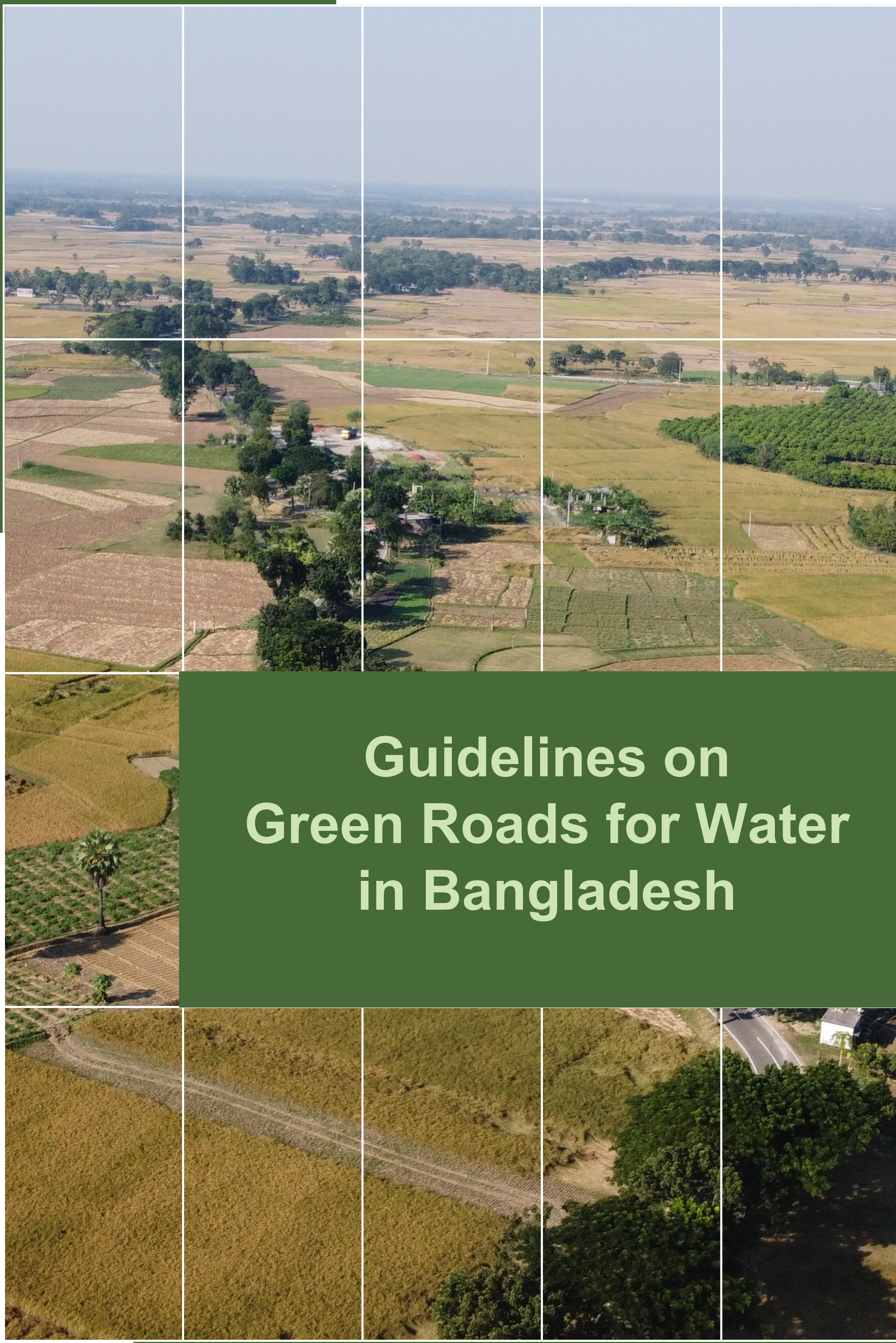

# Guidelines on Green Roads for Water in Bangladesh

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# Acknowledgements and note for reader

These guidelines aim to lay the groundwork for systematically integrating water management and climate resilience into LGED's road development and asset management program. With more than 400,000 kilometers of roads under the care of LGED, the imperative to combine road network operation with water management is huge: to preserve the connectivity in the road network as well as to optimally use the road network for disaster risk reduction, beneficial water use and land management, and many other functions: biodiversity, quality of life, and climate resilience.

These Guidelines provide an overview of key opportunities and challenges, along with practical guidance for implementation.

The Guidelines have been prepared as part of the project "Consultancy Services for Increasing Resilience of Rural Infrastructure and Local Communities through the Green Roads Concept", implemented by GOPA MetaMeta and ADSL. This work was made possible with support from the Global Facility for Disaster Reduction and Recovery (GFDRR), administered by the World Bank.

The development of the guidelines was informed by fieldwork and validation at both central and regional levels and built upon LGED's existing technical frameworks. A series of meetings was organized across all five hotspot regions in Bangladesh, and transect surveys were done of designated road sections. A number of in-house workshops were held at LGED, and a national stakeholder meeting was organized on 19 August 2025. The guidelines also benefited from the people's adaptation planning processes for Green Roads for Water project in Rajshahi, with support from Global Affairs Canada through the Global Center on Adaptation.

Additionally, they draw on the *Global Guidelines on Green Roads for Water and Climate Resilience* (World Bank, 2021). They also made use of the *Guidance Note - Recommended Good Practices: Road Development to Support Water Management and Flood Resilience (*Global Resilience Partnership, 2018), that first explored this topic in Bangladesh with contributions from all main stakeholders.

The core writing team comprised of Dr, Frank van Steenbergen, David Mornout, Md. Zahidul Islam, Anastasia Deliganni, Md. Shamsul Haque, Dr. Md. Saiful Islam, and Dr. Md. Lutfor Rahman. Extensive guidance and support were provided by Eng Dewan Abdus Sabur, Dr. Frederico Pedroso, B K M Ashraful Islam, Md. Shahrior Alam, Gordon Keller, Dr. Anisul Haque, Dr. Md. Saif Uddin, Zahidur Rahman, Ashik Khan, Alamgir Chowdhury, Dr. Md. Akram Hossain, Minhaj Kamal Faruqui, Saroj Yakami, Madiha Al Junaid, Mehmet Görüş, Md. Hasibul Hasan, Daan Boom, Shahrin Mannan, Natalya Stankevich, and Dr A K M Lutfur Rahman.

The guidelines are intended to be used in addition to the existing relevant manuals and guidelines LGED uses in its work program. These manuals and also other outputs developed under this projects as well as other relevant policies, reports, and outputs from LGED and others, will be made available via https://roadsforwater.org/bangladesh-green-roads-for-water/.

*This document represents the final draft and is pending approval from LGED.*


Validation workshop


Road assessment in Netrokona


Consultation in Barishal


Consultations in Bagerhat

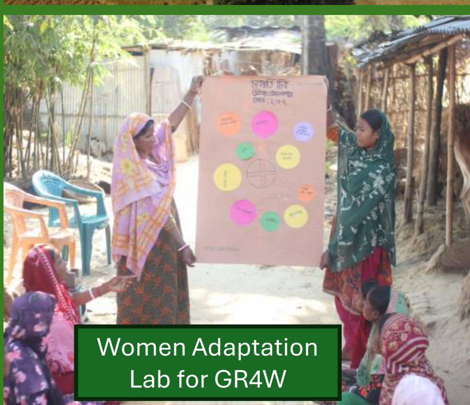

Consultations in Dinajpur

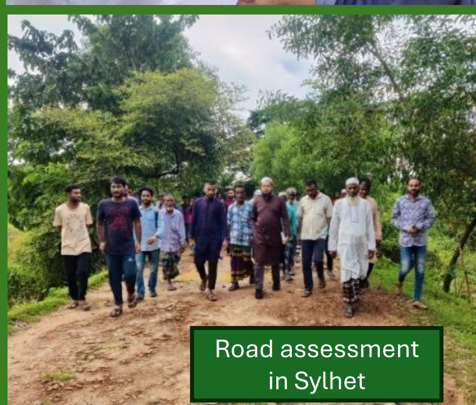
Validation workshop


Green corridor in Barind


Consultations in Rangamati


Officers providing input on GR4W


Women Adaptation Lab for GR4W


Road assessment in Sylhet


Validation workshop


Focus group discussion in Hill Tracts


Road and landscape in Barishal


Meeting in Sirajgonj

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# 1. Setting the Scene

Rural roads and bridges in Bangladesh have been critical to the growth of Bangladesh's rural and national economy and to the welfare of its citizens – creating access to health care, schools, markets, and social contacts. They have dramatically reduced travel time and costs (45%), increased access to clinics, hospitals, and schools (11-20%), brought markets to life, increased farmers' prices (20-30%), and reduced input costs (5%). No wonder this had a profound effect on socioeconomics, with road development reducing poverty by at least 4-15%, depending on the period in which it was measured.

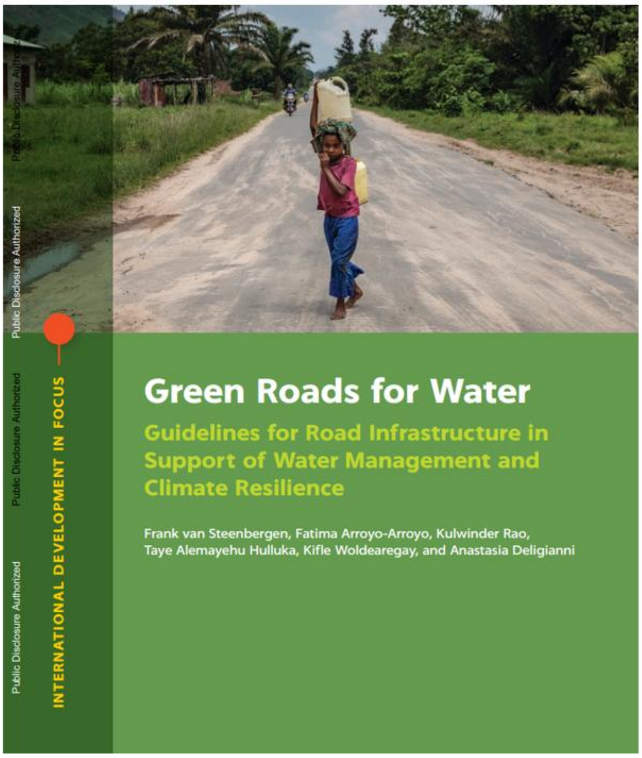
Roads and bridges are, however, not only gamechangers in socio-economic development. The road network, as it has evolved in Bangladesh - and still is – also has had a major imprint on the hydrology and landscape of the country. Bangladesh has one of the highest road densities in the world – at 164 meters per square kilometer. Roads have changed the country's topography and fragmented the landscape, with embankments running across the low delta land and the faces of hillsides altered. The national drainage system is redefined deep within its fine mesh by bridges, culverts, or their absence.

There are only a few interventions that have such an impact on water management in Bangladesh as the construction of roads. At present, however, the effect of roads on water management is often negative. Road construction undermines local water management: roads and bridges, among others, cause waterlogging, uncontrolled flooding, accelerated erosion, and the silting of tidal rivers.

It is not only the story of damage done, but also a story of opportunities missed. There is a tendency to view roads, bridges, culverts, and drains solely as transport infrastructure, rather than as hydraulic structures. Yet there is considerable scope for an integrated approach in which roads can become instruments for water management and flood and climate resilience. This is at the center of the **"Green Roads for Water"** concept.

Combining road development and planning with water management can bring multiple benefits. These are: better water storage, enhanced recharge, less waterlogging, better flood control and more effective flood response, enhanced biodiversity, and stabilization of rivers and hillsides.
Combining road development with water management also leads, if well done, to less road damage: reduced maintenance costs and less downtime. It is often said that the three main enemies of roads are (1) water, (2) water and (3) water. Indeed, water-related damage is a major factor in managing the road network. But as the relation is intimate, they can also be turned around in a positive – with Green Roads helping to preserve roads and optimize their functionality.

Green Roads for Water encompasses interventions in the planning of the road network, the development and maintenance of the main structures, and the use of the land immediately surrounding the road. It includes optimizing road embankments for flood control and flood relief, using road bodies for water harvesting, creating water storage with bridges and bridge sills, controlling water levels for agricultural production, removing drainage congestion and water logging, systematically introducing road side vegetation for multiple purposes, Central to the integrated approach of the Green Roads for Water concept is local participation, where the voices of roadside communities and the priorities of local governments inform and shape road development and maintenance.



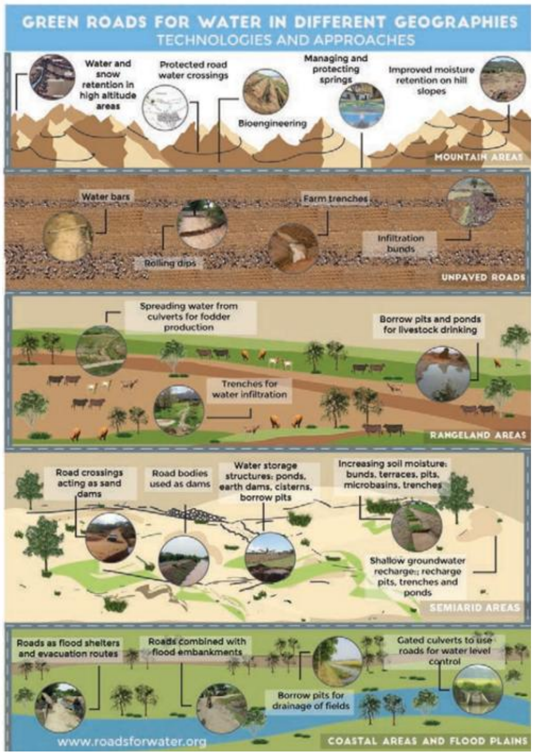



*Figure 1 - Global Green Roads for Water Guidelines (left) and the applicability of Green Roads for Water in different landscapes globally*

In 2021, the World Bank published Green Roads for Water: Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience (van Steenbergen et al., 2021). It provides strategies for using roads for beneficial water management tailored to diverse landscapes and climates, including watershed areas, semi-arid regions, coastal lowlands, mountainous areas, and floodplains.

The current guidelines build on this and describe the many opportunities and techniques relevant to Bangladesh. Green Roads for Water can make a big contribution to several challenges in Bangladesh. LGED's extensive road network - spanning over 400,000 kilometers - holds significant potential to enhance climate resilience and water management. The strength of the road sector is its presence everywhere with large and systematic opportunities to address major water, land, biodiversity and, transport challenges. The opportunities are illustrated by ten key potentials outlined below.

*Box 1 – Potential of Green Roads for Water in Bangladesh in 10 key points*

**Potentials of Green Roads for Water in Bangladesh in 10 key points**

**1. Reduce maintenance costs and reduce downtime**

As water is a major cause for road failure and maintenance costs, Green Road for Water reduces the spending requirements in road maintenance, starting with improving road maintenance problem spots rather than just restoring these. This will help reduce the maintenance funding gap.

**2. Enhance disaster risk reduction**

Disaster risk reduction is greatly enhanced by systematically mainstreaming this in road design and asset management – by raising roads and creating safe shelters, and by first- and second-level flood protection. This is important, as roads are lifelines during disasters..

**3. Enhance water storage in the system**
Roads can be used for water harvesting and retention, providing water security in water-stressed areas. In dry areas, shuttered bridges, heightened bridge sills, and gated culverts can help store water in the rivers and streams.

**4. Reduce waterlogging and increase agricultural production**
By systematically removing the blockage of natural drainage by roads and bridge sills, in amongst others the riverine areas and the coastal zone, waterlogging can be greatly reduced. This provides a significant boost to agricultural production and reduces disease.

**5. Safeguard moisture in the haor wetlands**
By designing roads, cross-drainage structures, and overflows in the Haor, they can help guide the recession of the floods. With this, the period of available soil moisture can be extended.

**6. Improve water level control – and agricultural production - with gated culverts**
By systematically introducing gated culverts in rice-growing areas, water control can be enhanced for HYV Amon Paddy, doubling yields and shortening the growing season, freeing up land for an additional crop.

**7. Protecting tidal rivers**
By avoiding too narrow ‘choking’ bridges in the Southwest of Bangladesh, tidal rivers can be salvaged.

**8. Control erosion and restore spring discharge**
At the landscape scale, bioengineering and spring shed protection around roads can help control erosion. Rubble from road construction can be used to retain water on hill slopes. This can help reverse the decline in spring discharges in the Chattogram Hill Tracts.

**9. Use sediments beneficially**
By responsible sourcing, excess sediment in low-lying areas can be put to good use for local road construction, boosting desilting. Borrow pits and borrow trenches for road construction can also be developed systematically as water storage or recharge structures.

**10. Support in-land fish production**
By tailoring culverts and other cross drainage structures to accommodate fish passages, fish capture can be enhanced importantly.

These guidelines first give a background to the road sector in Bangladesh (section 2), describing the different categories of roads and the running distances. This is followed by a chapter (section 3) on preconditions and the enabling environment for Green Roads for Water.

It then, in section 4, gives an overview of the opportunities for Green Roads for Water in the main geographies of Bangladesh, coinciding with the five rural hotspot regions, identified in the Bangladesh Delta Plan 2010: the Coastal Region, the River Systems and Estuaries, the Chattogram Hill Tracts, the Barind and Drought Prone Areas, and the Haors and Flash Flood Areas.

Section 5 is a deep dive into the main elements of the road system: embankments, road drainage, bridges, unpaved roads, and two special structures: borrow pits and roadside springs. Section 5 also describes roadside vegetation and bioengineering. For all these road elements, guidelines are given to optimize their hydraulic performance and contribution to water management, whilst safeguarding transport connectivity.

Section 6 is then a short perspective on the future, describing the elements of a transition towards green roads that goes well beyond the domain of water. Apart from the water and land focus of green roads for water, green roads reduce pollution, support restorative and regenerative ecosystems, and enhance safe and affordable mobility of people to deliver inclusive low-carbon, resilient development and environmentally considerate outcomes.

In addition to the different options and measures described in the Guideline, Annex 1 provides a worksheet to guide the planning of Green Roads Measures. The sheet helps identify the different road sections where Green Roads for Water measures may be implemented and provides a first indication of possible options. It is meant to inform the plan for upgrading roads and regular maintenance, with the idea of not just restoring or rehabilitating, but of 'building back better'. The sheet should be used by the district teams of the LGED to systematically screen the road networks under their jurisdiction and identify measures to be taken, either as part of new road construction or as part of the maintenance and repair program. The different measures are described in this Guideline, in particular in section 5.

## 2. Background

*Figure 2 - Road in coastal zone of Bangladesh*

### 2.1 Road program of LGED

LGED is managing a vast rural road network. Rural roads are critical to the growth of the rural and national economies and to the welfare of their citizens. Bangladesh has one of the highest population densities + one of the highest road densities in the world, at 164 meters per square kilometer. Besides connecting people and places, roads also fragment the landscape and interrupt the natural flow of water, which is pivotal to consider everywhere, but especially in a riverine deltaic country such as Bangladesh, with numerous crisscrossing rivers and canals and discharging huge amounts of water and sediments. Currently, the impact of roads on local hydrology is often neglected in road design in Bangladesh. But systematically integrating water management functions into road development will enhance climate resilience, improve water management, and prolong road life.

Green Roads for Water (GR4W) offers a powerful framework to address some of the most persistent water-related challenges in Bangladesh, including flooding, drainage congestion, erosion, waterlogging, and climate-induced damage to infrastructure. Roads play a defining role in shaping local and regional hydrology, and when planned, upgraded, and managed with water in mind, they can become key assets for improved water management rather than sources of disruption.

The large-scale upgrading, rehabilitation, and maintenance of roads – at all levels (see table 1) - across Bangladesh provides a significant opportunity to systematically integrate GR4W principles into road development. By embedding water-sensitive design and management measures - such as improved drainage, controlled conveyance, water retention, and infiltration - road investments can simultaneously enhance connectivity, reduce water-related damage, and contribute to climate resilience and local water security.

*Table 1 - Different types of roads in Bangladesh (Source: Planning Guidelines for Rural Road Master Plan, LGED GIS Unit, 2010)*

| # | Type | Definition | Ownership and responsibility |
|---|---|---|---|
| 1 | National Highway | Highways connecting National capital with Divisional HQs or seaports or land ports or Asian Highway | RHD (Roads and Highways Department) |
| 2 | Regional Highway | Highways connecting District HQs or main river or land ports or with each other not connected by national Highways. | RHD |
| 3 | Zila Road | Roads connecting District HQ/s with Upazila HQ/s or connecting one Upazila HQ to another Upazila HQ by a single main connection with National/Regional Highway, through shortest distance/ route. | RHD |
| 4 | Upazila Road (UZR) | Roads connecting Upazila HQ/s with Growth Center/s or one Growth Center with another Growth Center by a single main connection or connecting Growth Center to Higher Road System, through the shortest distance/route. (Former Feeder Road Type-B) | LGED/LGI |
| 5 | Union Road (UNR) | Roads connecting union HQ/s with Upazila HQs, Growth Centers, or local markets, or with each other. (Former Rural Road Class-1 (R1) | LGED/LGI |
| 6 | Village Road (VR) | a) Roads connecting Villages with Union HQs, local markets, farms, and ghats or with each other. (Former Rural Road Class-2 (R2)<br>b) Roads within a Village. (Former Rural Road Class-3 (R3) | LGED/LGI |

LGED is the custodian of more than 400,000 kilometers of roads. The footprint is enormous. Most roads in Bangladesh are rural (94%). 9.5% of the rural road network comprises Upazila Roads, and 11.2% comprises Union Roads. A large Majority of Bangladesh's roads (63%) are unpaved, with a smaller part (37%) paved (figures from 2017).

*Table 2 - Road types and lengths*

| Road Type | Earthen Length (km) | Paved Length (km) | Total Length (km) | Bridge/Culvert Length (m) | Gap Length (m) |
|---|---|---|---|---|---|
| Upazila Road | 2,435.35 | 34,337.47 | 36,772.82 | 444,092.26 | 79,205.60 |
| Union Road | 8,542.36 | 33,560.06 | 42,102.41 | 355,765.25 | 81,732.18 |
| Village Road A | 94,985.04 | 54,921.41 | 182,355.34 | 510,231.88 | 192,987.76 |
| Village Road B | 143,851.93 | 38,503.41 | 149,906.45 | 344,134.43 | 184,741.63 |
| Total Roads | 249,814.67 | 161,322.35 | 411,137.03 | 1,654,223.81 | 538,667.16 |

## 2.2 Benefits and principles of GR4W

Water is the single most influential factor affecting the performance and longevity of road infrastructure. While it is often regarded as the primary enemy of roads, this reality also highlights the central role that water management can play in improving road resilience. Research shows that water is responsible for approximately 80 percent of damage to unpaved roads (Chinowsky and Arndt, 2012) and about 30 percent of damage to paved roads. This makes water management a critical area of focus in road development and maintenance.

To date, road design and management have largely concentrated on controlling water to minimize damage to the road itself. As a result, the broader impacts of roads on surrounding landscapes and surface hydrology have often been treated as secondary considerations. This narrow focus has not only led to unintended negative effects on natural hydrological systems but also to missed opportunities to use roads as instruments for improved water management.

Historically, rural road planning in Bangladesh has prioritized construction and repair, with limited integration of hydrological data or watershed-scale analysis. LGED, which is responsible for the development and maintenance of rural roads, operates under the Rural Roads and Bridges Maintenance Policy, in which routine and periodic maintenance are emphasized with less attention to constantly 'build back better'. While GIS tools are increasingly used, detailed settlement-level spatial data along rural road corridors remain limited, constraining more integrated planning approaches.

Climate change, however, underscores the urgency - and the opportunity - for change. Increasing rainfall variability, more intense storms, flooding, and prolonged dry periods make it essential to design roads that are not only climate-resilient but also actively contribute to better water resource management.


*Figure 3 - Photos illustrating water as the prime enemy of road infrastructure*

Green Roads for Water (GR4W) represents a positive shift in how road projects are conceived and delivered. It promotes an integrated design process that brings together local communities and stakeholders from the social, environmental, water, and agriculture sectors. By rethinking how roads interact with their surrounding landscapes, GR4W transforms roads from potential barriers into multi-functional assets -reducing negative impacts while maximizing their potential to store, convey, and manage water.

In doing so, GR4W enables road infrastructure to support climate resilience, improve local water conditions, and deliver tangible benefits to communities living along road corridors, turning a long-standing challenge into a shared opportunity for sustainable development.

In the context of Green Roads for Water, one can recognize three levels of resilience, being basic resilience, which focuses primarily on protection, adaptive resilience, and lastly proactive resilience. Basis resilience has the objective of protecting road infrastructure, while adaptive resilience aims to make the best use of, and adapt to, hydrological changes introduced by a road.

Ultimately, proactive resilience aims to redesign road infrastructure to optimize the area's water management and climate resilience, often to benefit livelihoods. Green Roads for Water primarily focus on proactive resilience, and on making use of the opportunities that managing roads and water together can deliver.

# 3. Enabling environment

Implementing and scaling GR4W depends not only on technical design choices but also on the institutional, social, and governance conditions within which roads are designed, built, and maintained. This section outlines key enabling factors in this regard. These include interdisciplinary collaboration across sectors (3.1), meaningful local engagement (3.2), considerations regarding maintenance and asset management (3.3), and the involvement of women and vulnerable groups (3.4). Annex 2 elaborates on this chapter and enlists changes in road management, planning, and budgeting that are conducive to GR4W.

## 3.1 Interdisciplinary collaboration

The Green Roads for Water approach sits at the interface of roads and water – but also agriculture, climate, and disaster risk management. GR4W can succeed through and benefit from systemic collaboration that breaks traditional sectoral silos and values multidisciplinary benefits. Hence, it is essential to establish regular communication and coordination mechanisms between the road sector and other relevant sectors. Projects should be planned and implemented with input from various disciplines and community representatives to ensure that all benefit areas that road development can cover are optimized.

At the conceptual level, GR4W promotes a shift from single-purpose infrastructure to multi-functional systems that deliver transport, water, and ecosystem services simultaneously. This requires rethinking institutional boundaries: the road sector must work with agencies that manage water, agriculture, forestry, and local development to optimize shared outcomes. To operationalize this, cross-sector platforms or "Road–Water Task Forces" may be established at both national and regional levels. These may be formed through the capacity strengthening efforts and include those closely involved in the pilots.

## 3.2 Locally led processes and community engagement

Over the last two decades, the Bangladesh government's focus on national climate change adaptation policies has gradually shifted from 'community engagement' to 'enhancing community resilience and promoting local leadership', paving the path for the integration of locally led adaptation into the day-to-day reality. This also applies to the road sector. In this regard, it is worth noting that the National Adaptation Plan (2023-2050) (2022) elaborates on the need to acknowledge locally led adaptation as essential to catalyze effective, equitable, and transparent adaptation solutions based on local priorities and realities.

In Rajshahi, the Global Center on Adaptation (GCA) and its partners – GOPA MetaMeta, Socioconsult Ltd., and WAVE Foundation, are supporting locally led planning processes for two rural roads. Women from the hinterlands of these two selected roads - in Godagari and Mohonpur upazilas - are leading these locally led planning processes.

The framework for this is the GCA's People's Adaptation Planning Process. This process consists of a sequence of activities (Figure X) which ultimately culminate in the development of People's Adaptation Plans. The process may be followed in local road asset planning. Three core features define the People's Adaptation Process:

- **Locally led, evidence-based, and inclusive**: Planning is driven by community members, in partnership with government and non-government organizations. The process is inclusive down to the household level, with each household consulted on vulnerabilities and priorities. The planning relies on locally generated, disaggregated data (gender, age, disability) and is complemented by climate risk information from meteorological, research, and scientific institutions.

- **Multisectoral**: The community identifies key sectors of importance to them, and then the planning process ensures coordination across those sectors and institutions (government, non-government, and research) for coordinated rather than fragmented decision-making and investments. For example, infrastructure planning for roads, sewers, water pipes, and waste management must be coordinated for effective flood control.
- **Aligned with government systems**: Local government engagement is central, along with existing formal and informal governance structures and institutions. Where possible, plans are aligned or integrated with national and local strategies, including development plans, land use plans, and urban master plans.

The People's Adaptation Planning Process has so far mainly been used in the context of rural and urban settlements, and not yet for roads. In the pilot in Rajshahi, ongoing at the time of the development of these GR4W guidelines, this process is therefore tailored to the context of roads, which connect different geographies rather than represent them. As an outcome of this pilot, also a manual on how to scale People's Adaptation Planning process for rural roads will be developed and made available in 2026.

