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Burned Area Emergency Response Turf Reinforcement Mats

Photo: United States Forestry Service

U.S. Department of Transportation
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Russell, Mark L -FS
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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

Tech Brief: Burned Area Emergency Response with Turf Reinforcement Mats, February 2021

The Challenge

Roads damaged by wildfires can quickly deteriorate and erode. Wildfires leave a barren landscape in their wake. Roads and trails become extremely vulnerable to further erosion because of a lack of vegetation. Heavy rains or storms that follow an active fire season can further destablilize roads and embankments because land burned by wildfires generates far more runoff, sediment, and debris during storms than unburned areas. Culverts are overwhelmed by the increased flow of runoff and debris, and often plugged off. When this happens, roads are overtopped and become especially vulnerable to undermining and erosion. Most conventional mitigation methods (trash racks, etc.) are intended to keep water flowing through culverts rather than preventing the damage resulting from the overtopping flows. Much of the road-related BAER work goes towards clearing culverts where roads in burned areas cross streams, creeks, and drainages, and attempting to protect the culverts against plugging. Road embankments across streams or small drainages essentially become dams that are often overtopped by flows of water, sediment and debris resulting in back-cutting from the embankment toe and a classic overtopping dam-type failure in some instances (Figure 1).

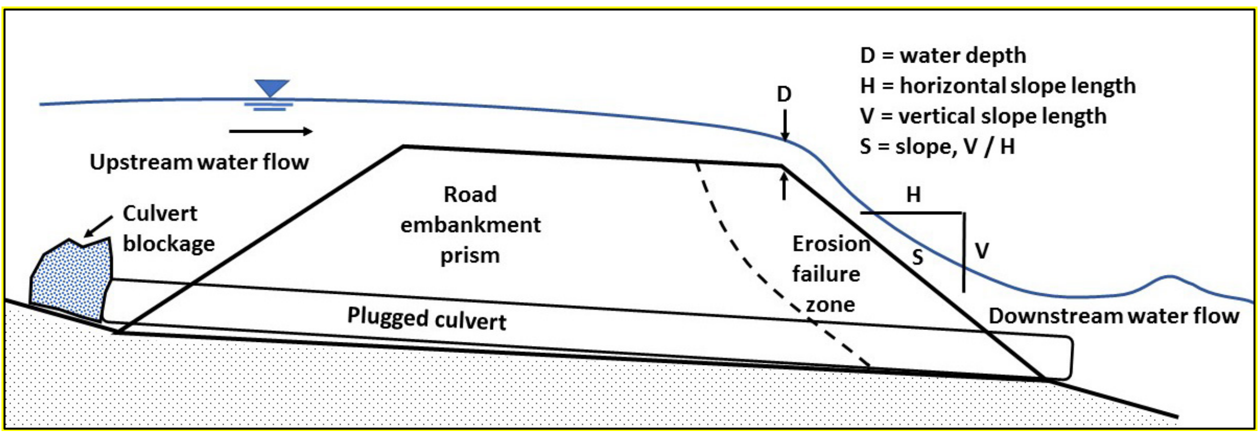

Figure 1. Road embankment with plugged culvert, failing due to overtopping (Provided by USFS)

It typically takes 1-3 years to re-establish vegetation in burned out areas and post-fire runoff can be up to 10 times greater than the runoff for pre-fire conditions. (Figure 2) Guarding roads and embankments from further devastation during this recovery period is crucial. Most of the existing tools for run-off mitigation, such as debris racks, drop inlets, and oversized culverts, are unsuitable for late summer and fall fires because of the time needed for implementation. Late season fires allow a very brief window for mitigation prior to the onset of winter weather.

