Training on

Roads for Water and Resilience

DRAINAGE
FROM UNPAVED ROADS

Outline

1. Introduction

- Drainage from unpaved roads is usually less developed:
  - Yet maintenance problems to unpaved roads are largely caused by lacking drainage
  - As a result sedimentation from unpaved roads can be 15% of sedimentation in upper catchment (data from Upper Tana Basin Kenya)
  - And opportunities to harvest water are lost

2. Important considerations

For an effective drainage system ask yourself:

- Where is the water **coming** from?
- Where is the water **going**?
- Where **should** it be going?
- What **treatment** is needed to make it go there?

2. Important considerations

Important factors:

I. Slope
II. Gradient
III. Hydrology

2. Important considerations

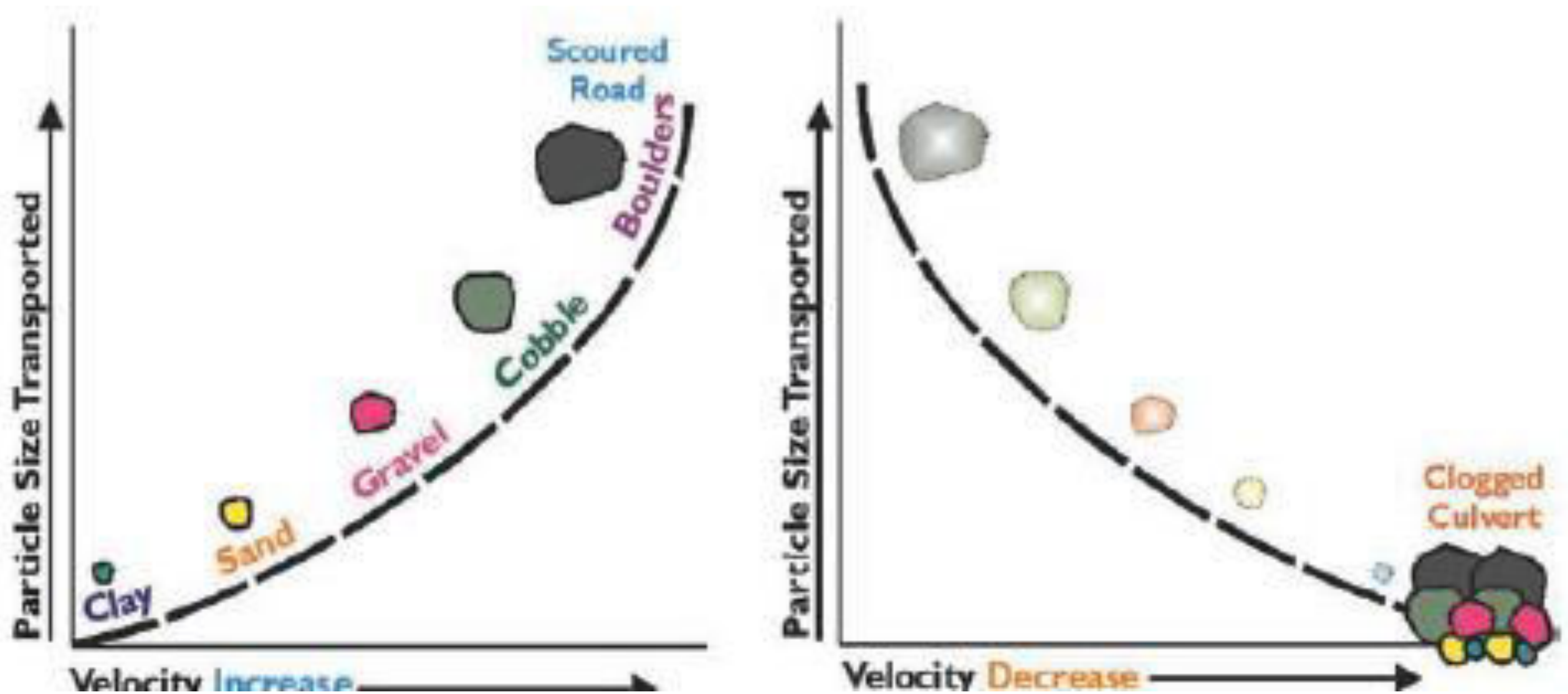
I. Slope = velocity of run-off

- Velocity increase:
  - The volume of sediment that can be moved increases 4x when the velocity is doubled
  - The size of particles that can be transported increases by 8 X when the velocity is doubled.
  - As water depth increases, velocity increases because relative surface tension decreases.
  - As water depth increases, velocity increases because relative surface tension decreases.

2. Important considerations

I. Slope = velocity of run-off

- Velocity decrease:
  - Surface roughness, however, can reduce shear force and erodibility of the exposed surface.
  - If the downslope is low gradient deposition and clogging will occur.


Scoured
Road
Boulders
Cobble
Gravel
Sand
Clay
Particle Size Transported
Velocity Increase
Clogged
Culvert
Particle Size Transported
Velocity Decrease

2. Important considerations

II. Gradient

- Ideal road grade:
  - The longer the segment, the greater the potential for erosion.
  - Grades ranging from 4-10% are ideal, with frequent grade reversals.
  - Drainage is assured if the road reverses grade every 60-100 meters.
  - Water naturally exits the roadway at every grade reversal

2. Important considerations

Further implications of slope and grade for drainage

- Try to reverse the slope of the road and avoid long stretches
- As road grade steepens, drainage features must be closer together.
- Maintaining vegetative cover increases roughness and reduces erosion,
- Drainage features need to be more closely spaced on fine grained soils.
- Drainage features with grades less steep than the road surface or road ditch will tend to become clogged
- A well vegetated buffer zone or row of stones at the edge of the road will tend to disperse flow, reduce runoff velocity and collect sediment from road runoff.
- To keep drains self cleaning, ditches and the road surface need to have a slope equal to or greater than the contributing source of sediment. The faster the water, the more sediment it can transport at an increasing rate.

2. Important considerations

III. Hydrology

- Important hydrological factors:
  - Number of stream crossings
  - Side slope
  - Moisture regime

3. Drainage Management

- Water either infiltrates, evaporates or it will contribute to overland flow or run-off.

- The proportion of rainfall that becomes streamflow depends on:
  - Size of drainage area: larger area means larger volume of run-off
  - Topography: run-off volume increases with steepness of slope
  - Soil: permeability and infiltration capacity

3. Drainage Management

Drainage of unpaved roads is critical to stand up to damaging effects of weather and traffic. And is moreover important for road water harvesting!

