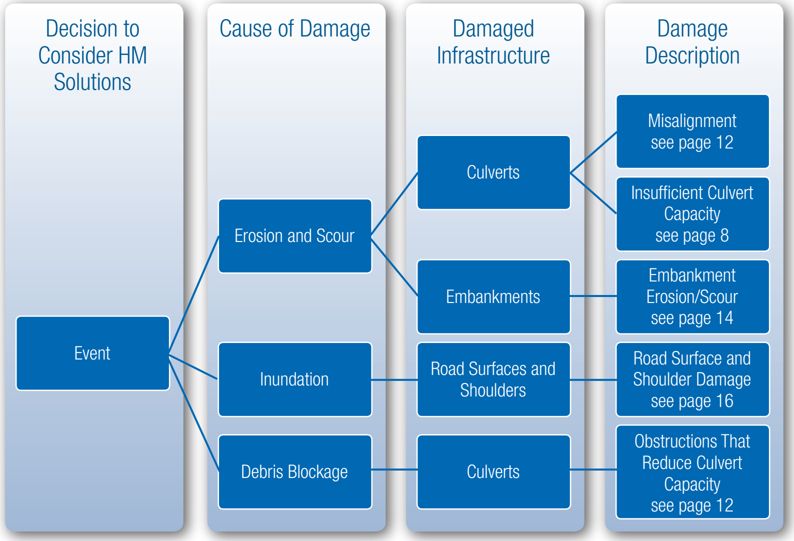
Hazard Mitigation Steering Committee

On December 4, 2009, FEMA convened a Steering Committee of experts in roadway hazard mitigation. Practitioners from several state Departments of Transportation, local Departments of Public Works, FEMA, Federal Highway Administration (FHWA), organizations such as the American Association of State Highway and Transportation Officials (AASHTO), Association of State Floodplain Managers (ASFPM), and private-sector subject-matter experts were represented. See the Contributors List on page 42.

The Steering Committee further identified the extensive source of existing technical information already available that need not be duplicated in a FEMA manual. Instead the Steering Group recommended that 1.) A decision process be identified for roads and drainage structures subject to disaster damages; 2.) Sample case studies be created using this decision process and; 3.) Additional sources of technical information be provided. This document is a direct response to those recommendations.

3 The HMFB does not discuss bridges. The discussion is limited to culverts, embankments, and road surfaces and shoulders.

Project Identification Diagram



- **Decision to Consider HM Solutions** – What has happened, or may occur, that will cause unacceptable impacts or damages to a community.
- **Cause of Damage** – Damage to roadways is related to three general water-related causes of damage to roadways.
    - **Erosion and Scour** – Damage occurs when moving floodwaters shift or remove sand along a coastline or shoreline (erosion) and/or undermine foundations (scour) that support road infrastructure. In some areas, the effects of erosion and scour can result in severe damage or collapse of infrastructure.
    - **Inundation** – Damage occurs when floodwaters surround and infiltrate infrastructure. This damage may be associated with high-velocity floodwaters.
    - **Debris Blockage** – Damage occurs when various natural materials and man-made objects are carried by moving floodwaters and either collide with or clog up drainage structures. In some instances, debris can collect on other infrastructure, such as bridges, and adversely affect flow, resulting in damage to the infrastructure leading up to or adjacent to a bridge or other structure.
- **Damaged Infrastructure** – Subdivides all non-bridge road infrastructure into three main categories: culverts, embankments, and road surfaces and shoulders.
    - **Culverts** – Drain crossing under a road.
    - **Embankments** – Raised structure to hold back water or carry a roadway.

- **Road Surfaces and Shoulders** – Portion of pavement designed to carry traffic. This includes the lateral support of pavement layers, and the edge of the roadway designed for accommodation of stopped vehicles, emergency use, and recovery area for errant vehicles.

- **Damage Description** – Identifies types of damage that occur when a cause from the "Cause of Damage" column interfaces with a structure from the "Damaged Infrastructure" column.
  - **Misalignment** – Damage to a culvert caused by its horizontal and/or vertical misalignment within the stream channel and subsequent erosion of the embankment.
  - **Insufficient Culvert Capacity** – 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.
  - **Embankment Erosion** – 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 result from inadequate culvert end sections.
  - **Road Surface and Shoulder Damage** – Damage caused by water flowing over the top of the roadway, due to low roadway elevation or inadequate drainage structure capacity.
  - **Obstructions That Reduce Culvert Capacity** – Damage or failure of a culvert caused by overtopping and erosion of the embankment due to plugging of the culvert with debris caught or wedged in the culvert, restricting water flow. A culvert can then be washed out or damaged due to increased water surface elevations upstream.

Step Two – Selection Matrix

Based on the final Project Identification Diagram selection, the user matches the appropriate "Damage Description" grouping to the Selection Matrix and begins a step-by-step process to evaluate each factor (consideration). The list of possible HM solutions includes a qualitative weight in each column for the user to determine if a solution is a viable option. With each selection, the user has a reduced set of possible solutions. Once the user has stepped completely through the process, a small number of possible mitigation solutions remain. At this point, the final selection from the remaining qualifying solutions is based on the discretion of the user as to which solution is the most appropriate. Additional sources of technical information are provided that can be used for the final solution decision/recommendation.

- **Design Components of the Selection Matrix**
  - **Columns** – The column headings are the factors that influence HM selection. They are grouped into four primary categories: Time to Implementation, Feasibility Considerations, Design Considerations, and Environmental Considerations. The cells below the column headings carry the ranking of the factor (column heading) to the corresponding HM solution (row).
  - **Ordering of the Columns** – The ordering of the columns from left to right creates a built-in assumption that columns (factors) to the left are generally more critical than the columns (factors) to the right. Therefore any column (factor) moving from left to right must be considered simultaneously or before any other column (factor) to the right is considered.
  - **Rows** – The rows contain commonly implemented roadway HM solutions.
- **Key Assumptions of the Selection Matrix**
  - The user is familiar with road construction, maintenance, and repair.
  - The Selection Matrix is designed to provide details about specific solutions. It is possible that multiple measures can be combined into a single project (e.g., a trash rack can be included as part of a modified culvert).
  - Qualitative weights are assigned to different solutions to ease use of this manual. The user may determine different weights that are more appropriate based on region, local practices, and availability of materials.

Five sample case studies are provided to illustrate how the user may proceed through the Selection Process under realistic scenarios. Please refer to the cases beginning on page 18.

Explanation of Selection Matrix – Factors and Weights

- **Time to Implementation** – This factor weighs the total time to receive permitting, make designs, and finish construction of an HM solution. Roads critical to emergency traffic, evacuation, or that function as the sole outlet for residents must be reopened as quickly as possible. Moreover, available funds, seasonal working conditions, acquiring permits, and other local considerations may influence the allowable time for repairs. The user must consider these variables and determine the maximum time available to restore services. Only then can they consider the HM solutions that can be implemented within that time. The HM solutions are weighted as shown to the right:

H – High	< 30 days to implement
M – Medium	30 – 90 days to implement
L – Low	> 90 days to implement

- **Feasibility Considerations** – This factor weighs the relative cost feasibility of implementing various HM solutions. Recognizing that prices may vary widely among localities, relative costs between HM solutions should generally remain constant. Factors that influence costs may include labor (force account vs. contract), overhead, cost of materials, availability, etc. Cost weights current as of the writing of this Field Book are shown to the right:

$ – Low	$ < 10,000
$$ – Medium	$10,000 – $25,000
$$$ – High	>$25,000

- **Design Considerations** – Certain mitigation solutions may inherently involve a greater degree of design complexity than others. The user must decide whether these considerations present an obstacle to selecting certain HM solutions.
  - **Engineer Required?** – The user must evaluate whether they have the staff with the skill-set(s) necessary to complete the job, or if they will have to seek outside assistance. HM solutions range from prescriptive engineering solutions, to requiring engineers to develop specific designs, to a combination of the two.
  - **Right-of-Way Constraints?** – Damage in a high-density traffic area may require traffic control to manage Right-of-Way (ROW) constraints and detours, which can substantially complicate reconstruction, impacting cost and time to implement.
  - **Permit Required?** – HM solutions may require an inspection and/or permit, which can impact the implementation timeframe.

