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GUIDELINE:
GREEN ROADS FOR WATER

ROAD INFRASTRUCTURE IN SUPPORT OF WATER MANAGEMENT AND CLIMATE RESILIENCE

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Dedication to Ian Neal, who is no longer with us in person, yet in spirit is.
Ian catalysed much of the early thinking on 'roads for water'.

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Executive summary

This Guideline discusses the beneficial use of roads for water management. Roads and water are currently seen as enemies, with water responsible for most of the damage to roads and roads being a major cause

of erosion, waterlogging, flooding and dust storms. This, however, can be turned around. This guideline discusses how with improved governance and with the use of a range of techniques, roads can be made into instruments for water management. Taking into consideration the global investment in roads, estimated at USD1-2 Trillion a year to which the recurrent costs of maintenance should be added, developing such green roads for multiple benefits can be a major transformative change to achieve climate resilience.

The Guideline argues for **adaptive** or **pro-active** resilience approaches to road development. In the adaptive approach roads are built in a conventional manner yet water management and landscape protection measures around the roads are systematically integrated in the construction and maintenance programs. The pro-active approach goes a step further: here road alignments and road designs are modified so as to serve not only the premier transport function but also to optimize water harvesting, flood retention, sedimentation and erosion control. Both these approaches yield triple benefits. First they reduce water-related damage to the roads. Second, damage to the landscape surrounding the roads, be it due to flooding, water logging or land degradation, is minimized. Third, and very significant, the beneficial use of water with roads is made possible.

The costs and benefits of the additional measures under the adaptive approach have been calculated for Ethiopia, where roads for water programs are implemented at scale. The cost of such additional measures along the roads were modest compared to the costs of the road and they earn themselves back four fold within a year. Similar returns are reported from Bangladesh and Kenya. In the pro-active approach the costs are generally higher because the design and alignment of the roads is adjusted. However, several of the modified designs under a pro-active green roads for water approach require less costs than the conventional designs. The adaptive and pro-active approach to climate resilient roads may be contrasted to the now more common **protective** approach to climate resilience for roads. Under this protective resilience approach the road itself takes centre stage and the road is shielded from any climate impact. This however generally leads to costly new specifications, typically in higher capacity cross drainage or different road material. Such enlarged cross drainage, however, though it may protect the road, will cause more flooding and erosion to the area surrounding the road, causing a net loss in resilience.

In different geographies there are different options in making use of green roads for water management and climate resilience. In semi-arid areas roads have a major imprint on the surface hydrology. Roads acts as barriers and drains for rain run-off. Because of this they can also be used for water retention at large scale. There are several techniques to systematically harvest water in semi-arid areas, whilst making use of the existing road infrastructure: flood water spreaders, flow dividers at culverts, road drifts or having road embankments act as storage reservoirs. It is useful to connect road drainage to water storage, such as infiltration trenches or farm ponds or use road bodies to divert water to where it is most useful. In pastoralist areas road bodies can be used to guide water to areas where grass is seeded and natural vegetation is regenerated.

Roads can also be used to improve watersheds. The choice for the road alignment and slope will influence drainage patterns in the catchment. This can be used to store more water in the catchment. The design and placement of culverts and water crossings affects run off velocity and can be used to counter land degradation. The road drainage system can be designed to guide water to productive land. Important structures are warping dams, road platforms, modified culverts and different water harvesting structures.

In mountain areas special attention is required to protect and manage the road environment with a range of land and water measures and by the careful selection of the road alignment. Where feasible, mass balance methods should be used whereby the material excavated for the road is used in road construction, so that the road and make wider roads without undue impact on the mountain landscape. Special care is required to create safe road water crossings, to make sure these do not damage the road and land along the road, but to safely guide the water to safe places Often the spoil can be used for such crossings. In mountain areas the development of roads also opens new springs and seeps, which may be major sources of domestic and productive water supply. This can be done in deliberate manner with springs systematically protected.

In coastal lowlands green roads for water management take on a different dimension. Roads double up as flood protection infrastructure and vice versa, flood embankments are used as roads. This requires cooperation between the responsible organizations in transport, water management and disaster risk reduction to optimize functions and co-benefits and come to joint specifications and better integrated concepts. In coastal lowlands roads also have a major impact on water management which is now often manifest in impeded drainage and water logging. As roads are the main infrastructure in these low lying areas, they can also be used to control water levels for productive use. Several techniques optimize the interface between roads and flood resilience: higher roads or road levees, flood shelters in flood prone areas, using excavation material to make local roads; having submersible roads in selected areas, evacuation planning and reinforcement of road embankments.

There are many green roads for water techniques that may be applied, explained in these guidelines: converting borrow pits, using non-vented road drifts, developing low embankment roads with flood ways. Unpaved roads deserve special attention. In most countries they constitute the majority of the roads and they connect the most remote settlements. They are also most vulnerable to damage caused by water, yet due to shortage of rural road maintenance budgets such damage is often not repaired. A range of techniques can both protect unpaved roads and make them function as instruments for water management: water bars, rolling dips, improved side drainage and infiltration bunds.

Special attention is also needed to systematically incorporate road side tree planting into road development: dust from roads is a neglected but major health hazard. Road side tree planting can mitigate this, and moreover, has other co-benefits: creating productive assets, reducing crop damage, reducing soil erosion, improving visibility, acting as a wind break, giving shade, sequestrating carbon, beautification. In planning road side tree planting one has to consider ownership of road reserve, plans of future road widening, economic value of tree species, shape of tree barrier, root development, road vision, road safety, access to water. Yet given the multiple benefits of road side tree planting, the Guideline argue that the practice should be far more widespread.

To introduce and make it work requires new types of governance: open to cooperation, focussed on sustainability and guided by trust and transparency. Experience in the on-going programs indicates that this is not difficult as there are gains for all parties. To get the process going may entail different steps: fact finding; getting sectors to talk; identifying champions; working on early implementation; working on different fronts; capacity building and research and consolidation in working methods. In Adaptive Resilience the road infrastructure as it is being optimally used for water management and climate resilience with additional - usually low cost - water control measures: it requires complementary programs; training for roadside users and farmers; special green funding arrangements for supplementary programs and Memorandum of Understanding between main sector departments. In Pro-active Resilience road infrastructure is from the onset designed to serve multiple objectives beyond transport: it requires multi-functional investment formulation; new integrated designs; training for engineers; modelling for specific challenges; special green funding arrangements for additional costs.

Finally, engagement of local communities is at the heart of green roads for water and climate resilience programs. Roads are at the heart of inclusive development. Besides their potential benefits for the physical environment, roads improve access to services and economic opportunities, road development offer direct labour and skill development opportunities and road programs can be a major injection into the local economy. To optimize all these opportunities requires the engagement of communities within the reach of the road, their representatives and other directly concerned parties at scale. The opportunities for engagement differ with the different steps of road development: in conceptualization and planning; in design; during construction; in maintenance and aftercare. The aim should be to undertake this at scale and have community engagement be part of the major programs. Communities can be a major force in the implementation of roads and green roads programs at scale – in the construction of rural roads, in the systematic maintenance and in undertaking additional adaptive green roads for water measures.

1. Introduction

1.1 Objective

The basic idea of “roads for water” is to make roads instruments of beneficial water management and resilience. Roads make a major imprint on hydrology. They block and guide water, concentrate runoff, interfere with subsurface flows, and change flooding patterns. Ibisch et al. (2016) describe the fragmentation of landscapes that has come with road development. They calculate that, at present, 20 percent of the global land surface is within one kilometer (km) of a road. These are also the areas where most people live and where economic activities are concentrated. If there is an opportunity to contribute to greater water security, it is this: ensuring that roads contribute to water management.

The impact of roads on landscapes and surface hydrology is often negative. Roads cause erosion and local flooding and trigger sedimentation. Road bodies are a main reason for drainage congestion and waterlogging. Roads disturb wetland hydrology, affecting fish movement. In some desert regions, roads trigger sand dune movement. Transect surveys undertaken along roads in upland Ethiopia and Uganda show that in every 10 km of roads there may be 8 to 25 flash points, such as local erosion, flooding, sedimentation, or waterlogging. According to research in Tigray, Ethiopia, road runoff affected 70 percent of roadside farmers, but only 20 percent were making productive use of that runoff (Teweldebrihan 2014). Data from two coastal polders in Bangladesh show that 60 percent of farmers are affected by impeded drainage due to roads.

The impact of roads on the surrounding landscape is not going to diminish; it will increase. Many more roads and railways will be constructed in the coming decades. Dulac (2013) estimates that 25 million km of paved road-lanes and 335,000 km of rail-track will be added from 2010 to 2050: a 60 percent increase. The estimated costs of this new infrastructure in highways and railroads over four decades are US$45 trillion. Unpaved road networks, the majority of roads in most countries, will also continue to expand, adding to this total. Another projection is from ADB (2017). The investment required in infrastructure in Asia is USD 1.3 - 1.7 Tr / year with the cost of climate proofing transport infrastructure USD 37 Bn. Most expert estimates are close to this bandwidth. In preparation for the Addis Ababa Summit on Finance, the High-Level Advisory Group on Sustainable Transport estimated that annual investments in transport amount to US$1-2 trillion, of which 40 percent is in developing countries.

However, there is another beneficial connection between roads and water management. Water is also considered the prime enemy of road infrastructure and the single greatest factor in road damage. A commonly used estimate is that for unpaved roads, the damage caused by water is around 80 percent (Chinowsky & Arndt, 2012) and for paved roads the proportion is 30 percent. Therefore, there is a strong case for road-asset management to better manage water around roads and to see roads as an integral part of the watershed and landscape in which they are situated. Such an integrated approach will preserve road infrastructure and reduce the maintenance burden, contributing to greater infrastructure productivity. Dobbs et al. (2013) advocate that there should be more upfront planning in infrastructure development. With other measures, this can contribute to a 40 percent savings in infrastructure needs.

1.2 Opportunities

These guidelines are targeted at road planners, infrastructure investors, private road developers – be it at the World Bank, the partner countries or elsewhere. They are also targeted at other communities of practice: those that work in flood prevention, land scape restoration, agricultural development, climate resilience, disaster risk reduction and environment in general.

This Guideline describes how the negative impact of roads on the surrounding landscape can be turned around and how roads can become instruments of beneficial water management. Roads in terms of the World Bank (2017) Environmental and Social Framework are often categorized as 'high risk' or 'substantial risk'. Yet precisely because of the close connection among roads, surface, and subsurface hydrology, roads provide an enormous opportunity to contribute to better water management and climate resilience. This will create the triple benefit of less road damage, less land degradation, and more beneficial use of water..

Many measures can be taken to manage water with roads. These are the main opportunities:

- In arid areas, roads can be used to harvest water (van Steenbergen et al. 2018). The water intercepted by road bodies can be guided to recharge areas or surface storages or applied directly on the land. With the enormous lengths of roads being built, roads in many semiarid areas present the main opportunity for water harvesting and water buffer management (Sambalino 2015).
- Roads can also be used to manage water catchments by controlling the speed of runoff, compartmentalizing and mitigating flood runoff, and influencing the sedimentation process in the catchments. The choices of where to place a road in a catchment and additional measures to include have a major impact on how a catchment is managed.
- High-altitude catchments present special challenges that require a more intensive integrated landscape approach than is common today.
- In floodplains and coastal areas, roads play a role in flood protection. Roads often double as embankments and provide evacuation routes and flood shelters. In low-lying wetland areas and floodplains, roads and bridges affect the shallow groundwater tables and have enormous consequences for land productivity. The way in which a road is built, and, for instance, the height of bridge sills and culverts will have considerable influence on the quality of the wetland on either side of the road.
- Roads can improve pastoralist areas for instance by combining the concentrated run-off from roads with planting native grass species. Similarly, the road run-off can be used to rekindle the roots of useful tree species under farmer managed natural re-vegetation programs in very dry areas. Under such programs dormant tree shoots that come up after a sporadic watering event are systematically pruned and local tree stands in such harsh environments.
- Roads can also be used to control sand dune movement or at least not aggravate it. The first consideration is to avoid constructing the road in the prevailing wind direction, because this will create a wind-tunnel effect that triggers sand motion. The second consideration concerns roadside vegetation that will stabilize newly opened areas.
- Roads may serve to protect wildlife areas. Wildlife movement is very much guided by the availability of water. The collection of runoff in designated storage within wildlife parks can support wildlife management and regreen designated areas within the wild life parks. It can also be used to improve buffer areas just outside wildlife areas so as to prevent encroachment by livestock keepers or farmers.

All such measures should be part of the Environmental and Social Commitment Plans of road investments, not just to address risks, but to make use of opportunities. Even much further, Green Road investments – either in new roads, retrofitting existing roads or systematically exploiting the scope for road related water management - should be developed as major ventures for climate resilience, addressing the challenges of scale and additionality.

1.3 Promoting resilience: three levels

This Guideline explains the positive contribution that roads can make to climate resilience. There is now considerable debate on the effect of climate change on road infrastructure and the need to reduce road infrastructure's risk of exposure to more intensive runoff and more frequent flood peaks, in addition to dealing with rising temperatures. The concern for resilient roads often translates into a protective approach under which road infrastructure is safeguarded at any cost from more inclement weather. [See Transportation

Research Board (2008) Farrag-Thibault (2014), NDF (2014), Hebson (2015) or Cervigni et al. (2016)]. Ebinger et al. (2015) rightly has made the point that the loss caused by disrupted transport infrastructure can be enormous and sheltering roads from climate impact is extremely important. Under a Protective resilience approach, road infrastructure specifications are adjusted to accommodate temperature rise and to be better able to withstand expected larger flood peaks or as the climate may be deal with deteriorating permafrost condition, more extreme freeze and thaw cycles or extreme colds.

Therefore, the key concern is the road itself. The downside of this protective Basic Resilience approach is that the road itself may be sheltered from the impact of higher flood peaks with better cross drainage. This is essential to keeping the economy running. However, the landscape around the roads will suffer even more from the effects of climate change, because all extreme weather events are immediately passed on to the area surrounding the road, causing larger floods, more inundation, and heavier erosion. The second downside is that no use is made of the road's potential to contribute to water management and greater resilience in the area of which it is a part.

Instead, we argue that by integrating water management in road development and design, a "plus" strategy to road resilience can be taken. The environment around the road is managed, and the road is made part of the landscape, even as a beneficial instrument for water management. In most cases, this roads-for-water approach will equally reduce road damage and bring down maintenance and sometimes even construction costs.

The Resilience Plus approach to climate resilience is a preferable addition to the protective Basic Resilience approach of adjusting road design specifications. By building roads that can serve several purposes beyond transport, and by making these functions part of the design and development of roads, it is possible to create roads that: (a) reduce the often substantial collateral damage of uncontrolled road water on the landscape around it; (b) are likely to have lower maintenance costs and downtime and are generally better able to withstand weather effects, including those that are caused by climate change; and (c) generate substantial benefits in terms of water harvested with the roads and other beneficial water management functions. In other words, rather than being a source of landscape degradation, roads can become instruments for climate change resilience.

There are two levels in this "plus" approach. The first level is Adaptive: it makes use of the road infrastructure as it is and adds a number of measures to improve water management.. The second plus level is Pro-active. It goes back to the drawing board and, from the onset, proactively plans the roads that serve to optimally contribute, within economic parameters, to better land and water management, besides offering better communication. These different approaches—Protective (basic), Adaptive (plus 1), and Pro-active (plus 2)—are largely complementary. Measures aimed at basic Protective road resilience can be incorporated and complemented by approaches at the Adaptive and Pro-active levels. Table 1.1 describes the road-resilience measures at these three increasing levels of road resilience for different geographies. Table 1.2 presents the same but for different elements of roads.

Table 1.1. Three levels of road resilience in different geographies

Level of Road Resilience	**0**	**1**	**2**
	Basic Resilience: Protective	**Resilience Plus 1: Adaptive**	**Resilience Plus 2: Proactive**

Key words	**Protecting road infrastructure**	**Making best use of and adapting to changed hydrology**	**Redesigning road infrastructure to optimize the area's water management/climate resilience**
Geographies			
Semiarid areas	Catchment measures to reduce water damage to roads	Use runoff guided from roads for recharge and storage; upper catchment protection	Design roads and cross-drainage facilities to collect runoff and guide to recharge area
Watersheds and catchments	Catchment protection to protect road infrastructure	Catchment protection to protect road infrastructure	Plan road alignment and drainage structures in support of catchment management
Coastal areas and floodplains	Increase height of flood embankments to deal with higher floods	Convert village roads for water-level management with gated structures	Consider low embankment roads with controlled floodways (Annex 5); develop road levees in flood-prone areas; use roads for land accreditation
High- and medium-altitude areas	Have safe road water crossing and protection measures; have adequate road drainage; reconsider road alignment to higher areas; train mountain rivers to reduce exposure of roads to mountain floods	Using water-retention and land-management measures suitable to mountain areas to stabilize mountain catchment and retain moisture and snowmelt; systematic spring management	Use cut and fill instead of cut and throw methods; observe maximum slope and gentle alignments; combine roads with additional storage to and drift for torrent stabilization
Desert areas		Revegetation and dune stabilization using road runoff Develop small roadside oases taking road runoff to depression areas	Adjust road directions to deal with wind directions to control sand dune formation

Table 1.2. Three levels of road resilience for different road elements

Level of Road Resilience	**0**	**1**	**2**
	Basic Resilience: Protective	**Resilience Plus 1: Adaptive**	**Resilience Plus 2: Proactive**
Key words	**Protecting road infrastructure**	**Making best use of and adapting to changed hydrology**	**Redesigning road infrastructure to optimize the area's water management/climate resilience**
Bridges	Increased dimensions to accommodate flood peaks and prevent flood congestions; deepen abutments	Integrate bridge crossing in catchment management to reduce riverbed siltation and mitigate flood peaks	Use bridge sills for controlled drainage and wetland management; consider drifts instead of bridges to stabilize riverbeds
Drifts	Higher spillways and larger aprons to accommodate peak floods	Use drifts and small fords to stabilize erosive streams	Use non-culvert drifts for water retention, river stabilization, and flood water spreading

Paved roads	Increase capacity of road drainage; reinforce drainage infrastructure; build more weatherproof road surfaces, impermeable pavements, and embankments	Manage catchments to retain water and control erosive runoff to reduce risk to infrastructure	Consider changed alignment and cross drainage for water storage and recharge
Unpaved roads	Increase cross drainage and protect road surface with additional layers of aggregate	Catchment management (see above); Protect road surface with water bars, dips, and infiltration bunds	Include basic drainage for water harvesting as part of road development; take measures to manage subsurface flows; protect catchments
Roadside slopes	Adjusting critical slopes	Bio-engineering and vertiver planting for productive use	
Drainage structures	Increase dimensions to accommodate larger flood peaks	Implement gated control and water spreading from culverts and drains	Place culverts to optimize drainage pattern for water harvesting
Borrow pits		Systematically convert borrow pits for storage, seepage, or recharge	Plan new borrow pits to optimize storage functions after conversion
Roadside vegetation		Systematically promote roadside planting for sequestration and better dust control and microclimate	

1.4 Costs and benefits

With "Green Roads for Water," we argue for a new approach where beneficial road water management is an integral part of the design, development, and maintenance of roads – promoting resilience but also tangible economic benefits. The economic case is based on a number of co-benefits:
1. Management of water with road infrastructure presents a triple win: reduced road maintenance costs; reduced landscape degradation; and productive and consumptive use of water harvested with the roads.
2. The approach has minimal costs compared to the overall outlays for road investment or road repair/maintenance (see chapter 15). The additional costs related to design modifications, including road water management from the start, is estimated at a maximum of 5 percent of original investments planned for the road. This may be funded from climate funding top-ups for road infrastructure programs.
3. The approach is the best option for climate resilient infrastructure. The costs associated with building roads that harvest water and manage floods provide a cheaper alternative to building road bodies with heavy new design specifications to deal with the expected impact of rain storms and other effects of climate change.

Conventional approaches to resilient roads may preserve the road in times of heavier weather but will do far more damage to the surrounding landscape and incur more economic costs. Larger cross drainage and higher and stronger road embankments will mean more uncontrolled flooding, erosion, sedimentation, and water logging triggered by road infrastructure. Whereas in the Adaptive Resilience approach the environment around the road is managed and the road is made part of the landscape, even using roads as a beneficial instrument for water management, in the conventional Basic Resilience approach road infrastructure design specifications are adjusted to make the road better able to withstand adverse weather effects. To deal with more intense rainfalls, culverts are adapted so that they can handle larger volumes of water. The cost of this conventional approach to road resilience is high: from US$31,000 to US$45,000 per km. In the case of unpaved roads, the costs may be prohibitive.

The cumulative annual dividend of the roads for water approach to resilience, as implemented in Ethiopia, is US$16,879 per km. This compares favourably with the direct investments of US$1,800 per km. These investments are largely in earthwork measures implemented under the Mass Mobilization Watershed Campaign. If one were to include the cost of organizing and developing this program, another US$1,800 could be added. Even then, a fourfold return on investment is achieved in the first year. It comes as no surprise that the program has spread quickly in the different regions of Ethiopia. The measures implemented in Ethiopia comprise simple earthworks-based interventions—floodwater spreaders, roadside water ponds, and infiltration trenches, many of which are explained in Chapter 2—with no engineering required. It is a minimum but cost-effective package. For the calculations, monitoring data from the Ethiopia's 'Roads for Water' program and from other sources has been used. We work out the case in more detail in Chapter 15.

Moreover, research in Kitui, Kenya, shows an average increase in a farmer's income of US$ 1,000, after one cropping season, whereas the average cost of road water infrastructure was US$ 400. This means that a net benefit of US$600 was achieved after just one cropping season. Hydrological modelling on Polder 26 in coastal Bangladesh shows that improved drainage will decrease waterlogging significantly: areas with high water levels (F1:31-90cm) decrease by 287 percent, increasing less inundated areas (F0:0-30cm) by 157 percent and making more land available for agriculture. Moreover, the duration of the drainage would be lessened by 10 days in low lying areas. When water logging is removed completely, farmers can do multi-cropping (70 percent Boro/Aman rice, vegetables, watermelon, and sesame), increasing agricultural productivity by 300 percent. Thus, if Boro rice could be cultivated (1680ha) without water logging, the net benefit will be 270 mill Taka (US$ 3.1 Mill).

1.5 Organization of the Guidelines

The Guidelines focus on the adaptive and proactive ('plus') approaches to road resilience (section 1.3), exploring how to make roads instruments of water management and climate resilience. The Guidelines are a complement to the normative work on resilience rating, the transformation of 'brown' infrastructure to 'green' infrastructure and the optimization of co-benefits. The Guidelines have drawn from work in the professional communities in road development, water management, climate resilience, disaster risk reduction, and agricultural development. The Guidelines aim to be as practical as possible. Building on Table 1.1, the scope of the intervention, the opportunities offered, and specific good practices are discussed in all chapters.

The Guidelines follow a matrix structure. They first discuss the approach for a number of different geographies: water-short semiarid areas (Chapter 2); water catchments (Chapter 3); low-lying flood-prone areas (Chapter 4); and middle- and high-altitude zones (Chapter 5). Each area has its own opportunities, sets of appropriate measures, and *dos* and *don'ts*. Chapter 6 looks at the relation between roads for water and rural water supply. The second section (Chapters 7 to 12) concentrate on some of the most important techniques, providing, to the extent possible, practical details of the available options. The following interventions are discussed: the conversion of borrow pits; the use of road drifts; the development of local storage; the development of roads in low-lying floodplains; harvesting water; and promoting groundwater recharge with unpaved roads and roadside tree planting. Specific details of a technical nature are covered in the annexes. Table 1.3 is a ready reckoner table showing the prime challenges and the appropriate techniques for the different geographies. The last chapters of the Guidelines discuss how to make Green

Roads for Water work: what governance arrangements are conducive to integrated road development and management with climate resilience and water management (Chapter 13) and how to effectively engage with roadside communities. The last chapter (Chapter 15) caps the Guidelines with a detailed economic assessment of the main early example of the approach, the roads for water program in Ethiopia as well as a preview into of some other programs.

Table 1.3: Matrix of geographies, challenges, and techniques

	Prime challenges	Techniques
Semiarid areas (Ch 2)	Water harvesting Water retention Erosion control	Flood water spreaders Flood diversion from culverts Infiltration trenches and other recharge techniques Surface storage including borrow pits and farm ponds Raised road embankments for water retention Road drifts as sand dams (Ch 8)
Watersheds and catchments (Ch 3)	Water harvesting Erosion control Flood control	Choosing road alignment Culvert placement and design (Ch 2) Road drainage Water harvesting and erosion control structures (Ch 9 and Ch 10) Road drift and platforms (Ch 8) Warping dams
Coastal areas and floodplains (Ch 4)	Water table control Drainage Water storage Flood protection Flood relief	Road alignment and heights Cross drainage and gated culverts Borrow pits (Ch 7) Fish passages Levees and flood shelters Evacuation routes Low embankment roads (Ch 11, Annex 5) Submerged roads (Ch 11) Bio-engineering and turfing (Annex 1)
High- and medium-altitude areas (Ch 5)	Stabilization of mountain areas Spring and stream management	Road alignment and slope Green construction methods Bio-engineering (Annex 1) Road water crossings Spring management Land protection measures including drifts (Ch 8) and regreening (Ch 12)
Rural water supply (Ch 6)	Source augmentation Water quality	Grass strips/ecological water control Recharge from roads (Ch 2) Surface water storage (Ch 7 and Ch 10) Spring management (Ch 5)

The Guidelines are prepared on the basis of considerable empirical knowledge. Complemented by information from secondary sources, they combine experience from different countries, in particular Bangladesh, Bolivia, China, Ethiopia, Kenya, Mozambique, Nepal, Portugal, Sudan, Tajikistan, Uganda, Yemen, and Zambia. In all these countries, a first step has been taken by promoting beneficial road-water management. The authors hope that this development will continue, that more countries will become involved, and that the Guidelines will contribute to this effort.

Geographies and uses

2. Roads for Water Harvesting in Semiarid Areas

Key message

- Road change the surface hydrology in semi-arid areas, now often causing extensive erosion, flooding and sedimentation with considerable damage to road bodies themselves too
- Because roads acts as barriers and drains for rain run-off, they can also be used for water harvesting at large scale

Main techniques

- There are several techniques to systematically divert or retain water in semi-arid areas by making use of the road infrastructure, such as flood water spreaders, flow dividers at culverts, road drifts (Ch 8) or road embankment acting as storage reservoirs
- It is useful to connect road drainage to water storage, such as infiltration trenches, converted borrow puts (Ch 7) or farm ponds (Ch 10)

2.1 Objective

Semiarid areas cover 15.2 percent of the world and are home to 1.07 billion people (14.1 percent of the global population). They are defined by an aridity index of 0.20 to 0.50, meaning that actual precipitation is between 20 and 50 percent of evapotranspiration. Because of the sheer population size and their climate being "on the edge," semiarid areas are most vulnerable to droughts.

There is enormous potential to connect road building and water harvesting in these areas. Semiarid areas are not only characterized by relatively low overall annual rainfall (typically less than 600 mm), but also by rain being concentrated in part of the year, usually in one or sometimes two rainy seasons. The retention of rainfall in semiarid areas is of vital importance: it assures the availability of water and moisture for productive and consumptive use in dry periods. Moreover, especially if done intensively, the impact goes beyond providing more water for agriculture. Having more moisture in the landscape, for instance, also improves soil fertility because nitrogen fixation is accelerated in moist soil conditions. It also improves the landscape microclimate: more moisture in the soil will affect soil temperature and thus the area's ability to deal with temperature shocks.

This chapter advocates for a systematic optimization of the effect of roads on moisture and water in semiarid areas and, as much as possible, the combination of water harvesting and road building. The sheer magnitude of road programs makes them a powerful asset for retaining water in semiarid areas. Moreover, as discussed in the first chapter, there is a triple win, because beneficial road water management in semiarid areas can also contribute to reduced damage to the roads.

Water from road culvert taken to storage reservoir, Waghmere Zone, Ethiopia

2.2 Opportunities

If one were to take a soil moisture map of an area and overlay it with a road map, one would likely see strong correlations. As roads influence surface and subsurface flows, the moisture in a landscape can be significantly affected by where the roads are located and how they are constructed. Roads can block surface and subsurface flows, creating moist stretches upstream of the road and dry patches downstream. Road drifts in riverbeds, if properly constructed, may retain subsurface flows and spread floods, again enriching the moisture in the area. On the other hand, erosion from culverts and road drainage may create gullies that deplete the moisture around them.

Road infrastructure itself can be used to harvest water and redistribute runoff to areas where it is beneficial. Roads either act as an embankment that guides water or as a drain that channels rainwater. This can be used in a systematic manner. The amount of water that can be harvested depends on the rainfall pattern, the catchment area as defined by the road, the rainfall patterns, and the land use and soil characteristics within the catchment area. For a road to act as water harvesting mechanism, the road drainage mechanism needs to be well developed by having the road on an elevated embankment, having a system of side drains or cross drains, or having drainage structures such as water bars and rolling dips integrated into the road surface (the latter particularly for unpaved roads; see Chapter 9).

Table 2.1 presents the order of magnitude of the amount of water that can be harvested from 1 km of road equipped with drainage facilities.

Table 2.1: Volume of water (m3) that can be harvested from 1km of road[1]

	Design rainfall (mm yr-1)								
	350 mm			500 mm			700 mm		
Catchment area (ha)	Runoff coefficient			Runoff coefficient			Runoff coefficient		
	10%	20%	30%	10%	20%	30%	10%	20%	30%
10	3,500	7,000	10,500	5,000	10,000	15,000	7,000	14,000	21,000
15	5,250	10,500	15,750	7,500	15,000	22,500	10,500	21,000	31,500
20	7,000	14,000	21,000	10,000	20,000	30,000	14,000	28,000	42,000
30	10,500	21,000	31,500	15,000	30,000	45,000	21,000	42,000	63,000
50	17,500	35,000	52,500	25,000	50,000	75,000	35,000	70,000	105,000
100	35,000	70,000	105,000	50,000	100,000	150,000	70,000	140,000	210,000
500	175,000	350,000	525,000	250,000	500,000	750,000	350,000	700,000	1,050,000

The challenge is not only to capture the rainfall runoff, but also to store it for later use. Runoff in the landscape that is guided by road infrastructure can be stored in three different ways:

i. In surface storage structures, such as ponds and converted borrow pits;
ii. Spread over land areas and used to replenish soil moisture, e.g., for rainfed cultivation or for rangeland improvement, retained by bunds, terraces, and micro-basins; and
iii. Routed to recharge areas where it will replenish shallow aquifers. Water can be lifted and pumped up from shallow aquifers.

Therefore, there are three types of storage: (i) surface reservoirs, (ii) soil profiles, and (ii) shallow aquifers.

- In the case of surface reservoirs such as ponds and borrow pits, the total storage capacity is limited but the water is readily available. On the downside, water from surface storage is reduced by evaporation. Chapters 7 and 10 describe the development of borrow pits and ponds.
- In contrast, great quantities of water can be stored in the soil and shallow aquifers, provided that the geology of the area allows this. The capacity of the soil to store water differs with the soil texture. Table 2.2 compares the storage capacity of different soils.

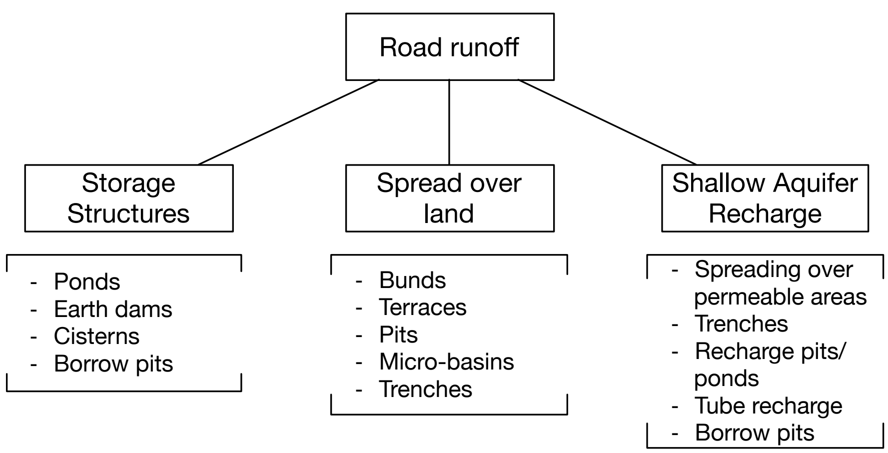
Table 2.2 Available water in different soils in Yemen's Abyan Delta

Soil textural class	Available water in 1m soil depth (mm)
Loamy sand	39
Sandy loam	83
Silt loam	163
Clay loam	170
Silty clay loam	202

[1] The calculation is simplified. It takes into account the design rainfall, which for water harvesting structures are usually chosen to have a probability of occurrence of 67 percent. This is determined using statistics on seasonal rainfall records for at least 30 years. Each of the design rainfalls is assumed to have three different Runoff Coefficients (10 percent, 20 percent, and 30 percent). Accordingly, for each design rainfall and runoff coefficient, the rough volume of water is that which can be harvested for a catchment of varying size. This is a simplified method that does not take into account the real runoff, the intensity of single rainfall events, the shape of the catchment, or losses on the way to the storage point.

- The infiltration characteristics and the capacity of shallow aquifers to store water differs with the type of geological formation (see Table 2.2), the soil crust, and the type of rainfall (heavier rainfall means more infiltration).
- The shallow aquifer's recharge capacity can be enhanced by techniques that accelerate the infiltration of runoff into shallow aquifers, such as infiltration trenches or infiltration ponds, tube recharge (called *bhungroo* in India), or well recharge.
- Several techniques, such as mulching or deep plowing, may be used to preserve moisture in the soil profile and ensure its availability in the growing season (van Steenbergen et al. 2010).
- The disadvantage of shallow aquifer storage is that the water must be pumped up, but many low-cost solutions are available. The advantage is that water will be available for a long time and can be accessed on demand, making it suitable for precision uses. Very shallow groundwater is particularly important, because up to a suction depth of 10 m it is possible to lift groundwater with low-cost centrifugal pumps or solar pumps, making smallholder irrigation possible as a route from poverty to prosperity.
- Runoff generally carries sediment. In the case of surface storage, the reservoirs gradually fill up with this sediment and need to be cleaned. This is not the case in soil moisture storage or shallow groundwater recharge. In fact, silt often improves the soil structure and is a rich source of micronutrients. Therefore, while in surface storage, sediment is a problem, but in the case of soil moisture storage it can be an asset. In the case of groundwater recharge, fine sediment such as clay may also be problematic. However, it may seal the soil surface and reduce the infiltration capacity of the underlying shallow aquifer. This sealing may be prevented by regular plowing or by the action of soil (rain worms, sow bugs, or termites) that tends to take fine sediment down from the surface and mix it with lower soil layers.

Figure 2.1 Runoff and sediments



The different storage methods are contrasted here. But in reality, for road water harvesting in semiarid areas, there is usually no "either/or," and all three storage methods can be used simultaneously. In many cases, road-water harvesting can be part of larger watershed improvement programs that deploy a broad range of methods to capture and store runoff, with road-water management being a part of this (see Box 2.1).

Box 2.1. Road water harvesting campaigns in Ethiopia: mobilizing millions to increase resilience

Every year, millions of people are engaged in Ethiopia to work on soil and water conservation and water harvesting during the Mass Mobilization. The 2016-2017 road and hillside water harvesting campaign in the Amhara Region involved 1,450,000 persons and benefitted 751,000. In Tigray, 1,306,000 persons were involved and 409,000 directly benefitted.

The main goal is to reverse severe land degradation and work on retaining runoff in the landscape. Men, women, and youth contribute 20 to 30 days of free labor during the February to April slack labor season. The approach involves organizing land users in development teams of 20 to 30 members, further divided into work teams of five members. Activity planning is done locally and includes the collection of field measurements. Women and men participate equally in the work groups and as team leaders. Activities undertaken during the Mass Mobilization are mostly carried out on cultivated lands. The regional Woreda (district) and Kebele (sub-district) administrators, specialists, and development agents coordinate the implementation and planning of the approach. Planning and measurement are conducted by land users themselves. The target area is defined by administrative and as well as watershed boundaries. The implementation plans are later discussed with the communities. At the end of each day the work group evaluates its activities and discusses the plan for the coming days.

Since 2015, the Mass Mobilization has placed special focus on road-water harvesting. A wide array of road-related water harvesting measures have been implemented to protect roads and increase farm productivity: floodwater spreaders, roadside infiltration trenches, water diverters from culverts, road-water storage ponds, and converted borrow pits.

The hydrological and socioeconomic impact of these technologies has been measured since 2015. Monitoring data have shown an increase of 1.2 to 2 m in groundwater levels during the dry period. Soil moisture next to the road has increased up to 100 percent in some cases and farm productivity has risen by 35 percent on average. Moreover, there is the added value of protecting the roads from erosion, flooding and sedimentation, and the drastically reduced damage to the landscape. The costs and benefits were calculated: against an average investment of US$1,800 in the road-water harvesting measures there was a benefit of ... due to reduced downtime and road maintenance, reduced damage from erosion, flooding and waterlogging, and of course the beneficial use of the water harvested.

2.3 Recommended practices

2.3.1 General principles

This section discusses the most common techniques for harvesting water on roads in semiarid areas. Topography, climate, and economic land use differ from place to place: different road-water harvesting techniques suit different conditions. In sloped areas, for instance, it is easier to collect and store water by making use of the natural topography and ability for land to be drained. In flat areas, water harvesting is different: there are more opportunities to spread water over large areas but waterlogging and sedimentation are major issues.

However, there are a number of general principles. The first is that runoff is preferably managed intensively throughout the entire water catchment. By developing different water conservation techniques (retention ponds, soak pits, infiltration galleries, terraces, eyebrows throughout the watershed, a large proportion of the runoff in a catchment is retained. In untreated areas, approximately 8 to 12 percent of the runoff is retained, but when intensive water harvesting is practiced this proportion can double or triple, exceeding 30 percent of the runoff. With this, the volume of potentially destructive storm water in the lower part of the watershed can also be reduced. This intensive approach ensures that a large amount of water is stored, creating a system change in water availability for crops, soil processes that accelerate natural fertilization, and more conducive and better buffered micro-climates. Moreover, with intensive catchment treatment, including the highly systematic use of all road-water harvesting opportunities, sedimentation can be brought under control.

The second principle for water harvesting is the "slowdown" of runoff, achieved by guiding water to level land and spreading it. As such, water runoff loses its erosive nature and sediments settle. If the speed of runoff is reduced, more water will infiltrate. This can be done by providing check dams, guiding water from steep slopes, building terraces and furrow ditches, and more. As more storm water infiltrates the soil, less water must be managed as surface runoff.

Third, it is important to understand the needs of the users of harvested water. This should be the central concern. During the planning, design, and implementation stages, the priorities of roadside users need to be discussed, taking into consideration all possible alternative water harvesting mechanisms and the purposes to which the water is placed. Gender is an important consideration and sometimes a divider: in Ethiopia it was found that women in poor female-headed households are less equipped to prepare their land for road-water harvesting, for instance, because they lack access to animal traction (Demenge et al. 2015). Different livelihood systems have different water harvesting demands. Smallholder/household-scale irrigation in many semiarid areas supplements rainfed systems. If rainfall is scarce or not timely enough, water harvesting from roads could help during periods of scarcity or water can be added to the buffer capacity. Shallow groundwater extraction and small storage structures could serve this purpose. The needs of pastoralist communities are different: their interest is in grazing lands. In this case, water harvesting techniques that spread flows as sheetflow over extended areas is the preferred option. Commercial farming usually comes at the expense of high water demands. Medium- to large-scale storage of runoff water is the preferred water-harvesting option, including borrow pits, earth dams, and ponds.

Fodder grown from road culvert water, South Gondar, Ethiopia

The sustainability of road-water harvesting structures needs to be ensured. Some earthwork structures need regular repairs. The water users will need a routine to inspect the water management systems periodically (after each rainy season) and modify or improve the systems as required to address any impacts caused, such as erosion, overflowing, health, safety, and environmental issues. In this regard, attention should be paid to the risk of mosquito breeding and waterborne diseases in standing water, and measures should be taken to prevent them (see Chapter 6).

2.3.2 Techniques for road-water harvesting

There is a range of techniques for harvesting water from roads in semiarid areas and different types of storage. This section discusses the main water harvesting techniques.

Table 2.3. Roads and water harvesting techniques

		Surface storage	**Soil moisture storage**	**Shallow groundwater recharge**
1	Floodwater spreaders along road surfaces		☐	
2	Flood diversions from culverts and road drainage		☐	☐

3	Infiltration structures fed from road drainage			☐
4	Cascading irrigation from road drainage			
5	Surface storage fed from road drainage (borrow pits, ponds, and cisterns)	☐		☐
6	Road bodies used as dams for water storage	☐		
7	Raised road embankments with raised culverts	☐	☐	☐
8	Road crossings used as sand dams or as water-spreading structures		☐	☐

2.3.2.1 Floodwater spreaders along road surfaces

Water can be harvested directly from the road pavement. Within the repertoire of road-water harvesting, this is a minor technique. In most cases water is harvested from the entire landscape (not just the road surface) with the help of road embankments and drainage systems.

A well-graded and compacted surface will generate a conspicuous amount of runoff water. Asphalt-paved roads have a rainwater collection efficiency (RCE, or runoff coefficient) of 0.65 to 0.75 (ERA 2011). For an unpaved road, the RCE varies more, from 0.25 to 0.30 in semiarid areas to 0.80 during heavy storms. This means that if during the year rainfall is 500 mm, 350 m^3 may be collected from a 20 m by 50 m stretch of paved road. In humid or sub-humid areas, due to the frequent rain and higher soil moistures, the RCE from unpaved roads is higher. Runoff generated by the road surface can be diverted directly to farmland, recharge areas, or storage ponds through the use of drainage techniques.

A common technique is to have a series of floodwater spreaders alongside paved road surfaces. These will guide the runoff from the road surface to farmland immediately adjacent to the road and contribute to greater soil moisture. These spreaders consist of low (30 cm) curved structures made of local material that can be used for collection. They are inexpensive to build but need to be rebuilt annually.

There is legitimate concern that water collected from paved road surfaces may have a high proportion of hydrocarbons and other pollutants from traffic. This makes the use of water from the road surface generally unsuitable for human or animal consumption. The degree of pollution is a function of traffic intensity and regular rainfall. Measurements were made along a paved highway section in Ethiopia, but the levels of oil and grease were not detectable (Woldearegay 2016). Nevertheless, areas with heavy traffic should be avoided for direct road-water harvesting: the pollution from hydrocarbons and oils may prohibit the reuse of road water.

2.3.2.2 Flow diversions from culverts and road drainage

Road drainage systems concentrate runoff. Culverts, in particular, are the embodiment of the changed drainage pattern that comes with road development. Because they concentrate runoff, there is always the risk of erosion downstream of the culverts. Gullies so created may even “creep” upstream and destroy the road body. Therefore, both to protect downstream land and to make beneficial use of water, runoff should be diverted from the culverts.

This also requires that the design of road culverts be optimized in terms of dimensions and appurtenant structures. Research on 15 culverts by Weldu (2018) along the Freweyni-Hawzien-Abraha-We-Atsbeha road in Tigray (Ethiopia) found that erosion could be reduced by 15 percent and water harvesting potential increased by 25 percent with changed designs.

The modification concerned:

Culvert sites on gentle sloping catchments	• Artificial settling basin on the natural stream • Longitudinal guide structure that keeps the runoff in the original channel bed to avoid flooding
Culvert sites on moderately sloping catchments	• Redirection of runoff through newly excavated channel upstream
Culvert sites on steeply sloping catchments	• Upstream artificial enlargement of the channel width. • Downstream drop structures with end of bed load settling basin

Different auxiliary structures may be constructed to gently divert flow from culverts to where water will be used or conserved. The structures may be constructed from different materials with different alignments, widths, and heights. V-shaped flood diverters are, in most circumstances, most appropriate, because they dissipate energy from the culvert runoff. If the flow from the culvert comes at low velocity, a diversion structure will be sufficient. The structures should also be placed at a reasonable distance of at least 3 m from the culvert outlets to avoid creating sedimentation inside the culvert.


V-shaped diversion structure constructed from soil and stone to spread water from culvert, Ethiopia

On steep slopes, the flows from the culverts have high scouring potential and should ideally be provided with energy dissipaters at a safe distance (to avoid full flow condition in the barrel of the culvert). The flow diversion structure should then be placed next to the energy dissipater.

2.3.2.3 Infiltration structures fed from road drainage

The purpose of cross and side drains is to evacuate water away from road structures. This is often done without taking into consideration the opportunities for water storage or recharge. Water from road drains, either culverts or lead-out ditches (or mitered drains), can be guided directly to groundwater recharge structures. Most common are infiltration trenches, recharge wells, and infiltration ponds.

Infiltration trenches should be placed at distance for road safety: the trench on the right (in Malawi) is too close to the road

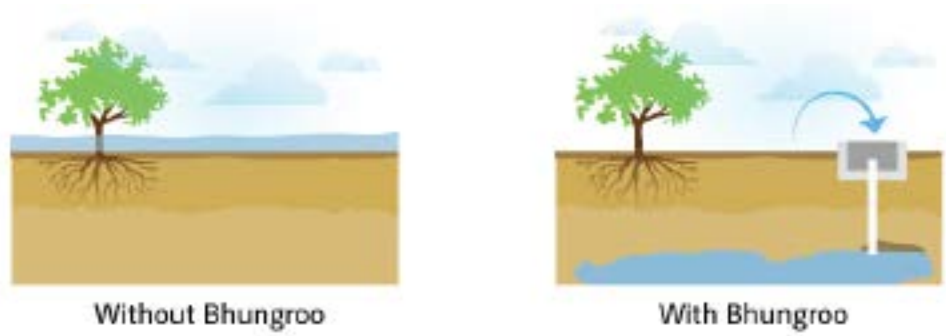
Infiltration trenches are quite popular in Ethiopia and have contributed to rising groundwater levels. Wells are in use in several areas where there never was groundwater before. Infiltration trenches consist of a chain of individual percolation ponds with water overflowing from one pond to the other. This keeps trenches in steep terrain from being scoured out, but instead allows water to overflow from one pond to the next in the trench. Typical dimensions for a single percolation pond in a trench are 1.5 m long x 0.4 m wide x 0.5 m deep. The infiltration trenches should be placed at a safe distance of at least 20 m from the road body on the downhill side to keep them from soaking the soil and affecting the road subgrade. Alternatively, the infiltration trench is led away from the road body.

Series of roadside infiltration trenches with bund to intercept additional surface runoff, Tigray, Ethiopia

Alternatively, runoff can be guided to recharge wells or percolation ponds. These collect the water for recharge in the shallow aquifer. In some cases, these may be abandoned dugwells or out-of-use borrow pits. Importantly, these recharge structures penetrate a water-bearing layer with good transmissivity (ability to convey water) and spare storage capacity (not saturated). Such conditions are easily found in most semiarid areas.

Collecting road water for groundwater recharge: recharge well (Ethiopia) and abandoned borrow pit (Mozambique)

A further sophistication to improve infiltration is the use of special tube recharge wells, or *bhungroo* as they are called in Gujarat, India. These recharge wells collect excess water during the rainy period and are best situated in areas that are temporarily inundated. The land is slightly tilted toward the recharge well, so that it "feeds" it with water. The *bhungroo* are equipped with small cemented collection structures measuring 1.5 by 2 m. The top of the recharge pipe sticks out of the bottom of the collection unit to prevent the entry of sediment and dirt. The recharge pipes are between 30 m and 100 m deep, and between 10 cm and 15 cm in diameter. They should penetrate into a sandy layer within this depth: the slotted screen will be placed here. In the case of groundwater use, in shallow aquifers the cost of pumping up water for agriculture may be prohibitive.

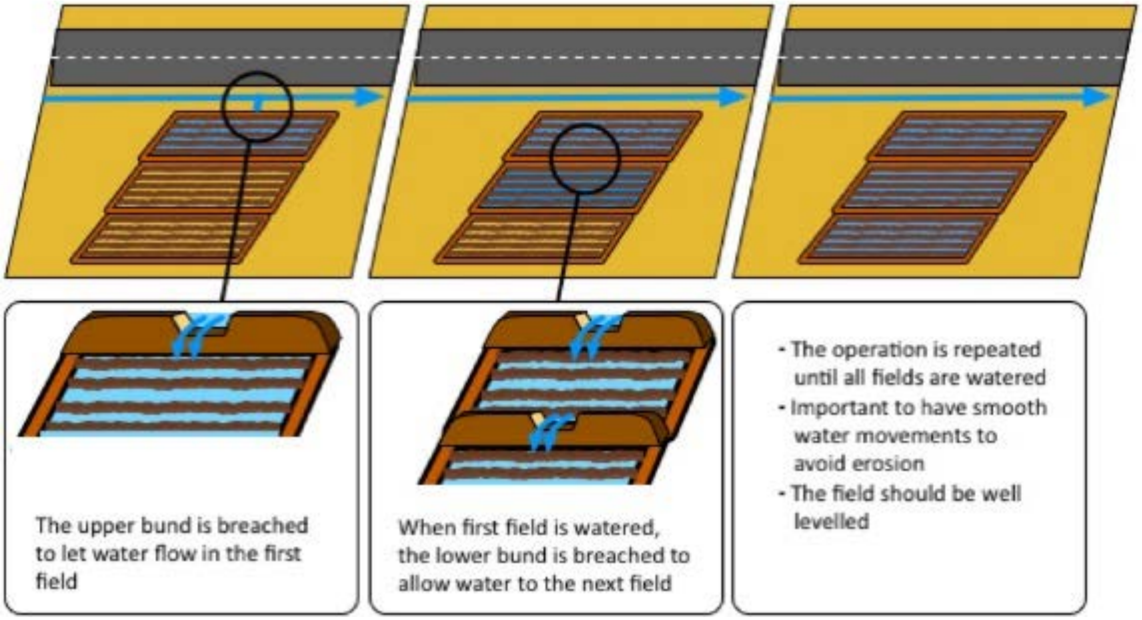


Tube recharge well collecting excess water for recharge
Source: Momentum4Change.org

2.3.2.4 Cascading irrigation fed from road drainage

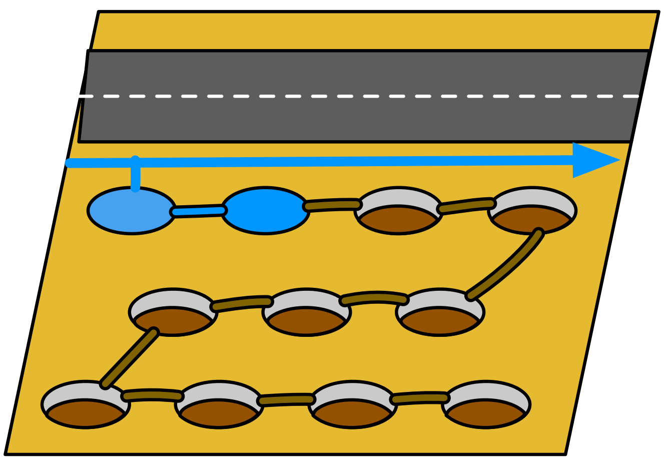
The water from road drainage may also be applied directly on the land. This can be done through a single leveled ditch at the top of the field that homogenously spills water to the field downstream, preferably by furrows. This prevents water coming from the road drainage system from immediately submerging the crop and causing damage. The field needs to have a very even, continuous gentle slope to avoid erosion and water ponding. A variation on this comes from relatively level humid areas where the single road ditch is also used in two ways: (i) during rainy periods as a drainage ditch collecting excess water, and (ii) during dry periods as the source of supplementary irrigation.

A more elaborate system is when a cascade of fields is served by the water collected from the road. The fields are divided into sub-basins. Water is allowed in the uppermost basin. Once filled, its retaining bund is breached to allow water to enter the next field downslope. This system is commonly used to grow rice in slightly undulating areas.



Cascading irrigation sequence (Sambalino et al. 2016)

Alternatively, water can also be routed to a series of planting pits that are connected to each other by ditches. Once a pit is filled, water continues to the next pit. This system is typically used to grow high-value trees. What is important in these three systems is that there is a degree of control at the intake: not all road drainage water is necessarily used.



Road runoff is directed to interconnected soaking pits (Sambalino et al. 2016)

2.3.2.5 Surface storage fed from road drainage (borrow pits, ponds, and cisterns)

Road runoff can also be collected in surface storage: small ponds, dams, borrow pits, or cisterns. Borrow pits can be systematically used as recharge, storage, or seepage ponds. These pits are excavations of source materials—sand, gravel, soil—for road construction and are usually located very near the road itself. The planned "second life" of borrow pits is discussed in Chapter 7. Another option is the development of ponds for road-water storage, as discussed in detail in Chapter 10. Cisterns, i.e., covered storage, are also possible. Because of their higher cost, they are used for domestic water or high-value productive use (see Chapter 6).

2.3.2.6 Road bodies used as dams

Road bodies can also be used as dam walls when the road is made with fill. They can act as:

- Dam walls creating storage by blocking valleys;
- Side embankments of reservoirs; or
- Guide bunds channeling water to storage ponds.

In particular, when roads double as dam walls or side embankments, some concern about their safety is warranted and all safety measures related to dams should include regular inspection of seepage and cracks, provision of spillways and emergency escapes, and protection from damage by livestock or rodents.

The functioning of storage reservoirs should be safe and the road itself should not be undermined. This may require special side protection through clay sealing, riprap, or geotextile.

Road embankment acting as side of temporary storage reservoir for livestock (Portugal)

Road embankment lightly armored, serving to store water (Burkina Faso)

2.3.2.7 Raised road embankments with raised culverts

A variation on the use of road embankments for water storage is the used of raised road embankments with raised culverts. The idea is that in semi-arid areas the raised embankment placed in drainage path or depression areas will retain water run-off that can be used in surface storage or recharge or in improved soil moisture. This can be used for improving grazing areas or wetlands, as the example here from North Uganda. The culverts in these road section are raised as well, the level from the ground defining the storage area.

Raised road embankment and raised culverts creating local wetland in Kotomor, Agago (North Uganda) (source: Aidenvironment)

2.3.2.8 Road crossings used as sand dams or as water-spreading structures

When roads cross dry riverbeds or water streams, it is common to construct drifts (also known as low causeways, fords, or Irish bridges). These road crossings can help retain groundwater upstream of the road crossing and can increase bank infiltration. These structures can have multiple functions. The first obvious function is to allow road traffic to cross the dry riverbed. However, the drifts can also double as a proxy sand dam, trapping coarse sediment behind them and creating small local aquifers that can store and retain water. Fords combined with roads also have another function, which is to stabilize the beds of dry temporary rivers.

Depending on the depth of the riverbed, the fords will also slow subsurface flows and retain groundwater upstream, allowing the development of wells or the construction of infiltration galleries to access the water retained upstream of the ford. This capacity to store and retain shallow groundwater is highly relevant in arid regions and improves water access and availability. Chapter 10 provides a detailed description.

A closely related technique is the use of water-spreading weirs combined with river road crossings. These have been developed with considerable success in several Sahelian countries such as Niger. With water-spreading weirs, temporary floods are routed out of the dry riverbeds to inundate the surrounding area. The water-spreading weir serves as the main river crossing, whereas the floodwater is further spread by roads connecting to the weir/river crossing. In this way, the combination of the river crossing as well as embanked roads leading to them act as flood spreaders. Drop structures and cross drainage are provided to the water-spreading weirs to ensure their stability. Arid and semiarid environments are thus regreened with forest and grass species (GiZ and KfW 2013).

Water-spreading weirs combined with river road crossings in Niger (source: GIZ and KfW 2013)

Water-spreading weir river crossing, also known as seuil-radier (credit Bender)

3. Roads for Watershed Management

Key message

- Roads affect watersheds as they concentrate and accelerate run-off, interrupt subsurface flows and increase hydrological connectivity. Because of this road development has typically contributed watershed deterioration, caused flooding and gullying and triggering erosion
- By the same token however roads can be used to retain water in a watershed and stabilize areas prone to erosion.