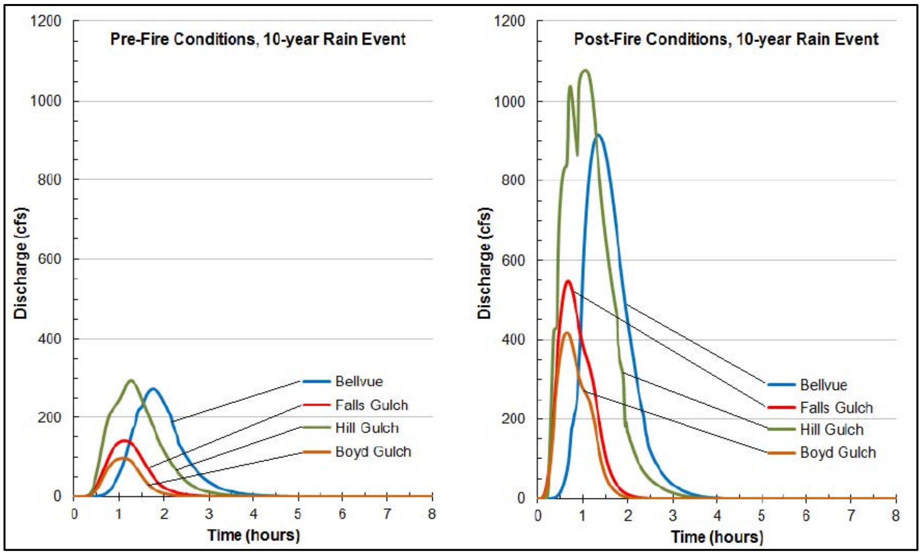

Figure 2. Pre-fire and post-fire discharge hydrographs (Provided by USFS)

When a very brief repair window exists, embankments can be temporarily storm-proofed to protect them from overtopping scour damage. Temporary storm-proofing may include installation of any of the following remedies: rip-rap armoring, concrete/shotcrete hardening, articulated concrete blocks, rock (Reno) mattresses and MSE walls. Although these methods usually prove effective, they are costly and not easily or quickly deployed.

Material	Site	Embankment Height/Slope	Approx. Cost*	Year Installed	Note
Rock mattress	Los Alamos Lab, New Mexico Cerro Grande Fire	20'-30' 2H:1V	N/A	2001	Still operational.
Shotcrete		30'-40' 2H:1V	N/A	2001	Still operational.
Articulated concrete blocks		30'-40' 2H:1V	N/A	2001	Failed in high flows following later Las Conchas fire.
Reinforced concrete	Los Alamos Lab New Mexico Las Conchas	30'-40' 2H:1V	N/A	2011	Followed failure of previous articulated concrete blocks.
Pyramat TRM	San Bernardino National Forest (NF) Sheep Fire	15'-20' 2H:1V	$7.50/SF	2009	Failed in high flow following fire.
Rock (Reno) mattress over Pyramat TRM over geomembrane	San Bernardino NF Sheep Fire	15'-20' 2H:1V	$6.50/SF**	2009	Still operational. Installed after TRM failure. Not tested by significant flows to date.
Oversized culverts, riprap	Custer NF Red Waffle Fire	10'-15' 6-8H:1V	$<5.00/SF	2002	Failed in high flow following fire.
K-rails and micropiles with MacMat TRM. Cellular design strategy.			$6.72/SF	2006	Followed failure of oversize culvert. Successful to date and has been subjected to successive high flows subsequent to installation.
Gravel road surface/	Klamath NF Happy Camp Fire	2'-5' 4-6H:1V	$0.50 – 1.60/SF	2014	Armor primarily on road surface; not on down-slope.

riprap at drain dip outlet					Still operational. Not tested by significant flows to date.

Table 1. Examples of road embankment temporary storm-proofing using conventional materials. (Provided by USFS)

One of the important lessons learned from most of these previous road storm proofing experiences is that most materials fail once flows actually occur. Failures occur as a result of excessive runoff volume as shown above in figure 2, and high velocities, high sediment load, large debris, sharp angular debris, or combinations of those factors, that occur after wildfires. Selecting the correct material and design is critical to the success of the remedial strategy. On the other hand, most burned land recovers enough within 1 to 3 years after a fire to reduce runoff back to near pre-fire levels. This reatively quick recovery makes over-conservative designs perhaps unnecessary and hard to justify.

More permanent solutions to the issue can include debris racks, drop inlets, and oversizing culverts to reduce the potential for culverts to plug with sediment or debris. These strategies are not easily implemented and may require a long lead-time. This leaves an inadequate repair window for late summer or fall fires. These approaches may be more permanent than necessary for the post-fire recovery period and may have limited utility during large post-fire runoff and debris flows ten times greater than pre-fire conditions. Large post-fire flows and debris can damage and overwhelm even oversized and protected culverts, especially when there is limited storage for debris or water behind a road embankment.