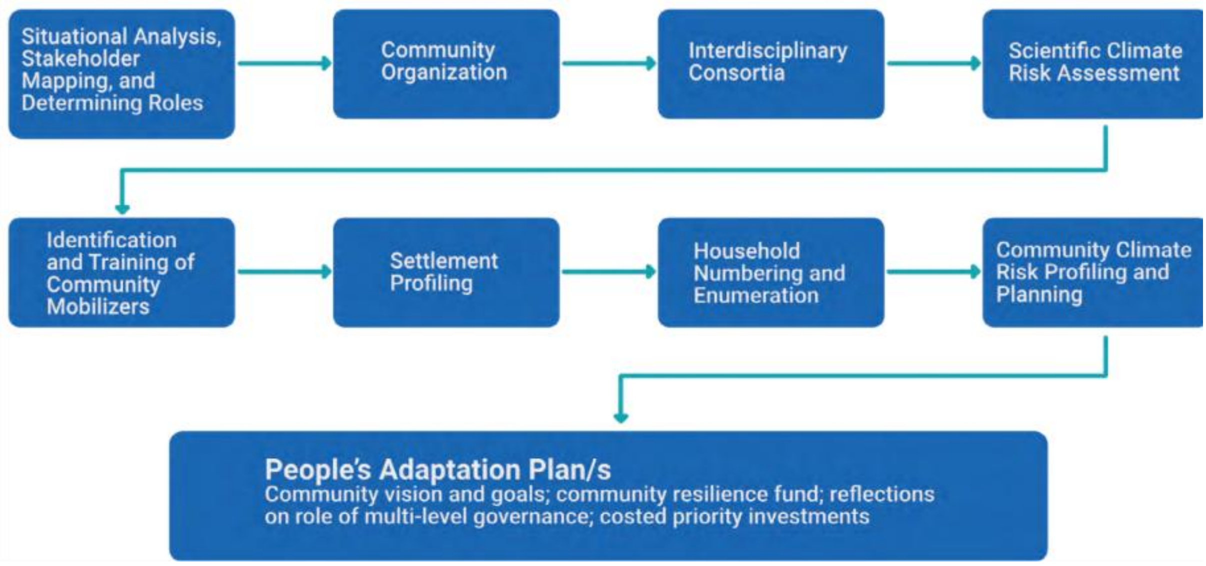



*Figure 4 - The People's Adaptation Planning Process*

**Tailoring the People's Adaptation Planning Processes to roads: Experiences from Rajshahi**
Central to people's adaptation planning processes is the leadership of local actors from start to finish. To operationalize this, in Rajshahi, following a training, 24 women enumerators – themselves all living along the roads covered in the pilot - completed a rapid census of 2,141 households and a detailed survey of 1,100 households to map local climate vulnerabilities and risks.

A second round of capacity-building equipped 14 community mobilizers with practical tools and facilitation skills to guide women's groups in developing locally led adaptation plans. Over five days, the mobilizers learned to connect road design with community priorities through participatory methods such as transect walks, resource mapping, and seasonal analysis. Field exercises in nearby villages enabled them to translate technical concepts into actionable community dialogues - turning women into facilitators of resilience.

The mobilizers subsequently conduct Focus Group Discussions (FGDs) across 15 villages (*mouzas*), using the participatory tools to help local women identify key road–water challenges and co-create feasible solutions. Each discussion began with sharing findings from the household survey, validating local insights, and visualizing the road network through mapping exercises. Together, the groups outlined problems, proposed solutions, and defined roles for communities, government, and landowners in maintaining Green Roads for Water.

*Figure 5 - Left: Training for community mobilizers with practical tools and facilitation skills to guide women's groups in developing locally led adaptation plans. Middle and Right: Focus Group Discussions.*

The mouza-level plans developed through these sessions were subsequently consolidated into road-level adaptation plans and validated through Women's Adaptation Labs (WALs). These labs will serve as interactive spaces where women representatives, community mobilizers, local leaders, engineers from LGED, and Union Parishad officials come together to discuss and refine proposed road–water solutions.

Through the labs, women presented the findings from their community sessions, shared practical insights, and jointly assessed which interventions are most viable for implementation. Technical experts helped translate local priorities into design and maintenance actions, while local authorities will guide alignment with existing road development plans. The WALs also helped identify potential areas for co-financing, maintenance partnerships, and follow-up monitoring.

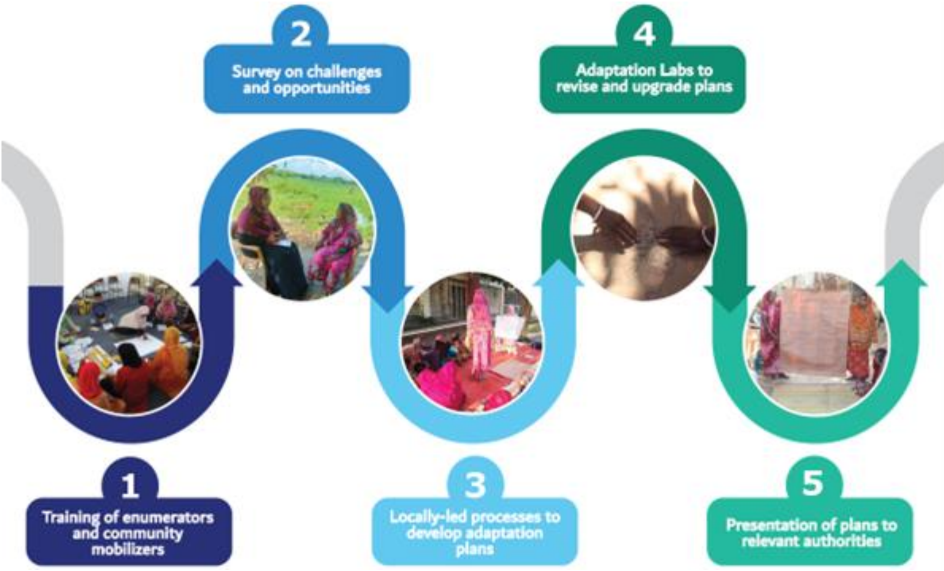



*Figure 6 - Summary of the process followed to in the development of locally-led adaptation plans for Green Roads for Water in Rajshahi*

### Preliminary guidance on scaling local engagement and local adaptation for GR4W

Building on the learning from the pilot in Rajshahi and on the framework for the People's Adaptation Planning Process, the table below outlines an initial overview of how to scale such local engagement and drive locally led adaptation planning for GR4W. This overview may be used to systematically organize community engagement for rural roads.

*Table 3 - Preliminary guidance on scaling local engagement and local adaptation for GR4W*

| # | Step | Elaboration |
|---|---|---|
| **1** | Situational analysis, stakeholder mapping, and determining roles | - Map key stakeholders around the road, with the goal to determine and divide roles in the planning process and in the next steps.<br>- Analyze the situation and context from multiple disciplines. |
| **2** | Community organization | - Work with existing community groups or develop representative groups that can be engaged in developing the people's adaptation plan for the road.<br>- Entry points for such groups can – amongst others - be established water management organizations, value chain groups, and credit and savings groups. |
| **3** | Interdisciplinary consortia | - Ensure that stakeholders and authorities from relevant authorities and interests are represented in the development of the plans, as well as in the subsequent roll-out. |
| **4** | Scientific climate risk and hydrological assessment | - Assess current and future climatic and hydrological features of the road and its surroundings, both upstream and downstream.<br>- Assess the risks and opportunities (especially in water management) faced by the road. |
| **5** | Identification and training of community mobilizers (optional) | - Train residents to be engaged as co-researchers to undertake data collection and other activities.<br>- The level of engagement of local community is depending on the context and priorities.<br>- The step can be replaced by working with local LGED staff or partners. |
| **6** | Road profiling | - With key stakeholders, get a broad understanding of the different risks and challenges faced by local communities, as well as the opportunities there are with integrating water management into the roads domain. |
| **7** | Survey | - Conduct a survey with a sample of households living in the proximity of the road to gather data related to challenges, requirements, and opportunities for local communities.<br>- The survey should consist of questions related to design, planning, construction, and O&M – exploring the role the local communities can have in each of them. |
| **8** | Community risk profiling and planning | - One or a series of dialogues and group discussions,<br>- Discuss risks – in areas of climate, water, and beyond.<br>- Diagnose impacts.<br>- Evaluate strategies and ideas for potential solutions to address these impacts.<br>- Assess opportunities and barriers to implement the proposed solutions. |
| **9** | People's adaptation planning | - With the community, represented by group members and local government, develop a list of costed priority interventions.<br>- Ensure consideration of people's adaptation plan in investment priorities of road projects. |

## 3.3 Maintenance and building back better

The management of LGED's enormous portfolio of road assets provides many benefits for optimizing road development and water management. To fully realize these benefits, GR4W must be integrated into asset management practices. Effective asset management provides a strategic framework to link planning, budgeting, performance-based delivery, operation, and monitoring with broader water management and resilience objectives. LGED has made important progress in this direction through the development of its Asset Management Policy (AMP) and Strategic Asset Management Plan (SAMP), which define the principles and requirements of LGED's Asset Management System (AMS). The publication of the SAMP in 2020 (LGED, 2020), following the development of an AMS roadmap in 2019, confirms LGED's commitment to continuous improvement through iterative planning and performance assessment.

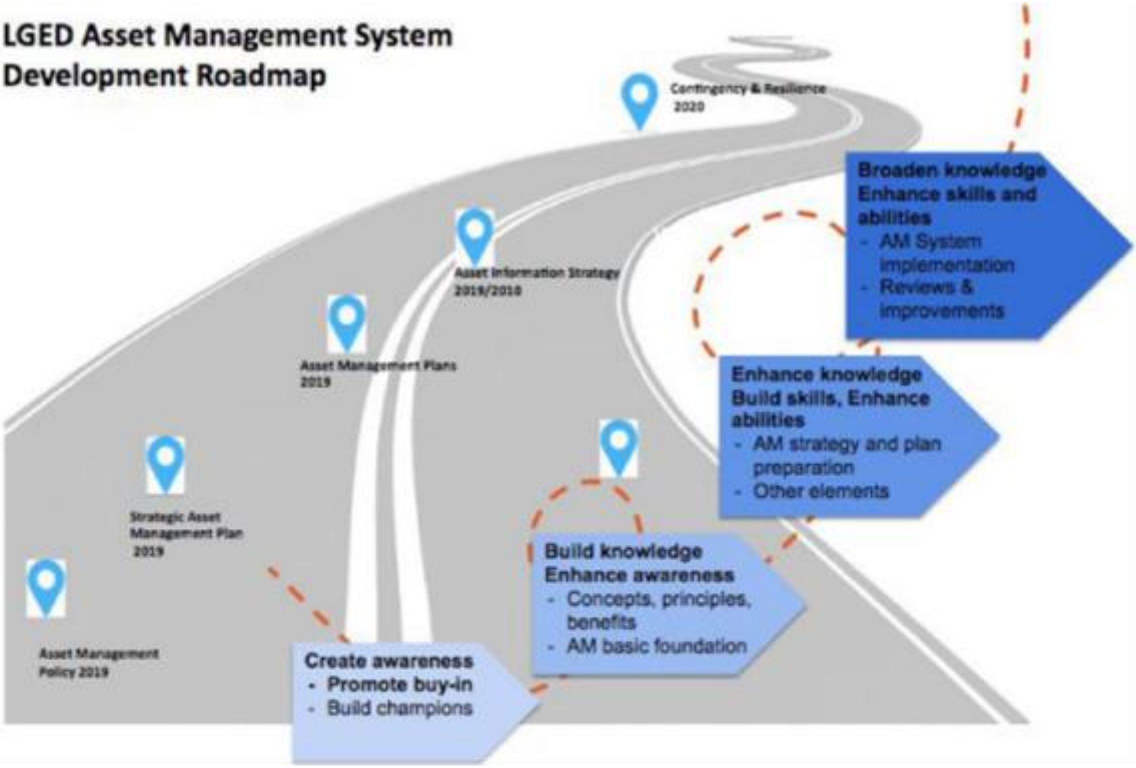



*Figure 7 - LGED Asset Management System Development Roadmap, linked to LGED's Professional Development Strategy (blue boxes) (LGED, 2019b)*

Integrating GR4W within asset management enables a strong *Building Back Better* approach. Many recurring road failures are water-related, and GR4W provides practical solutions to address these root causes. Instead of restoring damaged road sections to their previous condition, rehabilitation and maintenance activities can be used to incorporate water management improvements within existing road infrastructure. This approach reduces future risks, extends asset life, lowers maintenance costs, and delivers tangible benefits for surrounding communities.

By placing GR4W at the core of road upgrading and asset management, LGED can transform roads into multi-functional infrastructure that supports connectivity while actively contributing to better water management and long-term climate resilience across Bangladesh.

## 3.4 Engagement of women and vulnerable groups

Special consideration must be given to the engagement of women and vulnerable groups, not least because cultural, economic, and other barriers often bar them from full and equal participation in community discussions and in the implementation of community programs. It is sometimes safe to assume that women or members of vulnerable groups are unlikely to share all their concerns and experiences in the presence of the whole community.

For example, even when a road agency deliberately invites women to participate in public forums, men in their families may discourage them from attending or participating as equals; if women do attend, it is not safe to assume their presence in a meeting is sufficient. Understanding these community dynamics is essential to ensuring effective community engagement. It may be necessary to engage women as facilitators and to host women-only discussions (or discussions exclusively with members of vulnerable groups). This process will enable a broader range of perspectives to be expressed, open new opportunities for understanding the community's needs, and establish female role models in their own right - women who move about freely, exert influence over decisions, have much to offer in skills and knowledge, and who are unafraid to do so. Some of the same concerns about women's participation could also apply to other vulnerable groups.

Research in Ethiopia (Abhishek et al., 2020) as well as a pilot in Bangladesh (2025-2026) show that there is a strong demand among women for both road use and employment opportunities in road construction. Compared with men, women demonstrated specific priorities for rural road development, such as access to ambulance services, flat, wide, and levelled roads, and improved access to means of transport. Although women's concerns have been slowly but steadily pushed up the planning agenda, there are gaps between gender provision in rural road development and implementation. The benefits of roads for women can be enhanced by targeting gender mainstreaming measures to account for women's specific travel and transport needs.

**Findings from Rajshahi**

As part of the People's Adaptation Planning Process for the GR4W in Rajshahi, a household survey was conducted among 1,622 households living along two rural roads in Godagari and Mohanpur Upazilas. The table below synthesizes key survey results and field-based insights on issues relevant to women and translates them into implications for women's wellbeing and practical considerations for GR4W planning and implementation.

*Table 4 - Women and Green Roads for Water - Key findings from survey in Rajshahi along two rural roads*

| Women-relevant issue | Key learning from the survey | Implications for women | Considerations for GR4W planning & implementation |
|---|---|---|---|
| **Basic road access to services/markets** | Most households use asphalt/pucca roads (76.1%), while 21.3% rely on earth and concrete roads; small shares depend on feeder/mud roads (1.5%) and foot pathways (0.6%). | Women's access to markets, health, and essential services depends strongly on road type and year-round usability, particularly during rainy and flood periods. | Prioritize safe, all-season connectivity, especially where non-pucca roads remain, to ensure continuous access for women. Improve the quality of unpaved roads and their ability to deal with water. |
| **Road-related impacts on farming (livelihoods)** | Where roads pass through farm areas, reported issues include crop damage due to dust (61.0%), loss of land due to road construction (44.1%), crop damage/security due to livestock movement (44.1%), crop security issues due to human movement (27.1%), and waterlogging from drainage issues (15.3%). | These impacts affect household income and food security. Women are often heavily involved in crop processing, household food management, and farm labor, increasing their workload and vulnerability. | Integrate field water management, dust control, proper drainage, safe crossings/animal management, and land management or compensation measures in GR4W design. |
| **Women's safety on roads (harassment and insecurity)** | The transport section highlights road safety and insecurity concerns linked | For women, access to roads must also mean personal safety, | Integrate adequate lighting, improved visibility, safer pedestrian paths and stops, |

| | | | |
|---|---|---|---|
| | to daily road use. The most critical challenges include dangerous curves or steep slopes, high traffic speeds, and inadequate road lighting, all of which increase accident risks and limit visibility and safe movement, while also raising the risk of harassment. | particularly during frequent daily trips to markets, schools, and services. | improved access to road embankment, traffic calming measures near settlements, schools, and markets, and community-agreed safety measures to ensure safe use of roads by women. |
| **Women's time burden & frequent local trips** | Trips to nearby markets are very frequent, with daily and weekly trips dominating. | Women make frequent short trips related to household needs (e.g. water and fuel collection, market visits, care activities), making them highly sensitive to road condition and downtime. | Even small road improvements (surface quality, drainage, safer shoulders) can generate significant time-saving and safety benefits for women. |
| **Access to embankment roads (qualitative insight from field experience)** | Women face difficulties accessing embankment roads due to steep and unsafe slopes, particularly when carrying loads, accompanying children, or during wet conditions. | Limited physical access reduces women's effective use of elevated roads, even where such roads exist. | Include steps, gentle ramps, and handrails on embankments, considering the needs of women, elderly people, and children. |
| **Flood evacuation behavior (qualitative insight from field experience)** | During flood events, women often delay evacuation as they remain responsible for children, household assets, and livestock. | Delayed evacuation increases risks to women's safety and mobility during emergencies. | Prioritize high-ground access routes, evacuation-ready road sections, and support measures that account for women's roles and constraints during floods. |

## 3.4 Safe sourcing

Globally, the road sector is a major consumer of construction material – sand, gravel, bricks, cement, and tarmac. As such, the road sector has a responsibility to source material safely. This means not to destroy land and water resources in the process of obtaining construction and repair materials, but rather to use the demand for construction materials to support better resource management. There are several guidelines in this regard. Some of the techniques are relatively new in Bangladesh, and it is recommended to investigate and pilot them.

*Table 5 – Guidelines for safe sourcing of road construction and repair material*

| Topic | Elaboration |
|---|---|
| Sourcing of gravel and sand from vulnerable rivers | - Avoid sourcing of sand and gravel from riverbeds in drought-prone, groundwater-dependent areas, as this may interrupt the recharge from the riverbed to the adjacent aquifers. In this regard, comply with the Balumahal and Soil Management Act, 2010 (amended 2023).<br>- Use off-stream borrow pits.<br>- Alternatively, use crushed sand/ gravel instead, acknowledging that that is often of lesser quality than the rounded river sand. |
| Making use of dredging material | - Reuse the material from dredging local canals and rivers for road construction and repairs provide it conforms to the quality standard. What is to be avoided:<br>- Fine, poorly graded sediments (high silt/clay contents)<br>- High organic contents (>2-3%)<br>- Salt and sulfate contents (in particular in coastal areas) |
| Repurposing borrow pits and borrow canal | - Where borrow pits are used to source sand or gravel, plan their 'second life' for water storage or recharge (see also section 5.5) |

| | |
|---|---|
| Recycling of old tarmac | - Reuse old tarmac in road construction as sub grade or repurposed as surface material<br>- Explore in-situ recycling of tarmac roads, either by<br>- Full-Depth Reclamation (FDR). This is best for severely deteriorated pavements with base/sub-base failure. In FDR, the entire pavement structure, including part of the subbase, is pulverized, mixed with stabilizers (e.g., cement, lime, bitumen), and compacted to form a new base.<br>- - Cold In-Place Recycling (CIR). This is suitable for rural and low-to-medium traffic roads. Only the existing pavement is milled, mixed with stabilizers (like bitumen emulsion or foamed bitumen), and laid back in place. This is done on-site, without heating. |
| Phasing out brick pavement and replacing with alternative material (reuse) | - Phase out the use of bricks in road construction to mitigate the climate effects in their production and the conversion of valuable land, in line with the Government Circular/ Notification on Use of Blocks Instead of Bricks (2019).<br>- Consider alternative material such as compressed blocks. |
| Exploring the use of recycled material in road construction | - Use road construction to dispose off – after proper treatment – waste material such as discarded plastic or old tyres. |

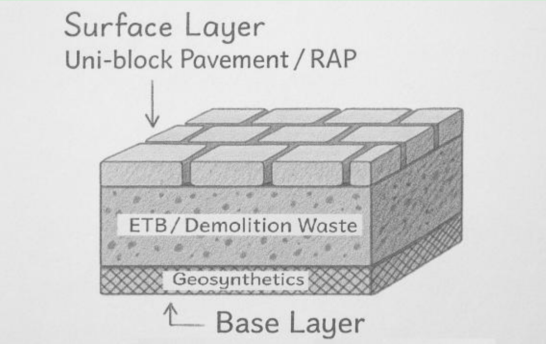
*Box 2 – Pavement and construction matierlas*

**Pavement and construction materials**

Sustainable and climate-resilient rural road infrastructure requires context-specific solutions that respond to Bangladesh's diverse geophysical and climatic conditions – this also applies to pavement and construction materials. This box outlines zone-specific recommendations building on the technical insights from the TRL-authored Design Report, detailed material specifications in Annexes, and insights obtained in the development of the GR4W Guidelines. Each recommendation considers the prevailing environmental stressors such as salinity, drought, erosion, and flooding and proposes suitable combinations of surface layers, binders or modifiers, and base materials. These recommendations aim to promote durable, cost-effective, and environmentally responsible road design practices that can adapt to the growing impacts of climate change. It should be noted that recommendations are at different readiness levels and are not necessarily recommended to be adopted at scale at this moment.

**Coastal Zone**

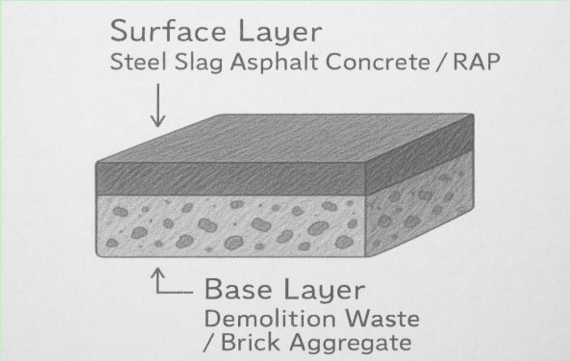
In coastal areas prone to salinity intrusion, high humidity, waterlogging, and shoreline erosion, the recommended surface options include Uni-block Pavement and Reclaimed Asphalt Pavement. These materials are selected for their durability, permeability, and maintainability under saline and wet conditions. The use of Polymer Modified Bitumen as a binder enhances the asphalt's resistance to oxidative degradation and deformation under extreme climate fluctuations.




For the base layer, Emulsion Treated Base and crushed demolition waste reinforced with geosynthetics are advised. This combination improves subgrade stability, reduces water infiltration, and increases structural performance on saturated soils. Geosynthetics such as geogrids and geocells play a critical role in preventing subgrade erosion and improving longevity in these challenging coastal terrains.

**Barind and Drought-Prone Zone**

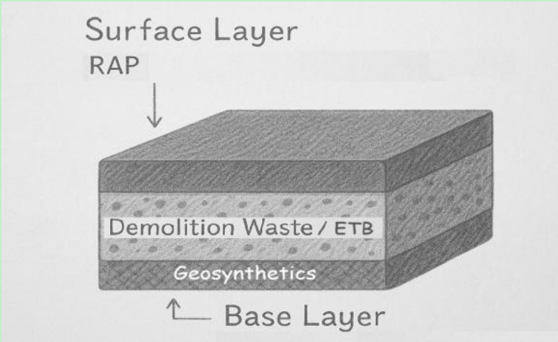
The Barind tract and drought-prone regions are characterized by hard, dry soils, high ambient temperatures, and low precipitation, which can lead to thermal cracking and dusting of pavements. For this context, Steel Slag Asphalt Concrete and RAP are recommended as surface layers due to their heat tolerance and resilience. The adoption of Waste Expanded Polystyrene provides enhanced flexibility and thermal stability while offering a sustainable outlet for plastic waste reuse




As base materials, Demolition Waste is preferred for its mechanical strength and cost-effectiveness on hard subgrades. Where necessary, brick aggregate may be used in low-impact or experimental sections, though it should be phased out in favor of more climate-resilient alternatives. This strategy aligns with GR4W principles by maximizing local reuse and adapting to dryland stressors.

**Haor and Flash Flood Zones**

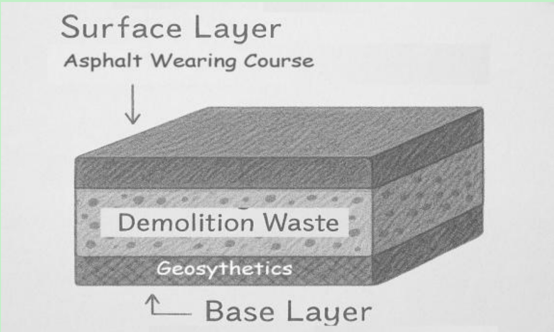
In low-lying Haor basins and flash flood-prone areas, pavements must endure repeated cycles of submersion and drying, which strain conventional materials. RAP is recommended for the surface layer due to its stiffness, water resistance, and capacity to recover binder value. Polymer Modified Bitumen is recommended for binder modification to improve durability under hydrostatic pressure and reduce moisture susceptibility.




For the base layer, a combination of Demolition Waste and ETB, enhanced with geosynthetics, is ideal. This setup provides quick-draining, high-strength layers capable of withstanding prolonged water exposure. Geosynthetics also facilitate rapid recovery after flooding, while improving the structural integrity of embankments in flood-sensitive terrain.

**Chattogram Hill Tracts**

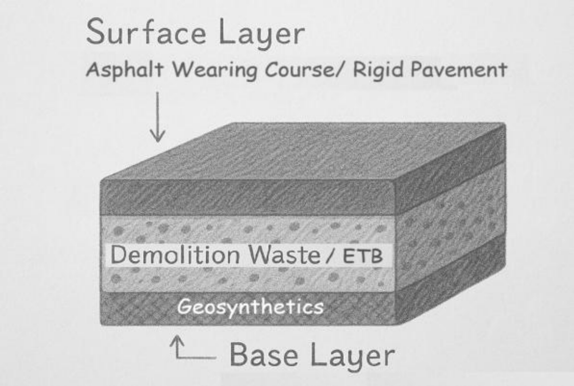
The hilly and erosion-prone terrain of the Chattogram Hill Tracts requires materials that ensure high slope stability and surface durability. Asphalt Wearing Course is the preferred surfacing option for its adaptability to steep gradients and ease of compaction. Polymer Modified Bitumen is again advised as the binder, given its improved resistance to rutting and thermal deformation.




For base layers, Demolition Waste offers strong and locally available material, while geosynthetics are essential for slope reinforcement, erosion control, and subgrade stabilization. The combined use of these materials addresses landslide risks and supports safe infrastructure in this geotechnically sensitive region, consistent with the water-sensitive design elements promoted in the GR4W approach.

**River Systems and Estuarine Areas**

Roads in riverine floodplains and estuarine environments face challenges including frequent water level fluctuations, scouring, and soft subgrades. The proposed surface options are Asphalt Wearing Course and Rigid Pavement with Recycled Aggregate, depending on traffic intensity and subgrade condition. Rigid pavement provides durability and resistance to saturation, while asphalt is more adaptable for intermediate-risk areas.




PmB is recommended across all flexible surface treatments to improve resilience against moisture and thermal variation. For the base layer, ETB or crushed demolition waste, reinforced with geosynthetics, ensures robust load-bearing capacity and controlled drainage. This combination supports embankment strength while reducing environmental impact through the reuse of materials and better water management.

# 4. Green Roads for Water Opportunities per Region

Different regions in Bangladesh have different prime opportunities and challenges for Green Roads for Water. What is common is that across each geography, there are important gains to be made, improving road quality and connectivity while also contributing to better water management and flood protection. A targeted approach ensures that road water management practices are adapted to opportunities and embedded in local hydrological conditions and landscape sensitivities.

The distinct geographic regions in Bangladesh have been defined as regional 'hotspots' in the Bangladesh Delta Plan 2100, and they are:

- Coastal Zone
- Barind and Drought Prone Areas
- Haor and Flash Flood Areas
- Chattogram Hill Tracts
- River Systems and Estuaries
-

Note that as per BDP2100 some districts fall in more than one hotspot.

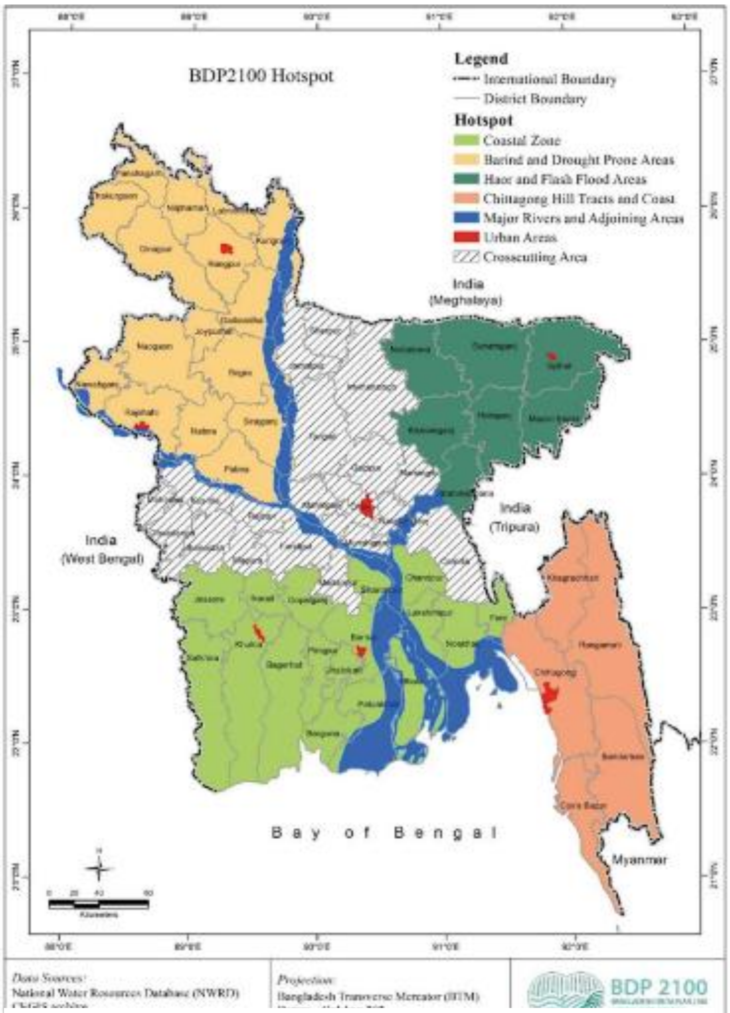


*Figure 8 - Bangladesh Delta Plan 2100 Hotspots*

In the following chapter, *for each* hotspot, the opportunities and challenges are presented. In each hotspot the location and orientation of the road network have a significant effect on the surface run-off, and subsurface flows, as well as the flood patterns. Besides the opportunities associated with specific road structures such as embankments, bridges, cross drainage structures, borrow pits are different in different areas.