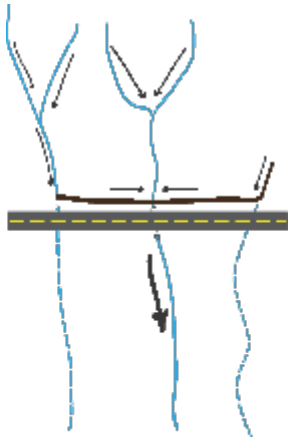
Key techniques

- Key techniques concerns the choice for the road alignment and slope (this chapter); the design and placement of culverts to divide and slow down run off speed (ch 2) and carefully designing the road drainage system and appurtenant structures so to ovoid erosive velocities and guide water to productive land(this chapter)
- Important structure to add are road platforms (Ch 9), warping dams (this chapter) and a variety of water harvesting and erosion control structures (Ch 8 and 10)

3.1 Objective

Watershed degradation is a pervasive phenomenon occurring in many parts of the world. Some have argued that its impact overshadows that of climate change. The degree of impact may be hard to assess, but it is clear that watershed degradation amplifies the turmoil caused by rainstorms and longer drought periods. According to IPBES (2018), land degradation is affecting the well-being of 3.2 billion people. Based on an extensive literature review, this same source estimates that land degradation costs more than 10 percent of the global gross domestic product (GDP), and it is related to the loss of services such as carbon sequestration and agricultural productivity. Fertile soil is lost at a mind-boggling 24 billion tons per year due to unsustainable agricultural practices. The main drivers of land degradation are the expansion of crop and grazing lands, current agricultural and forestry practices, climate change, urban sprawl, extractive industry expansion, and infrastructure development. Road network expansion has, in fact, been described as a trailblazer for this degradation (Ibisch et al. 2016).

An older study based on the GLADIS survey (Bai et al. 2008) also establishes that land degradation was on the increase in the 1991-2008 period and affected one-quarter of the global land area. However, the message from this global survey was that the picture is mixed. There are parts of the world where land quality has been declining—24 percent of the global land surface, in fact—but there are also areas where land quality has improved (16 percent). It is clear that managing watersheds globally remains an enormous challenge that is not to be underestimated, but that it is also possible to reverse the tide and improve the quality of our natural resources.



This chapter discusses the opportunities for roads to contribute to watershed management, rather than—as is often the case—causing the deterioration of watersheds. If a road is constructed, it changes the drainage pattern of the entire area. Surface runoff is blocked by road embankments and is typically concentrated in a smaller number of streams and drains within a watershed. Thus, there is more runoff in some of the natural drains, and other drains are no longer used (Figure 3.1). Because the first group of streams will carry higher volumes of water, this may create more floods and generate erosion and scouring flows that were previously unusual. In other streams that are blocked, downslope erosion will cease, and some areas may dry out. In general, however, sedimentation in water bodies will increase. The road network acts as an additional drainage network in the watershed, increasing the catchment's drainage efficiency. Napper (2008) quotes Wemple (1996) who estimates that 57 percent of the road length in two watersheds in Oregon function as flow paths, with some road segments draining directly into streams and others through newly created gullies. However, as discussed in this chapter, road alignments will differ in terms of their hydrological connectivity.

Figure 3.1 Changed runoff patterns

Furthermore, roads affect the movement of shallow groundwater. A road that is made in cut may drain shallow aquifers that are located close to the surface. Depending on the geology, this may create new springs. In some geological formations, there is a strong likelihood of springs occurring after a road is incised through them, e.g., in sandstone or in weathered and loose basalt formations. Such springs are even more likely to appear when there is an impervious layer underneath the water-bearing fracture zone.

Equally, when a road is made in fill and an impervious roadbed is put in place (Figure 3.2), these will affect the presence of shallow groundwater. In this case, shallow groundwater movement is blocked, creating wet or moist conditions upstream of the road and possibly drying land and wells downstream.

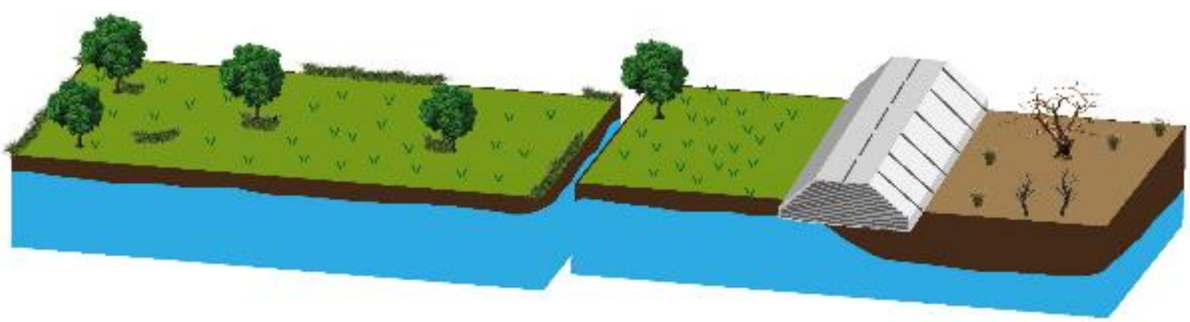


Figure 3.2. Before (left) and after (right): road in fill blocking subsurface streams, causing wetting upflow and drying downflow

All these phenomena add up to the risk of substantial landscape damage: erosion, sedimentation, flooding, waterlogging, and desiccation. Ultimately, this degradation of the catchment may turn against the road itself: roads in degraded landscapes are more vulnerable to damage by stream erosion, uncontrolled flooding, rockfalls, or landslides. The two-way impact can be immediate and spectacular, as when gullies developing from culverts regress and take the road with them or when heavy scour in drains along the roads undermines the road itself. The pictures below are examples of inadequate road drainage playing havoc with the road itself.

Ethiopia: Erosion from culvert undermining road.
Heavy scour in road drain destroying road

3.2 Opportunities

All these negative effects can be turned around. Roads, rather than being the nemesis, can contribute to watershed improvement. Changes in hydrological processes can be used to better manage the watershed, both by reducing the risk of damage and optimizing positive effects. In terms of the key objective of these Guidelines, we should better manage road-water interaction and create a “double-plus” resilience, not only to avoid landscape degradation, but also to designate roads to contribute positively to watershed improvement. This may increase water availability and vegetation cover, support economic activities, and reduce erosion in a catchment.

This section of the Guidelines discusses the positive interaction between roads and catchment management: how roads can become instruments in watershed management. It outlines a number of recommended practices in road development and maintenance. A main principle is to control water with road infrastructure and ancillary measures so as to decrease the speed of the water flows, guide water to appropriate areas, increase infiltration, and improve retention of subsurface water. A second principle is to use road development to address “erosion hotspots” and have controlled sedimentation processes.

Measures on and along the road can be further enhanced by supporting the development of new vegetation. The water channeled from the roads can be used to increase vegetation cover to water new plantations, support tree regeneration, or implement roadside tree planting.

3.3 Recommended practices

This section provides broad principles for aligning rural road development to watershed management. Several of these detailed practices are discussed in greater detail in separate chapters of these Guidelines.

This chapter discusses the following practices:

- Choosing the location and slope of road;
- Carefully designing the road drainage system; and
- Planning water harvesting and erosion control measures along with the roads.

3.3.1 Choosing the location and slope of road

The location of a road in a catchment has a major impact on the volume of water that can be captured by the road bodies and the sediment that is generated and intercepted. The location of roads in a catchment is guided by a number of important general considerations, as shown in Table 3.1.

Table 3.1. Socioeconomic, morphological, and environmental criteria for the location of (new) roads

Socioeconomic:	
Short connection	Preference for shortest connection between centers of activity
Property	Location away from valuable property or land use that would be negatively affected
Morphological:	
River crossings	When following a river course: minimize the number of crossings
Cuts and fills	In mountain areas: avoid high fills and deep cuts
Hairpin bend	In mountain areas: avoid or at least minimize the number of hairpin bends

Mid-slope areas	In mountain areas: for road development, avoid long, steep areas
Rise and fall	In general: avoid needless rise and fall of the road; preference for gradual climbing and descending of the road bodies
Sunny areas	Preference for sunny areas to reduce the potential negative effect of damage by soil moisture
Ridges	On smooth hill ridges, it may be preferable not to change runoff patterns, shifts, and high costs due to cut/fill
Foot of the slope	Expect high runoff pulses, especially in semiarid environments where rainfall intensity and runoff rates tend to be higher
Environmental:	
Forests	Prevent avoidable destruction of forest and tree plantations
Pristine areas	Do not enter into pristine areas or areas with unique ecological value and high conservation value
Marshlands	Avoid marshland or other low-lying areas with poor drainage
Erosion	Avoid areas that are highly susceptible to erosion
Unstable slopes	Avoid areas with unstable slopes
Flood levels	Stay above acceptable flood levels and stay away from areas with flooding risk
Secondary effects	Roads catalyze the concentration of economic activities (villages, gas stations, etc.) that are often detrimental to sensitive habitats and ecosystems.

Optimizing a road's impact on a watershed should be added to this list of general economic, morphological, and environmental principles. Because roads create opportunities to retain water in the watershed and help prevent erosion, there are a number of additional criteria to consider, as presented in Figure 3.3.

Table 3.2. Additional catchment management criteria related to road construction

Catchment management	
Location on hillside	Consider placing the road uphill, mid-hill or downhill so as to balance the upstream road catchment and downstream water-use areas.
Rain slope	In semiarid areas, place the road on hillsides with more rain to capture more runoff for productive use.
Compartmentalization of flood runoff	Use roads to compartmentalize and slow down runoff, especially in areas that are highly susceptible to flooding and deep erosion.
Slopes, curves	Provide sufficient curves and breaks on the slope. A steeper road straight up a slope is likely to act as a drainage collector. In some cases, a new road may impose a new drainage pattern on a landscape, with many minor drains discharging into the road. This can happen particularly on hilltops where the drainage pattern is usually not well defined. Care is required to provide an alternation of slopes and curves.
Bends	Bends are also exit points for water running along the road surface, and care must be taken to ensure that runoff on road bends is used productively and does not cause undue erosion.
Roads in cut	Roads that are at the level of the land or even lower will attract runoff and can become the main drain in hilly sections. These should be avoided. There is a risk of unpaved roads in soft material lowering over time due to erosion and wear and tear of the road surface. When the road is at the level of the land, construction of permanent water bars and rolling dips is recommended to prevent the erosion of the road surface.

Groundwater	Consider the effect of roads, either in cut or fill, on shallow groundwater tables and use this to regulate groundwater tables (for instance, creating secure shallow wells upslope from a road in fill) or to plan measures to mitigate the negative effects on groundwater levels (such as additional cross drainage and permeable road embankments).

Temmink (2015) undertook modeling on a watershed in Ethiopia using an existing 21km road to assess the impact of the road location). The modeling looked at the natural state, the location of the current road at alternative routes (different slopes, different positions on the roads), and various culvert strategies (i.e., different densities of culvert placement). These show the importance of the well-considered selection of road alignment on water harvesting potential, erosion, and road scouring.

- Water harvesting potential is greatly affected by the choice of road alignment. Placing a road lower on the slope and selecting a slope generating higher runoff volumes can increase the amount of water harvested from the road and its culverts by a factor of 7.

- As a general rule, road alignments should be set at toe-slopes ranging less than 40 percent gradient, making it easier to drain (Zeedyk 2006). If roads are developed higher on the slope, they will fail to catch a large part of the runoff; if set too low, drainage will be more difficult and road flooding can occur. In the Northern Hemisphere, roads facing south will dry up more quickly, while those facing north will take more time. However, soils facing north are deeper, thus facilitating road construction and maintenance work.

- Road construction typically increases erosion by at least 10 percent compared to the natural catchment. It is usually higher, i.e., ranging from 12 to 40 percent (Bryan and Schnabel 1994; Luce et al. 2001; Megahan et al. 2001; Wemple 2013).[2] However, this effect can be nearly halved with better road location and culvert placement (see Section 3.2). Erosion can be controlled by raising the road embankment, reducing the number of culverts, avoiding the most sensitive and erosion-prone areas, adjusting culvert size, and only using stable or reinforced waterways downstream of culverts and in steep areas that provide an adequate number of bends in the road.

- The scouring of the unpaved road surface is also greatly affected by the choice of road alignment, especially the road's length and slope. Avoiding long, steep slopes and placing adequate cross drainage can bring down road scouring significantly (see Chapter 11). This contributes to road durability and reduces sediment deposition in the watershed.

[2] When a catchment is heavily eroded, the road's additional impact on sedimentation is proportionally less; in fact, roads can help mitigate some of the erosion. Therefore, in relatively pristine watersheds a road's contribution to the sedimentation process is proportionally higher and may be lower in absolute numbers.

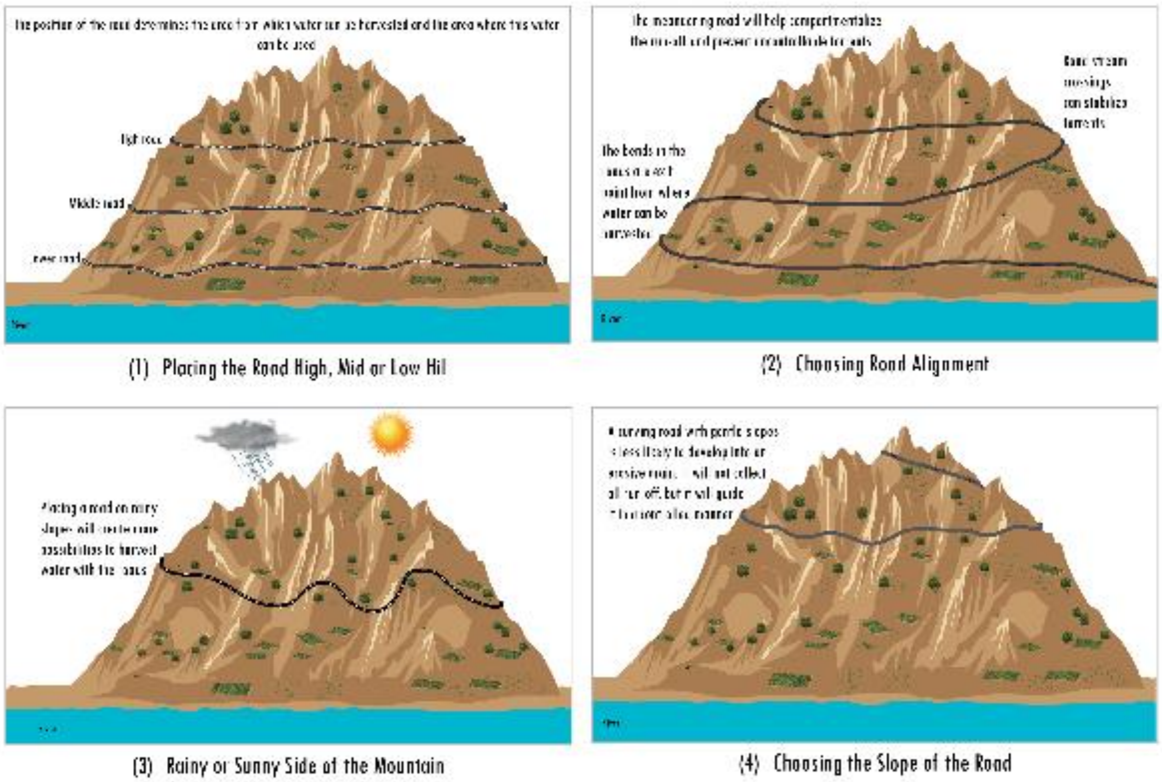


Figure 3.3. Road alignments for better watershed management

3.3.2 Designing the road drainage system

The design of the road drainage system is a major intervention in watershed management.

If a road is equipped with a (proper) drainage system, the water along the roads will collect and be removed from the road body. This will protect the road surface, especially in case of dirt roads, and make the water available for productive use. Typically, the *raison-d'être* of road drainage systems is to preserve the roads and prevent runoff from interfering with road operations. However, at the same time they are large water-harvesting systems and should be managed accordingly. When not well designed and managed, road drainage commonly causes uncontrolled flooding and erosion that affects the road body, neighbouring land, and the environment. It is also a missed opportunity in terms of water harvesting for productive purposes.

The runoff is preferably "given back" to the land through water harvesting and the diversion of water to farmland, spread over rangeland, or used for forest development. This is to keep the hydrological connectivity of the road network (i.e., the connections between the roads and the streams in the watershed) from becoming very high and water being rapidly drained from the watersheds. This would cause amplified flood peaks and give water less time to infiltrate and for aquifers to be recharged. Rather than road drains connected to the streams in the watershed, it is better to have road drainage water run into vegetation bunds, farm fields, or pastures. This would also reduce sediment deposition in the streams.

Tajikistan: totally scoured out gully from road

Tajikistan: inadequate road drainage system

An initial requirement is that a road drainage system be in place that is able to redirect peak runoff volumes, but also to make it available for reuse. The presence of a good drainage system can prevent road scour or erosion along road drains and waterways, provided that drains are properly aligned or alternatively protected with erosion-control measures. Especially when the road material is highly erodible, it is important to have road drainage that will protect the road from water running on it (Figure 3.4). If not, this will create rills and scour tracks on the road, and the fine grades in the road body will be washed out. The road itself may increasingly develop into a natural gully (see pictures from Taijkistan, above).

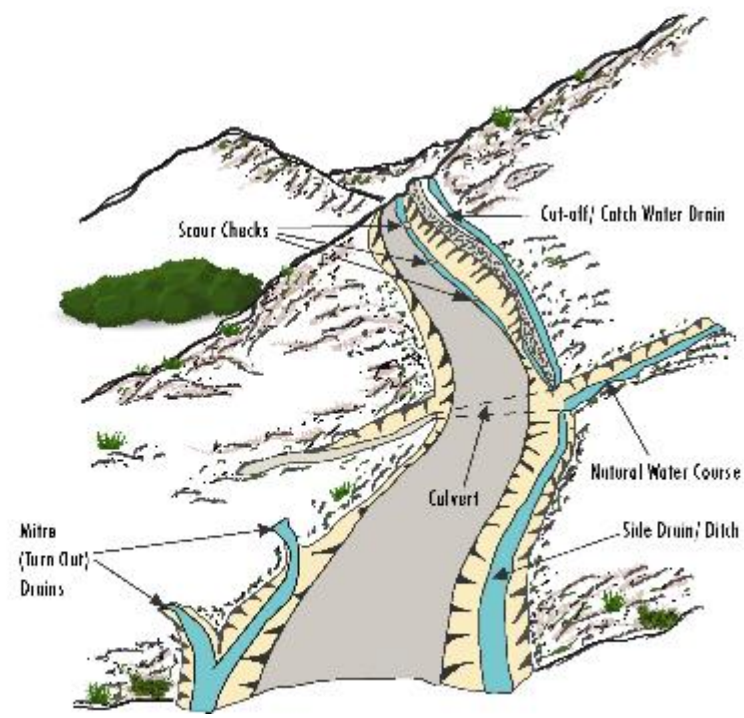


Figure 3.4. Road drainage system: asset for road protection, watershed management, and water harvesting

When in place, the road-drainage system can consist of: (a) cut-off drains (that shield the road from uphill runoff); (b) side drains that channel the water along the road; (c) culverts, pipes, and bridges that take water across the road body; and (d) mitered (turn-out) drains that divert water to the land adjacent to the road. The road template itself is also part of the road drainage. Road runoff can also be influenced by shaping the road surface and having it tilted downhill or having it crown shaped, guiding water to the side of the road from the middle section. Figure 3.5 shows several such road templates. However, depending on the road material, there is a risk that such purposely shaped road surfaces may disappear under the impact of traffic and rainfall.

In the case of unpaved roads, water bars and rolling drainage dips that remove water directly from the road surface to the adjacent land are also important. Another important measure, especially for unpaved roads without well-developed drainage systems, is the infiltration bunds running parallel to the road. These are stone lines that slow the road runoff and help it infiltrate (see Chapter 9).

Road drainage systems offer a number of opportunities to make a beneficial contribution to watershed management, as listed below:

Figure 3.5 Different road templates

Table 3.3: Recommended practices for road drainage systems and water harvesting

Systematically collect and divert runoff	The road drainage system is a mechanism to effectively collect and divert all water that is gathered around the road. If adequately designed, it can help to "harvest" a large part of the runoff from the catchment uphill of the road and avoid waterlogging upstream of the road. The capacity of the road drainage system should be sufficient to remove the peak runoff in time.
Disposing runoff in areas where it is used beneficially	Where the water from the road is disposed of is important. The road drainage water should not be disposed of in areas where it creates damage or where it serves no useful purpose, but should be led to agricultural areas, tree plantations, rangeland, recharge areas, or ponds. It is also important that road drainage water (including the sediment and other particles it carries) is not directly discharged into streams where it will create turbidity and cause stream sedimentation.
Having an adequate number of outlets from the drainage system	It is important to have adequate outlets from the road drainage system in order to distribute the water over a wide area rather than having it become too voluminous to handle from a limited number of outlet points. In a few cases, however, on steeper and erodible slopes where gullies develop below each cross-drainage structure, it is suggested that runoff be concentrated at fewer points that lead to well-reinforced waterways. This helps to optimize resources in waterway stabilization.
Reduce the hydrological connectivity of the road network	To keep hydrological connectivity low, it is important that the runoff collected from road drainage be diverted/distributed to vegetative bunds, pasture, or farmland and not allowed to quickly discharge in local streams and drains. This prevents the rapid buildup of flood peaks after rainfall in the watershed.
Harvesting sediment from road drainage systems	Road drainage systems can also be used to collect sediment. This requires the side-drain slope to be broken with drop structures such as scour checks. Sediment will be deposited in the flat sections. This can be collected and used as building material, particularly in the vicinity of towns. Sand harvesting from road drains can be an important job opportunity.

As part of designing drainage systems, decisions on the number and location of culverts and other cross-drainage structures along a road body have an important effect on the opportunities to collect water, retain moisture, and control erosion and sedimentation. Cross-drainage structures are commonly placed in line with existing natural drainage paths such as gullies and small streams. They allow water from the upper catchment to pass underneath roads and connect directly to the downstream portion of the catchment. Because of cost, the number of cross-drainage structures is often minimized. These cross drains then commonly constitute bottlenecks, whereby naturally distributed runoff water is concentrated at a few points.

Culverts are important elements in road water management. They can be major sources of damage where they discharge water in an uncontrolled manner, but they can also guide the runoff from the catchment to places where it is used beneficially. Culverts, including their bed-sill and some of the ancillary structures, can also help control erosion.

There are a number of important recommended practices:

- Culverts should be placed on drainage lines. As obvious as it sounds, culverts are often incorrectly located in the road design and construction process.
- There should be an adequate number of culverts. As discussed earlier, if the number of cross-drainage points along a road is limited and natural drainage patterns are distorted, highly erosive runoff and flooding are likely to occur by concentrating runoff in a limited number of culverts. This should be considered.
- Culverts should be installed close to productive land, storage ponds, and recharge areas and, when necessary, equipped with diversion canals to take the runoff water to benefitting areas and structures such as ponds or infiltration trenches.
- Proper design and protection measures on culverts upstream are required (Berhe 2018) to guide water with controlled velocity through the culvert. These may comprise:
  - Widened intake channels to slow the runoff passing through the culvert; and
  - Protection of the intake channels with riprap or vegetation to avoid erosion.
- Proper design and protection measures on culverts downstream are required, depending on the soils and slope immediately downstream, such as:
  - V-shaped floodwater spreaders (see picture);
  - Check dams and (stepped) drop structures;
  - Riprap protection; and
  - Diversion channels to take runoff to benefitting areas or storage/recharge structures.
- Proper design of the culvert is required, particularly in steep, erodible streams. The lower sill of the culvert can be raised and help to stabilize the stream and prevent further scouring out of the stream.

V-shaped floodwater spreaders

3.3.3 Planning water harvesting and erosion control measures along with roads

Rural roads' contribution to erosion is well documented, as clearly seen in roadside gullies and landslides[3] as well as in road aggregates washed from the surface of unpaved roads. Measures to control and prevent erosion should be part of road construction and maintenance. These include several of the measures discussed in sections of this chapter as well as in Chapter 10, which is concerned with unpaved roads: well-placed road alignments (slope, bends, and drainage system), check dams, infiltration bunds, rolling dips and water bars, reinforced culverts, and water spreaders.

The road represents a change in the natural topography, opening fresh slopes (as discussed in the previous section) that may be protected by several mechanical and biological measures. It is also important to introduce these erosion-control measures simultaneously with the road's development to keep erosion from developing.

There are several methods of biological treatment. The two most popular are bio-engineering and the use of stabilizing plants, in particular vetiver grasses (*Chrysopogon zizanioides*). Bio-engineering is the use of plants for slope stabilization and runoff control. It involves using plant parts such as roots, cuttings, and stems as a cost-effective and locally adaptable means of erosion control. Bio-engineering ranges from planting deep-rooted species to a combination of vegetation with civil engineering structures. Examples of bio-engineering include planting grass lines along contours vertically or diagonally, turfing, jute netting together with seedlings, brush layering, fascines, palisades, wattling, live check dams, bamboo fencing, and vegetated stone pitching (Devkota et al. 2014) (see Annex 1).

Vetiver grows in practically any soil and therefore also performs well in soils devoid of nutrients such as fresh cut/fill areas (Greenfield 2008). Its deep roots make the grass able to withstand high runoff speeds and volumes. Vetiver is a very resilient plant that can grow under a range of climate conditions with air temperatures ranging from -15° C to more than 55° C and rainfall varying between <300 mm and >5,000 mm. Vetiver has a range of uses: stope stabilization, vegetation rehabilitation, and as a source of fodder and thatch (Pinners, no date). Parallel hedges need to be established on steep slopes that are the result of road construction work in order to control runoff erosion. Although common in some countries, useful tested methods have not yet been introduced in many countries where they could make a significant contribution. The same applies for bio-engineering. While very popular in Nepal, for instance, it is unknown in other countries.

There are also opportunities for roads to positively contribute to erosion control in watersheds. This section gives a number of examples:

- Stabilizing erosive streams with small road fords or drifts;
- Controlling erosive areas with embankment roads; and
- Combing warping dams with roads

Stabilizing streams with road platforms

Road platforms or small fords may be placed at erosive stream crossings to stabilize them. They will retain the streambed material and allow water to spread over the breadth of the road body before it is discharged downstream. This will make stream flows much gentler. If such road platforms are raised on the uphill side, they can help stabilize the stream and even build up a small sandy layer in the streambed that can act as water storage and connect to the aquifer surrounding the stream. Chapter 8 discusses in greater detail the

[3] Because there is extensive and rich literature on preventing landslides during road development, this subject is not repeated in these Guidelines.

principle of such road drift acting as “sand dams.” If a river is filled with a thick layer of sand gravel, it will feed the groundwater adjacent to it. It is preferable to build a series of such stabilizing structures on a stream at different road crossings. Small sand dams may be added in some cases.

The fords may be straight with a dip-down road (see Figure 3.6). This will divert the runoff from the road surface and guide the water from the stream. The ford may also be parabolic in size to mainly facilitate natural streams overpassing the road. The advantage of these fords is that they spread the water over a larger width of the riverbed, causing less damage to the stream bed and stopping whatever rutting appeared in the riverbed. The fords also hold the bed material in place. An advantage of such stream crossings is that they do not become clogged. The disadvantages of the fords are that the road may not be passible during (short-term) floods and are most appropriate on low-volume roads.

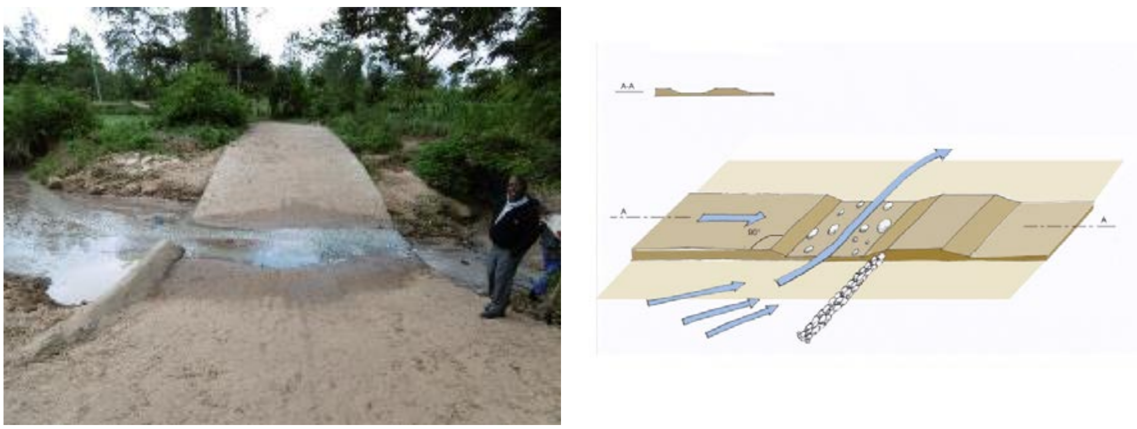


Figure 3.6 Road ford in Kitui, Kenya and diagram of road ford with longitudinal slope to allow the crossing of a natural stream with a permanent rolling dip added to divert water from the road surface (credit Masila). The rolling dip is done with either concrete, masonry, or rocks (source: Bender 2009)

Controlling erosive areas with embankment roads

When roads cross unstable and highly erosive landscapes, they can be used to reduce the land-degradation process. One should avoid placing cross drainage on the steepest or most erodible sections in a watershed, but instead concentrate runoff in the more stable streams.

In some highly erosive drainage lines, the choice can be made not to place a culvert or to place it with a high sill. This will disperse the runoff along the uphill side of the road and cause the stream to fill up in front of the road. This can help control the specific erosion hotspot.

Capturing eroded soils with roads in combination with warping dams

Warping dams are relatively high retaining structures constructed to capture soil in highly erodible landscapes. They fill up on the upstream side, creating stable and fertile terrace land from where runoff water can be better managed. Once the land area is filled up, the water streams can regularized. Roads can be combined with such warping dams. Warping dams were used extensively in China's loess plateau where the landscape was heavily degraded, but where hillsides were treated with a range of measures and valleys were blocked off with warping dams, creating fertile new land where there had been heavy erosion.

Road in combination with warping dam, making a degraded valley fertile with regularized drainage (Li 2016)

4. Roads for Water in Coastal Lowlands

Key message

- In coastal lowlands roads serve as flood protection infrastructure and vice versa: this requires cooperation between the responsible organizations in transport, water management and disaster risk reduction to optimize functions and co-benefits and come to joint specifications and better integrated concepts;
- In coastal lowlands roads also have a major impact on water management which is now often manifest in water logging;
- As roads are the main infrastructure in these low lying areas, they can also be used to control water levels for productive use;
- Such measures contribute to the longevity of the lowland road network.

Main techniques

- Several techniques optimize the interface between roads and flood resilience: higher roads or road levees/ flood shelters in flood prone areas, creating flood water storage, using excavation material to make local roads; using low embankment roads in selected areas (Ch 11); evacuation planning, turfing of embankment slopes;
- Several techniques improve the contribution of roads to water management in coastal low lands: road alignment to compartimentalize high and low lands, adequate cross drainage to retain and release water, using gated culverts for water level control, making use of borrow pits for drainage and water storage (Ch 7), using roads for land accreditation.

4.1 Objective

Road created with excavation material from drainage canal in coastal Bangladesh

This chapter discusses the systematic integration of road development with productive water management and improved flood resilience in low-lying coastal delta areas. It is based on work in Bangladesh but also refers to other countries. The combined planning and management of roads, cross-drainage structures, and flood embankments are powerful strategies to enhance climate resilience, improve flood-disaster risk reduction, increase agricultural production, and ensure the durability and reliability of road infrastructure in coastal areas.

Coastal areas represent 20 percent of the world's land, but they are home to more than half of the global population and an equal portion of economic activities (World Bank 2008). They offer a rich variety of ecosystems with a range of services, such as storm protection, water purification, nutrient recycling, fish spawning, and recreation (tourism). They also sustain food production (crops, fisheries, and aquaculture).

Due to their location, coastal systems are among the most productive but also one of the most threatened (Dayton et al. 2005). They are at the forefront of climate change with sea level rise, storm surges, floods, and changing rainfall patterns, but there is also a larger picture of changing river regimes, sedimentation patterns in coastal deltas, and land subsidence (World Bank 2008). The latter impacts may be greater than the effects of climate change. Land subsidence in the Ganges Delta, for instance, is estimated at 18 mm/year (Brammer 2014): much more that the expected global sea-level range, projected at 1-2 mm/year (Church et al. 2001).

Roads have a significant influence on the development of coastal areas. Because they are often combined with permanent embankments, they may influence the duration and extent of inundations and the dynamics of flooding in coastal deltas. Roads also fragment the landscape and interrupt the natural flow of water and the movement, sediments, and nutrients important for biological diversity, fertile agriculture, and fisheries (W. Douven, Goichot, and Verheij 2009). Douven et al. (2012) argue that a resilience approach rather than a resistance approach often works better in coastal areas. A resilient approach consists of managing the road infrastructure along with the surrounding landscape, adapting to the broad opportunities of the area rather than reclaiming and protecting as much land as possible, and accepting risks while building in mechanisms to deal with these risks. The resilience strategy aims at minimizing the consequences of floods, while maintaining natural floodplain dynamics as much as possible, whereas the resistance strategy aims at preventing and regulating floods, which has a strong impact on natural floodplain dynamics (Douven et al. 2009)

4.2 Opportunities

There is a strong connection among roads, water management, and flood protection in low-lying coastal areas, but this connection isusually not systematically operationalized. This represents both a major missed opportunity and, in several cases, the creation of a substantial problem.

There is considerable scope for an integrated approach in which roads can become instruments for water management and flood resilience in coastal areas. There are three main opportunities: (i) roads contributing to improved agricultural water management; (ii) roads combined with flood embankments; and (iii) roads serving more systematically as temporary flood shelters and evacuation routes. These opportunities are discussed below.

Roads for improved water management within low-lying coastal areas

Roads, bridges, culverts, and gates in low-lying coastal areas strongly influence the flow of water, its distribution, and its levels. The network of internal roads, including small village roads and pathways, divides the areas into compartments, separating relatively higher and lower lands. Road infrastructure may impede drainage and create waterlogging, affecting land use and the soil's capacity to absorb rain during high rainfall events. Cross-drainage structures (bridges, [gated] culverts, and pipes) are often insufficient, too narrow, and obstruct water flows. Likewise, bridge sills may be too high, impede drainage, and cause waterlogging.

At the same time, although they are now not constructed on these principles, roads can be powerful instruments to better regulate water levels in the fields and contribute to improved agricultural production. If properly fine-tuned, roads in low-lying coastal areas can serve as infrastructure to create areas with relatively low and high water levels and thus allow more varied, multiple-cropping land use patterns. At present, road alignment is not often designed in accordance with the catchment's hydrology. As mentioned, water-crossing structures may have inadequate dimensions, or may be incorrectly located or absent. Neither are they systematically provided with gates that would provide a major opportunity to actively manage water levels and store and/or release (flood) water between different sections of the low-lying coastal areas. At the same time, erosion and subsidence quickly damage new roads designed without attention to required drainage. In summary, combining road development with water management brings multiple benefits: less waterlogging, less road damage, improved agricultural production, and improved overall livelihoods of rural communities.

Roads combined with flood embankments

There is also a strong link between roads and flood embankments. Many of these embankments are also used as roads: the top of the embankment serves as a subgrade for the road pavement. There are also several examples of roads functioning as embankments of rivers, channels, and canals. There are sometimes mismatches between these transport and flood protection functions. This happens when a paved road is developed on an embankment that has not yet reached its safe and climate-proof level; because of the road, pavement cannot easily be increased. In some instances, the height of the embankment is reduced to create a wider road and improve transport functions. In addition, when a road is developed it tends to compact the body of the embankment: this makes it stronger but also may cause subsidence of the embankment body. This threatens the essential flood protection functions of an embankment. The construction of bridges in the flood embankment may also weaken or strengthen the flood protection functions. The current issues can be turned around by dovetailing road and embankment development, which would make both stronger, and by designing embankments following criteria to accommodate a future road.

Roads more systematically serve as temporary flood shelters and evacuation routes

The third important nexus between roads or embankment roads and flood resilience is that roads act as shelters and as safe havens during times of inundation. Also, after floods recede, roads serve as places where affected people and livestock can temporarily settle and rehabilitate. There is a need to systematically develop these linkages with roads in areas at high risk of inundation providing evacuation routes and safe places for people and livestock.

4.3 Recommended Best Practices

Best practices (Figure 4.1) are discussed below in terms of these three main opportunities to create more climate resilience, higher agricultural and fishery production, and to better preserve road bodies. This should ideally take place in an overall picture of adequate drainage in low-lying coastal areas with control structures and sufficient capacity for water storage and removal. The functioning of water-related infrastructure can make a major contribution to the agricultural performance and sustainability of all infrastructure in coastal areas, including roads.

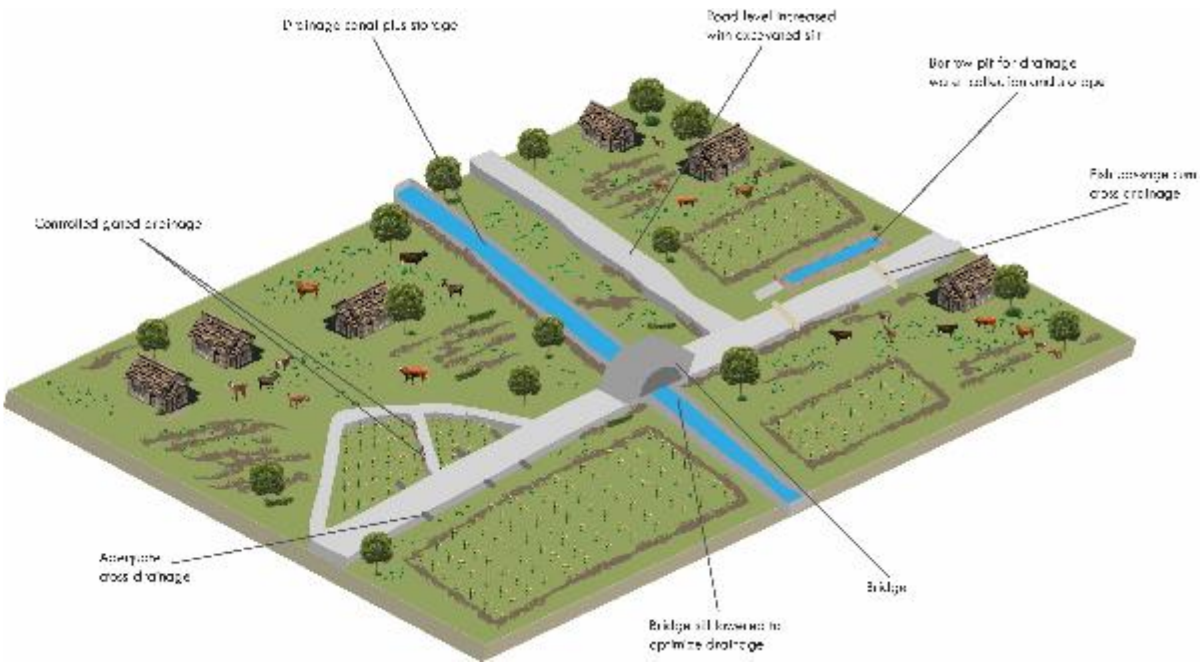


Figure 4.1 Recommended best practices in coastal lowland areas

4.3.1 Roads for water management in low-lying coastal areas

Coastal areas are major suppliers of agricultural produce due to their proximity to urban centers and the usually conducive circumstances of adequate land and moisture. An important challenge is to manage water levels in extensive low-lying flat areas. Roads in these areas can play a major role: they are usually the only infrastructure present in low-lying areas that can be used to control water levels. Table 4.1 considers a number of practices:

Table 4.1 Improved practices in low-lying coastal areas

	Improved practice
Roads for improved water management in low-lying coastal areas	Plan roads and paths to more systematically serve as boundaries that separate high-, middle-, and lowlands in low-lying coastal areas.
	Integrate cross drainage from the beginning in road development, as well as the dimensioning and placement of culverts and pipes in accordance with hydrological catchments in the polder.
	Use gated culverts and pipes to turn these road structures into instruments for water level control.
	Ensure fish passages in areas where there is wild fish capture.
	Have roadside borrow pits to serve as drainage ditches and provide critical dry peak/dry season irrigation or use for fisheries.
	In low-lying areas, consider the possible effect of roads on sediment retention, and use roads to trap sedimentation and allow land to rise gradually in order to deal with river water-level rise.
	Excavate ponds and canals to create adequate storage for the dry season and reuse the sediment for building road embankments or flood levees.

At present, the effect of roads on surface hydrology is generally not taken into account during road development, in particular for smaller roads and footpaths. This results in road damage due to seepage (see pictures) and waterlogging around roads, and opportunities for improved productive water management are missed. With the exception of major highways, local road management agencies/institutions do not typically conduct hydrological surveys for the development of new rural roads. The criteria often used in the design of village roads are mainly based on traffic, public demand, land availability, and socioeconomic connectivity (access to markets and surrounding villages).

Seepage on rural road

Water seepage caused road collapse

However, it is essential to take basic hydrological considerations into account when developing roads in low-lying coastal areas, including flood drainage, stream channels and topography, afflux, debris properties, scour risk, road alignment, soil conditions, and fish movement (Queensland 2015). If a hydrological survey is impossible due to lack of resources, local community groups could undertake landscape mapping. Such mapping could include location of the road, current land use on either side, the micro-relief of the area, the location of cross-drainage structures (culverts, pipes, and bridges) and the need for gates, and water retention and drainage requirements for agriculture and aquaculture.

Planning the boundaries of roads and paths as divisions among high-, middle-, and lowlands in low-lying coastal areas

Roads redefine the surface hydrology of low-lying coastal areas, dividing it into high-, middle-, and lowlands. Each level of land will have its own best usage and cropping pattern. To the extent possible, roads should follow contour lines and compartmentalize farmland at different levels. This will optimize productive use at each level of land.

If there is a suitably detailed Digital Elevation Mode (DEM), this can be used, but it is unusual to have DEMs that capture the micro-elevation in coastal areas, which may range from 50 to 150 cm. If no DEM is available, roads as divisions among high-, middle-, and lowlands in low-lying areas (as well as the location of cross-drainage structures) may be planned based on systematic discussion with local organizations and local governments.

The compartmentalization of land at different levels can also be used to slow peak rainfall runoff by storing it behind the polder road embankment before it overflows onto the next stretch of land. This slows the velocity of water, reduces erosion and siltation, and leads to more groundwater recharge. Water can be retained longer in higher areas and serve as storage for lower areas or be used for the cultivation of rice and shrimp in the wet season.

Integrate drainage structures in the initial road design

At present, drainage structures (culverts and pipes) are not always integrated into the initial road design. The location of culverts or pipes is sometimes decided later on, when road damage happens due to seepage or when waterlogging occurs. There is rarely consideration of how to remove drainage water. Rather than using such a gradual approach, it may be better practice to decide on the drainage requirements when the road or pathway is first constructed. A ready-reckoner "gap rule" may be used, especially for community roads. This rule is used in Bangladesh, for instance. It describes the recommended length (in meters) of drainage openings (bridges, culvers, and pipes) per 100 m of road (Table 4.2). It is based on the type of road and geographic location.

Table 4.2 Gap requirements by type of road, m/km in Bangladesh (LGED 2005)

Waterlogging in Bangladesh

Road type	Geographic location		
	Swampy	Hilly	Plain
Secondary and tertiary roads	10-15	7-15	6-10

In deciding the location and type of cross-drainage structures, the following steps are recommended:

- Observe the natural drainage patterns and place the cross-drainage structures along natural drainage paths;
- Discuss the need for drainage of the higher command areas and the opportunities to discharge the excess water; and
- Consider the controlled cross-drainage structures (see next) in those locations. Consider pipes or culverts with gates if there is a need to constrict flow or control water levels. If water must move freely at all times, a bridge is preferred for larger crossings.

Use gated crossings to retain and control water

Gated water-crossing structures (see pictures), particularly on box culverts and pipes, will help to control water levels with the road infrastructure, especially with roads inside the polder.[4] Water levels in a large area can be controlled with these relatively simple devices. They also make it possible to manage the water level in the upstream area for rice cultivation, for instance, by opening or closing the gate. By opening the gates, water upstream can be released, and the area can be drained, for instance, when fertilizers and other agricultural inputs need to be applied. In this way, controlled cross-drainage from roads goes hand-in-hand with the cultivation of high-yielding varieties.

[4] This practice is not recommended for roads that serve as flood embankments (see 4.3.2).

Gated culvert in Bangladesh (photo: Blue Gold)

The gates on the cross-drainage structures can also be used to manage water storage upstream of the roads, for instance, for dry season cultivation or for aquaculture. In this case, it may be useful to provide additional protection to the roadside to prevent it from being affected by the high water levels.

Gates should be provided at specific locations based on local discussion and agreement to control drainage; manage water levels of fields, canals, and ponds; and increase water availability for different purposes (irrigation, fisheries, and households). The gates may be made of wood or iron, but an important consideration is that they should be theft- and tamper-proof. Local discussion should also create clarity on the rules and responsibilities for operating the gates.

For gates on cross-drainage structures, the following are recommended:

- For box culverts, provide an internal slot or external railing for stop logs or gates; and
- For pipe culverts that have a superstructure, provide a hook or railing to attach the gate.

Especially where there is more than a 0.50 m difference between upstream and downstream land, scour protection may be provided with vegetation or small stone pitching both on the upstream section and the downstream flow path. This will prevent damage from water gushing through once upstream water is released.

Box 4.1: Controlling rice cultivation with dual purpose culvert in Liberia

In Liberia, lowland rice cultivation is common. Roads in several areas have disturbed their hydrology, but in other cases 'clever' dual purpose road culverts have been used to regulate the rice cultivation. The road culverts have a dual propose: they act as micro dam and a bridge to cross a small river. They have two outlets: a higher larger one (60 cm wide) in use during the high rain season allowing more water to pass and a smaller one (12 cm) for the dry season to let a controlled flow to the irrigated rice field on the downstream side. The small pipe directs the water to the irrigation canal built on the downstream side. The intake of the canal on the culvert is gated and can be opened or closed depending on requirements.

Ensuring fish passage

Roads also have an impact on the movement of wild fish in low-lying areas. The road should not obstruct fish migration routes, and bridges should be placed in accordance with major migration routes. Culverts have relatively small openings and are less suitable for maintaining fish migration routes. Therefore, bridges are preferred to minimize impact on fish ecology (Douven et al. 2009). Nevertheless, culverts and pipes are the main passages for fish and other aquatic animals in wetland areas. A number of considerations apply if culverts are used as fish passages (Figure 4.2):

- The flow velocity through the culvert should not be greater than the swimming capabilities of the fish. The swimming capacities of species vary and are often unknown. It may be useful to apply a very gentle slope through the culverts so as not to interfere with fish movement.
- The outlet of the culvert should not have a vertical drop that makes it difficult for fish to swim or leap out.
- The water level in the culvert should be minimum, at least during the fish movement season. Standing shallow water in the culvert or pipe will help fish to cross.

Figure 4.2 Pipe with fish passage

- There should be no debris or sediment accumulation in the culvert or pipe that causes physical blockage or increased turbulence, because it might prevent fish from moving across the culvert.

Use borrow pits for multiple functions

Borrow pits (see picture above) are excavations performed to collect materials—sand, gravel, soil—for road construction and maintenance. They are typically located parallel to the road. For instance, the standard criteria for borrow pits in Bangladesh (LGED 2004) are as follows: the depth should not exceed 1.5 m, and the width of the embankment's side berm and the edge of the borrow pit should be from 3 m to 10 m.

Roadside borrow pit for rice drainage and fishery in Bangladesh

Borrow pits will fill with water during the monsoon season. They serve several useful functions (see use in Nepal):

- They act as a drainage reservoir, taking excess water from the adjacent (paddy) fields;
- They serve as water storage and can increase the groundwater table; and
- They can be used for important functions such as fishery, harvesting aquatic plants, and jute retting.

It is useful in most instances not to backfill the roadside borrow pits but instead to discuss their location and dimensions with the users and owners of the land where they are located, preferably under the guidance of local community groups. The location of borrow pits in low-lying areas should follow a number of considerations:

- Clear ownership of land and future borrow pits;
- Definition of future function; and
- Ability to landscape the borrow pit and make it safe.

Practice of using roadside borrow pits and drains as drainage buffer, also practiced in the Terai Plains of Nepal

Use roads to raise lands

Use roads to capture sediments

Roads in low-lying areas can be used to capture sediment by increasing the land level on one side to gradually deal with river water-level rise. This practice now occurs by chance but can be managed better. The impact can be noticeable. For instance, in Polder 2 (Shatkira, Bangladesh) the ground level has increased 15 cm on the upstream since the road was built 20 years ago. The higher ground is less prone to flooding and/or waterlogging, and farmers can grow a wider variety of dry-season crops. The land rise (75 mm/year) in this area is higher than the sea-level rise (4 mm to 8 mm/year) and the land subsidence. There is reason to use roads to trap sediment in selected low-lying coastal areas. This can be done as part of polder-level road planning, informed by hydrological mapping. The following would be required:

- Mapping of intake points into the polder and an assessment of their silt levels;
- Mapping occurs in line with the internal drainage patterns in the polder and the high-, medium-, and low-lying areas; and
- Mapping of the opportunities for (new or existing) road infrastructure to guide relatively silt-laden water to low-lying areas and depressions by diverting part of the surface flow.

Reuse the excavation material from canals to increase road levels

The internal drainage in low-lying areas often consists of a network of canals, usually the original coastal creeks. These canals are multifunctional: they remove excess water when required but also serve as water storage or are used for aquaculture.

Water stored in canals, but siltation can cause drainage congestion

Siltation of canals is a constant challenge: it will increase the water levels in these drainage canals by causing drainage congestion and waterlogging. Regular cleaning and re-excavation of canals are needed to ensure system connectivity, continuous water drainage, and more water retention inside the polder. The excavated silt can be reused systematically to create land for agriculture, increase the level of cultivated areas, increase the level of settlements, and build roads and/or embankments and flood levees.

4.3.2 Roads combined with flood embankments

Flood embankments, next to their role in flood protection, are used in coastal areas for transportation. In addition, some newly developed roads in coastal areas double as flood embankments. Because different organizations may be involved (road departments, disaster risk reduction departments, or water departments), it is important to synchronize the criteria for roads and embankments with regard to width, side slope, and height. Similarly, the planning of the development of roads and embankments should be coordinated. Traffic functions and flood safety should be combined and not compromised. Table 4.3 and Figure 4.3 offer an overview of recommended improved practices in this field:

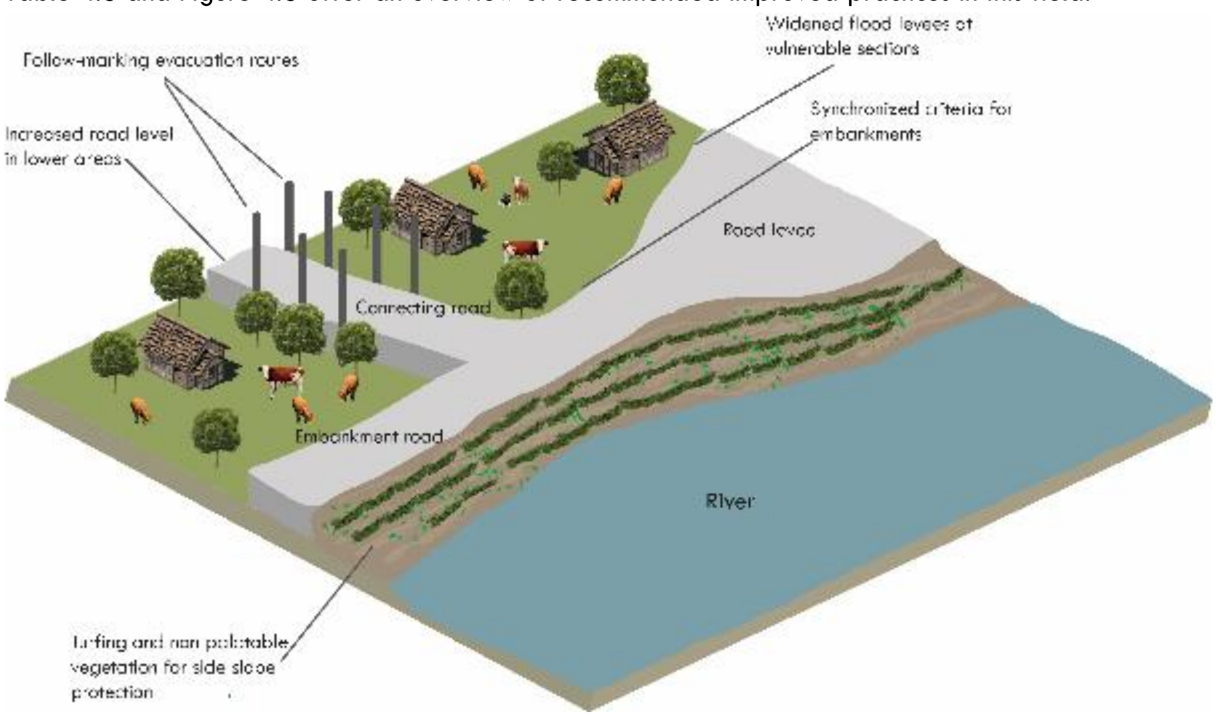


Figure 4.3. Recommended good practices for roads combined with flood embankments

Table 4.3 Recommended practices for roads as flood embankments

	Recommended practice
Roads combined with flood embankments	Synchronize criteria for flood embankment heights, widths, and slopes in line with climate change scenarios
	Coordinate development of embankment raising and road development
	Use turfing or vegetation with high value, non-palatable crops such as vetiver for side-slope protection

Synchronized criteria for embankment roads

Embankment roads should be designed and constructed with sufficient width and height to ensure protection from floods, land preservation, and transport functionality. Using Bangladesh as an example, the standard design of village roads for small-scale projects (<1,000 ha) (LGED 2004) establishes a minimum crest width between 2.5 m and 4.9 m for road embankments, while the standard Road Design Manual 2 (LGED 2005) establishes a crest width for village roads of 5.5 m. Moreover, the current crest width used by the Bangladesh Water Development Board (BWDB) for embankments is 4.3 m. It was proposed that an agreement among road and water institutions be reached on a common standard crest width for road embankments (a minimum of 5.5 m). This also creates extra space for human and livestock shelters during flood events.

Moreover, the development of new design criteria for embankments and roads should be based on future climate scenarios: standard crest width and height based on a return flood period of 1:100 (or 1:200 for large rivers), adequate side-slope protection, and size and number of drainage structures based on climate change. Road and water management organizations should work together and establish common standard criteria for embankment and road design.

Coordinated development of embankment raising, road development, and road paving

The development of roads and embankments is not always coordinated in practice. This is manifest in roads being carpeted on embankments before these have reached their safe flood levels. There are also instances where even the top of the embankment has been lowered to accommodate the width required for the road. Road and water organizations should come to agreements on what is required in advance of road construction. Because the crest width and the side slope prescribed by water organizations is binding, the budget for road development should include provisions for raising the road embankments to safe levels as well as road pavement and subgrades. When developing a road on an existing embankment, the effect of compaction of the existing embankment should be accommodated as well. If a road is constructed on an embankment that is not yet at prescribed levels, the pavement is considered temporary and may be demolished to be rebuilt after the embankment is raised.

Use turfing or vegetation for side-slope protection

Measures to protect side slopes should be incorporated in the initial design of roads or embankment roads and the berms of the embankments (Islam 2000). Local vegetation (grass and shrubs, but not trees) should be used to protect the side slope of roads, in particular the embankment roads. Suitable grass species such as vetiver at 0.3 m x 0.3 m spacing, mixed with *Ipomoea*, *Nypa*, *Typha*, and *Pandanus* (Islam 2000), may be used. Vegetation on the berm slopes is a barrier against runoff and erosion. Slope protection with grass increases the stability of the slope and decreases road erosion, leading to road stability and flood resistance. Turfing can be combined with the use of jute or coir netting to prevent soil erosion (Figure 4.4).