Engineered Solution Required?

S – Standard Design

O – Original Design

C – Combination

Right-of-Way Constraints?

Y – Yes, ROW will be affected

N – No, ROW will be uneffected

Permit Required?

Y – Permit Required

N – No Permit Required

- **Environmental Considerations** – Each HM solution may affect the environment differently. It is crucial that the user research the HM solutions' impacts on the local watershed and comply with federal/local laws/codes.
  - Floodplain/Wetland Impact
  - Comprehensive or Master Plan Requirement
  - Structural Aesthetics Impact
  - ESA – Endangered Species Act
  - CWA – Clean Water Act
  - NEPA – National Environmental Policy Act
  - CBRA – Coastal Barrier Resources Act
  - NHPA – National Historic Preservation Act

Environmental Impact

Y – Yes, Determination is required

N – No, Determination is not required

D – Depends on the situation

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Selection Matrix for Insufficient Culvert Capacity

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Insufficient Culvert Capacity	Improve Culvert Entrance Efficiency	H	$	S	N	Y	N	N	N	N	N	N	N	D
	Install Emergency Spillway/High-Water Overflow Crossing	M	$$$	C	Y	Y	N	Y	N	N	D	D	N	D
	Install Low-Water Crossing	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	D
	Increase Culvert Size	L	$$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
	Install Diversion Channel to Detention Pond	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	D
	Increase Floodplain Storage Capacity with Setback Levees	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	N

Explanation of the Mitigation Solutions

Insufficient Culvert Capacity Solutions

- **Improve Culvert Entrance Efficiency** – Properly designed entrance structures may improve the hydraulic performance of the culvert. A well-rounded entrance is more efficient than a sharp-edged entrance. Entrances can be made less sharp edged by installing flared aprons or wingwalls. To be most effective, the flared aprons or wingwalls should be oriented perpendicular to the approaching stream, not the culvert. If there is an abrupt change in flow direction at the culvert entrance, an "L" shaped endwall is the more efficient choice.
- **Install Emergency Spillway/High-Water Overflow Crossing** – If alteration of an existing culvert/embankment system is not feasible, an alternative is to construct an emergency spillway, or high-water crossing to accommodate flow in excess of culvert capacity. The entrance to the emergency spillway should be designed to carry flood flows in excess of existing culvert capacity. Generally the bottom of the emergency spillway will be lower than the existing roadway. Lowering the roadway to cross the emergency spillway creates a low-water crossing to accommodate high-water overflows.
  - New culverts can be used to carry emergency spillway flow beneath the existing roadway elevation. This effectively increases the number of culverts, but requires additional work in the existing embankment.
- **Install Low-Water Crossing** – In relatively flat areas where stream flow is infrequent and brief, eliminate culverts and install the roadway

Flood Damage at Culvert Locations

A requirement to provide access to homes, businesses, and recreational facilities occasionally requires roadway crossings of low-lying areas or small streams in flood-prone or Special Flood Hazard Areas (SFHAs). Those roadways are frequently constructed on earthen fill embankments with culverts through the embankments to accommodate normal and/or flood flow. Flows exceeding the Design Flood may exceed the capacity of the culverts and result in overtopping the roadway embankment and/or increased flood depths upstream of the embankment. For convenience, the mitigation solutions are arranged in three general categories:

1. Insufficient culvert capacity
2. Obstructions that reduce culvert capacity
3. Misalignments that reduce culvert capacity

This guide suggests and offers mitigation solutions to reduce the impact of flooding at roadway crossings.

directly on the stream bed. The upstream edge of the roadway should be even with the stream bed to avoid scour. The downstream edge should be protected with rock riprap or a cutoff wall for the same purpose. Roadway flood gauges, warning signs, and/or barriers are required to prevent vehicles from driving into the low-water crossing during flood events.

- **Increase Culvert Size:** The most direct way to reduce damages caused by insufficient culvert capacity is to replace the existing culvert with a larger one. For small to mid-size culverts, this can be accomplished by installing a new, wider pipe. If increasing the pipe diameter is not feasible because of a lack of clearance between the top of the embankment and the new pipe, alternate culvert shapes may be used (e.g., arch culverts, which allow widening the culvert while keeping the height low to meet site specific requirements). In extreme cases, sufficiently increasing the culvert size may lead to construction of a box culvert.
- **Install Diversion Channel to Detention Pond:** If sufficient land is available, it may be feasible to divert a portion of the stream flow into a stormwater detention basin, releasing it back into the stream as permitted by culvert capacity when flood flows attenuate.
- **Increase Floodplain Storage Capacity with Setback Levees:** An alternative to a diversion channel and detention pond is to increase stormwater storage capacity near the culvert entrance by constructing relatively low levees along the stream bank. If properly graded, the levees can also divert stormwater upstream of the culvert embankment, thereby increasing travel distance and time to entry into the culvert.

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Selection Matrix for Obstructions That Reduce Culvert Capacity and Misalignment

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Obstructions That Reduce Culvert Capacity	Clear Source of Flood Debris/ Increase Maintenance	H	$	N/A	N	N	N	N	N	N	N	N	N	N
	Install Trash Rack or Debris Barrier	H	$	S	N	Y	Y	N	Y	N	N	N	N	D
	Install Debris Barrier Riser	H	$	S	N	Y	N	N	Y	N	N	N	N	D
	Install a Relief Culvert	M	$$	C	N	Y	Y	Y	Y	D	D	D	N	D
Misalignment	Install Flow Diverters	H	$	S	N	Y	Y	N	N	N	N	N	N	N
	Realign Culvert	M	$$	C	Y	Y	N	Y	N	N	N	N	N	D
	Install Additional Culverts	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	N
	Realign the Stream Channel	L	$$$	O	Y	Y	Y	Y	Y	D	Y	Y	N	N

Explanation of the Mitigation Solutions

Obstructions That Reduce Culvert Capacity Solutions

- **Clear Source of Flood Debris/Increase Maintenance** – Remove debris accumulation in a culvert that led to blockage.
- **Install Trash Rack or Debris Barrier** – Install an entrance debris barrier to prevent blockage of the culvert, or debris fins, designed to orient the floating debris for easy passage through the culvert. Although effective in areas that have significant debris loading in the upstream drainage, there must be adequate stream channel storage available for debris accumulation.
- **Install Debris Barrier Riser** – Allows debris to float up with the rising floodwaters without blocking flow into the culvert. Area upstream should be suitable for storing floodwaters.
- **Install a Relief Culvert** – Located at the crossing site and in the embankment above the flow line of the primary culvert, providing an alternate route for the flow if the main culvert gets plugged, and prevents sedimentation through the high-flow scouring action.

Misalignment Solutions

- **Install Flow Diverters** – Design barbs to redirect the flow away from the embankment and into the culvert.
- **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 also require relocating a culvert.
- **Install Additional Culverts** – Locate additional culverts at previous and/or new stream alignments at road crossing site to increase drainage.
- **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 subsequent damage to the culvert.