This chapter describes the main opportunities for each hotspot region. It first gives a tabular overview and then zooms in on the specific opportunities. These opportunities have been assessed from several rounds of field visits and have been validated in working sessions in the hotspot area concerned. Roads can guide, direct, and retain water over the landscape. These functions should be optimized for each hotspot area - in the construction of new roads, in the upgrading of existing roads, and in the regular maintenance – following a 'building back better' philosophy, Equipping the extensive road network that LGED is the custodian of with GR4W measures will have a massive impact on water security, flood resilience and climate adaptation in Bangladesh, particularly as LGED roads penetrate even the remotest part of the country.

## 4.1 Coastal Zone

*Table 6 - Tabular overview of challenges, gains of GR4W, operationalization, and optimization of the road network in the Coastal Zone*

| Coastal zone | | |
|---|---|---|
| **Challenges** | **Gains of GR4W** | **Operationalization** |
| - Floods<br>- Siltation of rivers<br>- Water logging<br>- Salinization<br>- Rising sea levels<br>- Riverbank erosion<br>- Increasing variability in rainfall | 1. Unblock drainage congestion and reduce water logging | 1. Systematically equip roads with adequate cross-drainage structures and install additional bridges and culverts in critical areas; avoid high bridge sills. |
| | 2. Salvage tidal rivers, prevent them from silting up | 2. Ensure bridges with adequate spans and preferably no' few piers. |
| | 3. Support desilting of drains | 3. Use excavation material from silted up khals for local road construction. |
| | 4. Facilitate water management for high yielding Amon paddy | 4. Install gated culverts on local roads to allow field water ponding and release, when needed. |
| | 5. Improve flood preparedness | 5. Construct elevated roads in lower lying polder areas (for livestock evacuation) connecting to typhoon shelters, and include wide sections for temporary shelter. |
| | 6. Improve flood protection | 6. Build in flood protection requirements in river-facing roads – adequate height, armoring, and salt-tolerant vegetative cover. |
| | 7. Optimize functions with well-planned roadside vegetation | 7. Vegetation planting and species selection for direct productive use, embankment stability, dust/pollution control, noise reduction, and biodiversity. |
| **Optimization of the road network** | | |
| Contribute to flood protection | Coastal embankments as roads: harmonize flood protection and transport functions. | |
| Contribute to flood preparedness and recovery | Make roads at higher elevation (for instance, by using excavated sediment) in flood-prone high-risk areas and include widened sections as flood shelters. | |
| Reduce water logging | Follow drainage lines and provide adequate cross-drainage. | |
| Improve water control in irrigated crop areas | Position (minor) roads on the contour lines and equip culverts with gates. | |
| Avoid sedimentation of rivers | Ensure adequate cross drainage and wide enough bridges so as not to disturb the sedimentation process, particularly in the tidal rivers. | |

In the Coastal Area, roads, bridges, culverts, and gates strongly influence the flow of water, the way it is distributed, and the water levels. Water logging and the lack of drainage, amongst others, due to silted canals and blocked *khals* at multiple scales and reduced capacity of sluices and regulators, are among the core challenges of the dynamic coastal zone. Agricultural yields in the coastal zone can double if these and other water management issues are resolved[1].

The natural hydrology of the coastal polders has been heavily influenced by the development of polders and their embankments, making it impossible for water to enter the inland areas, resulting, amongst others, in the speedy siltation of the water system, and in unfavourable height

[1] https://www.cgiar.org/news-events/news/institutional-change-in-polder-water-management-governance-brings-revolutionary-potential-in-bangladesh/

differences between the river and the polders. Within the polders, water shortages occur due to inadequate and non-functional sluices/regulators. The central region of the polders often faces acute water scarcity, affecting agriculture, fisheries, and livestock production. An integrated approach encompassing water management, agriculture, and infrastructure is needed.

The network of internal roads, including small village roads and pathways, divides the polders – which a large part of the coastal zone consists of - into compartments, separating relatively higher and lower lands. Polder road infrastructure may impede internal drainage and create water logging, affecting land use and the capacity of the soil to absorb water during high rainfall events. Cross drainage structures (bridges, (gated) culverts and pipes) are often not enough and too narrow, obstructing water flows. Likewise, bridge sills may be too high and impede drainage, causing water logging.

Characteristics of the coastal zone include *ghers*, which erode the side slopes of rural roads due to wave action and to being constructed too close to the road. Specific types of roadside vegetation that can withstand the saline and harsh conditions of the coastal zone can help reduce impact. Salinity should also be considered beyond vegetation; it can have a detrimental effect on infrastructure and significantly reduce its lifetime if not carefully managed. Increasingly, rising sea levels must also be considered when maintaining existing roads and developing new ones. Lastly, what further characterizes the coastal zone are the tidal flows, which must be considered in developing any bridge infrastructure in the coastal zone. The benefits of combining road development with water management in the coastal zone are multiple: less water logging, less river siltation, less road damage, improved agriculture production, better flood protection and improved overall livelihoods of rural communities.

*Figure 9 - Landscape of coastal zone*

**1. Unblock drainage congestion and reduce water logging**

Roads should be systematically equipped with adequate cross drainage structures, with additional bridges and culverts installed in critical areas. Cross drainage structures, including bridges, are often insufficient and too narrow, which can obstruct water flow. For larger crossings where unrestricted water movement is needed, bridges are preferable, as they generally cost less than culverts of comparable size. It is important to avoid high bridge sills, as these can impede drainage and cause waterlogging. Within polders, water flow is regulated by existing sluices and regulators along embankments. Therefore, the design of bridges and culverts in these areas must account for these control structures to ensure effective drainage and hydrological performance.

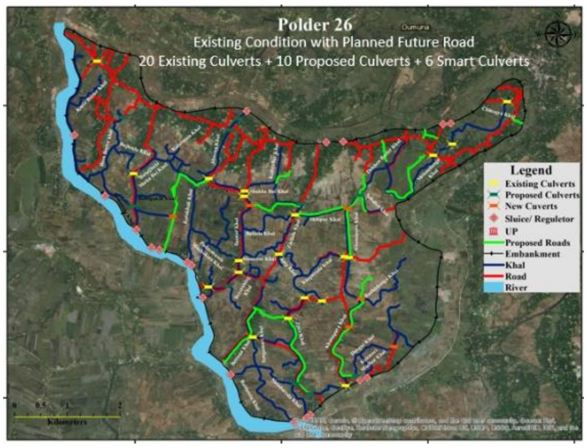



*Figure 10 - Remove waterlogging by retrofitting adequate road cross drainage – example from polder 26*

**2. Salvage tidal rivers, prevent them from silting up**

Bridges constructed too narrowly across tidal rivers can disrupt sediment balance, causing significant shifts in sediment loads and negatively impacting drainage over large areas. This can severely reduce the productive use of land. To maintain normal sedimentation processes and effective drainage, it is essential to provide adequate cross drainage and ensure bridges are wide enough and do not interfere with the tidal rivers. Bridges should be constructed with sufficient spans and, where possible, without piers to minimize disturbance to tidal river flows and sediment movement[2].

*Figure 11- Bridge disturbing bed load of tidal river*

[2] See also Choking bridges: the death of tidal rivers - TheWaterChannel

**3. Support desilting of drains**

Regular desilting of khals and drains is essential for maintaining effective drainage and preventing waterlogging. Accumulation of sediment in these channels reduces their capacity to convey water, leading to increased water logging, increased flood risk, and decreased agricultural productivity. Timely removal of silt and debris ensures that water flows remain unobstructed. Additionally, excavation material recovered from desilting operations can be repurposed for local road construction.

*Figure 12 - Repurposing sediment from excavating khals for local road construction*

**4. Facilitate water management for high-yielding Amon paddy**

Facilitating water management for high-yielding Aman paddy requires the installation of gated culverts on local roads to allow controlled ponding and release of field water. While gated culverts are currently rare for minor water control, they offer significant potential for managing water levels across Bangladesh.

These structures - such as box culverts and pipes with gates - enable precise water level regulation, supporting rice cultivation by allowing farmers to retain or drain water as needed, for example, during fertilizer application or dry season cropping. Properly managed cross-drainage infrastructure can also support aquaculture and other agricultural activities by storing water upstream of roads. Additional roadside protection may be necessary to prevent erosion from increased water pressure.

*Figure 13 - Left: Box culvert with slot for gate, Right: Gated culvert*

In low-lying coastal areas, roads can be strategically used to trap sediments, gradually raising land levels and reducing the risks of flooding and waterlogging. Integrating this approach into polder-level road planning, with guidance from hydrological mapping, can enhance land suitability for a broader range of crops. For example, in Polder 2 (Satkhira), the ground level upstream of a road has increased by 150 cm over 20 years.

*Figure 14 - Impact of road on ground level; using roads as a sediment trap*

**5. Improve flood preparedness**

To improve flood preparedness in low-lying polder areas, elevated roads should be constructed to serve as evacuation routes and temporary shelters, particularly for livestock, with connections to typhoon shelters and wide sections for safe refuge. Roads and embankments can act as critical shelters during inundations and provide safe havens for people and animals both during and after floods. Systematic planning is needed to ensure roads in flood-prone areas offer effective evacuation and rehabilitation options. Refuge sections of roads in these areas require different design considerations compared to flash flood or riverine zones.

**6. Improve flood protection**

Flood protection requirements should be integrated into the design of river-facing roads by ensuring adequate height, armoring, and salt-tolerant vegetative cover. Many of these embankments are also used as roads – the top of the embankment serves as a subgrade for the road pavement. There are, at times, mismatches between transport and flood protection functions. This happens when a paved road is developed on an embankment, which has not yet reached its safe and climate-proof level, but, because of the road pavement, cannot easily be increased. There are instances where 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 of up to 30 cm. This threatens the essential flood protection functions of an embankment. The current issues can be turned around by dovetailing road and embankment development, which would make both stronger, and designing embankments following criteria to accommodate a future road. It should, however, also be noted that it has been frequently observed that a paved road on the top of an embankment, that is well operated and maintained, possibly thanks to having a road on top, can improve the flood protection function of the embankment. This should be seen in the context of many embankments, for which BWDB is responsible, lacking regular routine maintenance.

**7. Optimize functions with well-planned vegetation**

Strategic vegetation planting and species selection along roads and embankments can enhance multiple functions. Appropriate vegetation supports embankment stability, reduces dust, controls pollution, and lowers noise levels. Selecting species for direct productive use - such as fodder, fruit, or timber - can provide economic benefits to local communities. Well-chosen plantings also promote biodiversity.

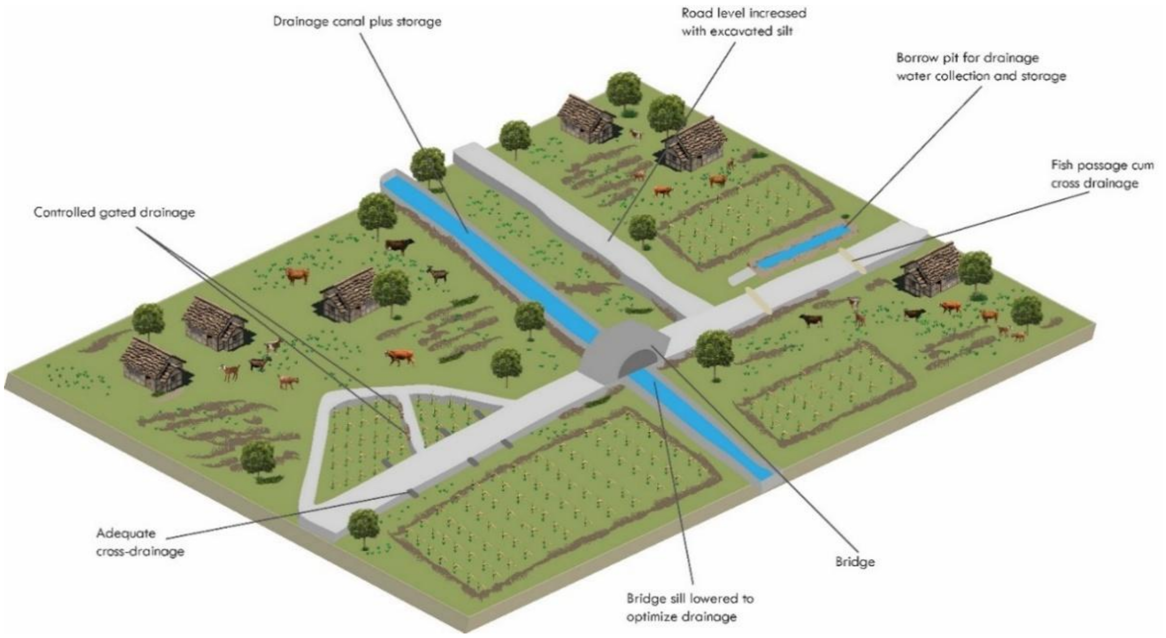



*Figure 15 - Visualization of some of the suggested good practices for coastal polders: agricultural water management*

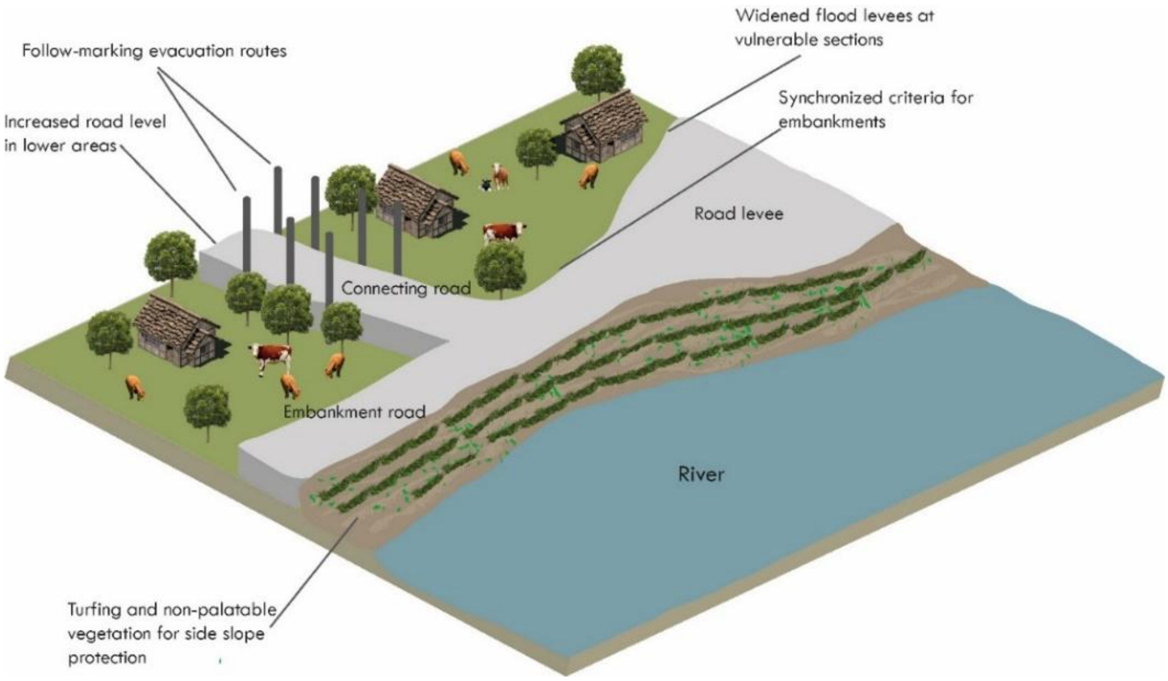



*Figure 16 - Visualization of some of the suggested good practices for coastal polders: flood management*

**Example: roads in Bagerhat and Barishal**

In Bagerhat, water logging and salinity threaten both roads and crops. Monsoon floods keep the area submerged for weeks, and the narrow embankment is eroding under truck traffic and storm surges. GR4W solutions - raising the road with suitable materials, adding gated culverts, converting borrow pits into retention ponds, and establishing salt-tolerant vegetation on slopes - would restore proper drainage and protect the embankment

In Barishal, limited cross-drainage causes the road to act like a dam, flooding adjacent fields for long periods. Pavements and shoulders are deteriorating under salt exposure and heavy vehicles. Interventions in the context of GR4W to counter these challenges are raising the road with suitable materials, adding gated culverts, converting borrow pits into retention ponds, and establishing salt-tolerant vegetation on slopes. Also, the importance and potential of engaging roadside communities in maintenance and roadside forestry came up as a key finding.

Left: Road in Bagerhat, Right: Road in Barishal

## 4.2 River Systems and Estuaries

*Table 7 - Tabular overview of challenges, gains of GR4W, operationalization, and optimization of the road network in the River Systems and Estuaries*

| River Systems and Estuaries | | |
|---|---|---|
| **Challenges** | **Gains of GR4W** | **Operationalization** |
| - River floods<br>- Storm surges<br>- Rainfall<br>- Discharge variability<br>- Erosion | 1. Unblock drainage congestion and reduce water logging | 1. Systematically equip roads with adequate cross drainage structures and install additional bridges and culverts in critical areas, avoidinh high bridge sills. |
| | 2. Improve flood protection | 2. Build in flood protection requirements in river-facing roads – adequate height, armoring, vegetative cover. |
| | 3. Improve flood preparedness | 3. Construct elevated roads in lower lying areas (for livestock evacuation) and include wide sections for temporary shelter. |
| | 4. Mitigate floods in critical areas | 4. Roads may be constructed in critical areas to cordon off the area from floods and compartmentalize it. |
| | 5. Facilitate fish migration | 5. Sufficient culverts and bridges; well-designed and well-placed culverts, i.e., culverts that are not too steep, and have low/moderate velocity; that may have roughened surfaces; that have adequate water levels in the dry season; and are connected to the downstream water body. |
| **Optimization of the road network** | | |
| Mitigate floods | Road networks to steer and compartmentalize floods by controlling the pattern of flood run-off. | |
| Contribute to flood preparedness and recovery | Make roads at higher elevation (for instance, by using excavated sediment) in flood-prone high-risk areas and include widened sections as flood shelters. | |

The major rivers of Bangladesh – and their estuaries - are the backbone of the delta system and are a separate hotspot area in the BDP2100. Many of the water-related challenges in Bangladesh – and opportunities - are related to the major rivers. The river systems and estuaries have to deal with, amongst other things, river floods, storm surges, rainfall, and discharge variability. At Chars and Islands, in the River Systems and Estuaries zone, severe erosion further challenges water management and livelihoods. Addressing water-related challenges can yield significant gains for infrastructure, agriculture, and livelihoods. It should be noted that there are chars under this zone, which are distinct in nature from plain land of the same category. Sustainable road development and maintenance in those areas are challenging.

*Figure 17 - Landscape River Systems and Estuaries*

**1. Unblock drainage congestion and reduce water logging**

As in the coastal zone, roads should be systematically equipped with adequate cross-drainage structures, with additional bridges and culverts installed in critical areas. Cross drainage structures, including bridges, are often insufficient and too narrow, which can obstruct water flow. For larger crossings where unrestricted water movement is needed, bridges are preferable, as they generally cost less than culverts of comparable size. It is important to avoid high bridge sills, as these can impede drainage and cause waterlogging. Within polders, water flow is regulated by existing sluices and regulators along embankments. Therefore, the design of bridges and culverts in these areas must account for these control structures to ensure effective drainage and hydrological performance.

*Figure 18 - Sufficient cross drainage to avoid water logging*

At other places, submersible roads are helpful in addressing the water challenges. Submersible roads, designed to withstand varying water levels, can provide a resilient solution. Submersible roads can be a sustainable solution to combine the needs for transport and connectivity, without negatively affecting biodiversity and flood risks. Often, the roads become waterways once submerged and are thereby still vital means of rural transportation.

*Figure 19 - Submersible roads in Singra Municipality, Bangladesh (https://singramunicipality.gov.bd/wp-content/uploads/2023/06/Submersible-*

**2. Improve flood protection**

Flood protection requirements should be integrated into the design of river-facing roads by ensuring adequate height, armoring, and salt-tolerant vegetative cover. Many of these embankments are also used as roads – the top of the embankment serves as the road's subgrade. At times, there are mismatches between transport and flood protection functions. This happens when a paved road is developed on an embankment that has not yet reached its safe, climate-proof level, but, because of the road pavement, cannot be easily raised. There are instances in which the embankment height is reduced to create a wider road and improve transport operations.

*Figure 20 - Armoring of river facing roads*

**3. Improve flood preparedness**

As in coastal/polder areas, to improve flood preparedness, elevated roads should be constructed as evacuation routes and temporary shelters, particularly for livestock, with connections to typhoon shelters and wide sections for safe refuge. Roads and embankments can act as critical shelters during inundations and provide safe havens for people and animals both during and after floods.

*Figure 21 - Elevated roads providing flood shelter for livestock*

**4. Mitigate floods in critical areas**
Flood mitigation in critical areas can be achieved by constructing road networks that serve to cordon off and compartmentalize vulnerable zones. Roads built with strategic alignment and elevation can act as barriers, steering floodwaters and controlling the pattern of flood runoff. By compartmentalizing the landscape, these road networks help manage water flow, protect key infrastructure and settlements, and reduce the overall impact of flooding. Careful planning and integration with broader water management strategies are essential to ensure that roads contribute effectively to flood mitigation without causing unintended disruptions to natural hydrological processes.

**5. Facilitate fish migration**
For fisheries and aquatic life, it is essential that culverts and bridges are designed to allow fish passage and maintain aquatic connectivity. Historically, many culverts have been undersized, set too high, or created waterfalls at their outlets, forming barriers to fish and other aquatic organisms. This fragmentation reduces available habitat and diminishes fish populations. To address this, stream simulation design should be applied: culverts should match or exceed the natural channel's full bank width, maintain a natural or simulated channel bottom, and align in slope and elevation with the stream. The culvert should include materials similar to the natural bed, such as sand, gravel, and boulders, to replicate upstream and downstream conditions. Well-designed and well-placed culverts must also have gentle slopes, low to moderate water velocities, roughened surfaces where appropriate, adequate water levels during dry seasons, and direct connection to downstream water bodies to ensure unimpeded movement of fish and aquatic life.

**6. Optimize functions with well-planned roadside vegetation**
Strategic vegetation planting and species selection along roads and embankments can enhance multiple functions. Appropriate vegetation supports embankment stability, reduces dust, controls pollution, and lowers noise levels. Selecting species for direct productive use - such as fodder, fruit, or timber - can provide economic benefits to local communities. Well-chosen plantings also promote biodiversity.

*Figure 22 - Mahogany roadside tree planting for productive use and as a shelter belt*

For slope protection, it is also highly recommended to work with local varieties to stabilise soil and reduce erosion. The use of eucalyptus for this purpose is strongly discouraged, in line with the Government of Bangladesh's May 2025 announcement, which classifies eucalyptus as an invasive species and prohibits its inclusion in any tree plantation programs.

**Example: road in Barishal**

In Barishal water logging and salinity threaten both roads and crops. Monsoon floods keep the area submerged for weeks, and the narrow embankment is eroding under truck traffic and storm surges. In Rajshahi, an area that experiences long dry spells following intense monsoons, heavy truck loads, inadequate drainage, and eroding embankments have left the road visited in poor shape. GR4W interventions - raising and compacting the embankment, adding gated culverts for controlled water movement, and stabilizing slopes with vegetation and drought-tolerant trees - would reduce erosion and improve water retention for farming.

Road in Barishal

## 4.3 Chattogram Hill Tracts

*Table 8 - Tabular overview of challenges, gains of GR4W, operationalization, and optimization of the road network in the Chattogram Hill Tracts*

<table>
<tr><th colspan="3">Chattogram Hill Tracts</th></tr>
<tr><th>Challenges</th><th>Gains of GR4W</th><th>Operationalization</th></tr>
<tr><td rowspan="4">- Erosion<br>- Landslides<br>- Rainfall variability<br>- Flash floods</td><td>1. Preserving and capturing springs</td><td>1. Develop roadside spring boxes with outlets and slope protection; also increase recharge in the spring sheds.</td></tr>
<tr><td>2. Stabilize roadside hill slopes, reduce erosion</td><td>2. Use bio-engineering techniques to reduce risk of erosion, slips, and landslides – with plants and small civil engineering measures catching, erosion, and armoring, reinforcing, anchoring, supporting, and draining vulnerable slopes.</td></tr>
<tr><td>3. Water harvesting from roads</td><td>3. Use road drainage system to collect run-off from road slopes and route to safe disposal recharge/storage areas.</td></tr>
<tr><td>4. Optimize multiple functions with well-planned roadside vegetation</td><td>4. Vegetation planting and species selection for direct productive use, embankment stability, dust/ pollution control, noise reduction, and biodiversity.</td></tr>
<tr><th colspan="3">Optimization of the road network</th></tr>
<tr><td rowspan="4">Use roads for water harvesting</td><td colspan="2">Develop roads at mid-slope hills to maximize water retention and water harvesting potential.</td></tr>
<tr><td colspan="2">Use non-vented drifts as road crossings and as structures to build up groundwater storage</td></tr>
<tr><td colspan="2">Develop water retention structures alongside roads.</td></tr>
<tr><td colspan="2">Use road profile and roadside drainage to collect water.</td></tr>
<tr><td rowspan="3">Stabilize hill slides and control erosion</td><td colspan="2">Use bio-engineering or seed spraying.</td></tr>
<tr><td colspan="2">Control erosion by baffle structures.</td></tr>
<tr><td colspan="2">Avoid water accumulation in landslide-prone areas.</td></tr>
</table>

The Chattogram Hill Tracts, located in the southeastern part of Bangladesh, are distinctly different from the rest of Bangladesh, as they are the only extensively hilly area of Bangladesh. Rugged hills, dense forests, and numerous water bodies characterise the area. The area has to deal with severe erosion and landslides induced by rainfall variability and flash floods. Deforestation and land degradation furthermore increase erosion and put livelihoods under pressure. While rural road infrastructure development has aggravated the pressing situation in the past, it is aimed at reducing the negative impacts by embracing the GR4W concept and instead using rural road infrastructure for better water management.


*Figure 23 - Landscape Chattogram Hill Tracts*

### 1. Preserving and capturing springs

In mountain areas, the development of roads- either through the removal of unconsolidated material or the cutting of rock formations - will affect the occurrence of seeps and springs. Seeps are different from springs; 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.

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

*Table 9 - Methods for managing different types of springs in different circumstances*

| *Spring type* | Description of use | 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 (capture) and conveyance to benefit community, or tap fitted onto protected spring. |
| | Used for domestic water supply and storage | Spring box (capture) and conveyance to benefit community; include possibility of spring closure (tap) to store water inside the mountain aquifer (especially in karst areas). |
| *Spring or 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. |


*Figure 24- Left: Roadside spring capture and protection in Nepal, Right: Spring shed improvement to enhance recharge in Nepal*

### 2. Stabilize roadside hill slopes, reduce erosion

Bioengineering, the use of plants for slope stabilization and runoff control, encompasses a range of vegetative measures to stabilize slopes along mountain roads. It involves using plant parts such as roots, cuttings, and stems as a cost-effective and locally adaptable means of erosion control. Bioengineering ranges from planting deep-rooted species to a combination of vegetation and civil engineering structures. Examples of bioengineering 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).

For the Chattogram Hill Tracts, bioengineering, including structural and vegetative measures, is considered very effective in avoiding landslides. Vetiver is commonly used for this purpose. Because of its deep, strong roots and high survival rate, vetiver rows have – globally - been applied widely on steep, erosion-prone slopes. Native plants that are known to adapt well to harsh settings and that have the positive mechanical and hydrological characteristics to strengthen the critical slope segments are preferred. Plant shoots are preferably planted when the live cuttings are without leaves. Vegetative measures are often combined with a gabion stone toe; the gabion stabilizes the slope while plants are placed on the upper sections.

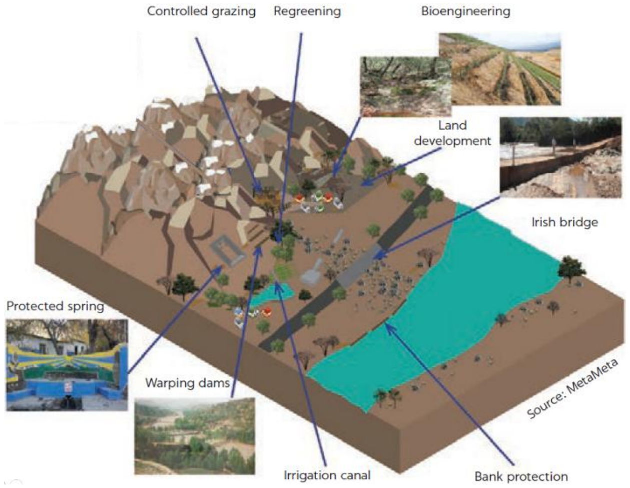


*Figure 25 - Integrated road-landscape management practices to be considered in mountainous areas*


*Figure 26 - Bio-engineering to stabilize road slopes*

**3. Water harvesting from roads**

As also in other areas of Bangladesh, it is very promising to better store the drainage water, to on the one hand, reduce damage to the roads and, on the other hand, have water resources available. For mountainous areas, the Green Roads for Water guidelines for Nepal recommend free-draining, downward-sloping road crowns that 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. An adequate number of causeways (or drifts) at stream intersections and other measures to control for stream crossing and spring management will be part of good road alignment and design. Note that this design requires the protection of the downside of the embankment to ensure that water running over it does not erode the embankment. Additionally, an ongoing water flow across the road can lead to the embankments becoming soaked, causing subsequent loss of strength and carrying capacity.