Figure 4.4. Use of turfing combined with jute netting

Species should be selected in consultation with the local community. Land in coastal areas is often at a premium and is heavily contested. The use of side slopes and the protection of newly planted vegetation should be discussed with the local government as well to decide on who is allowed to use the side embankment and who is responsible for guarding the side slope, and how this is to be supervised and enforced. In addition, grass vegetation should be evenly spread and well maintained, and no animal paths with associated gullies should develop and undermine the embankment. On the other hand, if the vegetation is evenly spread, the hoof action of animals may compact and strengthen the embankment.

Coastal-area embankment roads may be also protected by a 50 m to 200 m wide belt of mangrove (Figure 4.5) in tropical regions or by non-mangrove planting following the staggering method. This practice may also decrease the impacts of storm surges and the tidal effect (Islam 2000). Mangroves retain nutrients in their roots, increasing soil stability and keeping up with sea-level rise (Alongi 2008). Moreover, mangroves act as a buffer against strong winds and the cyclone tidal effect.

Box 4.2 Repairing embankments using Green Soil Bags

A special, newly developed method to prepare or repair embankments is the Green Soil Bag. This is a unique measure developed to block water like a traditional hessian sack. The major advantage compared with the traditional sandbag is that the Green Soil Bag is fully bio-degradable and filled with mix of grass seeds and rich earth. The seeds will germinate depending on the temperature and grow outward through the jute. For the first 1.5 years, the bag itself will ensure stability in the dike/embankment. Later, the bag will be digested and the grass net will take over the function, blocking erosion by rooting of the subsoil. Dutch water boards use this smart and simple invention to strength their levees and harvest the grass. Green Soil Bags were designed to repair dikes and flood defences, increasing their height. The Green Soil Bag was also introduced under a pilot project in Gondamari, Bangladesh, where local communities are very enthusiastic about evidence of good initial results.

Green Soil Bags used to build levees in Kalapara

4.3.3 Roads as temporary flood shelters and evacuation routes

Roads play an important role in flood disaster response. Because of their higher location, they serve as emergency flood shelters and provide evacuation routes. Emergency shelters have been constructed in several areas. However, these shelters are unable to accommodate the entire population in an effected area. For this reason, roads complement typhoon shelters and other flood-response measures. There are several good practices to better connect road development and emergency responses in coastal areas (Table 4.3).

Table 4.3. Recommended practices for roads as flood shelters and evacuation routes

	Recommended practice
Roads serving as flood shelters and evacuation routes	Prioritize the development and heightening of roads leading to designated emergency shelters.
	Create heightened road bodies in low-lying areas of the polder to create safe routes and safe temporary shelters during flood events and refuge areas in the post-flood scenario.
	Create levees along vulnerable sections of the roads to protect roads and embankments, and create flood and post-flood shelters for humans and livestock.
	Plan evacuation routes using road infrastructure.

Prioritize the development of roads that connect to emergency shelters

Cyclone shelters in Bangladesh

In developing roads, one priority must be the roads that connect to designated emergency shelters. In making a road development plan for a coastal polder, the road network should be designed in such a way that it is possible for humans (especially women, children, and disabled people) and livestock to reach the safe place in a short distance. Road development should be part of Disaster Risk Management planning.

Prioritize the development of roads in the lowest areas

Roads also provide important functions during floods, serving as safe shelters during and immediately after floods. These functions should be systematically strengthened. In designing new roads, priority may be assigned to the road sections in the lowest part of an area and to raise them to at least design specifications (1/20-year flood levels plus 0.3 m additional free board). Where possible, excavation material from local canals may be used.

Consider levees along roads to temporarily accommodate flood-affected persons

In addition to raising the roads in the lowest sections of low-lying coastal areas, levees may be created along internal roads and along specific embankment sections to shelter people and livestock during floods and high-water events. These higher sections should be created especially in high-risk areas, using the remaining silt from the excavation of canals, ponds, or rivers. Such sections along the roads could provide the opportunity to accommodate temporary flood victims (people, cattle, and goods) until their homes have been rehabilitated. The use of these levees should be regulated by the local governments to avoid the undesired permanent occupation of flood shelters. Levees should be spaced strategically at distances so that they are accessible throughout flood-prone areas, placing them along more exposed sections of flood embankments so they can serve as additional reinforcements. The same may also be done for the area outside the embankments.

Embankments used as temporary flood shelters

As a rule of thumb, the minimum space needed for a person to take shelter lying down is 1.5 m^2 or 3.5 m^2 for a sphere standards space (Red Cross 2013). An average household in Bangladesh, for instance, has 4.6 members (Begum 2004). A family needs a shelter area of approximately 15-16 m^2. For livestock, a space of 2 m to 4 m per head would suffice. Therefore, 85 people can take shelter (without livestock) on a longitudinal section of 100 m of embankment with a width of 3 m. If there are multiple areas of 300 m^2 in specific locations along an embankment, the number of people who would benefit from temporary shelter is proportionally higher.

It is also important to protect such levees by stabilizing their embankments through the planting of hedges, vetiver, and other grasses on their slopes and toes to protect them from erosion (Islam 2000).

Plan and mark evacuation routes

Despite emergency preparedness programs and early-warning systems, pre-emergency evacuation remains a challenge in coastal villages of developing countries. In rural areas there remains a lack of awareness and communication to enable people to understand the warnings and evacuate. Moreover, dissemination of warning messages is inefficient, because poor residents in coastal areas may not have means of communication (Haque et al. 2012). During floods and typhoons, roads are an important part of the evacuation of people and livestock. Part of emergency preparedness should be to plan evacuation routes. This can be done by:

- Mapping population centers;
- Mapping road networks and looking at the above-ground level of roads;
- Mapping for floods, inundation risk, and escape routes (Figure 18) (WMO & GWP 2011);
- Putting in place flood signs (boards, poles) along the roads as part of evacuation-route planning, especially in areas that are easily inundated: the aim is for escape routes to remain visible during emergencies (Figure 4.6) (WMO & GWP 2011)
- Raising awareness so that a large number of persons are familiar with evacuation routes.

Figure 4.6 Map of escape route in Thailand

5. Roads for Water in Mountain Areas

Key message

- The selection of the alignment and slope of roads and the provision of adequate water crossings is critical for the longevity of the road and to minimize the harmful effect of the road on the surrounding environment;
- Given the (climate) vulnerability of the medium and high altitude areas it is important to safeguard the road environment with measures that reduce the risk of disturbance whilst also improving the productive value of these areas.

Main techniques:

- For the development of new mountain roads, the mass balance method should be considered;
- Main techniques to manage the water road environment are spring capture, reinforced road water crossings (see also Ch 8 and 9) and bio-engineering.

5.1 Objective

Many high-altitude and middle-altitude areas are at the forefront of climate change. Much of the attention is placed on their medium- and long-term contribution as water towers, safeguarding the future water supply of minor and major rivers that originate from them. Climate change comes in several forms in high mountain regions: higher summer temperatures or more frequent short-duration warm spells; more rainfall but less snow; more wet snow and less dry snow. These changes often unsettle the precarious balance in the mountain regions, causing glacier retreat, more frequent landslides, and the emergence of temporary lakes (see Box 5.1). They also cause mountain areas to become drier in the long run with snow melt becoming a less reliable supplier of moisture. Within this overall pattern of climate change in high- and medium-altitude areas, there is a diversity of trajectories. Lutz et al. (2014) describe various trends in different parts of the Himalayan region, the world's foremost water tower. Most Himalayan glaciers are losing mass, often on the order of 23 to 56 percent, with significant repercussions for the water security of high-altitude areas. Within the Himalayas, the exception is the Karakoram range where glaciers are stable and are sometimes gaining mass (Bolch et al. 2012). In general, because of glacier melt, water availability will increase until 2050 but decrease between 2050 and 2100 (Immerzeel, Pellicciotti, & Bierkens 2013). Adaptation to seasonal shifts, changed water availability, and extreme events (flooding) are new challenges in the mountain regions.

Road development in mountain regions presents many engineering, logistical, and financial challenges. If done carelessly, the development of roads in these environments can have a heavy negative impact on the surrounding environment and undermine climate resilience. Road development can change runoff patterns and cause areas to further dry out. They can transfigure the face of mountain regions, leaving behind huge erosion scars and accelerating the rate of sedimentation.

This chapter discusses the development of mountain roads and the improvement of the landscape around mountain roads. It argues, as elsewhere, that the development of roads should be seen as an integral part of the development of the landscape in which the road is placed. Yet more than in other chapters, it makes the point that additional measures are required in the mountain landscape surrounding the roads to make the areas more stable and productive and to reduce the exposure of the road to extreme events.

This chapter first discusses the impact of roads on mountain environments (5.2). It then goes on to discuss investments in roads to make them instruments for resilience in their mountain environments (5.3) and the additional measures to be considered in bolstering the mountain road environment (5.4). We argue that road protection and landscape management should be combined to reinforce one another.

Box 5.1. A landslide triggering a new mountain lake

Here is an example of what a landslide can do to connections is Barsem Lake near Khorog in the Pamir Mountains of Tajikistan. Over two days in July 2015, a landslide came down from the small Bersam side valley to the Gunt River, the region's main river. The landslide came in a series of at least 12 bursts, each time carrying an enormous mass of rocks, sand, and gravel down the valley. It created a solid debris fan 500 m wide and stacked 15 m high in the Gunt River. The landslide took 64 houses along with it. Fortunately, there were no human casualties, because the first landslide burst came in the afternoon, giving people time to move to safer ground.

However, other consequences were dramatic. The landslide blocked the entire Gunt River. This created a kilometers-long lake overnight, covering land along the river and inundating the main road up to the border. It also submerged power lines from the Pamir-1 hydropower plant. This isolated the area and disrupted all logistical supplies. No power was provided to Khorog. Transportation in Tajikistan to and from China came to a halt. Disaster response was swift. Power connections were restored within days, using an entire new route of pylons. The emergency road higher up the mountain was constructed in 42 days, engaging all equipment that could be mobilized.

After one year of considerable effort, local engineers finally managed to slightly unblock the river with the help of dynamite and excavators. Only a narrow through-fare could be made in the debris fan, taking some of the pressure off the newly formed Barsam Lake. The larger part of the river is still filled with the landslide material that over time is becoming more compact. There are plans to remove all material, but looking at the blockage one is reminded that the human endeavor to resolve such problems is tiny in contrast to our capacity to create the problems in the first place.

5.2 Changing the mountain environment

It is unavoidable that the development of a road changes the environment of mountain areas: the hydrology, microclimate, and sedimentation patterns. The changes in hydrology concern several dimensions. First, the development of a road changes surface runoff patterns. Rather than flowing down a smooth gradient, the runoff is interrupted once or several times while descending from the newly cut hillside. The flow velocity is reduced as the runoff touches the road surface and erosive force is released. As the runoff touches the road surface it may concentrate and accumulate along the road surface, effectively changing the natural drainage pattern. Secondly, in a similar fashion the subsurface flows are interrupted in road construction (see figure 5.1, also chapter 3). The degree to which water travels in the upper soil layers and geological formations differs from place to place and from road section to road section. Roads disrupt these shallow moisture flows and, in many areas, cause new springs and seeps to emerge.

(a) (b)

Figure 5.1: (a) Increased air-surface exposure of hill slope; (b) Interrupted subsurface flow due to road openings along Mugu Humla Road (West Nepal)

A third effect on hydrology is that with the opening of the hilly terrain the road cut also opens up fresh mountainsides and increases the air-surface exposure of the hill slope (figure 5.1). This will dry out the hill slopes, particularly when the slopes are freshly cut. There is, moreover, a gully effect with soil moisture moving towards the road cut from where it constantly evaporates. Unless the side slope is covered again with vegetation, it may lead to a 'bleeding' of the subsurface moisture, drying up hillsides. Fourth, the construction of roads will also increase the so-called hydrological connectivity of the watershed. Hydrologic connectivity describes the degree to which elements in a landscape are interconnected. The higher the connectivity the faster the rainfall run off, causing peak flows in the rivers to emerge early and be more pronounced (Meng, Wu, & Allan, 2013) – see also Chapter 3. Road development has generally accelerated runoff, making new connections and concentrating flows in a smaller number of drainage lines.

Furthermore, the opening of the roads in steep mountain terrain has a large bearing on the microclimate (see figure 5.2) of roadside areas, which can be observed, for instance, when forest areas are traversed. The impact on the microclimate comes from the changed hydrology and from the greater exposure of the mountain slopes to sun and wind and reduced tree canopy once roads 'open up' the roadside environment. The general effect will be for the area surrounding the mountain road to dry. Such drier road environments and lowered soil moisture effect soil temperatures (more heat exposure) and microbiology. When soils are less moist there is less microbial action in the soil which will, for instance, reduce the capacity to fix nitrogen, with repercussions for vegetative growth. We also see gradual drying, the increase in day temperature, and a lowering of night temperature. This may also affect local rainfall patterns and the occurrence of dew, which is an important source of moisture for vegetation. To rebalance this, measures should be taken to retain moisture and regreen the area.

Finally, roads also trigger sedimentation in mountain environments. The cut section of the road and road surfaces are vulnerable to erosion. Much erosion occurs during road construction, further aggravated when slopes are unstable. Erosion control should be part of the methods of road construction and of additional measures taken. This is, of course, at its most spectacular in the shape of landslides and mudflows that may be triggered by the development of roads, either because they destabilize hillsides, cross unstable mountain sections, or cause seepage that triggers dramatic landfalls. The topic of roads and landslides is covered in a broad range of literature and is not discussed further in these Guidelines.

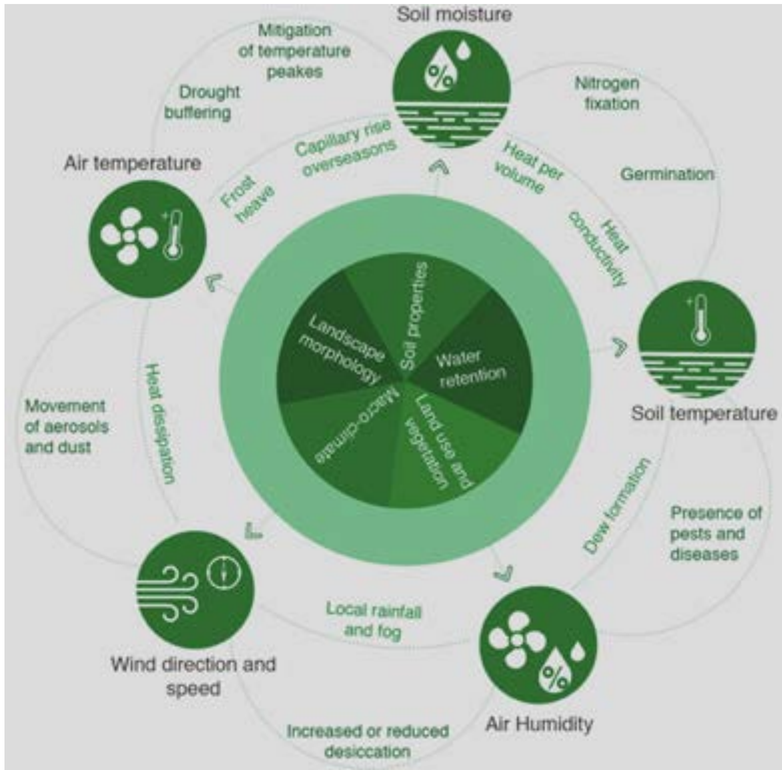


Figure 5.2: Interlinked components of micro-climate

5.3 Improving the mountain road

When making a mountain road that contributes to resilience and can withstand shocks and stresses, there are a number of considerations:

- Choosing the road alignment and design carefully;
- Choosing the appropriate construction method;
- Including protected road water crossings – such as tilted causeways, reinforced causeways (drifts) at ephemeral stream crossings, dissipation blocks, check dams and downstream protection infiltration road-side bunds;
- Managing roadside springs and seeps.

5.3.1 Choosing the road alignment and design carefully

The choice for the road alignment and design goes a long way to ensuring the sustainability of the road and its contribution to the resilience of the landscape. A first important consideration in selecting a road alignment is that it should not disturb runoff patterns. With steep slopes in mountain regions, the high speed of runoff can create havoc for sometimes unstable slopes. There are a number of considerations. First is to observe reasonable longitudinal slopes. In the Nepal Rural Road Standards, for instance, 7 percent is taken as the ruling gradient (for a maximum distance of 300 m). The recommended limiting longitudinal gradient in mountain roads is 10 percent, with a maximum slope of 12 percent as an exception. Beyond this, the road will act as a drain, collecting water during rainfall events and causing extensive rutting to the road surface. Such steep, rutted, and often slippery roads are dangerous for vehicles, and are sometimes impossible to pass. They also alter the drainage pattern of the mountain slopes. Choosing gentler slopes has cost implications, as the length of the road will increase and there will be more bends. However, these costs are recovered through road functionality and reduced damage to the surrounding landscape. A second point is road drainage. The Green Roads criteria developed in Nepal are recommended to have free-draining, downward sloping road crowns to gently spread the runoff that gathers on the road. Good water exits at hairpin bends are required so that water does not remain on the road surface in these sections and careen downstream where it will accumulate and cause damage. A final point in selecting a road alignment and design is to incorporate road water crossings with an adequate number of causeways (or drifts) at stream intersections and other measures to control for stream crossing and spring management/

A second consideration in selecting a road alignment is to keep a safe distance from existing streams and rivers and to prevent the road from getting inundated or damaged by floods in such rivers and streams. The road layout should be aligned with the current and predicted hydrological situation. Roads should be at a safe elevation and distance from mountain rivers. An analysis of current hydrological data and future scenarios can inform this decision.

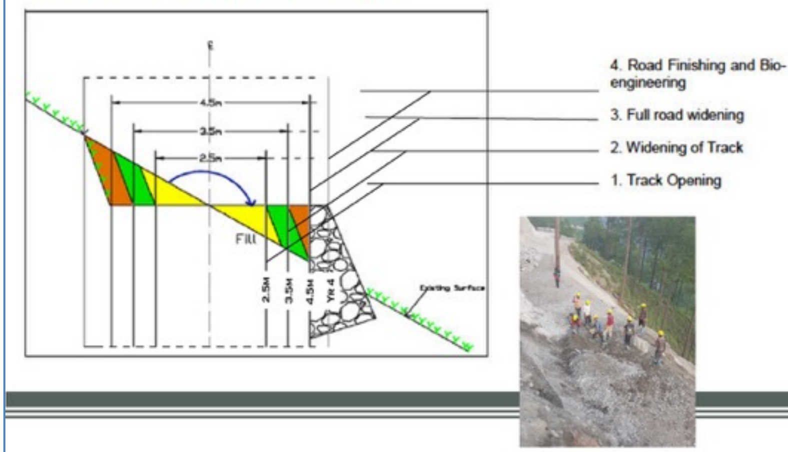
5.3.2 Choosing appropriate construction methods

Several methods can be chosen to develop mountain roads. A method that is worth considering is the cut and fill, applied in Nepal in several programs. One central element is 'mass balancing', i.e avoiding wastage of mountain material. In mass-balancing, the spoil that becomes available with the cutting of the road is used to make the downslope toe of the road. This has two main advantages. The first is that it reduces the amount of unused spoil significantly, because the spoil is reused in making the downslope toe. The second advantage that there is less cutting of the mountain slope, because the new road width is created both by cutting the mountain slope and adding the downslope toe. Compared to other methods, the height of the road cut is decreased and with this the risk of erosion, instability, and drying out of the hillside. The roads are ideally developed over a period of 3 to 4 years, allowing the road to settle and consolidate before it is further widened. The preferred method of construction is labour based, creating employment and skills (see Chapter 13) but also allowing careful handling of the construction process. Box 5.2 describes the green road cut and fill method[5].

Box 5.2: Green road cut and fill method explained

[5] Based on: RAP 3. 2018. Climate Resilience Audit of Maure-Kailasmandu District Road Bajura. April 2018. Rural Access Programme Phase 3, Lalitpur, Nepal

- Phase wise construction of road construction
  - Year 1- 2.5m track opening allowing one rainy season for natural compaction after track opening
  - Year 2- Track opening to 3.5m allowing another season for natural compaction
  - Year 3- 3.5 m to full width (4.5m)
  - Year 4- Road Finalization and bio engineering.



- Construction of retaining structures are started at required sections from the year-2 Vertical phase-wise construction of structures are carried out on yearly basis for natural compaction
- Back-filling on the backside of the structure is done with granular soil and layer-wise compaction in every 15cm
- Sub-surface drainage is provided for walls of height 5 m and above
- The survey is carried out in 2 stages; Stage 2 survey is carried out only after track opening. During Stage-2 Survey (watercourse) discharge on ravines, catchment area are better known and structures are designed accordingly
- Drains are provided in sections with a gradient greater than 7%, waterlogged areas and paddy fields. In the section of the road where drains are not provided, 5% outward slope is maintained to drain surface water off, and
- Geo-textile is used along the back of retaining walls for preventing loss of fine particles from backfill mass thus barring sinkhole/cavity formation in the backfill.

Instead of the labour-based approach described above, machine-based approaches are used in road construction to save cost and time. In this machine based approach, a 'cut and throw' method is used, whereby the upper hill slope is excavated and the excavation material, rather than being used for the down slope toe, is dumped downhill. A modified hybrid method may be used, whereby roads are opened up by (trained) excavator operators. Remedial work may be undertaken by labour groups, such as the development of slope protections, breast walls, and general road clearance. There is, however, a marked difference between the labour based cut and fill approach and the hybrid mechanical approach, captured in table 5.1. In general, the faster turnaround time and the lower the costs of the hybrid mechanical method comes at the cost of more environmental damage, less reuse of the spoil, less attention to springs, and a loss in labour opportunities. For Roads for Water, the labour-based approach is preferable. In the mechanized approach, the additional measures described below are even more urgent.

Table 5.1: Labour based and mechanical approach to mountain road construction compared

Parameters	**Labour intensive cut and fill method**	**Mechanised cut and throw method**
Design approach	Cut and fill	Cut and throw
Slope exposure	Shorter side slopes	Higher side slopes (up to 40% higher)
Loss of land	Estimated savings of 6,320 m^2 per km over conventional cut and throw methods[6]	Much land – including productive land - lost
Slope stability	More stable	Disturbance because of mechanical action – needs remedial action

[6] Phuyal et al. (2008) quoted in Mulmi (2009)

Road surface stability	Natural stabilization and compaction of road surface related to phased approach	Entire width of the road opened up at once creating less stability
Spoil composition	Smaller and more uniform rocks	Mixed including large boulders
Spoil displacement	Reuse of 86% of spoils in side fill[7]	Much excess spoil
Spring management	Possibility of spring handling	Larger disturbance of springs and seeps
Reuse of soil	Possible	Impossible
Labour creation	Approximately 25,000 labour days per km	Approximately 10,000 days per km, if proper aftercare and finishing built in. If not considerably less
Indicative costs	USD 260,000 per km	USD 160,000 per km[8]
Construction time	3 to 4 years	1 year

5.3.3 Including protected road water crossings

When a mountain road is opened up, many new road water crossings are created over regular streams that are interrupted or torrents that only flow during the rainy season and now descend on the road body. Unless measures are taken, these interrupted streams and torrents will damage the road surface by their erosive force and create extensive wet road sections that are easily damaged by traffic impact. Erosion may easily extend to the land alongside the road. To reduce the damage from these water crossings, several techniques are proposed: causeways, dissipation blocks, check dams, infiltrating bunds, and down-road protection. Many of these measures can make use of the spoil and rubble that becomes available if a road is constructed.

Tilted causeways. Roads are traversed by several mountain streams. At these places, causeways should be made of flat stones. Like the entire road, causeways are tilted at a slight angle (maximum 4 to 5 degrees[9]) towards the downhill side to facilitate the drainage of the water from the stream. This is a good practice, as it ensures the use of local material and provides structures that are easy to maintain. To improve and guide the removal of water, a depression can be made in the middle of the causeway. This depression is to be modest. If the causeway has a width of 25 m, the lowered section should be 25 cm to 50 cm. The depression should be at an angle of a maximum of 5 degrees so it does not interfere with the road trafficability. Where the road water exits the tilted causeway, it may be useful to armour the downstream part of the stream. Using a tilted causeway on sloped terrain has several benefits:

- It forces the stream and torrent flows towards the middle of the causeway and continues their flow in the existing drainage path, avoiding uncontrolled erosion of down road hill slopes.
- It reduces the chance of side-spills from the causeway during high discharges that may damage the road body.

[7] Phuyal et al. (2008) studied 7,900 cross sections of 286 km of hill roads in different regions. The study established that by adopting a mass balancing approach to green roads, 3,345 m^3 to 2,900 m^3 spoil per km can be reused for side slope filling. The remaining 465 m^3 of the spoil can be used along roads to improve the longitudinal gradient or for water retention or water protection measures.

[8] This is an initial estimate. The final cost per km of the hybrid mechanized approach will further decrease by 25% to 30% of the estimated value, as the filling work is reduced by two-thirds as per the experience of work in Bama of Mugu.

[9] As per the Nepal Rural Road Standard (NRRS), the maximum cross slope differs for different road types. For an earthen road, 5%; for a gravel road, 4%; and for a Bituminous seal coat road, 3%.

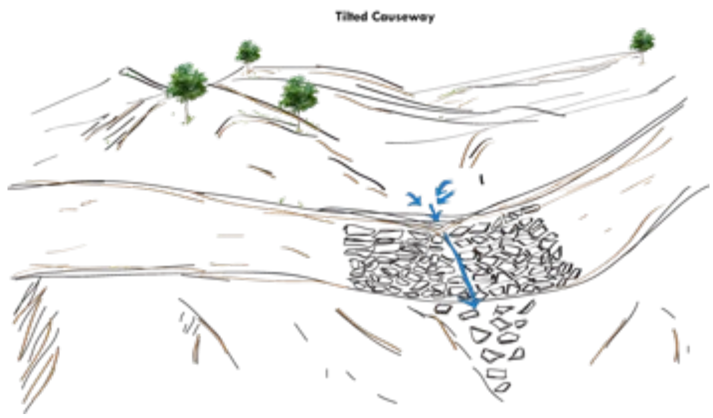


Figure 5.3: Tilted causeways

Reinforced causeways (drifts) at ephemeral stream crossings. Where roads cross the dry bed of ephemeral streams, reinforced causeways or drifts may be used. Besides their functions as traffic conduits, they help stabilize the unstable gravelly stream beds in mountain environments. They may also help to retain water in the sand and gravel of the river bed. Chapter 8 describes the application of such non-vented drifts in semiarid areas. For this, the drift may be reinforced beyond normal specifications so as to withstand the pressure of the torrential flows and the impact of rolling boulders. The drift should not be equipped with culverts. Besides the body of the drift itself, the drift consists of the approach road, the upstream protection of the stream, and the downstream apron. Because of the heavy natural armouring of mountain streams, they may not need a downstream apron.

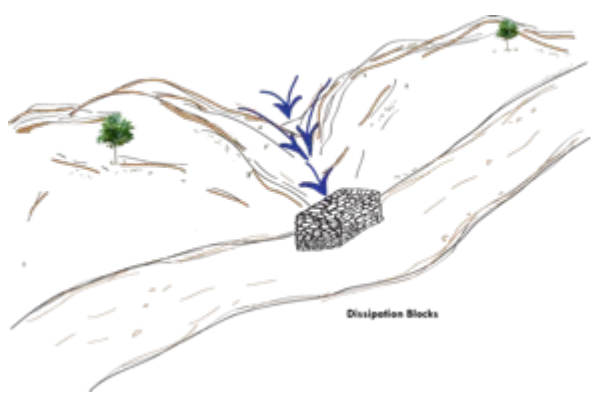


Figure 5.4 Dissipation block placement on the road

Dissipation blocks. Where a minor stream descends on the road, the use of dissipation blocks is recommended. This may be created by stacking up stones and rocks that become available when a mountain road is opened. These stockpiled stone blocks dissipate the force of streams and torrents if they are placed where those hit the road. This measure comes at no extra cost, as the stone blocks are stockpiled for use in future repairs yet are often placed off-stream. The blocks are best placed 30 cm to 40 cm away from the side-slope, and flat stones may be placed between the torrent coming from the hill slope and the dissipation block in order to break the velocity impact of the descending water. The stockpiled stones will further 'baffle' the force of the mountain stream. A small depressed section may be created in the road body, like a mini-causeway, to guide the stream water across the road.

Check dams and downstream protection. In the accented terrain, most streams will flow at high velocity. The development of a road section creates chutes that can do considerable damage to the road surface and side slopes. Making check dams in the upstream section of these road streams reduces the velocity of water crossing the road. Again, spare stone material from the road construction may be used to build up small check dams upstream. The excess material may also be used to armour the down road part of the stream by placing some stones there. This will prevent damage from erosion to the landscape and avoid upward gully development that could affect the road body. The general criteria for check dams are: [10]

- Spacing between check dams = height * 1.2/ slope of stream in decimals
- Side key of check dams 0.7 m to 1 m each side
- Bottom key and foundation 0.5 m deep
- Height of check dams 1 m (maximum excluding foundation)
- Stone face vertical to horizontal ratio 1:3 to 1:5
- Spillway (preferably in trapezoidal shape) width 0.75 m to 1 m; depth./ freeboard 0.25 m
- Using rock rubble for apron immediately downstream: length 1 m and width 0.5 m

Infiltrating road-side bunds. During the monsoon, fine material from the unpaved roads is washed into the adjoining agricultural land causing loss or damage to crops, often forcing farmers to replant. A good practice in mountain roads is to use an outward sloping road crown to drain water evenly from the road to the adjacent land. The slopes preferably have a maximum inclination of 5 percent to prevent runoff from traversing the road surface. Even so, a certain amount of concentrated flow along road sections is unavoidable, in particular in sloping road sections. To prevent this, infiltrating bunds in downslope road reserves can be used in areas where road water is expected to wash into agricultural land, comparable to those described in section 9.3.3.

Infiltration bunds can be made of road spoils, particularly uniform flat stones. The flat stones are placed in a dense mosaic in the road shoulder on the downstream side of the road. The width of the infiltrating bunds may be equal to the width of the road shoulder. The stones are placed in a pattern whereby larger stones (diameter of 20 cm to 25 cm) are placed close to the road surface, followed by a row of smaller stones (diameter 10 cm to 15 cm). The open space between the stones is preferably equal to 25 percent of the surface.

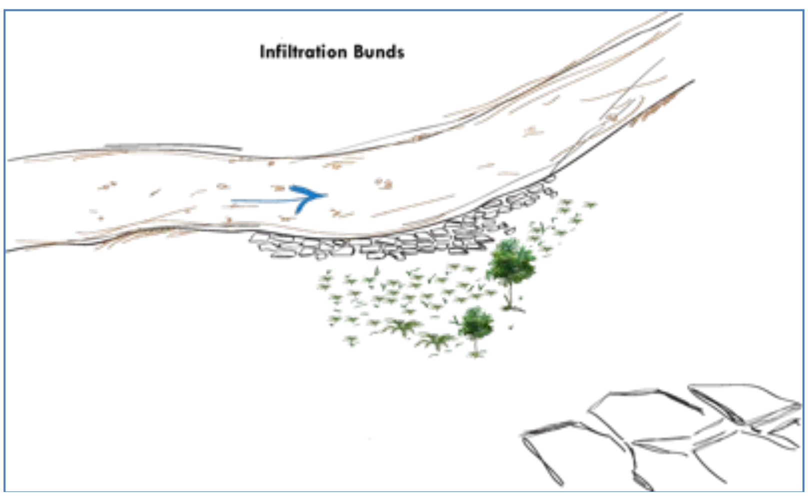


Figure 5.5: Infiltrating bunds

5.3.4 Managing roadside mountain springs and seeps

In mountain areas, the development of roads—either though the removal of unconsolidated material or the cutting of rock formations—will affect the occurrence of seeps and springs. Different from a spring, a seep does not have a clear orifice and water exits over the entire water bearing strata. The management of such springs and seeps is important: in many mountain regions they are the main source of domestic water supply and small-scale irrigation. Table 5.2 shows the effect of the opening of a new

[10] Based on ICIMOD and Desta et al. (2005)

road alignment on different spring types. The development of roads may distort existing springs but may also create new ones. Given the importance of springs for domestic water supply or agricultural use, the management of mountain springs in road development should be an integral part of road construction. The springs and seeps are also main sources of road damage, either by affecting the road surface directly or by creating (minor) depressions in the roads that grow during the monsoon and cause uncontrolled and erosive runoff from road bodies.

Figure 5.6 Road opening a seep that next damages the road surface (Mugu, Nepal)

There are several types of springs. Geomorphology, rock type, and tectonic history determine the type of spring that occurs. Two broad categories are springs with concentrated discharge through one or more clear orifices, and springs with more diffuse discharge. The different springs and the effect that road development will have on these springs is given below.

Table 5.2: Effect of road development on different types of springs

Spring Type	**Description**	**Effect of road development**
Springs with concentrated discharge (through one or more orifices)		
Fracture springs	Faults, fractures, and cleavage in semi-permeable and permeable formations connected with a water source (seepage, flow shallow, or deep aquifer)	Road development may expose the spring; rock cutting may change the location of the orifices – either blocking old or creating new ones
Contact spring	Permeable layer overlays an impermeable layer, forcing water to come out – often in a line of springs	Road may distort the outflow of the spring, causing orifices to be blocked or new ones to be created – highly dependent on geological faulting
Fault spring	Due to geotectonic movement, a permeable layer is moved on top of an impermeable layer	Road may distort the outflow of the spring, causing orifices to be blocked or new ones to be created – highly dependent on geological faulting
Depression springs	The groundwater table reaches	Road may create new

	the surface in topographical low	depression springs where the roads are made in cut, or dry existing springs by lowering the groundwater table
Karst springs	Relatively large flow from large openings – typically in karst areas where water erodes the calcium formation	Roads may expose new springs and expose new cavities
Springs with diffuse discharge		
Seep	Diffuse direct discharge of water, usually from soils or unconsolidated sediments (sand or gravel)	Road development may create many seeps, especially where roads are developed in areas with deep soil profiles
Secondary springs	Water issued from a primary spring that is typically covered by debris or rock fall	Road development may expose springs or change the outlet, in particular where unconsolidated material is removed

Managing the springs along mountain roads is important for safeguarding road quality and ensuring water supply for domestic and agricultural use. It is recommended that before the road is built, the geology must be understood and the areas where springs occur or are likely to occur should be mapped. When roads are being constructed, they effect the location of the spring if not handled carefully. The use of bulldozers or excavators in areas of potential springs should be avoided; manual labour should be used to excavate the road in such sections.

Once the road is developed, the presence of springs and seeps will be evident. A choice has to be made whether the spring or seep will be used or not. In areas with a low population density, springs may not be used, but they should still be managed to prevent discharge from damaging the road body. The following table suggests methods for managing different types of springs in different circumstances

Table 5.3: Recommended practices for spring management along roads

Spring Type	**Description**	**Spring management**
Spring with concentrated discharge	Not used	Retaining wall with weep holes or with longitudinal drain to collect excess water and traverse drains (French mattresses) underneath the road
	Used for agriculture	Retaining wall with longitudinal drain to collect excess water and traverse drains (French mattresses) underneath the road
	Used for domestic water supply	Spring box (captage) and conveyance to benefit community, or tap fitted on protected spring
	Used for domestic water supply and storage	Spring box (captage) and conveyance to benefit community. Include possibility of spring closure (tap) to store water inside the mountain aquifer (especially in karst areas)
Spring/ seep with diffuse discharge	Not used	Develop road drainage in up-road section to collect seepage and convey to safe place
	Used for agriculture	Use gravel section in road to convey water

		to agricultural land

By controlling the outflow of the springs, water can be better retained in the area. Equipping the orifice of a spring with a gated outlet and even a tap makes it possible, in some cases (especially karst springs or fracture springs), to store spring water in the mountain aquifer. The outflow is regulated and retained in a controlled spring, creating storage in the mountain aquifer and prolonging the time during which water is available.

Bio-engineering

Bio-engineering concerns a range of vegetative measures to stabilize slopes along mountain roads. One relatively widespread application is the use of vetiver grass. Due to its deep strong roots and high survival rate vetiver rows have been applied widely on steep erosion-prone slopes. In steep areas as in Nepal often a combination of vegetative measures with structural measures are used along road sections. Preferably native plants are used that are known to adopt well to the harsh settings and that have the positive mechanical and hydrological characteristics to strengthen the critical slope segments. Plant shoots are preferably planted when the live cuttings are without leaves still. Vegetative measures are often combined with a (gabion) stone toe that stabilizes the slope with plants placed on the upper sections. To further protect and reinforce the slopes additional measures are used a such as brushwood matrasses, fascine bundles, timber crib walls or rip rap in selected sections (see also Annex 1).

5.4 Improving the mountain road environment

Mountain areas are highly challenging for road connections at any time. To create resilience in these areas, it is necessary to work on both the roads (section 5.3) and the demanding environment in which they are located. Safeguarding the road environment will protect the road but will also create a large productive asset. The purpose is to create a more stable and productive environment, making better use of the opportunities that exist in high- and middle-altitude areas. The recommended measures serve to better retain moisture and to build up, enhance, and protect land. (See figure 5.7. In this section, several measures are discussed:

- Land-use planning;
- Water and snow storage measures;
- Artificial glaciers;
- Land development;
- Water retention on mountain slopes;
- Reusing soil;
- Controlled grazing; and
- Re-greening and roadside tree planting.

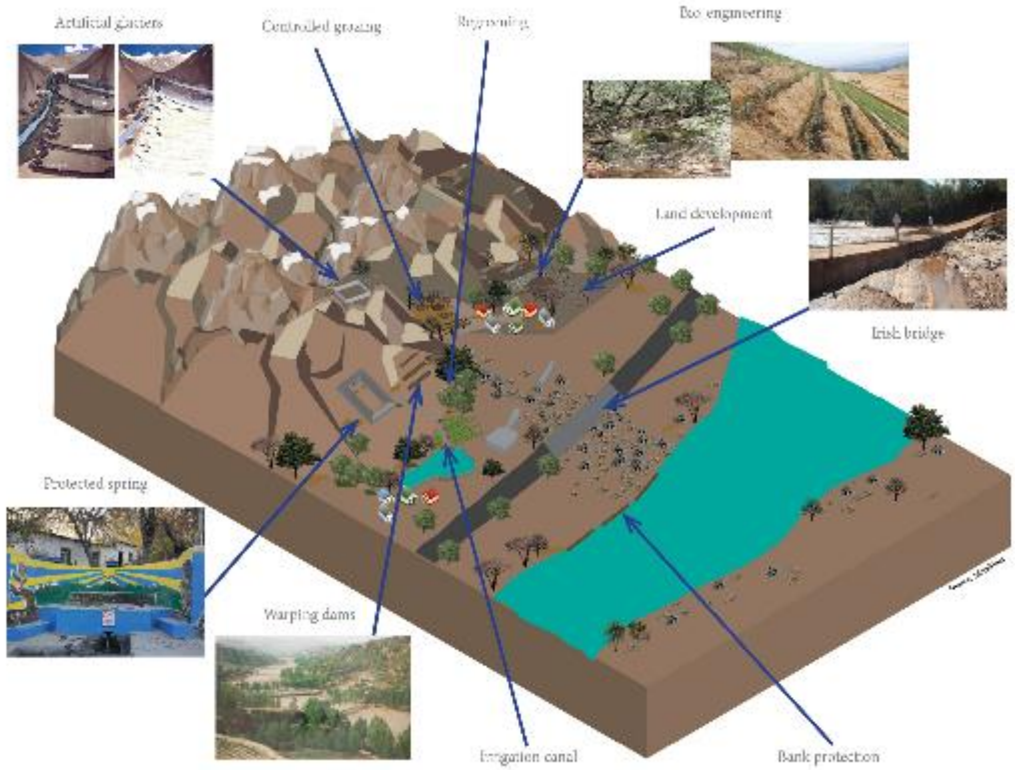


Figure 5.7. Integrated road landscape management measures to be considered in mountain areas

Land-use planning

Mountain areas are characterized by steep slopes and limited land for cultivation and habitation. At the same time, many areas are exposed to the risk of mudflows, rock fall, and flooding. Over time, people have encroached on these high-risk areas and, for instance, have built houses on scree slopes. Stronger land-use plans and regulations are required to prevent this and relocate those most at peril. At the same time, land-use planning for high-altitude areas can be used to introduce and plan several other measures in road development, create storage and regreening, and designate areas for pasture development.

Water and snow retention and storage

Over time, the water-storage capacity of high-altitude glaciers has been disappearing. This will need to be compensated by alternative storage methods and better retention of water and snow, which will also reduce the risk of disruptive floods. Several measures will slow snow retention, help keep the snow on the slope, and prevent avalanches in critical areas.

More water storage may be created, as in other Roads for Water programs, with special farm ponds or converted borrow pits or by using road bodies to create reservoirs. (See Figure 5.8.) Check dams and irrigation diversion channels can also be used to decrease the amount of water streaming down and delaying peak floods. Another advantage is that check dams provide an additional source of water that can be used in summer when seasonal streams and springs dry up. However, these infrastructure projects should be carefully planned so as not to increase the risk of floods and mudslides for populations downstream. Other measures, such as reforested areas and livestock enclosures, will also increase water retention in the soil.

Snow shed in alpine environment

Farm ponds in high-altitude Nepal

Figure 5.8 Water and snow retention measures for high altitude areas

Artificial glaciers

The development of artificial glaciers is an ingenious technique first developed by local engineers in Ladakh (North India). The principle consists of diverting water from glacial streams through canals and pipes (up to 4 km long) to shaded, colder, and flatter areas, where the difference in temperature and lower velocity of water are sufficient to make the water freeze again. When the meltwater reaches the artificial glacier site, it is spread and contained with retaining walls of stones or concrete built in series. The artificial glaciers may be up to 2 km in length and 2.5 m in depth. The water is stored there during the entire winter and melts in spring when temperatures and sun radiation increase. Artificial glaciers have several advantages for agriculture and road infrastructure:

- They make water available before higher glaciers start melting, enabling farmers to begin cultivating earlier in the season;
- They reduce the amount of meltwater lost to the high-altitude area; and
- They reduce peak floods, erosion, and damage to infrastructure.

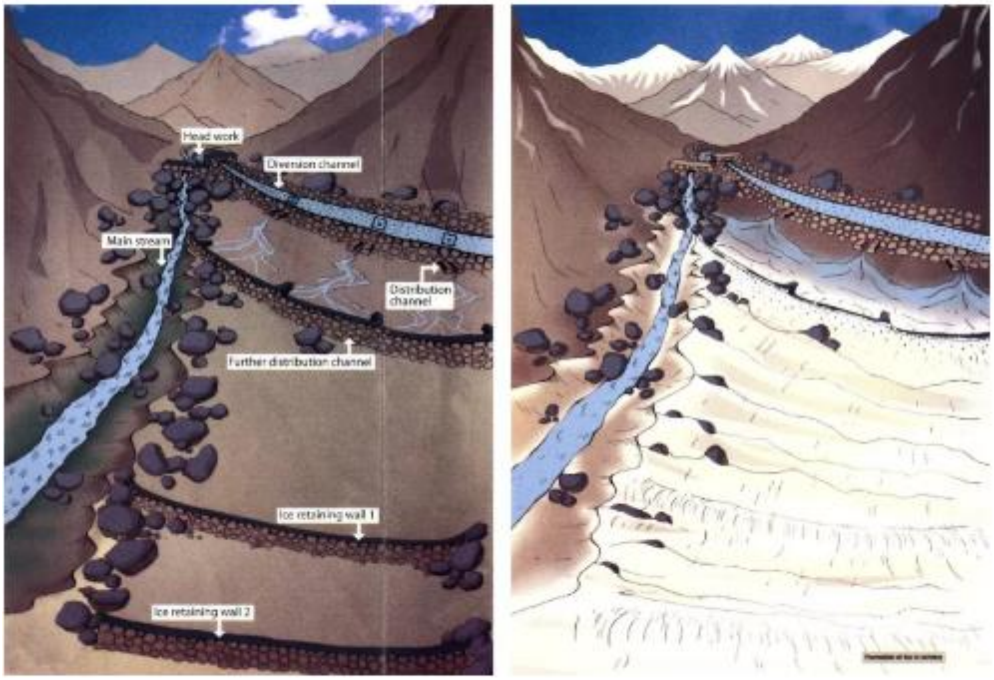


Figure 5.9 Technique for creating artificial glaciers in mountain areas.
Source: *Fondation Ensemble*

Land development with meltwater
Especially in young mountain areas, intense sedimentation may lead, for instance, to a reduction in downstream reservoir capacity. However, sedimentation is not necessarily a hazard: it can be an asset as well. It helps build or renew soils, creating new land and plugging gullies and depressions. "Warping" techniques can be used to trap sediment for beneficial use. Warping entails building up land with moisture-rich soil along rivers and streams. It can be done by letting turbid water flood onto agricultural land so that its suspended sediments form a layer, before letting the water flow away. Roads can be also be used to guide such meltwater. In this way, poor soils are enriched with fertile fine silt (or warp) or by trapping sediment behind warping dams built on gullies or steep valleys to intercept sediments and thereby create new land terraces.

Box 5.3. Warping dams

Warping dams are typically up to 5 m high, but they can be lower as well. The development of a warping dam consists of two stages: the land development stage and the consolidation and management stage. The land development stage takes several years (on average three to five years, but sometimes more than ten years). By then, warping dams have collected enough sediment for farming to begin. After this consolidation starts, stabilization is necessary when the dams are completely filled with sediment, in particular the creation of controlled water overflow structures. This can be done by changing the existing spillways into a circular shape, redesigning the top of the shaft as a spillway, constructing a side spillway, or designing an earth dam as an overflow dam (Steenbergen, F. van et al., 2011).

Improved moisture retention on hill slopes
The changes that come with the road construction are described in Section 5.2: changed hydrology, opened up hill slopes, more exposure to sunlight and wind). These changes add up to a severe effect on the microclimate that could affect the forest stands or the quality of the pasture. The impact on the microclimate will be less water retention, resulting in a loss of moisture, an increase in temperature, and more desiccating effects.

To counterbalance this effect, the capacity of the road affected area to retain moisture should be increased. This will also reduce the risk of erosion and degradation of forest hill slopes. This will contribute to the regreening of the area, including the compensation of those trees removed during road construction. The presence of large quantities of spoils (rocks and boulders) from road construction again presents the material for these measures. For steep mountain slopes, the use of eyebrow terraces/half-moons and stone strips/ rock bunds is recommended. Eyebrows/half-moons are small, semi-circular, and stone-faced structures that open in the direction of the run-off (figure 5.10). They can be built on steep slopes, usually with a maximum preferred slope of 50 percent, yet steeper gradients are possible, especially when rainfall is not torrential, as in the project area. On a slope, the steepest sections should be avoided, and the eyebrows may be reconstructed in the gentler sections. The suggested dimension and spacing of eyebrow terraces is given in Annex 8.

Figure 5.10: Eyebrow terraces on mildly sloping land (Ethiopia)

The eyebrow terrace can be complemented by stone strips or rock bunds, particularly on slopes that are relatively even and not too steep (<50 degrees). These stone strips will slow runoff, intercept sediment, and build up soil layers. They will stretch over the width of the slopes, allowing water to filter through as they are permeable.

Make better use of excavated soil
Soils are removed when roads are constructed. The construction of 3.5 m-wide section of road for 1 km with a soil depth of 30 cm would yield 1,050 m^3 of soil. This is a valuable asset in land development and in re-greening hillsides. These hillsides are often deforested and stripped of vegetation during the road building process. By setting aside this soil in combination with eyebrow terraces and stone strips, the replanting of trees on hill slopes can be accelerated, and the watershed can be protected.

Controlled grazing
Uncontrolled grazing can be a major cause of land degradation in medium- and high-altitude areas. To reverse this trend, area enclosures, better pasture management, and in some cases reduced livestock herds are recommended to restore pastures.

In controlled grazing, the areas are well defined, and their use, closure, and resting are regulated. “Resting” is generally proposed to restore perennial grasslands. This may result in an initial burst of growth in vegetation that was being overgrazed and can now grow freely. Properly grazed grasslands act like sponges, storing humus and carbon. The roots of grasses perforate the soil and open it up, increasing porosity and infiltration capacity. The trampling of the sealed soil surface, or soil crust, by animals helps this process. The increase in porosity and infiltration capacity allows water to soak in where it can be used by plants, or eventually trickle down to feed springs, rivers, and boreholes or wells, thus increasing the residence time of the rainfall in the catchment. Controlled grazing also decreases risks of floods and siltation downstream and the resulting damage to road infrastructure.

Grazing areas may be further enhanced by flood water or melt water spreading. When water is flowing in the mountain streams, it may be diverted to grazing areas if these are short of moisture. This will also prevent the risks of floods, as water is spread over a large area. Care should be taken to avoid interference with existing downstream water uses.

Re-greening

In several mountain areas, the demand for fuel wood and timber has had a severe impact on stands of trees and shrubs. Re-greening will stabilize slopes, help retain water, and even change the microclimate by achieving shorter precipitation cycles. Re-greening involves a series of measures: land use planning and controlled grazing are often prerequisites for successful revegetation. Regreening campaigns may incentivize mountain communities or forest enterprises to plant and safeguard new tree stands. Alternative arrangements can be powerful too, such as farmer-managed natural revegetation, whereby natural tree sprouts are protected and nourished; farmer-owned timber or fuel wood plantations; and agro-forestry farms or roadside tree plantings (see Chapter 11).

6. Roads and Rural Water Supply

Key message

- Road surface carry harmful heavy metals, PAHs and salts which will effect water quality;
- The very large portion of water harvested with roads, however, originates from the entire catchment – not from the road surface and are not affected by contamination form road surfaces;
- The water harvested with the roads improves water supply by augmenting the resource through recharge and feeding surface storage;
- Depending on geology, road development may also help develop new springs and seeps.

Main techniques:

- Road water can be collected in cisterns and ponds (Ch 10) or feed into recharge structures (Ch 2);
- Springs along roads should be protected and in some cases even have their outflow managed (Ch 5);
- Grass strips can reduce pollution loads (this chapter).

6.1 Objective

This chapter focuses on opportunities for harvesting and managing water around roads to increase water availability for rural water supplu. Although access to water and sanitation has improved over the past decades, the World Health Organization (WHO) estimates that 748 million people still lack access to improved drinking water, and 2.5 billion people do not have improved sanitation (WHO 2014). Because it enriches the resource, road water harvesting can contribute to better access to domestic water supply. This chapter brings recommended practices together to use water from roads for this purpose, particularly in dry areas.

6.2 Opportunities

This chapter discusses several opportunities to make roads contribute to improved rural water supply, especially to better access to drinking water:

- Road water harvesting can recharge groundwater, and the development of shallow tube wells can subsequently serve to source drinking water.
- Water harvesting with road bodies can feed surface drinking water systems, but care should be taken to ensure acceptable water quality;
- Protecting and managing springs opened by road construction can provide a safe and reliable source of water (for the latter see Chapter 5).

In domestic water, water quality is always a concern, particularly when road surfaces and intensely used highways are used to collect drinking water. However, using such runoff is uncommon. Generally speaking, water collected from roads originates from the entire catchment. Water coming directly from road surfaces plays only a minor role. Moreover, most water will be harvested with low intensity unpaved roads, which are numerous. Precautions are necessary close to intensely used highways.

There is concern that, especially in case of intensely used highways, the water captured in road water harvesting may have high contaminant loads associated with the traffic on the roads. Surface and groundwater would then be susceptible to pollution from road runoff. Surface waters are particularly vulnerable, as they are directly exposed to the contaminants. Pollution of groundwater tends to occur gradually as some of the contaminants are intercepted before reaching the aquifer system, but the clean-up process is difficult and expensive.

Common contaminants in highway runoff are heavy metals, inorganic salt, aromatic hydrocarbons, and suspended solids on the road surface due to regular highway operation and maintenance activities (FHWA, 2016). In addition, road surface runoff may contain grease, oil, rust, and rubber particles due to vehicle wear and tear. These materials are often washed off the highway during rainstorms. Heavy metals like lead, zinc, iron, chromium, cadmium, nickel, and copper, generally undergo physical, chemical, and biological transformations as they reach adjacent ecosystems. They are either taken up by plants or animals or adsorbed by clay particles, or they settle as bottom sediments that may or may not leach metals depending on the condition and sensitivity of the receiving water.

Low pH levels (below 7) trigger metal solubility and leaching (Hanes et al. 1970). However, the leaching of copper, iron, chromium, and nickel is limited in natural waters where aerobic conditions are maintained (Granato et al. 1995). Heavy metals from highway runoff are not necessarily toxic, yet the form of metal and its availability to organisms determines the toxicity of water. For instance, ionic copper is more harmful to aquatic organisms than elemental copper (Yousef et al. 1985). This is similar for ionic zinc and cadmium.

The second group of contaminants are polycyclic aromatic hydrocarbons (PAHs). These originate from asphalt pavement leachate, tire wear, lubrication oils, and grease. Increased traffic activity will generally lead to higher levels of PAHs in road surface runoff. Low molecular weight PAHs in runoff is indicative of a petrogenic origin, while the presence of high molecular weight PAHs is associated with potential pyrolytic sources (vehicle exhaust emissions, burning organic matter, etc). The presence of PAHs in surface water and groundwater is an indication of source pollution. They are slowly biodegradable under aerobic conditions and are stable to hydrolysis (WHO 2003).

Typical concentrations of pollutants in road runoff in intensely used (>10000 vehicles/day) road sections are given in table 6.1.

Table 6.1: Typical concentrations of pollutants in highway run-off

Contaminant	TSS	COD	Total N	Total P	Cd	Cu	Pb	Zn[11]	PAH
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Typical concentration	200	100	2	0.5	0.0015	0.1	0.03	0.5	0.003
WHO norm					0.003	2	0.01		NA

Source: (Buwal, 1996; Pfeifer, 1998; Heinzmann, 1993; Krauth et al. 1982; U.S. EPA, 1983; Dierkes, 1996) quoted by OWAV, 2002) WHO, 2017

The beginning of a rainstorm event usually has a much higher concentration of pollutants though. The highest pollution level is in the “first flush.” It is assumed that up to 70 percent of the pollution load is associated with sediments, as much of the oil adheres to such fine particles. The typical pollution levels as in table 6.1 can be compared with the acceptable levels: the main areas of conceen in =is the concentration of lead.

The third category of pollutants, de-icing salts, can be a problem in temperate and cold climates. The most common salts used are sodium chloride, magnesium chloride, calcium chloride, and special mixtures. Their harmful effects may be reduced by careful applications. Different types of cold weather conditions (sleet, ice, light snow, heavy snow, compacted snow, ice rain) require different applications of de-icing agents and methods, such as pre-wetting. Also, better understanding of the nature of road surfaces and their responses to different cold weather conditions will help to tailor the use of road salts to what is strictly required. Brick roads and wooden bridges, for instance, are much more prone to freezing than tarmac or earthen roads. There is a double benefit: less stress on the local water resources and the careful application of road salts will also help reduce the costs of de-icing operations.

There are several strategies to prevent or reduce the risk of water contamination from road surfaces, in particular close to intensely used pollution risk hot spots. A first strategy is to revisit road specifications: some PAHs, for instance, originate from the material chosen in constructing the road – coal, tar-based pavement sealants are a notorious source of PAHs (Valentyne et al, 2018). Second is to avoid the use of this category of road runoff, particularly near intensely used highways. To avoid accidental pollution, one can consider the safe removal of contaminated water from road drains. For

[11] No health based guidelines values are proposed for Zinc (Zn). It is assumed that drinking water seldom contains Zn concentration above 0.1 mg/l.

example, close to the world famous mineral water resources in Vittel, France, very strict care is taken that no highway runoff will recharge the aquifer systems. All such water is collected and disposed of away from recharge zones. A third strategy is the better operation of roads, in particular in de-icing. (See Box 6.1.) A fourth method is to make use of natural remediation (Wilson, 1999).