First considerations for management of unpaved roads:

- Maintain natural vegetation, buffers and drainage ways
- Minimize the creation of steep slopes
- Integrate in landscape

3. Drainage management

What we know now:

- Drainage management for unpaved roads is important
- Enable water harvesting from unpaved roads

- 2 types of drainage:
  - *Surface drainage*: Collect water from road surface and adjacent areas
  - *Subsurface drainage*: Transport water through pores as subsurface flow

4. Surface drainage

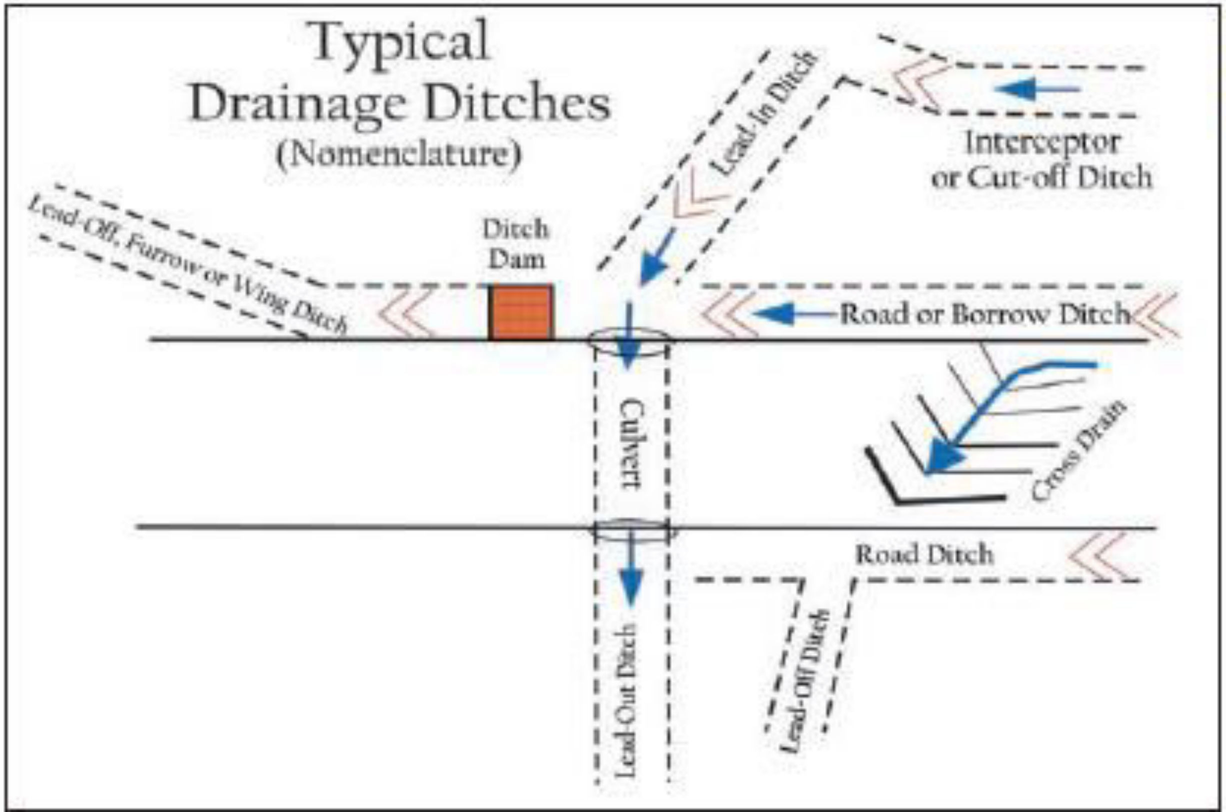
- Collect water from road surface, shoulders, side slopes and adjacent areas.
- Carry it away via slopes, ditches and pipes

- Purpose:
  - To cause water to leave the road as shallow, non-erosive sheet flow, and enable harvesting of run-off water.
  - In a direction and pattern to suit combinations of road material, slope and terrain.

4. Surface drainage

Ditches:

- Remove runoff quickly and reduce seepage into road subgrade
- Provide opportunity for sediments to be removed from run-off water before it enters surface waters or groundwater.



4. Surface drainage

Construction of ditches:

- Locate ditches on the up slope side to prevent water from flowing onto the road from uphill
- Design and grade ditches and bank side slopes at a maximum 2H:1V ratio
- Line ditches with a $<5\%$ slope with grass to filter sediments
- Line ditches with a $>5\%$ slope with riprap stone to prevent erosion
- Prevent water from standing in a ditch, this can weaken the road
- Check and clean ditches regularly, especially after major weather events

4. Surface drainage

- Multiple measures and structures possible:
  1. Road Crown & Cross-slope
  2. Rolling dip
  3. Water bar
  4. Flat land drain
  5. Cut-off drain
  6. Cross drain
  7. Filtrating bunds
  8. Soil bund

4. Surface drainage

1. Road crown & cross-slope

- Road profile is the cross-sectional shape of the road surface
- Different road templates and drainage systems determine where water is collected and where it can be used