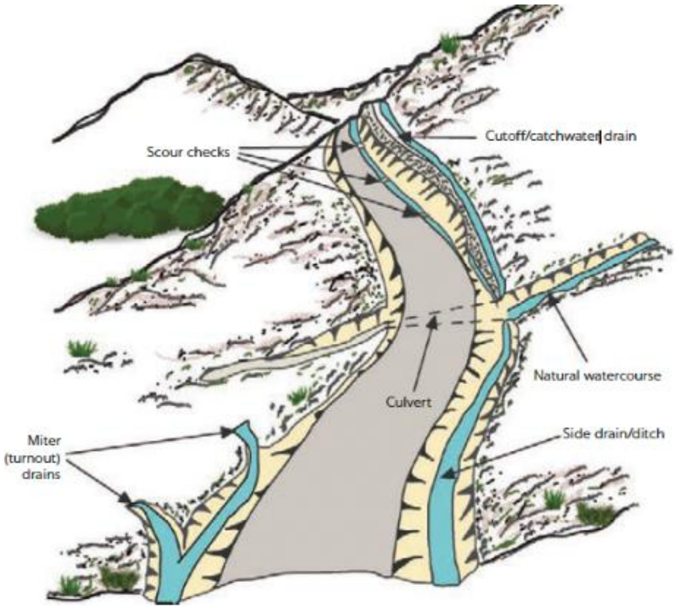


*Figure 27 - Develop road drainage system to capture run-off and feed water storage*

**4. Optimize multiple functions with well-planned roadside vegetation**

Strategic vegetation planting and species selection along roads and embankments can enhance multiple functions. Appropriate vegetation supports embankment stability, reduces dust, controls pollution, and lowers noise levels. Selecting species for direct productive use - such as fodder, fruit, or timber - can provide economic benefits to local communities. Well-chosen plantings also promote biodiversity.

**Example: road in Rangamati**

The Rangamati road passes through the steep slopes of the Chattogram Hill Tracts, an area prone to heavy rain and landslides. Its sensitive soils and poor drainage often lead to erosion, blocked culverts, and slope failures. The road connects 20+ villages to local markets and schools, and its improvement is strongly supported by residents. GR4W bio-engineering methods, vetiver hedges, bamboo palisades, fascines, infiltration bunds, and gated culverts would stabilize slopes and retain water for agriculture.

## 4.4 Barind and Drought Prone Areas

*Table 10 - Tabular overview of challenges, gains of GR4W, operationalization, and optimization of the road network in the Barind and Drought Prone Areas*

| Barind and Drought Prone Areas | | |
|---|---|---|
| **Challenges** | **Gains of GR4W** | **Operationalization** |
| - Drought<br>- Heatwaves<br>- Periods of cold<br>- Flash floods<br>- Depleting groundwater levels | 1. Water harvesting with roads to address water scarcity | 1. Use variety of road water harvesting measures: routing water from drains to recharge areas or storage ponds; using porous pavement for percolation; using roadside excavation trenches for storage and recharge. |
| | 2. Creating surface water and groundwater storage with bridges and bridge sills | 2. Use 'bandara' bridges to catch and store late monsoon flows in the rivers and use alleviated bridge sills to block drainage of raise groundwater levels in local rivers |
| | 3. Responsible sourcing: avoid depleting sand and gravel from vulnerable rivers, as this will undermine their water holding and flood retention and recharge capacity | 2. Use alternative non-sand road pavements; use crushed sand instead; or use excavation material from borrow pits that can be converted to storage reservoirs or recharge structures. |
| | 4. Road protection against flash floods – capturing as much as possible from flash floods | 3. Nature-based vegetative protection and armoring of exposed sections. |
| | 5. Optimize functions with well-planned roadside vegetation | 4. Vegetation planting and species selection for direct productive use, embankment stability, dust/ pollution control, noise reduction, and biodiversity. |
| **Optimization of the road network** | | |
| Use roads for water harvesting | Roads at slight elevation, guiding run-off to overflow areas to recharge zones and water storages. | |
| Use roads for water storage | Construct water retention structures and local mini-dams using road bodies. | |

The Barind region, located in the northern part of Bangladesh, is characterized by its vast stretches of barren lands, frequent droughts, and limited availability of water resources. With limited rainfall and inadequate water resources, farmers struggle to grow crops and maintain livestock. Embracing the Green Roads for Water concept, one would advocate for using roads for water storage. Currently, most of the rainwater is lost as runoff into nearby canals (*Khari*), rivers, and is not stored in the groundwater, of which the levels are dropping due to overexploitation

Roads can be pivotal instruments in ensuring water storage and making the most use of the limited available water. Drainage and culverts can be designed in such a way that they make water flow to roadside storage, which can also include borrow pits, ponds, or groundwater recharge areas. Especially in the monsoon, it is important to store as much water as possible, to have a buffer for the dry spells following, and to reduce the damage that comes with flash floods. Turning this problem around and ensuring that the flash floods, only limitedly present in the Barind area but disturbing in other drought-prone areas, are used productively is a promising approach in this area.

*Figure 28 - Landscape Barind and Drought Prone Areas*

**1. Water harvesting with roads to address water scarcity**

A variety of road water harvesting measures can be used to address water scarcity and enhance local water management. Roads can intercept and route water from drains to recharge areas or storage ponds, use porous pavement to promote percolation, and incorporate roadside excavation trenches for water storage and groundwater recharge. By guiding runoff to designated areas, roads help manage catchment water resources, control the speed and volume of runoff, compartmentalize and mitigate floodwaters, and influence sedimentation processes. Integrating these approaches makes roads an important tool for water harvesting and sustainable landscape management.

The challenge is thus 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:

- In surface storage structures such as ponds and converted borrow pits.
- Spread over land areas and used to replenish soil moisture, for example, as rain-fed cultivation or rangeland improvement, or retained by bunds, terraces, or micro-basins.
- Routed to recharge areas where it will replenish shallow aquifers; water can be pumped up from shallow aquifers for later use

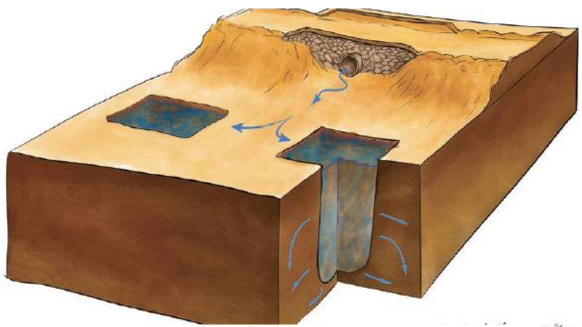


*Figure 29 - Water harvesting: guiding water from culverts to recharge areas and storage*

**2. Creating surface water and groundwater storage with bridges and bridge sills**

The bridges in the Barind, in principle, can function as control points in the local drainage network. The concept of 'bridge-cum-bandara' or KT Weir, that is common in India, can be applied in the Barind: it would involve outfitting bridges with a large number of piers and needle shutters, which can be closed at the end of the monsoon period. The water thus retained could be used as dry-season storage and as recharge to local aquifer systems. Similarly, bridge bed sills can be elevated so they create a higher hydraulic head in the local (sand/ gravel) rivers, thus also increasing groundwater tables.

**3. Responsible sourcing: avoid depleting sand and gravel from vulnerable rivers, as this will undermine their water holding and flood retention and recharge capacity**

More than any other area in Bangladesh, water conservation and water retention are essential in the Barind Tract. Groundwater is an important source of water in the Barind; at the same time, it is under pressure and depleting. Recharge of the aquifer to an important extent takes place from the water in the river, contained in the gravel and sand packets of the riverbed. These are connected to the adjacent aquifers. However, if this river sand and gravel is mined, the hydrological connection is lost, and no recharge can take place. Moreover, high flows during the monsoon can no longer be absorbed in the sand and gravel packets and high-water events become flash floods.

For all these reasons, dredging of gravel and sand from rivers in the drought-prone areas should be carefully handled and minimized. Rather than mining from the river, gravel and sand may be collected from carefully planned borrow pits that can have a second life as a storage reservoir or recharge structure. Another option is to alternative non-sand building material, such as crushed rocks.

*Figure 30- Left: Using porous pavement for water percolation, Right: Responsible sourcing: use manufactured sand instead of sand from vulnerable rivers*

**4. Road protection against flash floods – capturing as much as possible from flash floods**

To protect roads from flash floods and maximize water capture, flood protection measures must be fully integrated into road and embankment design. River-facing roads and embankments should be constructed with sufficient height, robust armouring, and vegetative cover to withstand high water flows and reduce erosion risks. Roads that double as embankments for rivers, channels, or canals require particular attention to ensure they meet both transport and flood protection standards. It is essential to avoid reducing embankment height for road widening or paving before reaching safe, climate-resilient levels. Incorporating nature-based solutions, such as vegetative buffers and reinforced armouring on exposed sections, further enhances resilience by stabilizing soil, absorbing runoff, and capturing as much water as possible from flash flood events.

**5. Optimize functions with well-planned roadside vegetation**

Strategic vegetation planting and species selection along roads and embankments can enhance multiple functions. Appropriate vegetation supports embankment stability, reduces dust, controls pollution, and lowers noise levels. Selecting species for direct productive use - such as fodder, fruit, or timber - can provide economic benefits to local communities. Well-chosen plantings also promote biodiversity. In the Barind and drought-prone areas, roadside tree planting ideally takes place with tree species that can absorb a lot of water in the rainy season to avoid settling roads in the wet season. Furthermore, roadside tree planting can be combined with other slope protection measures.

*Figure 31 - Optimize roadside vegetation*

**Example: roads in Sayedpur and Rajshahi**

The road in Sayedpur faces the dual challenges of drought and flash floods. The road connects villages, schools, and markets, but suffers from erosion at the Teesta river bends and cracking along its subgrade during dry spells. Field discussions revealed that culverts are too small to manage drainage and that embankment collapses threaten nearby farmland. GR4W interventions such as palisades, vegetative slope protection, and gated culverts linked to borrow-pit ponds can stabilize the banks and manage water better throughout the year.

In Rajshahi, an area that experiences long dry spells following intense monsoons, heavy truck loads, inadequate drainage, and eroding embankments have left the road visited in poor shape. GR4W interventions - raising and compacting the embankment, adding gated culverts for controlled water movement, and stabilizing slopes with vegetation and drought-tolerant trees - would reduce erosion and improve water retention for farming.

## 4.5 Haors and Flash Flood Areas

*Table 11 - Tabular overview of challenges, gains of GR4W, operationalization, and optimization of the road network in the Haors and Flash Flood Areas*

| Haors and Flash Flood Areas | | |
|---|---|---|
| **Challenges** | **Gains of GR4W** | **Operationalization** |
| - (Flash) floods<br>- Increasing rainfall and discharge variability<br>- Erosion<br>- Cyclonic storm surge | 1. Improved flood retention, enhancing post-flood soil moisture for early season crops and fish breeding and capture fisheries | Carefully plan – even retrofit - roads, including drainage structures and overflow areas/causeways to positively effect and flexibly manage patterns of flood recession and hence optimize soil moisture. The road can assist the *recession phase* by:<br>- Slowing drainage just enough to promote infiltration,<br>- Directing water laterally toward target recharge areas,<br>- Releasing water progressively rather than abruptly.<br>-<br>The embankment roads must therefore be designed as a directional regulator. Options include:<br>- Submersible road embankments.<br>- Road causeways with sluice gates/box culverts.<br>- Raised roads with designed spillways – preferably leading to recharge area or wetlands.<br>- Armored road embankments to create water storage.<br>- Small ponds alongside roads that slowly release water and improve soil moisture and serve as fish spawning ground. |
| | 2. Improve flood preparedness | Construct elevated roads with overflow capacity in lower lying areas (for livestock evacuation), and include wide sections for temporary flood shelter. |
| | 3. Facilitate fish migration | Sufficient culverts and bridges; well-designed and well-placed culverts, i.e. culverts that are not too steep, and have low/moderate velocity; that may have roughened surfaces; that have adequate water levels in dry season; and are connected to the downstream water body. |
| | 4. Optimize functions with well-planned roadside vegetation, protect (submerged) roads from scour | Vegetation planting and species selection for scour control, but also direct productive use, embankment stability, dust/pollution control, noise reduction, biodiversity and suitability to local soil and climate. |
| **Optimization of the road network** | | |
| Control flood recession | Roads at slight elevation, including controlled overflow sections to slow down and direct recession flows and feed into wetlands or shallow reservoirs. | |
| Contribute to flood preparedness and recovery | Make roads at higher elevation (for instance, by using excavated sediment) in flood-prone high-risk areas and include widened sections as flood shelters. | |
| Improve/protect fish movement | Provide sufficient and well-located culverts of appropriate design to guide and facilitate fish movement. | |

Roads have a major impact on the haor and flash flood areas: they often divide the floodplain into a wetter section and a drier section. Bridges may constrict the floodplain, and bridge sills may raise water and silt levels. Road building in a floodplain requires special attention to keep floodplain conditions alive and to prevent uncontrolled breaking of the road embankment.

Amongst the pivotal considerations are adequate drainage with fish passages (French mattresses and culverts will preserve floodplain conditions), low-embankment roads with floodways (to facilitate controlled flooding into wetland areas and recharge zones), and using submersible roads in floodplains that are inundated for part of the year. A common phenomenon in the Haors is earthen submergible flood embankments, which are every year reconstructed – as a form of fundamental routine maintenance - to protect crops from flash floods.

While important throughout Bangladesh, the orientation of roads is especially important in the Haor areas. Ideally, roads should be constructed or developed as much as possible perpendicular to the direction of flash flood to reduce potential damage, optimize rehabilitation, and reduce maintenance costs. The causeway (drifted rigid pavement) needs to be constructed alongside the bridges/culverts to allow passage of huge floodwater. This is in line with some of the sections below (on overflow sections and bridges), advocating for designing sufficient space for the water.

*Figure 32 - Landscape Haors and Flash Flood Areas*

**1. Improved flood retention, enhancing post-flood soil moisture for early season crops and fish breeding and capture fisheries**

In the haor and flash flood areas, retaining moisture from receding floodwaters is a promising application of Green Roads for Water principles. Roads and their (gated) cross-drainage structures should be considered as instruments for water management, requiring a shift in both planning and practice. Even with persistent flooding for much of the year, gated culverts and well-designed road infrastructure can help optimize water management during the drier months. Key options include:


*Figure 33 - Water reservoir created with road embankment*

- Submersible road embankments to allow controlled inundation and water retention
- Road causeways with sluice gates or box culverts for flexible water flow and level management
- Raised roads with designed spillways that direct excess water to recharge areas or wetlands
- Armored road embankments to create temporary water storage
- Small ponds alongside roads to gradually release water, improve soil moisture, and provide fish spawning grounds

These measures, when carefully planned or retrofitted, help manage flood retention patterns and create more favorable conditions for agriculture, aquaculture, and ecosystem health in flood-prone areas.

**2. Improve flood preparedness**

Roads in flood-prone areas may be built with lower embankments and equipped with controlled overflow “floodway” structures instead of high embankments. This reduces costs enormously because the expenditure on the embankments is considerably less, and roads do not wash out in unpredictable locations.

Overflow embankment sections, or floodways, prevent overtopping of the embankment in an uncontrolled manner by allowing high water to pass over part of the embankment in a controlled manner when necessary. Low-embankment roads will conserve floodplain functions and prevent uncontrolled overtopping, but they will suffer predictable flood damage when overtopped.

One disadvantage of floodways is that overtopping renders a section of the road unusable during flood events. This lack of access causes inconvenience and can be harmful to the welfare of adjacent communities and is a possible hazard to road users. Careful consideration and calculation are required to determine the direction of inundation to floodways and the implications of the resulting traffic disruption. Installation of poles with height markings along floodways can help road users estimate water depth and determine when crossing an inundated floodway would be unsafe, and may also reduce the disruption associated with inundation.

While all-weather roads have first been welcomed as a solution, they are – in the haor and flash flood areas – increasingly seen as a problem. Locals say that all-weather roads disrupt the free flow of water in the haor, causing untimely floods that damage crops. Some even go further and say that there should not be any road in the haor, and that the authorities should develop a modern water transportation system here, to prevent flooding problems and the loss of biodiversity[3]. Currently, in the monsoon season, boats are the main means of transportation in the haor area.

Submersible roads are inundated during the flooding season but facili-tate transport during the dry period when they reemerge. They can be reused, usually after some small repairs. These submersible roads do not interfere negatively or positively with the flood regime in the floodplain. However, drainage is still a key consideration, even in submersible roads. The road corridor should be low enough to release the drainage water. Frequently, the submersible roads are still made too high and, thereby, are still problematic. One issue with submersible roads is the sediments that settle on them after a flood. It has been reported that a settlement of 10-15 inches of clay is common. The construction of all-weather elevated roads, while often found fruitful for connectivity, can thus come with significant negative consequences if hydrological features are not properly considered.

**3. Facilitate fish migration**
Haors are critical fishing grounds. Yet road infrastructure, when poorly designed, can severely disrupt fish migration by altering natural water flow. Many culverts have been historically undersized, set high in the channel, or formed a waterfall at their outlet, forming a barrier to fish and other aquatic organisms' movement. This has effectively fragmented the stream reaches where fish can live, reducing their overall population. By using stream simulation concepts, the culvert width matches the channel bank's full width, and a natural channel bottom is preserved or built into the structure. This prevents either the flow being too fast, the flow being too shallow, the jump being too high, or there being no resting pool. Much can be gained by providing sufficient and well-located culverts of appropriate design to guide and facilitate fish movement. This benefits both ecosystems and livelihoods.

*Figure 34 - Arched culvert for easier passage of fish and other creatures*

[3] https://www.tbsnews.net/bangladesh/all-weather-road-kishoreganj-was-solution-now-its-problem-439910

**4. Optimize functions with well-planned roadside vegetation, protect (submerged) roads from scour**

Strategic vegetation planting and species selection along roads and embankments can enhance multiple functions. Appropriate vegetation supports embankment stability, reduces dust, controls pollution, and lowers noise levels. Selecting species for direct productive use - such as fodder, fruit, or timber - can provide economic benefits to local communities. Well-chosen plantings also promote biodiversity.

*Figure 35 - Left: Overflow area with armouring and vegetative protection, Right: Vetiver grass as slope stabilizer*

**Example: roads in Sylhet and Netrokona**

In the road assessment, conducted after the validation workshop, also roads in Sylhet and Netrokona were visited. The road in Sylhet faces chronic flooding and riverbank erosion due to monsoon and flash floods, and the area's specific hydrological and geographical characteristics. This road remains submerged for up to six months annually. Field consultations highlighted the urgent need for improved pavement and nature-based slope protection. GR4W interventions - such as gated culverts, vegetative reinforcement, and a strong cross-sectoral collaboration and community engagement - can significantly improve resilience.

In Netrokona, seasonal floods and heavy trucks frequently damage the pavement of the visited road, while poor drainage turns the raised road into a barrier that traps water in nearby fields. Villagers face long isolation during the monsoon months. GR4W measures - more frequent culverts and small bridges, gated outlets for controlled drainage, borrow-pit ponds for storing excess water, and bio-engineering with vetiver and grasses - would relieve waterlogging and extend road life.

# 5. Green Roads for Water for different road components

## 5.1 Embankments

*Figure 36 - Embankment*

The vast majority of roads in Bangladesh outside the hilly terrain are situated on embankments. This helps protect the roads from floods and water logging. The embankments also ensure that the road surface is higher than the adjacent land, allowing rainwater to run off quickly and keeping the road dry and usable after regular rains. Having the roads on embankments also helps to overcome high water tables and soils with low bearing capacity (soft, silty, and saturated), as is common in many parts of Bangladesh. Building a road at ground level in the floodplains would require deep and expensive foundational work to prevent the road from sinking or collapsing.

Not only do road embankments protect roads from floods and water logging. Road embankments – present almost everywhere - are an important part of flood management in Bangladesh. They protect against floods and guide run-off. Most prominent are the roads that face small and large rivers and the seashore.  Such embankment roads are the first line of defence against floods and must be developed in line with BWDB criteria. They also need extra protection in many cases, not only against flood by also from shifting rivers, particularly in coastal rivers.

This river erosion causes embankments to breach and large areas of land to be inundated. The process of river erosion is not easy to control, but can be slowed down, for instance, by protective vegetation along such high-risk embankment roads.

There is also a second line of defense against floods and inundations, which are the road embankments that may retain floods if the main embankments are breached – the so-called secondary dykes. The network of road embankments may also be tailored to control and reduce local runoff, a so-called compartmentalization. At present, there is no systematic plan or guideline to identify such secondary flood defenses, though on the ground during an emergency, many roads perform this role, including the relatively heavy-engineered roads under the Roads and Highways Department. There is a strong case, especially in critical areas, to review the existing road network to see how it can be tailored to compartmentalize floods and how certain roads can be used as secondary dykes. This will be a cost-effective way to improve flood resilience in large parts of Bangladesh.

*Figure 37 - Cyclone shelter*

Elevated roads are also an important part of evacuation and rescue operations during typhoons and floods. Because of their higher location, they serve as emergency flood shelters and provide evacuation routes. In the past years, many cyclone shelters and flood shelters have been constructed. The effectiveness of the cyclone shelters, however, depends on how they are reached, i.e., the presence and conditions of roads. Paved roads are particularly crucial, as earthen roads– particularly without proper water management – become muddy and impassible during such testing times. Upgrading roads in the most critical areas – increasing embankment height and paving – should be planned, taking into consideration the role of such rural roads during emergencies. Guidance for developing a plan is given below.

*Table 12 - Guidance for preparation of an integrated road and flood management plan*

<table>
<tr><th>Topic</th><th colspan="3">Elaboration</th></tr>
<tr><td>Mandate</td><td colspan="3">Authorize a committee to make an integrated flood resilience plan for the road network, consisting of at least BWBD, RWD, LGED and local government.</td></tr>
<tr><td>Identify priority areas</td><td colspan="3">Focus on areas most exposed to river floods, typhoons, and riverbank erosion.</td></tr>
<tr><td>Studies</td><td colspan="3">Develop shared roads database<br>Modelling of flood/ run-off patterns<br>Modelling of the impact of primary embankment failures, breaches, and overtoppings<br>Modelling of evacuation pathways<br>Review of earlier studies and analysis of road failure during emergency events</td></tr>
<tr><td rowspan="7">Categorize roads</td><td colspan="3">Categories embankment roads in classes, given their role in flood management, for instance:</td></tr>
<tr><td>Class</td><td>Function</td><td>Design implication</td></tr>
<tr><td>A</td><td>Transport only</td><td>Allow overtopping and drainage</td></tr>
<tr><td>B</td><td>Flood compartment boundary</td><td>Limited strengthening, controlled openings</td></tr>
<tr><td>C</td><td>Secondary dyke</td><td>Designed to retain water temporarily</td></tr>
<tr><td>D</td><td>Emergency flood barrier</td><td>High crest, protected slopes</td></tr>
<tr><td colspan="3">Identify priority road evacuation pathways</td></tr>
<tr><td>Identify gaps and priorities for the upgrading of the road network</td><td colspan="3">Prepare an integrated plan<br>Identify priority roads for primary and secondary flood defense<br>Identify priority roads for compartmentalization<br>Identify priority roads for evacuation</td></tr>
<tr><td>Set criteria for the different classes of roads</td><td colspan="3">- Hydraulic sizing<br>- Crest height tied to flood return periods<br>- Slope protection for prolonged saturation<br>- Seepage and piping resistance<br>- Operable structures (gated or removable) where roads function as compartment boundaries<br>- Pavement criteria<br>- Safe shelters<br>- Access ramps<br>- Vegetative measures</td></tr>
<tr><td>Investment</td><td colspan="3">Connect into asset management (building back better) road investment planning and disaster risk reduction planning</td></tr>
<tr><td>Institutional development</td><td colspan="3">Assignment of responsibilities<br>Operational procedures (inspection, gate operation, signage)<br>Awareness (communities, local governments)</td></tr>
</table>

Road embankments themselves also provide space for humans and livestock during floods. This is very important as many people do not leave their house during flood emergencies, as they do not want to part with their animals[4]. This is particularly relevant for women: research shows that women take 25% more time to evacuate as they are taking care of children, elder family members and household assets during disasters, including poultry and livestock[5]. Having close access to safe higher grounds in the shape of embankment roads is then crucial. Cyclone shelters are not in all areas able to accommodate the entire population in an affected area; hence, roads

[4] Research found that for people who decided not to leave their house during typhoons the most common reason (48%) was taking care of livestock.

[5] A case study found that whereas it took men 99 minutes to prepare for evacuation, it took women 125 minutes (Parvin et al. 2019).

complement cyclone shelters and other flood response measures. Moreover, in many flood-prone parts of the country, especially outside the coastal area  - such as the Haor -, the density of cyclone shelters or flood shelters is still relatively low, and de facto roads provide the main safe grounds.

In addition, road embankments almost everywhere are important social spaces and should be managed as such. They are often the main public space and connection lines and should be managed as such – securing accessibility and open space.

All this translates also into guidelines for the structural dimensions of the road embankment, the height and width, the conditions of the side slopes, as well as some additional measures, such as access staircases. Existing manuals and guidelines for road embankments remain valid. The guidelines presented here are additional measures to optimize the road for water functions, in particular flood management. The guidelines may be used for new roads, but also very much for repair and building back better of the road embankments in case of erosion or flood damage.

*Figure 39 - During: Re-sectioning work of the embankment*

### *5.1.1 Embankments: height and width*

Where roads function as primary flood defense, they should be developed and maintained in line with the criteria of the BWDB for flood protection, accounting for maximum flood levels (1 in 25-50 years), additional free boards, and, in coastal areas, the effect of storm surges, depending on the fetch. This fetch depends on the normal distance from the windward shore to the affected embankment. and wind characteristics. It allows for wave height, wave run-up height, and a factor of safety against overtopping.

In particular, for roads that are exposed to flood risk, i.e., adjacent to the sea, rivers, and streams, close coordination is needed with the BWDB to make sure the road embankments align with the latest BWDB standards for flood protection structures. It is also important to make sure the road embankment reaches the desired width and height and is not paved over before this height and width are reached.

There are three categories of flood embankments aimed to protect land against the highest flood flows. The free boards depend on the height of the embankment and should be based on the maximum flood level plus a free board. In the coastal areas, an additional provision is needed to account for storm surges and tidal surges, and to avoid the intrusion of salt seawater on the land.

The three categories of embankments are:
- Marginal embankments along small rivers/canals
- Interior embankments along big rivers
- Sea embankments along sea faces or large rivers close to the sea.

The embankment crest level is designed either: (a) for a 1 in 50 year flood plus a freeboard allowance to protect agricultural assets; or (b) for a 1 in 100 year flood plus a freeboard allowance to protect against loss of human life, property, and installations (especially along the main rivers)

*Table 13 - Embankment heigh considerations*

| # | Key points |
|---|---|
| **1** | Height based on maximum flood level plus additional provision for wave action – in particular at sea fronts and river banks. |
| **2** | For roads close to streams, rivers, and sea, close coordination is needed with BWDB to ensure the latest, to ensure the road maintain width and height, and is paved before the maximum height of the flood embankment has been achieved. |
| **3** | Inside low-lying flood-prone areas, the height of roads may be increased on a priority basis so as to provide shelter and evacuation routes for people and livestock. |
| **4** | Also, in areas prone to water logging road embankment must be raised with adequate drainage so that nearby houses are not inundated |
| **5** | Raising the height of these roads may be done with excavated material from khals and drains that is often easily available |
| **6** | In the haor areas, road embankments may be made with appropriate heights that support water management and all-weather access – e.g., slightly elevated in order to influence the retreating inundation and to control soil moisture in the recession areas. Care should be taken not to interfere with the flooding patterns and deploy overflow structures, flood causeways, or adequate cross drainage. When this is not possible or feasible, submersible roads may be made. |
| **7** | Having slightly elevated roads in the haors in order to influence the retreating inundation and to control soil moisture in the recession areas. |

*Table 14 - Embankment considerations*

| Item | Elaboration |
|---|---|
| **Height** | The height of the embankment is based on the maximum flood level, freeboard plus an additional provision for wave action, in particular at sea fronts and river banks, prescribed by BWDB.<br><br>In designing new roads or upgrading existing roads, priority may be given to the road sections in the lowest part of the landscape and to raising them to at least the design specifications (1/25-50 year flood levels plus 0.3-1 meter additional freeboard). |
| **Width** | For road width, the recommended embankment width for critical For roads close to rivers and sea, close coordination is needed with BWDB, to ensure roads maintain width and height and are paved before the maximum height of the flood embankment has been achieved. |
| **Extra width for flood shelters** | In flood/cyclone prone area aditional space may be created for levees that can serve as an emergency shelter/platform. During the cyclone, people must take shelter in the cyclone shelter because it is not safe to use roads/embankments as shelter during the |

| | |
|---|---|
| | cyclone. People can use roads/embankments as shelter after the cyclone for a period of 15-30 days when their houses are damaged or underwater (see next). |
| **Prioritize low lying areas** | The roads in low-lying areas are the most affected by water logging, road breaching, and muddy conditions. The essence of rural road development in low-lying areas should be accessibility to shelters in case of emergency, such as cyclone shelters, community centers, schools, and health clinics.<br><br>Roads also provide important functions during floods themselves, as a safe shelter during and immediately after floods. These functions should be systematically strengthened. In designing new roads, priority may be given to the road sections in the lowest part of a polder, and to raise them to at least the design specifications. |
| **Marking evacuation routes** | People in Bangladesh are well aware of the location of the nearest shelter and the evacuation routes. However, during an emergency, some prefer to stay at home to protect their properties, in particular their livestock. Despite the Cyclone Preparedness Programs and early warning systems, pre-cyclone evacuation remains a challenge in Bangladesh. In the rural areas, there is still a lack of awareness, illiteracy, and communication, which prevents people from understanding the warnings and evacuating. Moreover, dissemination of warning messages is not efficient because most residents in coastal areas don't have a radio or television, or power fails during the cyclone event, so they prefer to rely on natural warning signs (Haque et al. 2012). During floods and cyclones, roads are an important part of the evacuation of people and livestock. LGED is developing guidelines for Rural Roads development, applying GIS for investment prioritization. This will provide a disaster damage database of rural roads at Upazila level: flood-affected road segment information, road embankment damaged information, and structure damaged information, update of river data, and update on settlement data (LGED 2010). The Disaster Risk Reduction Teams could use this database to plan the evacuation routes at the Union level. This can be done by:<br>- Mapping population centers.<br>- Mapping the road network, looking in particular at the level above ground.<br>- Mapping for floods, inundation risks, and escape routes (WMO & GWP 2011).<br>- Creating flood signs as part of the evacuation route planning (WMO & GWP 2011).<br>- Analyzing main gaps and deficiencies and identify vulnerable areas.<br>- Identifying locations that are easily inundated and consider placing poles or other markers in such areas to mark the road bodies.<br>- Providing awareness so that a large number of people are aware of the evacuation routes. |

### *5.1.2 Guidelines for additional levees*

Levees or platforms may be created along specific rural embankment sections to temporarily shelter flood-affected people. This follows the traditional practice of elevated killa in some parts of Bangladesh. Such higher sections can be created along roads, especially in flood-prone areas. They could provide the opportunity to temporarily (15-30 days) accommodate flood victims (with their cattle and goods) until they have rehabilitated their houses, using the silt from excavations of khals, ponds, or rivers.