Selection Matrix for Embankment Erosion/Scour

	Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Embankment Erosion/Scour													
Extend Culvert Discharge	H	$	S	N	D	N	N	N	D	D	D	N	D
Riprap Slope Protection	H	$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
Construct a Wingwall and Endwall	H	$$$	S	N	Y	Y	N	Y	D	D	D	N	D
Install Energy Dissipation Measures	M	$$	C	N	Y	Y	N	Y	D	D	D	N	N
Enlarge Stream Channel	M	$$	S	Y	Y	Y	Y	Y	D	D	D	N	N
Toe Stabilization Using Gabions	M	$$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
Install Check Dams	L	$$	C	N	Y	Y	Y	Y	D	D	D	N	N
Bio-Engineered Slope Protection	L	$$	C	Y	Y	Y	Y	Y	D	D	D	N	N

Explanation of the Mitigation Solutions

Embankment Erosion/Scour

- **Extend Culvert Discharge** – For embankments that are only slightly susceptible to erosion or scour, and where the design discharge velocity of the culvert is relatively low (e.g., less than 2 feet per second), extending the discharge end of the culvert beyond the toe of the embankment may be enough protection.
- **Riprap Slope Protection** – Stream bank erosion can be reduced by protecting the embankment with a layer of riprap – large stones, rocks, or manufactured materials that are heavy enough to resist erosion and provide a dispersion of hydraulic energy when impacted by the stream flow. The effectiveness of this method can be enhanced by installing the riprap over a layer of geotextile erosion fabric.
- **Construct a Wingwall and Endwall** – Where discharge velocity is relatively low and erosion concern is limited to undermining the culvert, a straight or U-shaped endwall may be enough. As flow velocity increases, scour of the embankment may result, particularly if the culvert outlet is much narrower than the outlet channel. In those cases, flared wingwalls at the outlet will be more effective in mitigating embankment erosion and scour.
- **Install Energy Dissipation Measures** – Erosion and scour at the discharge of culverts can be mitigated by the energy dissipation. Three general types of energy dissipation measures are:
  - Aprons at culvert discharges to reduce turbulent flow that can scour the toe of the embankment or undermine the culvert. Aprons can be made of non-corrosive metal or reinforced concrete.
  - Baffle structures can be used to relocate the zone of high velocity discharge downstream to a location that does not pose a risk to the embankment.
  - Increase tailwater depth by excavating a discharge pool or stilling basin to control turbulent flow at the culvert discharge.
- **Enlarge Stream Channel** – The capacity of a stream is a function of the cross-sectional area and flow velocity. Erosion and scour are a function of stream velocity. Thus, enlarging the stream channel will decrease the flow velocity and reduce erosion and scour.

- **Toe Stabilization Using Gabions** – Gabions are wire mesh baskets filled with stone and placed along the toe of stream embankments to resist toe erosion, which can cause slope failure. Gabions typically increase slope stability of the stream embankment by increasing the weight of materials resisting slope failure.
- **Install Check Dams** – In small streams and man-made drainage channels, check dams can be used to retard flow velocity, trap a portion of the bed load, and allow settling of a portion of the suspended load. Each of these impacts can reduce potential downstream erosion.
- **Bio-Engineered Slope Protection** – Carefully selected grasses, shrubs, and other ground cover can be effective in reducing stream bank erosion. Selection and design of bio-engineered embankment protection should consider steepness of embankment, expected flow rates, and growing season of the vegetation selected.

Selection Matrix for Roadway Surface and Shoulder Drainage

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Roadway Surface and Shoulder Damage	Construct Shoulder Protection	H	$	S	Y	Y	N	N	Y	N	D	N	N	N
	Improve Shoulder Drainage	H	$	C	Y	Y	N	N	Y	N	D	N	N	N
	Improve Subgrade Using Geotextile Drainage Systems	M	$$	O	Y	Y	Y	N	N	D	D	D	Y	N
	Increase Ditch Capacity	M	$$	S	Y	Y	Y	Y	Y	D	D	D	N	N
	Increase Roadway Elevation	L	$$$	O	Y	Y	N	Y	Y	N	D	N	N	N

Explanation of the Mitigation Solutions

Roadway Surface and Shoulder Damage

- **Construct Shoulder Protection** – Protection of the structural integrity of roadway shoulders can reduce the amount of water that can enter the roadway subgrade, thereby reducing damage to the roadway. Structural protection can be added to dirt shoulders by adding a layer of clean gravel or crushed stone. A layer of macadam can be added to reduce permeability of the shoulder and to reduce material loss due to traffic on the shoulder.
- **Improve Shoulder Drainage** – Install shoulder subsurface drains. Typical shoulder subsurface drains consist of a perforated drain pipe placed near the bottom of a gravel-filled, geotextile-lined ditch. The pipes are directed to catch basins at designed collection and discharge locations.
- **Improve Subgrade Using Geotextile Drainage Systems** – Roadway strength and durability can be significantly improved using geotextile drainage blankets between the pavement section and subbase. The geotextile drainage blankets can be used with free draining base course material or natural subgrade soils. The drainage blankets are especially effective in removing water from the pavement section before it substantially weakens the subgrade support.
- **Increase Ditch Capacity** – Increasing the capacity of shoulder ditches will increase drainage capacity and reduce roadway flooding. An annual maintenance program will reduce future damages.
- **Increase Roadway Elevation** – In relatively small areas of localized flooding, it may be feasible to elevate frequently flooded sections of roadway above the base flood elevation. In most cases, elevating the roadway will require removal of the existing pavement, compaction, and potentially improving the exposed subgrade, as well as constructing a new pavement section.

Surface Damage to Roadways and Road Shoulders

Roadways experience millions of dollars of damage annually due to flooding. Damages include pavement and shoulder failure caused by loss of strength and durability in the roadway structure, including the subgrade, and erosion along roadway shoulders. Mitigation solutions to reduce roadway damages caused by flooding generally fall into the following groupings:

1. Elevating roadway
2. Improving drainage of the roadway structure
3. Improving shoulder drainage

Case Studies

Introduction

Five sample case studies have been included to illustrate how the HMFB can be applied by practitioners to a variety of realistic situations. By reviewing each case, the user can analyze the considerations, the assumptions, and the line of reasoning employed by the decision-maker in each narrative. In addition, each case uses the HMFB methodology to evaluate a different damaged infrastructure, with different solution type(s), relating to different considerations. Selected solutions in both the Project Identification Diagram and Selection Matrix are highlighted in green. Please review each case study and consider how the HMFB methodology can be broadly employed.

1. County Roads Endure After Mitigation Solution is Implemented

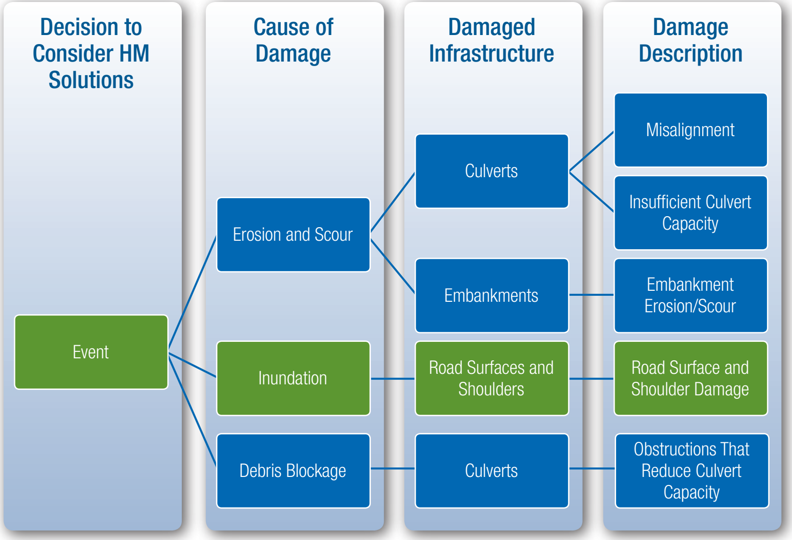
Background

A recent hurricane dropped nearly 20 inches of rain on the Florida Panhandle, making many of the sandy clay, unpaved county roads impassable because of very soft, slippery road surfaces and major washouts, especially in low-lying areas. Although the roadways lack drainage ditches, they are elevated on fill to be about 12 inches above surrounding grade. Although the roadways are crowned in the center to provide surface drainage to both sides, in heavy rains in even moderately windy conditions, run-off forms streams across the roads in the direction of the wind, creating small erosion channels. In severe storms, the erosion channels increase to become significant washouts in some areas. Further, as the erosion channels increase in size, the moisture content of the subgrade soils increases, resulting in a loss of shear strength and an inability to support traffic.

The area and depth of many of the washouts prevented access to neighborhoods requesting emergency assistance during and for several days after the storm. County officials recognized the need to not only reconstruct the roads to restore access to isolated neighborhoods, but also to include mitigation techniques that would make the roads more hazard resilient to future storm events.