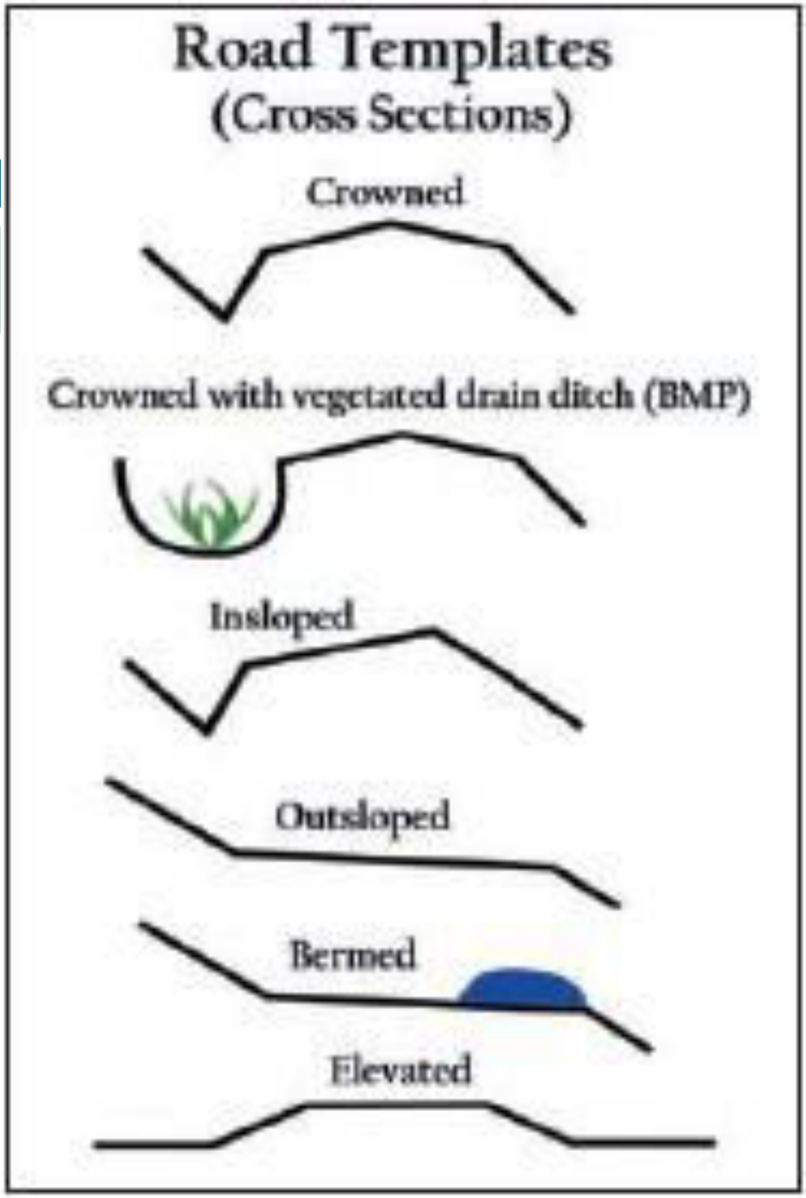
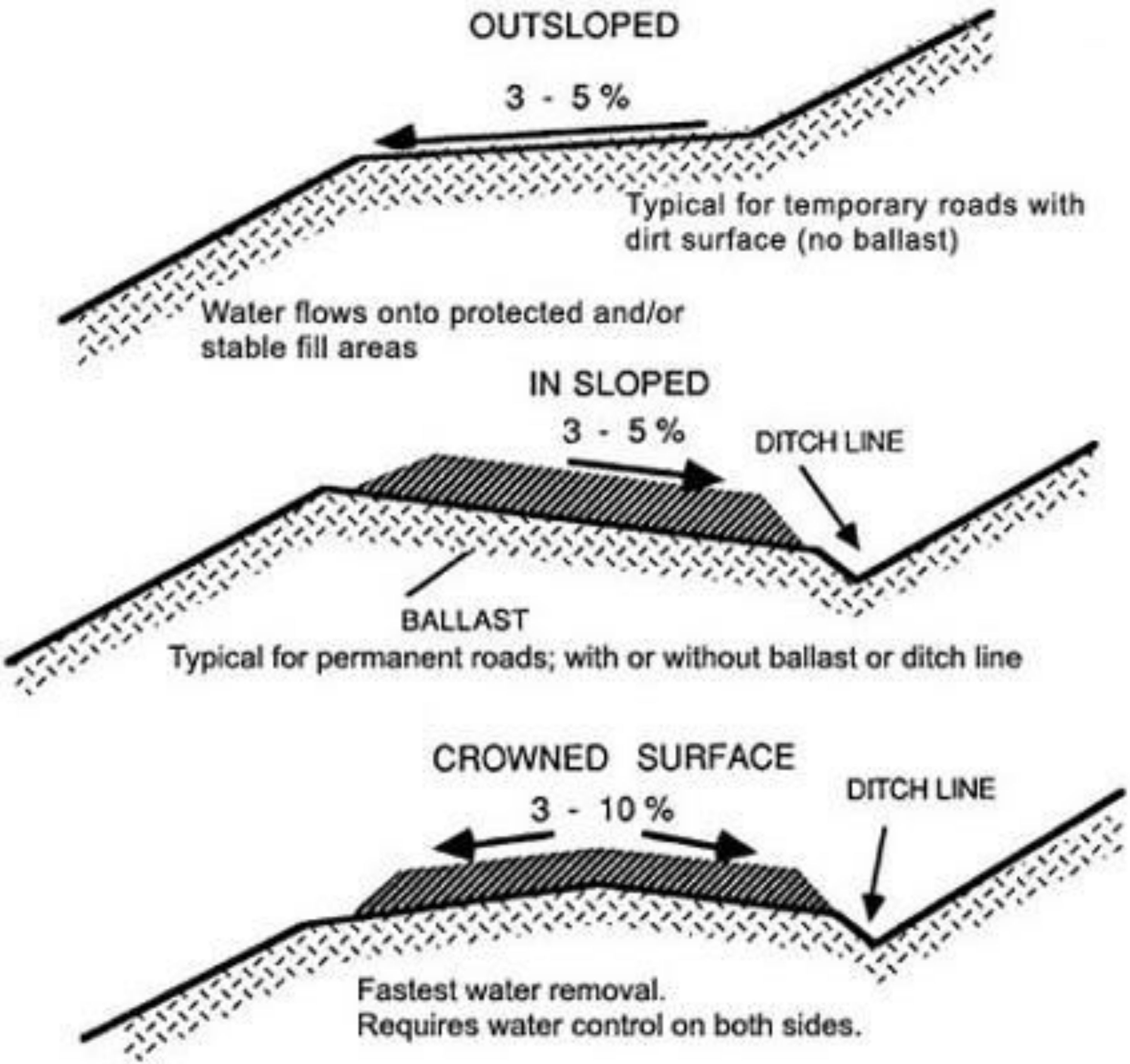


Figure III-3: Alternative cross sections used to assure sufficient cross sloping and drainage.

4. Surface drainage

1. Road crown & cross-slope

- Centreline crown: sheds water to both sides of the roads from a highpoint in the road centre.
- Cross-slope: slope angle to one side of the road
  - In-sloped: Drains water from entire road width toward the cut-bank or up-slope side. Used of steep hills, or with high flow velocities
  - Out-sloped: Drains water toward a fill-bank or down-slope side. In order to avoid concentration of water in a ditch.


OUTSLOPED
3 - 5 %
Typical for temporary roads with dirt surface (no ballast)
Water flows onto protected and/or stable fill areas
IN SLOPED
3 - 5 %
DITCH LINE
BALLAST
Typical for permanent roads; with or without ballast or ditch line
CROWNED SURFACE
3 - 10 %
DITCH LINE
Fastest water removal.
Requires water control on both sides.

4. Surface drainage

1. Road crown & cross-slope

Construction guidelines for grading:

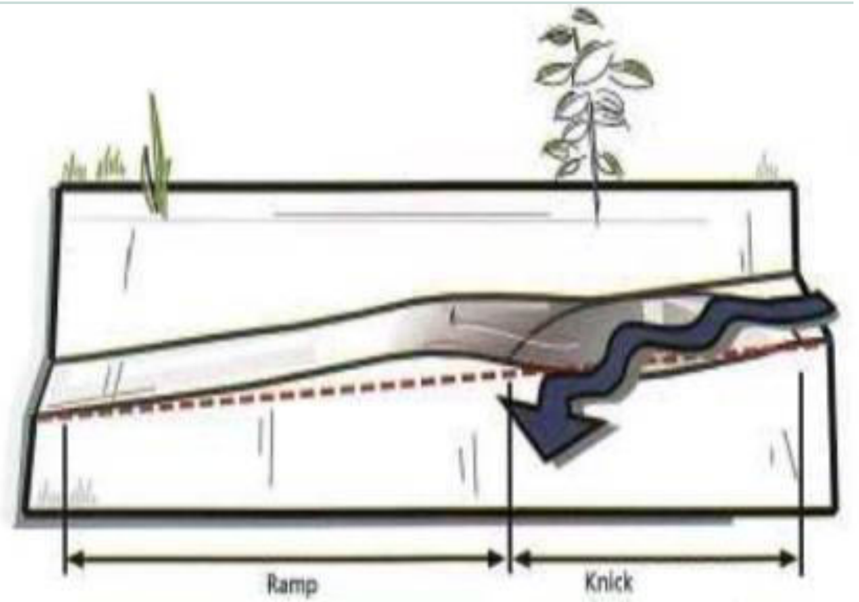
- Grade roads when moist but not wet
- Do not grade when heavy rains are predicted
- Crown roads ½ to ¾ inch for each foot of road width, from roadcenter, to ensure good drainage
- Outslope roads with over-the-bank drainage problems entirely to the ditched side of the road

4. Surface drainage

2. Rolling dip

Most reliable cross drain for low standard roads:

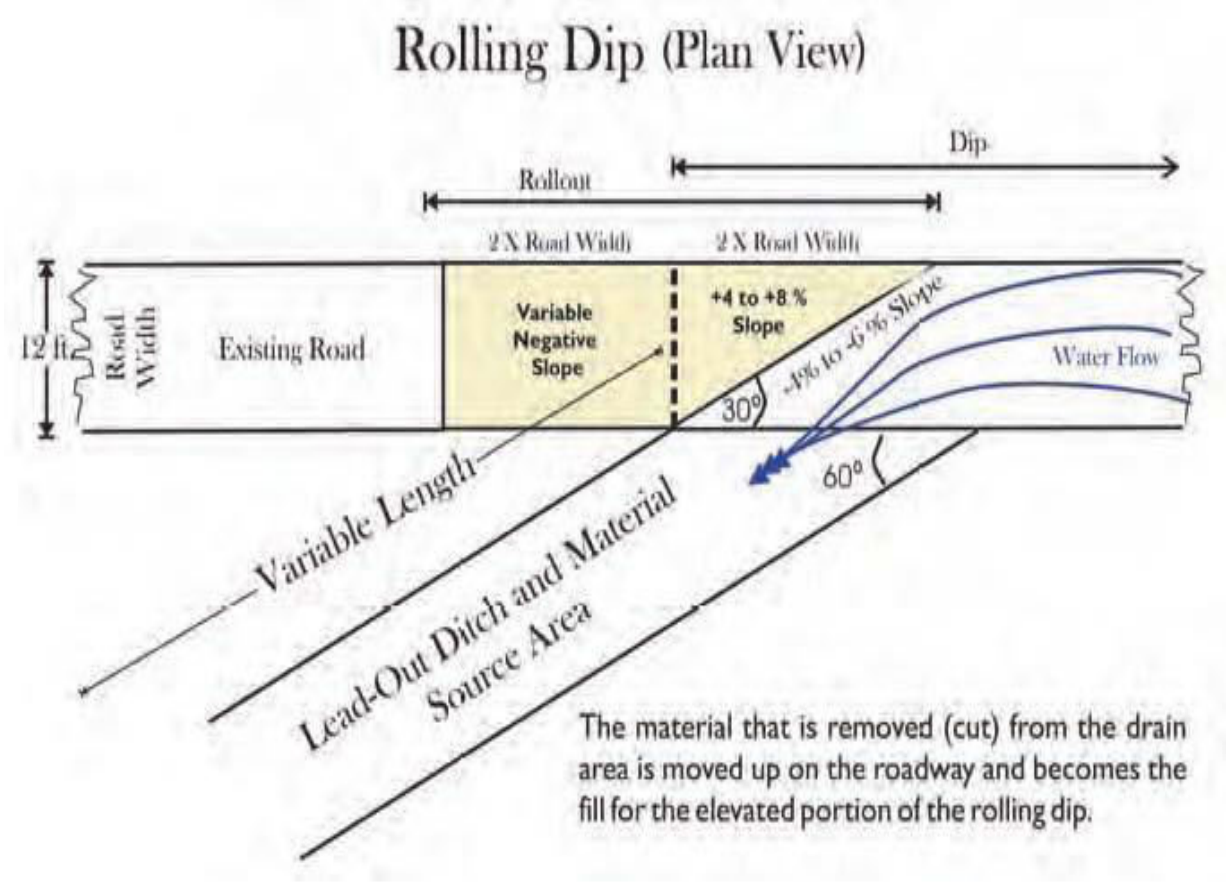
- Used to drain roads having grades between 3 and 15%
- Function: collect surface runoff from the roadway and/or road ditch and direct the flow across and away from the roadway
- Broadly angled dip drain with a cross slope of 4-8%, steep enough to flush away accumulating sediments



4. Surface drainage

2. Rolling dip

Design is excavated cross drain



4. Surface drainage

2. Rolling dip

Benefits:

- Prevent erosion from water flowing down the road
- Acts as a cross drain outlet drainage from uphill side of the road
- Cheap, easy, and effective on low volume roads

4. Surface drainage

2. Rolling dip

Construction:

- Part of the road and the adjacent areas is excavated so as to lead the road run-off to adjacent land
- The excavated material from the dip is used to create to a higher area in the dirt road, making the road to slightly undulate and so create different drainage segments
- The velocity of flow must be sustained through the dip to prevent puddling and to keep sediment moving through the dip drain.
- Can be channeled to land or ponds

4. Surface drainage

2. Rolling dip

Considerations on slope:

- Too flat terrain (road grade less than 3% or cross slope less than 5%)
  - Difficult to build a dip drain that will not lead to runoff. Instead make overland drain.
- Road grade too steep (greater than 15%)
  - The roll-out will be too steep on the downhill side and traffic will damage the structure.

4. Surface drainage

2. Rolling dip

- Make sure rolling dip goes to proper land!

4. Surface drainage

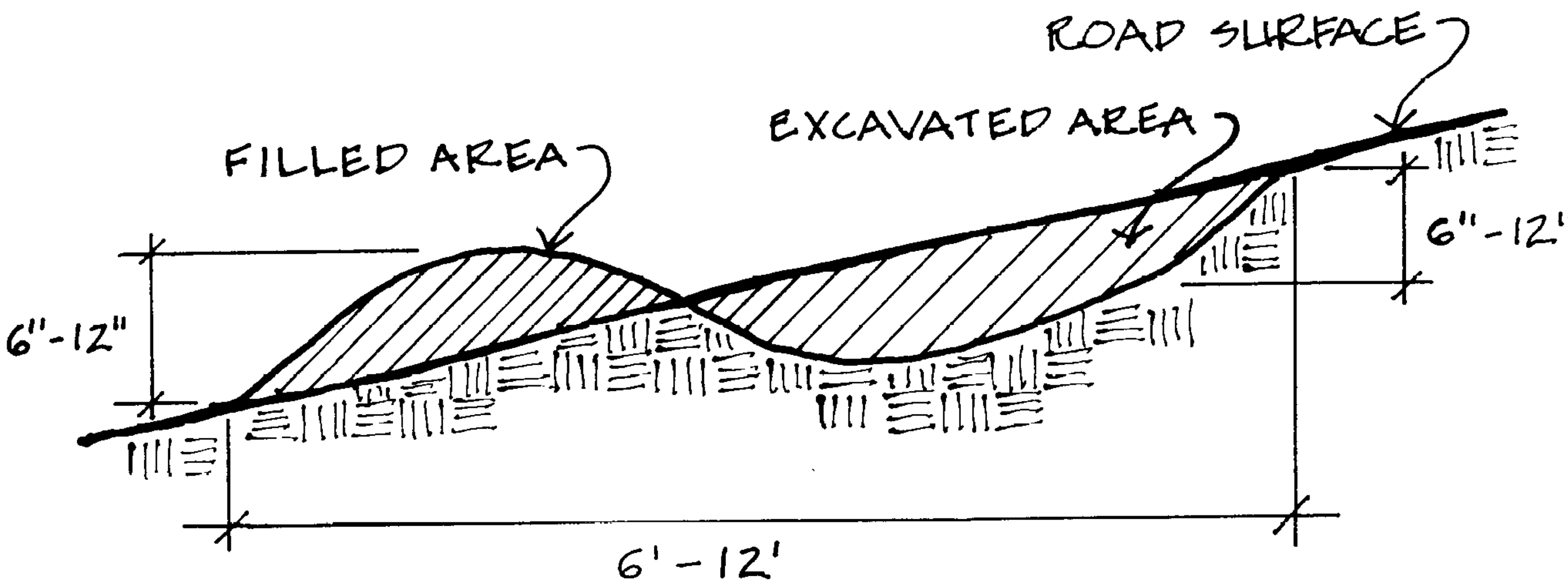
3. Water bar

- A water bar is a pushed up mound of earth or hump on the roadway used to deflect runoff from the road surface.
  - Quick, easy and cheap to build
  - More effective when built at an angle of 30% to the slope grade.
  - Waterbars are normally built to a height of 15-40 cm above the road surface
  - Protect drainage at outflow with stone, grass, sod or anything to reduce flow velocity.

