RESTORING WATERSHED AND CORAL REEF HEALTH IN HAWAI‘I BY REDUCING SEDIMENT TRANSPORT FROM DIRT ROADS INTO STREAMS

A Guide for Road Maintenance Crew and Land Managers across Hawai‘i

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Photo by Jennifer Vander Veur

In an undisturbed natural landscape, trees and soil help soak up rainwater. However, in a developed or urban landscape, rainwater falls onto streets, parking lots, roofs or other impervious (not absorbent) surfaces made of materials like concrete and asphalt. Instead of sinking into the ground or being stored in organic material, rainwater runs off the land, picking up harmful pollutants like nutrients, agrichemicals, heavy metals and petroleum residues along the way. Eventually stormwater ends up in our oceans – either by traveling down storm drains or by flowing into waterways like rivers and streams that lead to the ocean. When polluted stormwater flows into the nearshore environment, it poses a health threat to swimmers and causes significant harm to coral reefs and other marine life.

By following this guide, you can help reduce the amount of sediment reaching our oceans and create a safe, healthy nearshore environment for marine life and your community.

CORAL REEF ALLIANCE

WEST MAUI Ridge 2 Reef INITIATIVE

ridge to reefs

THE CAMPBELL FOUNDATION

NOAA CORAL REEF CONSERVATION PROGRAM

Affiliation:

1: Ridge to Reefs

2: Coral Reef Alliance

Sediment runoff from land harms our watersheds and coral reefs

Coral reefs provide our families with food, protect our homes from storms, and provide jobs for our communities. Unfortunately, sediment from degraded landscapes and dirt roads gets washed into stream gulches during storms where it degrades water quality and negatively impacts aquatic and marine environments and their inhabitants. Once transported to the coast, high levels of sediment can kill corals by suffocating them and blocking their access to sunlight.

Water pollution is damaging coral reefs across Hawaiʻi. In West Maui, water pollution has led to a decline of coral cover from 30 to just 10 percent in the last fifteen years (Sparks et al., 2015; Stock et al., 2016). Sediment pollution is also the cause of "brown water" events, which create dangerous ocean conditions that limit recreation and fishing in our nearshore waters.

How to use this guide:

This document is intended to guide you through the some of the best available options for retrofitting a dirt road to reduce sedimentation loading. We establish a practical set of recommendations, while recognizing that each site will have its own unique characteristics.

At the end of this document, we have included some reference documents for more detailed construction and engineering information, as well as a list of organizations that can offer technical assistance (see Section 5).

Consult this key to navigate within the document

Starting point (what situation are you dealing with?)	Directions
Dirt road with kickouts only	Start at Section 1: Diverting water from a road surface
Dirt road with diversions (e.g. water bars, rolling dips) already in place	Jump to Section 2: Slowing flow and trapping sediment using vetiver outlets
Dirt road with vetiver outlets already in place	Jump to Section 3: Stabilizing sediment using native plants
Dirt road with best management practices in place	Jump to Section 4: Proper maintenance of dirt roads
Need more details on construction and engineering?	Consult Section 5: For more information

Useful definitions

Ecological terms:

Erosion: A process in which surface soil and sediment is dislodged and transported, often as a result of water flowing across the land.

Headcut/knickpoint: An erosional feature of some streams where an abrupt vertical drop in the streambed occurs, resembling a very short cliff or bluff.

Legacy sediments: Sediments deposited in a watershed, following human disturbances such as logging, mining, or intensive agriculture.

Runoff: Water from rain or storms that "runs off" the landscape - over paved streets, across bare soil, and through lawns - into streams, gutters or storm drains that eventually lead to the ocean. As it flows, runoff can collect and transport pollutants from the land to freshwater sources and then the ocean.

Sediment: Loose dirt, sand, clay, and other soil particles.

Watershed: An area of land that drains to a common freshwater source like stream, river or lake. Smaller watersheds drain to larger watersheds which eventually flow to the ocean.

Technical terms:

Check dam: A small dam constructed in a gully or other small water-course to decrease the streamflow velocity, minimize channel scour, and promote deposition of sediment. Check dams can be constructed from wood, rocks as well as vetiver grass.

Cross drain: A pipe that sits under the road surface or an open culvert that conveys water across the surface of a road.

Culvert: A transverse drain that allows water to flow under a road or sidewalk from one side to the other. Can be made from a pipe, reinforced concrete or other material.

Kickouts: In West Maui, road kickouts are cleared areas at the side of a dirt road that are designed to quickly convey water from dirt roads and into stream gulches

Outlets: An outlet might be used to slow flow coming through a cross drain. Outlets are constructed of stones or rip-rap designed to reduce the energy from the flow of the water.

Rolling dips: A wide, shallow dip plus a berm installed diagonally across a road in order to interrupt the flow of water and redirect it to an outlet on one side of the road. **Storage capacity**: the amount of sediment that a given kickout can hold.

Water bar: A narrow berm (ridge) installed diagonally across a road in order to interrupt the flow of water and redirect it to an outlet on one side of the road.

Impacts of dirt roads in Maui

A huge network of dirt roads weave across West Maui's midslope region that used to service plantations which have now since closed (Figure 1). Nowadays, many of these roads are infrequently used and have fallen into disrepair. The roads that serve as the most active sources of sediment are small off-roads, former agricultural roads, and service roads. Huge amounts of sediment has been observed to be transported during even short and intense rain events (see Figure 1). The majority of these roads have "kickouts" next to them, which are designed to quickly remove water from the road surface and divert them into nearby stream gulches; as a result, large amounts of sediment are transported into streams and eventually the ocean.

Dirt roads and bare soils can transport sediments at a rate of 6 to 200 times the natural transport (Ramos-Scharron, 2018), and researchers estimate that sediment transport to coral reefs could be reduced by 43 percent if all roads were addressed (Oleson et al., 2017). Therefore, mitigating sediment transport from roads has been identified as one of the most important actions to be prioritized in watershed management plans (see https://www.westmauir2r.com/watershed-management-plans.html).

Given this research and future development plans in West Maui's mid slope region, we recommend:

1. Where feasible, decommissioning and restoring (vegetating) the land areas adjacent to the stream gulch (we call this a "stream gulch vegetation zone"); and

2. Implementing the best management practices outlined in this guide along roads, which are (a) close to the stream gulches and (b) hydrologically connected to streams or gulches, in order to prevent sediment transport into the gulches. These sites represent higher priorities than kickouts that have less connection to gulches and streams.