Selection

County officials decided they preferred a mitigation solution that increased the roadways' damage resistance to localized flooding by reinforcing the subgrade and by improving subgrade drainage. The County Department of Roads Superintendent consulted the FEMA HMFB to review and select feasible alternative solutions. Beginning with the Project Identification Diagram, the County quickly identified the problem as "Roadway Surface and Shoulder Damage" since the roadway washout was not the result of stream flooding, but inundation (see 1.1). As time was of the essence to restore the roadways to full service, the selection process started with reviewing the Selection Matrix (see 1.2) for relative project completion times for the listed alternatives. Although construction of shoulder protection was shown as the quickest alternative, less than 30 days to complete, it was decided that shoulder protection would not provide the level of mitigation needed. The "mid-range" project time of 30 to 90 days for "Improve Subgrade Using Geotextile Drainage Systems" was deemed to be acceptable and to provide the mitigation benefits needed. The relatively long project time (over 90 days) and high project cost made increasing the roadway elevation unacceptable.



1.1

The County Department of Roads Superintendent consulted several sources, including Florida Department of Transportation design standards, and *Design Manual for Roadway Geocomposite Underdrain Systems* (http://www.tenaxus.com/roads/designinformation/designmanual/DesignManual-Roadway-%20Drain.pdf). The design consisted of targeting and repairing those specific road sections highly prone to washout by reconstructing a reinforced patch with improved subgrade drainage. The patch design consisted of grading the washout area to a depth of 2 feet below the original roadway, compacting the exposed soils, and installing a geotextile drainage blanket. The drainage blanket was covered by 12 inches of crushed stone coarse aggregate, then by a biaxial geomembrane reinforcing grid, and finally by 8 inches of well-compacted, low plasticity sandy clay. The sandy clay was covered with 4 inches of base course aggregate compacted into the clay to add strength to the roadway surface (see 1.3).

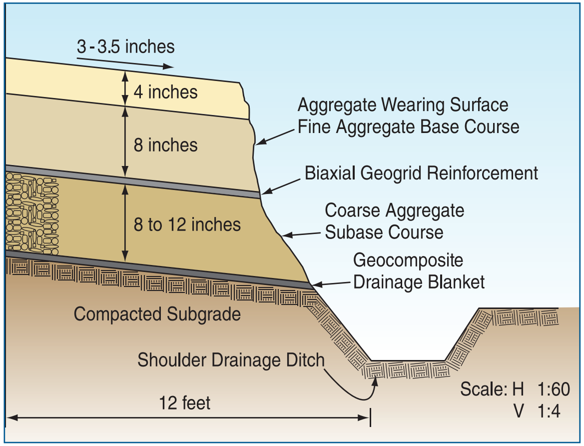
Although design and construction of the selected mitigation alternative was expected to be acceptable, the County needed to complete the review to determine if other variables presented impediments to the project. Information in the "Environmental Considerations" of the HMFB gave the County a reliable source for identifying specific environmental issues related to the chosen alternative. They noted that, because the roadway subgrade drainage system might have a small impact on the local floodplain, the mitigation plan should be reviewed by the County Floodplain Manager before implementation.

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Roadway Surface and Shoulder Damage	Construct Shoulder Protection	H	$	S	Y	Y	N	N	Y	N	D	N	N	N
	Improve Shoulder Drainage	H	$	C	Y	Y	N	N	Y	N	D	N	N	N
	Improve Subgrade Using Geotextile Drainage Systems	M	$$	O	Y	Y	Y	N	N	D	D	D	Y	N
	Increase Ditch Capacity	M	$$	S	Y	Y	Y	Y	Y	D	D	D	N	N
	Increase Roadway Elevation	L	$$$	O	Y	Y	N	Y	Y	N	D	N	N	N

1.2

Implemented Mitigation Solution

The County successfully used reconstruction of the roadways using force account labor from its roads department. The project took 75 days and used an original mitigation design for improved subgrade drainage and a stabilized road surface (see 1.4). Since completion of the mitigated roadways, sections have experienced several hurricanes and tropical storms with only very minor damage, none of which closed the roads to residents or emergency services.



1.3

Geosynthetic Systems

1.4

2. Highway Repairs are Designed to Avoid Damage

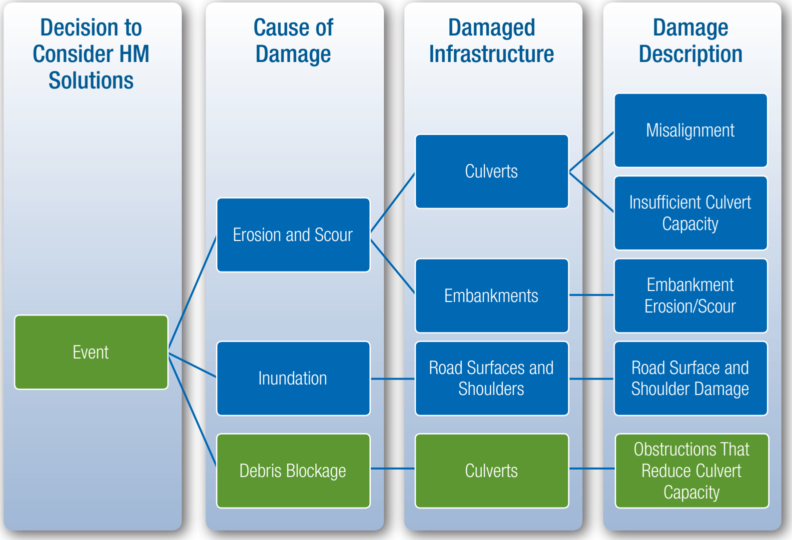
Background

Anytown, IA – Severe summer storms with record-breaking heavy rains caused flooding that washed out roads, eroded shoulders, and compromised ditches and culverts. One segment of County Road 16 received damage due to culvert blockage. Despite routine debris clearing from the Public Works Department, floodwaters lodged vegetative debris at the culvert inlet. The impeded water flowed over the embankment, causing water to run over the road and severely scour the road surface. Prior hydrologic and hydraulic studies indicated that the culvert size should have been sufficient to convey the flood flow. Had there been no blockage, the water would have flowed freely, causing only minor erosion and scour around the inlet and surrounding embankments.

The Director of Public Works wanted the repair project to go beyond restoration to reduce or avoid future damages. He thought, "A little extra money spent now may save untold expenditure of funds later." With this perspective in mind, the Public Works Director wanted to know his options.

Selection

Using the HMFB, he referred to the Project Identification Diagram to diagnose the damage (see 2.1). Beginning at "Event," the Director determined that vegetative debris lodging in the culvert would fall under the category "Debris Blockage" as a cause of damage. Debris blockage in the culvert had led to *plugging* – debris deposition across the culvert entrance that also led to increased water surface elevations upstream. With the root problem now identified, the Director cross-referenced "Obstructions That Reduce Culvert Capacity" with the Selection Matrix to find possible mitigation solutions.



2.1

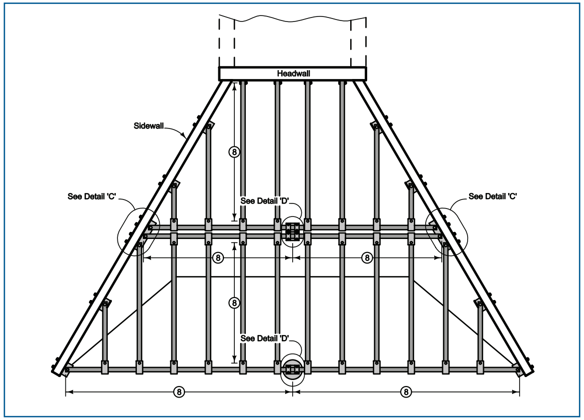
County Road 16, albeit small, serves as a route of commerce and commuting for the area. It is essential that the road be reopened as quickly as possible following a flood event. Additionally, the Director knew that Anytown had limited resources, both in money and personnel. Along with repairs to the roadway, any mitigation enhancements to the culvert would have to be economical.