The risk obviously is that the temporary shelters may be encroached and converted into permanent residences. The Bangladesh Water Act discourages the construction of any house, establishment or other structure on flood control embankment. As per Article 21 of the Water Act, to ensure the sustainability of the flood control embankment, no person shall, without the permission of the appropriate authority, be allowed to construct any house, establishment or any other structure on, or on the slope of such embankment. The EC may issue a removal order or impose any restriction by issuing a protection order. Usage should be regulated by the local government. The Union Parishad should have the written authority to remove people from these levees when required. To avoid encroachment, the levees may also be assigned for specific temporary functions. The following guidelines would apply:

*Table 15 - Levees guidance*

| Item | Elaboration |
|---|---|
| **Size of levees** | As an indication, the minimum space needed for a person to take shelter lying down is 1.5m² or 3.5m² for a sphere standards space (Red Cross 2013). An average household in Bangladesh has 4.6 members (Begum 2004). A family needs approximately a shelter area of 15-16m². For livestock, between 2 and 4 meters of space per head would suffice. Therefore, on a longitudinal section of 100m of embankment with a width of 3m (10 ft.), 85 people can take shelter (without livestock). If there are multiple areas of 300m² in specific locations along an embankment, the number of people who would benefit from temporary shelter would be much proportionally larger.<br><br>JICA (2015) has designed single story refuge platform with dimension<br>- 50x80 meter (large)<br>- 30x60 meter (medium) |
| **Spacing** | The spacing of the levees should be done strategically – placing them at distances so that they are accessible throughout the flood prone areas and placing them along more exposed sections of flood embankments, so they serve as an additional reinforcement. The same may also be done for the area outside the embankments. |
| **Facilities** | The platforms proposed by JICA (2015) were equipped with:<br>- Two hand tubewells<br>- Two latrines<br>- Twin community building<br>- Health centre<br>- Store room<br>- Additional linear livestock refuge embankment (5 m wide × 500 m long) with cross drainage |
| **Assign temporary function** | The platform may be assigned a temporary function – to make sure the space is used and not encroached, such as an open marketplace or collective threshing places, or on a narrow road section for cars to pass one another. |

### 5.1.3 Embankment side slopes

*Figure 38 - Damage to the side slope is not just to be restored but to be 'built back better' (Picture: LGED)*

Embankment slopes are a critical part of embankment roads. To ensure stability and prevent erosion, minimum slopes are prescribed based on soil characteristics and the risk of flooding. Embankment slopes are also important as they provide space for roadside vegetation. In several cases, however, there is no space for the recommended slopes, as LGED cannot acquire the land needed for the right of way and the prescribed slopes. In such a case, the steeper embankment slopes need to be protected. Ownership issues of roadside slopes should be addressed: this requires consultation and time to reach an agreement on ownership by LGED and/or land use by communities of the side slopes.

The backfilling of damaged embankment slopes is a major recurrent task for LGED. One should prioritize slide slope protection by timely repair and also by 'building back better' of the road slopes, in case of slump, erosion or flood damage. The aim is to prevent future damage by using different slope stabilization methods as appropriate for the road section concerned. An assessment of systematic improvement should be part of any embankment repair request.

In the hill tracts, road embankments differ from the low-lying plains; here, an important requirement is to prevent unstable roadsides that would affect the water retaining capacity of the landscape, cause local springs to lose their discharge, cause erosion and sedimentation of water bodies and increase the risk of disruptive landslides and landslips affecting the road bodies themselves. Bioengineering is an appropriate practice for roads in hill tracts. Useful manuals for these have been developed, as well as training packages. The main guidance for bio-engineering is given in section 5.7. The following Guidelines apply to embankment slopes.

*Table 16 - Guidelines for embankment slopes*

<table>
<tr><th>#</th><th colspan="5">Key points</th></tr>
<tr><td>1</td><td colspan="5">Standard embankment slopes are given in LGED road design standards (including Small Scale Water Resources Subproject Planning & Design Guidelines). They are as below. They come with the application of long-rooted grass turfing. Special provisions can be made for unstable soils (more gentle slope, slope protection).</td></tr>
<tr><td></td><td colspan="3">Embankment height 0–1.99 m:</td><td colspan="2">1V : 1.5H</td></tr>
<tr><td></td><td colspan="3">Embankment height 2.00–3.99 m:</td><td colspan="2">1V : 2H</td></tr>
<tr><td></td><td colspan="3">Embankment height 4.00–4.99 m:</td><td colspan="2">1V : 2.5H</td></tr>
<tr><td></td><td colspan="3">Embankment height 5 m and above</td><td colspan="2">to be determined from detailed slope stability analysis</td></tr>
<tr><td></td><td colspan="3">Low embankments where safety and recovery are important</td><td colspan="2">1V:3H and more</td></tr>
<tr><td>2</td><td colspan="5">For critical flood embankments, special guidelines apply for the side slopes:</td></tr>
<tr><td></td><td colspan="2">Marginal embankment (along drains and minor rivers)</td><td>Country side<br>River side</td><td colspan="2">1V:2H<br>1V:2H</td></tr>
<tr><td></td><td colspan="2">Interior embankment (along main rivers)</td><td>Country side<br>River side</td><td colspan="2">1V:2H<br>1V:3H</td></tr>
<tr><td></td><td colspan="2">Sea embankment</td><td>Country side<br>Sea side</td><td colspan="2">from 1V:2H to 1V:3H<br>from 1V:5H to 1V:7H</td></tr>
<tr><td>3</td><td colspan="5">Taking standard embankment height of 2-3.99 meters, for areas with challenging soil condition, special measures are recommended, following (BUET, 2018).</td></tr>
<tr><td></td><td>No.</td><td colspan="2">Method Name</td><td>Preferable Scenarios</td><td>Preferable Side Slope Ratio (V : H)</td></tr>
<tr><td></td><td>1</td><td colspan="2">Slope Protection work with Long Routed Grass Turfing</td><td>General Road Embankments</td><td>1 : 2</td></tr>
<tr><td></td><td>2</td><td colspan="2">Slope Protection work for High Embankment (Above 4.5 m) with Long Rooted Grass</td><td>High Embankments, Haor Areas / Coastal Areas</td><td>1 : 1.75</td></tr>
<tr><td></td><td>3</td><td colspan="2">Slope Protection Work with Grass Turfing & Geo-Jute on Slope for Sandy Soil with Long Rooted Grass</td><td>Sandy Soil</td><td>1 : 2</td></tr>
<tr><td></td><td>4</td><td colspan="2">Slope Protection Work with Grass Turfing, Geo-Jute & Geo-Bags on Slope for Clayey Soil</td><td>Clayey Soil</td><td>1 : 1.5</td></tr>
<tr><td></td><td>5</td><td colspan="2">Slope Protection work with Long Rooted Grass* Turfing & Geo-Jute on Slope for Hilly Areas</td><td>Hilly Areas</td><td>1 : 2</td></tr>
<tr><td></td><td>6</td><td colspan="2">Temporary Slope Protection work with Gunny Bagged Rip-Rap and Geo-Textile</td><td>Haor Areas / Coastal Areas</td><td>1 : 2</td></tr>
<tr><td></td><td>7</td><td colspan="2">Slope Protection work with Gabions</td><td>Haor Areas / Coastal Areas</td><td>1 : 2</td></tr>
<tr><td></td><td>8</td><td colspan="2">Slope Protection work with Long Rooted Grass*, Vegetation, Block and Gabions</td><td>Haor Areas / Coastal Areas</td><td>1 : 2</td></tr>
<tr><td></td><td>9</td><td colspan="2">Slope Protection work with Masonry Brick and Pre-Cast Gabions</td><td>General Road Embankments</td><td>1 : 2</td></tr>
<tr><td>3</td><td colspan="5">Where it is not possible to ensure the proper side slopes, rather than frequent back filling alternative reinforcement arrangement should be deployed such as (1) masonry retaining walls properly anchored and backfilled; (2) face geotextile face wraps or geogrid bamboo matrasses with vegetation; (3) armoring with concrete block (with weepholes) or riprap with graded filter; (4) bio-engineering for short slopes, with native grasses, vetiver, creeper mats, especially on lower part of the slope; (5) bamboo fascines (6) toe drains. Combinations of methods may be considered too. In general, the use of rigid systems in costly and should be applied where the risk of embankment damage is high.</td></tr>
<tr><td>4</td><td>No.</td><td>Method</td><td>Where / When to Apply</td><td>Key Advantages</td><td>Key Disadvantages / Limitations</td></tr>
<tr><td></td><td>1</td><td>Masonry retaining walls (properly anchored and backfilled)</td><td>Steep slopes with limited right-of-way<br>Urban or peri-urban embankments<br>High-value infrastructure (roads, flood protection)</td><td>High structural stability Long service life if designed correctly<br>Effective against deep-seated slope failure</td><td>High capital cost<br>Requires skilled construction and quality materials<br>Poor performance if drainage/backfill is inadequate Not suitable for very soft foundations without improvement</td></tr>
</table>

| | | | | | |
|---|---|---|---|---|---|
| | 2 | Geotextile face wraps / geogrid bamboo mattresses with vegetation | Medium slopes (typically 1V:2H to 1V:3H)<br>Rural embankments<br>New embankment construction | Cost-effective compared to rigid structures<br>Flexible and tolerant of minor settlements<br>Promotes vegetation and erosion control<br>Bamboo locally available | Limited durability of bamboo (unless treated)<br>Requires good workmanship and compaction<br>Not ideal for high-velocity flow zones |
| | 3 | Concrete block armoring (with weepholes) | Slopes exposed to wave action<br>Riverbanks near ferry ghats, regulators, bridges<br>Upper slopes subjected to rainfall erosion | Good resistance to erosion and wave action<br>Modular and relatively fast to install<br>Weepholes reduce pore water pressure | Higher cost than bio or bamboo solutions • Rigid—can crack or displace under settlement • Requires proper filter layer beneath |
| | 4 | Riprap with graded filter | Riverward slopes exposed to strong currents<br>Toe and lower slope protection<br>Areas with fluctuating water levels | Proven and robust solution Flexible and self-adjusting under minor settlement<br>High resistance to hydraulic forces | Requires availability of suitable stone<br>Transport costs can be high<br>Failure likely if filter design is inadequate |
| | 5 | Bio-engineering (native grasses, vetiver, creeper mats) | Short slopes (typically <5–6 m height)<br>Upper and mid-slope zones<br>Low to moderate erosion risk areas | Very low cost<br>Environmentally sustainable<br>Improves slope stability over time<br>Easy community involvement | Slow to establish<br>Ineffective against strong currents or waves<br>Requires maintenance during initial growth |
| | 6 | Bamboo fascines | Toe and lower slope stabilization<br>Soft, saturated soils<br>Temporary or emergency works | Very low cost<br>Locally available materials<br>Improves drainage and reduces surface erosion | Short lifespan (biodegradation) Limited structural capacity<br>Requires periodic replacement |
| | 7 | Toe drains | Slopes with seepage or high groundwater levels<br>Areas prone to sloughing during monsoon<br>Behind retaining walls or rigid armoring | Reduces pore water pressure<br>Improves global slope stability<br>Enhances performance of other protection methods | Ineffective alone for erosion protection<br>Can clog if not cleaned<br>Requires regular inspection and maintenance |

### *5.1.4 Multi-purpose road embankment side drains*

*Figure 39 - Road embankment borrow trench cum multipurpose drain (notice distance from embankment may be increased)*

To facilitate the timely repair of the road embankment, the ready availability of borrow areas for soil is required. A good practice observed in several areas is the multi-purpose elongated roadside borrow trenches, which can also be used to collect excess water from adjacent land and local rainfall, which may be used during dry periods. These trenches/ multipurpose drains are an important part of local water management and contribute to water storage for dry periods and reduced water logging in wet periods. Deeper ponds/trenches can be used for fish cultivation or for aquatic crops.

A concern is that these multipurpose drains may affect embankment stability, in particular in areas with soft soils (soft alluvial clays, silty clays, loose silts), especially with embankments that are not well-compacted. This may cause shallow rotational slips, slope sloughing and longitudinal cracking along road shoulders. A minimum setback distance is recommended, though it is realized that with the prevailing land scarcity in Bangladesh, this cannot always materialize.

*Table 17 - Guideline on set-back distance for roadside drains*

| Item | Elaboration |
| --- | --- |
| **Distance and depth of multi-purpose side drain** | Multi-purpose roadside ponds/trenches are in use to protect the road embankment from moisture and water logging. These side drains at the base of the embankment also collect local run-off and excess drainage water from adjacent fields. The drains, hence, serve as a local water storage as well and should be encouraged.<br><br>They need to have an adequate setback distance from the bottom of the embankment:<br>at minimum 3 meters from the base of the embankment<br>The preferred set back distance can be calculated with the following formula:<br>Where: SB = Ze x Dch<br>SB = embankment set back distance (m)<br>Ze = side slope of embankment (V/H)<br>Dch = depth of channel or drain (m) |

### *5.1.5 Access to embankments*

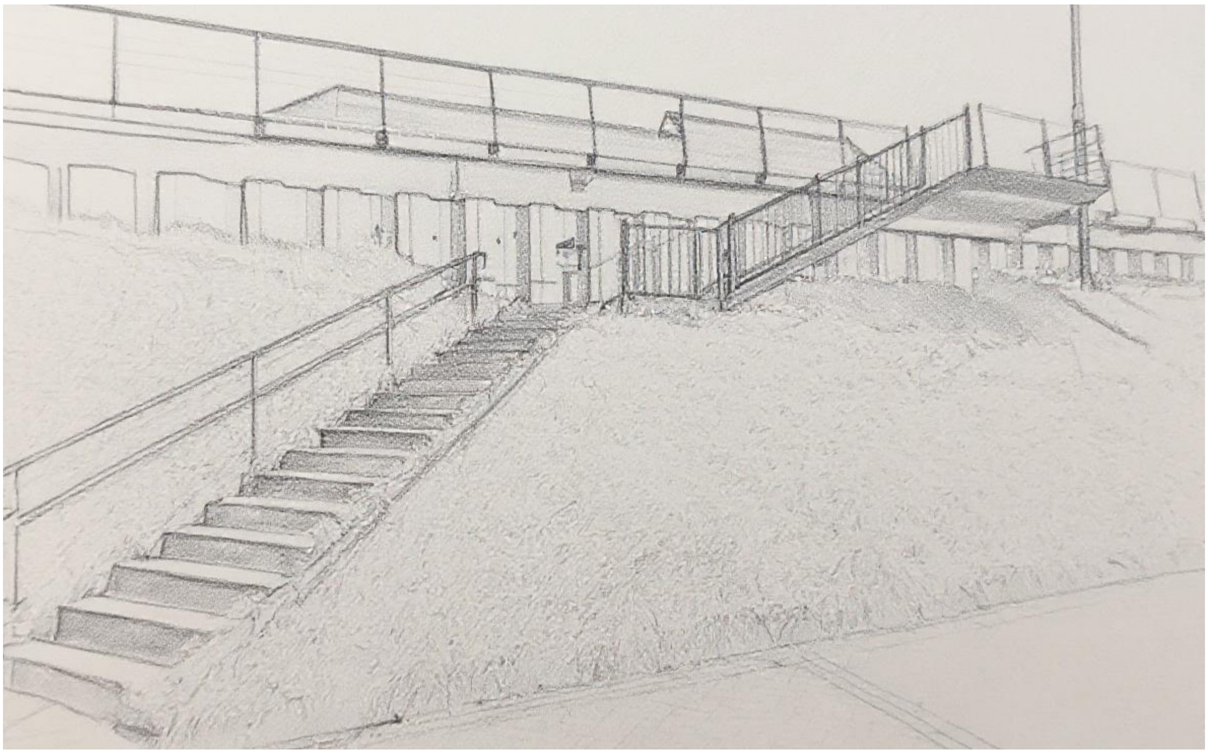


*Figure 40 - Switch back staircase*

Because of their omnipresence in Bangladesh, road embankments are important social spaces. It is a place where people meet and should meet safely and conveniently. Important considerations[6] are the avoidance of sharp bends in the embankment roads (often a cause of accidents) and using solar-powered streetlights. There are many other road safety requirements.

Embankments can become challenging barriers, especially for women. To provide convenient and safe access, staircases may be included in the embankment design or in the retrofitting, especially close to areas of much pedestrian traffic. The following guidelines apply:

[6] This was identified in the Women Adaptation Labs for Green Roads for Water in Bangladesh (see section 3.3).

*Table 18 - Guidelines for staircases on road embankments*

| Item | Elaboration |
|---|---|
| **Incline** | A gentle incline is recommended (30° to 35°), provided the side slope allows this. Yet many embankments in reality have steeper slopes.<br><br>In this case, a switchback staircase is proposed. A switchback staircase can handle steep embankments by changing (oblique) directions at one or more landings, rather than going straight up. The design helps reduce the effective slope of each flight of stairs, making the climb more gradual and easier. After a flight of stairs, the staircase reaches a landing and reverses direction (usually 180°) before continuing upward |
| **Topflight** | There should be adequate space and a protective railing on the topflight of the stairs, so that the pedestrians are sheltered from the road traffic |
| **Tread** | The depth of each step should allow for a secure footing. Typically, a tread of about 250–300 mm is used. |
| **Riser** | The rise of each step range from 150–175 mm so as to be manageable for the user |
| **Material** | A roughened surface of the steps will provide additional traction and prevent the stairs from becoming slippery. |
| **Drainage** | Drainage channels or proper water runoff arrangements are important to ensure the staircase remains stable. |
| **Railing** | For safety, a handrail should be incorporated, especially when the staircase is on a steep embankment or where there is a risk of falling. The handrail should be around 800-900 mm from the tread of the step. |

### *5.1.6 Visualizations*

On the next page, several visuals are provided to showcase different embankment (protection) options.

Backfilling and compaction (building back better)

Timely repair of embankment slopes

Bamboo fascine protection

Grass embankment protection

Embankment protection with brick armor

Embankment protection using riprap

Palisade protection

Retaining wall with proper backfilling

## 5.2 Cross drainage

### *5.2.1 General points*

| # | Key points |
|---|---|
| 1 | Cross drainage is important to evacuate water from the area around the road, avoid water logging in the landscape, and prevent water accumulation around the road. |
| 2 | In many areas, however, roads are built with inadequate cross-drainage – sometimes due to temporary funding constraints. This causes serious water logging in low-lying areas, resulting in large agricultural losses and worsened public health. Such inadequate cross drainage should be corrected on a priority basis. |
| 3 | A well-developed and well-maintained cross drainage system will prolong the life of the road and will also make it easy to collect the run-off water and direct it to areas for beneficial use, i.e., a storage reservoir or recharge areas. This is particularly important in drought-affected areas, where water supply is critical, such as the Barind. |
| 4 | Another important beneficial application is in rice growing areas, in particular where improved *amon* varieties are introduced. These need better water control: timely release and ponding. For this, road culverts equipped with gates are most suitable. The gates are usually placed at the outlet side of the culvert. |

*Figure 41 - Gated culvert to control water levels in rice fields*

Cross drainage is important to evacuate water from the area around the road, both to avoid water logging in the landscape and to prevent water accumulation around the road, which undermines road stability. In many areas, however, roads are built with inadequate cross drainage – sometimes because of temporary funding constraints. This causes serious water logging in low-lying terrain, stretching over large areas, because of the flat nature of the land. This is resulting in major agricultural losses and worsened public health. When land is water logged, the soil is not aerated, and crops can hardly grow. Also, stagnant water causes many human and animal diseases – malaria, fevers, and liver fluke.

Where such inadequate cross drainage exists, it should be corrected on a priority basis. A well-developed, well-maintained cross-drainage system will prolong the life of the road and ensure productive agriculture. Modelling work was undertaken in Polder 23 in the coastal zone. The roads built under the LGED were without adequate bridges, culverts, and pipes, as funds for these were not included in the road budget. As a result, waterlogging became widespread. It was estimated that improving road cross drainage by adding ten culverts and bridges would remove water logging to a significant extent. The benefits show the enormous economic importance of adequate cross-drainage around roads.

*Figure 42 - Road embankment (tragically) blocking drainage (photo G. Keller)*

A well-developed drainage work has several other important benefits, besides avoiding water logging, namely:

- It makes it easy to collect the run-off water in the entire landscape and direct it to areas for beneficial use, i.e., storage reservoirs or recharge areas. This is particularly important in drought-affected areas, where water supply is critical, such as the Barind
- By providing gates on bridges and culverts, water tail flows in the monsoon season can be stored in the khals. In drought-affected areas, this can increase water availability in the dry season and promote groundwater recharge.
- Particularly, in rice-growing areas, gated culverts can be used for water control in the rice fields. For this, road culverts equipped with gates on smaller roads and tracks are most suitable.
- Sufficient cross drainage in an area will ensure that fish movement is not impeded. For this, culverts need to be fish-friendly. Given the huge importance of wild capture fisheries in Bangladesh, this is an important measure.

This section discusses the main Green Roads for Water requirements for Bangladesh in the field of cross-drianage.

### 5.2.2 Providing adequate cross drainage to avoid water logging

In most polder areas, more cross drainage structures (culverts, pipes, and bridges) with a larger capacity are needed to reduce drainage congestion and water logging in low-lying areas during heavy rainfall and related damages (roads, loss of property, erosion, agriculture loss). It is recommended that the number and size of water crossings be determined through hydrological analysis of the area's internal drainage conditions.The rational method is recommended.

In this method, the evacuation of water from the upstream catchment area is assessed, including expected discharge during monsoon, and any local drainage features (e.g., rice fields, embankments) that influence flow. The Rational Method is a standard hydrologic analytical instrument for estimating peak runoff for the design of cross-drainage structures such as culverts and minor bridges along road sections in Bangladesh. The method is appropriate for small to moderately sized catchments, typically in road drainage design, and assumes that the maximum discharge is enabled when rainfall of uniform intensity persists for a duration equal to the time of concentration of the contributing catchment. Peak discharge is estimated using the equation:

$$Q = C * I * A$$

where $Q$ is the peak runoff ($m^3$/s), $C$ is the runoff coefficient reflecting land use, soil type, slope, and surface conditions, $I$ is the design rainfall intensity (mm/hr), and $A$ is the catchment area (hectares or $km^2$, with appropriate unit conversion). Drainage capacity should match the peak discharge.

In the context of Bangladesh, rainfall intensity $I$ is derived from Intensity–Duration–Frequency (IDF) curves developed using long-term rainfall records from meteorological stations. These curves relate rainfall intensity to storm duration and return period (e.g., 10-year, 25-year, or 50-year events), allowing selection of an appropriate design storm based on road classification and risk considerations. The selected rainfall duration is taken as equal to or greater than the estimated time of concentration for the catchment draining to each cross-drainage structure.

Data requirements for applying the Rational Method include catchment delineation from topographic maps or surveys, land use and surface condition data for selecting runoff coefficients, rainfall records for development or selection of IDF curves, and estimates of time of concentration based on catchment length, slope, and flow characteristics. Using these inputs, available from amongst other meteorological services and resources documents, the calculated peak discharge provides the basis for hydraulic sizing of cross-drainage

Alternatively, in the absence of data, a short cut method maybe be used as given in the Standard Design Road Manual (LGED, 2005) – the so-called Indicative Gap Rule, The 'indicative gap rule' (LGED 2005) describes the recommended length (in meters) of drainage openings (bridges, culvers and pipes) per 100 meter of roads (Table 19, derived from experience). It is based on the type of road and the geographical location.

At present, BWDB is discussing that achieving climate resilience may require additional drainage capacity. During the design of drainage structures, an addition 15% (total 115%) rainfall should be considered for climate change. It is recommended to also increase the recommended gap criteria (see also table 19). These are minimum requirements. It does not do harm to increase the cross drainage in an area, and add 20% of safety margin to the indicative, climate change-adjusted gap requirements.

*Table 19 - Indicative gap requirements by type of road in m/km*

| Road design type | Basis | Geographical location | | | |
|---|---|---|---|---|---|
| | | Swampy | Hilly | Hoar | Plain |
| **Type 6, 5, 4**<br>**Type 8, 7** | Standard gap rule (LGED 2005) | 10-15 | 7-15 | 10-15 | 6-10 |
| | Corrected for climate change | 12-17 | 9-17 | 12-17 | 8-12 |

| | | | | | |
|---|---|---|---|---|---|
| | Additional safety margin for consideration | 20% | 20% | 20% | 20% |

At the moment, LGED does not always systematically integrate the drainage structures (culverts and pipes) into the initial road design. In several instances, the location of culverts or pipes is decided later, or when road damage happens due to seepage, or when water logging occurs. This is called the gradual approach. Thus, rural roads have insufficient or inadequate drainage gaps to overcome the excess of water flow during the monsoons.

*Figure 43 - Locally constructed embankment footpath with no cross drainage, causing drainage congestion – this may have to be corrected by retrofitting culverts or pipes*

It is a better practice to decide on the cross-drainage requirements when the road or paths are first constructed. The Bangladesh Water Act states that normal flow should be ensured in planning the road network. Therefore, based on the land type (see above), the road network has to be planned/designed with enough and adequate drainage structures. However, some of the roads may need to be retrofitted with appropriate openings since they were not included in the initial planning. In other cases, these openings may need to be moved or relocated due to their inappropriate location. In several low-lying areas, local people have constructed small barrier dams over drainage *khals* to reach farmland. This is also a common cause of drainage congestion and localized water logging. It is also recommended that culverts or pipes be installed to remove such blockages. This leads to the following guidelines:

*Table 20 -General guidelines on cross drainage*

| Item | Elaboration |
|---|---|

| | |
|---|---|
| **Cross drainage capacity** | - Use 'rational method' to calculate cross drainage capacity.<br>- Alternatively, as quick methods use 'indicative gap rule' to determine total drainage openings. |
| **Siting of drainage structures** | - Observe the natural drainage patterns and place the cross-drainage structures along natural drainage paths. |
| **Width of cross drainage structure** | - Cross drainage width to match (or be wider) than the natural channel bank full width: this bank full is the flow level that occurs approximately every two years. |
| **Height of cross drainage structure** | - Accommodate high flood level (HFL) inside drainage canal in the last 5 years. |
| **Planning and retrofitting** | - Ensure that the existing cross drainage width corresponds with the requirements under the Rational Method or the Indicative Gap Rule.<br>- Where water logging occurs, assess the extent to which this is caused by inadequate road cross-drainage.<br>- Where necessary, retrofit cross drainage on existing roads or local foot paths. |

### *5.2.3 Disposal of road drainage water for beneficial use*

A well-articulated road drainage system with adequate side drains and cross drainage structure is essential for the preservation of the roads but can also be used to collect water from the surrounding area and use it for beneficial purposes, i.e. filling storage reservoirs, feeding groundwater recharge areas or even directly irrigating agricultural land. The design of road drainage systems is adequately covered in the 2021 LGED Road Design Guideline, which serves as the premier guidance.