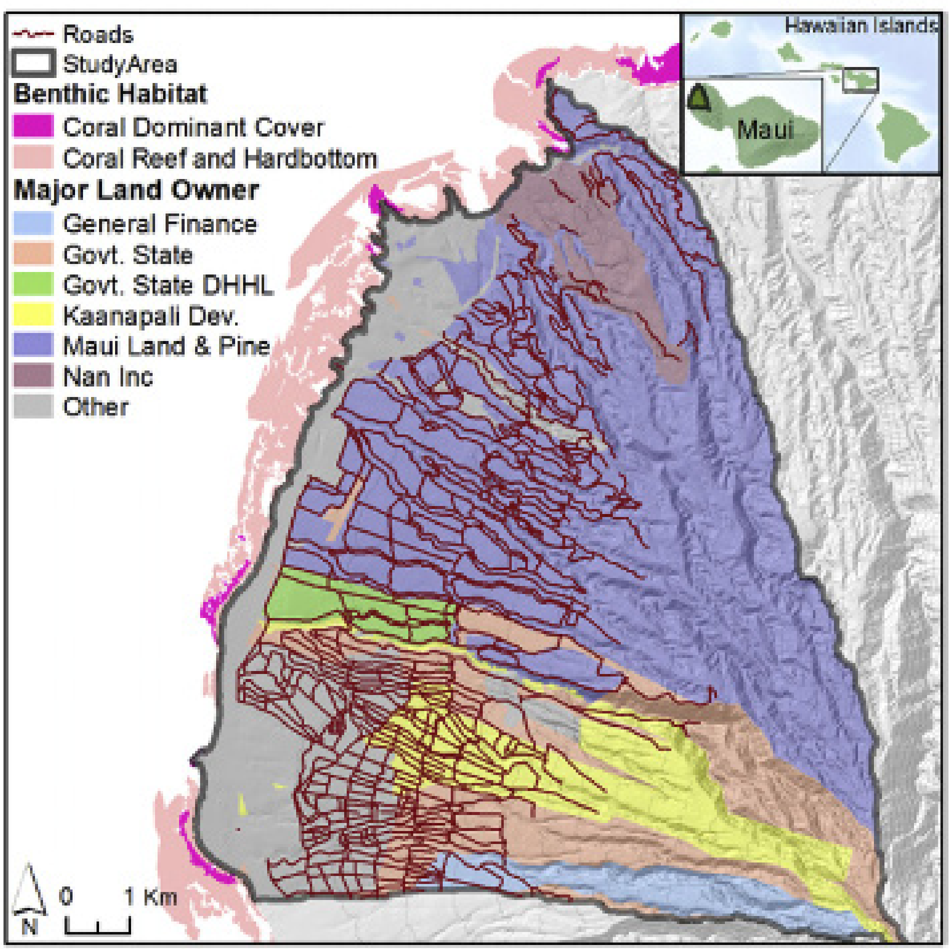

Figure 1. Extensive dirt road network on West Maui, Hi (Maui County, 2016)

Figure 2. Runoff generated after a small intense rainfall in Honokōwai watershed. Photo by Paul Sturm

Section 1: Diverting Water from a Road Surface

Diversion practices are used to remove water from a road surface. Flow on a road surface can destroy the integrity of the road, especially one that is unpaved. There are a number of effective practices and designs for reducing water flow and divert runoff. Currently, many roads in West Maui have kickouts which divert water to nearby streams. Here we discuss two effective and commonly-used practices that can redivert water away from stream gulches and reduce sedimentation loading.

A. Water Bar

What is it: A narrow berm (ridge) installed diagonally across a road in order to interrupt the flow of water and redirect it to an outlet on one side of the road.

When to use it: Water bars are not a preferred practice but can be useful in roads with very low usage (low vehicle traffic), and on roads running parallel to gulches (to ensure those roads drain inland). They should convey water very freely and non-erosively.

Construction material: Water bars are typically constructed from concrete, but can also be made of earthen materials on roads that have less usage.

Construction angle: 30-degree angle.

Construction slope: 2 to 5% to promote drainage and reduce clogging.

Figure 3. Example of a concrete or earthen water bar under construction (based on NYSF, 2011)

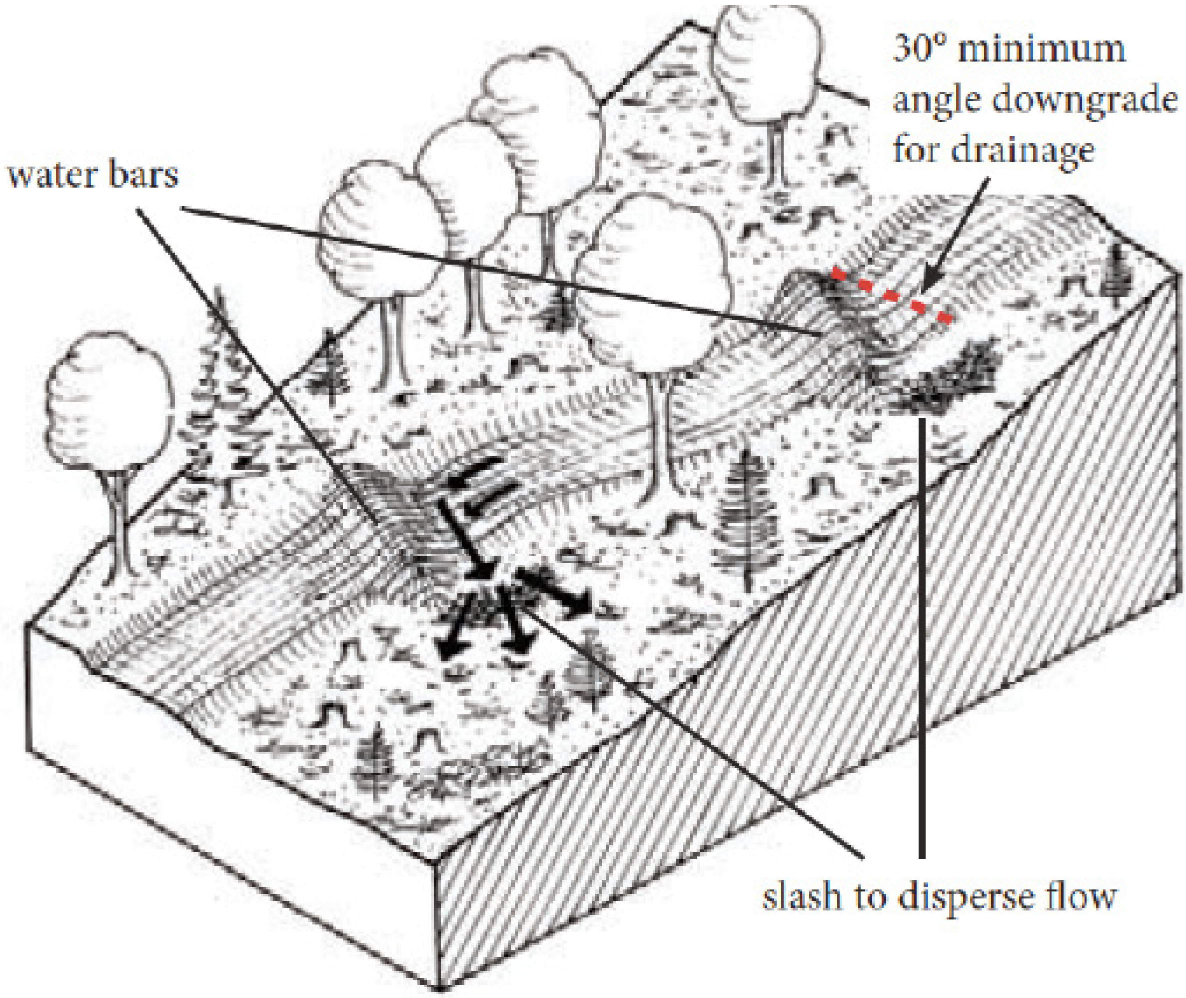

Figure 4. Illustration of a Water Bar (NYSF, 2011)

B. Rolling Dips

What is it: A wide, shallow dip plus a berm installed diagonally across a road in order to interrupt the flow of water and redirect it to an outlet on one side of the road.

When to use it: On roads where the slope/gradient is less than 30%.

Construction material: less erosive soils (clays and gravels) compacted to help minimize erosion.

Construction angle: 30- to 45- degree angle.

Construction slope: 0-30%.

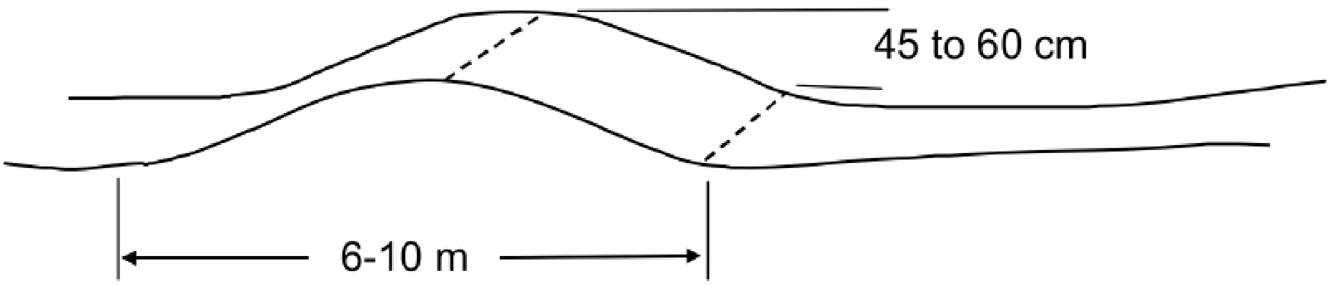

Figure 5. Cross Sectional view of a rolling dip (QDERM, 2010a)

Figure 6. Rolling dip delivering water to a kick out on a dirt road in West Maui. Photo by Paul Sturm

Frequency of installments (i.e. how often should a water bar or rolling dip be installed?)