An example of the latter is the use of roadside vegetation, in particular grass strips or vegetated drainage channels. This can improve the quality of water in two ways: by absorbing and adsorbing pollutants from water, and by stopping pollutants from the release of sediment. The effects of vegetation on contaminant removal depend on environmental conditions, the number and type of plants, and the nature and chemical structure of pollutants.

Vegetated channels along roads slow water runoff, trap sediment, and enhance infiltration. They are little artificial wetlands, engineered and planted to slow the flow of storm water runoff. The goal is to expose the dirty water to plants and soil, which absorb toxic metals, filter out water-clouding sediment, and neutralize noxious germs. According to the USDA Natural Resources Conservation Service, if properly installed and maintained, plants and soil have the capacity to:

- remove 50 percent or more of nutrients and pesticides
- remove 60 percent or more of certain pathogens
- remove 75 percent or more of sediment

Planting grass buffer strips along potential problem road sections can also decease the effects and costs associated with sediment deposition. The beneficial effects of grass strips in filtering nutrients, pesticides, and sediments from runoff has been demonstrated for instance by Morschel et al. (2004). Reduction rates fluctuate from about 50 percent to 95 percent depending on vegetation type, strip width, upslope inclination and area, and rainfall characteristics. Trials on high risk road sections suggest that a 12 m wide strip combined with a hedge might be enough to completely remove sediment deposits from the roadway.

6.3 Recommended Practices

6.3.1 Road water harvesting for groundwater recharge

The purpose of groundwater recharge is to store water underground in times of surplus for use during times of shortage and high demand. This is particularly useful where rainfall is concentrated in a short period and when there is no need for additional watering. The beauty of groundwater recharge is that subsurface aquifer systems can store large volumes of water at almost no additional cost.

There are several techniques to use roads for groundwater recharge (see Chapter 2). Water from roadside drainage can be diverted to percolation ponds, trenches, and swales (van Steenbergen et al. 2018) or spread over recharge zones. In recharge zones, runoff collected by a road body infiltrates through comparatively porous, unconsolidated, or fractured material like sand, fractured basalt, and old glacier deposits. The recharge zone is situated on top of the receiving water bearing layer or aquifer.

This water can then be extracted with existing or new hand-dug wells or shallow or deep tube wells, depending on the geology and the depth of the groundwater.

Recharge by infiltration takes advantage of the natural treatment processes that occur when water moves through soil. Thus, when groundwater is extracted, its quality will very likely have been improved over the earlier runoff quality. It will have become more suitable for household purposes (hygiene and sanitation) or as stock water, although further treatment may be necessary for drinking water.

Results from groundwater monitoring undertaken in Ethiopia reveal an increase in groundwater levels following the implementation of road-water management techniques for groundwater recharge (Figure 6.1). Infiltration systems designed for groundwater recharge require permeable soils (sandy loams, sands, and gravels) with relatively high infiltration rates. By storing water in aquifers, evaporation losses are reduced as compared to surface water storage. There are also indications that the intense recharge of groundwater by a large range of measures include water harvesting with roads can improve groundwater quality essentially by diluting natural contaminants. Woldearegay et al (forthcoming) found that total dissolved salt levels (TDS) decreased over a fifteen year period in well managed catchments in Tigray, Ethiopia., from 730 mg/liter in 1991 to 534 mg/liter in 2016 in the post rainy season. in Abreha Weatsbeha for instance.

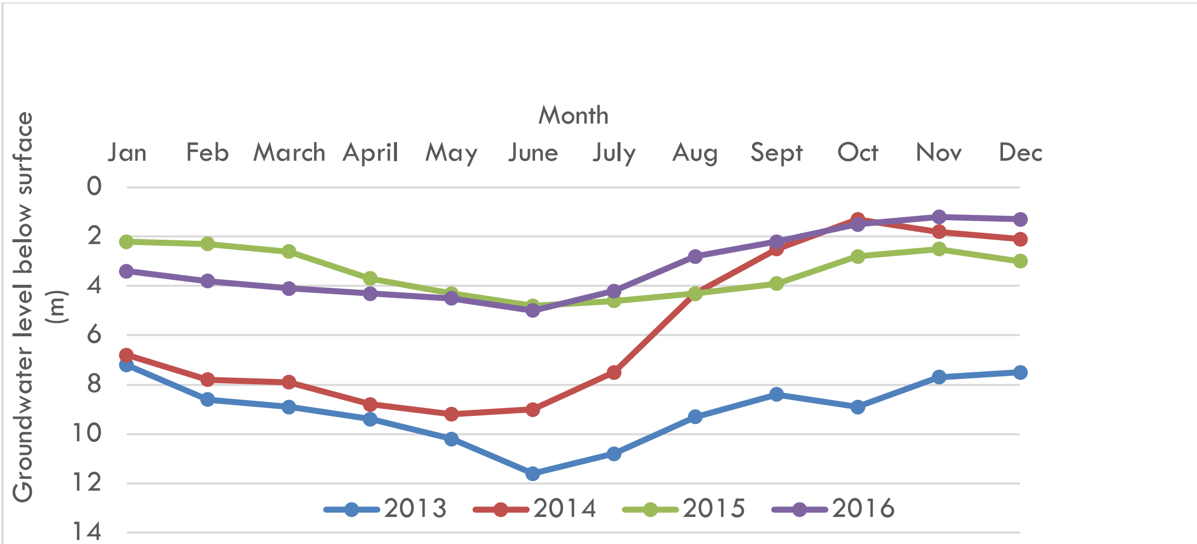


Figure 6.1. Change in groundwater levels over the years in an area with groundwater recharge from road water (Tigray)

Suspended solids may accumulate on the bottom of the infiltration structures, causing soil clogging. Once this happens, the infiltration process slows down and recharge ultimately stops. The suspended solids can be inorganic (e.g., clays, silts, fine sands) or organic (e.g., algae, bacterial flocks, sludge particles). When particles accumulate at the bottom of banks of infiltration structures, the particles should be removed after rain events or heavily disturbed. In some cases, soil organisms (rain worms, termites, or sow bugs) play this role of disturbing the soil and removing the clogging particles.

An important design principle for groundwater recharge structures is that the groundwater table must be deep enough below the infiltration system so that it does not interfere with the infiltration process. The water table must be at least 0.5 m below the bottom of the infiltration structure (trench, pond, etc.) so that infiltration rates are not constrained by the underlying groundwater. When there is concern about water pollution, a greater distance between the percolation or infiltration structure and the groundwater table is recommended so that there is an adequate unsaturated zone below basin bottom for natural water treatment, particularly for aerobic processes (that corrode possible pollutants) and virus removal to occur.

For relatively unpolluted water (i.e., without PAHs, see box 6.1), the most important parameters for groundwater recharge are suspended solids (SS) content, total dissolved solids (TDS) content, and the concentrations of main cations such as calcium, magnesium, and sodium. When there are too many suspended solids, it is recommended that sediment/silt traps be installed to avoid clogging. If the water is meant to be extracted for drinking supply, the main water quality parameters to consider are microorganisms, trace-inorganic chemicals, and anthropogenic organic chemicals. Soils generally act as natural filters that reduce the concentration of pollutants due to physical, chemical, and microbiological processes. In these processes, suspended solids are filtered out; biodegradable organic compounds are decomposed; microorganisms are adsorbed, strained out, or die; nitrogen concentrations are reduced by denitrification; synthetic organic compounds are adsorbed and/or biodegraded; and phosphorous, fluoride, and heavy metals are adsorbed, precipitated, or immobilized. The extent to which soil can remove pathogens depends on several factors, including the physical, chemical, and biological characteristics of the soil, the size and nature of the organism, and environmental conditions such as temperature. The largest organisms, such as protozoa and helminths, are removed effectively by filtration unless the soil contains large pores. Bacteria are also filtered, although viruses may be too small to be filtered by most soil pores (National Research Council 1994).

Groundwater recharge can have negative consequences as well. If the soil around the road is moist and waterlogged, this presents a risk to the stability of the road body itself (Pritchard et al., 2015). In the presence of expansive clays in the soil, a change in moisture content can lead to volume changes resulting in loss of pavement shape and cracking of sealed pavements. The combination of soil moisture and traffic (change in pressure) also leads to a build-up of pore pressure within the base that can cause the soil to crack. The movement of heavy traffic across the road pushes water and fine material out through these cracks, making them larger (NSW Agriculture 2003).

If the water table under the road is at the soil surface or within 2 m of the surface, there is a risk that capillary action will draw moisture into the road pavement. When moisture content reaches the plastic limit of one of the pavement layers, the stiffness of the layer may be reduced. Especially in intensely used road sections, the weight of passing traffic will change the shape of the layer, forcing upper layers to bend and stretch over the weakened lower layer.

In arid or warm dry climates, annual evaporation usually exceeds annual rainfall, leading to the upward migration of soil moisture. If soluble salts are present in this moisture, as reported from several areas in Australia, they will crystallise at or near the surface (NSW Agriculture 2003). The average expected lifespan of sealed roads is 20 years and 40 years for heavy duty pavements. Salinity can, however, shorten the expected lifespan of roads by accelerating the rate of deterioration. Low damage levels can reduce road lifespan by 10 percent, while severe damage can reduce it by up to 50 percent. In Pakistan and other countries where water logging and salinity is a risk, this is an important argument to improve cross drainage around roads and ensure the productive use of this water.

6.3.2 Road water harvesting for surface storage

Water from culverts and roadside drains can be diverted to surface water storage points, such as cisterns or ponds. In limestone areas, communities in Yemen have developed water cisterns along roads (Figure 6.2). During scarce rainfall events, the water cisterns are filled. Apart from storing water, they double as cold stores. The water from the cisterns is used for livestock watering in dry periods. Roadside cisterns may have reinforced covers to reduce evaporation and prevent humans and livestock from falling into the tanks.

In Yemen, the first runoff after a long dry spell is often not allowed to enter the cistern because this "first" water is contaminated and carries too much dust and sediment. Road water collected in the roadside drainage ditch channel is typically managed by two small porter stones installed across the trapezoidal ditch channel.

Mud, sand, or a piece of cloth are used to block the "gate" and divert water to the cistern. During the first flushes and later—after the cistern is filled—these temporary checks are removed. Some roadside cisterns include sediment-trapping facilities, using overflow structures and skimming the cleaner top layer of water. When designing cisterns, there are two major issues to consider: type and amount of storage, and contaminant removal.

Figure 6.2. Roadside cisterns in Yemen. ***Source: Mohammed Al Abiyad***

The following three boxes (Boxes 6.2, 6.3, and 6.4) show examples of water cisterns used for household purposes that benefit many smallholder farmers in India, Brazil, and China, respectively.

Box 6.1. *Taanka* or water cistern in Rajasthan, India

Taanka is a traditional rainwater harvesting technique used in the Thar desert region of Rajasthan, India. A taanka is a cylindrical underground rainwater storage cistern, wherein rainwater from rooftops, a courtyard, or a natural or artificially prepared catchment flows into the paved underground pit through filtered inlets made on the external wall of the structure. It can potentially be used for road-runoff harvesting by diverting water from culverts. The average water storage capacity of a taanka is around 20,000 liters. Materials used for constructing them can vary from stones to bare soil, or cement/lime with *Zizyphus Numularia* thorns.

Components of a taanka:

- *Circular Catchment:* 15 m to 25 m in diameter, paved with locally available *murrum* (stone fragments) sloping toward silt catchers.
- *Silt Catcher:* inlets into the underground tank lined to prevent sand and suspended material from entering along with rainwater and covered by an iron-mesh guard to prevent birds and rodents from entering the tank.
- *Storage Tank:* a 3 m x 3.3 m circular pit holding up to 25,000 liters of water, with a 60 cm x 60 cm opening at the top for people to draw water from it.
- *Outlets:* 30 cm x 30 cm covered vents to allow excess water to be released.

Taanka or water cistern in Rajasthan, India (Source: GRAVIS, 2012)

Box 6.2. One Million Cistern Program in Brazil

In the Semiarid Region of Brazil, 1.2 million cisterns were built between 2003 and 2016. This has benefited 4.5 million people. The program was implemented through partnership agreements with *Articulação Semiárido*

Brasileiro (ASA), a network of over 3,000 civil society organizations, state, and municipal governments, and other stakeholders. Financing came through the federal budget. To support the ASA's actions, the Association Program One Million Cisterns (AP1MC) was established in 2002 as a Civil Society Organization of Public Interest with the Ministry of Finance.

The Cisterns Program has four components:

1. Water for Human Consumption ("first water"): families are provided with the materials and training to build a 16,000-liter cistern to collect and store rainwater for domestic use.
2. Water for Production ("second water"): for families with a domestic cistern, the "second water" initiative introduces different systems for the capture and storage of rainwater in 52,000-liter cisterns for agriculture, vegetable gardens, and livestock.
3. Cisterns for Schools: the building of cisterns to capture and store rainwater for drinking and vegetable gardens in municipal schools in the Semiarid Region.
4. Seeds for the Semiarid: existing seed stores and banks are enhanced and supported and new ones are created among families benefiting from cisterns and associated training programs.

Box 6.3. Cistern program in Hezhang County, China

After the severe floods of 2010 in China, a total of 12,804 water tanks were installed to provide drinking water to 53,833 farmers in Hezhang County, China. These cisterns or water tanks are filled with rainwater. The water from these tanks can be used for the household (drinking, cooking, and washing) and livestock watering. Farmers save considerable travel time to fill water bottles/baskets. One farmer will pay only US$155 for a cellar to have water for domestic and livestock use (Meng 2011). Modern rainwater harvesting systems have been built extensively for household use and rainwater-harvesting agriculture with the government's support since the 1990s. The rainwater catchment includes a concrete yard, roof, earth, and asphalt road surface. The water storage tanks are made from concrete or red clay with a capacity of 20 m^3 to 30 m^3 in volume (Jiang et al. 2013).

Cisterns for drinking water in SW China (Meng 2011)

6.3.3 Using springs opened by road construction

When roads cross hilly areas and the roads are made in deep cut, the excavation may open springs and seeps in mountain aquifers or in saturated soil layers (see Section 5.3). These newly opened springs can damage cut slopes and erode land. On the other hand, they can provide a safe water supply source

(García-Landarte Puertas et al. 2014). To ensure that water quality is not threatened and that there is no damage to roads, springs need to be protected.

The following issues should be considered when a potential spring source is investigated:

- Understand the nature of the spring
- Ensure that the spring is not a stream that has gone underground and is re-emerging.
- Ensure that the source and the collection area are not likely to be polluted by surface runoff.
- Check that there are no latrines within 30 m, particularly upstream of the spring.
- Fence the area around the spring tank to prevent pollution.
- Make sure that, if the spring is to be connected to a piped water system, it is on higher ground than the area to be supplied so that the water will flow with gravity.
- Take care that the spring tank is not built on swampy ground or on land that is subject to erosion or flooding, and that the flow from the protected spring will not cause erosion or damage the road.
- Develop a 'captage' structure.

It is crucial to protect the catchment of the spring and the spring head from pollution, and to arrange for the spring water to be delivered at an appropriate height so that water falls with gravity directly into a container. An inspection of the ground upstream of the spring is essential to ensure that there is no danger of pollution or, if there is, to identify measures to prevent it.

To protect the spring, a fenced inner protection zone (with a radius of 10m to 20 m) should be established, and all activities posing a risk of contamination should be restricted (e.g., farming, grazing, burning, application of pesticides and fertilizers, construction of latrines, use of chemicals, etc.). The area should only be planted with grass. All trees and bushes should be uprooted, since roots can damage the catchment by cracking the structures or by blocking the pipes.

Springs can be protected by installing a spring tapping, a spring box, and a drainage system. Moreover, a surface-water drainage ditch should be dug above and around the spring area to keep surface water runoff from polluting the source. If the area around a spring intake is unstable or exposed to erosion, gabions or dry stone masonry can be used to stabilize the area.

Protection boxes (Figure 6.3) for newly opened springs collect the spring water, which can either be diverted to infiltration structures (such as soakways) or used directly in storage structures such as open ponds or cisterns. It is important to estimate the spring's flow rate to properly determine the dimension of the collection tanks and create spillover structures.

Box 6.4 describes the advantages of protecting the springs.

Box 6.4 Advantages of spring protection schemes

✓ Water coming naturally to the surface limits need for pumping

✓ Low maintenance and operating costs

✓ Can be a high-yielding source of good quality: no need for treatment

Disadvantages of spring protection schemes

✗ Yield can diminish or dry up during extreme drought periods

✗ Regular maintenance is needed around the spring head to prevent pollution

Source: WaterAid 2013

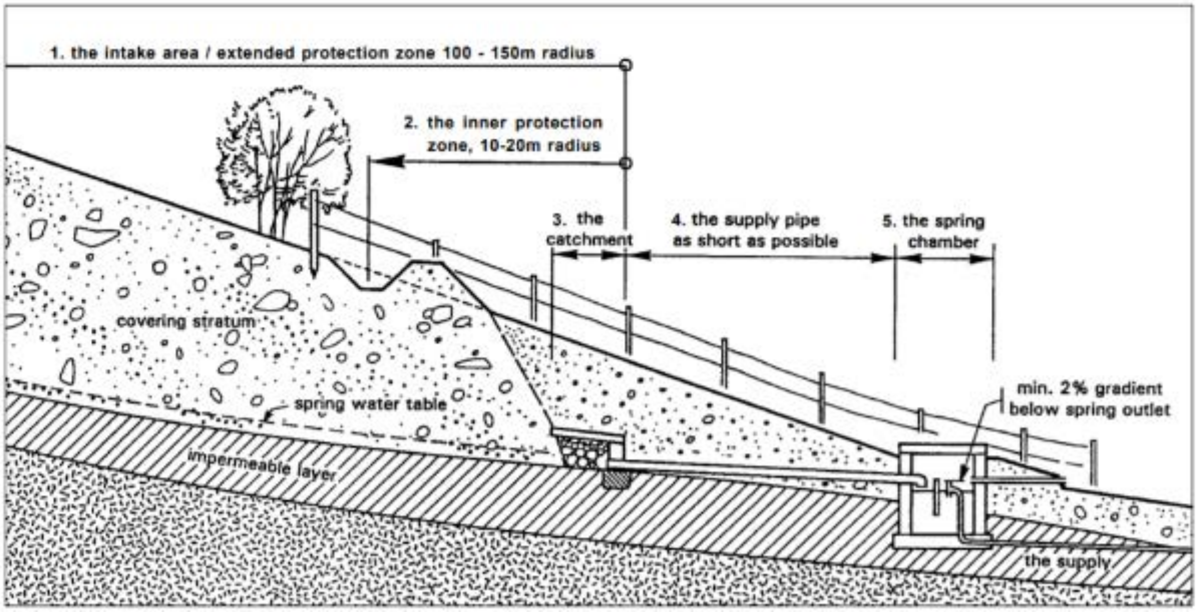


Figure 6.3. Spring protection area (Source: Meuli and Wehrle 2001)

A safe source spring should not have an increase in flow directly after heavy rainfall, but rather a few weeks later. If the flow increases after rains, it implies that rainwater flows quickly through the ground and the purification effect is insufficient to remove small and pathogenic bacteria. This type of spring is unsuitable for drinking water.

Figure 6.4 illustrates the stages in the construction of a spring collecting chamber.

Stage one:

- Clear vegetation above the head of the spring;
- Build a cutoff drain to divert surface water; and
- Divert the spring water temporarily to allow construction of the collection chamber.

Stage two:

- Place large stones above the head of the spring; and
- Construct the collection chamber.

Stage three:

- Further protect of the spring head with layers of impervious material above it.

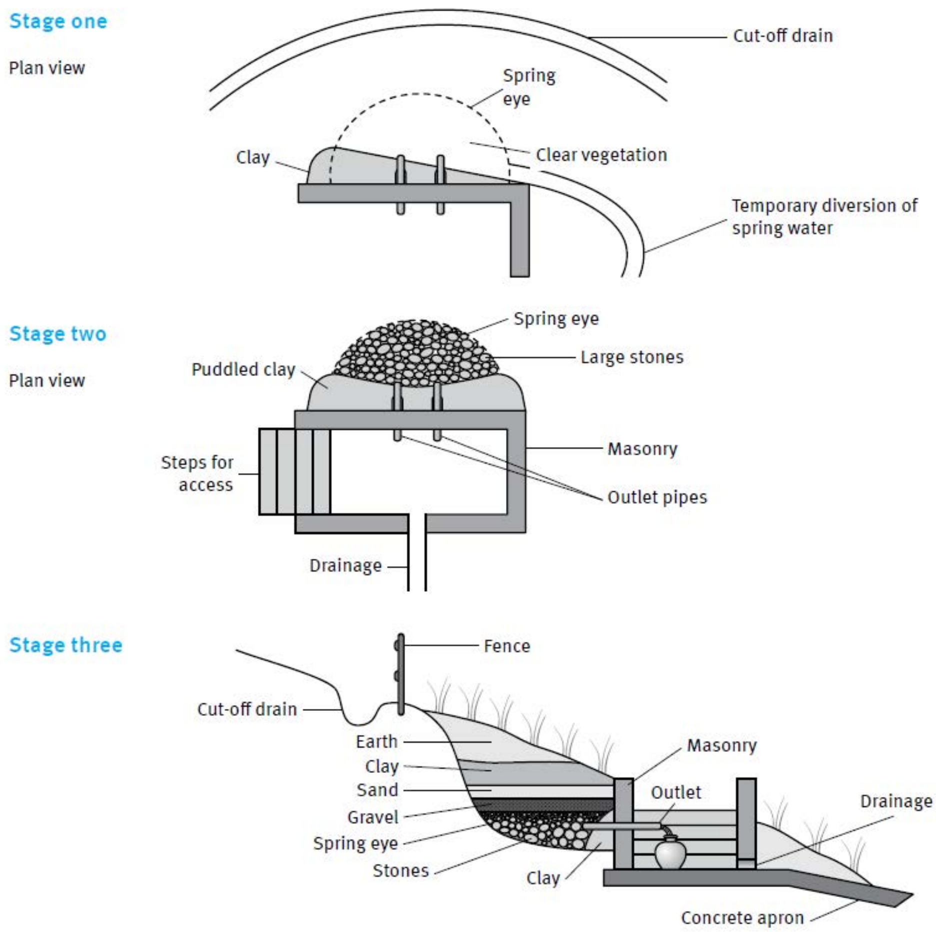


Figure 6.4. Stages in spring protection (Source: WaterAid 2013)

The supply pipe transports all of the spring flow from the catchment to the spring chamber. The pipe should be able to transport the maximum spring yield without stowing it back in the catchment. If the supply pipe becomes blocked, the spring source will build up pressure behind the catchment and flow to another outlet of lower resistance. This may cause the source to disappear completely.

Spring flow rates

Seasonal rainfall variations influence spring yield. Seasonality should be studied when designing the spring system to ensure that enough water will be available during the dry period of the year. To determine the reliable yield of a spring, it is necessary to measure the spring's flow at the end of the rainy season. A flow over 0.1 liter per second can fill a 20-liter container in over three minutes. If the flow is lower than 0.1 liter per second, a storage tank can be installed to enable the flow from the spring to accumulate. If the flow is 0.5 liters per second or more, the spring would be suitable to supply multiple outlets or a piped gravity scheme. The choice between an open or closed (with tank) distribution system depends on the spring's capacity and the demand. When the demand is higher than the spring flow, a closed circuit with a storage tank should be installed. On the other hand, when the demand is lower than the spring flow, an open circuit without a tank is recommended.

The following guidelines should be kept in mind when designing the supply pipe:

a) The distance between the catchment and the spring chamber should be as short as possible to reduce the chance of pipe blockage.
b) The pipe must be laid as straight as possible and without vertical bends to prevent blockage.
c) To prevent sediment buildup, the minimum supply pipe gradient from the catchment to the spring chamber is 3 percent.

d) It is recommended that an overflow pipe 5 cm to 10 cm higher than the supply pipe be installed.

Operation and Maintenance

To ensure long-term usability of the spring, frequent maintenance of the spring area by a local caretaker and adequate operation by the community are needed (Bruni, Marco Spuhler 2018).

The tasks of the caretaker should involve:

- Inspection, cleaning, and repair of spring installations (e.g., cracks in the apron, leaking parts, etc.).
- Monitoring of activities in the surrounding area to avoid spring pollution.
- Upkeep of the protection zone/repair of the fence.
- Checking for appropriate operation by users.

Roadside Spring, Sardinia, Italy: collection reservoir is too small, with overflow water damaging the road

Roadside spring opened after road construction in Tigray, Mulegat (Ethiopia)

Roadside spring in Klotten, Germany

Techniques

7. Borrow pits

Key message

- Borrow pits rather than being backfilled can be used as future water storages
- This will benefit – as far as the sourcing of building material allows - from appropriate planning: size, location, entry
- Borrow pits can be further upgraded with proper protection, entrance control, landscaping and if necessary lined

Main applications

- Converted borrow pits are a good option for water storage in semi-arid areas and in flood plains with high groundwater tables

7.1 Introduction

This section provides guidance on the systematic conversion of borrow pits to water-storage structures. Borrow pits provide the source material for the construction of road embankments. Depending on the local area, the source material can be gravel/aggregates, silica sands, laterite sands, and calcite. Once no longer in use for the mining of road construction material, borrow pits can become key assets for local water supply. Rather than backfilling the pits or leaving them unattended, the borrow pits may be systematically converted into storage structures to serve as sources of irrigation or livestock water. In areas where there is no alternative, borrow pits may even become sources of domestic water. In some areas, borrow pits have even been landscaped into attractive recreation areas and urban lakes. This section discusses the opportunities for converting borrow pits and the recommended practices in planning and implementation.

Borrow pit from high-speed railway track to be converted to storage reservoir and landscaped into a local lake: Gaomi (Shandong, China)

7.2 Opportunities

In planning new borrow pits or in converting decommissioned borrow pits into water storage, preference should be given to those pits that meet the following criteria:

1. The pit can be connected to a water source;
2. It is located in an area of water shortage; and
3. It is close to water users: domestic water, livestock, or irrigation.

There are three different uses of borrow points for water supply:

- Borrow pits may be used for water retention, i.e., direct storage of runoff water. In such cases they should have relatively impermeable beds to prevent the stored from water leaking away.
- Borrow pits can also be used as infiltration ponds. In this case, the water that is collected infiltrates and feeds the shallow groundwater. Such borrow pits should have relatively permeable beds to facilitate groundwater recharge. They may even be supplied by excess water from nearby streams diverted or pumped into the converted borrow pit. (See box 7.1.)

Borrow pit collecting and storing surface runoff (Chokwe, Mozambique)

- Borrow pits can also serve as seepage ponds. This is the case in areas with high groundwater levels, such as the floodplains of major rivers. In this case, the pits will fill constantly with groundwater seeping from adjacent areas and provide an almost permanent water source.

Borrow pit collecting seepage water from high groundwater table in floodplain (Lakes Region, South Sudan)

Box 7.1 Converting a gravel pit into an infiltration structure in Italy

In the past, gravel mining in the coastal area of Southern Tuscany, Italy was largely unregulated. Many gravel pits were developed and many were never refilled. The industry came to an end when the exploitation of gravel no longer come automatically with the ownership of the land.

The area has become water-stressed since the construction of storage dams upstream, exacerbated by the development of wells that sustain the cultivation of high value vegetables. Under the LIFE program, a gravel pit close to Forni was deepened and transformed into an infiltration structure aimed at replenishing local groundwater resources. The excavated pit was split in two: a relatively small sediment pond and a larger infiltration basin that received the overflow of clean water from the sediment pond. The choice of pond location and the deepening of the infiltration basin were designed to tilt the groundwater recharge away from the Cornia River, as it would not make sense for the new water lens underneath the gravel pit to feed back into the river.

The infiltration structure is fed by an intake from the Cornia River, equipped with a pumping unit. The pumping unit typically operates 75 percent of the time. If the level of the river drops below the environmental flow, the pump automatically stops. The pump also stops during flood events, as the river in flood carries iron, nitrate, and too much sediment. The measurement of water quality is fully automated. The piezometer around the infiltration pond detected an 80 cm increase in groundwater level in the first month of operation.

The investment in the pond is USD 360,000, creating a storage capacity of 200,000 m^3. Compared to surface storage dams this is low cost: USD 1,80 per m^3. Forty percent of the cost went into instrumentation. Replicating the concept on other abandoned gravel pits may be of even lower cost. The structure recharges water at 65 litres per second. It is conceivable that in the future such structures may be used to produce and sell water, and that the operation of the structures could occur by remote control.

7.3 Recommended practices

There is a need to systematically approach the reuse of borrow pits as water ponds, from the planning of these pits to their development, conversion, and after-care. The following elements should be considered:

- siting of borrow pits (7.3.1);
- designing, shaping, and protecting of borrow pits (7.3.2);
- taking care of safety issues (7.3.3);
- reducing excessive water losses (7.3.4); and
- reducing the risk of sedimentation (7.3.5)

7.3.1 Siting of borrow pits

It is important to consider the future use of borrow pits for water storage when the siting of these pits is first decided. Obviously, the siting is guided by the availability of source material for road construction, proximity to the road, and arrangements for acquiring borrow sites. When several potential sites are available, the following considerations should be used if the borrow pit is to be transformed later into a water storage structure:

- The borrow pits should be close to areas where people reside, or where there is interest in irrigation. Care should be taken to balance different possible uses. In some pastoralist areas, for example, there are concerns that converted borrow pits may attract non-pastoralists and create conflict. In pastoralist areas, moreover, it is important to plan the location of water resources, including borrow pits, taking into account rangeland potential so as not to create an imbalance between grazing area and livestock numbers.[12]
- There is often a choice to be made between having one relatively large borrow pit or several smaller pits. The choice for more but smaller borrow pits is often preferable in areas with dense populations: it will create more local storage at shorter distances. A larger borrow pit may be a more secure source of irrigation water, particularly if combined with water-saving measures (van Steenbergen 2017).
- In general, it is important to consider the local drainage pattern and to position borrow pits optimally so that they can capture surface water flows, optimize their contribution to recharge, or collect seepage flows. For instance:
    - The ideal location of a borrow pit in dry, sloping areas is often on the downslope of the road for a number of reasons:
        - Culverts and other road drainage structures can supply borrow pits located on downslopes with runoff. When built on an upslope, there are fewer opportunities to direct flows into the borrow pits through the road drain. However, in some areas the water flow may be impeded by road embankments and may consequently have to be guided to an uproad storage pond (such as a converted borrow pit).
        - There is usually more and flatter land for productive use on the downslope side of a road.
    - In areas with high groundwater tables where seepage flows can supply borrow pits, these are best located on the river side of roads where groundwater stocks are more

[12] Note that in grazing areas there may also be scope to enhance rangeland potential by systematically watering fodder grasses with road runoff.

secure. It is always useful to investigate and consult the local population to identify where groundwater availability is reliable.

"Ijzeren Vrouw" urban lake in 's-Hertogenbosch, the Netherlands: converted borrow pit

7.3.2 Size and shape of borrow pits

The size and shape of converted borrow pits are important. In the case of new borrow pits, the size and shape are largely determined by the availability of material for excavation and by the way excavators and dump trucks operate. Borrow pits often have irregular shapes. It is important that the original pits be modified and properly landscaped as part of the transition to their new function in water storage. This is done preferably by deploying the earthmoving equipment of the operator/contractor that formerly operated the borrow pits.

The following conditions apply with respect to the shape of converted borrow pit:

- Modify or remove potentially dangerous heaps and sides.
- Ensure stable slopes (see Box 7.1).
- Consider the overall shape of the converted borrow pit to optimize storage. In the case of unlined borrow pits turned into storage ponds, a convex shape is preferable. Convex pits are ideal for water storage, because they allow for maximum storage commensurate to the efforts of excavation. They are also inherently more stable than ponds with odd and square angles. Lined ponds are preferably trapezoidal in shape. For borrow pits lined with geotextile, a trapezoidal shape is preferred; the geotextile can be more easily installed. If a large number of borrow pits are to be lined with geotextile in a certain area, it is preferable (when possible) to use standard dimensions for the converted borrow pits: this will allow the lining to be stitched together centrally, generating cost savings.
- Depth: Where borrow pits are not constantly recharged from shallow groundwater seepage but depend on surface runoff, depth is an important consideration. This is particularly relevant during hot, dry periods when evaporation from borrow pits is high. The deeper the borrow pit, the less water lost to evaporation. A depth of 7 m or more is preferred. However, deep borrow pits are also likely to cross through several layers of rock/soil with different hydraulic properties. If water retention is the primary goal, the borrow pit should not extend below the impermeable layer.

- Access: Different water users will use the borrow pit, so the shape should allow access through an access ramp. Access may need to be provided to people or trucks. According to current guidelines in Mozambique, borrow pits are to be provided with single-access roads to allow for better control. Truck ramps can be easily modified to provide safe access for livestock and people. If possible, it is advisable to stone pitch the ramp to enhance its stability against cattle trampling.
- Contamination reduction: Special levees can be installed with small pumps to lift water out of the borrow pit. Although not ideal, special water troughs for livestock or sub-ponds, fences, or trenches can be installed to prevent livestock from coming into direct contact with the water, reducing the risk of contamination.
- Spillway facilities: Room for a spillway, especially in sloping terrain, is recommended. As borrow pits collect water, they may also spill over once they are filled, such as after a heavy rainstorm. It is important to consider a spillway that can release excess water to a natural drain in the layout of the pit. In some cases, the borrow pit is large enough in comparison to its catchment area and no spillway is required as it is unlikely to fill.
- Inlet reinforcement: Inflowing water often causes erosion and structural damage at the inlet–reservoir interface. Water dropping from the inlet into the storage structure can easily carve out borrow-pit walls and quickly trigger gully formation upstream of the water drop. Stone pitching, steps and masonry can be used to reinforce the inlet.

Box 7.1. Slope of the converted borrow pit

The preferred slope of the converted borrow pit in combination with a pond depends, among other things, on the type of soil. In the ANE Environmental Guidelines, a minimum slope of 1:4 is prescribed. The material of the borrow pits may necessitate much gentler slopes. As a rule of thumb, the following values can be used:

- Clay loam 1:5 – 2:1
- Sandy loam 2:1 – 2.5:1
- Sand 3:1

The average slope of the pond can be calculated as follows:

$$Y = \frac{100CI}{A}$$

Wherein

Y =	The average slope	%
C =	The total contour length	cm
I =	The contour interval	cm
A =	Drainage area	cm^2

Preferably, the slope is gentle and regular.

The following considerations should be followed with respect to the size of the borrow pit:

- The size of the borrow pit and its use for domestic purposes, irrigation, or livestock are closely related. Borrow pits often serve as a source of water where there is no alternative. Therefore, they should have sufficient capacity to provide water over a large part of the dry period. In some areas the pit may fill several times per year, depending on the rainfall pattern; in other areas the borrow pits are only filled once or twice per year. In the latter case, the borrow pits will be large.
- While converting abandoned borrow pits into water-storage ponds, it is important to make a good assessment of the runoff in the area and the required usage. Expected runoff can be calculated with the simplified rational method (see Box 7.2).

- Where the borrow pit primarily serves to recharge groundwater, it should be large enough to accommodate a large part of the runoff (with scope for some water to escape through spillways or other overflow structures into the feeder canal).

Box 7.2. Calculating the size of the converted borrow pits: supply and demand

To calculate the preferred capacity of a converted borrow pit, two factors should be kept in mind: the water supply and the water demand.

To determine the supply, it is necessary to:

1. Calculate the average rainfall over at least the last 20 years. Rank the cumulative seasonal rainfall (rainy season) in descending order.
2. Calculate the probability of each event using the equation:

$$P(\%) = \frac{(m - 0.375)}{(N + 0.25)}$$

with P being the probability of occurrence, m the rank, and N the number of observations. Plot the probability against the amount of rainfall for each season.
3. From the obtained curve, determine the rainfall with a 67 percent probability of occurrence (probability of occurring twice every three years).
4. Multiply the catchment area's obtained rainfall by the runoff rate (0.10 for permeable soils, 0.9 for paved roads). In this way it is possible to roughly estimate the amount of runoff reaching the borrow pit.

This is a rough estimation of expected water inflow. The borrow-pit design must also take into consideration the water demand in the area, expected losses (seepage and evaporation), and the need to dispose of excess water through a properly designed spillway.

$$V = I + E + S + H + L$$

Wherein

V = Volume of water to meet local needs	m^3
I = Water volume to meet irrigation needs	m^3
E = Water losses due to evaporation	m^3
S = Water losses due to seepage	m^3
H = Domestic water demand	m^3
L = Livestock demand	m^3

Ideally, the volume of inflowing water must exceed V in order to provide a year-round water supply.

When diverting water into a decommissioned borrow pit, the volume of inflowing water may be larger than the volume of the borrow pit. In this case, the spillway is necessary and should be planned ahead. The borrow pit can also be enlarged to store more water.

7.3.3 Ensuring the safety of the converted borrow pit

Several measures should be taken to safeguard the safety of the converted borrow pit. As an open structure, there are three main dangers:

- People, especially children, and animals may fall into the borrow pit.
- The water may become contaminated and a source for mosquito breeding.
- The water from the borrow pit may become unsafe for consumption.

To improve the safety of the borrow pit, a number of measures may be taken in close cooperation with the group of people who manage it:

- Install fencing to improve safety: The borrow pit may be fenced, either with plant material or by excavating trenches. This reduces the risk of people or animals straying into the storage pond. Tree fencing may also contribute to reduced evaporation from the pond surface. In some cases, the selection of trees may contribute to reducing the incidence of malaria (see next point).

- Reduce the incidence of vector-borne diseases, in particular malaria: Shallow ponds often become breeding habitats for mosquitos. Vector breeding is considerably less in deeper water. It is important to actively manage and use the pond so that there is sufficient movement of water. Introducing larvae-eating fish species to the ponds can also reduce the risk of mosquito infestation. Tilapia (*Oreochromis niloticus)* are particularly effective (known to remove more than 90 percent of the larvae) and are a commercially attractive source of protein. The management of vegetation around the borrow pit and the removal of small water-filled depressions can also reduce mosquito breeding. Some trees are known to repel malaria mosquitos, e.g., the olon tree (*Zanthoxylum heitzii*), native to Central Africa. A number of as-yet experimental methods may control mosquitoes, such as the use of vegetable oil with white colorant. This colorant will reduce evaporation losses (as sunlight is reflected) and the oil will make it more difficult for mosquitos to land on the water.
- Install hand pumps and sand filters to safeguard water quality: In some areas there is no source of water other than the borrow pit. However, by virtue of being open-surface water bodies, these pits do not provide safe water for direct human consumption. This can be overcome by placing a hand pump and sand filter on the borrow pit, or by household treatment of the water. It is essential to segregate the area where livestock is drinking in order to safeguard the quality of the borrow pit.

7.3.4 Reducing excessive seepage

When borrow pits are used for surface storage (rather than as infiltration or seepage ponds—see 7.2), much of the water can disappear because of seepage. In areas with fine sediment, this may cease to be a factor over time as fine material seals the bed of the pond. In addition, some low-cost measures can be used to reduce seepage from ponds:

- Compacting the bottom of the pond (using rollers, sheep-foot rollers, or hand compaction).
- Installing clay lining or lining with soil from termite heaps, provided that these materials are available.
- Fixing cracks and seeping areas with bentonite.
- Treating the pond with dispersants: salts that change the soil structure and increase permeability (only if the soil is 15 percent fine clay); common salts include sodium carbonate, sodium chloride, and sodium polyphosphate.

The measures above may be insufficient in areas with permeable soils. Lining with geotextile may be necessary to reduce seepage and make the borrow pit suitable for storage.

Polyethylene, butyl rubber, and vinyl membranes are commonly used for pond lining. These are the recommended practices:

- After the reservoir is shaped to the desired standards, it is important to let it settle and dry before the pond is lined.
- If there are sharp rock fragments, roots, and objects at the bottom of the reservoir, it is important to lay a thin layer of fine soil to prevent piercing of the lining.
- Ideally, the lining must be covered with a 15 cm layer of fine soil to protect it from light and piercing.
- The banks of the reservoirs should preferably be shaped to a 1:1 slope (if the lining is to remain exposed) or to a 3:1 slope (if the lining is to be covered with earth).
- The side of the lining (around 30 cm) must be anchored to a 25 cm deep trench over the edge of the reservoir.

Borrow pit lined with geotextile, Mozambique

Several kinds of geomembranes are available on the market, with different benefits and drawbacks, as highlighted in Table 7.1 below:

Table 7.1. Geotextile materials for reservoir lining

Type of liner	
Reinforced polyethylene (RPE)	Thinner material compared to EPDM and PVC Lightest material Does not stretch but is rather flexible Requires more time to apply over complex shapes More puncture resistant than PVC and EPDM Can last up to 40 years Fish and plant safe Can be welded with heat
Ethylene polypropylene diene monomer (EPDM)	Made of rubber Stretches and folds well around corners Requires an underlayer Sheets cannot be joined with simple heat guns Heaviest material; higher shipping cost Least puncture resistant Fish-safe material
Polyvinyl chloride (PVC)	Heavier than RPE but lighter than EPDM Less puncture resistant than RPE but more resistant than EPDM PVC sheets are often treated with chemicals toxic to fish Inexpensive Easily degraded by direct UV exposure PVC sheets are easily welded together

7.3.5 Reduce the risk of sedimentation

The lifetime of a borrow pit converted into a water storage pond may be curtailed if it is filled with high sediment-rich water flows. To prolong its life, a number of measures are recommended:

- Locate borrow pits in areas with protected watersheds and low silt content in the runoff feeding the borrow pit. This may not always be possible, but the health of the catchment may be a consideration in siting the borrow pits.

- Seek vegetation in the most critical sediment runoff areas if well-protected watersheds are unavailable.
- Take measures to trap sediments before they reach the converted borrow pits. Install sediment traps or employ vegetative measures.
- Maintain sediment traps and vegetative measures that can fill up quickly. The sand in the sediment traps can sometimes be repurposed for use as building material or agricultural soil and may be harvested and sold.

7.4 Borrow pit management

Converted borrow pits need to be well managed to:

- Regulate use of the borrow pit, which is particularly important in times of scarcity.
- Avoid contamination that makes the water unfit for use.
- Undertake basic maintenance and protection, such as protecting vegetation, cleaning sand traps, controlling entrance by livestock, and undertaking periodic de-siltation (see above).

It is important to regulate the future ownership of the borrow pits in combination with storage facilities. The land used for digging the borrow pits may have been privately owned at one time. It is important that ownership of the borrow pit is settled and that the original landowner is compensated.

A local committee or local government should look after the water source and attend to its access, protection, and maintenance. To the extent possible, management committees should not be ad hoc but linked to a legitimate local government.

If a committee is in place, it can also mobilize the resources to conduct maintenance work. There are several possible arrangements for fundraising by a local committee, such as:

- Charging for use of the converted borrow pit, or
- Dividing the maintenance work among users who each take care of a section of the pond.

8. Road drifts

Key message

- Road drifts can be used in sandy dry river beds to build up water storage in the sand deposited upstream of the drift, similar to the working of a sand dam
- The design of the road drift should culvert-less, the centre of the drift should be lowered and there should adequate spill over capacity
- Road drift can also be used to stabilize ephemeral riverbeds
- In a dry river a series of road drift and sand dams may be planned

Key applications

- Non vented road drifts can create water storage in semi-arid areas and prevent the braiding of river
- They can also be used in mountain areas to prevent the erosion of mountain streams and road-water crossings

8.1 Objective

This chapter discusses the siting, design, and construction of road crossings in dry riverbeds to harvest and retain floodwater. The use of road drifts, particularly culvertless "non-vented drifts" functioning as sand dams in semiarid and arid areas, is an important and often underutilized opportunity to harvest flood water. Excellent (2018) estimates that there are 156,000 and 233,000 such crossings in semiarid parts of Africa and Asia, respectively. These road crossings can be used to stabilize riverbeds and spread floods. This chapter draws on the experience of rural road construction in Kenya. The techniques are equally suitable for all semiarid areas, in particular with dry and sandy or gravelly rivers.

Ethiopia: culvertless road drift combined with sand dam with scope to further raise sand deposition upstream by gradually closing the gap in the side wall

8.2 Opportunities

Ephemeral rivers, which range in span from 5 m to 300 m, dry up quickly after rains cease in arid and semiarid areas. They typically flow for only a few days, or even a few hours, each year. Even when there is no rain, the rivers transport water. Although the rivers are dry on the surface for most of the year, they are a reliable source of water because of their subsurface flow. In fact, the volume of subsurface flow in ephemeral rivers in many cases exceeds the water carried during the occasional floods.

Moreover, the transport of water in the riverbed reduces evaporation and minimizes water losses. The water quality in the riverbed is usually improved with the riverbed material acting as a sand filter.[13] In the absence of other reliable sources, the water from the dry river, accessed through scoop holes, infiltration galleries, or wells, serves as a source of domestic water or as water for livestock or irrigation. In addition, the subsurface flow in an ephemeral river recharges shallow groundwater. By constructing a well upstream of the river, people can extract this water more conveniently.

The importance of these rivers is evident, especially in arid and semiarid areas where the single river flood may be the only source of water for an entire year; all the more reason to harness these rivers in the best manner possible and to increase their water-retaining capacity. This can be done by dual-purpose road drifts. On low-volume roads, road drifts are more economical and preferred over conventional bridges across expansive dry rivers with occasional floods. They may not be passable

[13] Sand is a very suitable water filter. It removes many pollutants, even though it cannot guarantee drinking water quality.

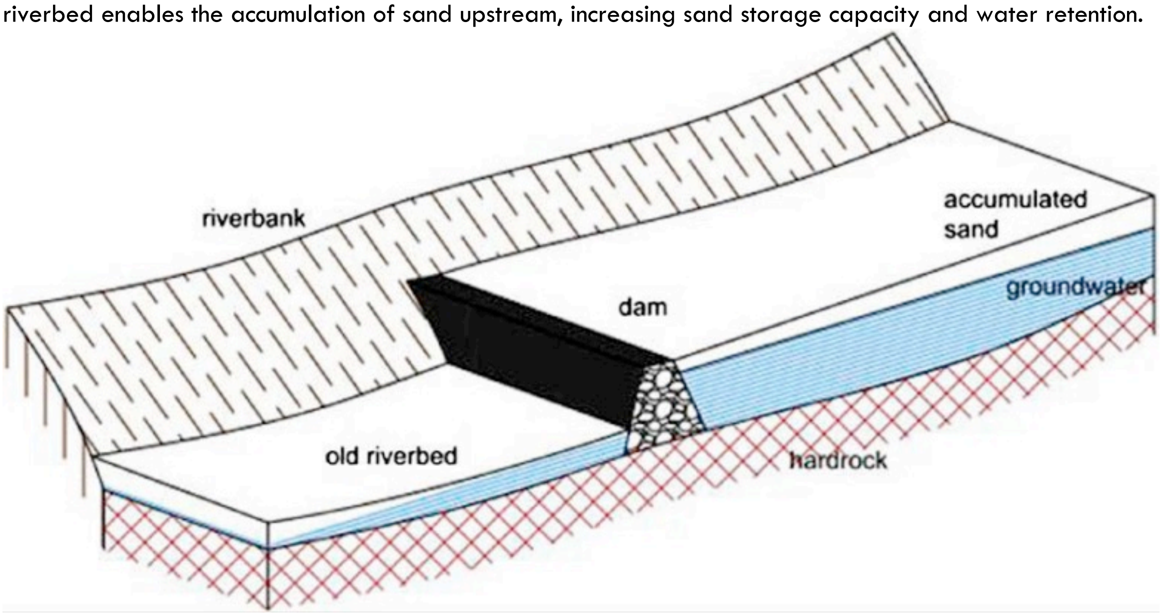
during floods, but the construction cost of a road drift is substantially lower than that of a conventional bridge. If constructed well, they will retain subsurface water upstream. Moreover, they may stabilize the riverbed and control gullying and rutting. The latter will make it easier to divert water for irrigation from the surface of the riverbed.

8.3 Recommended practice: river crossings as sand dams and bed stabilizers

Road drifts not only serve as a road crossing but should also function as a sand dam and riverbed stabilizer. Non-vented drifts[14] can act both as low-volume traffic conduits and water-retaining structures. They help capture and store floodwater and retain it for future use. Unlike vented drifts, non-vented drifts are not equipped with culverts. Drifts provide good opportunities to retain water from ephemeral rivers because they act as sand dams (see Box 8.1).

Box 8.1: Sand dams

Sand dams reinforce what sandy rivers are already doing: storing water in the sand. A retaining wall across the riverbed enables the accumulation of sand upstream, increasing sand storage capacity and water retention.



The principle of a sand dam: accumulating coarse sand upstream of the dam (or culvert)

It is important <u>not</u> to have vents (culverts) in these dry river crossings. Due to the absence of culverts in the drift, coarse sand and gravel will accumulate in the riverbed upstream of the drift. This creates a small manmade aquifer of sand and water. Coarse sand and gravel have large spaces between their pores, which can make for up to 35 percent of total sand volume. This means that up to 35 percent of the volume of sand/gravel can be used to store water. Thus, a non-vented drift builds on the natural capacity of a sandy riverbed. The newly deposited material will store floodwater and make it available during the dry season. The water retained in the riverbed will also connect to and feed aquifers on the banks of the river. The extent of this effect depends on local topography and geology.

Water-retaining sand dams come at no additional cost. In fact, they are even cheaper than the alternative option, i.e., vented drifts equipped with culverts. The exact cost of non-vented drifts depends on their height, which also determines their capacity to retain water.

Table 8.1. Drift construction costs per meter in Makueni County, Kenya 2015

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[14] Different words are used for drifts: fords, low causeways, or Irish bridges.

	US$ per meter
Drift type 1: Large drift, foundations excavated at maximum depth of 1.5 m and elevated 0.3 m above the existing sandy riverbed.	1240
Drift type 2: Large drift, constructed on bedrock, elevated 0.5 m to 1.2 m above the existing riverbed.	760
Drift type 3: Small drift, constructed on normal, ordinary river channels. Little or no elevation above the existing riverbed level. Depth 0.5 m to 1.0 m.	475
Type 4: Small drift (road slabs), constructed on bedrock or swampy plains. Little or no elevation above the existing riverbed level, maximum depth 0.5 m.	330

Non-vented drifts also provide other water management benefits. The first is the stabilization of the upstream riverbed. Depending on the lay of the land, non-vented drifts make it possible to divert water from the riverbed—either perennial flows or short-term floods or spates—using gravity upstream of the drift. This would be difficult where the riverbed is not stabilized and smooth but is instead rutted and incised.

Culvertless drifts also cause less damage to the riverbed immediately downstream of the road crossing, since water will not spout through the culverts during flood events to erode the area downstream of the drift. Water now has the chance to cross over the entire width of the drift, reducing damage to land downstream. As river crossings, non-vented drifts are more reliable and predictable and are much cheaper than bridges in their function as low-volume roads. During flood events, however, they are impassable for the duration of the flood, whereas vented drifts are passable (unless they are affected by blocked flotsam and uncontrolled flooding). Downtime on non-vented drifts can be reduced by placing pointed markers alongside the drift to guide vehicles across during low floods.

A possible solution to making culvertless drifts passable during flood events is to add a vented drift on top (Figure 8.1). However, prior analysis is required for roads with different types of traffic volumes to determine whether this construction would be economical and necessary. As mentioned, because floods are mostly limited to a few days a year, culvertless drifts are suited to low-volume routes. For high-volume roads, this combination of structures can be better assessed for suitability on a case-by-case basis.

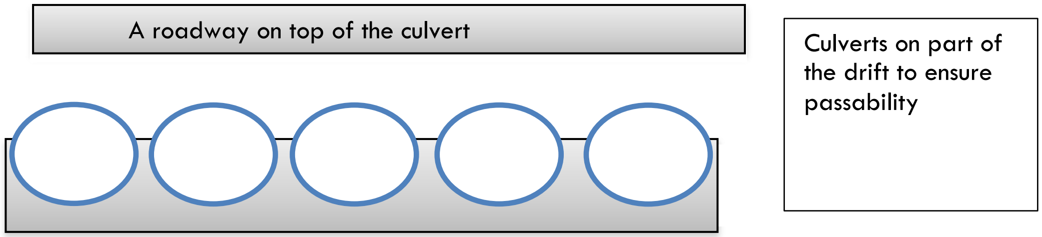


Figure 8.1: Sandwich drift to ensure passability

Drift = basic structure on the riverbed

8.3.1 Siting of a non-vented drift

There are several factors to take into account in selecting an appropriate site for a non-vented drift on a dry riverbed.

The first is to select a narrow, shallow section of the dry river. Narrow sections are preferred in order to save material and labor costs. It is also critical to conduct a geophysical survey at the riverbed to measure the depth of sand sediment on top of a rock/subsurface formation. The best location for a non-vented drift has shallow sand depth, narrow width, and low riverbanks, and should not be on a river bend.

A second requirement is to select sandy or gravelly rivers. Sand and gravel in the riverbed will store floodwater in the open space between the particles and make it easy to retrieve. Ephemeral rivers that predominantly carry clay or silt are unsuitable for a non-vented drift-sand dam, because the fine material will not hold much extractable water.

Third, it is important to understand hydrology. In selecting the site for a non-vented drift-sand dam, special attention must be given to the amount and periodicity of rainfall in the area, the floodwater within the catchment area, and historical flood levels. A hydrological study of the area and information from the local community are essential.

Fourth, the socioeconomic potential of a non-vented drift needs to be taken into account, including the presence of population, farmland, and the scope for non-agricultural activities. For instance, brickmaking is a rewarding rural economic activity that the presence of water can boost.

Fifth, there is preference for the development of a series of structures in a dry river. Preferably, a series of non-vented drifts and other structures (weirs and sand dams) are built in a dry river. This helps regulate the flow, stabilize the river, and improve floodwater retention across the entire river. None of these structures can be fully connected (as in a cutoff weir) to the river's bedrock: this will block subsurface flow to the downstream areas and deprive those living there.

Finally, prior assessment needs to be conducted to estimate the sediment load that comes in with a flood. It must be ensured that enough coarse sand and gravel can be accumulated in order to prevent fine particles from being stored upstream of the retaining wall. Fine particles diminish the storage capacity of sand-retaining structures. Walls that are too high trap silt and fine particles and let coarse material pass; therefore, little water can be stored.

8.3.2 Design of non-vented drifts

Road drift on a small river near Kitui town, Kenya

The design of a non-vented road drift consists of several elements: the body of the drift, the approach road, the upstream protection of the stream, and the downstream apron. Annex 2 provides a detailed description of the design of a non-vented drift.

However, the main points with respect to the design of the non-vented drifts are presented below:

- Expand the drifts by 5 m to 10 m on either riverbank, depending on the width of the river.
- Extend the approach above the experienced flood level to prevent damage when floods are high.
- In sandy riverbeds, anchor the structure at 1.5 m below the existing riverbed level; in rocky riverbeds, the foundations should be laid on the bedrock.
- Foundations should have a minimum width of 500 mm and a construction depth of 250 mm.
- The top slab, on which traffic passes, should have a constructed thickness of at least 150 mm to 200 mm, depending on traffic volume and load.
- The drift should be filled with hardcore material and compacted to a maximum depth of 1 m on sandy riverbeds and 0.6 m on rock riverbeds.
- The foundations, walls, and slab should be rigidly tied together to give the drift great resistance to being washed away by floodwaters.
- The width of the roadway slab should vary between 3 m and 5 m, depending on the anticipated type and volume of traffic.
- The height of the drift above the existing riverbed should be a maximum of 1 m to ensure sufficient depth for the accumulation of sand and water upstream.
- At the foundation of the drift on the downstream side, gabions should be installed to prevent the foundation from being undermined by the overflow of floodwater.
- The drift should have a curvature toward the center of the river to ensure that the water concentrates in the middle of the river, minimizing erosion along the riverbank
- The elevation of the drift and the walls above the riverbed determine the additional material deposited and the amount of water retained. Coarse material is deposited in the riverbed, while finer material is washed off the drift and walls to areas downstream of the river. The deposition takes place over a number of years. The height of the drift can be increased in stages so that mainly coarse material is deposited each year.