4. Surface drainage

3. Water bar

Cross section of a waterbar



4. Surface drainage

3. Water bar

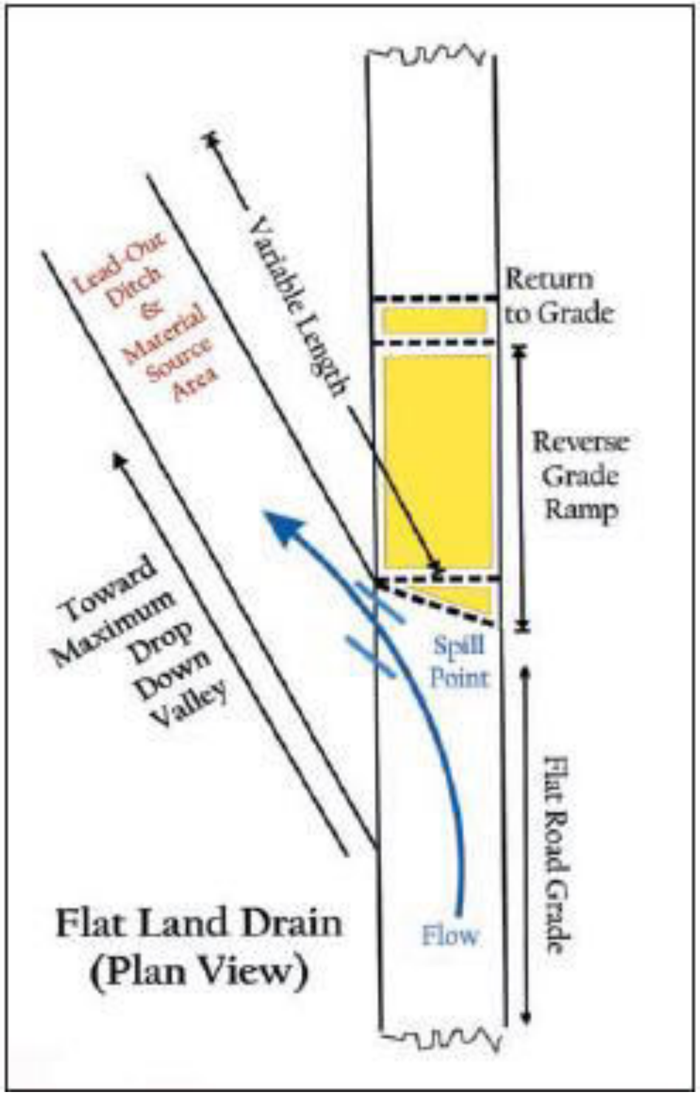
Spacing needed between water bars	
Slope	**Diversion spacing (feet)** *(1 feet = 0.3 meter)*
<5%	125
5-10%	100
10-20%	75
20-35%	50
>35%	25

4. Surface drainage

4. Flat land drain

- A flat land drain is a type of grade break, a small increase in road elevation on a downhill slope.
- It causes water to flow off of the road surface to a lead-out ditch
- Gradient should be <2%

Note: It is more difficult to apply for water harvesting



4. Surface drainage

5. Cut-off drain (turn out)

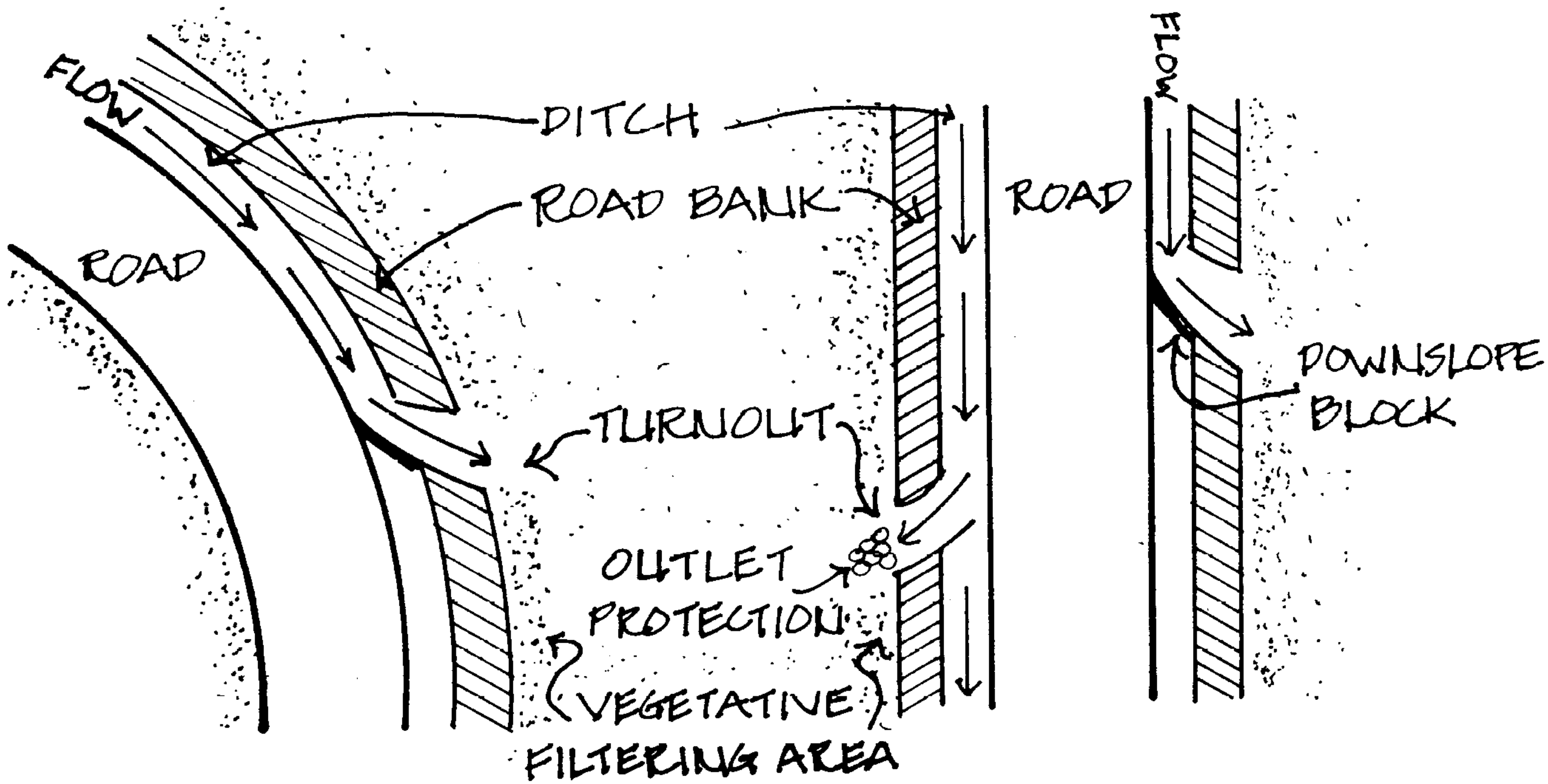
- This photo shows a cut-off drain that has been cut by a road grader for the purpose of diverting run-off water from the road into an adjacent field.

- They can be excavated by hand, or ox-scoops, to divert rainwater into borrow pits.