Water diversions (including rolling dips, earthen or concrete water bars) can be installed at the frequency proposed in Table 1, from roughly 27 feet (or 9 meters) separation at 30% slopes to 225 feet (75 meters) spacing at 2% slopes and may need to be higher on steeply sloped roads.

Table 1. Spacing of water bars on dirt roads based on Slope (NYSF, 2001)

Slope (%)	Spacing (ft)	Spacing (m)
Mild		
2%	250	75
5%	135	40
Medium		
10%	80	25
15%	60	20
20%	45	14
Steep		
25%	30	9
30%	30	9
>30% Slope consider using two track concrete or narrow concrete surface or realigning road		

Scenario 1.1: Road runs parallel to water flow (either uphill or downhill)

If your road is running in the same direction as flow (the road is going uphill or downhill, depending on your perspective), then water will flow down the road. The goal is to consistently remove water from the road and distribute that flow back to vegetation in a non-erosive manner and provide outlet for the water where it will not simply gather and re-cross the road (see Figures 7 and 8).

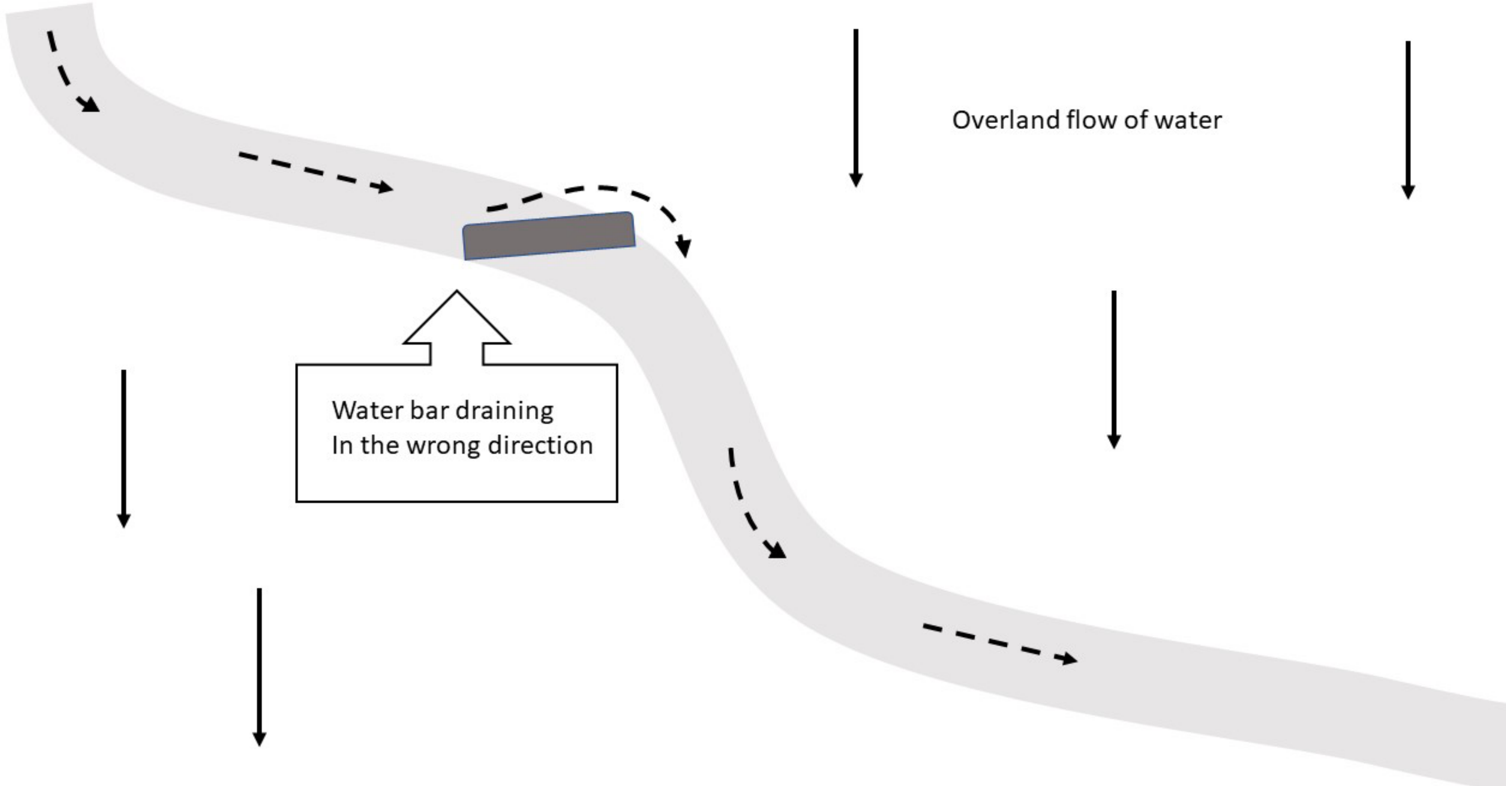

Figure 7. Incorrect drainage using water bar– flow returns to road surface. (Schematic adapted from QDERMa 2010)