Simple, less expensive embankment protection materials are needed that can be implemented rapidly after wildfires, and that have minimal environmental and visual impact once the land has recovered from the fire.

The Solution

Custer National Forest and Flathead National Forests successfully used draping to protect vulnerable embankments during the wildfire recovery period. Draping the embankments is a simpler, less expensive protection. A variety of “drape” materials have been used for decades on sites throughout the country for erosion control including geomembranes, articulated mats, and various geosynthetic erosion control mats. These materials can be left in place for one or more seasons as needed or removed and re-used at other embankment sites in need of post-fire protection. The draping material shields the soil slope from the effects of rainfall and prevents it from washing away prior to the re-establishment of vegetation. The matured roots of the re-established vegetation anchor the mat to the soil and provide reinforcement strength. This ensures the soil is equipped to handle steeper embankment slopes and higher run-off flow velocities.

The draping of flexible erosion control mats protects road embankments from the extreme runoff and debris that typically follow post-wildfire hydrologic conditions. The mats are easily and quickly installed and can protect embankments when the window for mitigation is brief because of seasonal weather concerns.

Product and Site Selection

Two products were initially considered for deployment: an articulated mat and an HDPE geomembrane. After further consideration of the availability of the products, the USFS chose to use only one of the embankment drapes, a turf reinforcement mat (TRM) product. TRMs were originally developed to mitigate soil erosion from sheet flow on slopes and to resist shear stresses that result from low velocity flows on channel bottoms. MacMat-R TRM manufactured by Maccaferri was selected for the demonstration because it includes wire reinforcing designed to resist debris impact and was successfully used in Custer National Forest.

MacMat is a double twist steel wire mesh enclosing a geosynthetic fabric that provides tensile mechanical strength and a higher shear resistance than other TRMs for erosion protection. It comes in 6-ft wide by 75-ft long rolls. Its use increases the soil's resistance to erosion by providing an environment that enhances the growth of vegetation through the mat. Initially the mat works to shield the soil slope from the effects of rainfall, preventing the soil from washing out before the vegetation has a chance to become established. As the vegetation matures, the roots anchor the mat to the soil to provide soil reinforcement strength, capable of handling steeper embankment slopes and higher run-off flow velocities.

Two demonstration sites were initially proposed, but three were eventually selected to gather as much data as possible on successful implementation. The three demonstration sites were selected for their hydrology and burn severity, and to represent geographic and climate diversity. All three sites had experienced recent onsite fires and were subject to past overtopping issues. The sites selected are described in the table below.

Site	**Location: Latitude N Longitude W**	**General Hydrology**	**Date of the Fire/TRM install Year**	**Embankment Height/Slope**	**Approximate Installation Cost ***
Sierra NF French Fire	37° 19.541'N 119° 22.520'W	Snow dominated zone	July 2014 /2014	25 feet 1.5H:1V	$12/SF
Okanogan-Wenatchee NF Carlton Complex Fire	48° 21.790'N 119° 56.144'W	Snow transition zone	July 2014/2015	10 feet 1.5H:1V	$ 6/SF
Klamath NF Happy Camp Fire	41° 46.998'N 123° 8.288'W	Rain dominated zone	Sept 2014/2015	60 feet 1.5H:1V	$10/SF

Table 2- Site characteristics (* MacMat price: $9.65/SY or $1.07/SF (2013 USD not including tax or shipping) (Provided by USFS)

The roads being treated had a very low volume ADT and were located in remote areas. Because of these characteristics, high budget, more conventional, repairs couldn't be justified.

The successful design and placement of the TRMs was similar to designing a channel or spillway liner. The hydraulics and hydrology onsite can be extreme following a fire (large flows and large debris loads) but resemble more normal levels 1 to 3 years after the event.