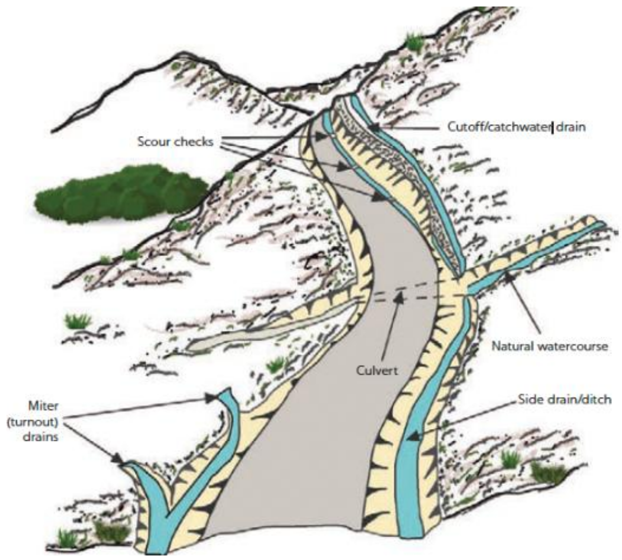



*Figure 44 - Well-developed drainage system collecting water and making it possible to route to areas of beneficial use*

What is considered here is the disposal of the road drainage water, so that it may serve beneficial use and not do harm, such as creating local floods or erosion. This should be systematically assessed and discussed with the roadside communities. If there is no scope to use the water guided by the road drainage system, it should be disposed safely – not causing local flooding or landscape damage.

Note that the beneficial use concerns the run-off and rainwater that is guided by the road embankment and road drainage system. Reusing water from the road surface should be discouraged, as this carries contaminants such as oils, rubber crumble and others. This leads to the following guidelines:

*Table 21 - Guidelines on beneficial use of road drainage water*

| Item | Elaboration |
|---|---|
| **Beneficial use** | - Identify areas for beneficial use – groundwater recharge zones, swallows or storage reservoirs.<br>- Connect the cross-drainage water to these areas of beneficial use.<br>- Consider the size of the catchment area to estimate the volume of water that can be harvested. |

| | |
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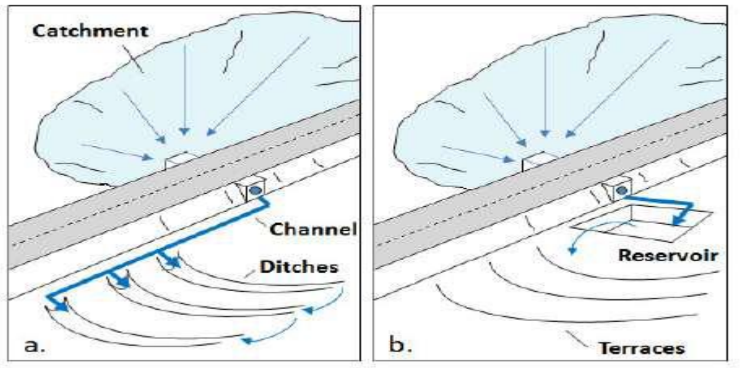
| | <br><br>*Figure 45 - Roads for beneficial water harvesting*<br>- In accidented hilly terrain (5-20%), consider spreading water at the outlet of culverts to promote recharge and avoid downstream gully development.<br>- Engage communities and local authorities in the decisions on the beneficial disposal areas. |
| **Direct beneficial use on land** | - Consider trenches, especially in clayey/ loamy soils to avoid overland washouts and provide irrigation in the rootzone |
| **Direct beneficial use for water recharge** | - Ideally these recharge areas are located at least 20–50-meter distance from the road, depending on the slope of the land.<br>- Ensure water is spread gently over recharge areas, giving ample time to infiltrate.<br>- In flat areas, this can be done by using low guiding bunds or developing swales in the recharge area.<br>- In steeper areas, additional retention structures can be developed to enhance recharge, such as infiltration trenches, infiltration ponds, stone bund, or half moons.<br><br>*Figure 46 - Swale for water storage and recharge* |
| **Direct beneficial use for water storage** | - Use or develop water storage facilities – these can be converted borrow pits, micro-basins, or ponds.<br>- Shade trees may be provided to reduce evaporation, and grass to avoid erosion. |
| **Avoid concentrating of flows** | - Follow natural drainage paths and avoid 'bundling; rather than combining drainage in higher cross drainage structure, as this may cause erosion and/or downstream flooding. |
| **Ensure adequate slope in the drains** | - Maintain a minimum slope of 1% in the drains to allow water to evacuate by gravity. |
| **Avoid scour in the road drainage canal** | - When the slope is >5%, provide grasses, turfing, or rip rap to prevent the scouring of the drains. |

| | |
|---|---|
| | - When the drop is high (slope is >15%), use a cascade of check dams to prevent scour and erosion of the drains.<br><br>*Figure 47 - Cascaded cross drain outlet* |
| **Safe disposal** | - When no beneficial use is possible, ensure safe disposal of road drainage water in local streams.<br>- If necessary, avoid steep drops of disposal by using chutes to prevent bank erosion.<br>- Consider diverting part of the road drainage water through controlled overflow to avoid uncontrolled peak flows. |
| **Avoid concentrating of flows** | - Follow natural drainage paths rather than concentrating drainage in a limited number of cross drainage points, as this may cause downstream flooding. |

### *5.2.4 Create water control with small gated culverts*

Small gated culverts and pipes can be used for water control, in particular in paddy fields. This is particularly important where improved amon varieties are introduced. These need more water control: the ponding and timely release of water from the rice fields to allow land preparation, irrigation, application of agro-chemicals, or harvesting.

This can be done with the help of gated culvert or gated pipes. These gates may range from simple corrugated iron sheets in front of the outlets to engineered structures equipped with stoplogs and handlebars on the gate. The gates are usually placed at the outlet side of the culvert. They can be put in place by farmer initiative and managed under local rules. It is common for farmers/ communities to build small bunds-cum-footpaths/ tracks to create the opportunity for water control – a practice that should be encouraged. The release of water can be to a downstream canal or to a lower-lying field.

*Figure 48 - Left: Engineered gated culvert in rice growing area, Right: Gated culvert discharging in local canal/ drain*

### *5.2.5 Supporting inland wild capture fishery with fish-friendly culverts*

As in other countries, road culverts in Bangladesh have formed barriers to the movement of fish and other aquatic organisms. They have been too small in numbers or undersized, had water levels that were too low, or flow velocities that were too high to allow fish movement. In other instances, culverts were set too high in the stream channel, forming a waterfall at its outlet rather than a resting pool. All this impeded the movement of fish, fragmented their natural habitats, and disrupted breeding and spawning patterns – causing wild fish stocks to decline and creating economic and environmental setbacks.

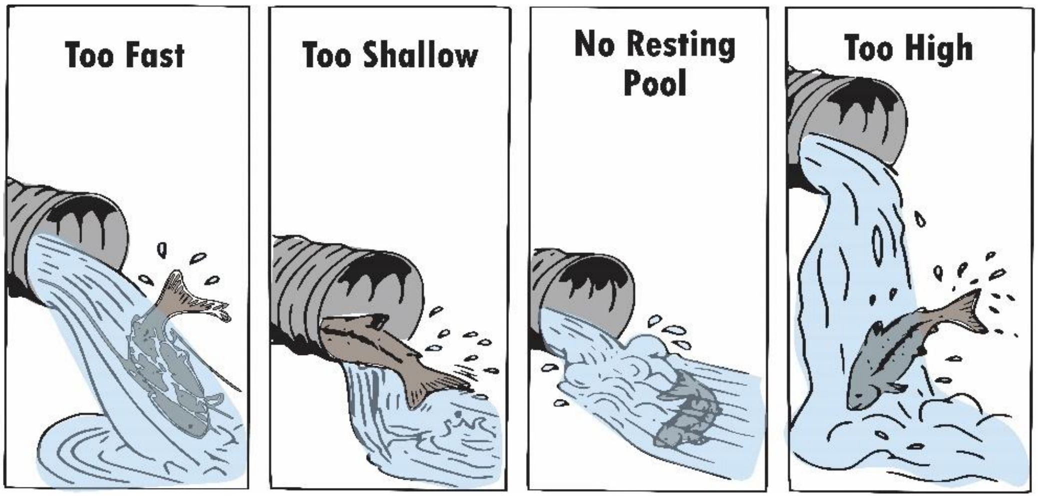



*Figure 49 - Problematic fish passage from road culverts*

There is an urgent need to ensure proper fish-friendly design of road culverts, including the retrofitting of existing culverts. Inland open-water capture fisheries still account for a significant share (estimated to be close to one quarter) of inland fish production in Bangladesh and are an important factor in the rural economies and a prompt to local biodiversity as well, being part of the natural food chain. Moreover, they are a main livelihood opportunity for poor landless or near-landless households, requiring little gear and investment. Inland capture fisheries often function as a safety-net livelihood. Landless or near-landless households, agricultural wage laborers, and marginal farmers frequently enter fishing during the monsoon or agricultural lean season on open water bodies. Disruption of fish movement by factors such as damming of local streams and overfishing, but also disrupted passage by local roads, should be urgently addressed. The following guidelines apply for fish-friendly road culverts.

*Table 22 - Guidelines for fish-friendly road culverts*

| Item | Elaboration |
|---|---|
| **General** | - Follow as much as possible, natural stream characteristics.<br>- Avoid culverts that disrupt fish passage either because the flow is too fast and turbulent, the flow is too shallow, the jump is too high, or there is no resting pool. |
| **Location** | - Particularly in areas with fish migrations, ensure adequate drainage openings so as not to disrupt seasonal inundation patterns. This is critical for fish breeding and feeding life stages.<br>- In general, in such areas, wide cross drainage on existing streams is preferable to a large number of small (pipe) culverts, which may distort the flow pattern.<br>- For culvert locations, avoid disturbing sensitive locations– such as bends in the streams or shallow areas where water moves swiftly over gravels and timbers, as they are often fish habitat pools.<br>- Avoid crossing waterways at or near sharp bends, sections of unstable |

| | |
|---|---|
| **Culvert shape** | <br>*Figure 50 - Arch culvert*<br>- **Arch culverts** – though not yet common in Bangladesh - are preferred for fish passage as they preserve the natural streambed (especially bottomless arches) and maintain near-natural depth, velocity, and turbulence. They also minimize behavioral barriers (light, sound, and flow pattern). These characteristics are particularly important for Bangladesh's small indigenous species, juveniles, and migratory fish, which are sensitive to velocity and habitat disruption.<br>- **Box culverts** (provided they are sufficiently wide) are the second best, cost-alternative option. They can be sized wide and shallow, reducing velocity. They are easier to embed and roughen than pipes and allow more daylight penetration than pipes.<br>- **Pipe culverts** should be avoided on fish migrations routes and highly productive floodplain channels – as they create more turbulent flows and are generally darker – and are also more difficult to retrofit/ adjust. |
| **Culvert width** | - Culvert width should match or be wider than the natural channel bank full width – this bank full is the flow level that occurs roughly every two years<br>- Single large culverts with cross-sectional area close to the natural channel width are preferable to multiple small pipes. Larger sections decrease velocities and reduce turbulence that inhibits passage. |
| **Water depth** | - Minimum water depth during passage flow should be 0.30 meter. |
| **Water velocity** | - Maximum mean velocity during passage flow should 0.30 meter /second – to allow two-directional movement also of juvenile fish.<br>- A maximum low culvert slope of 0.05% is hence preferred. If this is not possible, the roughness of the surface may be increased (see next) |
| **Culvert inlet or outlet** | - There should be no inlet or outlet drop.<br>- Preferably, a resting pool is created at the inlet and outlet across the width of the culvert, with a pool depth of 0.4–0.6 meter |
| **Rough surface** | - A rough surface will grade stream bed material, and meandering flow channels can simulate a safe passage for fish and other aquatic life, with small resting places.<br>- This is particularly important for longer culverts. This can be done by placing well graded material (gravel, boulders, bricks).<br>- To avoid washouts, these boulders may even be fixed with wire or cement.<br>- For larger culvert baffles or transverse vanes may be considered. |

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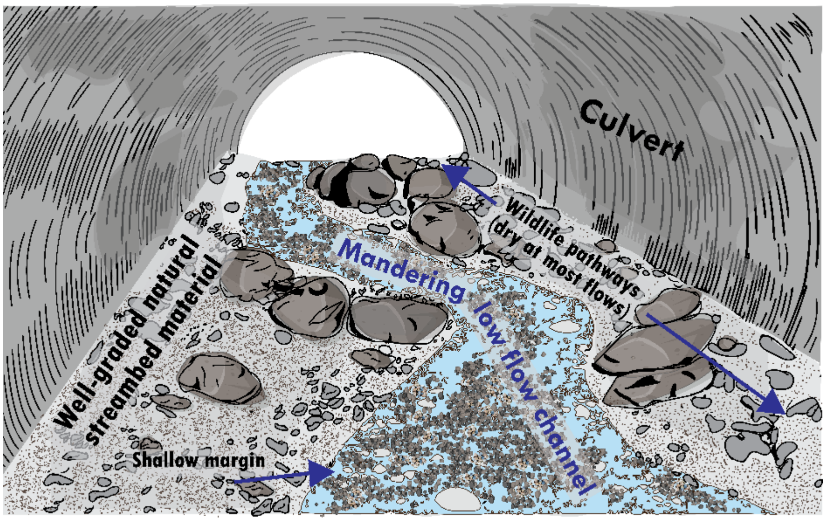
| | <br><br>*Figure 51 - Some of the key surface elements of fish-friendly culverts* |

## 5.3 Bridges

*Figure 52 - Bridge in rural Bangladesh*

Bridges can have a large bearing on water management. Bridges are pressure points throughout the drainage network in the country. Their effect can be beneficial or, if not done well, detrimental. All over the world, there are examples of bridges that have a negative effect on river morphology, that cause sedimentation, or that trigger floods. On the other hand, there are also encouraging examples where bridges and bed sills have raised the water level and promoted groundwater recharge or have helped stabilize riverbeds. It all depends on what is being done where.

It starts with looking at bridges not just as transport infrastructure but considering them as hydraulic structures too. As with culverts and pipes, bridges are essential in drainage. As they are placed over larger streams, their effect on local hydrology, if not designed properly, can be substantial In the sedimentation prone rivers in the tidal areas in South-West Bangladesh, bridges – particularly when they were ill-placed and too narrow – have played havoc with the bed stability in the rivers, causing the sediment loads to shift and disturb the delicate drainage pattern in the low-lying areas. The result of the silted-up rivers has been massive waterlogging of the surrounding farmland, with dramatic loss of production.

When equipped with bed sills, bridges also affect the drainage levels in the river systems where they are placed. There are examples of bed sills that have impeded drainage, by raising the drainage data, also causing upstream water logging. This is the negative picture. There is a positive picture as well. Bridge bed sills may also stabilize unstable rivers, preventing scour and changes in drainage patterns. Bridge bed sills may also 'fix' groundwater tables, especially in drought-prone areas, by plugging the drainage level. Again, all depends on what is being done where.

In drought-prone areas, moreover, bridges can be equipped with thin shutters or 'needles' to store water in the riverbeds for an extensive period. This has been popular in India with the construction of *bandara* or KT Weir. These structures – often combined with a bridge – are meant to block the post-monsoon flow in local rivers. The water so impounded can feed local aquifers through bank infiltration. The bandara have been successful in recharging heavily used aquifer systems. This is particularly important for the Barind tract.

The other application where bridges can contribute to water storage is the use of non-vented drifts (also irish bridges, fords, or low causeways) as sand dams. This is particularly relevant in hilly areas, in particular the Chattogram Hill Tracts. The drift causes the build-up of sand and gravel deposits on the upstream side of the drift during floods. With this, small local aquifers are created in the stream that feed the wells in the adjacent area.

Finally, bridges can boost local biodiversity. They often create tranquil, inaccessible places – close to water. This makes them ideal shelters for birds and bats. Nesting boxes can be placed underneath bridges to support specific species. Biodiversity can also be supported by the use of environmental blocks in bridge abutments. These are hollow blocks that provide habitats for fish, reptiles, and flora.

The general requirement is for bridges not to interfere with river flood levels and be designed in such as a way that maximum flood levels (1:50 years) can be accommodated with sufficient clearance. If not, bridges may create backwater effects that will accelerate flooding, apart from extensive damage to the bridges' structures themselves.

Beyond this bridge design needs to be sensitive to the local situation – the challenges and the opportunities. In this chapter, specific guidance is given on:

(1) Avoiding sedimentation from bridges in tidal rivers
(2) Avoid drainage congestion from bridge sills
(3) Increase recharge with bridge sills in drought-prone areas
(4) Increase water storage with bandara-cum-bridges in drought-prone areas
(5) Create local groundwater storage with drifts
(6) Promoting biodiversity with bridges

### *5.3.1 Avoiding sedimentation from bridges in tidal rivers*

The sedimentation of tidal rivers is a widespread problem in Bangladesh (see also figure 11). One major factor has been the inappropriate construction of bridges on the tidal rivers, restricting the flow and disrupting the sediment movement. Narrow and obstructing bridges cause tidal rivers to 'go dead', silt up, and lose their capacity to carry water. Local drainage is distorted, and extensive water logging with massive loss of production is the result of tidal river sedimentation.

What happens with inappropriate bridge design is that bridge abutments and bridge piers physically obstruct the river's flow. This constriction reduces the cross-sectional area, forcing the same volume of water to pass through a relatively small opening. As a result, flow velocity is drastically altered. At the bridge velocity increases as the water is squeezed through the constricted opening. This causes, for instance, local scouring around the piers. Upstream of the bridge, the constriction acts like a dam, slowing down the flow velocity upstream. Slower water cannot carry as much sediment. Sediment is dropped, and the riverbed silts up.

Furthermore, the tidal dynamics are disrupted. Tidal rivers have a unique "in-out" pattern. The flood tide (incoming) brings sediment from the sea, and the ebb tide (outgoing) should carry it back out. A poorly designed bridge will trap the flood tide. The incoming tide will be slowed, but less than the outgoing tide. This causes more sediment to enter than will be carried back out. The constriction caused by poorly designed bridges reduces the total volume of water moving in and out with the tides, reducing the river's natural flushing capacity and causing sediment to accumulate.

Finally, bridge piers change the flow path: The bridge piers can deflect the main flow, creating eddies on their downstream sides and along the banks. Sediment is deposited in these low-energy shadow zones, restricting the river width. Bridges must be designed as *hydraulic structures*, not just transportation links. This leads to the following guidelines for tidal rivers.

*Table 23 - Guideline: special consideration for bridges on sensitive tidal rivers*

| Item | Elaboration |
|---|---|
| **Cross sectional area** | The total cross-sectional area between bridge abutments (the "obstruction area") should not reduce the river's natural cross-sectional waterway by more than 5%. The "natural waterway" is the entire dynamic zone from the deep channel (thalweg) up to the grasses or trees that get wet during the highest predictable tides and floods, plus the historical area the river has moved through. The natural waterway should be determined from historical river morphology data (minimum 20-year record), bankline surveys, and paleochannel analysis—not from present silted conditions. It is a zone of energy dissipation, sediment exchange, and ecological function. is not just the water at low tide. A good bridge design seeks to span this entire zone with minimal interaction. Exceeding the 5% threshold may significantly increase flow resistance. |
| **Bridge height** | The underside of the bridge deck must be placed above the highest recorded flood level (HFL) with a sufficient freeboard (safety margin). The clearance should also allow the use of the river for navigation. Crucially, it must also not impede water movement in and out during floods. While a low bridge does not directly cause bed siltation, it can act as a weir during extreme floods, backing up water and slowing flow upstream, leading to sedimentation. *Vertical clearance must comply with BIWTA Guidelines for Inland Waterway Transport (specify applicable circular/guideline number) for the relevant river class* |
| **Bridge abutments** | The riverbed around all piers and abutments should be protected with riprap (stone aprons) or bio-engineering measures to prevent scour holes around these. The riprap should be sized to withstand the increased velocities during floods and high flows. This will prevent structural failure and reduce the amount of material scoured from the bridge site. |
| **Spans** | Span length on tidal rivers should be maximised the number of piers in the water should be minimized. Spans should be as long as economically and technically feasible. Each pier creates turbulence, reduces flow area, and acts as a sediment trap. Fewer piers mean less overall obstruction. A minimum of 3-5 low-flow channel widths for span length makes sense to align with the natural channel<br><br>The single pier should be placed on a stable part of the riverbed, ideally within the low-flow channel's width. This minimizes its impact during high flow when the river uses its full width. The pier must be designed to withstand the forces and be protected against scour. |
| **Bridge pier foundation depth** | Pile caps are often positioned at shallow depths that obstruct future river excavation/dredging works. When river restoration requires bed lowering to original levels, existing bridge foundations become impediments. *Pile caps and foundation elements must be placed at sufficient depth (minimum 1.5 times the anticipated excavation depth or historical thalweg level plus scour depth) to allow future river restoration activities without structural compromise.* |
| **Shape of piers** | Use circular or elongated hexagonal (streamlined) piers. Streamlined shapes minimize the formation of turbulent vortices that take energy out of the flow and contribute to local scour and sediment deposition downstream. Flat, rectangular piers should be avoided. |
| **Pier alignment** | The pier's longitudinal axis should be aligned parallel to the dominant ebb (outgoing) tide flow. The ebb tide is often responsible for flushing sediment seaward. By offering the least resistance to this critical flow, the flushing capacity of the river will be relatively unaffected. |

| | |
|---|---|
| **Complementary dredging** | If siltation occurs, dredging is the immediate solution. However, it should be strategic. Instead of just dumping dredged material, the dredging material should be reused for land reclamation, raising low-lying areas, or as construction material. This makes the process more sustainable. In some cases, private dredging operators can be guided. |

Virtually all tidal rivers in Bangladesh experience some degree of sedimentation, and a very significant number of them suffer from severe, problematic sedimentation that impacts navigation, agriculture, and livelihoods. There are several reasons – reduced upstream flows, changes in river morphology, and the inconsiderate construction of bridges. Once a river is silting up, it is hard to reverse. Dredging and river training provide stop-gap solutions. Instead, prevention through intelligent, hydraulic-based bridge design is infinitely cheaper and more effective than any attempt at a cure after the fact.

The Guidance above can be applied for smaller bridge crossings, as developed by LGED (up to 40 meters). Particularly for larger streams, detailed, site-specific modeling is recommended.

#### *5.3.2 Avoid drainage congestion from bridge sills*

*Figure 53 - Bridge causing congestions – natural stream restricted and bed sill too high*

In the flat, high-rainfall regions of Bangladesh - such as the haor basins, coastal plains, and lower floodplains - excess water management is a critical challenge. Bridge bed sills, while useful for preventing scouring at bridge foundations, can inadvertently act as low dams that impede natural drainage. In areas with minimal topographic gradient, even a small obstruction can cause significant upstream waterlogging, disrupt agriculture, and increase flood risk to communities.

A bridge sill that is too high will raise upstream water levels, disrupt natural drainage patterns, affect agriculture and ecosystems, and reduce the velocity of flow, leading to sedimentation and channel siltation.

To prevent such problems, bed sills must provide scour protection while minimizing impact on water conveyance. This can be achieved through:

1. Lowered heights that do not significantly raise upstream water levels.

2. Permeable or discontinuous designs that allow subsurface and partial surface flow.
3. Strategic alignment and spacing to maintain drainage continuity.
4. Integration with broader drainage planning, ensuring bed sills complement regional water management.

Other relevant solutions and approaches are:
1. Sill Lowering or Notching: Design bed sills with a crest elevation near the natural bed level or include notches/vents to permit unobstructed low-flow drainage.
2. Use of Gabion or Permeable Sills: Allow water to pass through while still dissipating energy and reducing scour.
3. Construction of Sill Series with Gradient: Instead of a single high sill, use multiple low sills with gradual drops to maintain flow velocity.

*Table 24 - Guidelines for Designing Non-Congesting Bridge Bed Sills*

| Aspect | Guidelines |
|---|---|
| Hydrological & Topographic Analysis | Conduct detailed hydraulic modeling to assess the impact on upstream flood levels.<br>Ensure the bed sill crest elevation is below the critical flooding threshold for the area.<br>Analyze channel slope, flow velocity, and sediment transport capacity, and consult with local communities. |
| Design Adjustments to Prevent Congestion | **Crest Height:** Keep sill rise minimal (less than 0.2–0.3 meters) above natural bed level.<br>**Permeability:** Use gabion mattresses sills to allow through-flow.<br>**Notchess:** Include openings to facilitate low-flow drainage.<br>**Profile:** Use streamlined, rounded crest profiles to minimize head loss.<br>**Width:** Avoid full-channel obstruction; consider segmented sills aligned with flow paths. |
| Structural Integration with Bridges | Coordinate with bridge span design to avoid flow contraction.<br>Ensure the sill does not reduce the effective waterway area under the bridge.<br>Anchor sill adequately to prevent undermining without raising crest height. |
| Drainage System Synchronization | Ensure bed sill design aligns with regional drainage plans and embankment gradients.<br>Incorporate with existing regulators, sluices, or outlet structures where applicable. |
| Environmental & Social Considerations | Avoid designs that disrupt fish migration or local navigation.<br>Conduct community consultations to assess historical flooding patterns.<br>Ensure no adverse impact on downstream water users or ecosystems. |
| Regulatory Compliance | Follow Bangladesh Water Development Board (BWDB) guidelines for drainage structures. |

### 5.3.3 Increase recharge with bridge sills in drought prone areas

Whereas in flat areas with the risk of drainage congestion, caution is required to make sure bridge bedsills do not distort drainage patterns, the reverse logic applies in drought-prone areas. Bridge sills can retain groundwater and, in a way, ‘plug’ the local drainage system. When strategically designed, they can also retain water upstream during and after monsoon flows, creating temporary subsurface storage and enhancing groundwater recharge. As with bridges-cum-bandaras (see next), this is particularly promising in the Barind Tract, which is characterized by seasonal drought and falling groundwater tables. Integrating water retention features into existing and new bridge infrastructure— through the use of bridge bedsills— can enhance local water security. Bedsills, typically constructed as protective aprons or sills at the base of bridge piers and abutments, can be designed to double up as subsurface dams or submerged weirs, slowing river flow, encouraging deposition of coarse material (sand and gravel), and increasing water infiltration into adjacent and underlying aquifers. For this, the bedsill designed for water retention is slightly raised (typically 0.3–1.0 m) above the general riverbed level. It creates a localized hydraulic head, allowing water to pool up and retain low to moderate flows. Water infiltrates through the sandy riverbed, recharging the aquifer. During high floods, water flows over the sill without causing upstream flooding, as the crest height is kept low. This leads to the following design guidelines.

*Table 25 - Guidelines for Development and Design of Water-Retaining Bridge Bed Sills*

| Aspect | Guidelines |
|---|---|
| **Siting** | Prioritize bridges over sandy or gravelly seasonal rivers (clay beds are less effective).<br>Select sites with gentle upstream slopes to maximize the spread of retained water.<br>Avoid sites immediately upstream of major water intakes or sensitive ecosystems.<br>Assess subsurface hydrogeology: ensure permeable layers exist for recharge – in the absence of a survey, an impression can develop from the presence of a well adjacent to the riverbank |
| **Hydrological Assessment** | Analyze historical flow duration to determine optimal sill height (target water retention for 2–4 weeks post-rain).<br>Calculate infiltration rates based on riverbed sediment texture<br>Ensure the sill height does not significantly increase flood risk upstream. |
| **Design Specifications** | **Height:** 0.3–1.0 m above natural riverbed, based on desired storage and flood safety.<br>**Length:** Span full riverbed width; key into both banks to prevent bypass flow.<br>**Profile:** Broad-crested weir profile for stable overflow.<br>**Material:** Preferably impermeable and anchored on hard rock to create a permanent barrier<br>Reinforced concrete, stone masonry, or gabions filled with local rock.<br>**Foundation:** Extend below scour depth (typically 1.5–2 m in sandy beds).<br>**Upstream Seepage Control:** Optional clay core or impermeable layer if bedrock is shallow to direct infiltration laterally. |
| **Water Retention & Recharge Enhancement** | Encourage coarse sediment deposition upstream by designing for low flow velocities.<br>Consider a series of low bed sills along a river reach for the cumulative recharge effect.<br>Monitor groundwater levels upstream to assess recharge performance. |

### 5.3.4 Increase water storage with bandara-cum-bridges

Bridges can be combined with seasonal weirs – called bandara or KT weirs. The bridge function obviously accommodates traffic, but also enables the operation of these special water retention structures. Bridges-cum-bandaras are not full dams. Rather, they are run-of-river, temporary/seasonal weirs, used on monsoon rivers. They have a large uptake in India, but are not common in Bangladesh. In drought-prone areas such as the Barind, however, there is high potential to combine bridges with bandara. It may be useful to systematically explore the options, including the retrofitting of existing bridges.

Bridges-cum-bandaras pond up water and raise the water level within the existing stream course so that water can be stored after the monsoon for use in agriculture or for aquifer recharge. As they create the storage in the natural river, no land acquisition is required for the storage.

They are built with a series of piers (like a bridge), with removable tall and high shutters, called needles, that can be placed between the piers. At the end of the monsoon, the shutters are placed so as to store water in the upstream water course. Before the monsoon, the needle shutters are removed, letting flood waters pass and sediment flushed out.


*Figure 54 - Bandara-cum-bridge to retain groundwater*

Bandara works especially well where the aim is to store modest water quantities of water and/or recharge groundwater. They are not meant to create large reservoirs. Indeed, one of the advantages cited over conventional dams is limited siltation and no need for canal maintenance. In the monsoon, the channel is flushed out and cleaned of the sediments deposited. There is limited experimentation with bandaras in the Barind, but the potential is much higher.

Operation is important. It concerns the placement of the shutters at the end of the monsoon season and their removal and safe storage before the monsoon. When the monsoon flow recedes, the needle shutters are placed back again in between the piers to create a crest and retain the receding flows. If the water level rises too fast and the crest is in danger of overtopping, the needs may be opened again to reduce the volume of water stored behind the structure. Ease of operation is important, and hence the preference for tall and narrow shutters, as these will have manageable weights and are not at risk of bending, which makes it possible to manually install and remove them when necessary. Because of the preference for relatively tall and slender shutters, the bandaras are outfitted with a large number of piers (typically placed 75-150 centimeters apart). Provided the shutters are removed in time, and there is no flotsam trapped between the piers, there is no significant risk of afflux effect and flooding. In general, the design has low mechanical complexity (no hinges, gates, or hoisting devices). Needles can be removed quickly and easily.