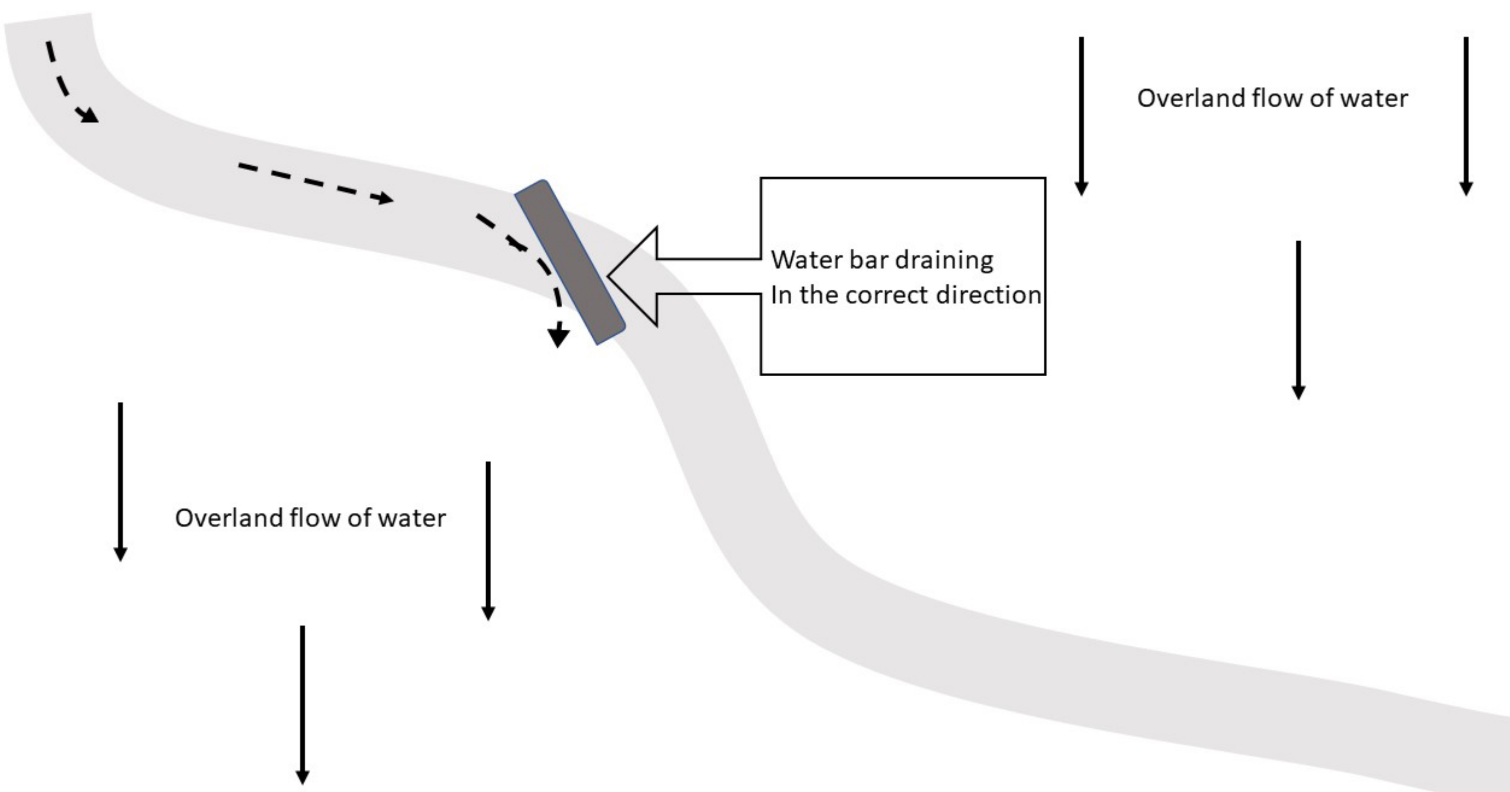

Figure 8. Correct drainage using water bar – flow is removed from road surface. (Schematic adapted from QDERMa 2010

Scenario 1.2: Road runs perpendicular to water flow

If your road is running roughly perpendicular to the flow, then the road will intercept water flow. It is important to note the direction of drainage, paying attention to where nearby gulches and streams are to ensure the flow does not drain into the gulch or watershed. You must also ensure that there is sufficient space for sediment storage and plant growth.

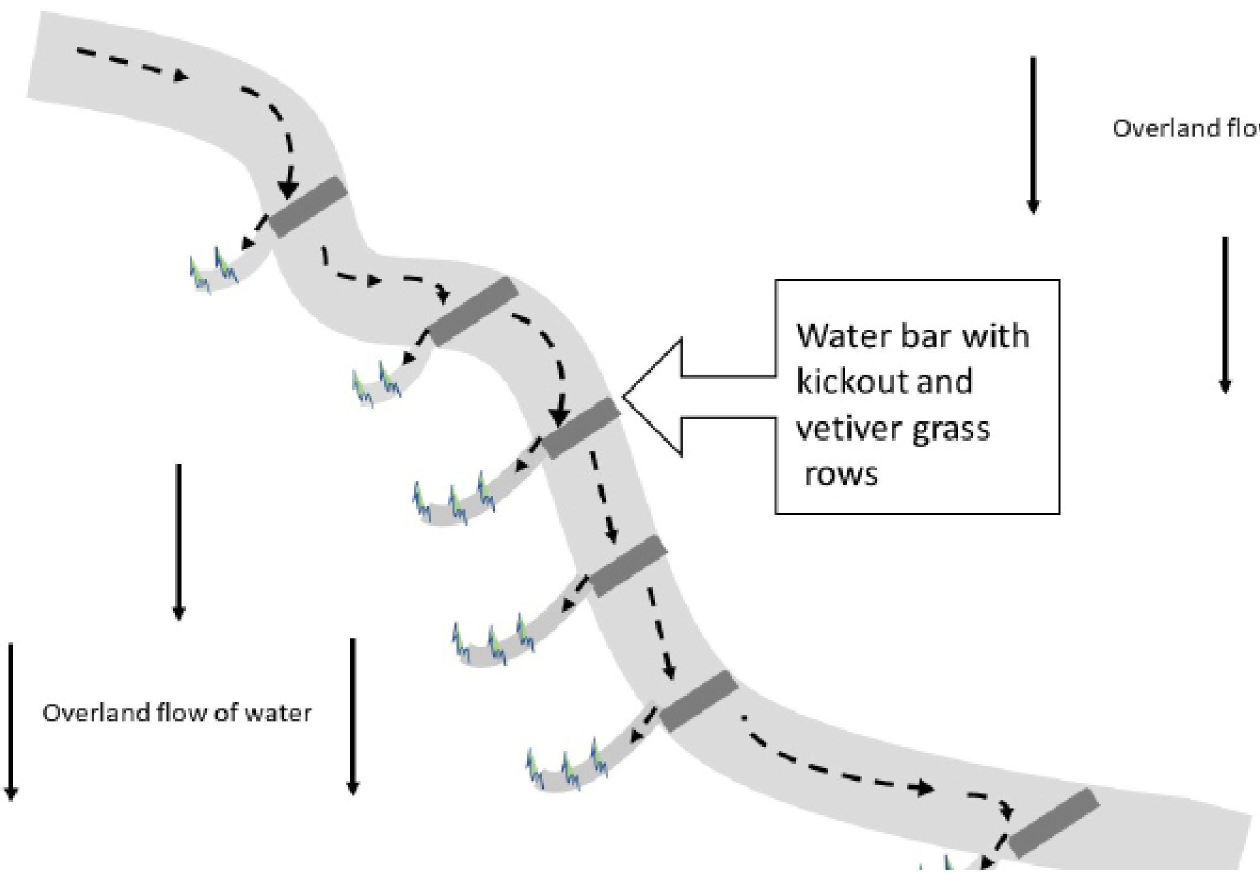

Figure 9. Using diversions (concrete or earthen water bar or rolling dip) to convey flow off and across the road surface—vetiver sediment traps are used to convey the flow back to the land and minimize erosion (Schematic adapted from QDERMa 2010)

In this scenario, the road is intercepting overland flow as well as flow generating from the road surface itself. Again, the goal is to get water off the road quickly via diversions and convey the overland flow safely across the road in a culvert or concrete swale. In cases where the road is near the top of a hill, the road can be sloped to allow water to sheet flow across it or into the water bars and vetiver outlets or stone rip rap outlets (see Figure 9). Flow should be conveyed to a natural channel or vetiver outlet after velocity dissipation. In this scenario, water is also conveyed along the front edge of the road non-erosively with vetiver or riprap check dams.

In this scenario, three options exist for the road surfacing:

1) a convex road to shed water to both sides (optimal);

2) a road which sheds slightly to the downhill side (can be problematic if the surface is slippery when wet);

3) road sloped toward the inside of the road (less optimal because it generates roughly twice the runoff from the road surface and requires more maintenance).

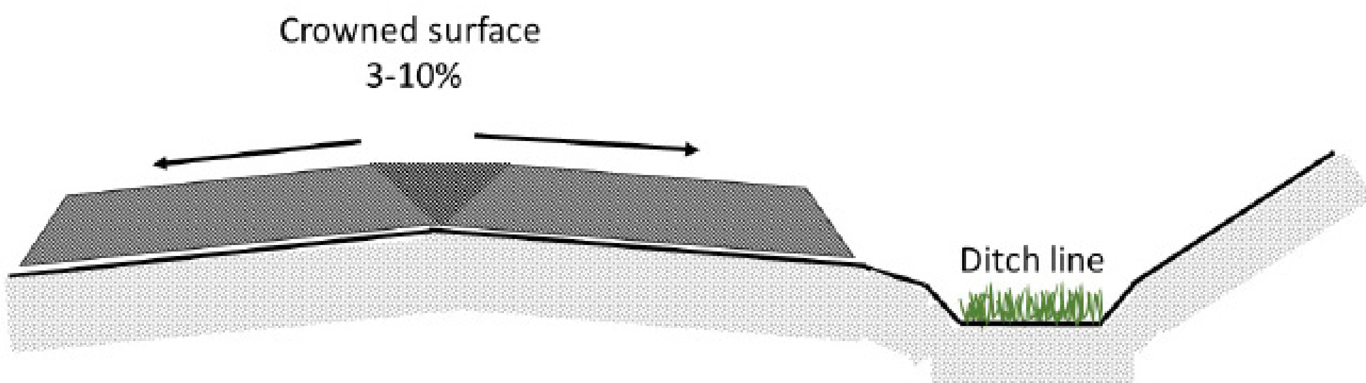

Figure 10. Road is Crowned – channel is grassed with vetiver check dams (Schematic adapted from FAO, 1998)