8.3.3 Measures to prevent failure

The constructed drift is an investment that provides livelihoods for communities. Therefore, it is important to prevent its failure and washing away by floodwater. Figure 8.2 illustrates the possible failures of a drift. The risks should be considered during design and construction of a drift. There are a number of designated measures:

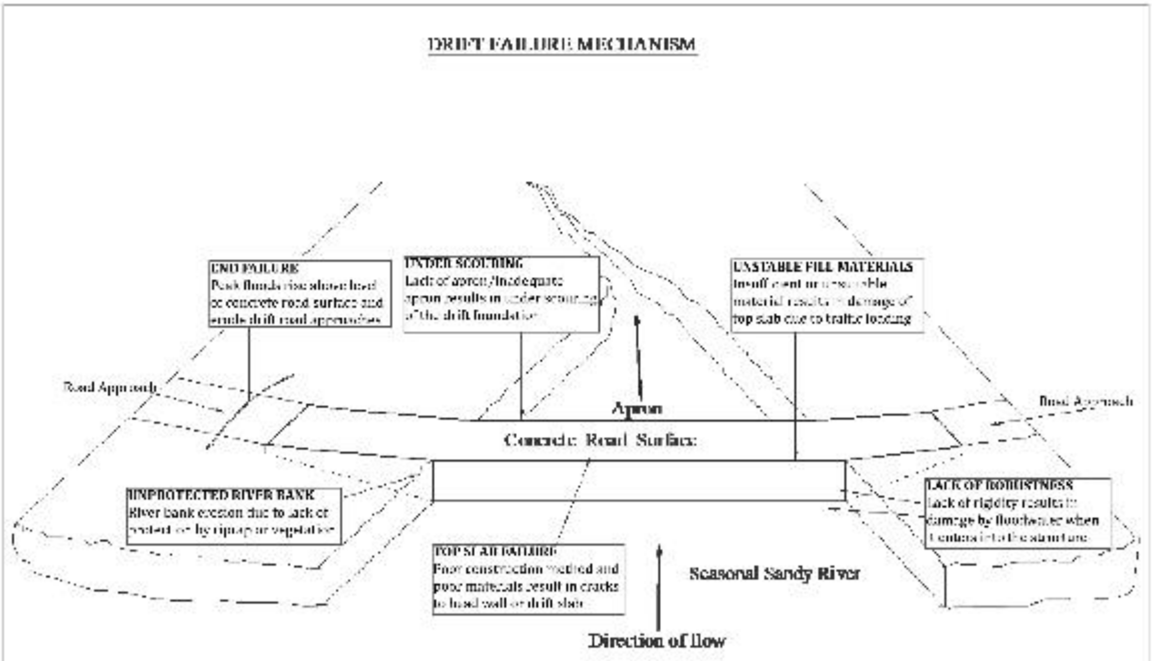


Figure 8.2. Overview of non-vented drift with preventable failure features.
(Source: Neal 2014)

Body of the drift. There should be adequate support to the top slab of the drift to avoid collapse under traffic load and to create mass resistance so as not to be washed away by floodwater. Fill material of adequate strength should be placed in the structure to give it firm resistance to floodwater. The fill material also ensures adequate resistance to traffic load and thus prevents crashing of the drift's top slab. Rock fill is typically recommended, with a minimum depth of 1 m underneath the top slab in sand riverbeds and 0.6 m in drifts constructed on rock riverbeds. (See Figure 8.2.)

Robustness. Care should be taken to ensure that the foundations, walls, and top slab are rigidly tied together by high-tensile reinforced steel to ensure the structure's firmness, so that floodwater does not penetrate the structure and carry it away. The materials for making concrete should meet all requirements in accordance with the recommended standard specifications for road and bridge construction. The structure should be extended and anchored adequately beyond the riverbanks to prevent floodwater from going over the edges and undermining the drift ends. If the water undermines the drift ends, this could cause approach failure and cut the road off from the drift. If the drift links directly to an unpaved road, this can trigger erosion. As a rule, the drifts should be extended by 5 m beyond the banks of the river with spans less than 50 m, and by 10 m for rivers with spans greater than 50 m. Historical flood levels should also be assessed together with estimations of total river discharge. The drifts should be extended at least above the (expected) peak flood levels.

Lowered middle section of the drift. A middle curvature should be introduced in the drift body to ensure that floodwater concentrates in the middle of the river. This will prevent floodwater from washing away the approaches of the structure. The depression at the center should be up to 50 cm in a drift that spans 50 m in order to ensure adequate floodwater spreading and prevent bankside erosion.

Anchorage to the bedrock. The drift should be firmly anchored to the bedrock of the river across its full span in rocky riverbeds. Anchoring ensures that no water flows under the foundation, which would undermine the drift. Excess stormwater passes over the drift. For drifts constructed in a sandy riverbed, seepage underneath is allowed through the sand to infiltrate water to the downstream side of the river.

Downstream gabion protection. The structure's foundation should be protected from being undermined by the river's flood flows. Undermining of the structure washes away the rock fill, which results in the structure collapsing under the traffic load and the drift being washed away. Gabion boxes measuring 2 m x 1 m x 1 m should be placed at the foot of the foundation on the downstream side of the structure.

8.4 Construction

All materials to be used for the construction of the drifts and water-retaining structures should be tested to ensure that they meet the standard specifications for road and bridge construction. The recommended specifications are:

- Drifts should be constructed with reinforced concrete with twisted Y12 steel bars in a single layer spaced at 250 mm center to center.
- Structural concrete should be class 25/20 and blinding concrete should be class 15/20, with 1:1½:3 and 1:3:6 ratios of cement, fine aggregates, and coarse aggregates, respectively (as detailed in the drawings supplied by the design engineer). The concrete should be mixed well in the concrete mixer and compacted in place using a poker vibrator.
- The water/cement ratio should be well controlled. Ideally, the water should be half the amount of cement in the mix.
- The concrete design mix should be prepared by a qualified engineer and tested to meet the required strength before application. Well-compacted rock fill should be placed up to a minimum depth of 1 m to give the drift sufficient mass.

9. Water harvesting and drainage from unpaved roads

Key message

- Most damage to unpaved roads – as much as 80% - is caused by rain run-off;
- Related to this unpaved roads surfaces are a major cause of sedimentation (up to 35%, excluding gullies) in mountain catchments;
- This can be minimized when water is systematically directed to the land rather than running along the road surface;
- This requires the consider design of unpaved road alignments – regular slope reversal, avoid sunken roads and include basic road drainage
- Several additional measures preserve unpaved roads, enable water harvesting and reduce erosion: water bars, rolling dips and infiltrating bunds

Main applications

- Providing water harvesting measures combined with road drainage is essential to unpaved roads all over the world. Maintenance of unpaved feeder roads is in many countries heavily underfunded. Measures that have the double purpose of reducing damage and promoting beneficial water use will contribute to longevity of vital rural road connections.

9.1 Introduction

This chapter discusses basic measures that reduce damage to unpaved roads while guiding water away from the surface to use it productively or for recharge. Maintenance of unpaved roads is a challenge in many countries. The ballpark figure is that 80 percent of the damage to unpaved roads is water related. Unpaved roads are usually built to much lower standards than paved roads. For instance, they may not be equipped with a road drainage system.

Moreover, funds for maintenance of lower-tier roads are chronically insufficient. Because the financing of maintenance is a challenge, repairs may take a long time, with a major impact on connectivity in remote areas. The lack of maintenance is compounded by the fact that in some areas unpaved roads are made from highly erodible material for lack of a better choice. The rutting of such unpaved roads constitutes an important road safety issue. For these reasons, preventive measures that reduce the degradation of the unpaved part of the road network are extremely important.

Ethiopia: water damage in action on an unpaved road; note the gully at the end of the slope

Mozambique: roads constructed with highly erodible red sand washed away in each major runoff event

9.2 Opportunities

Preventing damage to unpaved roads by combining adequate road drainage with water harvesting is essential. More than 75 percent of the roads in many countries are unpaved. They are the largest single intervention in the rural landscape. As discussed in Chapter 3, they are also main contributors to the sediment in a catchment: ranging from 12 percent to 40 percent, according to the literature. Several studies on forestry development in the United States establish that road development, more than logging, accelerated sedimentation in local streams. This is because roads start to behave as tributaries of the streams, "creating a more efficient sediment delivery system" (Castro and Reckenhoff 1995). Practices that keep the sediment out of the stream, like vegetation buffers, are bypassed and sometimes even destroyed during the construction of rural roads.

Where a rural network is expanding in the upper catchment of a hydropower dam and no water management measures are taken, the accelerated sedimentation may considerably shorten the lifespan of the hydropower reservoir. There is a risk of this happening in the upper catchment of the Grand Ethiopia Renaissance Dam, Africa's largest dam: even though part of the catchment consists of deep and highly erodible soils, new rural roads are constructed without adequate drainage and water harvesting facilities.

High sediment loads in water have other effects as well. Turbidity affects much of the aquatic life. It can reduce the spawning of fish (Noss, no date). Higher sediment loads have an optical effect by blocking light penetration and slowing biological activity. Second, many fish, such as salmonids, spawn in the gravelly bed load of a river, placing their eggs at different depths (Castro and Reckenhoff 1995). The eggs require fresh, fast-flowing water. However, medium-textured sediment that is suspended in water at medium speeds will settle and clog spawning grounds. The same can affect benthic organisms. The effect of sediment loads depends on the type of stream as well: in fast-flowing streams, much of the additional sediment may be carried further along, but in streams with lower gradients the riverbed morphology will change much more under the impact of sedimentation. Another variable is the sediment composition that is released: the size of the sediment as well as the shape. Flat particles (like clays) are more likely to form a relatively immobile film on the riverbed.

In the construction of new unpaved rural roads there are several *dos* and *don'ts* to reduce sediment release and improve the capacity to harvest and recharge water. The measures taken are usually low cost and will help to preserve the integrity of the road. This chapter discusses three sets of measures that help to preserve the road:

i. Planning the alignment of unpaved roads by avoiding long and steep slopes without drainage facilities.
ii. Using basic road-surface drainage: a series of rolling dips (small depressions with a small bump) or water bars (small slanted humps) to divert water from the road surface to the land for productive use.
iii. Using infiltration bunds to slow own the side erosion from the roads and promote recharge.

Box 9.1. Creating youth employment with sand harvesting

In Ethiopia, organized groups of youth (with equal numbers of males and females) are given permits by the government to mine sand for a period of time. This activity is very successful and may be considered for more countries. For one year, the group is expected to retain the profit from sand harvesting as seed capital for business activities. For this business graduation, the government contribution is 80 percent provided as a loan on top of the US$850/year that the group member may have saved. In total, each member may establish his/her own business with about US$4,250. This employment opportunity has resulted in better regulation of sand and gravel mining through the local government; the business had previously been captured by local thugs.

Controlled sand mining from road hydraulic structures can enhance the safety of the road and provide livelihood opportunities for nearby communities.

9.3 Recommended practices

9.3.1 Planning road alignments for adequate drainage and water management

Much damage to unpaved roads can be prevented. The main requirement is to avoid water running along the unpaved road surface at high speed, taking out fine material and then small stones and gravel, causing a large part of the road material to be removed. Requirements for reducing the speed of runoff include an alternation of slopes, the use of bends where runoff can evacuate the road surface, and the presence of a basic road drainage system.

The angle and length of the road's slope are very important in reducing the risk of water-related road degradation (Zeedyk 2006). These two factors determine the velocity of the water running along the road surface and with it the scouring effect. A number of factors are at work:

- When the velocity of the runoff on the unpaved road surface doubles, the volume of sediment that can be moved increases fourfold.
- The size of particles that can be transported increases eightfold when the velocity is doubled.
- Velocity increases as water depth on the road surface increases, because the relative surface tension decreases.
- As flow velocity increases, sheer force "plucks" larger particles from the road surface.

Much of the eroded material will be deposited downstream, clogging drains and covering fields. Part of this sediment will travel further downstream, reducing the capacity of downstream storage. In some cases, however, the nuisance can be turned into an asset with sand being harvested as a business opportunity (see Box 9.1).

Ideally, the grade of an unpaved road should range from 4 percent to 10 percent, with frequent grade reversals. Natural drainage is assured if the road reverses grade every 60 m to 100 m (Zeedyk 2006). Water naturally exits the roadway at every grade reversal. According to Napper (2008), the most important dos and don'ts are:

- Try to reverse the slope of the road and avoid long uniform stretches.
- Where possible, use crowned and/or out-sloped/tilted road templates to drain the water immediately to the side of the road, although such templates are sensitive to wear and tear.
- Use rolling drainage dips and water bars to remove water from road surface (see Section 9.3.2) at designated places where the water can be used productively.
- Locate drainage features at greater spacing on soils that are fine-grained and erosive, or cover the most vulnerable sections with at least 10 cm of coarse aggregate.
- Ensure a well-vegetated buffer zone or row of stones (infiltration bund) at the edge of the road to disperse flow, reduce runoff velocity, and collect sediment from road runoff (Section 9.3.3).
- Avoid long road sections that are entrenched with no opportunity for water to be evacuated to either side of the road. For the same reason, avoid degradation of the unpaved roads over the years that causes the road to sink and become a drain.
- Where there is considerable subsurface flow, provide side drains to collect this flow and reuse it. Alternatively, provide permeable fills and French mattresses close to saturated water pockets.
- Alternatively, provide full road-drainage systems in such places with side drains and cross culverts. Such well-developed drainage systems will not only protect the road but will also help to more systematically collect and harvest water from around the road.
- Maintain a vegetative cover around the roads to increase roughness and reduce erosion. Where vegetation is removed (by road construction), sedimentation may increase sevenfold.

- 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.
- On very steep hill slopes (>35 percent), develop internal drains guiding water away from steep cut slopes and intercepting subsurface flows to keep them from causing severe erosion on the downward fill slope.
- Take care with stream-road crossings to ensure that the diversion of the stream to the road at times of high flow is controlled.

Care is required to connect the drainage from the unpaved roads to land where it can be used productively. This can be for farming, in particular for building up soil moisture ahead of planting or for direct use during the growing season. In this case, the use of farm trenches is preferred: the runoff is guided to the farm and directly irrigates the root zone. This is preferred over using runoff on the land, where it may damage the crop.

Farm trenches in Kenya: road drainage water serving the root zone

Box 9.2. Connecting drainage cuts to farm trenches in Mozambique

In the absence of a developed road drainage system along most roads in Mozambique, it is common to have drainage cuts on the sides of paved and unpaved roads. These cuts serve to remove water from the road surface and are usually made by a road grader during construction or maintenance. The drainage cuts, also called *sanjas*, are often made close together, typically 100 m or less apart. At present, these drainage cuts end in the road reserve and do not serve farmland, although they could be used in this way.

Sanjas in Mozambique

To help direct water to farmland for productive use, *sanjas* can be made longer. By connecting the *sanjas* through trenches to farmland, more moisture will be available for crops, and water will be carried directly to plant roots. This should enable a 20 percent increase in yields and make it possible to grow other, more profitable crops. The practice of using road cuts to water farmland is common, as seen in Kenya.

Below are recommended practices in making trenches that connect drainage cuts to farms:

- In consultation with the farm owner, extend the drainage trench beyond the center of the farm. If the land is terraced, the trench should follow the terraces.
- Make the trench approximately 50 cm deep.
- The ideal width of a trench is around 40 cm: a relatively narrow and deep trench will preserve most moisture. Some crops, like bananas, require wider trenches.
- The trench should ideally be rectangular.
- Make sure the water from the road flows naturally to the land: choose the inlet at a position that makes best use of the slope.
- Make gentle curves in the trench to minimize erosion.
- Make sure the trench is not too steep: i.e., less than 3°. If the trench is too steep, it will erode easily.
- The main trench can branch into side trenches. The drainage trench can feed a farm pond (discussed in the next chapter). In that case, it is recommended that a silt trap be installed before the pond entrance to catch the sediment in the trench water.
- To strengthen trenches and prevent collapse, plant grasses and small trees on the banks.
- If there is heavy rain, it is recommended that the entrance to the fields be closed with an earthen heap to prevent overflow of the road to the agricultural land.

9.3.2 Use basic road-surface drainage

Water bars and drainage dips are the main low-cost solutions to provide basic drainage for unpaved roads. They are inexpensive and should become standard elements of unpaved road development and maintenance. They will preserve these ubiquitous low-volume roads and help turn the runoff from the road into a productive asset.

Water bars are narrow structures akin to speed breaks or speed bumps. While their primary purpose is to divert water from the unpaved road surface, not to reduce driving speed, they also serve this purpose.

Figure 9.1 Water bar in place (Source: United States Forest Service 2017)

The specifications for the implementation of water bars are as follows:

- The position of the water bar should be at an angle to the road direction, preferably between 45° and 60° (out-slope to daylight). Water bars are prone to clogging if they are at less than a 45° angle to the road direction.
- Typically, water bars have a height of 75 mm to 150 mm with a width of 0.3 m to 1 m (see Figure 9.1).
- Water bars may be made of soil, but in very loose soil they can be made of reinforced material: rock, timber, and pre-cast concrete. In the case of prefabricated structures, two-thirds of the structure needs to be embedded in the road body (see Figure 9.2).
- For optimal erosion and runoff control, the ideal number of water bars that should be constructed depends on the slope or road grade. The greater the slope, the less space there should be between water bars. In the case of highly erodible roads with many aggregates of less than 2 mm material, the distance may be further reduced (see Table 9.1).

Table 9.1. Spacing of water bars (after Packer 1967)

Road grade %	General space between water bars (m)	Space between water bars in highly erodible roads (m)
2	75	45
5	40	25
10	25	15
15	18	11
20	14	9
25	12	7
30	10	6

- The outer extremes of the water bar need to be extended at least 300 mm beyond the road tread.
- The outflow end remains open to avoid accumulation and preferably leads to land where the water will be used for farming or pasture. The runoff should not flow directly to a stream.
- The outslope of the road must be between 6° and 10°.

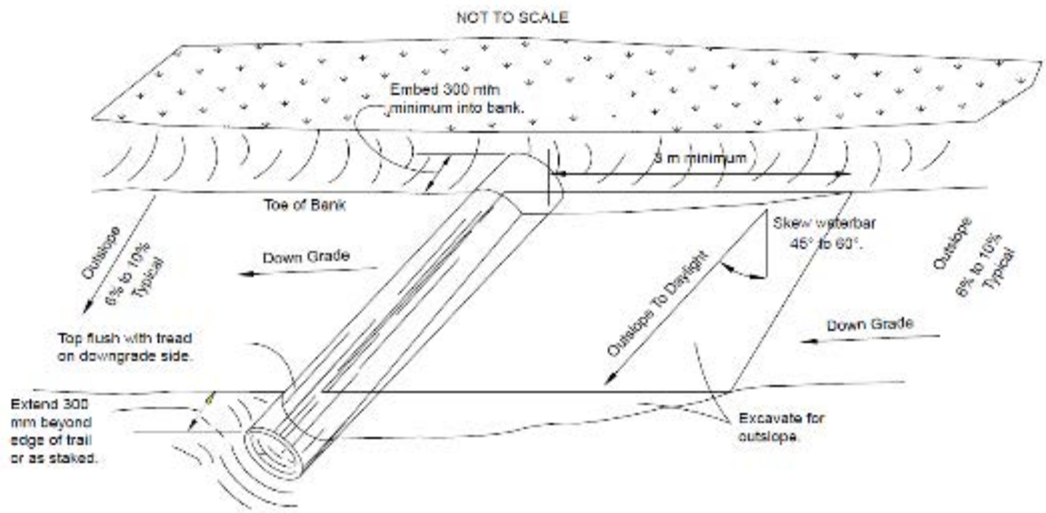


Figure 9.2. Rock water bar specifications
(Source: United States Forest Service 2017)

Another drainage feature, closely related to water bars, are rolling dips or drainage dips. Different from a water bar, they consist of a small depression and a pushed-up hump, akin to a water board. The excavated material from the dip is used to create a higher area in the unpaved road, causing the road to slightly undulate, creating a double drainage feature of dip and ramp.

Rolling dips (Figure 9.3) are the most reliable cross drains for low-standard roads. They collect surface runoff from the roadway and/or road ditch and direct the flow across and away from the roadway. The main features are:

- Rolling dips are used to drain low-volume roads with grades between 3 percent and 15 percent.
- The minimum slope of 3 percent is to ensure that the velocity of flow is sustained through the dip. This prevents puddling that would damage the road and keeps sediment moving through the dip drain. Part of the road and the adjacent areas is excavated (for at least 30 cm) to lead the road runoff to adjacent land.
- If the road grade is too steep (greater than 15 percent), the rollout will be too steep on the downhill side and traffic will damage the structure.
- The drainage dips are placed at an angle to the road, similar to water bars. They should have a cross slope of 4 percent to 8 percent. This is steep enough to flush away accumulated sediments.
- The size and criteria for spacing drainage dips are similar to that of water bars, discussed above.

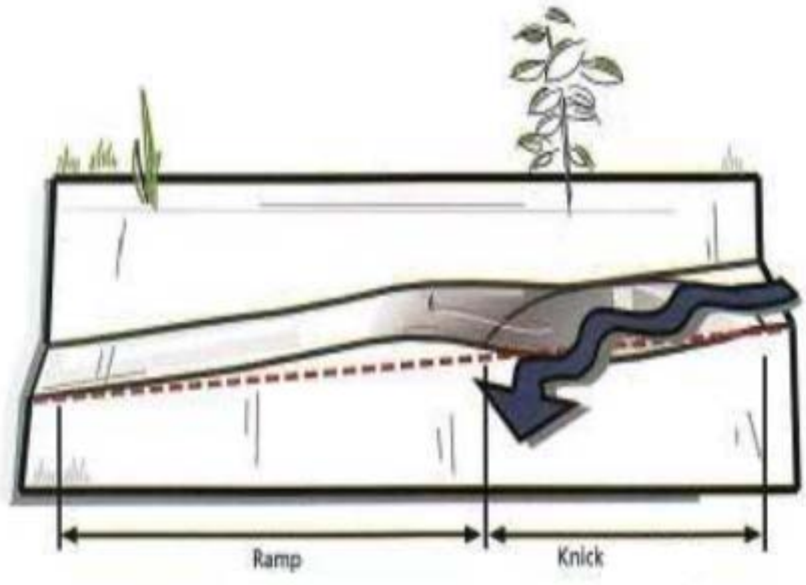


Figure 9.3. Rolling (drainage) dip in low-volume road

9.3.3 Use infiltration bunds to control erosion and enhance recharge

As mentioned, road runoff is a major reason for erosion and sedimentation. This flow may come from the road surface itself as well as from the surrounding area, with the road typically acting as a drain for the area around it. The volume of water conveyed from the road surface can be considerable and can cause considerable erosion to the road surface and the areas adjacent to the road.

Several measures may be considered to curtail this erosion. Along rural road alignments, trees, shrubs and grasses may be planted to reduce the erosive effect of runoff from the road template, in particular if no side drain is provided and the road template is out-sloped or crowned. This is discussed in Chapter 12, which deals with roadside vegetation.

An alternative or complement to roadside vegetation is the use of infiltration bunds. These may be more appropriate in arid areas because of the difficulty for roadside vegetation to take root. Infiltration bunds can be placed on the downhill side of the road or at any other location in the catchment where they intercept sheet flow. The stone bunds disperse water and slow runoff. They ensure more infiltration of the runoff, contributing to improved soil moisture and recharge of groundwater.

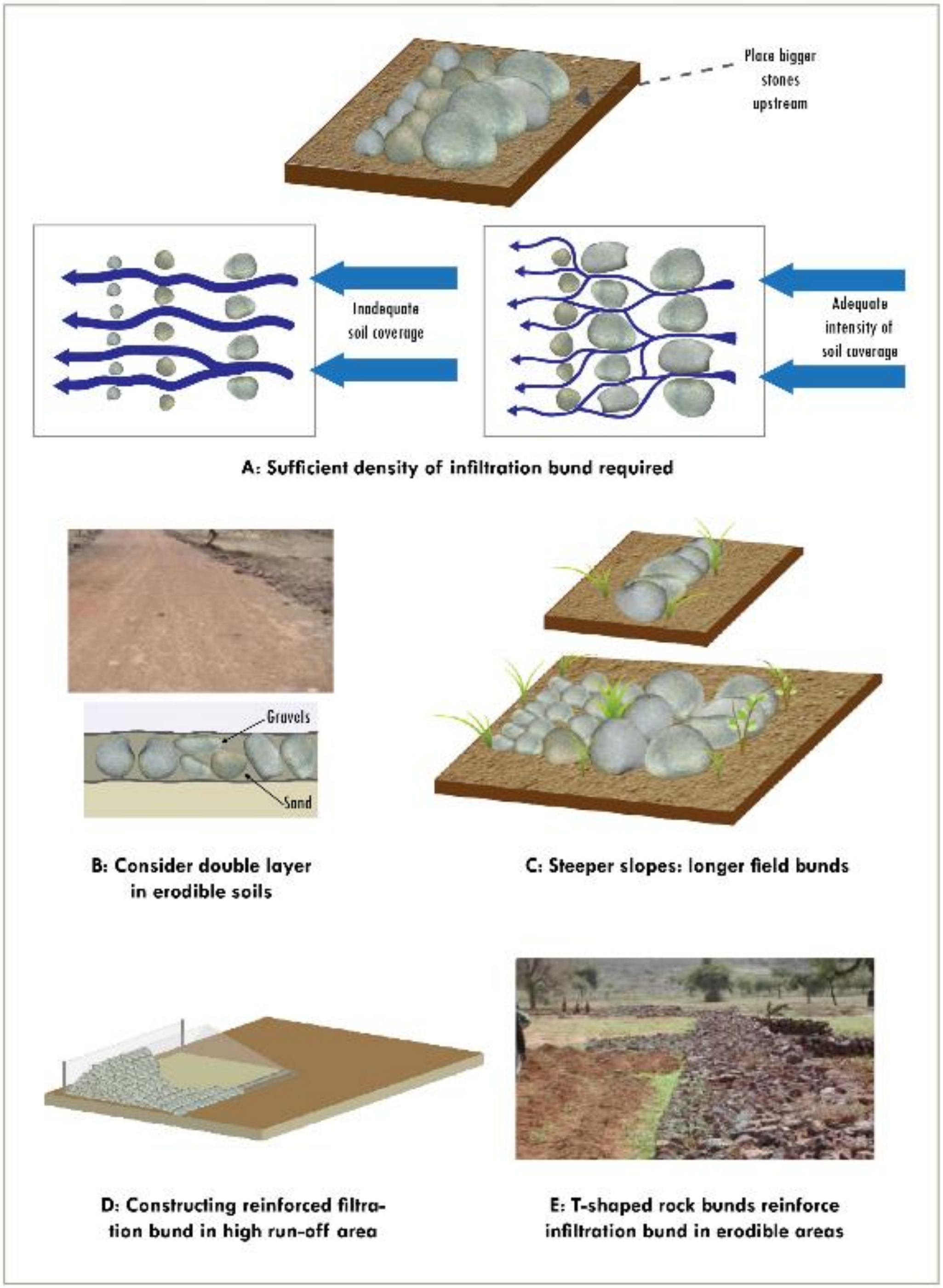
Based on the work of Bender (2009), the following recommendations apply (Figure 9.4 presents an overview):

- Rock infiltration bunds are best placed within three meters of the road border.
- The stones in the rock infiltration bunds should be placed at sufficient density to disperse the water and avoid erosion. In other words, if only a few stones are placed the slowdown effect will not work.
- Large stones should be placed upstream.
- A single layer of stones is sufficient in medium erodible road slopes, but good compaction is critical. An initial compaction under dry conditions followed by a second compaction under wet conditions is recommended. A double layer of stones may be used in highly erodible soils.
- The thickness of the infiltration bund is 15 cm for terrains of medium sediment transport capacity. This can be increased in areas with higher transport capacity. Wider infiltration bunds with

larger head stones or a second bund are recommended for loamy soils, vertisols, and areas with concentrated runoff.

- Masonry uphill protection for the infiltration bunds may be considered in areas with highly erodible, very soft loamy soils, concentrated runoff, and long-standing water. A T-shape layout may also be considered.

Figure 9.4. Best practices with regard to roadside infiltration bunds, based on Bender (2009)



A: Sufficient density of infiltration bund required

B: Consider double layer in erodible soils

C: Steeper slopes: longer field bunds

D: Constructing reinforced filtration bund in high run-off area

E: T-shaped rock bunds reinforce infiltration bund in erodible areas

10. Roadside farm ponds

Key message

- Road side ponds can be important sources of water. They need to be planned carefully in terms of catchment (in proportion to storage capacity), soil characteristics (not too porous), lining, their capacity (serving the requirements), sediment interception and protection from diseases (such as measures to control malaria)

Key applications

- Road side farm ponds can represent a critical additional source of water in dry lands. They can also be used in wet areas for irrigation and livestock watering during dry spells

10.1 Objective

A recurrent application to harvest water is to direct the runoff that is guided by the road body and the road-drainage system into farm ponds. These ponds will store water for additional irrigation, livestock water, or domestic water use. They can sustain high-value agriculture (see Box 10.1) or be a lifetime support for livestock. Roadside ponds are common in many countries, but they are not widespread everywhere. In many areas they could be connected to roadside drainage cuts or miter drains. The objective of this chapter is to discuss the development of these ponds, the opportunities they provide, and the recommended practices.

Box 10.1 Growing grapes with road water in Bolivia

In the area immediately to the south of the city of Tarija, grape production is the main cash crop for the majority of the farming community, which mostly relies on reservoirs for irrigation water. However, water distribution does not meet the ever-growing demand. High erosion rates are also decreasing the dams' overall capacity. Some farmers along roads are successfully experimenting with road-water harvesting. There are many forms of storing road water: one of the most common is the use of water-harvesting ponds *(atajados)*.

An example is from the San Jacinto Dam. The piped water running along the road is distributed at long and irregular intervals. The atajados help to buffer water and redistribute it. The small farm ponds were built at first as night storage infrastructures with the intention of storing water during irrigation turns. This gave farmers the freedom to apply water to their fields at the most convenient times. With growing demand and dwindling water supply, the atajados assumed a dual role. While storing water from the piped water system, they also began to be recipients of road runoff to compensate for the intermittent water supply.

10.2 Opportunities

Farm ponds are dug-out structures with definite shape and size, and with proper inlets and outlets for collecting the surface runoff flowing from a small catchment or part of a catchment, including the water guided by road bodies. The water leading to farm ponds can come from the roadside drainage system or its culverts, or can be guided by road embankments. As shown in Box 10.1, the ponds can receive water from several sources.

Farm ponds are one of the most important rainwater harvesting structures. In general, water leaving an area without serving the needs of that area can be considered as a lost opportunity. It is useful to systematically develop farm water ponds along road sections to capture the concentrated runoff, rather than letting it play havoc with the areas surrounding the road and eventually also undermining the road bodies themselves. An important method to capture this road-guided runoff is the systematic development of farm ponds.

One of a string of ponds collecting roadside drainage water for irrigation in Shandong, PRC

Farm ponds may be used for irrigation (full or supplementary) and livestock watering. Upon treatment they can be used for domestic applications. Ponds can also be used for recharging groundwater, catchment protection (i.e., soil erosion control), ecosystem/biodiversity conservation and rehabilitation, and recreation.

The primary application of farm ponds is in dry lands where they can represent a critical additional source of water. However, farm ponds are not only developed for dry areas but can also be used in wet areas for irrigation and livestock watering during dry spells.

10.3 Recommended practices

This section discusses the recommended practices with respect to the planning of farm ponds (10.3.1) and subsequently their design (10.3.2) and development (10.3.3).

10.3.1 Planning of Farm Ponds

Developing a roadside pond in Kenya

Farm ponds are developed in different types of catchments. The nature, size and slope of the catchments differ, and different types of farm ponds are possible. It is important to consider three factors in the siting of farm ponds: soil type, topography, and catchment sizes.

Soil Types

For construction of a roadside farm pond, the soils preferably should have low hydraulic conductivity with minimum seepage and percolation so that water can be retained for a longer time in the pond. Soils with a low infiltration rate are most suitable for pond construction. **Fout! Verwijzingsbron niet gevonden.**10.1 shows the infiltration rate of different soils. Clay and clay-loam soils have good potential for rainwater harvesting without lining, and the seepage losses are minimum. In such areas capturing runoff in ponds and existing depressions occurs naturally. Soils for pond construction should preferably meet the following criteria:

- Soils at the pond site must be fairly impervious in the pond bottom.
- Soils to construct a pond must be compactable. Gravelly soils, sandy soils or soil with certain clays are not suitable.
- The best soils are sandy clay, sandy clay loam, or clay loam.

When geotextile liners are considered, it is useful to standardize the dimensions of the ponds so that the geotextile lining can be pre-prepared rather than being made on the site, which is more laborious and cumbersome.

Table 10.1. Infiltration rates of different soils

No.	Soil type	Infiltration rate in mm/hr
1	Coarse sand	20-25
2	Fine sand	12-20
3	Fine sandy loam	12
4	Silty loam	10
5	Clay loam	8
6	Clay	5

Source: (www.nabard.org)

Soils having outcrops and stones must be avoided for the digging of farm ponds. The soil profile depth must be investigated before digging the pond. Soils having a good depth of >1 m, free of stones, low pH, low electrical conductivity (EC) and groundwater level may be selected to site the farm pond. Other soils may be problematic. Peat soils have special problems since they are usually very acidic in nature and need copious liming. Soils rich in limestone create problems of precipitating phosphate and iron.

Soil depth is also an important factor during the development of farm ponds. Deep soils have the capacity to store harvested water for a longer duration. Soils measuring more than 1 m are ideal for the construction of farm ponds. The greater the soil depth, the greater the depth of farm pond: a deeper pond will reduce evaporation losses. For farm ponds, a depth of 2.5 m is often recommended: it ensures adequate volume of storage, low evaporation, and ease of access.

Topography

Topography is important for a number of reasons:

- It can affect the size, shape, and depth of a pond.
- It affects dam/pond embankment height.
- It affects the speed and intensity of runoff into the pond.
- It greatly affects the simplicity or complexity of pond design and construction and thus cost.
- It directly affects safety issues.

The topographic features of the farm catchment vary from place to place. In general, the proposed land for pond construction must have minimum earth excavation so that costs can be reduced with increased storage. A narrow, deep pond will have a much smaller evaporation loss than a broad, shallow reservoir. If the land has some slope, the pond does not need to be excavated but a U-shape bund can create the pond. In some cases the road body itself can be part of the pond.

Drainage/catchment area

The drainage/catchment area that produces runoff for storage of farm ponds is very important. Road construction has a major effect on a catchment's drainage. Basically, the road infrastructure reshapes the catchment. Roads in general tend to combine smaller sub-catchments and bundle runoff in a limited number of drainage canals. This effectively enlarges the source area of the pond.

In pond-site selection, excessively large source areas should be avoided, particularly if the rainfall is concentrated in a short period (80 percent in less than two months). They increase the sizes required for the levees and translate into higher construction costs. More important, oversized source areas may result in washouts and flushing. Ponds with an oversized source area require spillways and other water-control structures, and are difficult to manage. In such cases a cascade of ponds maybe useful, where water overflows from one storage into the next. If rainfall and runoff are more evenly distributed over the year, pond sizes can be smaller.

On the other hand, the pond must be filled at least once in the season so that farmers can use the water for critical irrigation and other uses during dry spells. Depending on the rainfall pattern, a pond may be filled several times a year, increasing its effectiveness as a water-storage facility. Ponds with too small a catchment will have difficulty in filling up; and if the drainage area is too small in relation to the pond size, the pond may not fill adequately, or the water level may drop too low during extended periods of hot, dry weather.

Box 10.2. Siting of roadside farm ponds

- Selection of the site for farm pond depends on local soil conditions, the topography of area, drainage capacity, infiltration, rainfall pattern and distribution.
- Identification of natural depressions where rainwater/runoff either flows or accumulates during the rainy season. A good pond site contains: (a) level topography that provides for economical construction, (b) soil with sufficient clay to hold water, and (c) an adequate water supply;
- Deep clay soils are best for lining ponds because they minimize leakage. Because a pond is simply a depression for holding water, the sides and bottom must be composed of soil, which minimizes seepage.
- Coarse-textured sandy soils should be avoided: these are highly permeable and water will drain through them. If seepage is believed to be high, they can be plastered with clayey soil and compacted with tree trunks or lined with plastic.
- Sites with underlying strata of sand, gravel, limestone, shale or fractured rock at a shallow depth may also result in high leakage and seepage losses, and should be avoided unless they are sealed with clayey soil. Peat soils have special problems: they are usually highly acidic in nature and need sufficient liming.
- In terms of topography, locate a farm pond where there is enough road catchment that runoff can be generated, collected and directed with gravity. Ensure that the ponds can be supplied with water: the road embankment guides it either from road drains or culverts or from the runoff in drainage cuts. In unpaved roads, water exiting at bends and low points, guided by water bars and rolling dips, may be used
- For embankments and their compaction, soils having a wide range of grain sizes are preferable to soils with relatively uniform particle size.
- Before making the final site selection, one should examine potential sites by considering economics, accessibility and safety. Economically speaking, a pond that provides the largest volume of water with the least amount of landfill should be constructed. Liability is also a final consideration. For example, what would happen if the pond or dam fails, causing loss of life or injury?
- Ensure that no water is harvested in farm ponds that are polluted or contaminated.
- Provisions must be made for a pipe and emergency spillway if necessary. Runoff flow patterns must be considered when locating the pond/pit and placing the spoil.

Based among others on Nissen-Pedersen (2006)

10.3.2 Designing Roadside Farm Ponds

The main factors in designing a roadside farm pond are the capacity of the water pond based on water demand and rainfall patterns, and the pond's layout, including shape, side slopes, and features such as silt traps and spillways

Pond Capacity

The capacity of a roadside farm pond depends on the purpose for which water is needed and the amount of inflow that can be expected in a given period. The seasonal water yield can be estimated using past historical weather data (i.e., mean annual, mean seasonal, or certain probability-based rainfall [mm] multiplied by runoff coefficient, which is usually 0.1 to 0.3, and multiplied by catchment area).

The pond's capacity depends on the catchment size and factors affecting its water yield. The pond should have sufficient capacity to meet the demand of the crops or integrated farming system for which it is constructed. Using a conservative estimate, a dependable minimum value of 20 percent of the seasonal rainfall can be expected to go as runoff in the case of black soils and 10 percent in the case of red soils with mild to medium slopes.

Storage losses such as seepage and percolation will also influence the pond's storage capacity. The type of soil in the catchment area contributes to siltation; this must be considered because it affects the pond's storage capacity. Natural soil-type seepage losses (in mm/day) are presented below, according to FAO 1981.

Table 10.2. Natural soil-type seepage losses

Soil type	Seepage Loss
Sand	25.0–250.0
Sandy loam	13.0–76.0
Loam	3.0–20.0
Clayey loam	2.5–15.0
Loamy clay	0.25–5.0
Clay	1.25–10.0

In addition, a suitable provision should be made for the loss in storage capacity due to silting, which is generally kept as 5-10 percent.

Estimating Water Demand

Water-demand estimation is central to the design of farm ponds because it informs the preferred capacity of the pond. The following formula helps to assess the water demand for applied for irrigation, livestock and human needs.

$$Ir\ (m^3) = \frac{10 \times ETcrop\ (mm) \times Ca\ (ha)}{Ef}$$

Ir: Irrigation water requirements in m^3 for the entire dry period
ETcrop: Crop water requirement in mm during the dry period
Ca: Area irrigated with water from the reservoir in ha
Ef: Overall water application efficiency

$$WL = \frac{NL \times Ac \times T}{1000}$$

WL: Water needed for livestock during the entire dry period in m^3

NL: Number of animals to be watered from the reservoir

Ac: Average rate of animal water consumption in liters per day per animal 25-60 liters/animal/day

T: Duration of the dry period in days

$$Wd = \frac{Po \times Dc \times T}{1000}$$

Wd: Domestic water supply during the dry period in m^3

Po: Users of the reservoir

Dc: Average rate of water consumption in liters per day per person 40 liters/person/day

T: Duration of the dry period in days

Rainfall Analysis

The demand must be linked to an understanding of the rainfall and runoff patterns. Rainfall is one of the most important and critical hydrological input parameters for the design of farm ponds. Its distribution varies both spatially and temporally in semiarid and humid regions of a country. The quantity of surface runoff depends mainly on rainfall characteristics, such as intensity, frequency and duration of its occurrence.

- Frequent rains mean that the pond may fill up several times during the year. This will make it possible to have a smaller (and less costly) pond. The timing of the rainfall and filling of the pond in relation to agricultural requirements are important.
- High, intense rainfall exceeding the infiltration capacity of soil can produce more runoff than the rainfall event with low intensity for longer duration

Rainfall analysis is very critical for optimal economic design of farm ponds (see Annex 3). However, because long-term data on rainfall intensity are seldom available in the country, this available rainfall must be estimated based on probability analysis.

Design rainfall (DR) is defined as the total amount of rain during the cropping season at or above which the catchment area will provide sufficient runoff to meet the crop's water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress for crops. If the actual rainfall exceeds the DR, there will be surplus runoff that may cause damage to the structures. Timing is important: the creation of storage, as in the development of ponds, will transfer water from peak periods to periods of scarcity (see Annex 3).

DR is calculated from the probability analysis. It is assigned some probability level of occurrence or exceedance. Suppose the probability of 67 percent is given to rainfall: this indicates that the seasonal rainfall may occur or exceed two years out of three; therefore, the crop's water requirements would also be met two years out of three in a crop season. The higher the probability of rainfall, the more reliable it is for getting assured runoff into the farm ponds.

10.3.3 Layout of the roadside pond

Once the capacity of the roadside farm pond is clear, the layout of the pond can be prepared. This includes the decision on the shape of the pond, its dimensions (including depth and side slopes), and the additional structures

Pond shape

Roadside farm ponds may normally be of three shapes: square, rectangular and circular. However, because a curved shape presents difficulties in construction, either square or rectangular ponds are normally adopted. Compared to square and rectangular ponds, structurally circular ponds are said to be more stable because there are no weak joints (edges).

Digging the pond itself or closing the surrounding area with well-compacted levees or a combination of both creates square and rectangular ponds. Ponds of this type are recommended and easily constructed, particularly in areas with flat topography. An excavated pond is often built on level terrain and its depth is achieved solely by excavation. The pond is relatively safe from flood damage, requires low maintenance, and can be built to expose a minimum water surface area in relation to volume. This is beneficial in areas of high evaporation losses and a limited amount of water supply.

Depth and side slope of farm pond

The depth of a pond is generally determined by soil depth, type of material excavated, and type of equipment used. Pond depth is the most important dimension among the three. In semiarid regions, evaporation losses can be reduced by deepening the pond for the same volume of water stored, because the area occupied by the pond is smaller. However, with increased depth, seepage losses also increase. On the other hand, when ponds are constructed using manual labor, any increase in depth beyond 3.5 to 4 m becomes uneconomical. It also becomes uneconomical and difficult for lifting devices operated by people. Therefore, a depth of 2.5 to 3.5 m may be suitable in general for ponds.

The pond's side slope is based on the angle of repose at which the material is excavated. This angle varies with the type of soil. In most cases, side slopes of 1:1 to 1.5:1 are recommended for practical purposes. Based on practical experience, it is recommended that selected side slopes generally be no steeper than the natural angle of repose of the material. Table 10.3 presents the recommended side slopes for different soils.

If livestock will water directly from the pond, a watering ramp of ample width should be provided. The ramp should extend to the anticipated low-water elevation at a slope no steeper than three horizontal to one vertical. If water is collected for irrigation, provisions also need to be made to access the pond, such as a ramp or a platform for a pump.

Table 10.3: Suitable side slopes for different soils
Source: FAO 2011

Soil type	**Slope (Horizontal:Vertical)**
Clay	1:1
Clay loam	1.5:1
Sandy loam	2:1
Sandy	3:1

Additional features

A number of ancillary features are important:

Inlet protection

If surface water enters the pond in a natural or excavated channel, the side slope of the pond must be protected against erosion.

Spillways

A spillway is an important feature of a pond. It is designed to accommodate the removal of excess runoff in a controlled manner. The spillway must be reinforced with stone pitching, concrete or, at a minimum, grasses. The spillway should be located at some distance from the road embankment so that it does not undermine the road pond embankment.

Silt traps

The runoff from the road embankment will carry significant quantities of sediment. These will fill the pond and end its economic life prematurely unless the sediment is either removed regularly or intercepted before it reaches the pond. The runoff is best routed across a vegetated area to intercept large part of the sediment. A silt trap will further remove sediment. It consist of a small settling basin where the sediment is trapped and then removed.

Fencing

Roadside ponds may be fenced, preferably by native tree species that do not have root systems that will penetrate the pond. The fencing will help to regulate access to the pond and also provide a shelter against wind and thus reduce evaporation from the pond.

Box 10.3. Controlling sedimentation and contamination

It is important to take measures to improve the quality of the water in the pond, reduce silt loads, and avoid contamination. High, intense rainfall events cause soil erosion and the runoff carries the silt load into the farm pond. Other contaminants attach themselves to the silt. These problems can be resolved through proper soil and water conservation treatments around the pond. In order to achieve the desired depth and capacity of the proposed pond, the inflow must be reasonably free of silt from an eroding catchment. The best protection is adequate erosion control through on-site soil and moisture conservation or land-management practices in the drainage contributing area. To control sedimentation what is proposed:

1. Use sediment traps. To reduce the immediate inflow of sediment into the pond the run-off is best routed through an area with vegetation – this can be grasses, wild vegetation or for instance banana trees. Sediment can also be removed from the ponds by hand or by using pits that trap the sediment.
2. Land under permanent cover of trees or grasses is the most desirable drainage area. If such land is not available, consider treating the watershed with proper soil-conservation practices to control erosion before constructing the pond, or include silt traps as part of the pond design.
3. Generally, the catchments must be selected in such a way that contaminated drainage from farmsteads, feedlots, sewage lines, dumps, industrial and urban sites, and similar areas does not reach the pond. Similarly, runoff from intensely used road sections—bringing hydrocarbons, rubber and oils—must be prevented from ending up in the ponds.

Grass preventing sediment to wash into roadside pond

10.3.4 Constructing the roadside farm pond

Ponds can be constructed using road-building equipment as part of the road construction or rehabilitation contract. Alternatively, they can be made by land users' initiatives, using earthmoving equipment or manual or animal labor.

After the site selection and pond shape and dimensions are decided, the pond site should be cleared of all stones and woody vegetation. The selected site should be free from vegetation, bushes and other obstacles. The site should be leveled so that the demarcation line of the pond area can be drawn.

Before construction of the farm pond, the proper layout should be marked on the ground. This can be done with the help of rope and lines, with lime powder, or by making small cuts. The idea is that the demarcation lines must be visible for the equipment operator, thus enabling him or her to excavate earth from the pond area. Stakes are used to mark the limits of the excavation and spoil-placement areas. The depth of cut from the ground surface to the pond bottom should be indicated on the stakes.

The use of a bulldozer for excavation is usually for medium-sized ponds, due to its inefficiency in transporting the material. If the excavated material is placed near the pond, it can be used as a berm or dike. After the earth is excavated, the subgrade and banks should be compacted.

When landowners develop ponds, they often use manual labor or tractor-pulled wheeled scrapers. An alternative method for developing ponds is to make use of animal traction with the help of scoops. This method is less common than expected but has greater potential.

Developing a roadside pond with oxen scoop and compactor in Tanzania

The following are the main do's in using animal traction for farm pond development (see Annex 4):

- For animal digging, use staged ramps and develop the pond in layers.
- The area to be excavated is to be softened by plowing to a depth of 20-30 cms. This can be done by an ox-drawn plow attached to one or two oxen pairs using normal yokes. It is important to plan the space to enable easy turns for the animals.
- The softened soil is removed with the ox scoop. To load the scoop, the operators simply raise the handles of the device to augment the incidental angle between the soil and the scoop. The

forward movement of the animals will do the rest. Once the scoop is loaded, the handles are lowered again, and the scoop will be pulled until the disposal area is reached. To offload the soil, the operators need to raise the handles until the scoop topples together with its load. These scoops are not usually available but can be made in local workshops.

- Excavated soil needs to be properly disposed of and is commonly used to build a berm around the pond. It is important to compact the berm to avoid erosion problems. A simple roll compactor can be built with secondhand bearings, scrap metal, and an old oil drum. The drum is filled with sand and rotates as the oxen pull it.

Farmer extracting water with a diesel pump

11. Roads in floodplains

Impact of Gambela-Lare road on wetland vegetation: 1984-2016, Ethiopia

Key message

- Roads have a major impact on flood plain – hydrology: they often dissect the flood plain in a wetter and drier section;
- Bridges may constrict the flood plain. whereas bridge sills may raise water and silt levels;
- Road building in flood plain requires special attention to keep flood plain conditions alive and prevent uncontrolled breaking of the roaded embankment.

Main techniques:

- Adequate drainage (with fish passage) through French mattresses and culverts will preserve the flood plain conditions
- Low embankment roads with floodways may facilitate controlled flooding into wetland areas or recharge zones
- Submerigible roads can made in flood plain that are inundated for part of the year.

11.1 Objective

Floodplains are among the highest-potential areas for agriculture in the world, bringing together many different functions. A cautious estimate is that 50 million ha are under floodplains globally, many of them relatively pristine. Floodplains are also vulnerable to relatively minor changes in hydrology: changes in the water supply upstream or changes in the morphology of the floodplains themselves can have a drastic impact.

The development of roads in low-lying floodplains presents a special challenge and opportunity: roads in these terrains have a major effect on the area's hydrology, both positive and negative. Roads, if built properly, will preserve and even enhance the different ecosystem services of the floodplains, but they may also undermine the floodplain, cause it to silt up, dry up, or be permanently inundated.

A road passing through a low-lying floodplain alters the movement of water within the floodplain and with it the wetland ecosystem and flood-based livelihoods: fishery, rangeland or flood recession, or flood-rise agriculture. This is particularly true when the road is constructed on a high, impermeable embankment. This type of road acts as a barrier that divides the floodplain into wet and dry zones. The wet zone on the upstream side will have floodwater spreading along the road embankment. In the dry zone, on the downstream side of the embankment, floodwater will be obstructed from entering. It is important to take this effect into account: it can be used to plan land use in floodplain areas. Furthermore, cross-drainage structures on these roads in particular can have a significant effect on water management. The objective of this chapter is to discuss the opportunities and recommended practices in constructing roads in floodplains.

Dry and wet side of road in Gambela Floodplain, Ethiopia

11.2 Opportunities

The opportunities for using roads to manage floodplains differ with the type of floodplain and its predominant use. In relatively dry floodplain areas, floodwater can, for instance, be stored in the upstream zone for use in the dry season. In wetter floodplains, the road will create wetter conditions in the upstream areas, affecting the local ecology and creating conditions conducive to the cultivation of submerged crops such as rice or sugarcane. It is also important to take into account the possible effects of road construction on land submergence and silt deposition: a road or bridge in a floodplain that blocks the movement of floodwater can cause land levels to rise. Competing interests of upstream and downstream communities on either side of the road can lead to conflicts.

A too-narrow bridge has caused the floodplain to silt up and change, Portugal

In developing roads in low-lying floodplains, there is a need for clarity on:

(1) the preferred land use and wetland functions in the floodplain area;
(2) the objective of the road, whether it should be passable under any circumstance; and
(3) the financial resources available for the road's development.

In general, there are two key strategies while developing infrastructure in floodplains: the "resistance strategy" and the "resilience strategy" (Beever et al. 2012). The resistance strategy, in principle, aims at preventing and regulating floods, whereas the resilience strategy aims at minimizing the consequences of floods while maintaining natural floodplain dynamics as much as possible. Typically, the resistance strategy will overcome the risk of floods to the road and traffic by providing ample freeboard, which protects against all flooding. The road will be designed to withstand adverse situations without necessarily taking into account the road's effect on the surrounding area. The resilience strategy, on the other hand, takes into account the best possible road alignment while carefully siting water crossings (at the bottom of sag curves) to minimize flood damage and ponding on the road surface. The provision of flow-through and flow-over relief structures is also part of the resilience strategy.

11.3 Recommended practices and preferred options

If the overall strategy for road development in floodplains is clear, a number of points must be settled. During road development, the following need to be decided:

- Selecting the location and height of road embankment;
- Considering the use of controlled overflow sections;
- Providing adequate cross-drainage and subsurface flow capacity;

- Controlling the upstream water level with cross-drainage structure; and
- Ensuring fish passage.

11.3.1 Location and height of road embankments and controlled overflow sections

There are important fundamental choices to be made with regard to the design of roads in flood-prone areas, in particular with regard to the location of the road and the height of the road embankments.

First, the location of the raised road embankment will divide the floodplain, with one side of the embankment free from inundation and the other side more exposed. People living on the downstream side of the road will not face flood hazards. However, during normal and low-flow periods, these same people may not have access to the beneficial uses of floods: fishery, grazing area, and farming using residual moisture once a flood recedes On the other hand, the upstream side of the road will face greater risk of floods during the rainy season, since the spreading of the flow is restricted to only part of the original floodplain. Therefore, the siting of the road in a floodplain must be done carefully.

A closely related choice is whether to opt for high or low road embankments. In some cases, high embankment roads are prone to breaches during peak flood periods as the floodplain area becomes more restricted. During extreme floods, the road can be overtopped, and damage can occur in an uncontrolled manner. In the wake of this, the movement of traffic may be disrupted for an extensive period. Damage to road embankments can be substantial, not only because of breaches. Debris and silt may accumulate on and along road embankments, and scouring may necessitate repairs to road shoulders. In addition, the stability of stream channels in low-lying floodplains is uncertain because the debris and silt that floods deposit may cause channel shifts and, in general, changes to the floodplain's morphology.

The alternative to high embankment roads is low embankment roads. These low embankment roads can be designed to allow overflowing, or to route floodwater through designated sections called floodways (see Annex 5). These designated overflow areas will make it possible to lower the height of the road embankment along its entire length, resulting in considerable cost savings.

Overflow embankment sections, or floodways (Annex 5), allow high water to pass over part of the embankment in a controlled manner, when necessary. They prevent overtopping of the embankment in an uncontrolled manner. Low embankment roads will conserve floodplain functions and prevent unpredictable damage.

Floodway (Sado Plain, Portugal)

When overtopped, a floodway typically operates as a broad-crested weir with a large potential overflow capacity. The following aspects should be considered in its design:

- The depth of flow over the embankment should be inversely related to the width of the embankment's overflow section. Deep flow over the road can interfere with transport. Therefore, the overflow depth should be kept to a minimum.
- The upstream and downstream faces of the embankment should be blanketed with impermeable material such as stone masonry or concrete lining.
- While designing the top of the road surface, consider the scouring effect of the overtopping flow and select a material that protects the road base from saturation: rigid pavement (ford or vented ford) is a good option.
- The downstream side of the embankment and its toe need protection from scouring by the overflowing water. A toe apron, stilling basin, downstream pool, or stone riprap are good alternatives for this purpose.
- The downstream side should be well aerated to avoid sub-atmospheric pressure. Flow splitters should be positioned at the top edge of the downstream face of the embankment.
- Trees on either side of the floodway will provide further protection against scouring by overflowing water.
- The overflow should lead to an area where it does not do harm but serves useful purposes: for instance, the recharge of groundwater, the improvement of grazing land, or the preservation of a wetland.

A disadvantage of the floodway is that its overtopping during floods causes inconvenience and is a possible hazard to road users, because the road section is not passable during the floods and traffic will be disrupted. Therefore, careful consideration and calculation are required to assess the periods during which the floodway will be inundated and the implications in terms of traffic disruption. However, the use of poles along the floodway will make it possible to pass sections inundated with water. Annex 2 discusses floodway design.