One of the most important considerations for successful implementation is an accurate shear calculation for the site. The severity of the shear is a good indicator of how the mat will perform, and whether it will actually prevent erosion. The basic relationship for the shear imparted on a liner by water flow is: $\tau = \gamma_\omega D S_w$, where γ_ω = weight of water, D = depth of water, and Sw = slope of water surface, which is typically equal to channel slope (FHWA, 2005). To properly calculate the shear, a knowledge of the flow channel and volume of flow will need to be estimated, which will allow the depth to be calculated. With the depth and the formula above you can determine estimated shear and make an appropriate lining material selection.

For example:

where γ_s = Unit weight of water equals 62.4 PCF.

D = Assumed depth of water, 2 inches (0.17 feet)

Sw = Slope of flow surface is 3H:1V or 33.3%

$\tau = (62.4) * (0.17) * (0.33) = 3.5$ PSF

The allowable shear for water flow against various materials is featured in the table below and was taken into consideration when the MacMat was selected.

Material	Particle Size Range	Roughness, n (Manning)	Allowable Shear Force, τ_f (psf)	Roughness, n (Manning)	Allowable Shear Force, τ_f (psf)
		End of Installation (unvegetated)		Vegetation reestablished 1-3 years	
Bare Soil (Silts and Clays)	<0.075 mm	0.016-032[ab]	0.027-0.14[a]	--	--
Bare Soil (Sands)	0.175 – 4.75 mm	0.025-0.035[b]	0.02-0.072[a]	--	--
Bare Soil (Fine Gravel)	1/4 – 1 in	0.026-0.035[b]	0.12[a]	--	--
Bare Soil (Coarse Gravel)	1 – 3 in	0.028-0.035[b]	0.24-0.4[a]	--	--
Bare Soil (Small Cobbles	3 – 6 in	0.030-0.050[b]	1.1[d]	--	--
Riprap, 6-inch	3 – 15 in	0.056–0.069[a]	2.4[d]	--	--
Riprap, 12-inch	8 – 27 in	0.060–0.080[a]	4.8[d]	--	--
Gabions (18 inch)	4.0 – 10 in	0.030[c]	7.14[c]	0.07-0.4[c]	8.35[c]
Rock (Reno) Mattress (6 inch thick)	2.8 - 5.0 in	0.028[c]	4.26[c]	0.07-0.4[c]	8.35[c]
Erosion Control Blankets	--	0.028-0.045[a]	0.5 – 2[d]	0.028-0.045[a]	0.25-1.75[d]
Turf Reinforcement Mats (TRM)	--	0.004-0.020[d]	1.5 – 4[d]	0.024-0.036[a]	0.4 - 15[d]
Macmat-R (TRM)	--	0.030[c]	0.74-3.34[c]	0.07-0.4[c]	6.26[c]

Table 3- Shear calculation for various materials.

Table compiled using data from: a) FHWA-NHI-05-114, b) USGS Water-Supply Paper 2339 (1989), c) Maccaferri MacMat tech data, d) Tensar/Forester Univ. presentations (Robeson/Pack)

Designing for flows with sediment and debris loads can be complicated. Depending on assumptions, the forces imparted on a liner by large debris such as boulders and logs can be estimated using impact-momentum equations. Pore fluid pressures within debris flows can exceed static equilibrium pressures due to local or global contractions in the debris flow (Iverson, 2010). Experimental debris flows of poorly sorted, water-saturated sediment can move as an unsteady surge or series of surges. Measurements at the base of experimental flows show that coarse-grained surge fronts have little to no pore fluid pressure. In some instances, shear stresses in the debris front might be equivalent to $\tau = \gamma_s D Sw$, where γ_s = weight of soil.

Debris flows are two phase in nature – solid and liquid. The leading edge and tail end of a debris flow tend to be solid with shear capacity throughout the matrix, while the intervening zone behind the leading edge is liquid with near zero shear capacity.