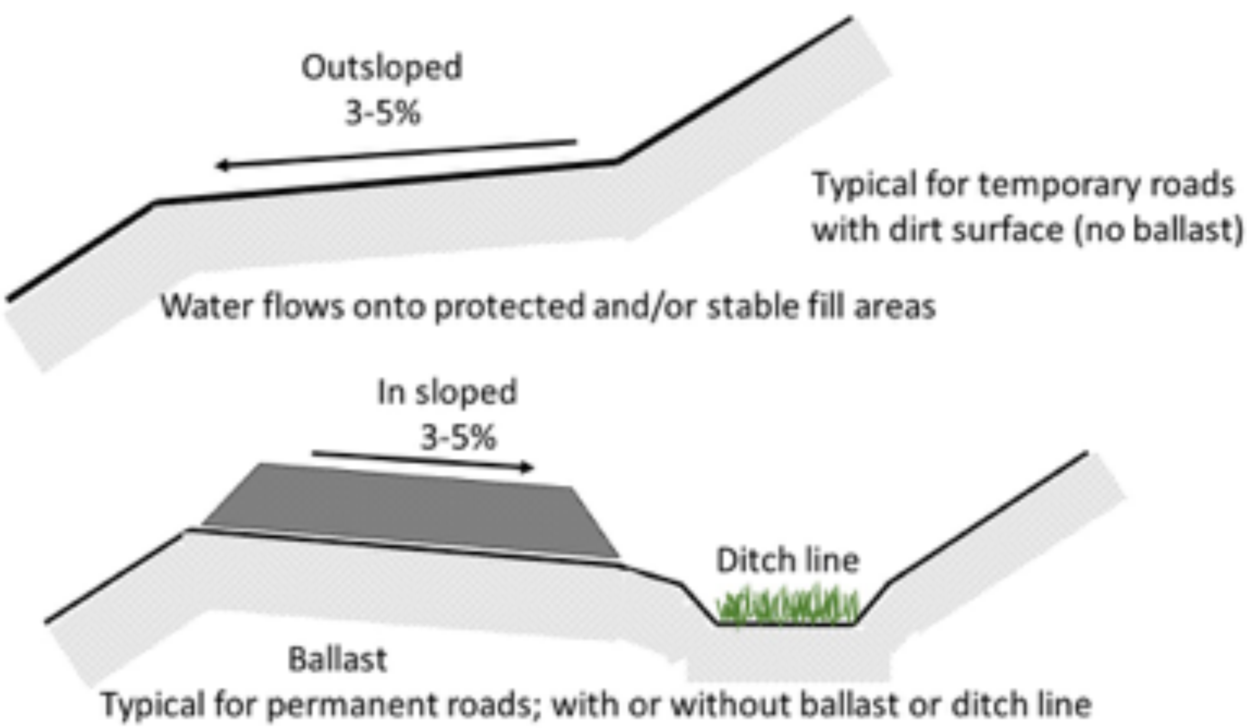

Figure 11. Road slopes to the outside; or inside and channel is grassed with vetiver check dams (note ditches should be u shaped where possible) (Schematic adapted from FAO, 1998)

In all scenarios, you should ensure that 1 -2 feet of water can collect below the highest elevation of the Rolling dip, and that there is no evidence of water breaching the rolling dip (this can destroy a road).

Section 2: Slowing Flow and Trapping Sediment Using Vetiver Sediment Traps

There are practices that can slow down flow, help trap sediment, and decentralize flow so that it is less erosive and flows as distributed sheet flow rather than as concentrated flow. In particular, sediment traps within kickouts can hold runoff from road segments, detaining water for long enough for sediments to settle and soak into the soil, rather than flow into streams. In this section, we focus on the “best practice” of using deep-rooted vetiver grasses to trap sediment and nutrients, while improving the environment for successful replanting of native vegetation.

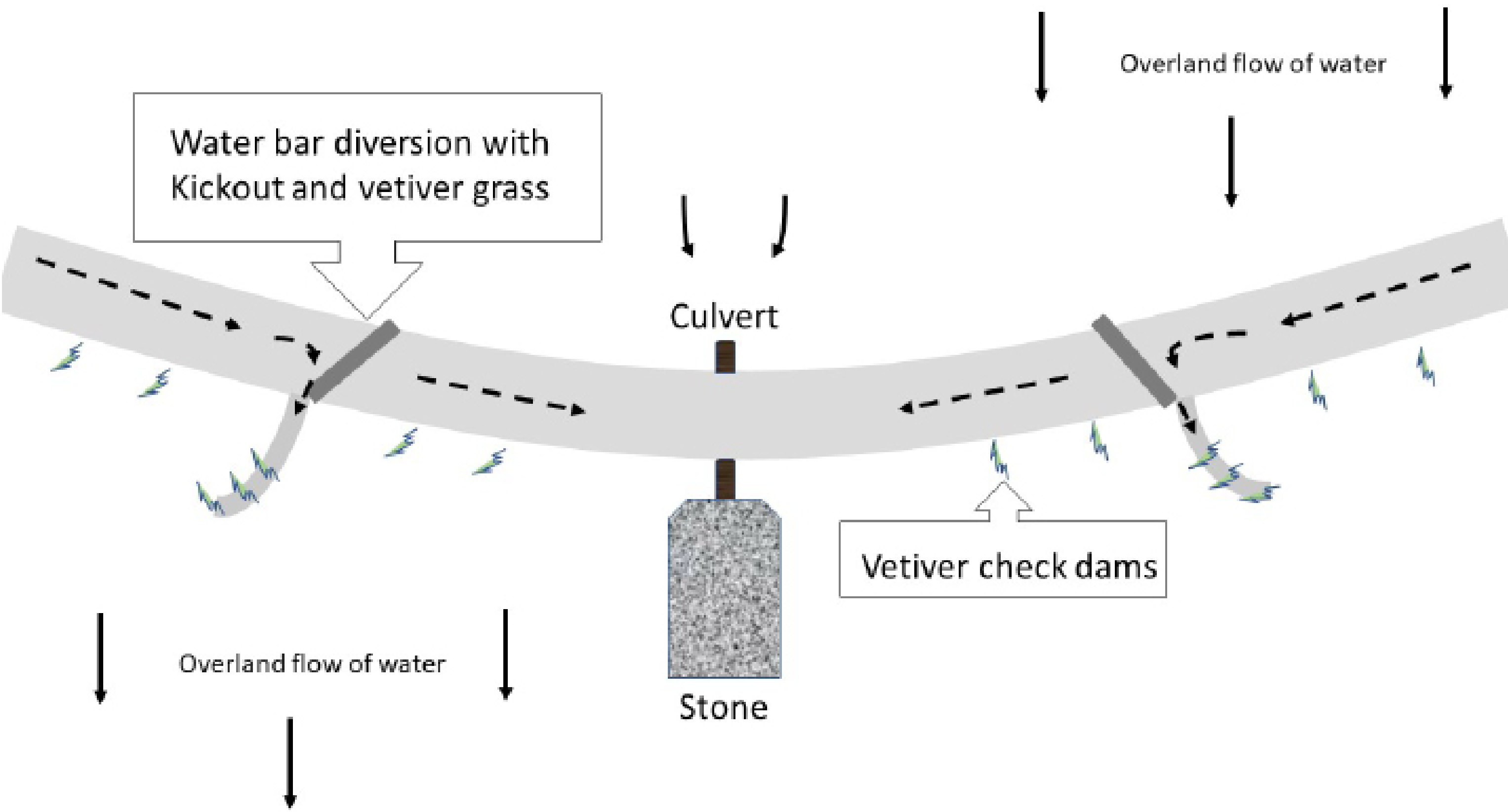

Figure 12. Road running across a slope with a natural drainage. In this example, diversions are used as well as a culvert with a rip rap outlet pad to reduce erosion. Note that two diversions are used at the bottom of the hill to reduce likelihood of headcutting at the terminal point near the culvert. The diversions can be either water bars or rolling dips.