As with many structures, local consultation is an important part of the development of the bandara-cum-bridges – to understand the preferred crest height, and avoid overtopping; to regulate interaction with fishermen that may use the river section as well, and to set the basis for local operations (as has been the case with sluices elsewhere in Bangladesh). The guidelines for bandara-cum-bridges are given below.

*Table 26 - Guideline: bandara-cum-bridge*

| Item | Elaboration |
|---|---|
| **Siting** | - Bandara-cum-bridges are sited on seasonal streams/ monsoon rivers, with no or very low flows after the monsoon.<br>- The stream bed slope should be gentle (not extremely steep), so adequate storage can be created within the natural stream banks. The river banks must be firm and stable, with no risk of breaching or diverting,<br>- The bandara-cum-bridges are preferably developed in sandy terrain, so that groundwater will be recharged through river bank infiltration. This is particularly important in the Barind and other parts of Bangladesh, where clay layers seal the alluvial sandy layers, resulting in limited recharge opportunities from the land surface.<br>- There should be no tidal effects or excessive sedimentation in the stream, as the bandara structures will distort the sedimentation process in the rivers. Hence, bandara structures are not suitable in coastal areas. |
| **Main com-ponents** | - A head wall (main barrier),<br>- A series of piers, side and wing walls, apron (toe protection),<br>- Corresponding number of needle shutters<br>- Bridge |
| **Foundation** | - Bridge bed sill is part of the design. It is important to set the bedsill at the appropriate level. It is important to set the sill deep enough so that it allows the passage of the monsoon flows without obstructions.<br>- If the river at the bridge site has a level, firm rock or stable foundation, the bedsill may be omitted or minimized so as to create the bottom slots for the needles. |
| **Crest height** | - The crest height (with all needle shutters in place) is determined by the slope of the river bed.<br>- The crest height is below (1-1.5 meters) the high flood level in the river. |
| **Width** | - The maximum width of the river should be used. |
| **Number of piers, distance between piers** | - The distance between the piers should be between 75 and 150 cm, to allow ease of operation of the needle shutters.<br>- The distance between the piers should be uniform in width so multiple needles sit side-by-side with minimal gaps. |
| **Dimension of the piers** | - Width: Preferred range 300–600 mm<br>- Needs to accommodate two guide faces (upstream and downstream), slot housing, but at the same time avoid increasing the afflux<br>- Length (in flow direction): preferred range: 1.5–3.0 m<br>- Needs to resist local uplift, impact loads during floods, vortex-induced forces, and help stabilize the flow<br>- Height (above needle shutter crest) preferred range: 0.5–1.0 m<br>- Allows handling clearance and flood freeboard |
| **Slots in the piers** | - Vertical guide slots should be cast or bolted into the piers.<br>- The slots are slightly wider (2-4 mm) than the shutter thickness and may have front and rear guides to keep the needle shutter vertical<br>- Slots are placed parallel to the opposite pier |
| **Other characteristics of the piers** | - Particularly in a river with floating debris, the piers should be rounded off to prevent flotsam from getting stuck between the piers. |
| **Removable needle shutters** | - Tall and narrow, with a rectangular cross-section<br>- Material: Metal, wood, or composite<br>- To operate the needle shutters, they should be relatively light (10-40 kg) so that they can be lifted out of their slots by one or two people. Wooden needles are lighter than metal ones. Composite shutters would be ideal. A handle of hole will add to the ease of operation<br>- Width: 0.75-1.50 meters<br>- Height: determined by crest height.<br>- Thickness: 100 mm, depending on material |

| | |
|---|---|
| | - The shutters should be equipped with a hand grip or lifting hole at the top to allow easy operation |

### *5.3.5 Water storage through non-vented drifts*

Non-vented drifts are raised road crossings built across seasonal riverbeds without culverts. They act as sand dams, trapping coarse sand and gravel upstream during floods. The sand and gravel naturally store water within the pore spaces. With this, small local aquifers are created. This stored water is then available for abstraction via wells, scoop holes, or infiltration to adjacent shallow aquifers.

The Chattogram Hill Tracts (CHT) region of Bangladesh is characterized by hilly terrain, seasonal rivers (*chara*), and acute water scarcity during dry months. Road infrastructure in the region is often disrupted by flash floods, erosion, and sedimentation, while communities struggle to access reliable water for domestic use, livestock, and small-scale irrigation. Integrating water harvesting with road construction through non-vented drifts offers a sustainable, cost-effective solution to enhance both road resilience and water security. Non-vented drifts differ from vented drifts in that they have no culvert to remove water, but instead are inclined towards the centre to allow safe passage of water. Given the growing road network development in CHT and the prevalence of sandy/gravelly seasonal rivers, non-vented drifts offer a strategic opportunity to integrate water harvesting into transport infrastructure planning.

*Figure 55 - Non-vented drift acting as sand dam*

*Table 27 - Guidelines for Development and Design of Non-Vented Drifts*

| Item | Elaboration |
|---|---|
| **Siting** | - Select narrow, shallow river sections with low banks and avoid river bends.<br>- Prefer sandy or gravelly riverbeds (not clay/silt).<br>- Ensure shallow sand depth over rock/sub-surface (confirmed by probing).<br>- Prioritize areas with socio-economic need (populated, agricultural potential).<br>- Consider building a series of structures (drifts, weirs) to maximize water retention. |
| **Hydrology & Capacity** | - Assess historical flood levels and sediment load (coarse sand preferred).<br>- Estimate water storage using sand volume and porosity (typically 15–35%).<br>- Use geophysical surveys to measure sand depth, width, and gradient. |

| | |
|---|---|
| **Design Specifications** | - Height above riverbed: max 1.0 m to avoid trapping fine sediments.<br>- Width of carriageway: 3–5 m, depending on traffic.<br>- Foundation: min 500 mm wide, 250 mm deep; anchor to bedrock if present.<br>- Top slab: 150–200 mm thick, reinforced with Y12 bars at 250 mm spacing.<br>- Include gentle curvature towards the river center to concentrate flow and protect banks. |
| **Construction** | - Use reinforced concrete (mix 25/20) and well-compacted rock fill (min 1.0 m depth in sand).<br>- Extend approaches 5–10 m beyond riverbanks.<br>- Install gabions (2×1×1 m) downstream to prevent undermining.<br>- Consider staged construction: start low, raise height after successive floods. |
| **Protection & Maintenance** | - Extend the slab beyond the peak flood level.<br>- Use gabions and retaining walls upstream/downstream for stability.<br>- Ensure reinforcement ties between foundation, walls, and slab.<br>- Monitor sediment accumulation and remove fine sediments if necessary.<br>- Engage local communities in maintenance and water management. |
| **Materials & Standards** | - Use locally available materials where possible.<br>- Concrete and steel must meet national road/bridge standards.<br>- Gabions filled with local stone for erosion protection.<br>- Ensure proper curing and vibration during concrete placement. |

### *5.3.6 Enhancing biodiversity with bridges*

*Figure 56 - Bridges can provide safe habitats for birds and bats*

Several measures can be taken to enhance biodiversity, making use of existing bridge infrastructure in Bangladesh. In all of this, it is helpful to work together with a local biologist/

wildlife expert to discuss priorities in biodiversity management (priority species, realistic numbers) and special requirements.

A straightforward measure that can be taken to improve biodiversity is the placement of bat or bird nesting boxes underneath bridges. The dark, damp spaces beneath bridges are ideal for bird and bat nesting. This is important as the bat and bird population in Bangladesh is in decline. Given the crucial role birds and bats play in pollination, seed dispersal, and rodent and insect control, their revival will have cascading effects on ecosystems and agriculture. Bird and bat nesting boxes provide artificial refuges in a landscape where natural ones are vanishing rapidly. It will help biodiversity and contribute to the overall attractiveness of the environment. Installation should be done outside the breeding season. Ideally, such measures are part of a broader program that includes habitat protection and local public education to address the root causes of the decline in Bangladesh's bat and bird populations. For placing nesting boxes on the bridges, the following guidance applies:

*Table 28 - Guidelines for placing nesting boxes on bridges for biodiversity*

| Item | Elaboration |
|---|---|
| Shape and dimensions of nesting boxes | Consult with a local biologist, as different species have different preferred designs. |
| Placing of nesting boxes | Bats prefer higher locations; some birds are less sensitive to heights; again good to consult with a local biologist<br>Also, avoid places that are at risk of being submerged |
| Protection from elements: | Place under the bridge deck overhang to shield from direct rain, wind, and sun. Face away from prevailing winds and rain. |
| Proximity to water | This is a given. It is ideal for insectivorous birds (such as swallows and swifts) and bats, as it provides a feeding area. |
| Bridge integrity | Do not drill into critical structural elements of the bridge. Use existing bolts, clamps, or straps attached to non-critical surfaces to hang the nesting boxes. |
| Cleanliness | Plan for droppings management. Avoid staining of piers or falling onto pathways/water below. If necessary, use a board. |

The second measure is the use of environmental blocks on bridge abutments. Environmental blocks are modular armoring elements (hollow concrete blocks, gabion boxes, riprap, geocells, etc.) and their associated bedding/filter/drainage works. They are used to stabilize slopes and protect embankments from erosion, overtopping, and flow forces.

The primary use of the environmental blocks on LGED bridges would be (1) protective and (2) ecological. The main protective functions are to stabilize slopes, prevent surface erosion and soil loss, allow controlled drainage, protect bridge foundations and approach embankments against wave action or reservoir level changes. The main ecological functions are to foster a green ecosystem to be part of the bridge construction, adding ecological and aesthetic values. They are a system of individual, pre-cast concrete blocks designed to interlock and form a flexible, permeable, and high-strength "mat" or "blanket" that covers the slope. They will act as a heavy, durable armor layer that dissipates the energy of flowing water. The water's force is spread across the entire interlocked mat instead of attacking individual soil particles.

The ecological function is fostered by openness, creating spawning grounds. They can be applied to new bridges, but existing bridge abutments can be retrofitted. The guidance for the use of environmental blocks are:

*Table 29 - Guidelines for use of environmental blocks on bridges for biodiversity*

| Item | Elaboration |
|---|---|
| Preserve/ safeguard the hydraulic function | Any ecological retrofit must preserve conveyance capacity for design floods and avoid creating scour at the bridge foundations. Use low-profile, permeable features that dissipate energy rather than create blockages. |
| Use porous/graded structures | Replace or augment impermeable concrete with permeable blocks, vegetated gabions, stone weirs with openings, or modular eco-blocks that allow flow through and around. |
| Use local materials for filter medium | Geotextile, stone, locally quarried gravel, reclaimed logs, and vetiver grass are cost-effective and locally familiar. |
| Mimic natural microhabitats | Create variations in depth, velocity, and substrate (a mix of cobble/pebble/sand, root tangles, logs) to support different life stages. |
| Prefer native vegetation | Use local riparian species that establish quickly, control erosion, and support animals/insects. |
| Design micro-habitats | Leave small planting pockets on wingwalls with soil and native shrub cuttings, include small pools in the abutments |

## 5.4 Unpaved roads

Unpaved roads make up a substantial part of the Bangladesh road network – close to 250,000 kilometers out of 410,000 kilometers of roads. They are essential for connecting the last mile – reaching those in smaller settlements or isolated habitations, enabling the movement of people and commodities. According to the Road Access Indicator (World Bank), at present, 13% of the population of Bangladesh does not have access to an all-weather road within 2 kilometers. This means that almost a quarter of the rural population is primarily served by unpaved roads.

Unpaved roads are widespread in agricultural areas, making farm operations possible. In fact, they are frequently constructed with a dual purpose – not just facilitating transport but also creating boundaries around an agricultural area so as to enable better field water management. Combined with gated culverts, the road-cum-field embankments make it possible to irrigate crops, such as the high-yielding *amon* paddy varieties. They make it possible to inundate and drain farm fields as the cultivation demands. These are highly effective interventions for raising farm productivity and reducing road damage from adjacent waterlogged fields and should be welcomed and facilitated.

*Figure 57 - Culvert with slot for temporary gate - this is very useful for water level control in the adjancent fields and is practice to be encouraged*

Unpaved roads are more prone to damage – often related to the presence of water on the road surface – making the road muddy, creating puddles, which typically result in heavy rutting, making the unpaved road impassable. This is particularly severe in areas with clay and silt soils (see Table 30). The coastal area of Bangladesh is particularly vulnerable due to the preponderance of heavy clays. The clay is often highly plastic, with significant shrink-swell potential. In other cases, roads and road embankments are damaged by water traversing the road in an uncontrolled manner.

*Table 30 - Unpaved roads*

| Soil Type | Particle Size | Water Effect | Muddiness Level | Impact on Road | Mitigation Notes |
|---|---|---|---|---|---|
| **Clay** | Very fine | High water retention, sticky when wet | Very high | Roads become sticky, rutted, and slippery | Use lime or cement stabilization, gravel, crushed brick topping, drainage or geotextile |
| **Silt** | Fine | Moderate water retention, soft when wet | Moderate | Roads soft, prone to rutting and erosion | Compaction, chemical stabilizers, good drainage |
| **Loam (mixed)** | Balanced (sand, silt, clay) | Moderate water retention | Moderate-low | Better drainage than pure clay/silt, some soft spots | Occasional grading, good drainage |
| **Sand** | Coarse | Low water retention, drains quickly | Low | Roads dry quickly, loose under traffic, dusty when dry Scour is a major challenge | Dust control, occasional grading |
| **Gravel / Coarse** | Coarse with rocks | Very low water retention | Very low | Minimal muddiness, stable under vehicles | Maintain drainage and surface grading |

The Standard Design Road Manual (LGED 2005) includes design templates (crest width, slope, pavement, subgrades) for the main paved rural roads: Upazila Roads (template types 4, 5, and 6), Union Roads (template types 7 and 8), Village Roads A (template type 8).

For Village Road B, however, there is no template available. Village roads B and earthen roads constructed under ‘Food for Works’ programs are often not planned and designed following any guidelines. The same is true for minor roads and footpaths made by community initiative. Such unpaved, earthy roads often become inaccessible with rainfall, becoming muddy, rutted, and eroded. This is problematic for many reasons, but one is that during emergency evacuation is often frustrated by damaged, muddy roads.

*Figure 58 - Unpaved road*

### 5.4.1 Overview of measures

To reduce the damage to these vital unpaved roads and to use such unpaved roads for beneficial water use, several measures are recommended:

- Use of camber (road profile)
- Use of side ditches
- Use of rolling dips
- Use of water breaks
- Use of crushed bricks or gravel.

The appropriateness of these recommended measures is related to the road slope and the prevailing soil type, see Table 31. Different measures can be combined. In general, on flat clay roads, camber, water breaks, side ditches, and the use of a gravel layer are most appropriate. On gentle to moderate slopes, the use of camber, side ditches, rolling dips, and gravel layers works well. The same combination is recommended for steeper slope unpaved roads. Clay soils need stabilization in the form of gravel or crushed bricks. In the case of sandy soil, scour protection at the outlets is required.

*Table 31 - Appropriateness of different measures to protect unpaved roads*

| Measure | Flat | Gentle slope | Mod-erate | Steep slope | Clay Soil | Silt Soil | Sandy Soil | Comments |
|---|---|---|---|---|---|---|---|---|
| **Camber** | Moderate | High | High | High | Moderate erosion risk | Good | Low | Needs surface stabilization on clay |
| **Side Ditches with Mitre Drains** | High | High | High | High | Must stabilize sides | Good | Stabilize | Essential for drainage |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Rolling Dips** | Low | High | High | High | Outlet can be sticky | Good | Erosion risk | Best on slopes |
| **Water Breaks** | High | Moderate | Moderate | Low | Works well | Good | Limited | Slows water, prevents ponding |
| **Gravel/Crushed Bricks** | High | High | High | High | Reduces mud | Good | Improves surface | Stabilizes road, works with other measures |

*Figure 59- Water management measures and adequate maintenance are essential to ensure longevity of unpaved roads*

The guidelines as they relate to different measures are described below. What is important is that though these measures contribute significantly to longevity and functionality of the unpaved roads, maintenance is important. Improving the arrangements for maintenance is important. This would see permanent – not project-based responsibilities for maintenance with regular frequencies and defined tasks.

### 5.4.2 Protecting unpaved roads with road camber (profile)

The camber or road profile is important to guide water off the road. In particular, in flat areas, water has to be removed sideways from the road surface. There are different cambers to do this, each suitable for specific situations.

Maintenance is essential to keep the road profile intact, to plug potholes and ruttings and restore the slope. If roads are neglected and no regular maintenance is done, the disintegration of unpaved roads is accelerated. It is hence important that responsibilities are clear and a regular force is available. In Bangladesh, labor contracting societies are engaged to do the repair. At the same time, it is important to assign responsibilities for the day-to-day care of rural roads, too.

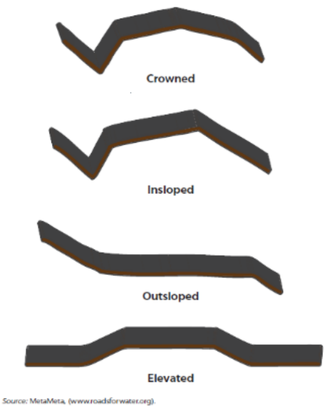



*Figure 60 - Alternative cambers used to ensure sufficient cross sloping and drainage (van Steenbergen et al., 2021)*

*Table 32 - Guidelines for camber on unpaved roads*

| Item | Elaboration |
|---|---|
| **Camber profile** | There are several shapes of camber. Crowned or sloped surfaces are preferred to connect to side drains. Out sloped may discharge direct in adjacent land, but should be provided with grass or dense stones to reduce erosion and facilitate infiltration of the road, based on the presence of a roadside drain. |
| **Slope** | With climate change, the camber should have a minimum of 3.0 % on unpaved roads. Preferably, it is 4-6%. On curves, super-elevation should match or exceed camber. |
| **Gradients** | Longitudinal gradients should be at least 0.5% on curbed roads. Flat areas should be avoided, and surface water drainage should be considered at rollovers, roundabouts, and junctions. |

### *5.4.3 Protecting unpaved roads with side drains*

The purpose of side drains is to collect the runoff from the road and to direct it away from the road safely. Preserving the roadside drains is critical: probably as critical as the road surface itself.

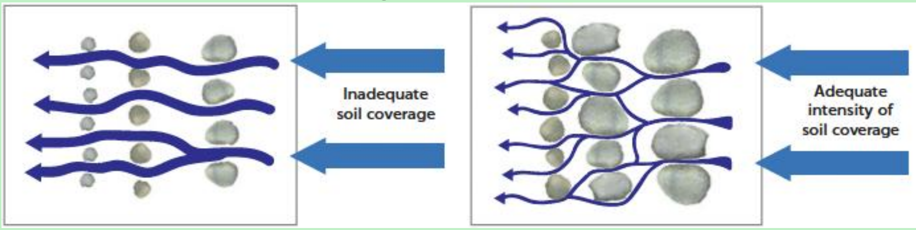
Moreover, water thus collected can also be used beneficially – to feed a reservoir or to irrigate farmland. This is particularly important for Bangladesh's drought-prone areas. When a road is made on a high embankment, side drains along the road will not be needed, as the run-off will exit from the embankment slopes.

The run-off collected with the side drains should be spread over the adjacent areas. For this, there should be outlets/ turnouts at regular intervals (50-150 meters). These can connect to mitre drains that take the water away from the roads to the land. The mitre drains may be deepened so that when they discharge on the land, they irrigate the subsoils and do not cause overland erosion.

The development of the side drains, the location of the outlets and the excavation of the mitre drains should be done in close consultation with and approval of the local community (see also chapter 4). This is necessary to make sure that the drains are designed to benefit the local community and that the disposal of the drainage water will not be a source of conflict or damage. Consultation will also be able to address sensitivities around land ownership and plan the location of side drains on unpaved roads, according to the following guidelines.

*Table 33 - Guidelines for side drains*

| Item | Elaboration |
|---|---|
| **Capacity** | Design for short-duration, peak-intensity monsoon storms, not annual averages |
| **Location** | Drains should be lower than the road shoulder by at least 15–30 cm to ensure water exits the unpaved road.<br>The drains should connect to the road camber, the water breaks/ rolling dips, and smaller cross drainage structures. |
| **Slopes** | Use gentle slopes (at least 0.2-0.3%) so that water moves within the drain.<br>In areas with high velocities (on slopes of more than 3-5%), use brick/CC lining or vegetation reinforcement to avoid scour and damage.<br>Provide continuous fall, avoid sag points where drainage water will accumulate. |
| **Cross section** | Trapezoidal drains are most common and practical. V-shaped drains erode easily and are not recommended in clay soils. |
| **Typical dimensions** | Bottom width: 300–600 mm<br>Depth: 450–750 mm<br>Side slopes: Clay: 1V:1.5H to 1V:2H. Sandy/silty soils: 1V:2H to 1V:3H |

| | |
|---|---|
| **Outlets** | Depending on the slope, ensure outlets every 50–150 meters .<br>Connect with (deepened) mitre drains to direct water to fields or ponds gently.<br>Create deepened outlets or bunded entry points to avoid erosion.<br>Based on extensive local discussion. |
| **Improved water management** | Add grassed swales or use buffer strips of sufficient density along drains to slow water, trap sediment, and recharge the soil.<br>Alternatively, in rocky terrain use stone cover of sufficient soil coverage to slow water, trap sediment, and recharge the soil.<br><br> |
| **Special considerations for flood-prone areas** | Drains should allow bidirectional flow during floods.<br>Use relief openings or culverts at regular intervals. |
| **Special considerations for saline/ tidal areas** | Use one-way gates of filters at the outfall. |
| **Special considerations for sandy areas** | In sandy soils, provide extra protection to avoid erosion of the drain by vertiver grass turfing, brick pitching, riprap, or geotextile. |
| **Special considerations for congested areas** | Consider using slabs to cover the drain to avoid accumulated garbage blocking the drain.<br>Alternatively, where slabs cannot cover the drain, use infiltration blocks. |
| **Frequent access** | Include slabs for crossings. |
| **Consultation** | Work with Water Management Groups and local government to site outlets and avoid downstream conflict. |

### *5.4.4 Protecting unpaved roads with rolling dips*

Rolling dips are slope reversals that push water off the road surface. They are gentle elevations and depressions created in an earthen road surface to reduce water-related damage and wear-and-tear, and to create a supplementary water source generated from the road-run-off.

Rolling dips are best used on low–moderate grade unpaved roads (at least 2–8%, maximum up to 12%) with low-speed, low-volume rural traffic (motorcycles, rickshaws, motorbike vans, light trucks, tractors). Heavy traffic should not be allowed on unpaved roads for the damage they cause, including to rolling dips. Rolling dips should not be used as the crossing for natural streams, perennial drains, or locations with concentrated flood flows. In such cases, culverts or bridges should be used. The purpose of the rolling dip is to collect run-off from the road surface and guide it off the road, so as to preserve the road and to use this water, where possible, for productive use. The run-off from the rolling dip should go to a stable outlet – a field, stabilized drain, retention pond, canal, or an irrigation trench.

In the flat floodplains and haor/char areas, surface gradients can be near zero, and flood depths large. Rolling dips are ineffective where water ponds or where road grade is less than 1% or when flood flows will overtop the road; in those locations, culverts, causeways with multiple openings, or raised embankments with gated outlets are preferred. Main guidelines for a rolling dip are in the table below.

*Table 34 - Main guidelines for a rolling dip*

| Item | Elaboration |
|---|---|
| **Length and profile** | A typical dip runs several meters long (15–40 m) overall, depending on depth and road width. It has a gradual cut-in (3-6°) and a gradual lift-out (2-5°), so vehicles pass with low shock. |
| **Depth (low point):** | Have the low point of the rolling dip at 280–450 mm (11–18 inches) below the running surface for unpaved roads; deeper dips would increase discharge, but would hamper the drivability of the road |
| **Orientation** | Have the axis of the dip at an angle with the road centerline at 30°–60° so runoff is moved off the road gently |
| **Reverse (dip) slope:** | Provide a short reverse grade through the dip (the bottom should have a small downhill slope of about 2–3° so the dip is self-cleaning) |
| **Outlet stabilization** | Armour the outlet (rip rap, bricks, geotextile and rock, or well-vegetated swale) to prevent scour where the dip discharges to the roadside. Avoid discharging on an erodible slope or directly into a village homestead. |
| **Spacing** | Adjust the distance between rolling dips according to the gradient of the road. On steeper roads, the distance should be smaller to avoid the runoff accumulating at high and erosive speeds. Recommended distances differ between 40 meters (12°) and 90 meters (2°gradient). |
| **Maintenance** | Maintenance is key. Iinspect and reprofile the water breaks after every monsoon |

*Figure 61 - Rolling dip in hilly area (photo G. Keller)*

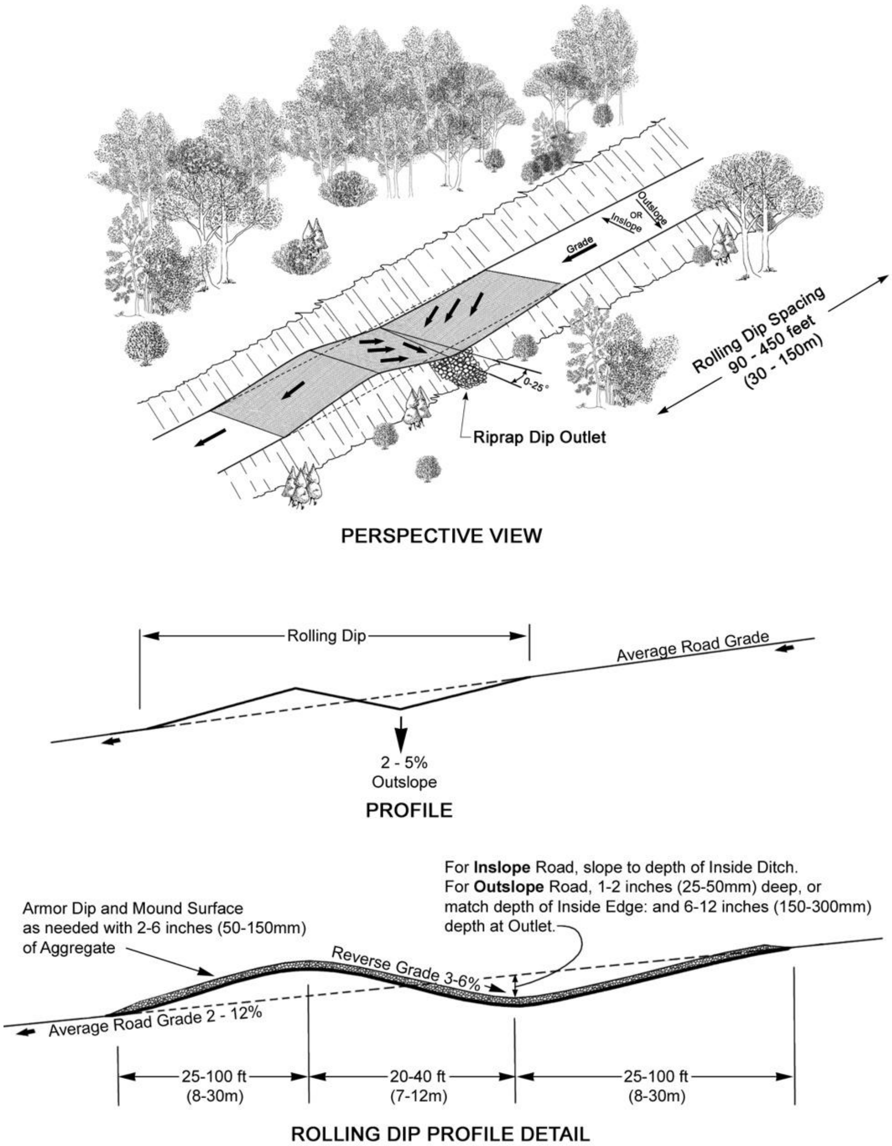



*Figure 62 - Rolling dip schematic overview (G. Keller)*

### *5.4.5 Protecting unpaved roads with water breaks*

Water breaks are shallow ridges across the road to slow water, not block vehicles. A water break is essentially a small, shallow depression or notch that cuts across the unpaved road surface. It usually spans the full width of the road or at least up to the wheel tracks. The slope of the depression directs water off the road surface into a side ditch, vegetated area, or natural drainage path. The main purpose - as with a rolling dip - is that it interrupts long stretches of water flow along the road. In this way, it reduces the speed and erosive power of runoff.

*Table 35 - Guidelines for water breaks on unpaved roads*

| Item | Elaboration |
|---|---|
| **Depth** | 5–15 cm (2–6 inches), enough to intercept flow but not impede vehicles significantly |
| **Width** | 30–50 cm (12–20 inches) or enough to cover the wheel paths. |
| **Outward slope** | Gentle, typically 1–5% toward the drainage side, so that water moves slowly without causing erosion.<br>Place at a slight angle with the wheel path to improve the evacuation of water |
| **Distance** | Install every 20-50 meters depending on slope |

| | |
|---|---|
| **Construction** | - Mark the road where water tends to accumulate or flow.<br>- Cut a shallow depression across the road width.<br>- Place the excavated soil downslope to form the berm<br>- Smoothen the side slopes so vehicles can pass without damage.<br>- Ensure the water exits onto a safe area (side ditch, grass verge, or vegetated swale).<br>- Compact the surrounding soil slightly to prevent washout<br>- Cover with grass or mulch to prevent erosion |
| **Maintenance** | Maintenance is key. Inspect and reprofile the water breaks after every monsoon |

### *5.4.6 Protecting unpaved roads with gravel or crushed bricks*

Gravel or crushed bricks on the road surface helps water drain through the coarse material rather than staying on the surface. This is particularly important in areas with clay soils.