11.3.2 Adequate cross drainage and subsurface flow capacity

Roads in floodplains should also have adequate provision for cross drainage, both of surface and subsurface flow. Adequate cross drainage will help to maintain wetland functions on either side of the road and sustain several of the economic functions, for instance, keeping wells functioning on the downstream side of a road body. An understanding of wetland and floodplain hydrology will inform the placement of the appropriate number of cross-drainage facilities. This surface and subsurface cross-drainage capacity can be provided through culverts, sections with very coarse gravel (called French mattresses), or porous sections in the road embankment structure made of boulders and gravel that are graded from coarse to fine (from the bottom to top of the embankment).

Culverts

Culverts can provide cross drainage for both surface and shallow subsurface flows. If culverts are partly buried, they will convey both surface and subsurface flows. They will also mitigate (slow) flooding events. For partly submerged round culverts, the common embedment depth is 40 percent. Where culverts only carry surface flows, they will be placed above ground level.

The number of culverts is most critical. Given the slow flow of water in a floodplain, multiple culverts are required. The culverts balance the amounts of water on either side of the road. They rarely flow at capacity but are required for unusual events. The dimension of the culverts is a second consideration. For a seasonally fluctuating wetland, such as a floodplain, the amounts of water passing through for part of the year will be high and thus large culverts are required. Table 11.1 below indicates the preferred spacing and dimension of culverts.

Table 11.1. Road culvert spacing and dimensions for flood plains

	Stagnant	**Slow lateral flow**	**Fast lateral flow**
Culvert spacing	Widely spaced	Mid- to widely spaced	Closely spaced
Maximum culvert spacing; permanent road	200 m	150 m	100 m
Maximum culvert spacing; temporary road	250 m	200 m	150 m
Culvert diameter	250-500 mm	500-800 mm	> 800 mm

Source: Partington et al. (2016).

Where the floodplain and wetland hydrology is not well understood, proactive spacing of culverts can be considered to maintain road connectivity and preserve the preferred wetland functions. This means that rather than spacing at 100 to 200 m, a distance of 50 to 100 m or even less may be maintained. In central parts of the wetland, the distance should be reduced, whereas at the dry edge of the wetland it should be increased. There is always scope to adjust, especially with unpaved roads, by adding culverts in sections where the water becomes ponded.

A special consideration for placing culverts in floodplains and wetland conditions is that the underlying soil may not have much bearing capacity, and reinforcement may be required to improve this capacity. There are several ways to do this, but the most common are:

- the placement of compacted gravel and geotextile (or a local substitute) beneath the culvert, often using a small notch; and
- the above measure, combined with small-diameter wooden logs in a “corduroy” pattern.

French mattresses

As an alternative measure to provide cross drainage to culverts, permeable sections may be provided. These sections typically consist of coarse clean rock enveloped in geotextile or a local alternative material. They are known as “French mattresses” or “rock sandwiches.” They have added value over culverts in a number of instances:[15]

- Where water saturation risks destabilizing the road base (also between two culverts);
- Where a two-directional flow of water through the road base should be allowed;
- By making it possible to disperse flows, thus preventing gully erosion that may occur downstream of a culvert in areas with considerable slope; and
- Where the lowering of wetland water levels could occur as the result of having a large number of culverts: instead, the release of excess water through French mattresses is more gradual.

These French mattresses may be used in different ways depending on the local hydrology, either by installing a number of short sections at set intervals or, particularly in very wet conditions, by using a long section over a large area (up to 300 m).

Although the costs of transporting rocks may be considerable and result in high initial investment, French mattresses require virtually no maintenance and have a long service life. Unlike culverts, they are also difficult for rodents to block. Moreover, they help maintain natural vegetative communities and habitats by keeping different sections of floodplains connected.

French mattresses are constructed through the following steps:

1. Excavate a trench of the desired depth in the road body, allowing for a minimum 25 cms cover over the mattress.
2. Place geotextile fabric (preferably Class 2 woven) or a local alternative in the trench, leaving enough fabric on the sides to go around and overlap on the top of the finished mattress.
3. Place porous stone on top of the fabric and spread it out uniformly. The size of the stones should preferably be 6 to 10 cms.
4. Wrap the ends of the fabric over the top of the structure. Place a piece of fabric on the top if the existing fabric does not completely cover the mattress. Overlap all fabric joints by at least 25 cms.
5. Compact the fill material on top of the finished mattress.
6. Install French mattresses to match the slope of the land. In wetland situations, the slope may be minimal. In sloped areas, a 1 to 2 percent slope should be used to aid drainage.

11.3.3 Controlling upstream water levels with cross-drainage structures

Road cross-drainage structures also control upstream water levels in floodplains. An important consideration is the level of the bed sills in bridges and culverts. These will effectively determine the water level in the upstream section of the road. Because these bed sills define the level of the main drainage outlet, they effectively determine the water level in a very large area. This creates the conditions for wetland development, ensuring adequate water levels for submerged or aquatic crops such as rice or sugarcane. Bed sills of bridges and culverts are an important factor in the drainage and waterlogging of large floodplain areas.

[15] Penn State (2013) Technical Note: French Mattress.

Bridge sill determining water level in upstream floodplain, Mozambique

One can move a step further and regulate the water levels in the upstream area where land is used productively. This will enable the land to be used, for instance, for submerged crops such as rice and sugarcane, for aquatic crops, or for aquaculture under varying degrees of regulation.

To manage water levels on the land for these productive uses, gates may be provided on the culverts. This will make it possible to either raise the water level or drain the land. The placement of such gates should be determined in close cooperation with the land users. It is also important to assess the effect of impounding water upstream on the integrity of the road body. Reinforcement may be provided, if required. Generally, the preferred type of gate is the stop log with wooden planks sliding in a railing. These wooden logs can be maintained by the land users and will be less prone to theft and vandalism than permanent gates.

Water in canal controlled by gates on the culvert, Uganda

11.3.4 Ensuring fish passage

Culverts in wetland areas are the main passage for fish and other aquatic animals. A number of considerations apply if culverts are used as fish passages:

- The flow velocity through the culvert should not be greater than the swimming capabilities of the fish. The swimming capacities of species vary and are often unknown. It may be useful to apply a very gentle slope through the culverts so as not to interfere with fish movement.
- The outlet of the culvert should not have a vertical drop that makes it difficult for fish to swim or leap out.
- The water level in the culvert should be minimum, at least during the fish movement season. Shallow water in the culvert will enable fish to cross.
- There should be no debris or sediment accumulation in the culvert that causes physical blockage or increased turbulence that might prevent fish from moving across the culvert.

11.4. Alternative road option in floodplains: submergible roads

Submergible road in floodplain in Bangladesh (http://www.lged.gov.bd/)

The preceding part of this chapter discussed roads on embankments in floodplains. These are all-weather or, in cases of flood, roadways are closed for a limited number of days. There is an alternative concept for roads in floodplains: roads that are submerged for large part of the year during the flooding season.

Downstream protection of a horizontal submersible track: every three to four meters an opening of an overture 10 to 15 cms wide is set to drain the road (Bender 2009). These roads are inundated during the flooding season, but facilitate transport during the dry period when they re-emerge. They can be re-used, usually after some small repairs. These submersible roads do not interfere negatively or positively with the flood regime in the floodplain.

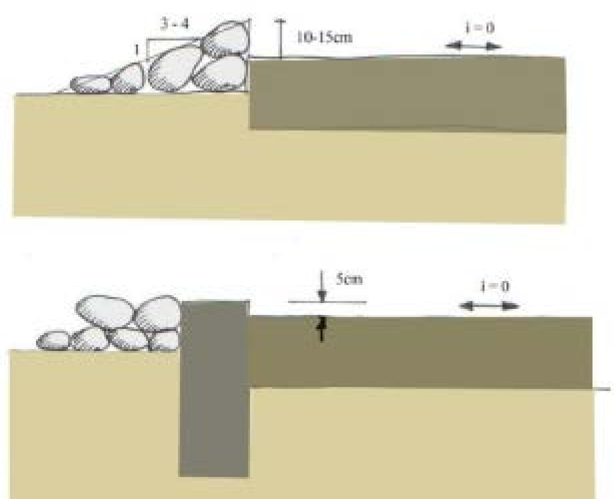


Figure 11.1. Submersible road criteria

The following requirements apply for submersible roads (Figure 11.1):

- They are based on stable bed material capable of coping with waterlogging conditions, preferably free draining and solid material: coarse sand is preferred.
- The road is slightly elevated and may be anchored at the side.
- The slope gradient is 0 percent.

- In order to avoid prolonged flooded conditions after a flood, it is possible to make one or two parts of the road 5 to 20 cms below the lower level of the ground.

12. Roadside tree planting

Key message

- Dust from unpaved roads is a forgotten but major health hazard
- Road side tree planting has many co-benefits beyond dust control: productive asset, reduced crop damage, reduced soil erosion, improved visibility, wind break, shade, carbon sequestration, beautification
- In planning road side tree planting one has to consider ownership of road reserve, plans of future road widening, economic value of tree species, shape of tree barrier, root development, road vision, road safety, access to water.

Key applications:

- Given the multiple benefits of road side tree planting, it is surprising that it is not more widespread. Its application extends to almost all geographies
- Promoting road side tree planting and road side forest can off-set part of the carbon dioxide emissions that come with new roads.

12.1 Objective

This section provides guidance on how to plan, implement and monitor roadside vegetation activities without compromising road longevity and safety. Roadside vegetation is any vegetation growing along the roads. Planting trees, shrubs and grasses along the road can create a productive asset and can alleviate the negative effects of roads on the local environment. Negative effects include erosion, loss of fertile soils, gully formation that undermines road foundations, heavy dust, and more. In particular, dust lifted by vehicles, especially along unpaved roads, has a direct effect on the health of people and livestock living near the roads and on crop production. In a survey conducted in Ethiopia, close to 44 percent of the respondents said that the occurrence of dust had increased after road construction (Agujetas et al. 2016). Road dust is composed of coarse particles that can worsen heart- or lung-related conditions when inhaled through the nose and mouth (Greening 2011). High levels of dust can cause skin irritations and diseases, eye irritations, shortness of breath, chronic obstructive pulmonary disease (COPD), asthma, interstitial lung disease, lung fibrosis, lung emphysema, and increased risk of lung and skin cancer (Krzyżanowski et al. 2005). The human body can handle particles larger than 10 µm, but it becomes more difficult for the body to block smaller particles (Nordstrom and Hotta 2004). Dust can have a physical and chemical impact on crops and lead to yield reduction. In the survey cited above, 11 percent of respondents recorded such a decline. Dust from unpaved roads settles on the flowers of crops, impeding them from producing fruit. Moreover, dust affects photosynthesis, respiration and transpiration and therefore interferes with plant growth (Leghari et al. 2013). Dust on plants can smother the leaves, block stomata, and obstruct photosynthetic activities (Rahul and Jain 2014).

Road dust: source of health and other problems

12.2 Opportunities

The scope for roadside plantation is enormous. The benefits of roadside vegetation are multiple (see Box 12.1). It can create barriers against road dust. Trees and shrubs especially can trap the dust with their leaves, minimizing the amount of dust reaching farms and houses. There is little research on how effectively roadside tree lines intercept dust. However, Maher et al. (2013) estimated that more than 50 percent of particulate matter is reduced by roadside tree planting, even more so if the leaves are hairy. Moreover, trees provide shade and contribute to the beautification of the area. This is a significant service because in many countries a large number of people walk alongside the road.

Roadside vegetation can also protect the road. Grasses can especially help to reduce runoff velocity and trap sediments, thus reducing roadside erosion. In some waterlogged areas, trees that use large quantities of water (such as eucalyptus) can be used to dry the road subgrade and help protect the road.

Furthermore, roadside plantations will not only check the deterioration of roads and the environment but will also create productive assets for local communities. This can be from the direct benefits of trees—timber, fruits, and bee pollination—or by acting as windbreaks that reduce desiccation and wind erosion.

Roadside plantations can also improve road visibility and break the monotony. Care should be taken not to disturb views. A very special use of roadside tree planting comes from the Netherlands. On some roads in flat areas, where speeding was common, trees were planted at a slightly closer distance in the direction of the traffic. The idea is that this gives drivers the impression they are speeding up and causes them to slow down.

Box 12.1. Advantages of roadside vegetation

1. Removes dust and other pollutants from the air, protecting crops, roadside communities, and livestock.
2. Reduces soil erosion: holds soils in place.
3. Wind breaks that reduce desiccation and wind erosion.

4. Flood control: slows and absorbs road runoff.
5. Carbon dioxide sequestration.
6. Direct benefits: timber, fodder, fuelwood, fruits, pollinator habitat.
7. Provides shade and keeps the road cool for road users.
8. Beautification.
9. Improves visibility.
10. Can be used to guide road speed.

12.3 Recommended practices

In spite of the considerable benefits it brings, roadside vegetation is still exceptional. India is a main exception: it launched the Green Highways Policy in 2015. This includes the provision to set aside one percent of all road investments for a roadside tree development fund.

However, it is recommended that roadside vegetation everywhere be systematically integrated into road-building programs, in particular for unpaved roads. Detailed planning for roadside vegetation should be developed as part of road development programs, showing the main objective of the roadside vegetation (dust control, beautification, improved visibility, erosion control, etc.) and the preferred planting for different roadside stretches. Site characteristics, such as rock content, soil depth, accessibility, steep slopes, and access to water resources, as well as road visibility, expected speeds, and impact risks, need to be assessed. It is also important to actively engage the local community for purposes of management and to identify tree species that will provide economic and environmental benefits. In developing roadside vegetation, the following are the recommended practices with respect to the different steps in developing roadside vegetation.

Roadside tree-planting campaign in Amhara, Ethiopia

12.3.1 Site selection

Site selection for roadside vegetation should take into account land ownership, the practicalities of roadside plantation and aspects of road visibility and road safety.

Land ownership

Prior to developing roadside vegetation, the ownership of the land along the road should be established. Roadside plantations are often established within the right-of-way, also called the road reserve. This right-of-way is the land allocated and preserved by law for public use in road construction, maintenance and expansion. In Mozambique, for instance, the ANE has the mandate over these road reserves, especially for highways, for maintenance, bush clearing, and sanctioning the widening of the road, but also for placing traffic signs and billboards. It is important that roadside plantations be aligned with the plans for future road development and that trees, for instance, not be removed for road expansion in the near future. In other cases, such as in unscheduled roads, the land along the road belongs to local communities and the planting of roadside vegetation needs to be coordinated with the roadside communities and land users. In general, close consultation and engagement with roadside communities and local governments is critical to success in roadside vegetation.

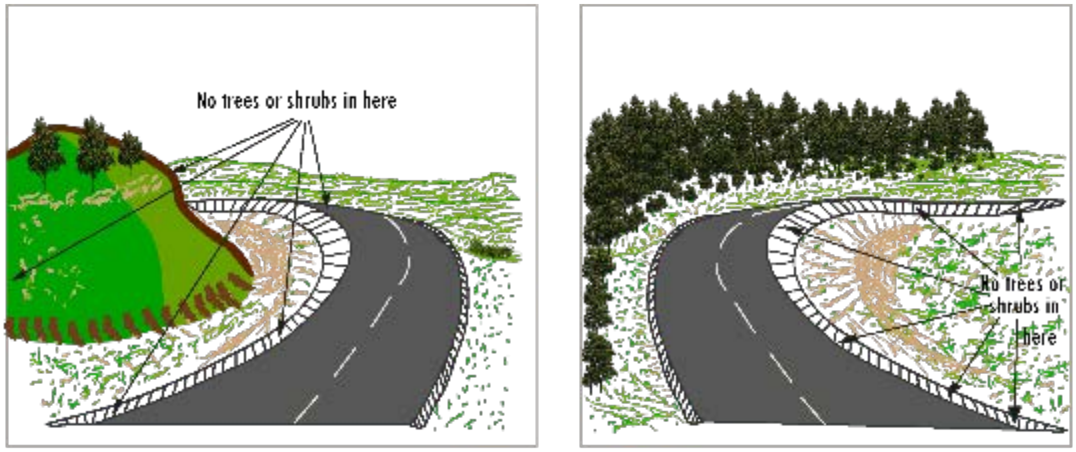
Practicalities of planting

A number of considerations will aid the planting of roadside vegetation and contribute to high tree survival rates. The following criteria in particular should be considered during the selection of sites for roadside vegetation purposes:

- Planting sites should have access to water sources; this can also be the water harvested from the roadside (see 12.3.5).
- Sites with established animal paths should not be considered because the protection of saplings will be difficult.
- Sites with nearby households engaged in farming or other activities should have priority.
- Sites should preferably have easy access to a tree nursery.
- Nearby communities should have a positive attitude toward the benefits from the plantations (firewood, fruits, bee-keeping).
- Planting sites must be at a reasonable distance from farmlands as well as from the edge of the road. The effect of shade on crops (sun direction) must be taken into account when deciding on location.

Visibility

Roadside tree planting can improve road visibility, but it can also obstruct views. This should be considered in the selection of sites (Figure 12.1).



1. No trees or shrubs on the inside of cut-slopes around curves

2. No trees or shrubs on the inside curve of an embanked road construction

Figure 12.1. Tree planting and road visibility

Care should be taken in placing trees on bends. In general, no trees or shrubs should be planted on the inside of cut slopes around curves, nor should trees or shrubs be planted on the inside curve of an embanked road construction. However, trees planted on the opposite of these positions will enhance visibility and alert drivers to curves in the roads. No trees should be planted at intersections or exits. Overgrown trees are a particular problem and care should be taken not to plant trees with horizontal crowns.

Road safety

A very important factor to consider when designing roadside plantations is road safety. Trees can be the cause of fatalities during accidents, in particular in high-speed zones (Budzynsky et al. 2016).

Tree planting should not compromise road safety. Tree planting should avoid high-speed zones and a safe distance should be kept in medium-speed sections (see Table 12.1). If a road is upgraded, it may be necessary to cut down trees to ensure safety.

Table 12.1. Roadside vegetation and road safety measures
Source: VicRoads Tree Planting Policy 2015.

Speed zone	Road safety measures	
40km/h	Because the impact force during an accident is unlikely to exceed human tolerance, no specific mitigation is needed.	
50km/h	A minimum lateral distance of 1 m from the road edge should be maintained to reduce incidental interaction between vehicles and trees.	
60km/h	Intersections	At least 10 m beyond intersections on the approach and departure sides
	Driveways	At least 3 m between driveways and trees
	Lane-merging locations	3.6 m lateral distance from road edges
	Curves	3.6 m lateral distance from road edges for gentle curves; a barrier should be placed on moderate curves barrier for moderate/tight curves
70-100km/h		Safety barriers are the most appropriate mitigation to fence the plantations (wire rope safety barrier, guard-approved safety barrier that is suitable in high-speed environments). Trees are not suitable.

Distance to electricity lines

The distance to electric poles and wires should also be considered to keep trees from coming into contact with electrical wires. A distance of 8 m from the poles is recommended to avoid interference. In rural areas, very high trees are avoided in the vicinity of electricity lines.

12.3.2 Species selection

In general, plants selected for roadsides must be able to resist harsh conditions because the land adjacent to the road is often degraded. Native species are preferred since they adapt to local conditions. The choice of species is based on the objectives of the plantation (economic or environmental) and the space available. Multipurpose trees (fruit, fodder, timber, fuelwood species) can be incorporated to provide economic benefits. If the prime purpose of the plantation is to block dust (such as along unpaved roads), it is recommended that species with pointed leaves, such as conifer needles, or rough, hairy and sticky leaves, be selected.

Roadside tree planting with short-rooted, pot-grown mahogany trees for timber in Bangladesh

These are the main criteria for selecting species:

- Tree species should be evergreen or remain green for most of the year.
- Species should be fast growing.
- Tree species should not be broad rooted because tree roots may penetrate the road surface.
- Tree species should have crown architecture with a more horizontal than vertical extension.
- Tree and grass species should be tolerant to seasonal drought and insect and pest attacks.
- Tree species should be deep rooted to resist the force of wind and drought stress.
- Deep-rooted trees are also strongly preferred because they will avoid damaging the road.
- Thorny plants are to be avoided because they may cause tire punctures.
- Tree and grass species should never be invasive.
- Tree species should preferably be fast growing.
- Tree species should have one or more social and economic values, such as medicinal, food, fuelwood, feed and shade.
- If tree species are edible by livestock, fencing in the growing stages is needed to protect the tree and enable it to mature.
- Tall-growing trees should not be selected for planting beneath power lines.

12.3.3 Site preparation

The site needs to be prepared properly. This requires the elimination of weeds, the preparation of soil, and the use of planting pits.

Eliminating weeds

The survival and growth of tree seedlings depends on the quick re-establishment of their root systems. Competition from the roots of other plants growing in the area will hinder the re-establishment of newly planted grasses and seedlings. For this reason, weeds should be removed from the planting site. The roots of weeds and grasses directly compete with the emerging roots of the seedlings. They can also release chemicals that impede the growth of other plants. All vegetation around the newly planted trees and shrubs should be removed before planting.

Preparing the soil

To facilitate the growth of seedlings, the soil must be loose enough and have adequate pore space to allow roots to penetrate and absorb enough water and oxygen. In many instances, the highly compacted soils that often result from roadside construction do not provide ideal soil characteristics. Moreover, people and animals tend to walk along the roadsides, compacting the soils even more. Adding materials (compost, manure or other soil) to the soil is not recommended, unless it is of very poor quality. If that is the case, it is best to incorporate a maximum of 25 percent of organic matter by volume. Ultimately, it is better to select plants that can tolerate the existing conditions rather than trying to improve a large area of soil.

Several actions can be undertaken to loosen the soil and make it suitable for planting. Tillage can increase porosity in the rooting zone, increase infiltration rates, and increase surface roughness. For vegetation work associated with road construction, it is important to break up deep compaction at depths of at least 0.5 m. Soil shattering involves pulling one tine, or a set of tines, at various depths through the soil to break up the compaction by the roadsides.

Topsoiling should be done when possible. It involves the removal, storage and application of topsoil material to provide a suitable growing medium for vegetation. Topsoiling increases nutrient availability, water-holding capacity, and microbial activity for the plantation. Topsoil should only be removed from areas that will be excavated, are highly compacted, or are buried with excavated material, such as fill slopes. When possible, laboratory tests and field surveys should be conducted to determine topsoil quality. Topsoils with high salinity, very high or very low pH, or any other condition that may obstruct plant growth, should be avoided. It is better to remove and collect topsoil when soils are relatively dry to avoid soil compaction. The depth of topsoil application depends on the amount available. Generally, the deeper topsoil is applied, the higher the productivity at the site will be.

Preparing planting holes

Tree survival is improved with the use of planting holes. Planting holes should be dug vertically rather than perpendicular to the ground surface. Preferably, the planting hole should be five to seven centimeters deeper than the total length of the root system and wide enough to fully cover the width of the root system. Species that can be rooted from cuttings can be planted deeper, since portions of the stem will root when buried. The roots of the seedlings should not be forced into the planting hole, nor damaged or broken during planting. After placing the plant in the hole, excavated soil should be placed firmly around the root system so there is no loose soil or air pockets around the root plug. The root system must not be damaged during this operation.

12.3.4 Design of roadside vegetative barriers

In designing the roadside vegetative barrier, there are a number of decisions to be made: the combination of trees and shrubs, the porosity of the barrier, and the number of tree lines.

The selection of species will determine the plant spacing, i.e., the distance between the different shrubs and trees. Shrubs, for instance, grow at a much closer spacing than trees, and this should be taken into consideration when determining the combination of species to be planted. For row plantings in general, larger trees are planted 3 to 5 m apart, larger shrubs 2.5 to 4 m apart, and lower shrubs 1.5 to 2.5 m apart. Single-row plantations should only be used on land of highest value and where space is limited.

When possible, it is preferable to have plantations of two to four rows to protect a larger area. However, one- and two-row plantations are cost-effective options but require a uniform and high survival rate.

Figure 12.2 shows different types of roadside plantations. The best effect on dust control is from porous barriers. Porous plantations allow a large part of the airflow to go through it. Dust will be trapped better because there is more contact with the leaves of the trees and shrubs. To achieve a good degree of porosity, plantations should be approximately 5 to 20 m wide, consisting of tall trees with a bush layer underneath. Dust capture is enhanced by the turbulence in the plantation. This turbulence is caused by the presence of irregularities, such as branches, leaves and leaf structure. The more irregularities the structure contains, the more dust and pollutants will be trapped. In comparison, in solid barriers all dust will "leap" over the barrier and little will be intercepted.

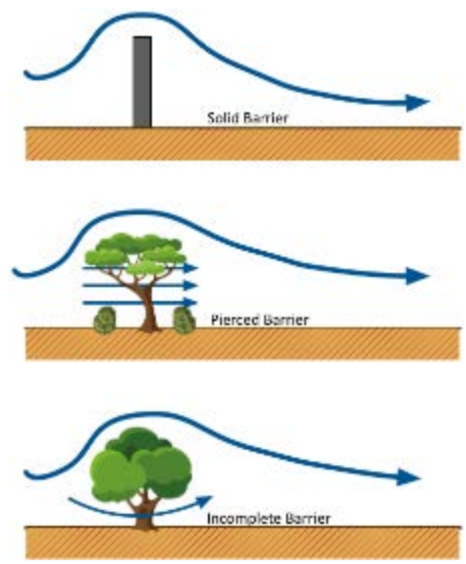


Figure 12.2. Roadside tree barriers and dust movement

Hagen and Skidmore (1971) investigated the effectiveness of windbreaks and established that the porosity of a windbreak should be less than 35 percent for the windbreak (including roadside planting) to have a significant effect on wind speeds. This is best achieved with double rows of trees and bushes. This would balance both effects: trapping dust and other pollutants, and bringing down wind velocity on the lee side.

12.3.5 Combining water harvesting and tree planting

As discussed in the previous chapter, there are substantial opportunities to harvest water along roads. This can be combined with tree planting. Small diversion channels can be constructed to slowly divert surface flow from roadside drainage systems toward the tree seedlings. These diversion structures can be combined with small storage structures around the trees to retain this water for the tree. Smaller bushes and grasses can also complement water harvesting by slowing down the flow of drainage. Grasses will allow water infiltration and trap sediments, thus restoring soils, reducing erosion, and improving hydrological soil conditions.

Network of shallow trenches

A network of shallow trenches can be made along the road to route road runoff over a large area, water trees, and even create small roadside forests. This together with the single line road side tree planting can sequester carbon and off-set some of the negative effects of road development in this regard.

Network of trenches for roadside tree planting in Uzbekistan (Photo: J. Demenge)

Microcatchment water harvesting

Microcatchment water harvesting is one of the methods used to collect surface runoff from a small catchment area into the root zone of an adjacent infiltration basin. This basin can be used for plants. Microcatchments are alterations of the topography to direct rainfall runoff to plants. They are simple and inexpensive, and provide many advantages over alternative irrigation schemes. Microcatchment techniques are more effective on slopes not exceeding a seven to eight percent gradient. The optimal size of the microcatchment depends on the site characteristics and the size of the seedlings.

Semi-circular bunds (also known as eyebrows or demilunes) are stone structures that contain a water-soaking pit and a planting pit. They are commonly used on steep land (>50 percent).

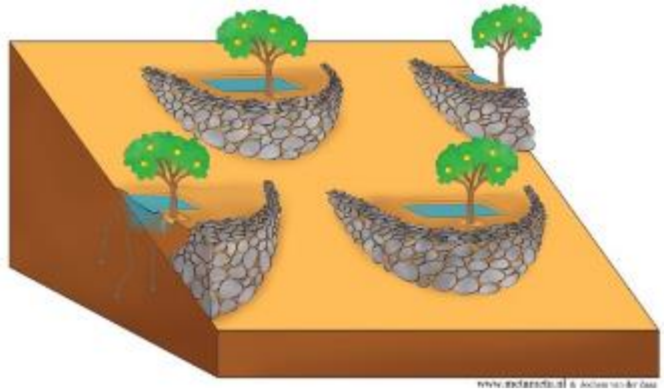


Figure 12.3. a) Ethiopia: communities building stone eyebrows at the roadside to catch runoff and support the growth of tree seedlings; b) diagram of a semi-circular bund

Infiltration trenches

These trenches are large, deep pits that protect cultivated land from flooding and erosion while recharging groundwater (see Chapter 2). Road runoff can be channeled to infiltration trenches where water will percolate. These infiltration trenches will increase the soil moisture of the adjacent area. Trees can be planted next to the trenches where the roots of the seedlings will benefit from the increased soil moisture. Grass strips can be planted at the edges to protect the bunds of these infiltration trenches.

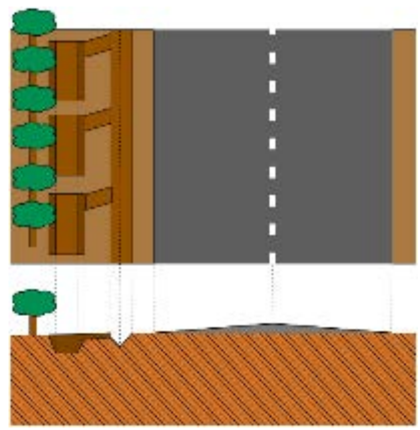


Figure 12.4. Infiltration trenches collecting road runoff to enhance the growth of seedlings

Swales

A swale is a broad, shallow channel (natural or man-made) designed to promote infiltration and reduce the flow velocity of runoff. Its main purpose is to slow, spread and infiltrate runoff. Swales are appropriate for harvesting road runoff and intercepting silty or contaminated runoff. Swales are never compacted or sealed: their main purpose is groundwater recharge. On the contrary, swale soils can be loosened to increase recharge and infiltration rates. They also provide an opportunity for tree planting because of the soil moisture increase along and around the swales.

Swale with overflow option along road in the Netherlands

Contour stone bunds

Contour bunds (Figure 12.5) are designed to collect enough water to recharge soils and provide water for plant growth during the dry season. They also protect soils from erosion during peak rain events. Design criteria for determining the distance betwee bunds include slope gradient, rainfall intens infiltration rates. In very dry areas, trees car grown above the bund; in more humid areas, it is better to plant them on the downside to avoid waterlogging risk.

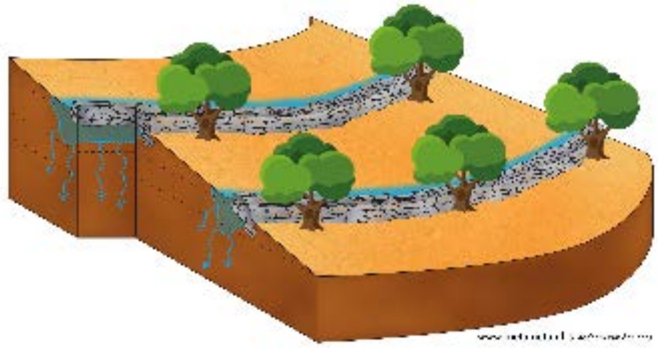


Figure 12.5. Stone bunds

Planting pockets

When terraces are filled with growing media (topsoil or amended subsoil) and planted, they become "planting pockets," akin to planting holes (discussed above). Planting pockets must have adequate soil depth to store the intercepted runoff and allow the establishment of planted seedlings. The surface of the planting pocket should be in-sloped to capture water and sediment, and the face of the pocket should be protected from surface erosion.

Figure 12.6. Planting pockets

Use of polymers to increase survival rates

Trees are at their most vulnerable just after transplanting. A prolonged drought can cause the saplings to die or to become stunted and twisted. By placing polymers in the root zone of the saplings, they will have more secure access to moisture. One effective method is the use of water pads, where the polymers are wedged in between jute and brown paper in order for the polymers to stay in place.

12.4 Conclusions

What matters is not how many trees are planted along roads, but how many trees survive and thrive. Maintenance is the most important component for the establishment of roadside plantations: it requires careful planning and preparation. All necessary resources and arrangements for maintenance should be arranged in advance. Nursery seedlings often die because of animal damage, high surface temperatures, high evapotranspiration rates, lack of soil moisture, and competition with other vegetation.

Water is the main element in the establishment of new plantations. Trees and shrubs should be watered systematically at the time of planting and several times during the first two years. The use of irrigation bags or a large container that will trickle water into the soil is convenient for irrigating large plants. Sandy or rocky soils have low water-holding capacities, causing wetting fronts to travel deeper and in a narrower band. Less water but more frequent irrigation is recommended for these soils. On the other hand, finer textured soils, such as loams and clays, have a higher water-holding capacity and wider wetting fronts. More water can be applied in these soil types and at less frequent intervals than in sandy soils. It is important not to wet the leaves or needles to help prevent disease.

Seedling quality will influence the amount of water that the seedling needs. Healthy seedlings grow new roots faster and can access deeper soil moisture. Poor-quality seedlings are slow to develop roots and must be irrigated more frequently. Seedlings also have to adapt to a new location: while in the nursery they were watered daily, they now must be hardened to sustain their new environment. To make them adapt and survive over time under harsh conditions, it is important to reduce the amount and rate of watering slowly until the tree has fully adapted and can survive on its own.

Moreover, when weeds and other undesirable vegetation are growing near planted seedlings, soil moisture is depleted sooner, requiring more frequent irrigation than if seedlings were free from competing vegetation.

The question is who will take care of the maintenance and management of the roadside vegetation. Numerous modalities can work. The question is not so much which modality is best, but whether there is a clear arrangement in place. Given the highly distributed nature of roadside tree planting, local management is generally best. Three other factors that contribute to effective management are: (i) restrictions of free movement of cattle and ruminants; (ii) clearly assigned ownership and usufruct rights to the roadside plantation; and (iii) the ability to economically use the plantations, even if it means harvesting and replanting.

The returns to roadside tree stands, particularly if native species are used, are generally not immediate. Returns from planting may take several years to materialize, during which time and money may be spent to look after the plantations. There are several arrangements to overcome this income gap, such as:

- Making a payment to local caretakers based on the survival rate and health of the roadside vegetation.
- Joint tree ownership shared between caretakers and investors, whereby investors annually compensate the tree caretaker for his or her efforts, and upon tree maturity proceeds are shared.

Box 12.2. Roadside vegetation maintenance practices

Mulch. Mulch is a protective material placed on the soil surface to prevent evaporation, decrease surface temperatures, avoid weed establishment, enrich the soil, and reduce erosion. Applying mulch immediately after planting and maintaining it for several years helps hold moisture in the soil and suppresses weed germination. Several materials can be used as mulch, such as wood fiber, erosion mats, hay, straw and compost.

On sites where vegetation is expected to take several years to establish, such as arid or high elevated sites, it is important to apply mulch that will last more than one year. Materials with the highest durability are most long-fibered wood mulches, as well as erosion mats made from polypropylene. Straw, hay, and short-fibered wood products are less likely to be present after the first year. Mulching around seedlings is specially recommended for hot and dry sites and those with competing vegetation. It is less important to mulch around seedlings on sites that have a low potential for establishing competing vegetation the first several years after planting. Mulching is also less critical on sites that have low evapotranspiration rates or high rainfall.

Pruning. It is important to develop well-spaced structural branches early in the life of a tree. Branches that grow close together when the trees are young will grow into each other with age, and they will not be able to develop their full structural strength. Once the structural branches have been established, little pruning should be needed. It is advisable to examine the trees yearly and prune or cut branches for reshaping, if necessary. Uncontrolled growth of trees and shrubs could cause problems for vehicles, such as reduced sight distance, and vehicle or personal injury. Trees also need to be pruned to remove dangerous hanging branches or to prevent lower branches from blocking a path or obstructing visibility.

Protecting the seedlings. Fencing will be necessary in free-grazing areas and places subject to damage. Social fencing is sometimes considered an alternative to a physical fence. If all the residents of the area agree to keep their cattle off the plantation, and if there is no risk of cattle from other villages encroaching upon it, it is possible to establish the plantation without a physical fence. However, social fencing is particularly challenging in roadside plantations that often cross several districts.

There is a range of methods to protect seedlings, including rigid and non-rigid netting, fencing and animal repellents. When selecting fencing materials, it is preferable to use materials that allow sufficient sunlight for photosynthesis. Stone or brick fences are not advisable because they block the sunlight and impede plant growth. Individual trees can be fenced by surrounding them with sticks made with small branches from nearby trees.

Plastic netting can be installed to protect seedlings from animals browsing over each seedling. The netting acts as a barrier to foraging for foliage, stems, and even root systems, without impeding plant growth. There are two general types of netting: rigid and non-rigid. Non-rigid netting is a soft, fine-mesh plastic material. When installed on a seedling, it fits perfectly around the seedling. Rigid netting has larger mesh openings and keeps its shape when installed. Rigid netting, while typically more expensive, is usually preferred over non-rigid because it is easier to install and seedling growth inside the netting is less restricted.

Netting must be installed as soon as possible after planting to ensure immediate protection.

Tree shelters are translucent plastic tubes placed around seedlings after planting. They create a favorable growing environment while protecting the seedling against animal damage. Tree shelters enhance plant growth by creating a microclimate, which has lower light intensities, higher temperatures, and higher humidity. Tree shelters should be considered for sites where the potential for animal damage is very high. Tree shelters are not suitable for all species or site conditions. Tree shelters must not be removed until a portion of the seedling crown has grown out of the shelter. If the tree shelter is removed while the seedling is still growing inside the shelter, it will not be capable of supporting itself. Tree shelters are more effective than other methods, but they are also costlier.

Management

13. Making it work: governance for green roads for water

Key messages

- In Adaptive Resilience the road infrastructure as it is is optimally used for water management and climate resilience with additional - usually low cost - water control measures: it requires complementary programs; training for roadside users and farmers; special green funding arrangements for supplementary programs and Memorandum of Understanding between main sector departments.
- In Pro-active Resilience road infrastructure is from the onset designed to serve multiple objectives beyond transport: it requires multi-functional investment formulation; new integrated designs; training for engineers; modelling for specific challenges; special green funding arrangements for additional costs.
- These changes are helped by trust and integrity, cooperation with other sectors, focus on sustainability and community engagement.
- To get the process going may entail different steps: fact finding; getting sectors to talk; identify champions; work on early implementation; work on different fronts; capacity building and research and consolidation in working methods.

13.1 Objectives

Using roads for water management is a new practice. Introducing this new practice requires not only that new techniques are mastered, but also that governance is adjusted. The overall change is for road development and water management to be more intimately linked. The desired state is for road alignments and designs to include water management objectives (see also Section 1.3). Together with this, working methods need to be adjusted ideally: in preparatory surveys (see Annex 7), in design, in budgeting and in community contacts (see Chapter 14). None of these changes is insurmountable or complicated: they just need to be done.

This chapter describes the current governance in the road sector, the impediments and the direction in which governance should move to be more responsive to the opportunities that green roads for water offer (Section 13.2). Using roads as instruments for water management and climate resilience and more reliable connection requires a different method of working. Section 13.3 zooms in on this, giving experiences in different countries where the road for water practice is being introduced. Section 13.4 discusses different methods that may be used to introduce the change.

13.2 Governance for roads for water

There are several challenges in the road sector that affect the uptake of new practices, be it the integration of beneficial water management in road development and maintenance or the promotion of economic opportunities that road development can possibly bring (Diagram 13.1).

The first challenge is integrity. As it is a sector in which large amounts of money are moved around, corruption and corruption scandals are often around the corner. The consequence of this is, of course, a misuse of resources and a lax implementation of work standards, but also a culture of controversy, compromised leadership and instability in the management of the organization. The shadow of corruption is often as damaging as the corruption itself.

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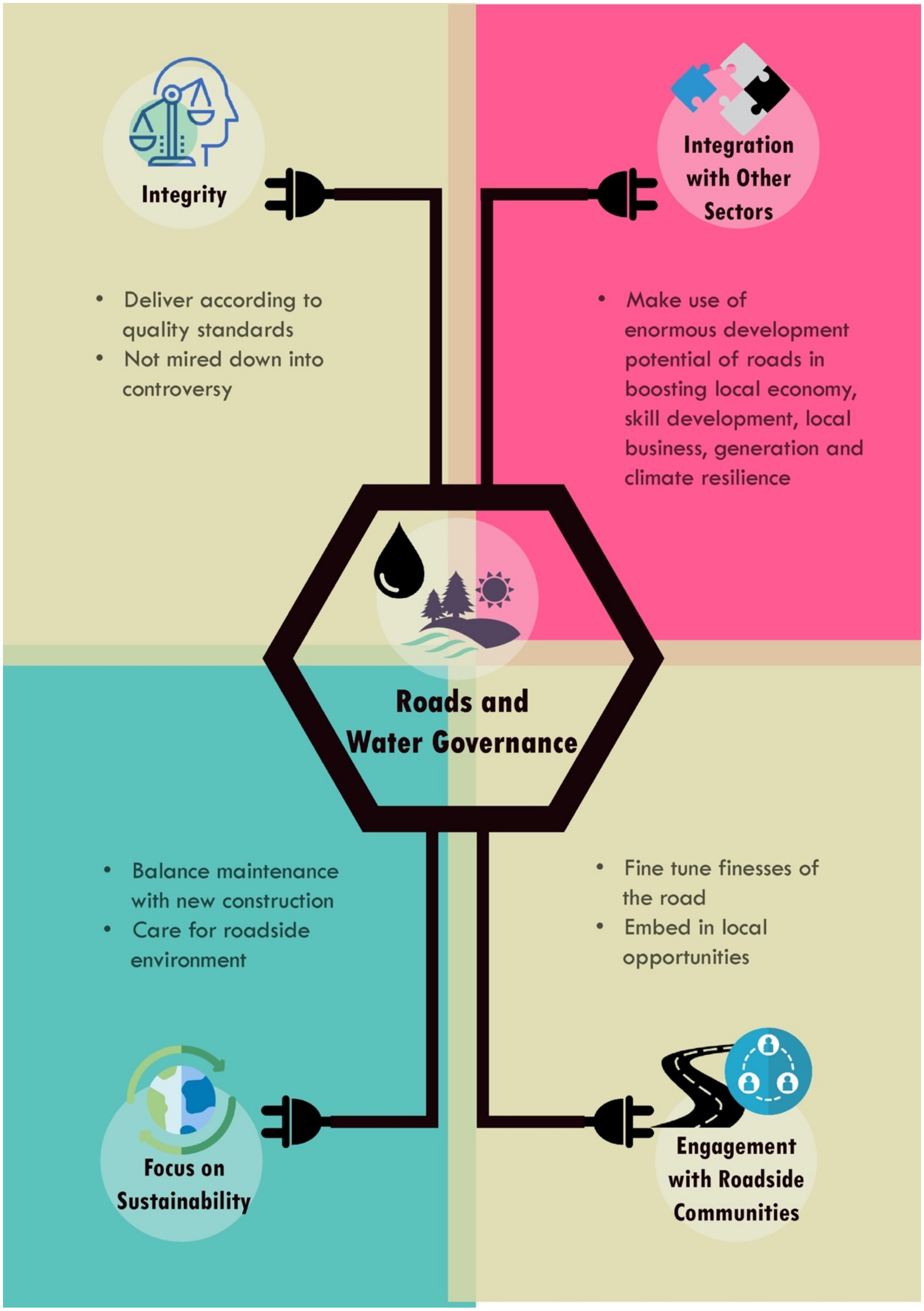

Diagram 13.1. Improved governance for green roads for water

A second challenge is that there is no integration with other sectors. It is hard to quantify, but from experiences in the roads for water programs of different countries, it is evident that the road sector often operates in isolation and this needs to change (section 13.3). There is often very limited or no awareness within the road sector about the positive impact they can bring to water management and climate resilience or on the economic development they can trigger and even improve with appropriate measures. There is often an obsession in protecting the road against all external influences—and concern that water management measures will affect the road rather than improve the conditions. The single focus also shows in practices such as closing borrow pits after they have been used, even though this is costly and not effective, or in planning minimal cross drainage based on cost considerations rather than on effect on hydrology. There are also impediments where roads are purposely built at too low a cost—solely to have the road in place, with disregard to its sustainability or the impact on the environment.

Bangladesh: discussing the integration of roads and footpaths for better management of drainage and water levels in low lying polder areas with a large range of stakeholders

A third challenge in the road sector is that community engagement is not common. Whereas in the water sector, for instance, participatory water management has been commonly practiced since the late 1980s, and stakeholder engagement has been promoted as one of the central elements of integrated water management since 2000, there is no equivalent in road development. The scope and mechanisms for community management in the road sector are discussed in detail in the next chapter.

Finally, in the road sector—particularly for unpaved roads—there is, in many countries, more attention for new construction than there is for maintenance or functionality in general. Maintenance of the rural road network is heavily underfunded almost everywhere. In some cases, the construction of new roads is politically very expedient and much attention is given to getting the road in place, even at gradients that are not sustainable or without cross drainage, thus playing havoc with the environment around the road. Maintenance is not only underfunded, but in many instances it is also completely forgotten and ignored. A larger focus on road sustainability will bring the quality of the roads and its environment more into focus.

13.3 Improved working methods for roads for water

A larger focus on climate resilience with roads will require different levels of engagement with other parties (see also above). The framework for road resilience described in section 1.3 helps parties to understand the challenges and opportunities and the need to have different stakeholders involved. It distinguished three level of resilience:

- Protective Resilience: protect the road infrastructure against climate change effects, no attention to the larger picture;
- Adaptive Resilience: make best use of the road infrastructure and adapt to changed hydrology with range of measures around the road;
- Pro-active Resilience:: redesign road infrastructure to optimize water management/climate resilience of the area.

These approaches have different implications for the stakeholders involved. If the sole objective is to protect the road (Protective Resilience) against changed climate with, for instance, better pavements or large cross drainage, then the main stakeholders are the road authorities. However, if the focus is on making use of the road as it is with water harvesting measures and making secondary use of the road body for water management (Adaptive Resilience), then agricultural and water authorities are the main players with consent of the road authorities. However, if road infrastructure is critically assessed and designed so as to serve different functions (resilience plus 2)—transport, water management, disaster preparedness, and climate resilience—then multiple stakeholders have to be on board.

Table 13.2. below describes the activities and changed working methods under each of the resilience approaches. In the protective "basic" approach, road designs are changed—requiring higher costs with cost implications—and catchment programs may be started along the most vulnerable road sections. In the adaptive) approach, farmers and agricultural/water organizations undertake complementary measures around the road infrastructure. This requires sensitization of related authorities: in agriculture, water resources, environment and disaster risk reduction—to be facilitated with training for farmers and implementers, special additional funding arrangements and MoUs between road authorities. An example of this is the agreement in Kenya between the Water Sector Trust Fund and the Kenya Road Board—whereby the Trust Fund takes care of funding additional measures, such as storage ponds. In the third pro-active level of resilience (resilience plus2), different sectors work together. New practices are tried out and also captured in guidelines and new designs. This is also reflected in new working methods whereby road development is not only the responsibility of road authorities, but is shared and discussed with many others and the conceptualization of a road project takes into account the multi-functionality (for a recommended Terms of Reference for team working on this see Annex 7). An example of the wider cooperation is the Interministerial Committee on Roads for Water that was established in Uganda.

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Table 13.2. Working methods in the three resilience approaches

Resilience approach	Activities	Main stakeholders	Changed working methods
Protective: Basic resilience "to protect the road"	New specification on cross drainage and road surface Catchment management for road protection	Road Authorities, some coordination with Land Management Authorities.	Increased construction budgets Catchment protection program
Adaptive: Resilience Plus 1 "make best use of the road"	Training farmers and implementers on road water management techniques Integrate roads for water in existing catchment management programs Complementary investments in road for water measures Combining road maintenance arrangement with water management measures	Agriculture Authorities Water Authorities Disaster Risk Reduction Authorities—working complementary	Complementary programs Training for roadside users and farmers Special green funding arrangements for supplementary programs Memorandum of Understanding between main sector departments (road, water, disaster risk management)
Pro-active Resilience Plus 2 "modify the design and function of the road"	Change road building and watershed management guidelines Creation of task forces within main government departments (road, water and agriculture)	Road Authorities Agriculture Authorities Water Authorities Environmental Authorities Disaster	Multi-functional investment formulation New integrated design and guidelines Training for engineers and

	Creation of inter-ministerial steering committee Integration in main country policies and programs (green growth, climate resilience, agricultural growth) Including the approach in university curriculum Working with main infrastructure funders	Preparedness Infrastructure investors—working together	experts of all related sectors Modelling for specific geographies Special green funding arrangements for additional costs Inter-sectoral task forces

13.4 To get the process going

Today, roads for water management has been introduced in different countries. While there is interest everywhere, the speed of uptake varies. This is partly related to the overall governance systems in a country, including the management culture.

The uptake in Ethiopia, for instance, was fast. A large lever existed and could be used—the Watershed Programs, orchestrated by the Regional Bureaus of Agriculture. This mobilized large numbers of people every year in the lean season (see also 14.4). Water harvesting measures were systematically integrated in this program and large-scale Resilience Plus 1 measures were reached fast. In addition, in Ethiopia, moreover, there is a strong “can do” mentality. The concept of roads for water was quickly owned by the regional governments and also incorporated into the Five Year Plans.

This may be compared with Kenya, where the decentralization of 2013 placed large parts of budgetary resources, including the responsibilities to build and maintain rural roads with the counties, numbering 47 in total. With this move, the Kenya Rural Roads Authority (KERRA) assumed an advisory rather than a commanding role. To introduce a new practice thus requires a larger number of decisions, i.e. at each county. Also, in Kenya there is no equivalent of the Watershed Campaigns found in Ethiopia—so even at a county level there is no single mechanism to introduce the additional water harvesting measures.

In introducing green roads for water, it is thus important to understand the driving forces in the road and water sectors to assess the best opportunities to introduce the green roads for water practice: are their organizations with large leverage? How are responsibilities distributed between central government and local government for different categories of roads? What is the distribution between construction and maintenance? Are roads maintained? Are there private sector players (like toll road operators)? What are the main opportunities to improved road quality or water management, and where do things hurt? How politicized is road development? Are there coordinating arrangements between the road sector and the water, environment, climate or disaster risk reduction sector? How does the road sector score in climate or resilience funding?

In introducing roads for water activities in a given country, there are a number of lessons:

- Getting people to talk. There has often been zero communication between the road sector and other sectors and bring the different perspectives together can open up a lot of appreciation and fertile ideas.

- Do basic fact-finding—to better understand the driving forces (as above) and identify the win-win opportunities on green road for water, it is important to do basic fact-finding in a region or a country to define the opportunities and provide an anchoring point. In sharing the findings of such fact-finding, it is important to and cast the net wide—and brief the main organizations related to roads, water and land management but also associations and civil society groups that may own the program.

Malawi: first discussion on roads for water with representatives of road sector, water sector, agriculture and universities

- Find champions. There are individuals with a mission drive, large convening power and ability to convince—within government, experts or funding agencies—that can fast-track the uptake of roads for water program, particularly if they are working for organizations that have high leverage.

- Work on implementation early on. Almost all the green roads for water measures are "no regrets": they hardly can do a wrong; in the worst case they may not be so effective. Many opportunities to introduce green roads for water (especially the ones in the Plus 1 category) require limited additional funding and can be done with local initiative. The preparation of flow dividers and spreaders, the clever use of road spoil (chapter 5), the gating of road culverts, the conversion of borrow pits (chapter 7) are all examples of measures that do not require extensive preparation and can be undertaken very quickly to start the change.

- Do not get grounded in pilots. There is a pressure with innovative approaches to first test them and demonstrate them in pilots. This, however, is not advised: there is a large risk of getting stuck in such pilots: they take a long time to complete and even longer to prove their points. Pilots are always contextual—what works in one place does not necessarily work elsewhere, so the capacity to convince is limited. They risk losing the momentum.

- Work on different fronts. It is important not to focus on a single activity in introducing the new approach, but to work on different fronts—engagement with champions, motivational trainings, early adaptation projects and documenting and broadcasting result, so that different experiences reinforce one another.

- Think of capacity building and research. These are useful but slow drivers. They help engage future generations of experts but they do not usually create momentum. When training, motivational events are more important in the early stage—to create enthusiasm and interest—and connect with people who have introduced roads for water programs in their own areas.

- Consolidate in due time. In the first instance, it is important to get the programs moving and look for early adaptation. At a later stage the learning needs to be consolidated in guidelines and new designs, supplemented by good practices from other areas, and supported by new ways of working where possible (see also section 13.3).

14. Making it work: community engagement

Key messages

- Roads are at the heart of inclusive development – roads improve access to services and economic opportunities, road development offer direct labour and skill development opportunities and can be an injection into the local economy; roads stimulate local business and roads change the physical environment in as the topic of this guideline in a beneficial way
- To optimize all these opportunities requires the engagement of communities within the reach of the road, their representatives and other directly concerned parties
- The engagement is meaningful but will differ in the different steps of road development: in conceptualization and planning; in design; during construction; in maintenance and aftercare
- Communities can be a major force in the implementation of roads and green roads programs at scale – in the construction of rural roads, in the systematic maintenance and in undertaking additional adaptive green roads for water measures

14.1 Objective

Compared to other sectors, community engagement in road development and road maintenance has not developed extensively. This is unfortunate as road development has such an enormous potential impact—also beyond the transport function—that could be used better if roads were developed together with the people directly affected and possibly benefitting. The importance of stakeholder engagement and information disclosure is also highlighted in the Economic and Social Framework (ESF) of the World Bank (2017). To improve the process of engagement and consultation the ESF proposes a documented approach to: (i) stakeholder identification and analysis; (ii) planning how the engagement with stakeholders will take place; (iii) disclosure of information; (iv) consultation with stakeholders; (v) addressing and responding to grievances; and (vi) reporting to stakeholders. Moreover, roads are also development corridors. They create not only better connectivity, but also opportunities for better work, skill development, business facilitation. They are the back and bones of improved local value chains and access to services. To optimize these functions requires systematic engagement of local stakeholders.

This chapter first discusses the scope for community engagement in different dimensions of green road for water development (Section 14.2). Section 14.3 discusses the practicalities of community engagement in different stages of road development, whereas section 14.4 gives examples and takes lessons from three large-scale community engagement programs.

14.2 Scope for community engagement

The impact of roads and transport is well known—on access to new services, on jobs, the flow of ideas and aspirations, but also the effect on water and environment and the danger of unlocking pristine areas. There is a current challenge in many local rural economies in that they have so little to offer to young people. There are not enough jobs; the economy has no diversity and no opportunity for services and commodities to circulate. The local economies are often not inclusive—not for vulnerable people, but also not for aspiring young people in the productive peaks of their life. Instead there is much idling away and empty dreams. There is a need to create vibrant rural economies—with diverse jobs that add value, where services are provided and move from one person to another, where the local economy promotes local specialization in things that individuals are good at and have a talent, where a strong and level relation exists with the larger world and where the natural asset base is well protected. In this respect there is a huge difference between rural economies in different parts of the world—in the diversity of their services, their ability to preserve their land and water resources and their outward outlook.

It is important to consider any investment as a huge multi-facetted opportunity to bring such changes, with roads development and maintenance foremost in this. It is also important to better understand the uses and changed values that roads and transport bring beyond the immediate task of putting in place new infrastructure. Developing roads, however, has the potential to address many issues at the same time and make an enormous impact on inclusive growth:

(1) roads unblock access for rural goods and services, particularly if the development of the road is matched with the promotion of local transport—from carts, bikes and motorbikes, to intermediate means of transport to small buses, trucks and lorries. The development of rural roads and especially rural transport can be "the best thing ever" for local value chains, the local circulation of goods, where are a large part of the economy takes place. The development of highways can open up areas and increase their competitiveness.

(2) road development and road maintenance create direct labor opportunities. There are several examples. The labor-based cut and fill method used in Nepal (see Chapter 5.2), for instance, creates 26,000 labor days per kilometer, helps introducing safety procedures and equal pay for women and is constituting an environmentally best practice. Road development may be directed at labor opportunities for those that are most vulnerable and those who have the largest future potential (young people). With labor opportunities come opportunities to build new skills and set aside small financial reserves. There is a case to see the investment in road development as a "shot in the arm" for the local economy: once people have money in hand they will spent it locally and a multiplier of local expenditures and transactions may start to work.

(3) road development boosts the development of local business—road side stalls, bars, hairdressers immediately, but also hardware shops, repairers, agro-vet dealers, storage facilities, financial services and more. In Ethiopia, it was found that 78 percent of business came in place after the road development. We may go further in investing in local production and services by systematically rooting programs through local business, by stimulating local value chains and promoting more business development in areas that are just opening up.