Vetiver Sediment Traps

Vetiver is a deep rooted grass that is commonly used to retain sediment. A sterile strain of the plant, which does not spread or send out runners, is used for restoration purposes in Hawai‘i. A vetiver sediment trap is created by planting rows of vetiver grass perpendicular to the flow of runoff. They can be used to prevent sediment transport via road kickouts and along decommissioned roads in a similar way to how check dams are usually used. Vetiver sediment traps are used to reduce flow velocities, promote filtration, and trap sediment within kickouts and in other areas where water flow concentrates adjacent to the road (such as where two roads intersect). Vetiver sediment traps should be used in conjunction with a road maintenance program where water bars or rolling dips are maintained and used to convey water into kickouts.

Vetiver roots are effective because they grow up to 3 - 4 meters deep in the soil, uptake water through evapotranspiration, and have a fine root system which can penetrate poor soils and enhance filtration. Vetiver sediment traps distribute the water along the contour and prove a permeable barrier that slows the flow between rows of vetiver and is very effective at capturing fine sediment before it flows into streams.

Section 2: Slowing Flow and Trapping Sediment Using Vetiver Sediment Traps (cont)

In areas of compressed soil, plants are unable to spread and root, making recolonization in these areas difficult. Vetiver sediment traps are able to effectively set the stage for native plant colonization in the following ways:

a) The loose sediment accumulated in front of the vetiver is easy for young plants to root in and grow.

b) Water and nutrients taken up by the vetiver enhance the quality of the soil.

c) The traps reduce erosion and restore soils.

See Section 3 for guidance on planting native species after successful implementation of vetiver sediment traps.

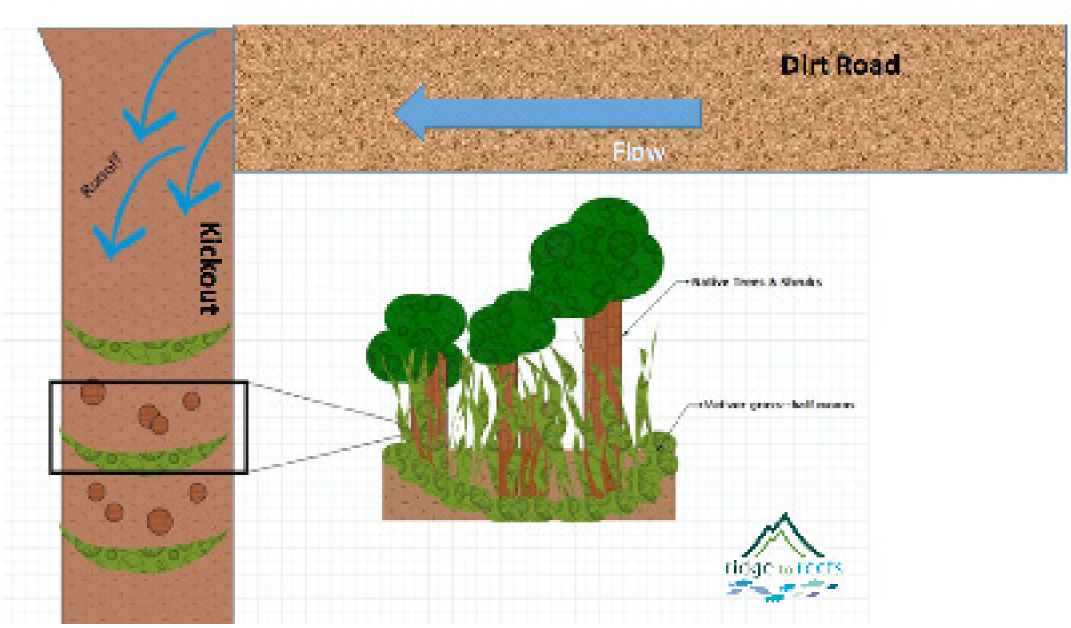

Figure 13. Restoration diagram for vetiver sediment traps along road kickouts. (Ridge to Reefs)

General guidelines for using vetiver sediment traps as a practice:

1) **Rows**: Vetiver grass should be planted in series of at least three rows to help filter both coarse and fine sediment particles, the latter of which have been shown to be extremely damaging to coral reefs.

2) **Distance from road**: Vetiver rows must be placed at least 10 feet away from the road to allow for proper storage capacity (the amount of sediment that the kickout can hold). They will need to be set even further back in steep areas (slope >12%) with frequent rain events. Setting them away from the road allows time for the water flow to slow down and prevents it from breaking through the vetiver rows.

3) **Retrofitting kickouts**: The minimum amount of vertical storage of the kickout needs to be 2 feet. The length of the kickout should be at least 10 feet in steep areas and 20 feet in less steep (mild slope) areas. On mild sloped kickouts, the first vetiver row should be set back as far from the road as possible to maximize the storage capacity. If these parameters are not met, it is important to retrofit the kickouts, otherwise there is a high risk of sediment storage being overwhelmed during large storms and high water being conveyed back out to the road. See Figures 9-12.

What should I do if...

…the road is steep (slope greater than 12%)?	On steep roads, the water velocity may cause the force of the water to breach the vetiver row and allow sediment to bypass the trap. Small check dams may need to be installed to reduce water velocity in order to prevent high flows from breaching vetiver sediment traps. These check dams should be placed near the entrance of the kickout and will require periodic maintenance. In addition to check dams, stones, burlap sand bags or logs should be placed behind the first two rows of vetiver.
…there is insufficient storage capacity within a mildly sloped area?	The kickout may need to be re-graded using heavy equipment to allow for adequate storage.
…the kickout is not on a flat slope along its width?	Vetiver should be planted along the contour of the slope to disperse the flow and energy and better allow for settling of sediment. Burlap bags filled with sediment can be used to fill in eroded patches of road to help construct a consistent contour and should be reinforced with extra material, stone, or logs to reduce wear and disintegration of burlap bags.
…there is shade from trees?	Where shade is present and could impact the growth of vetiver plants, tree limbs should be pruned to allow for maximum sun exposure.

Figure 14. A vetiver sediment trap without proper vertical storage. That is, the first vetiver row is at the same elevation to the road. (Photo by Paul Sturm)

Figure 15. A vetiver trap with proper vertical storage. That is, the ground elevations drops between each row, allowing space for sediment build up. (Photo by Paul Sturm)

Figure 16. View (from the kickout) of a vetiver sediment trap with adequate vertical storage. (Photo by Paul Sturm)

Section 2: Slowing Flow and Trapping Sediment Using Vetiver Sediment Traps (cont)

Figure 17. Vetiver sediment traps stationed along a decommissioned road to prevent sediment from being transported down the road. After the sediment has started to accumulate, native plants can be put in to hold remaining soil in place and return the area to its natural ecosystem. (Photo by Jennifer Vander Veur)

Section 3: Stabilizing Sediment Using Native Plants

Ultimately, non-natives such as vetiver should be used temporarily and in combination with soil amendments to help restore soils and degraded landscapes. After installing vetiver traps and other road maintenance activities, you can begin planting native plants in restored soils where loose sediments have been trapped. Planting native species is an important aspect of promoting native land cover and restoring ecological function. It also has the added benefits of beautifying the area, providing plant material needed for Hawaiian cultural practices, and reducing maintenance due to the natural adaptations of the plants. As soil health is restored and sediment transport is reduced, you can turn your attention towards the ultimate goal of restoring a native ecosystem.