Referencing the Selection Matrix (see 2.2), the Director began by evaluating his choices under the "Speed to Implementation" column, the most important factor due to how vital the road is to the local community. He then considered the mitigation solutions with a "High" weighting under the "Speed to Implementation" column. The "High" ranking signifies the most rapid completion of a given mitigation solution for "Obstructions That Reduce Culvert Capacity."

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Obstructions That Reduce Culvert Capacity	Clear Source of Flood Debris/ Increase Maintenance	H	$	N/A	N	N	N	N	N	N	N	N	N	N
	Install Trash Rack or Debris Barrier	H	$	S	N	Y	Y	N	Y	N	N	N	N	N
	Install Debris Barrier Riser	H	$	S	N	Y	N	N	Y	N	N	N	N	N
	Install a Relief Culvert	M	$$	C	N	Y	Y	Y	Y	D	D	D	N	N

2.2

By selecting the "High" weighting, he reduced his choices for mitigation solutions for "Obstructions that Reduce Culvert Capacity" from four choices to three. Those choices with "High" speed to implementation ranking are "Clear Source of Flood Debris/Increase Maintenance," "Install Trash Rack or Debris Barrier," and "Install Debris Barrier Riser." Given the remaining solutions were all rated "$", or economical, he then considered the design requirements and environmental constraints of each and chose "Install Trash Rack or Debris Barrier" as the best possible solution. Given Anytown's steady maintenance of debris clearing at the culvert site and around the area upstream, "Clear Source of Flood Debris/Increase Maintenance" was not considered since it was already being implemented – leaving only "Install Trash Rack or Debris Barrier" and "Install Debris Barrier Riser" as the remaining solutions.



2.3

Iowa Department of Transportation

Implemented Mitigation Solution

After the Director selected the "Install Trash Rack or Debris Barrier" as a mitigation measure for County Road 16, he referred the project to the town's road and bridge department, who had prior experience implementing trash racks on other culverts around town. Using prior designs (referenced from the Iowa Department of Transportation – Office of Design's *Design Manual Chapter 8 Safety Design 8B-4*, pg. 3 [http://www.iowadot.gov/design/dmanual/08b-04.pdf]), the road crews began to construct the trash rack (see 2.3 and 2.4).

2.4

Haala Industries, Inc.

3. Saving Our Roads: Larger Culverts Help

Background

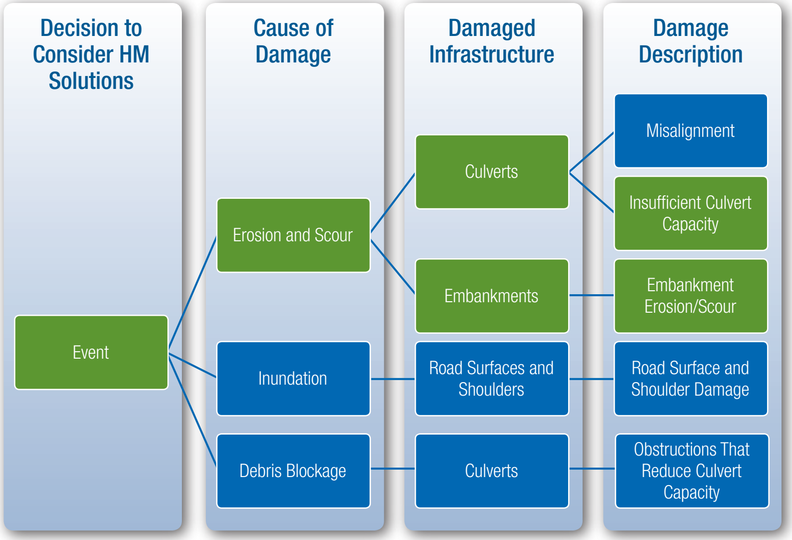
Central Arkansas – In March 2008, levees along rivers in northern and central Arkansas were straining to hold back floodwaters that were cresting at levels not seen in more than a quarter-century. Subsequent flooding particularly damaged County Road 357, a low-trafficked road used only by an estimated 50 to 70 vehicles daily to transport farm equipment. Flooding at two sites resulted in the washouts of a 36-inch diameter x 32-foot long corrugated metal pipe (CMP) culvert and another 48-inch diameter x 45-foot long CMP culvert. The primary cause of damage was erosion to the culvert entrances, the culvert outlets, and the roadway embankment. In addition, culvert misalignment occurred (see 3.1).

Butler County Engineer's Office, Butler Co., OH

3.1

Selection

County officials wanted to compare the relative characteristics of standard mitigation solutions and decided to use the HMFB. They referred to the Project Identification Diagram to confirm the damage. They determined that the erosion to the existing culverts would fall under the categories "Insufficient Culvert Capacity" as the cause of damage to the culvert inlet and outlets, and "Embankment Erosion/Scour" for the embankment erosion (see 3.2). Consequently, the project needed two mitigation solutions to address the chronic culvert washout problem. With the sources of the problem now confirmed, officials reviewed the mitigation solutions in the Selection Matrix listed under each category to address both hazards (see 3.3).



3.2

Beginning with solutions relating to “Insufficient Culvert Capacity,” the officials evaluated the choices under the “Speed to Implementation” column. Due to the low volume of traffic of the road, the County officials considered mitigation solutions with a “Low” weighting under the “Speed to Implementation” column. By selecting the “Low” weight, all solutions in that category would be considered. Moving to the “Feasibility Considerations” column, the County officials determined that County funds would be able to finance solutions within the “$$$” range. With ample time to implement the solution, ready funds available, and near identical design and environmental considerations among the remaining solutions, the County was only able to focus on which solution would be the most effective. Therefore, they performed a final analysis of the six mitigation solutions listed under “Insufficient Culvert Capacity.” The analysis was based primarily on determining a long-term answer for each solution because of the continuing frequency of flood events. The final choice was “Increase Culvert Size” at the respective damage sites.

However, when the officials evaluated solutions for the “Embankment Erosion/Scour,” they allowed for a “Med” time to Implement. They assumed that an embankment erosion solution would be implemented after a new larger culvert had been put in place. Given the time to install the new culvert, the County would have less time available to improve the embankments. The available funding for the “Embankment Erosion/Scour” solution also fell in the “$$$” range, affording them the broadest range of solutions. Lastly, they reviewed the “Design” and “Environmental” considerations and, like the “Insufficient Culvert Capacity” solutions, found that they were very similar. “Toe Stabilization Using Gabions” was selected to prevent erosion by increasing slope stability of the stream embankment and to provide a dispersion of hydraulic energy when impacted by the stream flow (see 3.4).

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Insufficient Culvert Capacity	Improve Culvert Entrance Efficiency	H	$	S	N	Y	N	N	N	N	N	N	N	D
	Install Emergency Spillway/High-Water Overflow Crossing	M	$$$	C	Y	Y	N	Y	N	N	D	D	N	D
	Install Low-Water Crossing	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	D
	Increase Culvert Size	L	$$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
	Install Diversion Channel to Detention Pond	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	D
	Increase Floodplain Storage Capacity with Setback Levees	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	N

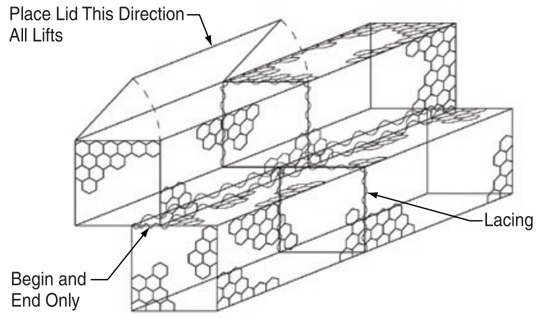
3.3

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Embankment Erosion/Scour	Extend Culvert Discharge	H	$	S	N	D	N	N	N	D	D	D	N	N
	Riprap Slope Protection	H	$$	C	Y	Y	Y	Y	Y	D	D	D	N	N
	Construct a Wingwall and Endwall	H	$$$	S	N	Y	Y	N	Y	D	D	D	N	N
	Install Energy Dissipation Measures	M	$$	C	N	Y	Y	N	Y	D	D	D	N	N
	Enlarge Stream Channel	M	$$	S	Y	Y	Y	Y	Y	D	D	D	N	N
	Toe Stabilization Using Gabions	M	$$$	C	Y	Y	Y	Y	Y	D	D	D	N	N
	Install Check Dams	L	$$	C	N	Y	Y	Y	Y	D	D	D	N	N
	Bio-Engineered Slope Protection	L	$$	C	Y	Y	Y	Y	Y	D	D	D	N	N

3.3 Continued

Implemented Mitigation Solution

The County undertook the project using an emergency management assistance contract with a neighboring county. The contract provides mutual aid between governmental jurisdictions following a disaster. Since the damaged county road and culverts were within the city boundaries, a cooperative project was carried out that used County force account labor and equipment with city design and engineering supervision services. Culvert design and placement, as well as gabion design and placement, followed guidelines and specifications set forth in the Arkansas State Highway and Transportation Department's (ASHTD's) *Drainage Manual* (http://www.arkansashighways.com/foi_list.aspx). ASHTD's *Roadway Design Plan Development Guidelines* (http://www.arkansashighways.com/foi_list.aspx) were also used to implement the project.