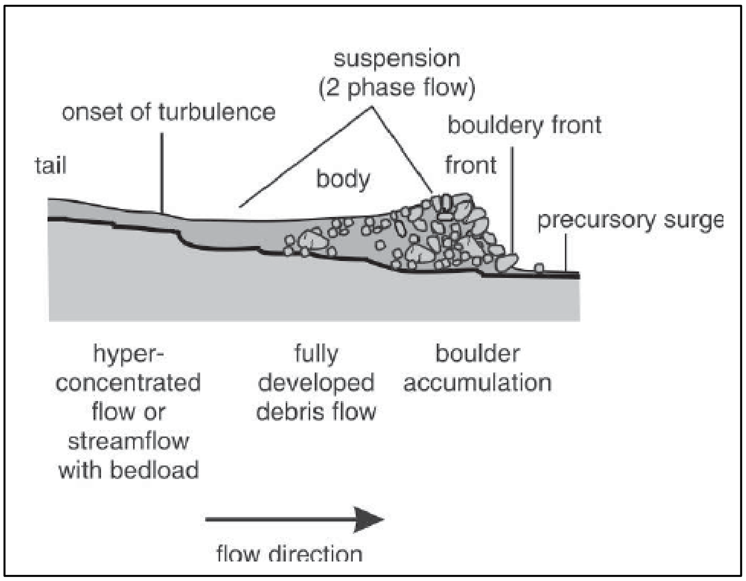

Figure 3. Depiction of Debris Flow Structure

A successful storm-proofing strategy accommodates the need for a wide variation in imparted shear and phase states of debris flows. So far, most erosion control design strategies have focused exclusively on the characterization of hydraulic forces and neglected sediment and debris impacts. The appropriate protection of burned areas is dependent upon a consideration of sediment and debris impacts.

Installation

The USFS used the following large equipment to install the TRM: skidsteer, backhoe, dump truck, track hoe, bulldozer, and pickup truck. The equipment wheels were used to compact material. The following hand tools were used: pliers, wire cutters, shovels, and sledge hammers.

<u>Site Preparation</u>

- Form a transverse dip in the road surface near the center of the embankment to direct any overtopping flows to the area covered by the TRM. Make sure the dip is deep enough to direct flows but mild enough to allow passage of traffic along the road.

- Cut any trees and large brush growing on the slope face (stem 1-inch diameter or larger). Cut stumps flush with ground surface as close as possible.
- Remove any protruding large rocks and fill significant depressions with soil as needed to achieve a reasonably smooth surface. (Keep surface variations to less than 3-4 inches if possible.)
- Compact loose soil on the slope if possible.
- Apply straw or other suitable weed-free organic material to the slope surface to inhibit soil erosion and encourage vegetation growth.

Anchor Trenches

- Excavate a longitudinal anchor trench in the road at least 5 feet back from slope hinge point. The trench should be 2 to 3 feet deep and at least 6 inches wide.
- Excavate intermediate anchor trenches across the face of the slope at intervals of approximately 20 – 30 feet of slope height (i.e. a 90-foot high embankment slope would have 1 main anchor trench in the road at top and 2 intermediate anchor trenches on the slope face).
- Lay the end of each panel of TRM into the anchor trench to entirely cover the sides and bottom of the trench and backfill with soil. Moisture-condition the soil to near optimum and compact it in place.

TRM Placement

- Start at the bottom of the embankment slope to be protected with the lowest intermediate anchor trench (if any). After installing the lowest row of panels, continue to the next panel up so that panels overlap in a “shingle” pattern.
- Overlap side-by-side panels approximately 3-4 inches and tie them together with a suitable connector such as wire ties. Links for gabion baskets or rockfall netting are preferred.
- Install metal anchor stakes on a staggered pattern approximately 3 – 4 feet on center. The 12-inch long U-shaped 8-gauge metal “staples” provided by Maccaferri are not considered adequate. Metal stakes made of No. 4 rebar, approximately 36 inches long, with a hook at the top end are effective.
- Drive the anchor stakes into place with a jackhammer or a sledge hammer.
- Leave the installed mat in place permanently.

Road Surfacing

- Use suitable gravel aggregate to cover the TRM at the road surface with at least 12 inches of material.
- Use suitable gravel, aggregate, or even pavement to surface the road through the dip section and over the TRM and anchor trench. This will help protect the TRM in place and reduce erosion of the road surface from rain and any overtopping flows.
- Place riprap at the outflow.

At each site, the MacMat-R TRM was installed on the downslope embankment according to the following pictorial steps:

All photos provided by USFS.