Figure 18. Native plants (from front to back: Ilima, *Carex spp*, and A'ali'i) (Photo by Jennifer Vander Veur)

Several native species are recommended for planting along with vetiver, including the Koai'a (*Acacia koaia*), a nitrogen-fixing low-elevation Koa tree, Nanea (*Vigna marina*), a nitrogen-fixing ground covering vine, and A'ali'i (*Dodonaea viscosa*) a fire resistant shrub that creates leaf litter and quality soil. These species can help restore the soil as well as provide a natural nutrient source for other plants. A variety of species and different functional groups of species (grasses, shrubs, trees) should be planted to help recreate the canopy structure of native forest ecosystems. Grasses that have been successful in West Maui include Pili grass (*Heteropogon contorta*), 'Uki 'uki grass (*Dianella sandwicensis*), and *Carex spp*. Shrubs that have done well include: Ma'o (*Gossypium tomentosa*), 'Ulei (*Osteomeles anthylidifolia*), and Ilima (*Sida fallax*). Trees that have been successful include Wili wili (*Erthrina sandwicensis*) and the aforementioned Koai'a.

Native plants should be planted once 2-3 inches of sediment have accumulated, approximately 6 months to 1 year after vetiver plantings, depending on rainfall and storm frequency in the area. All native plants should be planted at a minimum distance of 1 foot away from the vetiver grass. Native trees and bushes should be planted 3 ft apart with grasses planted in between at a distance of 1.5ft.

If collecting native seed in the area, be sure to propagate the seeds in pots before planting to allow a root ball to form. This increases the likelihood of success when outplanting. When collecting seeds, keep the following tips in mind:

- Don't collect seeds in protected areas such as cultural reserves or sites, natural preserves or other protected areas.
- Don't break branches or harm the mother plant when collecting seeds.
- If seeds have fallen to the ground, collect those seeds first.
- Ensure seeds are at the appropriate maturity for germination (e.g when seed pods are opening, seeds are drying out, etc.).

For more information on proper seed collection techniques please visit: https://www.fs.fed.us/wildflowers/Native_Plant_Materials/developing/collecting.shtml

Figure 19. Vetiver and native species being used to stabilize a slope in Wahikuli. (Photo by Jennifer Vander Veur)

Planting using hydroseeding techniques

Hydroseeding can also be used as a planting method (in lieu of broadcasting or sowing dry seeds), to establish native vegetation and further control erosion. Hydroseeding is a process where seeds and a combination of fertilizers, tackifiers, and other additives are combined with water and mulch to form a slurry that is sprayed on the ground. It is an effective erosion control technique, although it can be expensive for small areas due to mobilization costs. Daily watering is recommended especially for the first several weeks to promote reestablishment of vegetation.

Section 4: Proper Maintenance of Dirt Roads

Maintenance is one of the most important aspects of dirt road management but is often not practiced frequently enough. Proper maintenance is critical to minimize damage to the roads themselves, reduce long-term costs, and prevent sediment pollution from entering our streams and nearshore environments.

10 best practices for maintenance of dirt roads:

1. Minimize flow and velocity of water on the roads, and distribute runoff inland in as small and discrete amounts as possible to increase sediment retention.

2. Distribute flow to areas of natural vegetation and areas with flat or mild slope, increasing ground water infiltration.

3. Minimize exposure and disruption of bare soils to avoid conveying flow on bare soils or recently exposed soils to minimize sediment carried in runoff into stream gulches.

4. Never push sediment into the gulches. This was a frequent and destructive practice in the past and slows the trajectory of restoration efforts and contributes to the impact of sediment on coral reefs.

5. Minimize rutting on the road (i.e. deep tracks from the wheels of vehicles or the flow of water) and amend steep areas with gravel; for persistent erosion areas consider using concrete or a 4x4 ATV rather than trucks.

6. Minimize exposure of new bare soil as much as possible consider seeding and watering for stabilization.

7. Carry out maintenance assessments 3 times per year; once during the dry season in July-September and twice during the rainy season in November - February. Maintenance should be conducted promptly following an assessment that reveals some damage has occurred. Maintenance may only need to be carried out 1-2 times per year.

8. Perform assessments and conduct work with the supervision of the trained assessor.

9. Where practical, and especially when practices have been built correctly, use hand labor over machinery, as large machinery can dislodge sediment and create additional impacts.

Maintenance of Specific Practices

Vetiver Grass / Sediment Traps

- Vetiver grass should be irrigated and checked regularly (every 1-2 weeks) after installation for the first 2-3 months.
- Dead plants must be replaced for the traps to continue to be effective. If some plants die or there is a break in the sediment traps, water can find its way through and it compromises the BMP.

Vetiver Sediment Traps and Stone Check Dams

When these BMPs are half full of sediment (particularly the first and second vetiver rows; 2 feet of storage below the road elevation should be considered a minimum), they must be cleaned out. The steps involved are:

- Scoop dirt out from in front of them to make way for more sediment to collect. It should be either removed by heavy equipment or shoveled out from harder to reach areas.
- Scoop out the rock with deposited sediment
- Add in fresh stones and/or replace old stones after removing the sediment

The sediment should be removed and not placed in the path of water or potential runoff. There are a number of things you can do with the removed sediment, including using it to grow native species on site (in pots), or placing it in burlap bags to attenuate flow.

Note: At road kickout outlets, vetiver sediment traps may need more diligent maintenance.

Native plants

Check plant survivorship regularly after planting until the plants have established. Replace dead plants as needed.

Water Bars

Sediment deposited along the water bar should be removed with a shovel or spade, and the area should be compacted with a tamping bar or portable roller.

Section 5: For more information

Technical assistance can be provided by:

• West Maui Ridge to Reef Initiative (WMR2R): www.westmauir2r.org

Please provide the WMR2R Coordinator with an update on road maintenance in order to help us track watershed restoration efforts

• National Resources Conservation Service (NRCS): https://www.nrcs.usda.gov/wps/portal/nrcs/main/pia/technical/engineering/

• West Maui Soil and Conservation District: http://www.mauicountysoilandwater.org/west-maui/

• Ridge to Reefs: www.ridgetoreefs.org

Additional technical information can also be found in the following guides:

• Guide to Forest Road Engineering in Mountainous Terrain (Fannin and Lorbach, 2007): http://www.fao.org/docrep/012/a1241e/a1241e00.pdf

• Unpaved Road Standards for Caribbean and Pacific Islands (Horsley Witten Group, Inc; and Protectores de Cuencas, 2017).