Picture 14.1: Roadside service providers in Kenya

(4) road development, as is the theme of this document, changes the physical environment. A survey done among 162 households in Tigray, Ethiopia, living within 2.5 kilometer distance from the road found that 49 percent complained of the dust affecting health and crop production (see also Chapter 12), 41 percent complained of floods from the roads affecting their houses and cropland, 34 percent had witnessed erosion, 21 per cent had seen some sediment deposits in their land and 9 percent complained of water logging in some sections along the road. Environmental impacts of roads are thus significant, and as should be systematically harnessed. Demenge et al. (2015) have

argued that this could enhance positive impacts such as '*improved physical assets (road, irrigated land, new land under cultivation, ponds); livelihoods diversification (sale of water, commercial agriculture, raising fish, increased demand for labour); reduced vulnerability (seasonal water availability reduced, climate change resilience); and saved time in transport /travelling /irrigation/chores.*' It has been argued in this Guideline that the impact of the road on its immediate environment should be managed as instruments for socio-economic development, environmental rehabilitation and climate resilience. An example of complementary measures is the program in Ethiopia, for instance, where sand harvesting is well organized and used to create business opportunities for young people (Box 14.1.).

All of this amounts to a new vision of rural roads: as development vectors, as breakthroughs for change, as instruments for inclusive climate resilience and green growth. It is important to see roads as more than transport lines, but as bringers of change and local development. Roads can bring much change, facilitate chances at the doorsteps, especially when investments are made in the opportunities that go with them: transport, credit, water and trees, capacities and business skills and visions.

Box 14.1. Sand harvesting by groups of young people

Around new road river crossings sand often accumulates. Whereas this may hamper the capacity of the river to convey floods, sand is also a useful asset, much sought after in the construction sector. In many countries the mining of sand is unregulated and often controlled by local strongmen. This may further disturb river hydrology. All this does not need to be so. In Ethiopia, the Regional Departments of Mining mapped all areas with exploitable sand deposits. They next set up programs to give young people a start in business by giving them opportunities in sand mining. The formula is that groups of 25-30 young people—half women, half men—are given a one-year concession to mine sand in a well-demarcated area. The money that they earn, they can set aside if they want to do so as individual savings. After one year their savings are multiplied and they are supported to set up their own business.

14.3 Mechanisms of community engagement

In making full use of the opportunities of road development, community engagement best takes place in different stages of road development: during conceptualization, during design, during implementation and during after care (Figure 14.1). To make use of the potential for roads as development vectors, the community engagement should not be limited to the finalization of road infrastructure, but should also look at enhanced connectivity and road use; at the economic development roads can trigger and at the beneficial use of roads for water and other environmental functions. If done well, it will also enhance local ownership and create an interface between the road-implementing organizations and the people living in the area where the work takes place, including their representative organizations. At present, such a positive partnership in many instances does not occur and it leads to discontent—disputes and litigations over land, labor and compensations; frustration about the collateral damage caused by road development. This slows down work and adds to costs, whereas opportunities to align with local knowledge and priorities are missed.

Box 14.2 Roads in development corridors

- Community engagement is essential to make full use of the opportunities for road development – for beneficial road water management but also for optimizing the impact of roads on access to services, creation of labour opportunities, developing local skills and vitalizing local economies
- It should be well thought through throughout the different stages of road development and maintenance – not making stereotype assumptions on the composition of communities and optimizing the scope for local initiative and entrepreneurship around the development of roads
- This will place roads at the heart of 'green development corridors'.

It is also important not to be naïve about community engagement. There are a number of misconceptions about community engagement that should be avoided. The first misconception is to consider community engagement as a "good" in itself without being clear on the objectives, the mechanisms and the rules of engagement. Community engagement should be well thought through and planned—not different from how engineering works are planned. It should have clear programs for facilitators and experts. The second misconception is that local contributions in labor, land or in kind automatically create "ownership", which then suffices for the sustainability of the infrastructure. First is that there are many ways to contribute—not necessarily just local people "participating" in a program designed by others: it may just as well be the other way around—resources being made available to support local initiatives. This often leaves the organizing power with the communities rather than removing it. Second is that there are many opportunities to engage and develop joint programs around roads, beyond the physical contribution to road development—co-developing the opportunities in labor creation, economic development, climate resilience and water management.

Figure 14.2. Different stages in community engagement

A third pitfall is to assume "the community" exists. It is important to be aware of the diversities among the people concerned, their cultural practices and inhibitions and the imbalances in power and access. The latter can also avoid that one "engages with the wrong people" and that community engagement unwittingly becomes a force for exclusion or repression. A special consideration is the engagement of women, to which there are often cultural or economic barriers. For instance, one cannot assume that the presence of women in a meeting is enough. Programs that enable them to take part in economic activities, receive fair equal play, but also by engaging women facilitators who made communication easier but also became role models in their own right—women had moved about freely and had a lot to offer in terms of skills and knowledge.

It is good to have an understanding on the social relations and the perceptions of people. A recommended method is the "well-being" method that tries to understand the opportunities and issues from the life priorities of the persons directly concerned (see Box 14.2). A related technique is participatory rural appraisal—that engages group discussion around mapping, preparation of time-lines, doing a transect walk or priority setting—see also Annex 8.

Community engagement should ideally take place in different stages of road development and should cover the wider ramifications of road development: the development of infrastructure, its usage and transport functions and the promotion of related economic opportunities and economic services, particular the development of green roads for water.

Box 14.3 Well-being method: How to create a connection between the interviewed person and the person interviewing.

Step 1: Common human interest

The first stage concerns the establishment of common human interest. As humans, there are a number of areas that touch us all deeply, whatever our background: our health, our autonomy and security and the future of our children. This we can share and discuss and exchange our experiences. A number of questions that can be asked at this stage:
– How is your health and what are your concerns? – How do you see the life and future of your children?
– Do you feel safe and secure? Can you manage with your income? – How do you feel from day to day?
– What risks do you see for your family?

Not all questions need to be asked—what is important is the natural flow of the conversation and the understanding that is jointly developing. It is good to do this as equals and exchange experience—with interviewer/visitor comparing one's own life with that of the interviewee and also encouraging mutual questions. This stage of questioning establishes the human connection. It also triggers thinking about what is important for one's self and the choices one is making.

Step 2: Reflections

Following the common human-interest stage, more reflective questions can be asked. These encourage light analysis of one's situation and that of others and gives a lot of mutual and often unexpected holistic insight. Examples of such reflective questions are: – How are things done? – How do other help each other? – How is your relationship with members of family? – How is your relationship with your neighbors? – How do you look at things in your life, how do you look at others; how do you look at yourself? – What are your roles, and are you content with these? – Would you say that people help each other? – Do you think things will be different in the future?

One can also ask for examples and relate to what is in the house or immediate environment to illustrate the points. What is important is to listen to what is behind something out of empathy. This will often generate new perspectives/understandings of priorities. It will help one to understand what is driving them, how decisions are made, and what boundary constraints exist.

Step 3: Thematic discussions

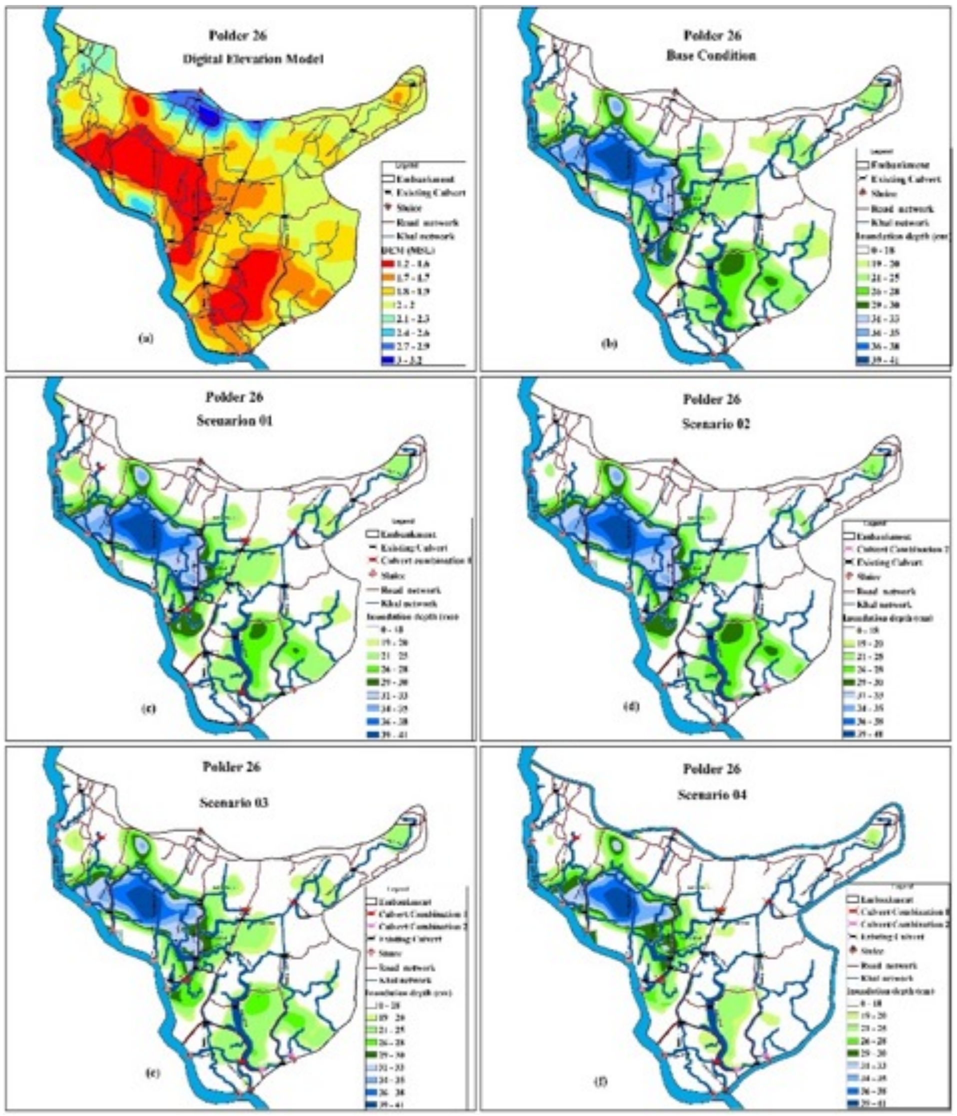
From these two stages, one can move to topics that originally triggered the learning visit (e.g. road construction program, mobility and access and environmental effects) and that one wants to understand better. One can raise these in a conversational way and see how they relate to the person's well-being. By this time there is a good, deep understanding of each other's lives and the thematic question can relate to these interests. It is best to use a checklist that one either has memorized or quickly glances at.

The type of engagement changes with the different stages in road development. In the early stage of conceptualizing and planning, when decisions are being taken on where to build the road, under what specifications and contractual arrangement, the interface is with local government and with representative interest groups, such as associations of traders or transporters or farmers groups. Important decisions at this stage concerns the alignment of the road and the main specification—for instance, to make a low embankment road with a designated spillover in a lowland area or go for high embankment roads, or to plan a road that will protect and help manage a watershed or a mountain environment with appropriate gradients and water harvesting structures, or in low-lying areas how to use the local road network to optimize water management in the extremely flat terrain (see Box 14.3). The conceptualization stage is also the time to discuss the inter-linkage with transport and the development of economic opportunities—such as measures to stimulate local business as part of road development or the designation of road reserves and land for economic activities along the road. The increased value of such designated lands can make an important contribution to the financial and economic viability of the road.

After the planning stage, the design of roads will put the specific details in place (Wattam, 1998). At this stage, representative groups and local government may still play a role, but structured discussions with roadside communities will be important too. Such discussion need to have an official character—with the persons talking mandated to do so and the results of the discussion recorded. The nature of the consultation should be clarified: informing or binding or something in between. It is important to manage expectations on what suggestions are practical to follow up and what recommendations cannot be accommodated. The engagement with local communities will add much value in this stage: the detailed understanding of the terrain, the local priorities and also setting the ground for implementation—through land release, work arrangements and sourcing of building materials, such as planning the location of borrow pits with an eye to later reuse for water storage (chapter 8). This is also the opportunity to discuss and agree on roadside tree planning—the location, species and modalities. As much as possible the planning of complementary economic activities and road water management measures should be in the hands of those in charge of it—not just by a road agency. This requires cooperation with agricultural and water management bureaus, organizations for business promotion, educational and health service providers and transport agencies. In the case of road water management measures, this is also the stage to discuss operation and ownership of the additional water resource—to which land the water is distributed and under what conditions to operate, for instance, gated culverts, roadside dams or overflow structures.

Box 14.4. Using modeling to inform the road network in coastal areas in Bangladesh

Based on discussion with local government and key stakeholders, the likely future road network in a polder was mapped—in addition to the current network. In the current network a large number of bottlenecks were identified where the roads impede drainage—seriously reducing farm production and also causing vector-borne diseases. With the help of a detailed digital elevation model the drainage patterns could be traced. With the juxtaposition of the current and future road network it helped to: (1) locate the most important cross-drainage works (bridges and culverts) and define the bed sill of these; (2) calculate the amount of water to be stored in the lower part of the polder with the help of road embankments to be released during dry seasons; (3) identify the higher and lower lying areas of the polders and explore the scope to place the road on the boundary lines so as to compartmentalize the areas and have a better dry-season water control, using gated culverts and pipes, and (4) identify most the flood-prone area where roads at a higher elevation could be a source of relief during flood events. These models were made with the inputs of different local stakeholders and then were re-discussed so as to become part of district infrastructure plans.



The next phase is implementation. This offers large opportunities for local employment, skill development, and economic business development. First, the road itself may be constructed by young contractors, in the case of paved roads, as was done in Ethiopia—whereby groups of university graduates were supported through training, credit and access to heavy equipment to take on local road-building contracts. This helped build up local and national capacity in the construction industry. In the case of unpaved roads, the work can be allocated to local contracting groups, as with the Labour Contracting Societies in Bangladesh (see Section 14.4). The performance of these groups in terms of quality of work and entrepreneurship has often been very high—amazing considering the level from which these groups started. These groups are composed of people living below poverty lines: landless and marginal labor. The engagement of such groups in basic road building has had an enormous impact on poverty alleviation, encouraging members to use the earning for productive assets. Road construction also provides other economic opportunities—the operation of community borrow pits and quarries and the development of support services to the road construction (shops, restaurants, etc). The money that is spent in the local economy can be a boost to further economic activities. At this stage, work can also start with additional road water management measures—individually or as part of a community effort, as in the mass mobilization campaigns in Ethiopia.

The final stage is the aftercare of roads. In this stage the interaction is again with local groups and local government and possibly special interest groups, such as transporter organizations. Also, with the roads constructed, more road water management measures can be developed, following the need and opportunities that have emerged. As has been mentioned throughout the Guideline particularly, the maintenance of unpaved roads is a challenge, as budget provisions are often inadequate. The combination of maintenance and road water management is thus very powerful, and should be combined where possible with road maintenance groups taking care of maintenance (as in Nepal see Section 14.4) or with individuals taking care of designated road sections and the water harvesting opportunities contained therein. This is also the stage to fully use the economic activities by promoting transport and facilitating business opportunities in local value chains. Table 14.3 gives a snapshot of the opportunities and the interstices for community engagement in different stages of road development and in different fields of road impact. The next section discusses a number of programs where community engagement in road development was undertaken on a large scale.

Table 14.3. How to engage communities in road development

Infrastructure Development Stage	Engagement through:	Infrastructure development	Infrastructure usage	Related economic opportunities	Related environmental services
Conceptualization and planning	Local government Repre-sentative interest groups Stake holder dialogue	Road alignment selection Decisions on type of contract and construction method	Choices on supporting transport measures	Choices on type of economic opportunity to promote Decisions on use of road reserves Special economic zones	Major choices on multi-functionality Road alignment to optimize environmental functions specific to local opportunities
Design and preparation	Community discussion Local government Participatory methods Consultation with other parties	Design of roads and water crossing and additional measures Freeing up land for road and road reserves Community contracts Agree on interface in participation	Design to accommodate specific transport	Freeing up land for side activities Roadside tree planting concessions	Identification of measures and locations for road water management Consultation on location of road drainage structures Consultation on location of water harvesting structures and borrow pits
Construction of road and water infrastructure	Community groups Local government Participatory methods	Community road construction groups Start up contractors Community contributions in land and labor Complaint handling mechanisms		Community concessions "Start up" contractors Training in income generating activities Additional provisions	Community and individual development of roadside water management infrastructure
Maintenance and continue care	Community groups Local government	Community road maintenance groups/contracting societies	Community road safety measures	Roadside tree planting	Maintenance and rebuilding of water structures part of individual responsibility

14.4. Examples of community engagement at scale

Community engagement is often organized on a project basis, but if it is part of a national system it is easy to reach scale. In this section we discuss three examples of nationwide systems for community engagement in road development and maintenance: the road for water activities in Ethiopia, being part of the large watershed movement; the engagement of labor contracting societies in road development in Bangladesh, and the road maintenance groups in Nepal.

Ethiopia: implementing road for water activities at scale

In Ethiopia, soil and water conservation programs have been in place for many years. Since 2014, road water harvesting is included in the repertoire of measures that are considered in the local planning processes.

Soil and water conservation "watershed" programs have been in place in Ethiopia since the 1990s. Several techniques were introduced over the years: afforestation, gully control and stone bunds. The earlier programs were often associated with food-for-work programs and the main purpose was sometimes the creation of work opportunities rather than building lasting productive land and water assets. The area covered was substantial. The main focus was reducing erosion through trapping and retaining sediments. In spite of the effort, the results were often unsatisfactory—due to a lack of effective community engagement, a limited sense of responsibility over assets created—and unmanageable.

From 2007, the program was thoroughly revived and reoriented. Particularly from the year 2009 onwards, a new thrust in soil and water conservation was introduced in different regions in Ethiopia. The new impetus had several elements. First, soil and water conservation was to focus on cultivated <u>and</u> uncultivated land. The farmers who farm the land should primarily conserve the cultivated land, and watersheds should be conserved by public mobilization. This helped to create a density of interventions that ensured a systemic change in the landscape—compared the more scattered intervention earlier. Second, there was—in addition to erosion control—more emphasis on harvesting water and retaining moisture. In this practice this meant several new techniques. For instance, in low rainfall zones infiltration ditches were added to the stone bunds so that more water recharged the land and storage ponds were added to the range measures.

The work was undertaken through free labor in the off-season under the so-called "mass mobilization" campaigns. Under this arrangement every able-bodied community member was required to work 20 to 40 days in a year, free of any payment. There were norms as to what was to be done in a day's work—for instance: for a man, 5 m of stone bunding was to be completed in a day's work. The norm for women was half of that for men. The work was done in the off-season: January to March, with a smaller campaign in June/July. In addition to the free labor, contributions from the so-called Productive Safety Net Programme were integrated with the soil water conservation program. Under this program, chronically food insecure people were registered and provided with work opportunities against payment in cash or kind.

The amount of work that can be done is enormous. In contrast to the earlier initiatives, the program was very popular as the starting point was local planning and the results were significant. The work was usually accompanied with festive events, such as rallies and meetings. By concentrating on one section of a watershed at a time, and not spreading thin, the result of all the intense efforts was usually quickly noticeable.

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Figure 14.3:. Community mobilization for road water harvesting in Amhara, Ethiopia

Apart from the collective work, farmers also invested considerably in their own land improvement (leveling, terracing, soil amelioration) and in some places well development. Key to the success of the program has been local planning and implementation—something that was missing in the earlier efforts. Capacity building consisted of:

- The regional Bureau of Agriculture providing training and planning support to the districts (woredas).
- Woredas giving training and support to village clusters.
- Village clusters (in coordination with woreda representatives) offering training to farmers at sub catchments.
- For each watershed, local experts and farmer leaders made a watershed plan.
- Groups of five farmers worked together and combined their efforts in combined groups of 25. The location of the structures is planned locally with farmers setting out stakes

The strong local-driven implementation meant a break with earlier soil and water conservation efforts—where people mainly participated to receive food for survival. In the past there was often little awareness of the effect that soil and water conservation activities could achieve. Implementation at scale also meant a change in environment—as witnessed from the re-emergence of springs, the regulation of local flows and the growth of indigenous trees—causing larger momentum. It created an effect of "success breeds success" —as it encouraged experimentation with new crops (fruit trees) and new land management methods. The road for water activities were integrated in the implementation from 2014 in Tigray and from 2015 in other regions of Ethiopia, in particular in Amhara, SNNPR and Oromyia. The measures consisted of flood water spreaders from road surfaces, flow dividers at culverts, infiltration trenches parallel to or perpendicular to road alignments, storage ponds and recharge ponds supplied by the run-off guided by road bodies. These measures gained in popularity quickly and from 2016 formed 25 percent of all the measures undertaken under the watershed campaigns. In the campaigns from 2016-2018 1,670,000 people were involved, if calculated on a full-time engagement (40 days) (ITAD 2018)—hence mobilizing 67 million labor days.

Bangladesh: labor contracting societies working on road development

To create labor opportunities for the landless and marginal farmers (owning less than 0.2 ha) in the construction and maintenance of small infrastructure the model of Labour Contracting Societies (LCS) was developed, since the 1980s. The LCSs are usually groups of 50 either ultra-poor male or female landless farmers for whom this income opportunity is very important. To facilitate this form of community engagement, the Public Procurement Act, 2008, and Public Procurement Rule, 2008, endorsed "direct contracts" with LCSs. The concept is to bypass the conventional mode of works contracting to facilitate the involvement of local people where the poor members from the neighborhoods directly benefit from development projects. A public procurement entity—such as the Local Government Engineering Department in case of local roads—has the legal mandate to make such contracts with groups of local people in a bid towards their poverty alleviation.

The LCS groups are largely self-selected and as such present themselves to the contract issuing authority. The criteria for membership are age (18 -50 years), fitness, local residence and interest in joining the LCS. Each group has an executive committee. The remunerations are such that it provides an attractive opportunity for those poorest in the lean agricultural season. The process is that the work to be done under LCS is identified by the contracting authority that undertakes a pre-work assessment. Next, a work order is prepared for the LCS based on the estimated volume of work. The standard rates for construction work applies as determined periodically for every region of the country. The payment to the LCS is made as is done with other contractors—an advance payment and then several installments. The final payment is based on a post-work assessment of the work—in which the actual volume of work is calculated. A security deposit is also taken, which is paid at the finalization of all contractual arrangements. Payment is made to the bank account of the LCS—from which individual members are paid based on their contribution to the work.

Under several programs in Bangladesh, large volumes of work have been completed and the LCS formula has placed money in the hands of poor—who have typically used this to acquire some household economic assets, such as a cow or goats for fattening. This has remained popular. In road building also, equipment was introduced that facilitated the work and enhanced its quality, such as compact rollers and wheelbarrows. The smooth implementation of the LCS activities hinges on several factors:

- Sincere selection of landless and marginal farmers as group members.
- Preventing contracts from being captured by local contractors who then engage outside labor and mechanical equipment.
- Timely issuance of work orders so that work can be comfortably undertaken outside the monsoon season or the season of peak agricultural labor demand.
- Correct pre-work assessment so that there are no major discrepancies post-work—leading to payment deductions and disturbed relations among LCS members.
- Smooth handling of all payments – including the return of the security deposit.

Nepal: involving road maintenance groups in mountain road maintenance

In the past fifteen years, Nepal undertook an ambitious road-building program, lifting its road coverage above the average of neighboring countries. To ensure the sustainability of these roads in often very challenging terrain, Road Maintenance Groups (RMGs) have been formed in several parts of the country. The functioning of these groups is formalized in a number of guidelines. The RMG activities have been determined by selecting those maintenance activities that can be carried out by unskilled workers using basic hand tools. The main objective of the RMGs is to ensure the proper functioning of the road and to reduce damage to the road by ensuring the proper working of the road protection measures, particularly the drainage system and support walls. They are also responsible for recurrent maintenance aimed at repairing minor damage to prevent the damage from becoming more serious. Some of their activities are: clearing culverts, clearing and cutting vegetation on roadsides and drainage structures, clearing drainage ditches and landslides. They carry out minor specific maintenance aimed at creating basic road protection structures to prevent damage to the road. Some of these measures could also include the road water management techniques presented in previous chapters of this Guideline, such as creating side drains that divert water to farmland, stone-paved water crossings to prevent erosion, and the protection of slopes by planting vegetation.

For rural road network a “length worker” system is applied where the workers engaged for a road are grouped together for maintenance for the entire road. Rather than having one person working on a dedicated stretch of road, as is common in many countries, the RMGs can allocate their members according to need, which allows them to spent more time on problematic road sections. In this way, with the RMGs an important administrative bottleneck is removed in contracting, supervision, planning and inspection. This is particularly convenient on unpaved rural roads, where maintenance often is cumbersome. The RMGs model is used for all the routine road maintenance activities, but also for recurrent and specific maintenance and emergency maintenance that do not required skilled labor, equipment or special materials.

Figure 14.4. Road maintenance group in Nepal with work safety measures

The size of RMGs is flexible and depends on the length of road, required work input, and estimated number of person-days to be used by RMG members each year. The input of person-days depends on the characteristics of the road (condition, topography, and road surface type, traffic levels and existing road protection structures). An example of the work norm used in Nepal is given in Table 14.4.

Road Type	**Approximate Input Level**
Tarmac Road	
Road in good/fair condition in dry season, i.e. road is passable by normal car at min. road design speed (20 & 40 km/hr for hill and Terai respectively)	65 person-days/km/year
Road in poor condition in dry season, i.e. road is passable by normal car in below road design speed (20 & 40 km/hr for hill and plains respectively)	104 person-days/km/year
Earthen/Gravel Roads	
Road in good/fair condition in dry season, i.e. road is passable by normal car at min. road design speed (20 & 40 km/hr for hill and Terai respectively)	80 person-days/km/year

Road in poor condition in dry season, i.e. road is passable by 4*4 bus, truck or tractor or normal car in below road design speed (less than 20 & 40 km/hr for hill and Terai respectively)	104 person-days/km/year
Road in poor condition in dry season, i.e. road is only passable by 4*4 bus, truck or tractor and required heavy maintenance	156 person-days/km/year

Table 14.4. Example of work norms for Road Maintenance Group in Nepal

Members are selected from communities along the road (sections) to be maintained or from those communities nearest to the road. Before the start of the selection process, the district development committee (DDC) body conducts a meeting and approves selection criteria and modality. Group members either apply through interview or are selected in a mass meeting by the Village Development Council. The common criteria for the members are:

- The workers must be above 18 years of age;
- They must be physically and mentally able to do road maintenance;
- They live near the road to be maintained. This reduces travel time;
- The candidates must be unemployed or employed less than 25 per cent of their time;
- The priority need to be given to poorest and marginalized people of the community;
- Preference to female candidates. Women participation should not be less than 33 per cent but can go up to 100 percent too;
- At least 40 percent of the group must be from disadvantaged groups.

Once the selection is finalized, the RMG is registered with the local government. The RMG should also elect the representatives of a group, in particular the general chairperson and treasurer. Individual bank accounts are opened for the payment of wages for each member of the RMG. The local government will be responsible for payment to each member based on their monthly performance and certification by the technical team. Alternatively, a bank account is opened in the name of the RMG with at least two nominations from the RMG members. This prevents the mismanagement of the payment and secures timely payment.

Prior to the works, training is provided on technical issues concerning the maintenance contract (what is road deterioration, how, when, and where to implement the different maintenance activities, how to do, what tools to use?), as well as the managerial aspects of the maintenance contract (how the work effectively, how to distribute the work activities, how to plan, how to supervise, how the payments are made, what documents need to be presented).
Once the member has been trained, the RMG group can sign the maintenance contract. The payment for the maintenance activities is made according to performance, based on the conditions of the different road sections. Because it is not possible to maintain the entire section of road at one time, the RMGs are expected to prepare monthly work plans on a monthly basis to determine which road elements and on which sections of the road the performance-based system is applied. The frequent inspection of the work plan and work at the road is needed to ensure the condition of road elements and road section included in the plan is appropriate. Inspection forms a basis of the payment made to the RMGs. Inspection, supervision and monitoring work is carried out by technicians or engineers in DDC/DTO from the project/program on a weekly basis.

For payment, the district rate is used for the payment to unskilled labor There are two methods of payment: either payment to each RMG member directly in their personal bank account or payment to the RMGs with the RMG is responsible for paying each member according to their attendance. In the latter case, the local government monitors the payment distribution regularly. There are also allowances like for tool maintenance, for safety equipment, for transport, and for the expenditures made by the chairperson, treasurer and other office bearers

14.5. Conclusions

There is considerable scope for community engagement in road development, to not only introduce the water management measures, but also to make use of the wide range of benefits that roads can bring. It requires a careful thinking on the methods used. In effective community engagement, the devil is in the operational details as much as it is in the overall remit.

It is important to structure community engagement in road development as in many instances the interface is not there and the interaction is defined by litigations and complaints. Given the opportunities for roads to work as development vectors, including having green roads for water or having roads as the center of development corridors, systematic community engagement is a 'must have'.u

15. Conclusions: it pays off

Key message

- There are multiple co-benefits in reduced maintenance costs and reduced down-time of roads; in reduced damage to environment; in beneficial use of water or in flood resilience
- In the on-going green roads for water the sum total of these co-benefits greatly exceeds the additional costs
- The costs of particularly the adaptive road resilience measures are modest compared to the total infrastructure investments and the cost of protective climate-proofing of roads

15.1. Multiple co-benefits

In most "roads for water, roads for resilience" applications, there are multiple co-benefits. By making roads that can serve more purposes than transport, and by making this part of the design and development of roads, it is possible to create roads that (a) reduce the now often substantial collateral damage that uncontrolled road water causes to the landscape around it; (b) are likely to have lower maintenance costs and downtime and are generally better able to withstand weather effects, including those that are caused by climate change; and (c) generate substantial benefits in terms of water harvested with the roads and other beneficial water management functions. In other words, rather than being a source of landscape degradation, they can become instruments for climate-change resilience. Table 13.1. summarizes these triple benefits using the resilience dividend framework of Tanner et al. (2015).

Table 13.2. Benefits and co-benefits of the "Green Roads for Water" approach

1	Reduced damage in the wake of disaster and unusual events	Reduced cost of road maintenance
		Reduced damage due to erosion Reduced damage due to flooding Reduced damage due to sedimentation
2	Unlocking the economic potential	Less downtime of roads
3	Co-benefits	Beneficial use of water harvested from roads

Based on the work in Ethiopia, where the most substantive integrated program is under way, the different resilience dividends were calculated, making use of the multiyear monitoring of erosion, sedimentation, moisture, and groundwater levels near road-water harvesting structures (Woldearegay et al. 2015). The cumulative annual dividend of the roads for the water approach to resilience, as implemented in Ethiopia, is US$16,879 per km (see Table 13.2.). This compares favorably with the direct investments of US$1,800 per km. These investments were largely earthwork measures implemented under the Mass Mobilization watershed campaign. If one were to include the cost of organizing and developing this program, another US$1,800 could be added. Even then a fourfold return to investment is achieved in the first year. It comes as no surprise that the program has spread quickly in the different regions in Ethiopia.

The measures implemented in Ethiopia comprise simple earthworks-based interventions—floodwater spreaders, roadside water ponds and infiltration trenches, many of which are explained in Chapter 2—with no engineering required. It is a minimum but cost-effective package. Other measures may be added that are more encompassing and will require a redesign of the road, for instance using non-vented road drifts (Chapter 8) as sand dams and stream stabilizers; reconsidering the number and locations of road culverts; changing the alignment of the road to optimize runoff capture; or using road embankments for water storage. These will come with their own costs and benefits and as such should be calculated. Indications so far are that such measures do not necessarily add many additional costs and that their costs/benefits may be equally attractive. In several instances, they may make use of the road infrastructure as is and add functionality to it at a very modest additional cost. Several Roads Adaptive and Pro-active Resilience "Plus" measures may even reduce construction costs.

- An example is the re-use of borrow pits for permanent water storage rather than backfilling them, often done with low-quality soil material (see Chapter 7). This is a considerable cost-saving measure and it creates a local water resource almost for free, especially when site-selection criteria and safety measures are included in upfront planning (van Steenbergen 2017).
- Another example concerns building roads in flood-prone areas with lower embankments and equipping them with controlled overflow "floodway" structures instead of going for high embankments (see Chapter 11). This reduces costs enormously, as the expenditure on the embankments is considerably less, and prevents roads from washing out in unpredictable locations.
- A third illustration is the use of culvertless, "non-vented" drifts as road crossings. These come at the same costs as road drifts with culverts but prevent the scouring of rivers and encourage the buildup of sand-water storage immediately upstream of them, combining the function of a road crossing with that of a sand dam (Neal, 2012). Excellent (no date) has made a calculation of costs and benefits and estimates that maintenance costs on culvertless drifts are only 13 percent of the maintenance costs of vented drifts.
- Fourth is the management of water levels in the coastal lowlands, such as the polders in Bangladesh (see Chapter 4). The only option to do so is to make use of the road network in these areas, expand it wisely, and equip it with appropriate cross-drainage structures.
- Fifth is the use of road embankments for water storage, as is done in countries as different as Burkina Faso, Portugal, Turkmenistan, Uganda and Yemen. Because the road embankment is already there, the reservoirs can be developed on the basis of sunk costs.
- The final example is the use of low-cost measures, such as drainage dips, water bars and infiltration bunds, on the widespread network of unpaved roads to guide water to productive uses and prevent damage to those roads that usually are not repaired (see Chapter 9).

Table 15.3. Comparing the costs and benefits from a conventional and inclusive roads resilience approach per kilometer of road in Ethiopia

Costs		Paved roads	US$1,800	US$45,000[16]
		Unpaved roads	US$1,800	US$31,200
Resilience Dividend				
1	Reduced damage	Reduced cost of road maintenance: unpaved	US$1,100	Comparable
		Paved	US$2,200	
		Periodic: paved	US$3,400	
		Periodic: unpaved	US$1,870	
		Reduced damage due to erosion	US$2,675	Negative: considerably more flooding than in base situation

[16] This figure comes from (Cervigni, Losos, Chinowsky, & Nuemann, 2016) and is based on the estimated prices for new planned investments of 796 km of multi-country roads under the Program for Infrastructure and Development (PIDA).

		Reduced damage due to flooding	US$1,762	Negative: considerably more flooding than in base situation
		Reduced damage due to sedimentation	US$180	
2	Unlocking economic potential	Less downtime of roads	US$3,800	Comparable
		Reduced impact from climate change	US$550	Comparable
3	Co-benefits	Beneficial use of water harvested from roads	US$4,500	Not there

15.2 Adaptive and Pro-active Resilience against Basic Protective Resilience

The cost and benefits of the investment in roads for water-resilience measures may also be contrasted with the Basic Resilience approach. This more conventional approach to resilient roads is described, for instance, by NDF (2014) and Cervigni et al. (2016).

Whereas in the Resilience Plus approach the environment around the road is managed and the road is made part of the landscape, even using roads as a beneficial instrument for water management, in the conventional Protective Resilience approach design specifications of road infrastructure itself are adjusted to make the road better able to withstand adverse weather effects. As discussed this can be justified in many cases as roads are vital for local economies and the cost of disruption is high (Protecting the road against the impact of climate change can consist of wider paved shoulders, stronger subgrades, and increasing the gravel-wearing thickness by using an improved crushed aggregate, so that there is less infiltration into the subgrade layers (see Table 13.3.). To deal with more intense rainfalls, culverts are adapted so that they can handle larger volumes of water. The cost of this conventional approach to road resilience is high: from US$31,000 to US$45,000 per km – which limits the stretch of roads that can be climate-proofed under this approach. In the case of unpaved roads the costs may be prohibitive.

The other concern is that in this Protective Resilience approach roads may be protected, but the surrounding landscape may be more exposed. Making larger culverts, for instance, to deal with larger flood peaks will create more damage in the area surrounding the road. Moreover, the co-benefits of beneficial water management are also missed: see the last column of Table 13.2.

Another suggestion that is made in the same context is to upgrade unpaved roads to paved roads. This comes at a cost of US$395,000 per km: with 90 percent of roads in Sub-Saharan Africa (SSA) being unpaved, this at best can be implemented in only a few selected locations.

Table 15.4: Examples of design modifications to road infrastructure under conventional Resilience Basic approach (Cervigni, Losos, Chinowsky, & Nuemann, 2016)

Paved	Unpaved
Add wider paved shoulder to improve surface drainage	Increase gravel-wearing course thickness to protect subgrade layers
Increase base strength	Upgrade to paved road
Increase protective layer of subgrade layer	Increase culvert size, making for greater flood resistance
Increasing flood design return period by increasing culvert size	

15.3 Opportunities for infrastructure productivity

There is certainty that road networks will further develop, and the challenge is to integrate inclusive resilience measures in road development from the beginning. In SSA, for instance, road density will still have to catch up. The classified total road-network density stands at 109 respectively149 kms per 1,000 km^2 in SSA; or 2.5 resp. 3.4 per 1,000 persons, or 152 kms per 1,000 vehicles. Compare this to a global average road density of 944 km/per 1,000 km^2 and it is obvious that there is a large unfulfilled transport need (Foster and Briceño-Garmendia, 2010). On other continents the emphasis is on upgrading roads and having a larger portion of all-weather roads while still expanding the network.

The increase and upgrading of the road networks present considerable opportunities to build in infrastructure productivity from the very beginning. Additional costs are a small fraction of overall road investment. The main cost is in foresight and coordination with other stakeholders: roadside communities, local governments, and other economic sectors.

This Guideline argues for an approach in which resilience improvement and beneficial road water management are part and parcel of the design, development, maintenance and retro-fitting of roads. It is the essence of resilience planning to build systems that are more productive and better able to withstand shocks and stresses. At present, spending on disaster-risk reduction is typically small and isolated rather than integrated in many programs (Watson et al. 2015). Moreover, the emphasis is on preparedness, not on prevention. Drought risks are largely overlooked. This Guideline explains how this should change. It provides practical details on the systematic introduction of the Roads for Water concept in infrastructure programs, and adjusts the design criteria, budgeting systems, and maintenance arrangements. We argue for close cooperation between road authorities and those responsible for agricultural development, water resources management, disaster-risk reduction, and local governments in general. Roads have much to offer in terms of local development and, perhaps unexpectedly, better water management is one prime manifestation of this.

In Chapter 1 we advocated hence the use of Adaptive and Pro-active Approaches to Roads Resilience. The Adaptive Approach takes the existing roads as the point of departure – making good use of the road infrastructure to introduce measures to manage and control water and make beneficial use of it. This can be the basis for entire road climate retrofitting projects and for campaigns to promote roads for water measures along the roads – implemented by farmers and land owners. Such campaigns consist of motivation, capacity building and coordination, as the example of the Ethiopia programs. Coordination is essential in order that the integrity of the roads is respected and safeguarded and that the benefits of water use are spread wisely, not only to those immediately adjacent to the roads. The threshold to start with Adaptive Approaches is low. The cost per kilometer in Ethiopia were in the order of USD 1800 per kilometer. Other figures come from Kenya, where road water harvesting measures were promoted in the semi-arid counties of Kitui and Machakos and adopted by farmers. The initial average investments for the road water diversion and the land preparation (levelling, terracing) were low, on average USD 421 per farmer. This amount was recouped in less than a year with average of USD 1048 (Kadeni et al, 2019). These benefits then accrued in the subsequent years as well. The benefits were particularly high in short rainy season (as the rainfall is more gentle and a large portion of the run-off can be controlled) and in the drought year (with 30% less of adapting farmers effected than non adopting farmers suffering from droughts). Similarly, in Bangladesh in the development of water control structures on culvert (see chapter 4) is a low cost Adaptive Reslience measure: it can range from the use of simple sheet iron gate on a pipe culvert to a fully gated structure: the first one having almost now cost, the latter within USD 700 but with the ability to manage water of several hectares of land.

The Pro-Active approach is associated with new road development programs or major rehabilitations and build roads right from the beginning as instruments for climate resilience, landscape management and water management. The cost of the measures are not necessarily much higher (as the example of the non-vented road drifts show), whereas in other cases it needs to be calculated on a case by case basis. Even then integrating the roads with the environment around it may be much more cost effective than merely defending the road against water and climate change, two threats that need not be but can all be part of the same agenda of inclusive green growth. There is moreover scope to make creative approaches on new roads with the development of road side tree planting (Chapter 12) or local forests along the roads offsetting part of the carbon emissions of the indispensable but increasing traffic.

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Dedication to Ian Neal, who is no longer with us in person, yet in spirit is. Ian catalysed much of the early thinking on ‘roads for water’.

ANNEX 1 Bio-engineering measures for road side-slope stabilization

Introduction

Bio-engineering is a suite of techniques used for the stabilization of slopes, either road side slopes or quarry sides or gully sides and stream banks. Its distinguishing feature is that it makes use of living vegetation. This is done as stand-alone or in combination with with civil engineering structures and non living plant materials. The aim is to reduce shallow-seated instability slopes on slopes and prevent erosion.

With vegetation being a central elements in bio-engineering, the positive mechanical and hydrological characteristics of plants are employed to secure the stability of the road-side or other slops.

Measures such as stone pitching, gabions and placing soil-cement layer have been used to protect road side-slopes. Bio-engineering is an alternative relatively low-cost and very effective methods, that is particularly suitable in environment with relatively fast vegetative growth.

Side-slope protection with vetiver[17]

Vetiver grass on road embankment slopes

Vegetation is the cheapest way to protect steep slopes of earth embankments. One commonly used plant is vetiver grass (*Chrysopogon zizanioides*). This hardy bunch grows naturally across many of the humid parts of the world. It is extremely resilient and can survive deep inundation of up to 6 m (Howell 2008). Vetiver grass is being used as an efficient bio-technology for slope protection in many countries, especially for its attributes: longer life, strong and long finely structured root system, and high tolerance of extreme climate conditions. This technique has recently been employed successfully in certain areas of side-slope protection against rain-cut and wind-induced erosion (Shariful Islam 2013). Vetiver shows successful erosion control in fresh water, brackish rivers, and canals. Moreover, farmers can use it as an animal feed supplement, or to tie up rice seedlings and rice straw (Dung et al. n.d.). Studies show that vetiver application is about eight times cheaper than masonry wall protection and about five times cheaper than the revêtement stone-slope protection system. Thus, vetiver grass plantation for slope protection could be a sustainable, green and cheaper bio-engineering solution (Shariful Islam 2013).

Bio-engineering: turfing and mulching

Over time the range of plants used in bio-engineering has broadened. In many case the preference is to use local plants such as the example from Nepal in table 1.

Table 1. Common plants colonizing roadsides in Nepal. Source: Howell 2008

	Botanical name	Comments
Grasses		

[17] Extremely rich information can be found at http://www.vetiver.org . This is the platform of the Vetiver Network International that has worked tirelessly to promote the use of vertiver as a powerful green solution.

	Phragmites vallatoria	Large-leaved tall grass found very commonly on river edges
	Cynodon dactylon	Small, creeping sward grass, very common on grazed land; withstands heavy grazing and long inundation, but rooting is shallow
Shrubs and small trees		
	Pithecellobium dulce	Small tree, 6 to 10 m tall, small leaves and thorny branches, common on embankments; edible fruit
	Eucalyptus sp.	Two main species are most common: *E. tereticornis* and *E. camaldulensis*; spindly tree with white bark, up to 15 meters tall
	Jatropha curcas	Shrub 2 to 5 m high; grows easily from cuttings; widely used for hedging; shallow-rooted but easy to propagate
	Mimosa pigra	Thin, thorny shrub that grows widely on the edges of wet areas and the lower edges of embankments; not liked by farmers who say that it damages young fish during floods and causes infections
	Calotropis gigantea	Bushy shrub, large pale green leaves and milky sap, that colonizes embankments; deep tap roots; difficult to germinate from seeds in nurseries
	Barringtonia asiatica	Tree that colonizes embankments; very common
	Pandanus humilis	Shrub with long thorny, fleshy leaves, 2 to 3 m high, producing many suckers; grows on riverbanks, used for hedges
	Combretun quadrangulare	Small tree common on embankments
	Acacia auriculiformis	Fast-growing Australian tree often planted along roadsides
Non-grass herbs and other small plants		
	Cassia tora	Annual leguminous herb or sub-shrub with purple flowers and small seed pods
	Eichhornia crassipes	Water hyacinth, an aggressive, invasive weed in slow-moving waterways
	Eupatorium adenophorum	Weedy annual herb with weak, shallow roots
	Mimosa pudica	Creeping herb with sensitive leaves; colonizes many bare areas

Turfing

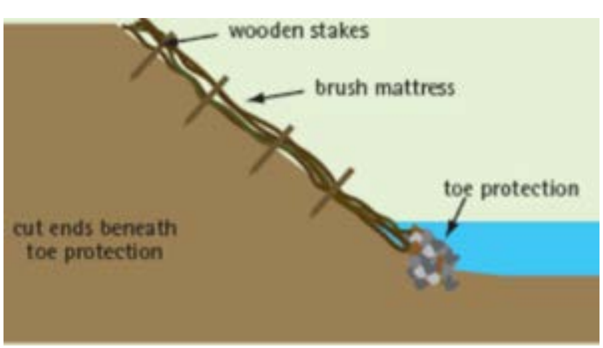
Recently, road projects have used seeding/mulching or turfing (Figure 1) techniques for grassing road embankments (Howell 2008). This is sometimes applied by truck-spraying a liquid mix of vegetative seeds and mulch, Vegetative turfing can be covered by biodegradable geotextiles or geosynthetic nettings. A mixture of straw/wood shavings and cow dung can be used as mulch and applied as a 2.5 cm layer. This is very helpful for embankments less than three meters high. They should be fixed in place with bamboo to avoid being washed away (CSIR-CRRI 2013).

Under the Coastal Embankment Rehabilitation Project (CERP) in Bangladesh, several biological means have been used for protection against embankment erosion. Several grass species have been used for erosion but also as fodder, including vetiver (*Vetiveria zizanioides*), Napier grass (*Pennisetum purpureum*), Para grass (*Brachiaria mutica*), and German grass (*Echinoclora grousgali*), in addition to other suitable plants like Ipil-Ipil *(Leucaena leucocephala*), Jhau (*Casuarina equisetifolia*), and Akashmoni (*Acacia auriculiformis*) (Islam 2000).

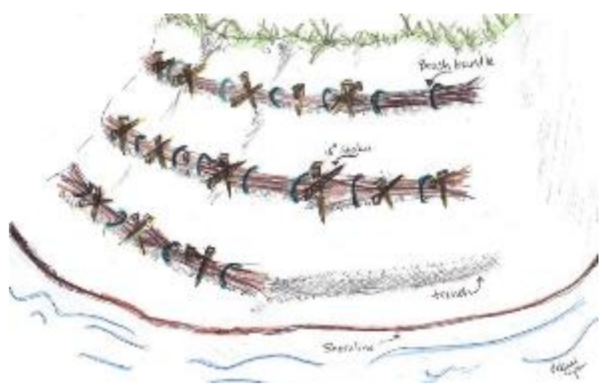
Planting shrubs and thorny bushes along the bank channels provides good protection on the slopes of the embankments (CSIR-CRRI 2013). Planting trees along the side slopes is not recommended because the roots can cause breaching. Tree planting on embankments was not accepted by the BWDB for 30 years. However, the integration of timber and fruit trees, grasses, shrubs, other agricultural elements, and animal husbandry has not been tested systematically in the field on sea-facing embankments (Islam 2000).

Bio-engineering combined with inert techniques

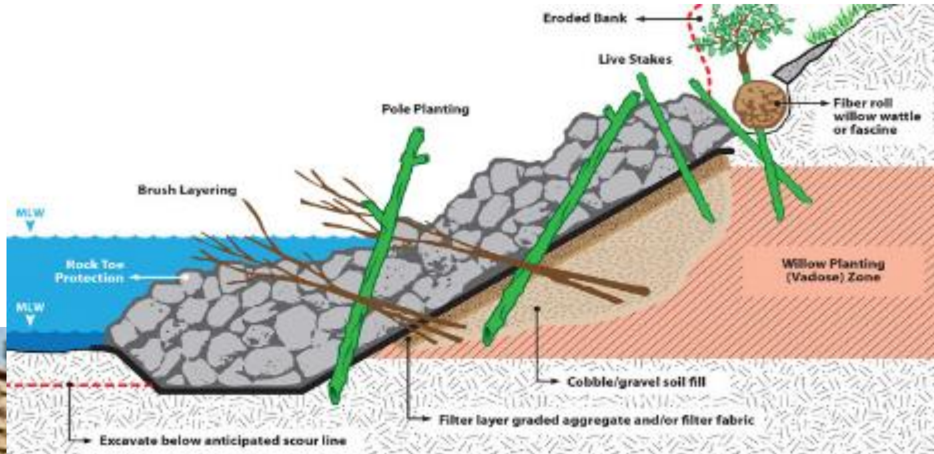
Other methods can be used in combination with vegetation: bamboo, cut branches, banana leaves and other brush mats can be applied as a cover on the slope's road embankments (Howell 2008). Moreover, wattle fences or brushwood can be placed on the side slope of the embankment with stone protection of the toe (Figure 2); barriers made with bundles using brush work, fascines or wattling (Figure 3); stones mixed with strong timber sections (Figure 4); timber crib walls (Figure 5); reed planting among stone pitching (Figure 6); riprap and reed rolls, or wire netting filled with stone, gravel and clumps of reeds (Figures 7 and 8) (Schiechtl and Stern 1997); and root wads (Figure 9) (SEPA, 2005).



Brushwood mattresses with toe protection

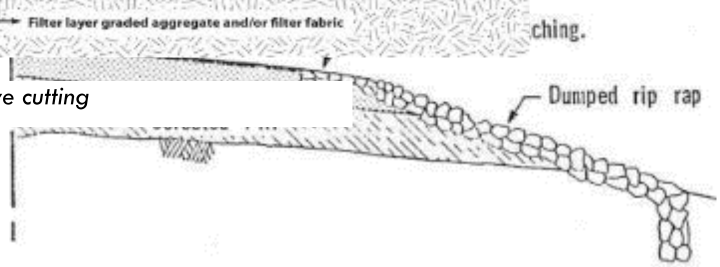


Fascine bundles



Stones with live cutting

Timber crib walls



Stone pitching

Riprap

Rock rolls

Root wads

ANNEX 2 Design of non-vented drifts

The design of a non-vented road drift consists of several elements: the body of the drift, the approach road, the upstream protection of the stream, and the downstream apron. These are important structures for retaining water in dry riverbeds. This annex describes the design of non-vented drift, based on the work undertaken by the Kenya Rural Roads Authority.

The drift approach roads should be extended by 10 m on either side of the riverbank on rivers with spans equal to or greater than 50 m and by 5 m on rivers with spans of less than 50 m. The approach road should be extended above the experienced flood level to prevent damage at the road end when the floods are high. The figure below shows a non-vented drift with design considerations.

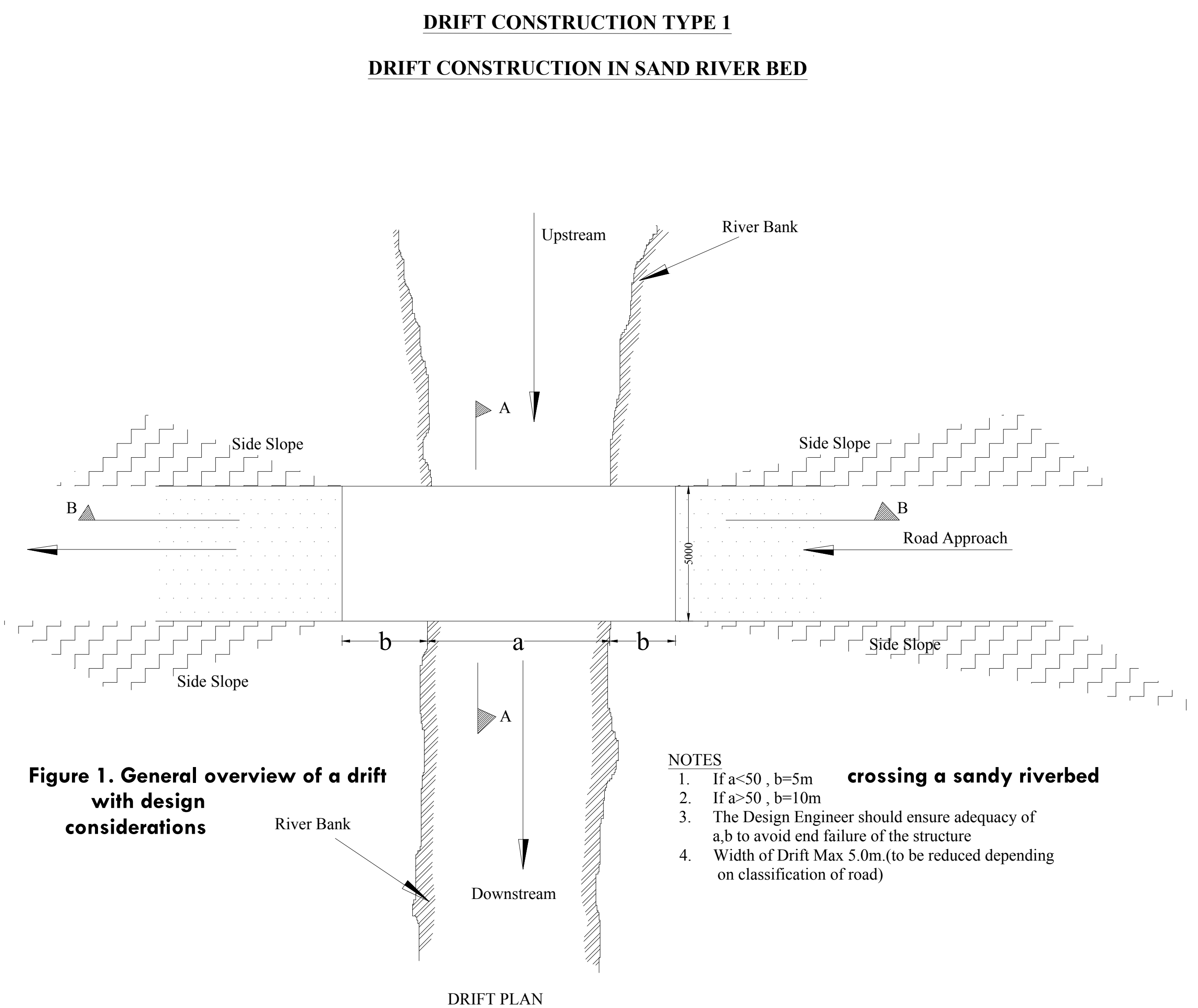


Figure 1. General overview of a drift with design considerations crossing a sandy riverbed

During construction, excavation should be done to a maximum of 1.5 m below the existing riverbed level in sandy riverbeds. In rocky riverbeds, the foundations should be laid on the bedrock.