1. Clear the slope face

2. Excavate anchor trench in road

3. Transport TRM roll

4. Embed top end of TRM in anchor trench

4. Backfill/compact anchor trench

6. Unroll TRM down slope

7. Anchor TRM to ground with stakes or rebar

8. Tie TRM panels together with wire ties or gabion clips

9. Surface the road dip and place riprap at outlet

10. Allow vegetation regrowth

Challenges

The three sites had widely varying results. The draping was effective at only one site located within Sierra National Forest. The debris flow at Okanogan National Forest included large boulders and logs against which the draping proved ineffective. The turf reinforcement mat liner and the embankment failed at the Okanogan site. Because of the nature of the surrounding terrain, Forest Service personnel concluded that the better strategy may have been closing the road and delaying repair rather than using turf reinforcement mats. In addition to appropriately calculating shear, and considering debris and sediment flow impacts, it is crucial to consider the terrain surrounding the site. Forest Service personnel concluded that a site with extremely steep terrain consisting of large circumference trees and large boulders may not be appropriate for this type of remedy.

The Klamath site did not experience a weather event severe enough to demonstrate the effectiveness of the turf reinforcement mat.

Table 4. Summary of TRM demonstration results

Site	Storm occurrence after TRM install	Overtopping Flow	Note
Sierra NF French Fire	6 Months	Q = 5 – 15 cfs τ = <1 psf 2 – 5-year event	Road and embankment are still operational. Highly erodible soils experienced erosion beneath mat. Minor repair needed. Expect effectiveness after vegetation re-growth.
Okanogan NF Carlton Complex Fire	9 months	Q = 230 - 250 cfs τ = 17 – 19 psf 2 – 5-year event	TRM liner and embankment failed due to very high flows and very large debris. Leaving the road closed and delay the repair rather than storm-proofing may have been a better strategy.
Klamath NF Happy Camp Fire	No occurrence to date	N/A	Road and embankment are still operational. They have not been tested by significant flows to date.

The Q and A

Q: What size of work crew is needed to install a TRM?

A: At a minimum two workers are needed, but ideally five is better.

Q: Any special skills needed?

A: Other than equipment operation, no special skills are needed.

Q: How soon after a fire should I install a TRM?

A: as soon as the ground cools off after the fire. It is important to provide protection as soon as possible.

Q: Are there products similar to MacMat that should work also?

A: Table 2 shows several options that function similarly to the MacMat.

Q: Can I reuse the TRM elsewhere?

A: No. TRMs are left in place. To remove the TRM you would destroy the established vegetation

Q: Are there some slopes you would not use a TRM?

A: Yes, TRMs are useful for slopes that you do not anticipate shear forces greater than 4 PSF. In some cases, for example, using riprap, gabions, or shotcrete will provide protection for when greater shear is anticipated.

Q: Does a product manufacturer need to be onsite during the installation?

A: No. Installation is simple and strait forward. However, it is always beneficial to get advice from the manufacturer.

Q: Do you need to seed the site for vegetation establishment?

A: Yes. The heat from the forest fire may have destroyed all naturally occurring seeds that would have otherwise grown.

The Wrap Up

- Alternate, rapidly deployable, strategies are needed to protect road embankments in burned areas after wildfires. Traditional methods are expensive, slow to implement, and unnecessarily permanent.
- Storm-proofing a road embankment is one alternative strategy.
- TRMs are one type of liner material that can be used to stormproof road embankments in certain cases.
- *Hydraulics and hydrology are critical.* The effectiveness of any given armoring depends on flow rate, velocity, type of debris, and debris load.
- As the steepness of embankment down-slope increases, the shear force increases. TRMs performed well with in their shear specifications.
- The erodibility of the embankment soil also appears to be important. Large scale and small-scale erosion were observed on the sites with erodible silty soil.
- Post fire (BAER) mitigation need only be effective for a limited time – typically 3 years or less until runoff is abated by new vegetation growth and restored to near unburned conditions.
- Study post-fire hydrology at road crossings. Estimate peak flow rates and debris loads. Then add a generous safety factor!
- Consider anticipated shear forces from overtopping flows and debris. Use a TRM to stormproof your road embankment if suitable for the anticipated conditions.
- Heavier lining materials, such as riprap, gabion baskets, and Reno mattresses are still good alternatives when anticipated flows, debris loads, and shear forces are high.

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