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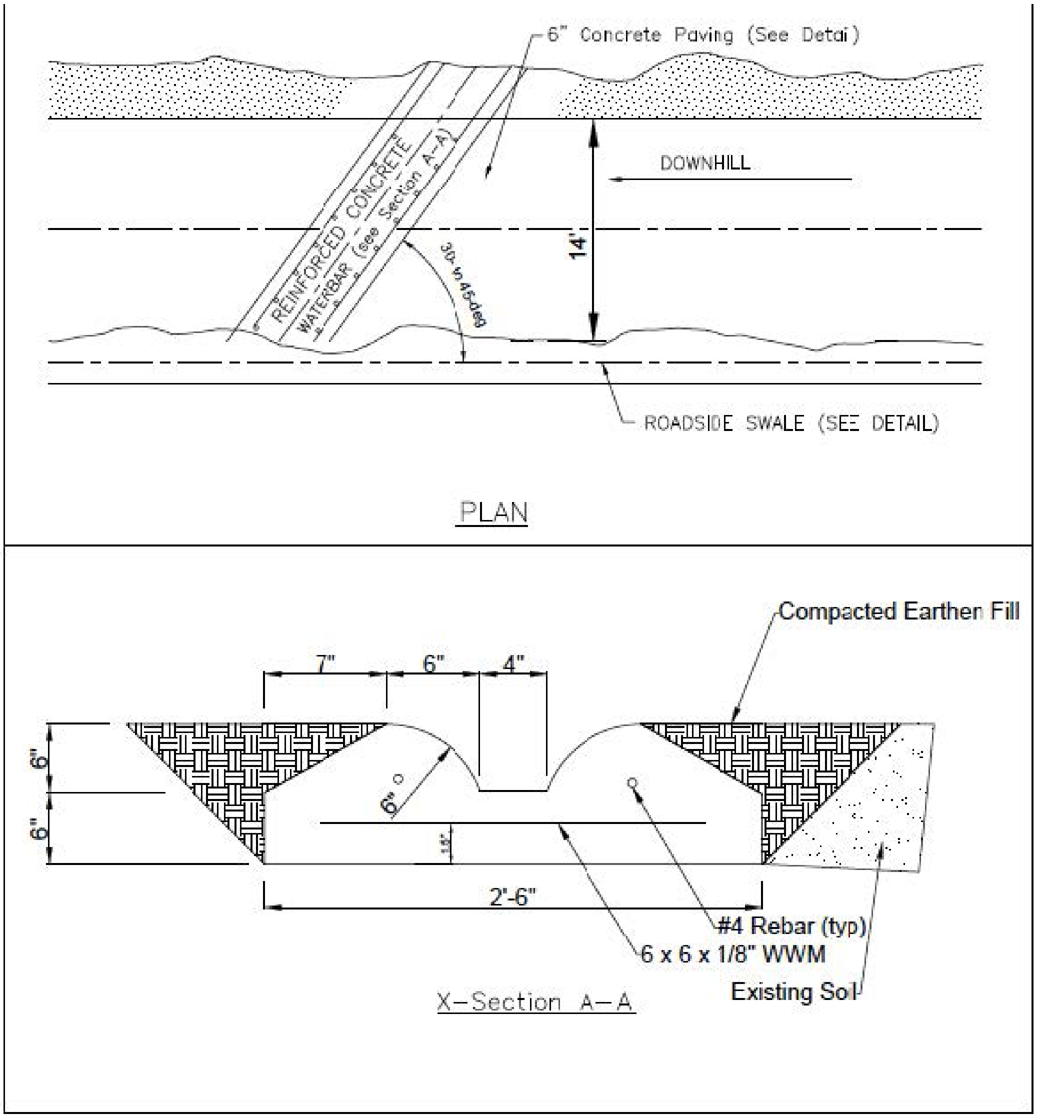

Figure 20. Concrete swale (Coral Bay Community Council)

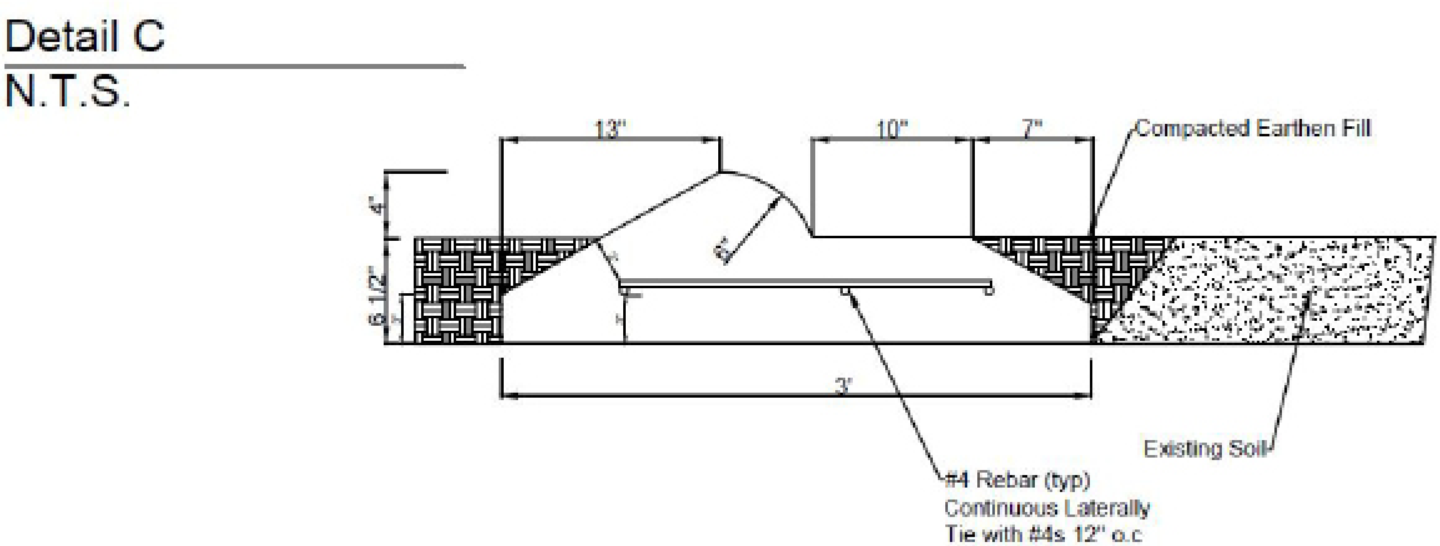

Figure 21. Concrete swale (for when drainage channels begin above the elevation of the road and must cross it perpendicularly) (Coral Bay Community Council)

Appendix I: schematics for greater design detail

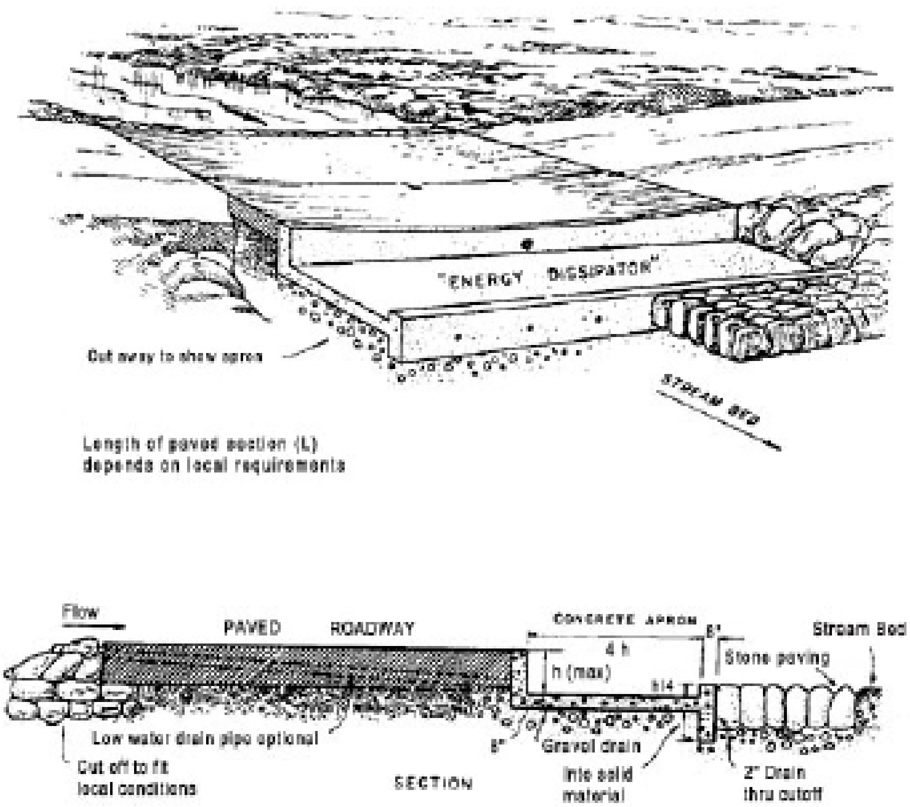

Figure 22. Concrete swale for where there is already intermittent concentrated channel above a road and flow is primarily during wet weather Hardened fill stream crossings provide an attractive alternative for streams prone to torrents or debris avalanches (Amimoto 1978).