4. Surface drainage

5. Cut-off drain

Example of cut-off drain construction



4. Surface drainage

5. Cut-off drain

Spacing needed between cut-offs	
Road Grade (%)	**Distance (feet)** *(1 feet = 0.3 meters)*
2	250
5	135
10	80
15	60
20	45
25	40

4. Surface drainage

6. Cross drain

Install a drain/pipe /culvert at an angle across the road considering natural drainage.

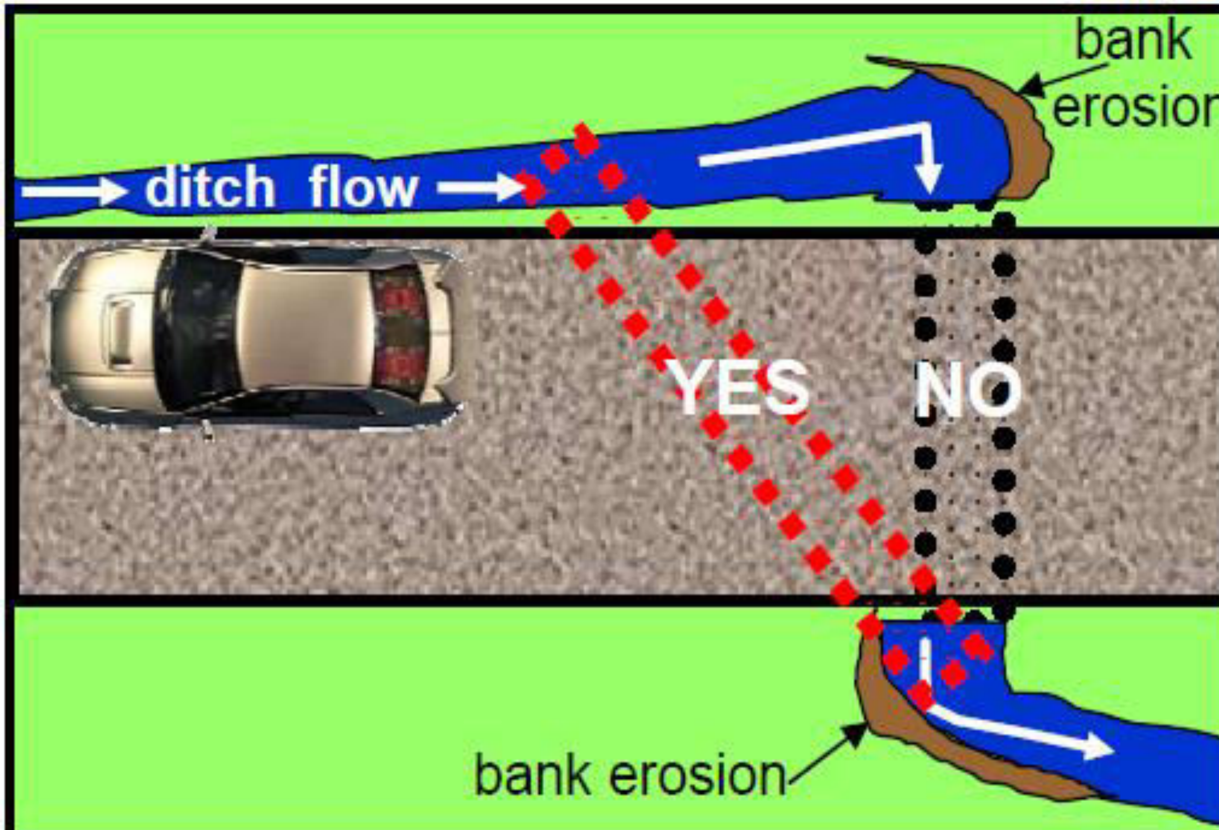


Figure 1. The crosspipe shown in black is improperly aligned straight across the road. The red pip e indicates a better pip e placement that will carry more water and cause less erosion.

4. Surface drainage

6. Cross drain

Benefits:

- Reduction of bank erosion
- Pipe efficiency and flow capacity are increased when water does not have to make a sharp turn
- Possibility to continue stream flow
- Water harvesting options

4. Surface drainage

6. Cross drain

Considerations:

- Fill the cross pipe with material similar to existing road material
- Pipes should have headwalls and endwalls to reduce erosion
- Outlet the drain/culvert to a vegetated area, never directly into a stream

4. Surface drainage

6. Cross drain

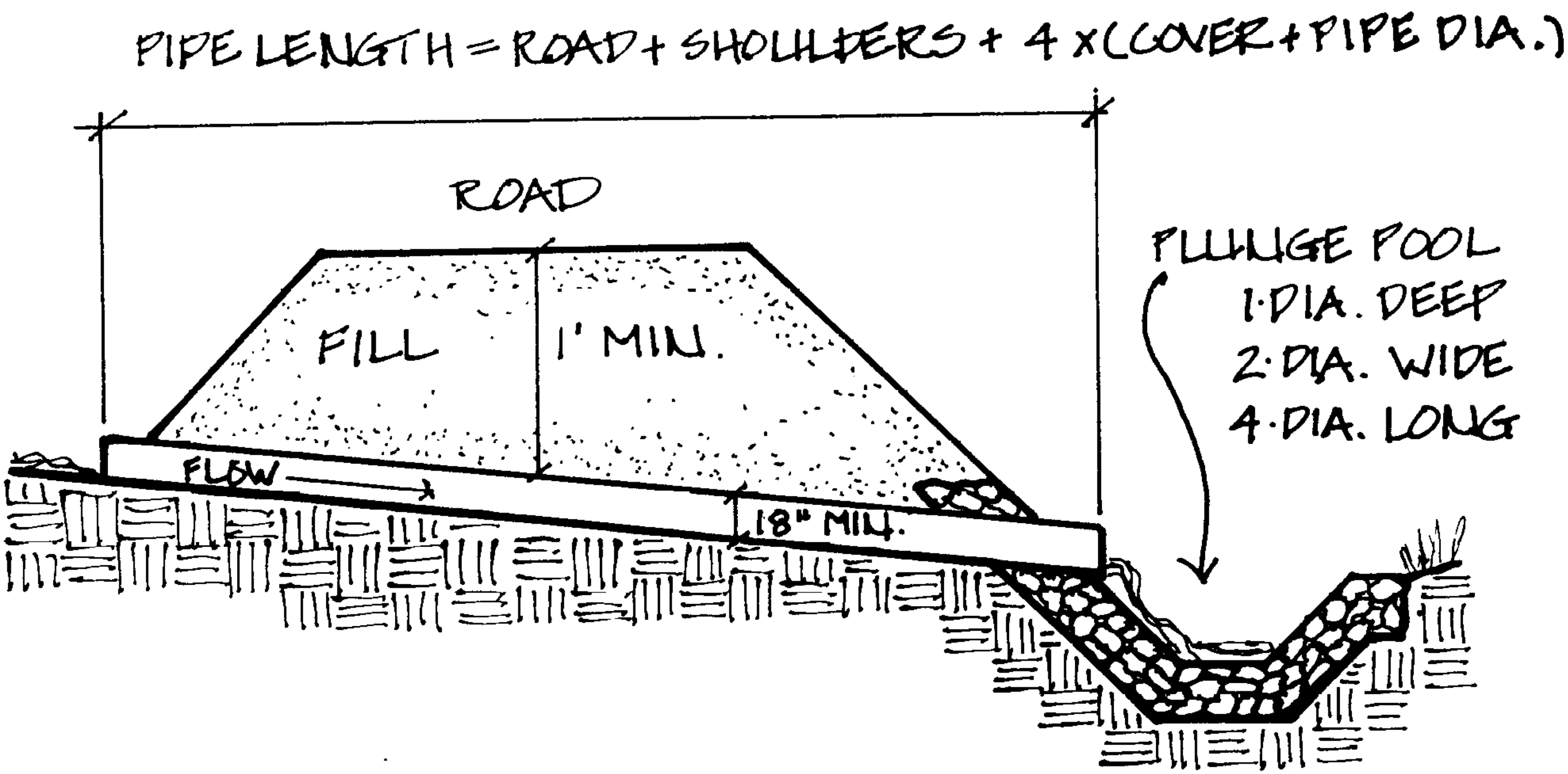
Construction:

- Install culvert during period of low water flow
- Place culverts no more than 500 feet apart, and wherever needed due to crossing streams and steep slopes
- Ensure a slope of 0.5% or greater to allow for positive drainage flow
- Extra length of culvert should be considered to accommodate for headwalls
- Design culverts to handle at least a ten-year-frequency storm

4. Surface drainage

6. Cross drain

Culvert profile and cross-section



4. Surface drainage

6. Cross drain

Spacing needed between culverts	
Drainage area (acres) *(1 acre = 0.4 hectare)*	**Culvert diameter needed (inch)** *(1 inch = 2.54 cm)*
0-5	12
5-10	18
10-15	24
15-20	30
>20	Detailed design needed

4. Surface drainage

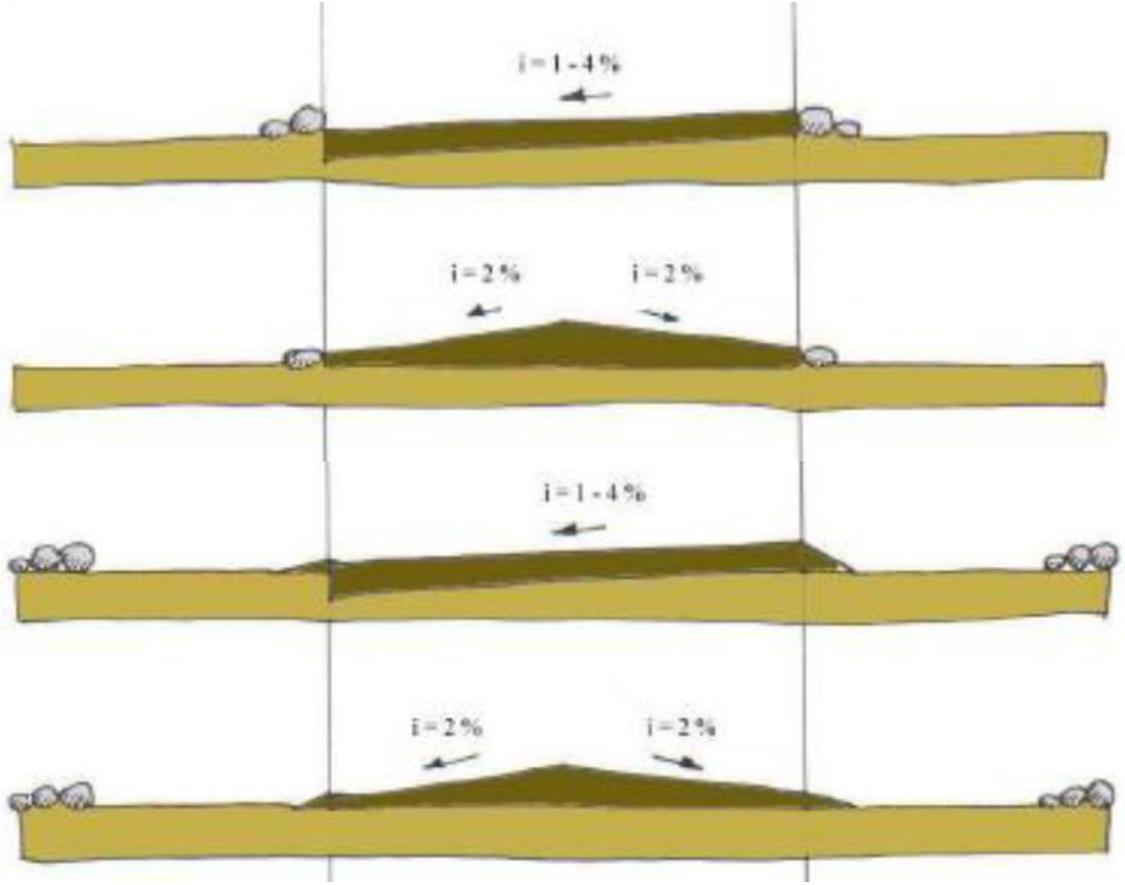
7. Filtrating bunds

- Very low permeable bunds along the road made of boulder rocks (also called filtrating bunds, or *diguette filtrante* in French)

- Purpose: To decrease runoff speed and to spread runoff gently to the adjacent fields
- Bunds 3-4 m from the border of the road are very effective

4. Surface drainage

7. Filtrating bunds



4. Surface drainage

7. Filtrating bunds

Niger: Stone bunds along road to reduce erosion

4. Surface drainage

7. Filtrating bunds

Combine with planting pits on upstream side

4. Surface drainage

8. Soil bund

- Used to conduct run-off from cut-off drains to water storage structures
  - Grass waterways for slopes up to 25%
  - Steeper slopes, channel lined with stones, masonry or reinforced concrete