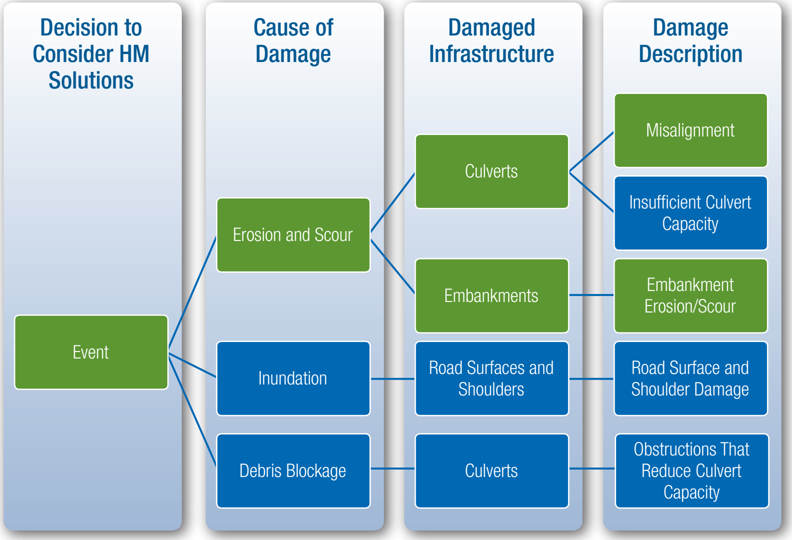
Lacing: Basket to Basket

3.4

4. Pond Culvert Upgrade

Background

Anytown, ME – During periodic rain events, West Street, a major road in Anytown, is often closed due to flooding. The area of West Street, near the pond outflow culvert, overtops during these events, causing washout and structural damage to the road bed. In addition to the loss of road access, the washout creates a 7-mile detour for public safety vehicles and the potential for hazards to the health and safety of the residents. Although overtopping can often be attributed to a culvert with insufficient capacity, the stream leading up to the culvert has sharp curves, which contributes to scour at the upstream culvert opening. A further site inspection performed by the City's Public Works Department revealed that the location of the culvert, in relation to the stream's geometry, increased the likelihood of undercutting and scour.



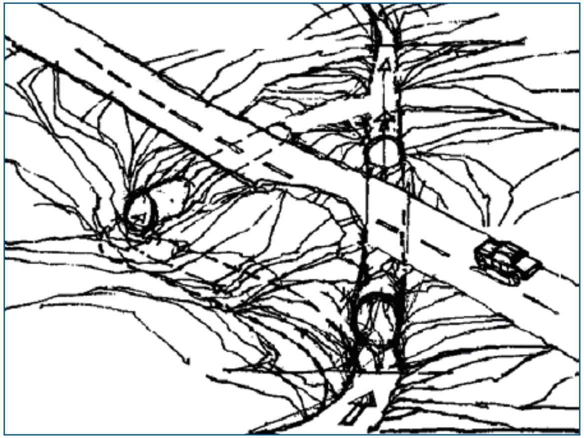
4.1

Selection

After inspecting the damage to West Street from the outflow culvert and considering the disruption in road access, Anytown's Director of Public Works decided that the City should investigate repair alternatives to help mitigate further damages. Referencing the HMFB, the Director used the Project Identification Diagram to quickly diagnose the problem (see 4.1). Selecting "Culverts" as the damaged infrastructure, and "Misalignment" as the underlying cause of damage (see 4.2), the Director then viewed the Selection Matrix (see 4.3) to determine the appropriate alternatives.

Although there was pressure from the public to reopen traffic on West Street, there was also a clear mandate to find a solution that would prevent future damage. So when the Director evaluated “Speed to Implementation,” he was able to select the “mid-range” choice, which estimates 30 to 90 days timeframe for implementation. Mitigation solutions that could be completed within that timeframe included “Realign Culvert” and “Install Flow Diverters.” Although “Installing Flow Diverters” would be more cost-effective, the Director knew that Anytown was willing to spend a little more to get a better solution (thereby choosing the “$$” Cost Selection).

In addition, the Director wanted to consider other mitigation solutions to fortify against embankment erosion after the culvert was reset. Referring back to the HMFB under “Embankment Erosion/Scour,” the Director reviewed the alternatives (see 4.1). Given the reduced timeframe (after the culvert realignment was complete), the Director sought out solutions that could be implemented quickly and were moderately priced. In the end, the City decided that during the pond culvert upgrade, they would have the contractor reset the culvert angle to permit direct outflow downstream and install riprap on the stream banks and around the culvert opening to reduce erosion (see 4.4).



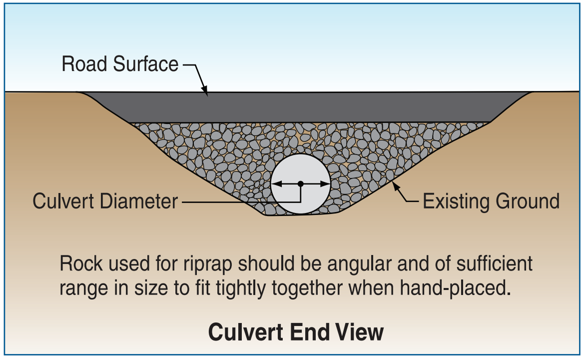
4.2

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Misalignment	Install Flow Diverters	H	$	S	N	Y	Y	N	N	N	N	N	N	N
	Realign Culvert	M	$$	C	Y	Y	N	Y	N	N	N	N	N	D
	Install Additional Culverts	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	N
	Realign the Stream Channel	L	$$$	O	Y	Y	Y	Y	Y	D	Y	Y	N	N
Embankment Erosion/Scour	Extend Culvert Discharge	H	$	S	N	D	N	N	N	D	D	D	N	D
	Riprap Slope Protection	H	$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
	Construct a Wingwall and Endwall	H	$$$	S	N	Y	Y	N	Y	D	D	D	N	D
	Install Energy Dissipation Measures	M	$$	C	N	Y	Y	N	Y	D	D	D	N	N
	Enlarge Stream Channel	M	$$	S	Y	Y	Y	Y	Y	D	D	D	N	N
	Toe Stabilization Using Gabions	M	$$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
	Install Check Dams	L	$$	C	N	Y	Y	Y	Y	D	D	D	N	N
	Bio-Engineered Slope Protection	L	$$	C	Y	Y	Y	Y	Y	D	D	D	N	N

4.3

Implemented Mitigation Solution

To implement the project, the City's Public Works Department hired a local contractor to provide labor and equipment and had the City Engineer's staff supervise the project. To design the project, department engineers used culvert placement information from Maine Erosion and Sedimentation Control BMPs[4] (http://www.state.me.us/dep/blwg/docstand/escbmps/index.htm).