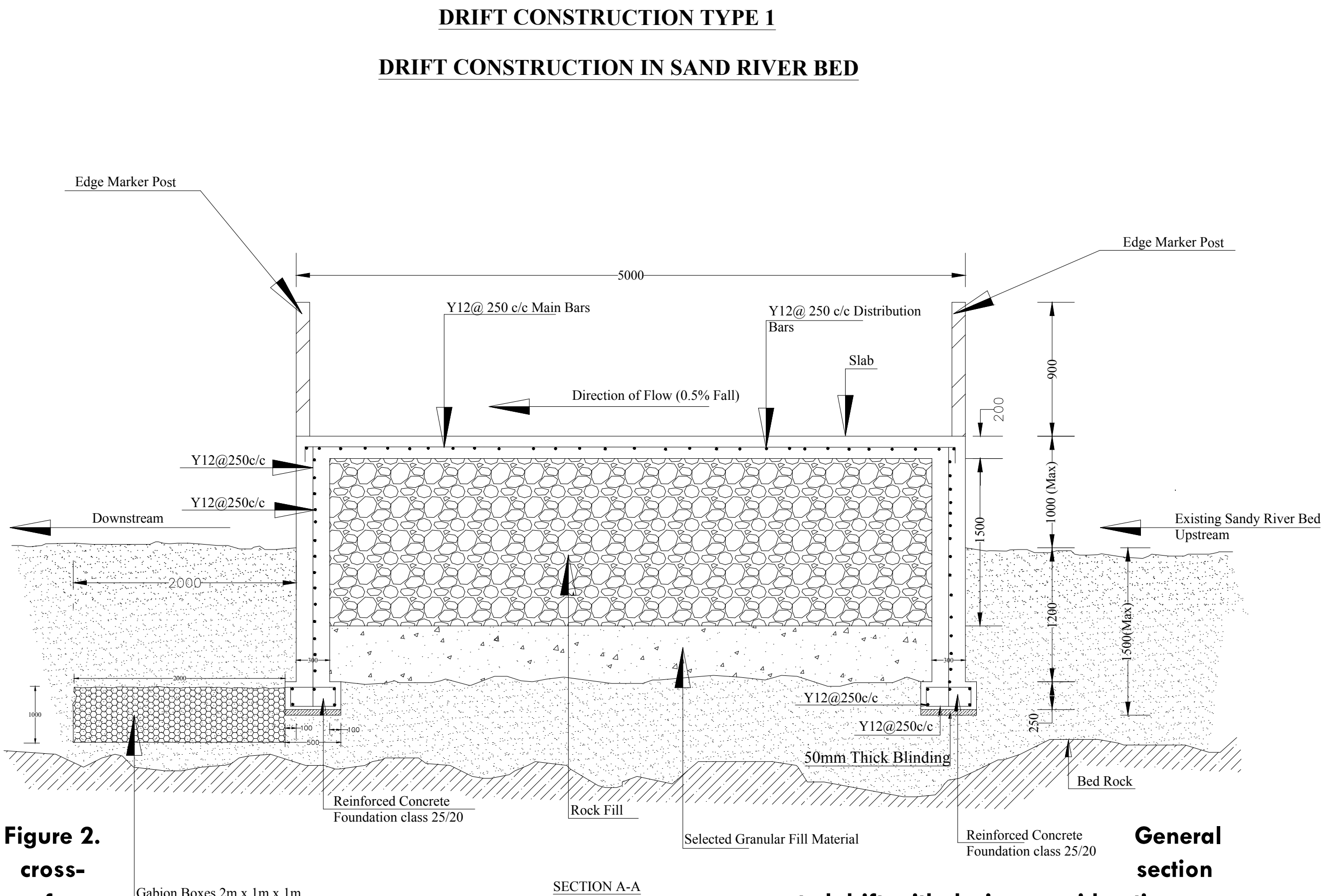


Figure 2. General cross-section of a non-vented drift with design considerations

The foundation is the bottom of a structure that is formed by both side walls. Foundations should have a minimum width of 500 mm and a depth of construction of 250 mm. Figures 2 and 3 show the general cross-section of a non-vented drift. Figure 4 shows the longitudinal profile of the drift.

The walls should be 300 mm thick. The top slab, i.e. the top layer (on which traffic passes) should have a constructed thickness of 150-200 mm, depending on the traffic volume and typical load. The drift should be filled with hardcore material and compacted to a maximum depth of 1 m on sandy riverbeds and 0.6 m on rocky riverbeds. Single-layer size Y12 reinforced steel bars should be fixed at a spacing of 250 mm both for main bars and distribution bars. The foundations, walls and the slab should be rigidly tied together to give the drift strong resistance to being washed away by floodwaters. The width of the roadway slab should vary between 3 and 5 m, depending on the type and volume of the anticipated traffic. The height of the drift above the existing riverbed should be a maximum of 1 m to ensure sufficient depth for the accumulation of sand and water upstream. The height of the drift should not exceed 1 m because there will be additional costs and the likelihood that such a retaining wall will also accumulate finer particles, thereby failing to achieve the maximum water-storage capacity.

Gabions should be installed at the foundation of the drift on the downstream side to prevent the undermining of the foundation by the overflowing of floodwater. The drift should have a curvature toward the center of the river to ensure that the water concentrates in the middle of the river, thus minimizing erosion along the riverbank and at the outer ends of the drift. The curvature should also be gentle enough to spread the floodwater over the width of the drift while not extending to the riverbanks.

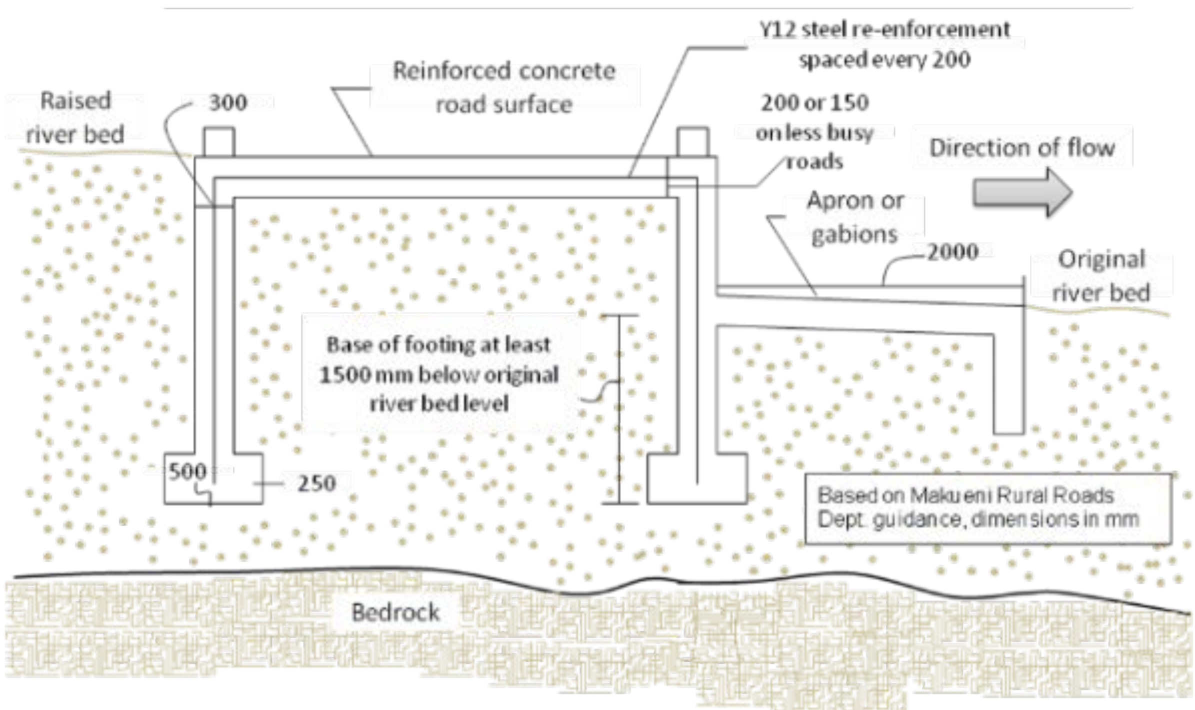


Figure 3. Cross-section of a rise drift crossing in Makueni County

DRIFT CONSTRUCTION TYPE 1
DRIFT CONSTRUCTION ON SANDY RIVER BED

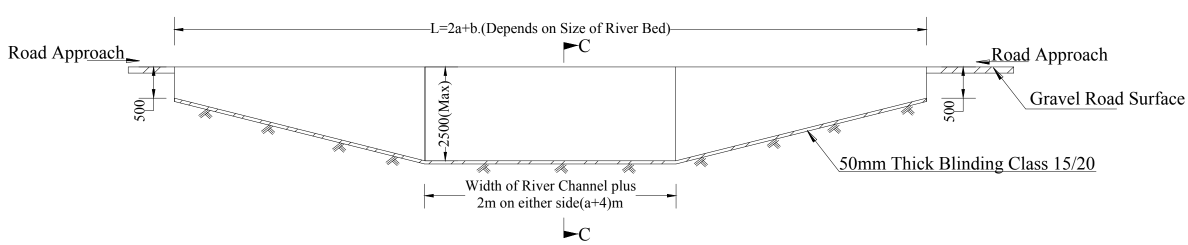


Figure 4. Longitudinal profile of non-vented drift

Dimensions

LONGITUDINAL PROFILE

Table 2 below shows the dimensions of a drift.

Table 2. Dimensions of a drift

	Excavation in riverbed	**Elevation above riverbed**
Large drift in sandy riverbed	Up to1.5 m	0.5-1.0 m
Large drift constructed on bedrock	On bedrock	0.5-1.2 m
Small drift constructed on ordinary river channels.	0.5-1.0 m	0.3 m

Small drift (road slabs) constructed on swampy plains	0.5 m maximum	0.2 m maximum

Additional retaining walls

Additional retaining walls can be constructed on the upstream and downstream sides of the drift to increase sand and water collection. The walls can be constructed as reinforced concrete or as gabions. Gabion walls are generally constructed at the upper parts of the river course and concrete walls at the lower parts of the river, as the concrete walls are stronger and resist the strong forces of floodwater.

Figure 5 below shows the general arrangement for the design of a water-retaining wall. Figure 6 shows the longitudinal profile of a water-retaining wall.

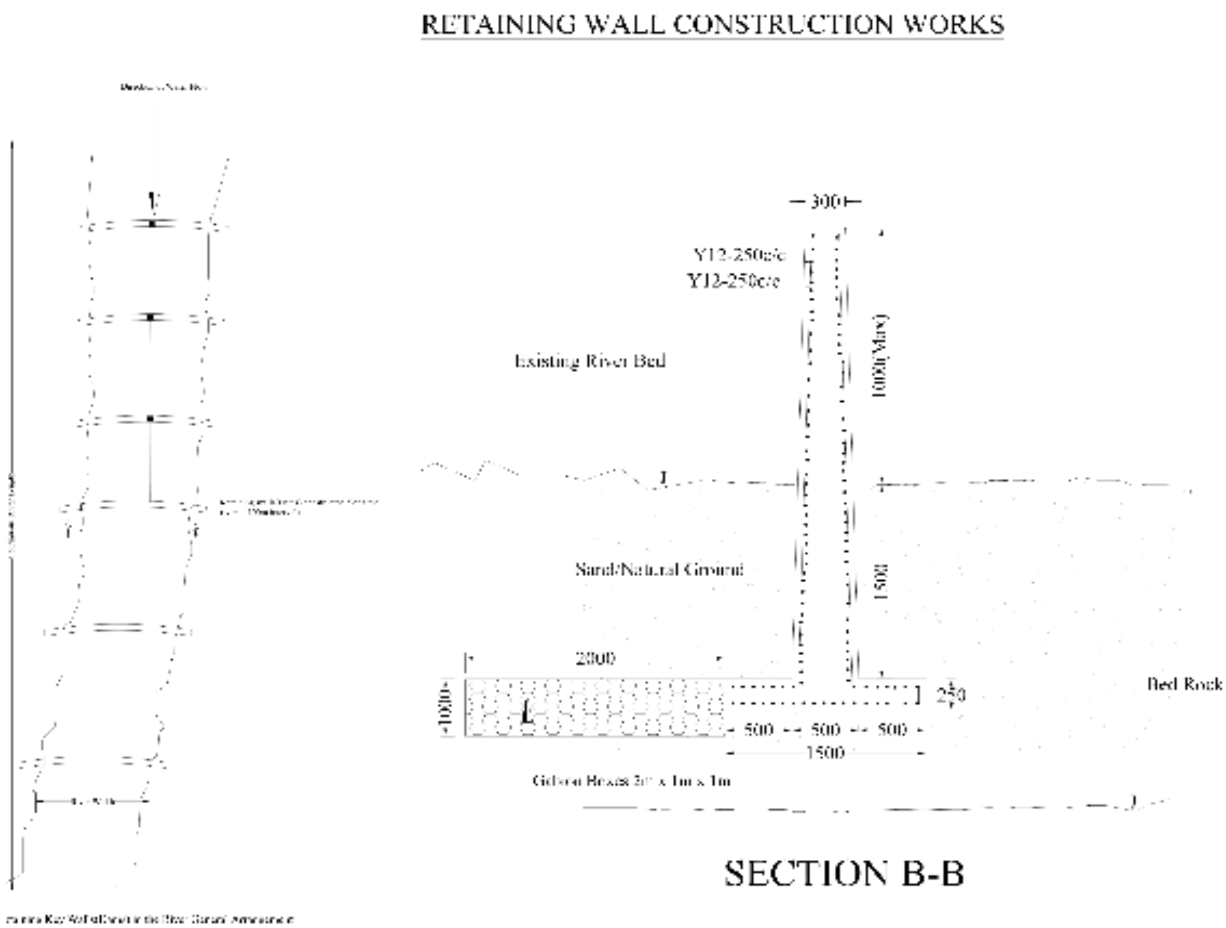


Figure 5. Design of retaining walls in rivers

RETAINING WALL CONSTRUCTION WORKS

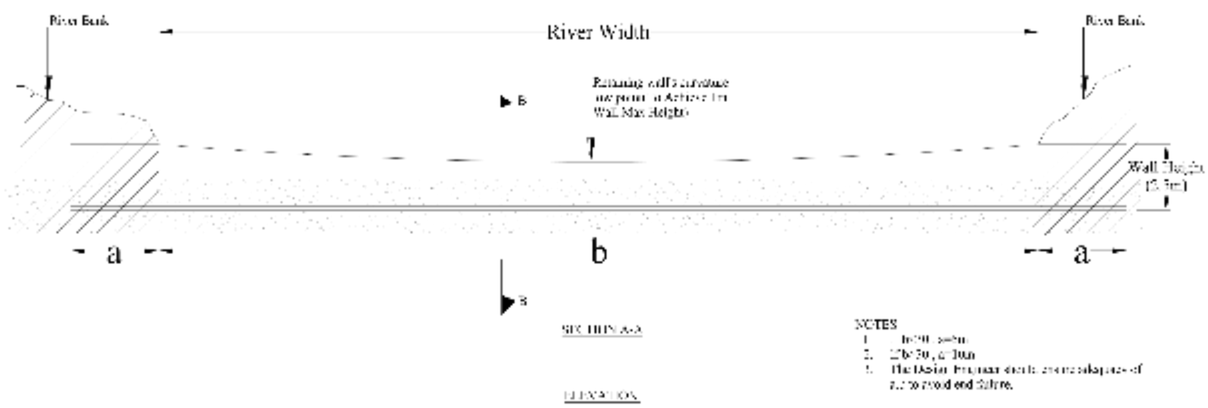


Figure 6. Longitudinal profile of a water retaining wall

Gabion mesh boxes measuring 2.0 m x 1.0 m x 1.0 m are also used as retaining walls in the upper parts of the river course to act as erosion-protection works and water-retaining structures.

Figure 7 shows the general design arrangement of gabion works on a riverbed.

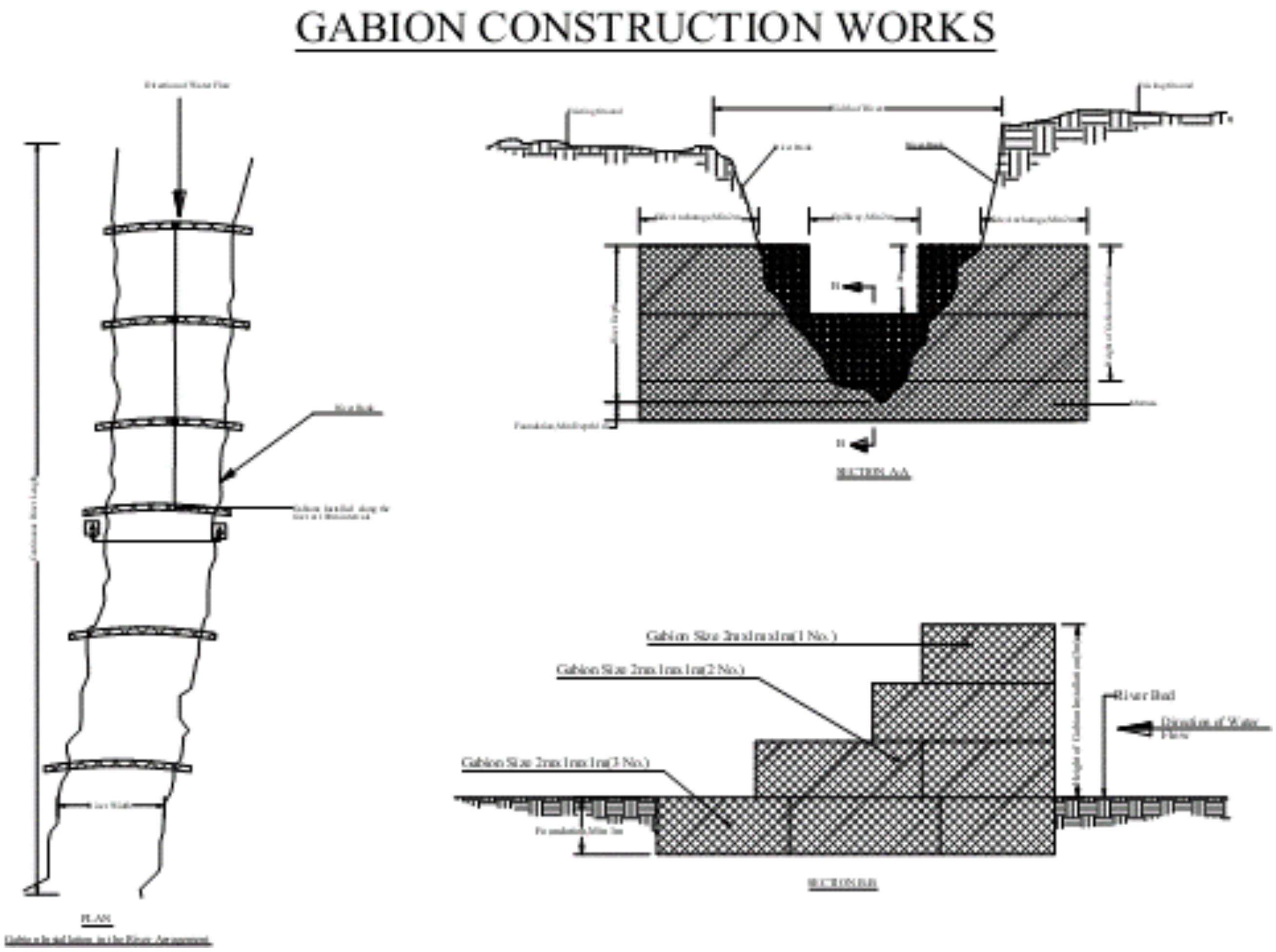
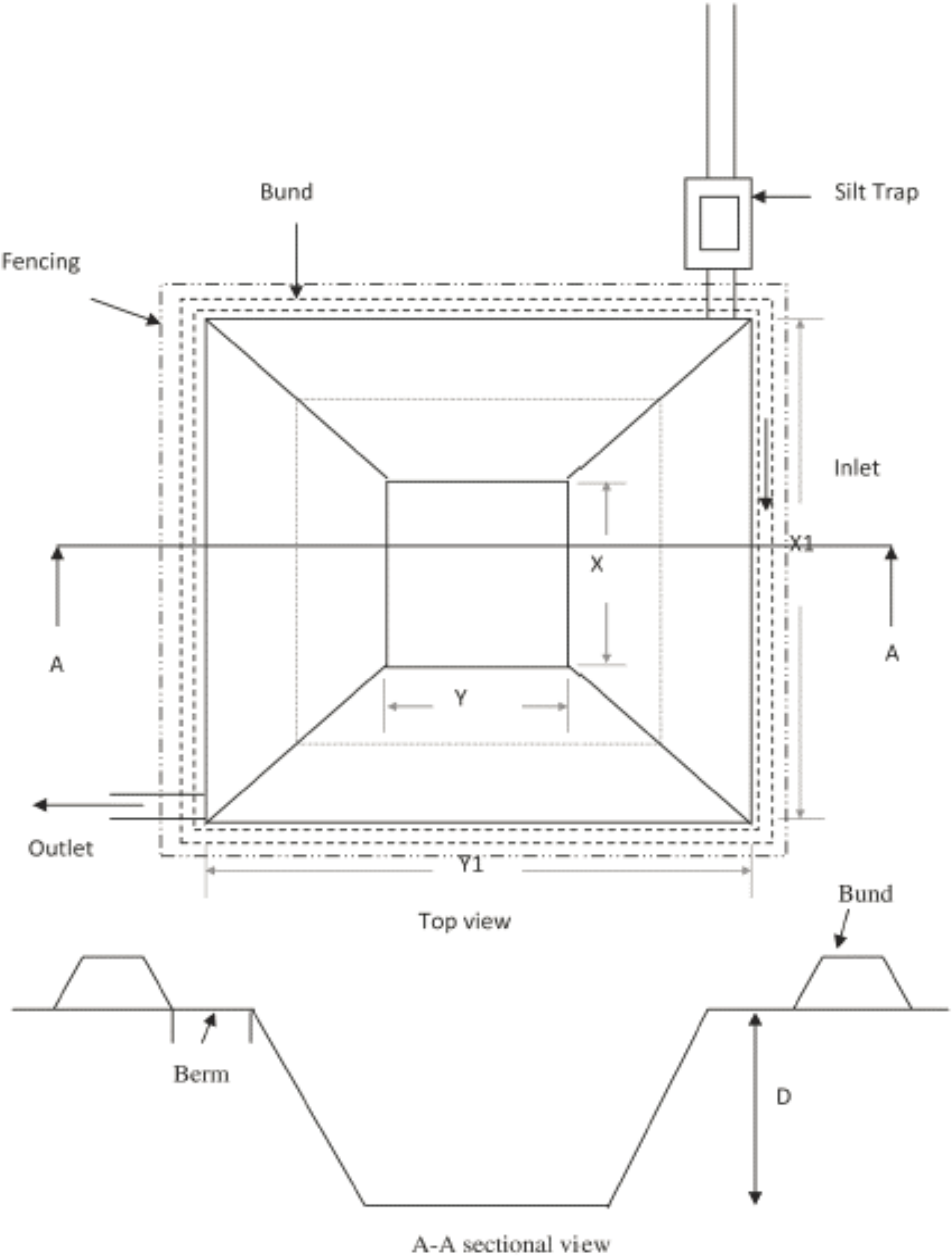


Figure 7. Design of gabions as water-retaining structures on a riverbed

The elevation of the drift and the walls above the riverbed determine the additional material deposited and the amount of water retained. Coarse material is deposited in the riverbed, while finer material is washed off the drift and walls to areas downstream of the river. The deposition takes place over a number of years until the drift and walls are filled. Their height can be increased later to increase storage and adjust river levels. It is important to ensure that only coarse material is accumulated; this material has the greatest capacity for water storage. Therefore, the drift height should not be too high when it is first constructed, and it is recommended that the drift height be raised in stages to add a layer of coarse material each time.

ANNEX 3 Sample design of a farm pond



ANNEX 4 Using animal traction to construct ponds

Digging ponds is a labor-intensive activity when there is no access to excavators and trucks. Nevertheless, most small (<1,000 m^3) ponds in rural areas are dug by hand. Labor is required for digging, removing the soil, and transporting it to the area designed to dispose excavated soil. If all these activities are done manually, there are also some simple technologies that allow the construction of ponds with the aid of draft animals.

Table 1: Comparison of tools for dug-out pond construction

Activity	Traditionally	With aid of draft animal
Soil softening	Hand-digging with hoes, pick-axes and hand chisels	Ox-drawn plow
Soil removal	Shovel and buckets	Ox-drawn scoop
Soil compaction (embankments)	Hand compactors	Ox-drawn compactor

While ox-drawn plows are readily available in most villages, the ox-drawn scoop and ox-drawn compactor need to be introduced. Luckily, an experienced workshop can easily build them from scrap metal that is locally available. The ox-drawn plow is attached to two or three oxen pairs using normal yokes. The area to be excavated is thus softened by plowing the area to a depth of 20-30 cm. It is important to plan the space so as to permit easy turns for the animals.

Ox-drawn plow is used to soften the soil in the excavation area of a dug-out pond

The softened soil is thus removed with the ox-scoop. To load the scoop, the operators simply raise the handles of the device to augment the incidental angle between the soil and the scoop. The forward movement of the animals will then do the rest. Once the scoop is loaded, the handles are lowered again, and the scoop will be pulled until reaching the disposal area. To offload the soil, the operators need to raise the handles until the scoop topples together with its load.

An ox-drawn scoop (locally constructed) is used to remove the soil from the excavation area and dispose it where the embankment will be established

Excavated soil needs to be properly disposed of and is commonly used to build a berm all around the pond. It is important to compact the berm to avoid erosion problems. The process is commonly done with hand-rams. Nevertheless, a simple roll-compactor can be built with secondhand bearings, scrap metal and an old oil drum. The drum is filled with sand and rotates as it is pulled by the oxen.

An ox-drawn compactor was built from an old oil drum and is used to compact the embankments

ANNEX 5 Design of floodways

Floodway in Inhambane, Mozambique

The use of floodways in floodplains may be considered as an alternative to the construction of bridges. Floodways are relatively long, lowered, reinforced road sections that allow the controlled overflow of floodwater during the flood season. They are common in several countries. Compared to bridges and culverts, floodways have a number of advantages and disadvantages that should be taken into consideration (see Table 1 below).

This annex provides guidance on the choice of a floodway as an alternative to other options (Section 1) and the main design considerations while constructing them (Section 2). This section was prepared by making extensive use of the Floodway Design Guide (2006) by MRWA Waterways Section and BG&E Pty Ltd., one of the exceptional references on this engineering option.

Table 1. Advantages and disadvantages of floodways

Floodways: Advantages	**Floodways: Disadvantages**
Maintain (wetland) functions of the floodplains	Cause road downtime: the road will not be motorable during high flood levels
Ensure controlled, well-directed areas of overflow: these can be wetlands or recharge areas	
Allow roads in floodplains to have lower embankments, thus saving costs	
Cost less than bridges	

1. Considerations in the development of floodways

Floodways are constructed on drainage paths of floodplains that carry water during the flooding period but that are dry in other parts of the year. Rather than building a bridge for the occasional flood, a floodway may be considered a more economical and ecologically sensitive option.

Floodways have a number of advantages related to costs, the preservation of wetland functions, and the ability to control flooding. Their main disadvantage is that during high flood levels it is not possible to pass through them. Planning and constructing a floodway requires a good understanding of the topography of the relevant section of the floodplain, the flood patterns, and the minimum service level of the road.

Understanding the local topography of the floodplain

The following are typical minimum requirements to understand the topography of the floodplain:

- A cross-section across the river, extending beyond the water level for the discharge being considered. Cross-sections upstream and downstream of the proposed structure are also required.
- A long section (profile) along the streambed, including the water-surface profile if available, in order to estimate the hydraulic gradient of the drainage path.
- A long section (profile) on the road centerline if an existing road is being analyzed.

Understanding flooding patterns
To understand flooding patterns, it is necessary to know the typical development of flood levels over time and the frequency of floods.

Flood hydrographs are needed to evaluate floodway safety and serviceability during times when floods overtop the road at different heights. Flood hydrographs also support the evaluation of whether a river section has sufficient surcharge storage and/or dedicated flood-control space.

Probabilistic extreme flood hydrographs can be developed to assess the reservoir flood/surcharge space to temporarily store a portion of the flood volume and to attenuate or pass the hydrograph peak without overtopping the floodway.

Deciding on road-service levels
While planning a floodway it is important to determine how much road downtime is acceptable. Taking into consideration car axle heights, the interaction between car tires and road surface, and the lateral pressure against the side of the cars, cars operate safely through flows up to 365 mm deep under ideal conditions. Under real conditions, because of the presence of debris, potholes, and waves, a depth of 230 mm is more appropriate. In recent years, cars have become lighter, so a critical depth of 200 mm is best used as the motorable limit for cars. Thus, the road is closed to traffic when the critical depth of flow over the floodway crossing exceeds 200 mm. For heavy vehicles, the maximum motorable critical depth is 500 mm.

Serviceability is then related to the acceptable closure time of the road connection. Decisions on acceptable downtime may also be influenced by the importance of the road as an access in emergency situations.

The duration of closure can be calculated by drawing a horizontal line on an average hydrograph at the discharge level corresponding to the 200 mm level and measuring the time for which the flow is above this level. Roads will be off-limits for light vehicles if the total head (static plus velocity) on a roadway with a two-way crossfall or across the highest edge of a roadway with a one-way crossfall exceeds 200 mm. The height of the floodway above the stream may be adjusted to accommodate the requirement of motorability/passability.

2. Design considerations

The following are the main considerations in designing floodways:

- Deciding on the dimensions of the floodways (2.1);
- Deciding on the road surface (2.2); and
- Deciding on the armoring of the floodways and other scouring protection measures (2.3).

2.1 Deciding on the dimensions of the floodway

Floodways are constructed in the lowest part of the floodplain. The dimensions (width and height) of the floodway should be chosen to ensure that floodwater spreads widely across it. This should bring flow velocity down to acceptable levels (reducing scour) and ensure that the level of the water passing over the waterway during the flooding period is in line with the accepted downtime (see above). If fish migration is expected to occur across the floodway during times of flood, then a check should be done on allowable flow velocities.

In the design of a floodway, hydraulic analysis is required for a number of reasons:

- To estimate stage and tailwater levels for various flows;
- To determine the backwater caused by the floodway;

- To estimate the closure time during flood events; and
- To calculate the velocities at the floodway.

Where a floodway is used together with a bridge or major culvert, the hydraulic analysis should take all these structures into account.

Natural section discharge

For the natural section, Manning's formula for open channel flow is typically used to determine the stage-discharge curve:

$$V = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$, with the discharge given by Q = AV

Values for the Manning roughness coefficient 'n' should be assessed onsite. Alternatively, tables may be used to determine its value. Natural sections of the floodplain are usually irregular. A roughness coefficient is selected for each part of the stream cross-section. For natural sections, it is preferable for the hydraulic gradient 'S' of the stream to be estimated from the water-surface profile.

Stage and tailwater levels

The stage is defined as the water level at the floodway or structure on the natural section for the design flow. It is the water level in a scenario that assumes no structures present at the crossing and is typically taken at the road centerline.

The tailwater level is the water level downstream of the structure. It is similar to the stage level but is taken at the outlet of the floodway. The outlet is generally only a few meters downstream of the road centerline. The hydraulic gradient is typically very small; there is often little difference between the stage and tailwater levels. The same value can be used for both levels.

The capacity, discharge and velocities at the floodway can be estimated using Manning's equation. To calculate the capacity of floodways, different widths and heights may be assumed to arrive at floodway dimensions that are practical and financially/economically acceptable.

The discharge over the floodways can be determined using the "Submergence Factor Curve":

1. For design discharge, obtain the tailwater level and the mean flow velocity, V, approaching the flow channel, from an open channel analysis (Manning's equation).
2. Select a crest level (linked to flood hydrograph and serviceability criteria) and the length of the flood channel, L. Assume the water height, h, above the crest of the flood channel.

Calculate H/l

Where: H = total head (static plus velocity) = $h+(V^2/2g)$

With: H/l and obtain free-flow coefficient of discharge, Cf. Should the value of H/l be less than 0.15, Cf should be read from curve "Discharge Coefficients for Floodways".

If there is submergence (e.g., if D/H>0.76), calculate the percentage of submergence D/H x 100 and read off the submergence factor Cs/Cf.

Calculate discharge (m^3/s) over the floodway using the broad-crested weir formula:

$$Q = C_f L H^{3/2} \frac{C_s}{C_f} \quad (m^3/s)$$

If there is submergence, check whether the discharge over the floodway matches the design discharge. If it does not, adjust the depth of flow above floodway crest, h, and repeat the procedure. Alternatively, the floodway crest level or length can be adjusted.

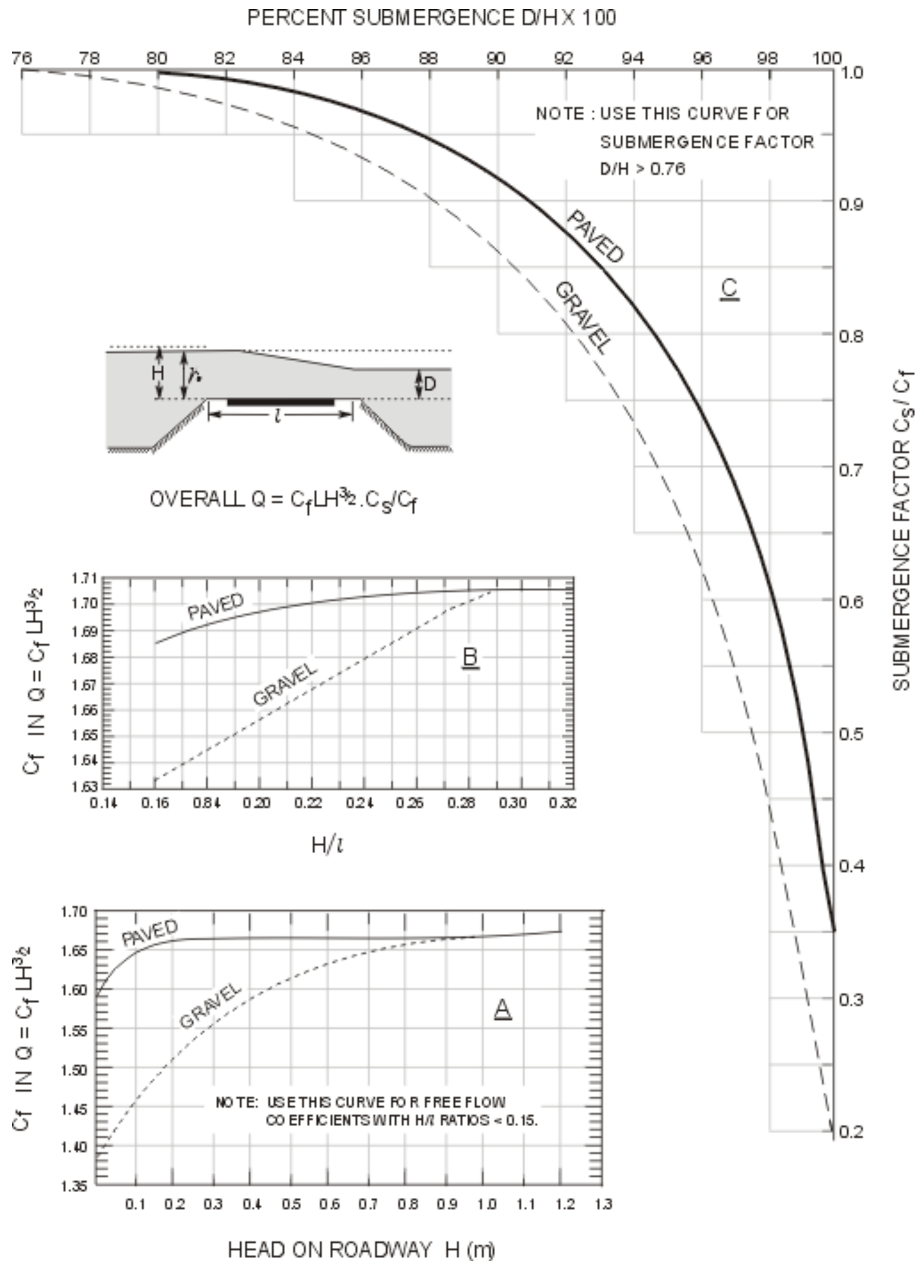


Figure 1. Discharge Coefficients for Floodways

Simplified until step, 6, assume that Cf with H/I is a constant value of 1.69 outfall conditions (unsubmerged). The simplified equation is shown below:

$$Q = 1.69 H^{3/2} L$$

Backwater and upstream flooding

Upstream assets that cannot cope with increased flood levels will typically necessitate a higher-capacity floodway structure to minimize backwater effects.

Culverts on the floodway

In designing a floodway, the use of drainage culverts may be considered. These culverts may serve one or more of the following functions:

- Reducing backwater effects;
- Raising the tailwater level and reducing the head through the flow channel;
- Facilitating drainage and avoiding stagnation behind the embankment; and/or
- Facilitating drainage and avoiding the overflow of smaller and more frequent flows.

2.2 Deciding on the road surface

In designing a floodway, a decision must be taken on the length of floodway, its width and pavement characteristics.

Length

The length of a floodway should be limited to 300 m. If the floodway is longer, drivers may become disoriented when confronted with wide, open stretches of water.

Pavement

Two types of pavement are generally used in floodways:

i. Stabilized base course: This is used for floodways in areas where periods of inundation are relatively short (less than 30 hours per year) and in areas without heavy traffic during submerged conditions.
ii. Concrete pavement: This is typically used where periods of inundation are long and the road is subject to heavy traffic during wet conditions.

Horizontal alignment

Floodways should be located on straight stretches and not on horizontal curves. Curves cause problems in defining the edge of the pavement. The water depth will be deeper on one side of the road than on the other, affecting passability and creating safety problems.

Floodways should be designed with a horizontal longitudinal profile so that the depth of water over the road is as uniform as possible over the flooded section.

Signaling

Floodways should have a warning sign. Depending on the depth of the flood, an indication of the road route and depths at different points on the road should be provided. Barrier rails and other barriers are a significant obstruction to flow over the avenue channel and should be avoided, but sticks may be used.

2.3 Deciding on armoring and scour protection of a floodway

Scour protection works are an important element in floodway design. The floodway sections that are prone to scouring are (in order of severity):

(a) Toe of the downstream batter slope
(b) Surface of the downstream batter slope
(c) Edge of the downstream shoulders
(d) Road surface
(e) Upstream batter slope

The causes of scouring at these positions are:

(a) The impact of overflowing flood water at supercritical velocity at the toe of the downstream batter slope
(b) The drag/shear resistance on the batter slope
(c) The uplift force caused by embankment geometry
(d) The drag/shear resistance on the running surface
(e) The effect of approach velocity

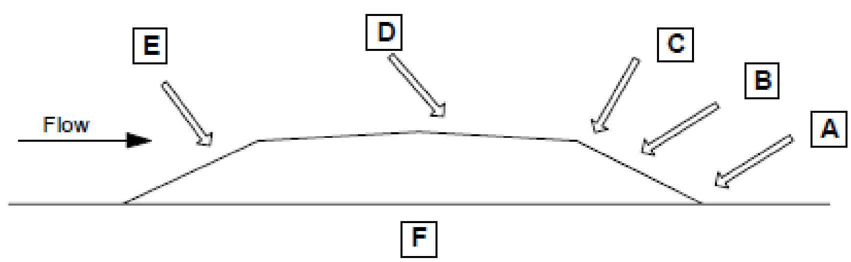


Figure 2. Scour Locations on a Typical Floodway

Scouring below the floodway can also cause failure (F). This scour is caused either by piping or riverbed instability due to sediment transport.

The first consideration in protecting the floodway from scouring concerns the choice of the armoring material. There are several options, the suitability of which depends on the availability of material, rock protection, and the likely flow velocity and potential scouring over the floodway. These options include:

- Concrete protection;
- Cutoff walls (end walls);
- Rock fills below the embankment;
- Cement-stabilized batter slope/embankment fill;
- Cement-stabilized subgrade/base course; and
- Two-coat bituminous seal.

To determine the level of protection required or the type of pavement to be used, the maximum flow velocity at various sections on the embankment cross-section needs to be calculated.

The peak velocity on the pavement (Vp) will always occur at the downstream edge just before submergence (supercritical regime).

During a low-tailwater condition, the flow will accelerate down the batter until one of three things happen:

i. It reaches a steady-state velocity. Under these conditions the maximum velocity attained by the flow occurs above the tailwater surface and equals the steady-state velocity.
ii. It penetrates the tailwater surface while still accelerating. Under these conditions the maximum velocity obtained by the flow occurs at the tailwater surface and will be less than that described by Manning's equation.
iii. It reaches the natural surface and remains supercritical until a hydraulic jump occurs further downstream. (Observations made in the field have shown that this does not usually occur and thus this condition will not be further considered here).

The steady-state velocity of flow on a slope (Vs) may be calculated from Manning's equation. Values of Manning's 'n' will vary: 0.012 for a batter protected with concrete slab and up to 0.06 for dumped rock.

Table 2. Values of Manning's 'n'

Pavement/Batter Protection	Manning's 'n'
Bitumen Seal	0.013-0.016
Concrete	0.012
Grass	0.030
Rock Mattress	0.050
Dumped Rock: Facing Class	0.055
Light Class	0.055
¼ ton	0.060
½ ton	0.060
1 ton	0.060

Manning's equation:

$$V_s = \left(\frac{1}{n} q^{2/3} S^{1/2} \right)^{3/5}$$

Equation (4)

A flow with an upstream head H above the crown and that is known to have a steady-state velocity (Vs) on the batter will achieve this steady state at a vertical distance Δp below the crown, such that

$$\frac{V_S^2}{2g} + \frac{q.\cos\theta}{V_S} = H + \Delta p = E_S$$

Equation (5)

Maximum velocity on the batter (Vb) will occur when the flow reaches steady state at the tailwater level, that is, when Δp. To simplify the analysis, flow on the batter is given by the simplified energy equation

$$E_S = \frac{V_S^2}{2g} + \frac{q}{V_S}$$

Equation (6)

Maximum batter velocity will occur at the transition discharge, when flow changes from plunging flow to surface flow. Vbo will be the lesser of Vs.

In this regime, we assume that the plunging flow will be decelerated below the shoulder level because of the high tailwater; thus we use Δp = p – downstream shoulder level. $V_m = K\sqrt{H}$

Equation (7)

Where:

Vm = the velocity of flow

K = a proportionality constant dependent upon the ratio Δp/H and is given in Figure 4.6.

The maximum velocity (Vp) on the pavement occurs at the downstream shoulder at submergence.

The velocity of flow for any other discharge may be calculated using a similar procedure.

For a discharge greater than the submergence discharge, Vp may be approximated as q/D.

Other flow characteristics that may be useful to know are the critical velocity and critical depth at the crown of the road:

Equation (8)

$$V_c = (\frac{2}{3} gH)^{1/2}$$

Equation (9)

$$y_c = \frac{2}{3} H$$

Note that these formulas are only valid for a free outfall type of flow, i.e. D/H < 0.76.

Additional measures

Several additional measures need to be considered to eliminate road damage due to scouring:

- Avoid the buildup of negative pressures caused by changes in flow direction. It is recommended that the shoulder be rounded with a radius of approximately 3.3 m.
- Use concrete slabs and pumping lining mattresses to make the surface and slopes impermeable.
- Construct spillways on the embankment and use drainage culverts to prevent pressure buildup.
- Avoid installing guardrails and posts near the shoulder downstream.
- Plant trees on the upstream and downstream batter of the floodway to reduce the velocity of the water flowing over the floodway.

Embankment batter protection

Downstream protection of floodway embankment batter slopes may be flexible or rigid. All protection should sit easy with the road pavement at the shoulder to avoid high pressure resulting in sharp steps or grade changes. Examples of flexible and rigid protection are listed below.

Flexible Protection

- Riprap: graded rock/stone dumped on a prepared slope. Hand-placed graded rock, which is inferior to dumped rock, is seldom used today.
- Gabion mattresses/rock mattresses: rocks placed in wire baskets or on wire-covered mats.
- Flexible mats, individual small high-density concrete blocks, cast onto geotextile loop matting.
- Flexible pump-up revêtement mattresses: concrete-filled nylon mattresses in which the concrete flows into discrete segments that are largely independent once the concrete has set, providing a degree of flexibility.
- Vegetative cover can form an effective scour-protection system for floodways where the embankment and approach velocity are low.

Rigid Protection

- Grouted rock: dumped or hand placed with the voids filled with mass concrete.
- Rigid pump-up revêtement mattresses: nylon mattresses into which a small aggregate concrete is pumped.
- Concrete slab protection: plain or reinforced concrete slabs poured or placed on the surface to be protected.

Rigid protection is susceptible to undermining by scour. Combinations of flexible and rigid systems may also be considered.

The use of a concrete cutoff wall at the downstream shoulder is recommended when high flow velocities are expected.

A permeable geotextile filter should be placed between the embankment fill and the flexible scour protection. A graded sand/gravel filter may also be used for extra protection.

Design tables for dumped graded rock and gabion mattresses are provided below.

Table 3. Design of Rock Slope Protection

Velocity (m/s)	Class of Rock Protection, Wc (tons)	Section Thickness, T (m)
<2	None	---
2.0-2.6	Facing	0.50
2.6-2.9	Light	0.75
2.9-3.9	¼	1.00
3.9-4.5	½	1.25
4.5-5.1	1.0	1.60
5.1-5.7	2.0	2.00
5.7-6.4	4.0	2.50
>6.4	Special	---

Table 4. Standard Classes of Rock-Slope Protection

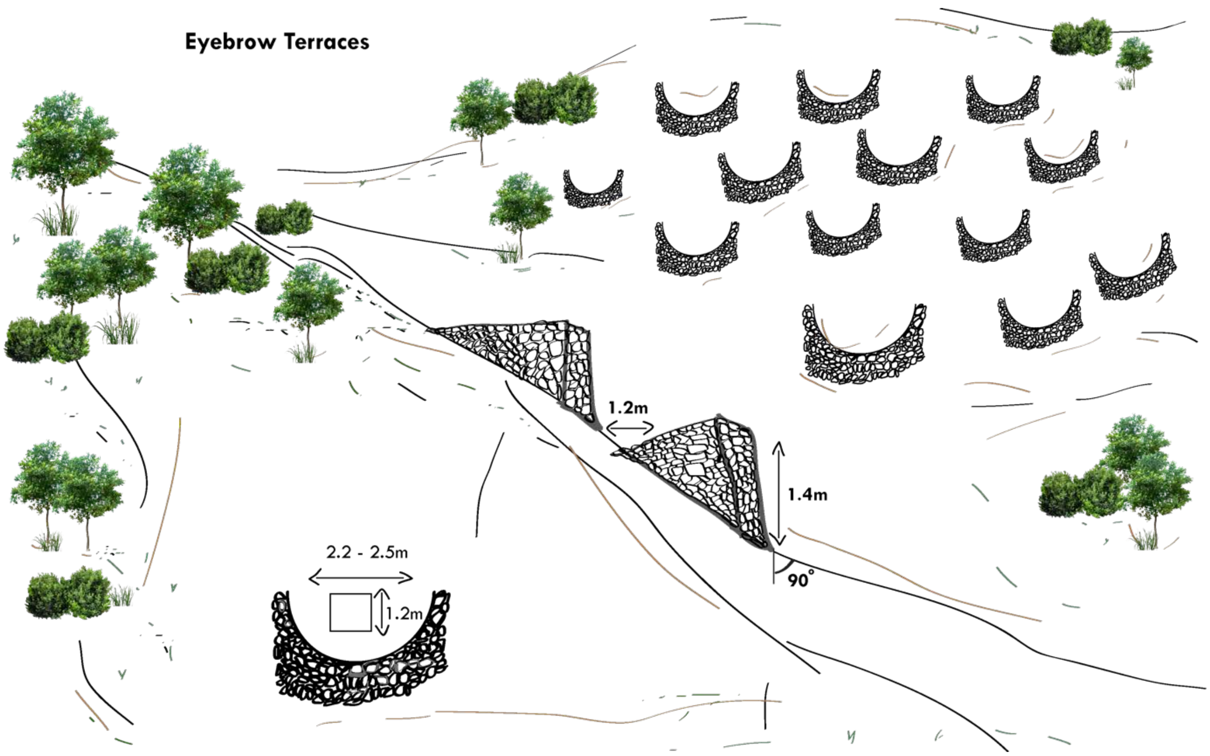
Thickness (m)	Rock-Fill Size (mm)	D50 (mm)	Critical Velocity (m/s)	Limit Velocity (m/s)
0.15-0.17	70-100	85	3.5	4.2
	70-150	110	4.2	4.5
0.23-0.25	70-100	85	3.6	5.5
	70-150	120	4.5	6.1
0.30	70-120	100	4.2	5.5
	100-150	125	5.0	6.4

Rock Class	Rock Size (m)	Rock mass (kg)	Minimum Percentage of Rock Larger Than
Facing	0.40	100	0
	0.30	35	50
	0.15	2.5	90
Light	0.55	250	0
	0.40	100	50
	0.20	10	90
¼ tons	0.75	500	0
	0.55	250	50
	0.30	35	90
½ tons	0.90	1000	0
	0.70	450	50
	0.40	100	90
1 tons	1.15	2000	0
	0.90	1000	50
	0.55	250	90
2 tons	1.45	4000	0
	1.15	2000	50
	0.75	500	90
4 tons	1.80	8000	0
	1.45	4000	50
	0.90	1000	90

ANNEX 6 Dimensions and spacing of eyebrow terraces and stone strips

Eyebrows/half moons are small, semi-circular and stone-faced structures that open in the direction of the run-off (figure 5.6). They can be built on steep slopes, usually with a maximum preferred slope of 50 percent, yet steeper gradients are possible, especially when rainfall is not torrential.

The steeper the gradient, the more the bunds have to be reinforced (by stone) in the downward toe and the higher the downward toe section becomes. The typical diameter of the eyebrow should be between 1.4-2.5 m with an infiltration or planting pit of size 40 cm wide by 50 cm deep. The suggested size of eyebrows with different gradients are given in Annex 7.



Sizes of eyebrows with gradient

Gradient	Stone ring diameter	Inner cross width	Backwall height	Reinforced backwall
30	30 cm	220 cm	70	-
45	30 cm	180 cm	120	10 cm
60	30 cm	140 cm	180	20 cm

Abundant spoil material can be used to build up the semi-circular eyebrows. The topsoil that was removed whilst making the road can be used to fill the inner side of the semi-circular stone structure. This can be used for tree planting and can contribute to the regreening of the area. Around eyebrows/half moon, controlled grazing is essential if the area is regreened. In the forest areas, it is good to have a high density of eyebrows (see Figure 10). The preferred distance between lines of eyebrow terraces is given in the table below.

Preferred distance between lines of eyebrows terraces

Gradient	Distance between lines of eyebrow terraces (meter)
30	15-20
45	10-15
60	8-10

Stone strips

The eyebrow can be complemented by stone strips or rock bunds, in particular on slopes that are relatively even and not too steep (<50 degrees). They are built from coarse stones and boulders (see Annex 1). These stone strips will slow down run-off, intercept sediment and built-up soil layers. They will stretch over the width of the slopes, allowing water to filter through, as they are permeable. See Figure 11 and Table 4.4 for layout and design of stone stripes for different gradients. In the atmospheric conditions of Karnali the stone bunds and the eyebrows will also act as dew traps in part of the year, including the important post-monsoon period when moisture availability is at a premium. This is particularly true for spoil that contains mica and that has high thermal conductivity and will cause the stones to cool off significantly at night, triggering the formation of dew.

The minimum criteria of the stone strips are:

Basic parameters for stone strips at different gradients

Gradient	Heigth (m)	Vertical Interval (m)	Distance between stone strips (m)
30	1	2.8	6
40	1	2.8	5
50	1	2.8	4

Note: though the table shows the possibility to build stone stripes even on a 50 percent slope, the field situation needs to be observed carefully when the slope increases.

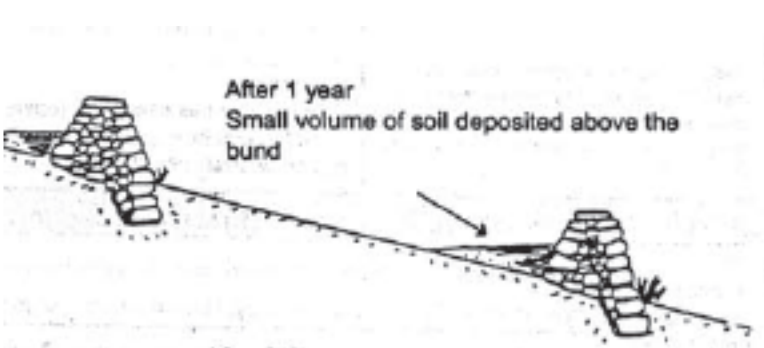


Figure 5: Side view of stone strips (from Lakew et al, 2015)

ANNEX 7 Sample Supplement Terms of Reference Road Programs

Contribution to Terms of Reference for Road Infrastructure Programs

Road infrastructure has a major influence on the environment immediately surrounding the roads. There is a genuine risk that this influence translates to negative impact in the shape of erosion, flooding, water logging, sedimentation, or even sand dune movement. Yet this influence can also be turned around and roads can contribute to better environmental management and beneficial water management[18]. As such, roads can make an important contribution to climate resilience. In many instances this also reduces the costs of road asset management and the risk of road disruption.

As part of the formulation of the infrastructure program, the consultant is required to investigate and report on the potential beneficial contributions of roads to environmental management and beneficial water use and identify the measures required.

The consultants are requested to look at three areas in particular:

(1) **Assess what measures can be built into the design of road and bridges infrastructure to ensure that roads contribute in a positive way to the environment and water resources surrounding them.** This can be the placing of culverts and road drainage so as to optimize run-off patterns for water harvesting; the optimizing of road embankment heights and overflow structures for flood management; the systematic conversion of borrow puts for water storage, the developing of road drifts that retain and store water in the river bed; the use of road embankments as dam walls for water storages; the gating of road culverts for the control of water levels; the inclusion of water bars and rolling dips in feeder roads to divert water to surrounding fields and prevent road erosion; the inclusion of flood shelters in road infrastructure; the aligning of road routes to control sand dune movement and optimize recharge and water harvesting areas.

(2) **Assess what additional measures are required to make use of the potential that roads and bridges offer for environmental management and beneficial water use.** This can be additional measures to channel water from road drainage for use in water harvesting; roadside tree planting and beneficial bioengineering programs or the incorporation of measures that reduce the risk of erosion and stabilize fragile environments and others.

(3) **Assess the additional institutional activities required to better integrate beneficial water management and pro-active environmental management into road programs.** This may be in the shape of modification to manuals and guidelines; changed budgeting systems, improved consultation and coordination processes; revisited maintenance arrangements; special workshops and training or pilot activities or modeling.

[18] For resource material see www.roadsforwater.org

ANNEX 8 Participatory rapid appraisal

Participatory Rural Appraisal techniques are social research techniques used in the field. These techniques require trained facilitators and substantial investments to be effective. They are aimed at strengthening the analyzing and decision-making power of the affected community. They can be used in program design, implementation, monitoring and evaluation. The activities described below are usually carried out in small focus groups. In this section the main methods are described.

Making a community map

Mapping

Community mapping is used to collect information from the community concerning the location of resources and land uses that might not be obvious from observation alone. This may help to explain how the community views their situation and where they see opportunity and constraints. This method is more effective when used by a small group, preferably representing women and men, working to produce a large sketch map of the area in which they live. In the context of road water harvesting, some important features to be mapped are:

1. **Main objects and topography in the landscape such as roads, villages, churches/mosques, big trees and rocks**. This will help the community and the practitioner to read the map.
2. **Water resources**: use different symbols to represent different types, different uses and availability during the year. If necessary, describe also the water quality;
3. **Soil moisture:** depict the areas where soil moisture is depleted faster and where the plants stay greener for longer;
4. **Accessibility:** draw all paths that people move across
5. **Hotspots:** places where there are special issues related to the roads and the relation with water.

Transect walk

Transect walk

Transect walks are systematic walks through a selected area from one side to the opposite side. During the walk the field worker observes the landscape and the local practices and at the same time he/she interacts with the community members encountered.

A transect walk is a precious tool because it allows the community to look at their area with an innovative point of view. The participants can stop during the walk and discuss what they are seeing around them. One can even decide to stop at fixed intervals – for instance every 100 meters and then make observations. It helps in visualizing processes that need to be understood in order to plan and implement road water harvesting measures. During the exercise a sketch is drawn taking into account the changes that take place in different locations of the area investigated.

Timeline

To better understand how thing evolved, a timeline is constructed. It also helps to put the present in context and see how things may turn out.

Questions can be asked on different important aspects—like the main economic activity, means of transport, population settlements and more. To refresh the memory, important events can be used—such as what the road connection was like during the time of the last election.

The development of these timelines helps to collectively understand the past and future trends better.

Ranking

In the ranking or scoring exercise, community members are asked to list their priorities in terms of their water needs. It helps communities to prioritize solutions and challenges. It simply implies giving a score (vote) to the different discussed items and then prioritizing according to the items that got the most (or the least) votes.