4. Surface drainage

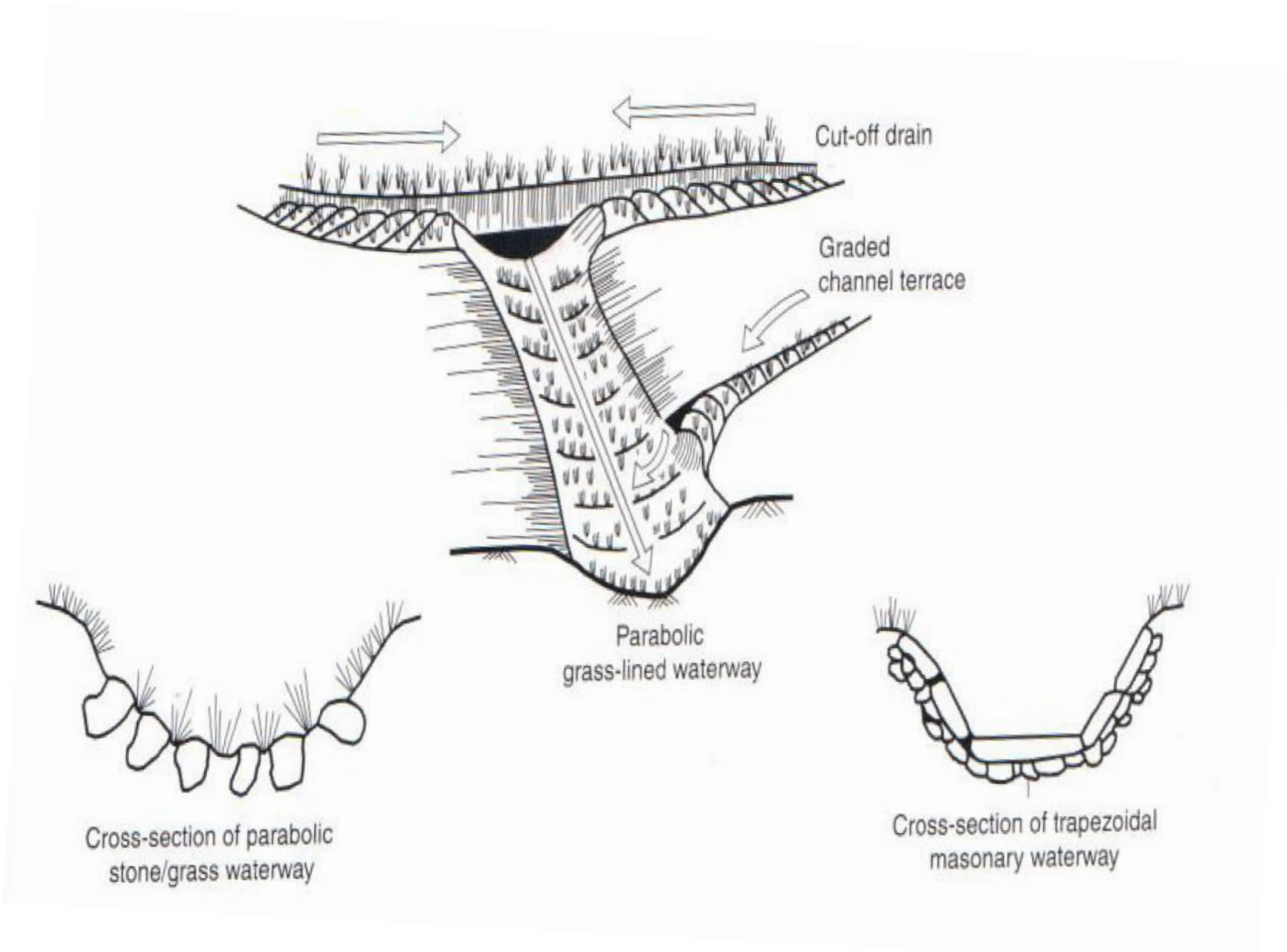
8. Soil bund

Considerations:

- Dimension depends on expected discharge
- Diagonally across de slope not recommended, if they break or overtop can cause serious damage
- The preliminary position should be determined from a reconnaissance field survey
- Where possible, it should be located in a natural depression or drainage way.
- Should be inspected after every heavy storm

4. Surface drainage

8. Soil bund



5. Subsurface drainage

- Purpose: To collect subsurface water before it appears on road surface or in the ditch. Water which is collected can be directed to a water storage location

- Underdrain: drainage system under a road ditch to collect and transport subsurface water.
  - Variety of shapes and sizes which allow water to enter the conduit, while keeping sediment out
  - Consists of a trench parallel to the road with a free draining aggregate and perforated pipe to carry the water to an outlet

5. Subsurface drainage

Benefits:

- Low cost, easy to install
- Separate clean subsurface water from road runoff
- Decrease volume of water on road surface
- Allows water conduit to storage without overflow of road bank

6. Additional measures

Additional measures are useful for maintaining the drainage system over time.

These measures include:

- Outlet protection
- Headwalls and endwalls
- Bank stabilization
  - Vegetation
  - Structures
  - Combinations

6. Additional measures

1. Outlet protection

Outlet protection is important for the control of erosion at the outlet of a channel, culvert or ditch.

- It reduces the velocity of water and dissipates energy
- It serves as a type of buffer and removes sediments and other pollutants

6. Additional measures

1. Outlet protection

- Structural outlet protection:
  - Install at all pipe, culvert or other water diversion where erosion can occur
  - For example with rock apron, riprap conveyance channel, splash/plunge pools and level spreaders.
- Non-structural outlet protection:
  - Filter zones, natural buffers, vegetation

6. Additional measures

1. Outlet protection (structural)

- Rock apron:
  - Size and placement depends on culvert diameter and expected water flow.
  - Only use this with a vegetative filter strip
- Riprap:
  - Use riprap conveyance channel to remove sediments from runoff.
  - Use on steep slopes where otherwise erosion would occur, and with an outlet that goes directly into surface waters.

6. Additional measures

1. Outlet protection (structural)

- Splash/plunge pools:
  - Detain water and allow sediment to settle out
  - Use in areas with <10% slope to consolidate sediment for easier removal
- Level spreaders
  - Should be flat (0% grade) to ensure uniform spreading of runoff
  - Drainage area limited to 5 acres
  - Stabilized with appropriate mixture of grass

6. Additional measures

1. Outlet protection (non-structural)

- Filter zones:
  - Natural sediment traps
  - Slowing and filtering water before it enters surface waters
  - If little/no vegetation exists, create or enhance a filter zone by planting diversity of native grasses, shrubs and trees.
  - Routine and careful maintenance need to ensure healthy vegetation

6. Additional measures

1. Outlet protection (non-structural)

Recommended filter zone widths	
Slope of land between road and water	**Recommended filter zone widths (feet)** *(1 feet = 0.3 meters)*
0-10%	50
11-20%	51-70
21-40%	71-110
41-70%	111-150

6. Additional measures

2. Headwalls and endwalls

Walls at the opening of a pipe to protect it from erosion due to waterflow. (Headwall at the inlet, endwall at the outlet.)

- Purpose: Support the road and protect the ends of a pipe. Also improve capacity and efficiency while reducing erosion.
- Necessity: water is turbulent when it changes direction, and water accelerates in a pipe, both increase erosive potential.

6. Additional measures

2. Headwalls and endwalls

Examples

6. Additional measures

2. Headwalls and endwalls

Benefits:

- Low-cost, long-lasting solution for erosion problems
- Prevent water flow to damage drainage structure and road
- Increase flow capacity of pipes by reducing turbulence and direction of flow

6. Additional measures

3. Bank stabilization

I. Vegetation – seeding
II. Vegetation – shrubs and trees
III. Structures: walls/revetment systems
IV. Combinations of structures and vegetation

6. Additional measures

3. Bank stabilization

I. Vegetation – seeding

- Effective and inexpensive method
- Stabilize bank or any bare area
- Grass and legumes slow the movement of water, allowing water to seep into the ground and minimize impact of runoff
- Surface should be left rough, to reduce water velocity and to help hold seed and mulch.
- Select preferably a native mix appropriate for site soil and drainage
- Mulch after seeding

6. Additional measures

3. Bank stabilization

II. Vegetation – shrubs and trees

- Use live plant materials to stabilize steep slopes and stream banks
- Create vegetative filter zone
- Erosion control

6. Additional measures

3. Bank stabilization

III. Structures: walls/revetment systems

- Gabions: Rectangular wired mesh baskets filled with stone
  - Slow velocity of runoff
  - Protect slopes from erosion

- Riprap: Layer of large stones as a protective wall
  - Place on roadside slopes and stream banks
  - Use on steep slopes and in sharp turns
  - Size of riprap depends on quantity and velocity of water flow

6. Additional measures

3. Bank stabilization

IV. Combinations of structures and vegetation

- Vegetated gabion:
  - Combine a gabion wall with live branches
  - Live branches root in gabions and slope, so binding gabions to the slope
- Vegetated riprap/joint planting:
  - Plant live stakes and branches between the open spaces in the rocks.
  - Roots improve drainage and reinforce the soil

7. In summary

- Standing water, seeping water, rain, snow, ice, frost and even a lack of water can contribute to road maintenance needs.
- Unpaved roads often lack proper drainage and require continuous frequent re-grading or other costly maintenance activities.

- With better drainage:
  - These costs are reduced
  - Water harvesting potential is increased
  - Sedimentation from roads is reduced

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