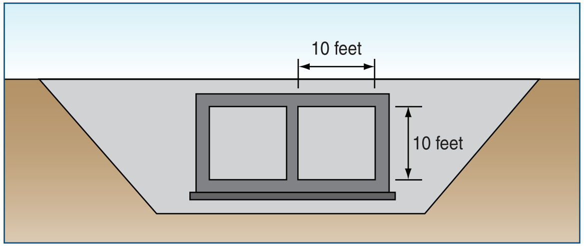
4.4

4 BMPs = Best Management Practices

5. Mitigating County Road 55

Background

Central Arkansas – Continued heavy rainfalls often caused washouts on County Road 55 in the community. Although County Road 55 has ditches and is crowned 10 inches to provide drainage, soils underlying the road are extremely susceptible to erosion and collapse when they become saturated. Severe spring flooding caused a 32-foot washout on County Road 55. The ends on two 48-inch diameter x 30-foot long corrugated metal culverts were bent and undermined at one location. A hydraulic study conducted by the County Floodplain Manager suggested that larger culverts were needed to convey the high volume of water from the floods. Mitigation measures were developed that recommended replacement of the two 48-inch diameter x 30-foot long culverts with two 10-foot wide x 10-foot high x 40-foot long box culverts (see 5.1). In addition, the County Director of Public Works decided to consider enforcing the culvert embankments as an added mitigation solution to prevent culvert misalignment and embankment erosion.



5.1

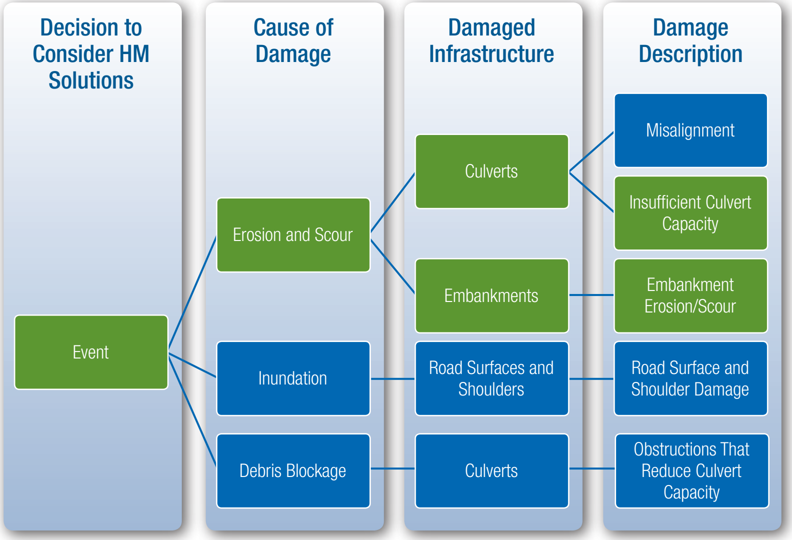
Selection

Although two mitigation solutions were recommended as part of the hydraulic study, County officials decided to verify those suggested solutions by using the HMFB. Using information from the hydraulic study, they determined that the existing culvert would fall under the category "Insufficient Culvert Capacity" as the cause of damage (see 5.2). With the root problem now confirmed, officials reviewed the mitigation solutions in the Selection Matrix under that category (see 5.3).

They began by evaluating the choices under the "Speed to Implementation" column. Although one of the key concerns was the criticality of the road to the local community, the officials were willing to accept a longer implementation time if it meant choosing the best option. They started to consider the mitigation solutions with a "High" or "Medium" weighting under the "Speed to Implementation" column, signifying the most rapid completion of a given mitigation solution for "Insufficient Culvert Capacity." However, the only mitigation solutions with those rankings, "Improve Culvert Entrance Efficiency" and "Install Emergency Spillway/High-Water

Overflow Crossing," were deemed as insufficient. The first solution was insubstantial given the high volume of floodwaters and the second solution did not maintain roadway access. So officials decided that a slower implementation time was acceptable if it broadened their options to include more robust solutions. By accepting a "Low" "Speed to Implementation," all mitigation solutions remained available.

Continuing on, County officials considered the "Cost" weighting, of which all five of the remaining mitigation solutions had a "$$$" ranking. Accepting the high price tag to increase the culvert capacity, the County officials then considered the design requirements and environmental constraints for each mitigation solution and determined that each one was relatively equal in that they would all require an engineer (either as an original design, or as a combination of an original design with a standard design).



5.2

They performed a final analysis of the remaining solutions based on the appropriateness and long-term answer for each solution. They chose the solution that most closely mirrored the two solutions suggested in the hydrologic and hydraulic study. The final choice was "Increase Culvert Capacity."

In addition, the County officials decided to strengthen the embankment from erosion and scour. Seeking a solution that could be implemented quickly ("H") and fairly economically ("$", "$$"), the officials selected "Riprap Slope Protection."

Implemented Mitigation Solution

County officials conferred with two engineers from the Arkansas State Highway and Department of Transportation (ASHDT) to determine design specifications for the project. Once a "modified standard" design was established, the County provided force account labor to complete the project while an ASHDT engineer supervised (see 5.4).

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Insufficient Culvert Capacity	Improve Culvert Entrance Efficiency	H	$	S	N	Y	N	N	N	N	N	N	N	D
	Install Emergency Spillway/High-Water Overflow Crossing	M	$$$	C	Y	Y	N	Y	N	N	D	D	N	D
	Install Low-Water Crossing	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	D
	Increase Culvert Size	**L**	**$$$**	**C**	**Y**	**Y**	**Y**	**Y**	**Y**	**D**	**D**	**D**	**N**	**D**
	Install Diversion Channel to Detention Pond	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	D
	Increase Floodplain Storage Capacity with Setback Levees	L	$$$	O	Y	Y	Y	Y	Y	D	D	D	N	N

5.3

		Time to Implementation	Feasibility Considerations	Design Considerations			Environmental Considerations							
	Mitigation Solutions	Speed to Implementation (source of funding, funding cycle, and seasonal effects)	Cost (material type, labor, overhead, and availability)	Engineer Required? (standard design, original, or combination)	Right-of-Way Constraints?	Permit Required?	Floodplain/ Wetland Impact	Comprehensive or Master Plan Requirement	Structural Aesthetics Impact	ESA	CWA	NEPA	CBRA	NHPA
Embankment Erosion/Scour	Extend Culvert Discharge	H	$	S	N	D	N	N	N	D	D	D	N	D
	Riprap Slope Protection	H	$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
	Construct a Wingwall and Endwall	H	$$$	S	N	Y	Y	N	Y	D	D	D	N	D
	Install Energy Dissipation Measures	M	$$	C	N	Y	Y	N	Y	D	D	D	N	N
	Enlarge Stream Channel	M	$$	S	Y	Y	Y	Y	Y	D	D	D	N	N
	Toe Stabilization Using Gabions	M	$$$	C	Y	Y	Y	Y	Y	D	D	D	N	D
	Install Check Dams	L	$$	C	N	Y	Y	Y	Y	D	D	D	N	N
	Bio-Engineered Slope Protection	L	$$	C	Y	Y	Y	Y	Y	D	D	D	N	N

5.3 Continued

5.4

General Design Guidance

There are a number of regulatory authorities and industries dealing with public infrastructure impacted by flooding and erosion, but it is the transportation industry that generally experiences the widest range of impacts from those hazards. Over the years, the transportation industry has been a leader in research and development of procedures and design standards for surface and subsurface drainage systems, erosion and scour mitigation solutions, and embankment stabilization methods. The Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO) are leaders in conducting and sponsoring research in the sciences and engineering fields that develop methods and materials to mitigate the adverse effects of water on national transportation infrastructure.

Although federal funding supports much of the road construction in the U.S., the roads are owned and managed by states and localities. In many areas, state and local roads are not part of the national highway system and are constructed and maintained without benefit of federal funds. As a result, establishing roadway design standards, including drainage, erosion, and scour mitigation, and embankment protection is the responsibility of state and local governments. That responsibility is frequently fulfilled by adapting national research findings to local conditions and by using new and improved design approaches and standards that are appropriate for local conditions.

General Design Guidance – Examples

Examples of federal (FHWA), State Departments of Transportation, and industry organizations (AASHTO) manuals are provided below. They include general design standards, drawings, and methodologies for developing custom applications for culverts and embankments. These links are not intended to be prescriptive of the designs endorsed by the HMFB. Instead they serve as example resources on where to locate design/detail information.

	Mitigation Solutions	Designs/Details Source, Title, Website Links
Insufficient Culvert Capacity	Improve Culvert Entrance Efficiency	Federal Highway Administration, *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5*, FHWA-NHI-01-020, Washington, DC, 2001, revised 2005 (http://isddc.dot.gov/OLPFiles/FHWA/012545.pdf)
	Install Emergency Spillway/ High-Water Overflow Crossing	Federal Highway Administration, *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5*, FHWA-NHI-01-020, Washington, DC, 2001, revised 2005 (http://isddc.dot.gov/OLPFiles/FHWA/012545.pdf)
	Install Low-Water Crossing	U.S. Department of Agriculture, Forestry Service, *Low-Water Crossings: Geomorphic, Biological and Engineering Design Considerations* (http://www.fs.fed.us/eng/php/library_card.php?p_num=0625%201808P)
	Increase Culvert Size	Iowa Department of Transportation (http://www.iowadot.gov/design/stdplne_rf.htm)
	Install Diversion Channel to Detention Pond	Requires detailed hydrologic and hydraulic analyses
	Increase Floodplain Storage Capacity with Setback Levees	Requires detailed hydrologic and hydraulic analyses
Obstructions That Reduce Culvert Capacity	Clear Source of Flood Debris/ Increase Maintenance	Federal Highway Administration, *Debris-Control Structures, Hydraulic Engineering Circular No. 9*, FHWA-EPD-86-106, Washington, DC, 1971 (http://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm?archived=true)
	Install Trash Rack or Debris Barrier	Federal Highway Administration, *Debris-Control Structures, Hydraulic Engineering Circular No. 9*, FHWA-EPD-86-106, Washington, DC, 1971 (http://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm?archived=true)
	Install Debris Barrier Riser	Federal Highway Administration, *Debris-Control Structures, Hydraulic Engineering Circular No. 9*, FHWA-EPD-86-106, Washington, DC, 1971 (http://www.fhwa.dot.gov/engineering/hydraulics/library_listing.cfm?archived=true)
	Install a Relief Culvert	Iowa Department of Transportation (http://www.iowadot.gov/design/stdplne_rf.htm)
Misalignment	Install Flow Diverters	Mississippi State University (http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/streambarbs.pdf)
	Realign Culvert	Federal Highway Administration, *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5*, FHWA-NHI-01-020, Washington, DC, 2001, revised 2005 (http://isddc.dot.gov/OLPFiles/FHWA/012545.pdf)
	Install Additional Culverts	Requires detailed hydrologic and hydraulic analyses
	Realign the Stream Channel	Requires detailed hydrologic and hydraulic analyses

	Mitigation Solutions	Designs/Details Source, Title, Website Links
Embankment Erosion/Scour	Extend Culvert Discharge	Iowa Department of Transportation, *Standard Road Plans – RF Series* (http://www.iowadot.gov/design/stdplne_rf.htm)
	Riprap Slope Protection	Federal Highway Administration, *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5*, FHWA-NHI-01-020, Washington, DC, 2001, revised 2005 (http://isddc.dot.gov/OLPFiles/FHWA/012545.pdf)
		Federal Highway Administration, *Geosynthetic Design and Construction Guidelines*, FHWA-HI-95-038, 1995, revised 1998 (http://www.fhwa.dot.gov/engineering/geotech/library_sub.cfm?keyword=020)
		South Carolina Department of Transportation, *Standard Drawings* (http://www.scdot.org/doing/sd_book.shtml)
	Construct a Wingwall and Endwall	Nevada Department of Transportation, *2010 Standard Plans Index* (http://www.nevadadot.com/business/contractor/standards/index/)
		Tennessee Department of Transportation (http://www.tdot.state.tn.us/Chief_Engineer/engr_library/structures/stdboxculvertdrawings.htm)
	Install Energy Dissipation Measures	Federal Highway Administration (http://www.fhwa.dot.gov/engineering/hydraulics/pubs/06086/hec14ch01.cfm)
		South Carolina Department of Transportation (http://www.scdot.org/doing/sd_book.shtml)
	Enlarge Stream Channel	Requires detailed hydrologic and hydraulic analyses
	Toe Stabilization Using Gabions	Federal Highway Administration (http://www.fhwa.dot.gov/engineering/hydraulics/pubs/05114/hec1507.cfm)
		Nevada Department of Transportation, *2010 Standard Plans Index* (http://www.nevadadot.com/business/contractor/standards/index/)
	Install Check Dams	Federal Highway Administration (http://www.fhwa.dot.gov/environment/fish5.htm)
		State of Washington Department of Transportation (http://www.wsdot.wa.gov/publications/fulltext/Standards/english/PDF/i50.10-00_e.pdf)
	Bio-Engineered Slope Protection	Iowa Department of Transportation (http://www.iowadot.gov/design/stdplne_ec.htm)
Roadway Surface and Shoulder Damage	Construct Shoulder Protection	Iowa Department of Transportation (http://www.iowadot.gov/design/tnt/PDFsandWebFiles/IndividualPDFs/e7153.PDF)
	Improve Shoulder Drainage	South Carolina Department of Transportation (http://www.scdot.org/doing/sd_book.shtml)
	Improve Subgrade Using Geotextile Drainage Systems	Iowa Department of Transportation (http://www.iowadot.gov/operationsresearch/reports/reports_pdf/hr_and_tr/reports/TR-525%20Final%20Report.pdf)
	Increase Ditch Capacity	Iowa Department of Transportation (http://www.iowadot.gov/design/SRP/IndividualStandards/erf19c.pdf)
	Increase Roadway Elevation	Iowa Department of Transportation (http://www.iowadot.gov/design/stdplne_rl.htm)

General Design Guidance – References

Examples of state and local websites containing schematic and/or construction drawings for the mitigation measures outlined in this document.

- Federal Highways Department of Transportation Master Site to All State Roadway Design Manuals (http://www.fhwa.dot.gov/programadmin/statemanuals.cfm), (http://flh.fhwa.dot.gov/resources/pse/standard/state.htm)
- State of New Jersey Department of Transportation Design Manual, Standard Roadway Construction Details, Aug. 2006 (http://www.nj.us/transportation/eng/docsuments/drainage/drainage.shtm)
- South Carolina Department of Transportation (http://www.scdot.org/doing/sd_book.shtml)
- Nevada Department of Transportation (http://www.nevadadot.com/business/contractor/standards/index/)
- Iowa Department of Transportation (http://www.iowadot.gov/bridge/v8eculstd.htm)
- Idaho Department of Transportation (http://www.itd.idaho.gov/design/StandardDrawings.htm)
- Hamilton County, Ohio Department of Public Works (http://www.hamiltoncountyohio.gov/pubworks/std_drawings.asp)
- Metropolitan Planning Council for the Twin Cities Metropolitan Area, Minnesota (http://www.metrocouncil.org/environment/water/BMP/manual.htm)
- Colorado Department of Transportation (http://www.dot.state.co.us/DesignSupport/MStandards/2006%20M%20Standards/2006%20Index/2006%20M%20Standards%20Index.htm)
- Mississippi State University (http://www.abe.msstate.edu/csd/NRCS-BMPs/pdf/streams/bank/streambarbs.pdf)
- State of Washington Department of Transportation (http://www.wsdot.wa.gov/Environment/WaterQuality/ErosionControl.htm)
- Five Counties Salmonid Conservation Program (http://www.5counties.org/Projects/FinalGeneralProjectPages/RoadsManual800.htm)

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Evaluation

This is the first edition of the Hazard Mitigation Field Book. Please email any feedback or suggestions you may have regarding the content, format, or methodology of the document to the FEMA Office of Building Design at FEMA-Buildingsciencehelp@dhs.gov or call our office hotline at (866) 927-2104.

Comments are encouraged and will be considered in the development of future editions.

Thank you.

Notes

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