Gravel performs better under coastal conditions and is more cost-effective over the road's life despite a higher initial cost. It does not disintegrate in saline water or under waterlogged conditions. Generally, the lifetime of gravel is 2-3 times longer than that of bricks. Crushed bricks are cheaper but absorb water, causing them to become brittle. They also do not stand up to salinity. A combination of a base layer of gravel and a top layer of crushed bricks may have the best of both worlds in some cases.

Bricks from demolished buildings may be used or rejects from brick kilns, as there is a (not effectively enforced) ban on the use of bricks in road construction. If bricks are used, always test the bricks for density and water absorption. The guidelines for the use of gravel or crushed brick are given below:

*Table 36 - Guidelines for water breaks on unpaved roads*

| Item | Elaboration | | |
|---|---|---|---|
| **Material specifications: gravel** | 20–40 mm for base layer, 10–20 mm for surface layer.<br>For weak soils, consider using lime, fly ash, or cement before mixing gravel. | | |
| **Material specifications: crushed bricks** | 20–40 mm for base layer, 10–20 mm surface layer. | | |
| **Layer Thickness** | **Layer** | **Recommended Thickness** | **Function** |
| | Subgrade preparation | 150–200 mm | Remove soft spots, compact clay/silt subgrade. |
| | Base layer (gravel or crushed bricks) | 150–200 mm | Provides strength, drainage, and reduces rutting. |
| | Surface layer | 50–100 mm | Smooth driving surface; prevents surface mud from mixing with base. |

| | |
|---|---|
| **Construction** | Roadbed Preparation:<br>- Remove vegetation, soft clay, or ponded water.<br>- Shape the road with a crowned camber (3–5%) to allow water runoff.<br>- Compact subgrade with a roller or manual tamping.<br>Base Layer Placement:<br>- Spread 150–200 mm of coarse gravel or crushed bricks.<br>- Compact in layers of 75–100 mm for better interlock and stability.<br>- Consider placing geotextile under the base to prevent mixing<br>Surface Layer Placement:<br>- Spread 50–100 mm of finer gravel or crushed bricks.<br>- Shape to maintain road camber.<br>- Compact thoroughly to reduce displacement under traffic |
| **Maintenance** | Maintenance is essential. After every monsoon season the road protection should be inspected and restored. During the monsoon regular minor restorations are important to prevent damage from becoming bigger |

There is considerable innovative work ongoing in developing binders for unpaved roads. It is important to stay abreast of these promising developments, such as the development of microbial binders.

## 5.5 Borrow pits

Bangladesh's extensive and expanding road network requires significant earthwork, resulting in numerous borrow pits— excavated sites from which soil, sand, or gravel is taken for road embankments. Often left abandoned, these pits can be systematically repurposed into valuable water storage assets, enhancing water security in both drought-prone regions (e.g., Barind, drought-prone coastal areas) and flood-prone landscapes. Additionally, the common practice of digging elongated, shallow drains along roadsides for drainage can be redesigned to also function as linear water storage or recharge features. Transforming these excavated spaces into managed ponds and drains aligns with the "Green Roads for Water" approach, turning infrastructure liabilities into community resources for irrigation, aquaculture, livestock, and groundwater recharge.

Repurposing borrow pits and redesigning elongated roadside drains represent a practical, low-cost strategy to enhance water storage and security in Bangladesh. By integrating water harvesting into road planning, construction, and maintenance, these interventions can provide multiple livelihood benefits while increasing climate resilience. Success depends on collaborative planning between road authorities, water agencies, and local communities, ensuring that these converted structures are safe, sustainable, and equitably managed.

*Table 37 - Guidelines for Development and Design of Repurposed Borrow Pit and Roadside Drains in Bangladesh*

| | Guidelines for Borrow Pits | Guidelines for Elongated Roadside Drains (Cum Borrow Pits) |
|---|---|---|
| **Siting & Planning** | - Locate near communities/farmlands for easy access.<br>- Prefer the downslope side of roads to capture road drainage.<br>- In floodplains, site on the river-side of road sfor reliable seepage.<br>- Avoid areas prone to flooding or contamination.<br>- Plan for multiple smaller pits rather than one large one to distribute benefits. | - Design along roads in areas with water scarcity or high runoff.<br>- Ensure gentle longitudinal slope (0.1–0.5%) to allow flow yet retain water.<br>- Widen and deepen sections to create localized storage pockets.<br>- Integrate with culvert outfalls to channel road runoff into drains. |
| **Hydrology & Sizing** | - Estimate runoff capture using local rainfall data and catchment area.<br>- Calculate storage need based on dry-season water demand.<br>- In sandy areas, prioritize recharge function; in clay areas, storage function.<br>- Recommended depth: ≥7 m to reduce evaporation (where feasible). | - Size for dual function: drain peak flows and retain water for 2–4 weeks.<br>- Use permeable beds in sandy areas to enhance recharge.<br>- Include overspill structures to prevent road flooding during heavy rains. |
| **Design Specifications** | - **Shape:** Convex or trapezoidal with stable slopes.<br>- **Side slopes:** Clay: 1:1–1:2; Sandy loam: 2:1–2.5:1; Sand: 3:1.<br>- **Safety:** Install gentle access ramps for pumps/livestock; fence perimeter.<br>- **Spillway:** Include for safe overflow in sloping terrain.<br>- **Depth:** Minimum 3–4 m for storage pits; up to 7 m for evaporation control. | - **Cross-section:** Trapezoidal or shallow V-shape.<br>- **Width:** 3–6 m; **Depth:** 1–2 m (deeper in storage pockets).<br>- **Lining:** Natural clay lining, if needed, to reduce seepage in storage zones.<br>- **Check structures:** Small weirs or gabions to create cascading pools. |

| | | |
|---|---|---|
| **Water Collection & Conveyance** | - Divert road drainage via culverts and channels into pit.<br>- Install silt traps upstream to reduce sedimentation.<br>- In high-water-table areas, allow natural seepage inflow. | - Use road camber and side drains to direct runoff into elongated drain.<br>- Provide sediment traps at inlet points.<br>- Plant grass along edges to stabilize banks and filter silt. |
| **Safety & Health** | - Fence with vegetative or wire fencing to prevent accidents.<br>- Design separate watering points for livestock.<br>- Introduce tilapia fish to control mosquitoes.<br>- Avoid direct human consumption without treatment (e.g., sand filter, hand pump). | - Ensure gentle side slopes to prevent accidents.<br>- Avoid stagnant water via flow through/overspill design.<br>- Plant useful vegetation (fodder grass, trees) to stabilize banks and provide shade. |

## 5.6 Roadside springs

Roadside Spring Protection (RoSPro) is an integrated approach that brings together road construction and water resource management in mountain areas, where springs are often the main source of water for local communities. It is particularly important for the Hill Tracts in Bangladesh.

RoSPro focuses on the systematic identification, protection, and management of springs and seeps that are encountered or affected during road construction and maintenance. Rather than treating spring water as a nuisance to road works or ignoring its presence, RoSPro promotes targeted interventions for springs that emerge due to road construction. These interventions ensure that spring water is safely captured or redirected to where it is needed, while at the same time protecting roads from damage caused by surface seepage.


*Figure 63 - Road damaged because of uncontrolled spring seepage*

**Importance of Roadside Spring Protection**

- Vulnerability to Road Construction: Conventional road building in mountain terrain can disrupt the hydrogeology, intercept groundwater flows, and lead to spring depletion. Unmanaged spring water can also undermine road stability, causing erosion, landslides, and increased maintenance costs
- Protecting Vital Water Source: In Bangladesh's mountain regions – in particular the Chattogram Hill Tracts - , springs are often the main or only reliable source of water for drinking, domestic use, and small-scale agriculture. There is much reporting of springs that have dried up. For the remaining springs, discharge is declining due to climate change, deforestation, and poorly planned infrastructure.
- Climate Resilience and Sustainable Development: Protecting springs during road development helps maintain water availability, supports local agriculture, builds resilience against climate change, and improves the livelihoods of mountain communities.

In brief, the benefits of roadside spring protection are (1) Reliable Water Supply (year-round clean water for communities and agriculture). (2) Road Longevity and Safety (reduced erosion, landslides, and maintenance) (3) Environmental Protection (maintaining hydrology, supporting groundwater recharge, and preserving biodiversity, and (4) Livelihood Enhancement (improved roads and water availability boost health, food security, and local economies).

In road development and asset management in the Hill Tracts it entails intervening in the spring recharge area and development of the roadside spring outlets (see infographic).

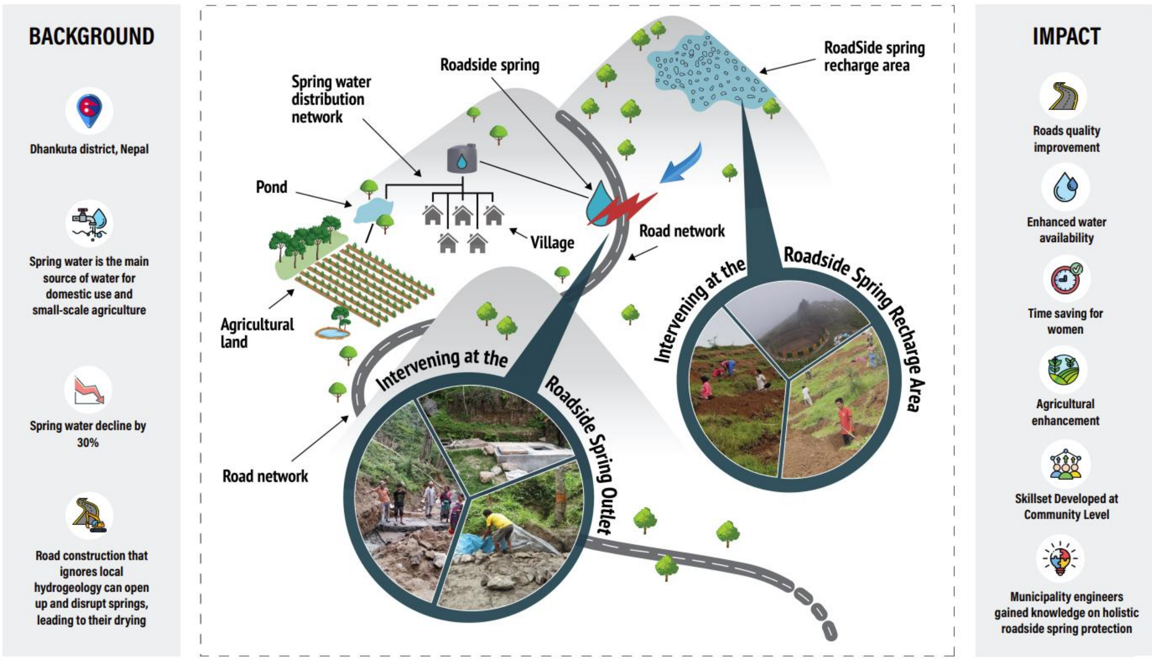



*Figure 64 - Roadside Spring Protection (RoSPro) infographic illustrating the background challenges, the RoSPro approach, and its impacts. The infographic was developed as part of the RoSPro pilot project implemented in Nepal*

The following guidance applies for roadside spring protection.

*Table 38 - Guidelines for roadside spring protection*

| # | Item | Elaboration |
|---|---|---|
| 1 | **Hydrogeological Survey and Mapping** | - Gather baseline data: Use topographic maps, satellite imagery, and local knowledge.<br>- Conduct field surveys with GPS, hydrogeological tools, and use local knowledge.<br>- Delineate spring sheds: Map geology and understand groundwater flow paths.<br>- Identify and map all springs and seeps.<br>- Document flow rates, water quality, and seasonal variations. |
| 2 | **Development of Roadside Spring Outlets** | - Spring Box Design<br>• Assess spring yield and water quality<br>• Select appropriate spring box size based on estimated flow (typical: 0.5–2 $m^3$).<br>• Use reinforced concrete or masonry, with inlet screens and overflow pipes<br>- Pipe Conveyance System:<br>• Design pipe sizes for peak flow<br>• Use durable, corrosion-resistant materials |

| | | |
|---|---|---|
| | | • Route pipes away from road foundations<br>- French Mattresses/Longitudinal Drains:<br>• Use for safe water conveyance along road edges<br>• Design depth and width based on expected flow and soil type |
| **3** | **Water Quality Management of Roadside Springs** | - Test water quality before and after intervention.<br>- Design filtration and sedimentation systems as needed<br>- Prevent direct runoff from road surfaces into spring capture systems<br>- Use vegetative buffers to filter contaminants. |
| **4** | **Downstream Interventions** | Irrigation ponds (agriculture), tap stands (drinking and domestic uses), distribution pipes<br>• Locate at the downstream settlement area<br>• Beneficiaries: depending on the water available from the springs. |
| **5** | **Interventions in Spring Recharge Areas (Upstream Spring sheds)** | Identify spring recharge areas<br>Develop recharge and retention structures: Ponds, Trenches, Half Moons, Recharge Pits and vegetative measures<br>Size and number of structures based on catchment area and rainfall (e.g., pond volume = runoff × retention time)<br>Repurpose excavation material (rubble) to create the recharge structures |
| **6** | **Other Green Road Measures for Runoff, Erosion, and Slope Protection** | - Drainage Design<br>• Size side drains and culverts for peak rainfall events (use Rational Method or similar)<br>• Select materials and slopes to prevent clogging and erosion<br>- Gabions and Protection Walls<br>• Assess slope angle, soil type, and expected loads<br>• Design gabion dimensions and wall heights per site-specific geotechnical analysis<br>• Ensure proper foundation and drainage behind walls<br>- Bioengineering Techniques/ Vegetative measures<br>• Select suitable species for brush layering/live check dams (use of bamboo, for instance) along the contour and at critical sections to stabilize the soil, to reduce soil erosion from water, and to divert flood water directly entering the springs area.<br>• Space interventions based on slope length and expected runoff. Integrate with structural measures for maximum stability. |
| **6** | **Participatory Planning and Co-Design of Roadside Spring Protection Measures** | - Hold stakeholders/community workshops to gather input and discuss usage, operation, and maintenance<br>- Facilitate co-design sessions for spring protection solutions<br>- Develop site-specific protection designs with community feedback<br>- Build local capacity for future maintenance. |

## 5.7 Bioengineering for hill slopes and road embankments

*Figure 65 - Bio-engineering on road embankment*

Bioengineering is a form of green infrastructure in which vegetation and natural materials are used to perform engineering functions such as erosion control, slope stabilization, and surface protection. In Bangladesh, bioengineering is an important nature-based solution, widely applicable for the protection of hillslopes, road embankments, bridge approaches, and other earth structures that are vulnerable to erosion and shallow slope failures. These techniques are particularly suitable for roads in hilly areas where conventional structural measures alone are often costly, environmentally intrusive, or difficult to maintain.

Bioengineering measures shall be considered an integral part of the design of hill roads and of embankments, particularly in erosion-prone, flood-prone, and high-rainfall areas. The measures are applicable to both cut slopes and fill slopes, including the natural hillsides disturbed by road construction. Measures shall be tailored to site-specific conditions, and hybrid solutions combining bioengineering with civil engineering shall be adopted at critical locations. Bioengineering should also be considered in a “build back better” strategy where previous stabilization measures have failed.

*Figure 66 - Before and after images from bio-engineering*

Bioengineering measures are effective primarily against surface erosion and shallow slope movements where the depth of potential failure does not exceed approximately 0.5 m. Where deeper-seated instability is anticipated, bioengineering should only be applied in combination with appropriate civil engineering measures such as retaining walls, gabions, or reinforced earth structures. When properly designed and maintained, bioengineering is a very cost-effective and sustainable method of slope protection while delivering additional environmental and social benefits. The applicability of bio-engineering measures is described in the table below.

*Table 39 - Guidelines on applicability of bio-engineering measures.*

| Item | Elaboration |
|---|---|
| **General effectiveness** | Most effective where the principal risks are rain-cut erosion, surface runoff concentration, and shallow slips. |
| **Slope length** | Suitable for slopes of less than 6–8 m in height.<br>For slopes that are exceeding this length, intermediate berms shall be provided, and the bioengineering measures shall be applied in stages. |
| **Slope angle** | Generally suitable for slopes up to 1V:2H, while for cut slopes in hilly terrain, slopes up to 1V:1.75H may be treated, subject to site-specific assessment |
| **Depth of potential slope failure** | Most effective when the depth of potential slope failure does not exceed approximately 0.5 m.<br>If the depth of potential slope failure exceeds 0.5 m, it should be used only in combination with appropriate civil engineering measures |

In planning the bio-engineering measures, in combination with civil engineering measures the following steps are required:

- Determine the engineering functions of bioengineering measures
- Select the most suitable combination of bioengineering measures
- Select the plant species
- Determining the Engineering Functions of Bioengineering

Bioengineering measures perform several distinct but interrelated engineering functions. These include (1) catching and retaining soil that would otherwise move downslope, (2) armoring the slope surface against rainfall impact and runoff erosion, (3) reinforcing shallow soil layers through root systems, (4) anchoring soil mass by deep-rooted vegetation, (5) supporting slope material, (6) reducing the velocity and volume of surface runoff, and (7) facilitating drainage of excess water. See diagram.

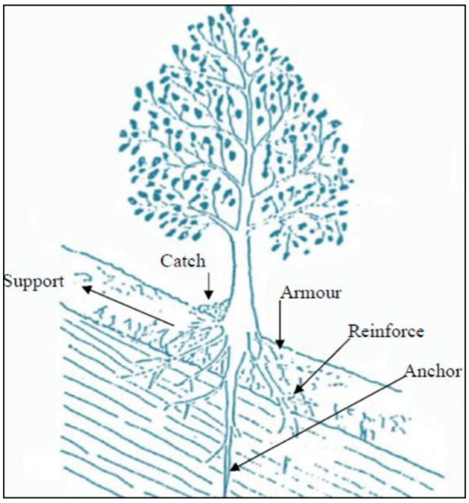


*Figure 67 - Different engineering functions*

In practice, a single bioengineering intervention often performs multiple functions simultaneously. For example, dense grass covers both armors the slope surface and reinforces the shallow soil layer, while shrubs and small trees contribute to reinforcement and anchoring. At critical locations, these functions shall be supplemented by civil engineering measures such as check dams, toe walls, stone pitching, or surface drains to ensure overall slope stability. The table below gives an overview of the engineering functions and the associated bio-engineering and civil engineering measures.

*Table 40 – Overview of engineering functions and associated bio-engineering and civil engineering measures*

| Engineering function | Bio-engineering measures | Civil engineering measures |
|---|---|---|
| **Catch:** Stop material from falling or sliding down a slope | - Contour lining of grasses, brush layers<br>- Live check dam<br>- Stems of shrubs and bamboo | - Check dams<br>- Catch walls<br>- Jute netting |
| **Armor:** Protect the surface from erosion | - Storeys of mixed plants providing complete cover<br>- Grass carpet of clumping or spreading grass with dense and fibrous roots<br>- Use green soil bags | - Revetment wall<br>- Stone pitching |
| **Reinforce:** hold particles together and reduce the risk of shallow-seated movement | - Grasses, shrubs, and trees that are densely rooting<br>- Most vegetation structures | - Soil nailing<br>- Reinforcing earth |
| **Anchor:** reduce risk of deeper-seated movement | - Trees and shrubs that are deeply-rooting with long string roots | - Rock anchors by bolting |
| **Support:** hold material on the slope | - Large trees and bamboos having deep and dense root system | - Retaining walls<br>- Prop walls |
| **Reduce:** reduce material and water movement | - Strong, numerous, and flexible stems<br>- Many strong, fibrous roots | - Check dams<br>- Catch walls |
| **Drain:** remove excess water | - Down slope and diagonal vegetation lines<br>- Angled fascines | - Surface drains<br>- French drains |

### 5.7.1 Designing the bioengineering package of measures

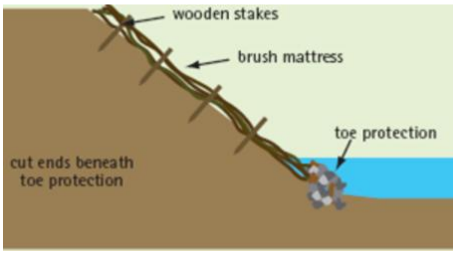
The design of bioengineering measures has to follow a systems approach, treating the slope as an integrated unit consisting of the surface layer, drainage network, and toe support. Proper drainage is essential and shall be given priority in all packages. Crest drains, side drains, and cross-drainage structures shall be provided to prevent uncontrolled runoff from flowing over the slope face.

Toe stability is critical for both hillslopes and embankments. The toe of the slope shall be protected using appropriate measures such as gabions, stone pitching, geo-bags, or other suitable armoring, particularly where erosion or undercutting is likely. Slope lengths shall be broken by berms, contour planting, or small check structures to reduce runoff velocity and erosive power.

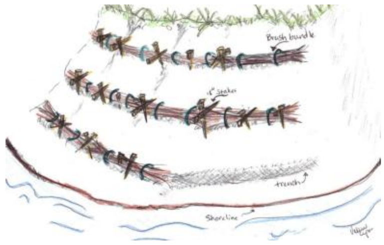
At locations identified as sensitive or hazardous, bioengineering shall be combined with grey infrastructure to achieve the required level of safety and durability. Commonly applied bioengineering techniques for hillslopes and embankments include turfing and grass seeding, brushwood mattresses, fascine bundles, live cuttings combined with stone protection, timber crib walls, riprap integrated with vegetation, and root wads for toe stabilization. The selection of techniques shall be based on slope geometry, soil conditions, hydrology, and the level of erosion risk.

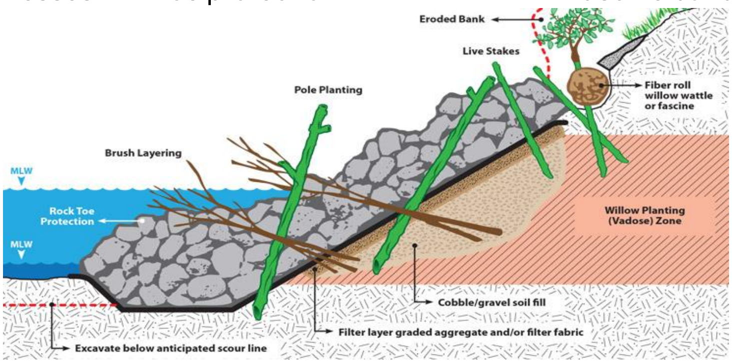
*Table 41 - Selecting bioengineering techniques - Applications, site requirements, effectiveness*

| System | Functions | Method of operation | Applications and site requirements | Effectiveness / Full strength |
|---|---|---|---|---|
| Horizontal line grass planting | Catch, armour, reinforce | Dense line retards surface water flow | Dry, slope <45°, erodible, cut slope | Immediate / 2 seasons |
| Diagonal line grass planting | Catch, armour, reinforce | Dense line guides water along the line | Wet, permeable, fine, cut slopes | Immediate / 2 seasons |
| Grass seeding | Armour, Catch, reinforce | Dense grass, mat, rooting system | Consolidated debris slopes <45° | 1 season / 3 seasons |
| Palisades | Catch, reinforce | Dense line above and below the ground retards surface and shallow water flow | Slope <35°, dry, erodible and consolidated debris | Immediate / 2 seasons |
| Brush layering | Catch, reinforce | Dense line, strong buried branches retard surface and shallow ground water flow | Slope <45°, dry, erodible and consolidated debris | Immediate / 2 seasons |
| Fascines | Catch, support, drain | Woody bundle, dense stems, porous, can drain soil if laid down slope | Consolidated debris slopes, <45° | Immediate / 3 seasons |
| Shrub planting | Catch, armour, reinforce, anchor | Bunchy leaves, multiple stems, lateral roots, tap roots | Any slopes < 45°. | 2 seasons / > 3 seasons |
| Tree planting | Support, reinforce, anchors | Lateral and near vertical rooting systems, root cylinder | Any debris slopes <30°, gully side slopes | 3 seasons / > 4 seasons |
| Bamboo planting | Catch, armour, reinforce, support | Dense poles, massive rooting systems, dense leaves, grows all year | Slope <35°, base of slope, erodible slopes, preferably wet places | 2 seasons / > 4 seasons |



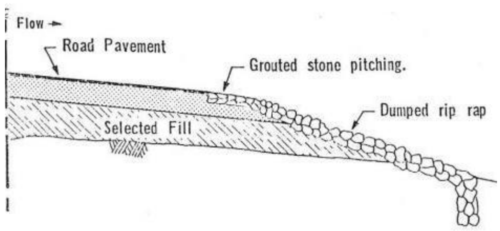
Brushwood mattresses with toe protection


Fascine bundles



Stones with live cutting


Timber crib walls



Stone pitching


Rip rap


Rock rolls


Root wads

### *5.7.2 Selection of vegetation*

The selection of plant species is a critical aspect of bioengineering design. Species shall be selected based on their ability to perform the required engineering function (see above), their adaptability to local climatic and soil conditions, their long-term sustainability, and their additional functions.

Preference shall always be given to indigenous plant species that are known to perform well under local conditions. Selected plants shall be capable of establishing in disturbed or nutrient-poor soils commonly found on cut and fill slopes. Where possible, plants should also provide secondary benefits such as fodder, fuelwood, agricultural products, biodiversity enhancement, or visual screening.

*Table 42 - Common plants colonizing roadsides. Source (Howell 2008)*

| Botanical name | Comments |
|---|---|
| **Grasses** | |
| *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. |
| *Jatropha curcas* | Shrub 2 to 5 meters 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 meters high, producing many suckers; grows on river banks, 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. |

Certain species shall be avoided, including invasive plants, species with excessively dense canopies that inhibit undergrowth, or plants that are unacceptable to local communities. The selection process shall be undertaken in consultation with local stakeholders to ensure acceptance, protection, and long-term maintenance of the vegetation

Vetiver grass has proven to be a highly effective bioengineering species for hillslopes and road embankments in Bangladesh. Owing to its deep, strong, and finely structured root system, vetiver provides excellent resistance to surface erosion and shallow slope instability. It performs well in freshly cut or filled soils and tolerates a wide range of climatic and hydrological conditions.

Vetiver shall generally be planted in continuous contour-aligned hedgerows along the slope. This arrangement reduces runoff velocity, traps sediment, and promotes infiltration. Vetiver-based bioengineering is significantly more cost-effective than conventional masonry or stone protection measures and is therefore recommended wherever site conditions permit.

Vetiver grows in practically any soil and therefore also performs well in soils, such as fresh cut and fill areas, that are devoid of nutrients (Greenfield 2008). Its deep roots make vetiver able to withstand high runoff speeds and volumes. Vetiver is also a very resilient plant that can grow under a wide range of climate conditions, including air temperatures ranging from −15 °C to more than 55 °C and rainfall varying from less than 300 millimetres to more than 5,000 millimetres per year. Given this versatility, vetiver has a range of uses, including slope stabilization, vegetation rehabilitation, and as a source of fodder and thatch (Pinners, n.d.). Planting parallel hedges of vetiver on steep slopes can control runoff erosion related to road construction or drainage.

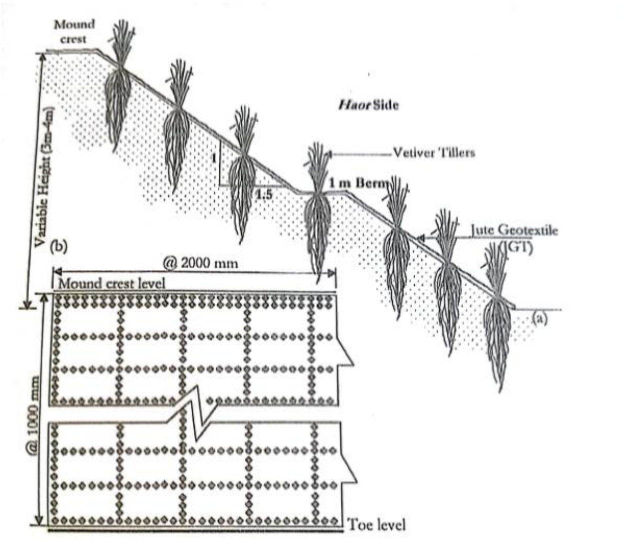



*Figure 68 - Normal lay-out design of vetiver grass (source: bioengineering training jointly arranged by LGED & ADB)*

Coastal area embankment roads may be also protected by a 50-200 m wide belt of mangrove in the tropical regions or non-mangrove plantation following the staggering method. This practice may protect embankments from erosion caused by the tide effect but not from the impacts of storm surges (Islam, 2000). Mangroves retain nutrients in their roots, increasing soil stability and helping to keep up with sea-level rise (Alongi, 2008). Moreover, mangrove acts as a buffer towards strong winds and cyclone tidal effects.

*Figure 69 – Mangroves in Bangladesh*

*Box 3 – Geo-bags and Green Soil Bags*

**Geo-bags and Green Soil Bags**

Geo-bags and green soil bags may be used as complementary measures within bioengineering schemes, particularly for embankment repair and slope armouring. Conventional geo-bags, filled with sand or soil, provide immediate surface protection and toe stabilization. Green soil bags, made of biodegradable materials and filled with soil mixed with grass seed, provide temporary structural support while vegetation becomes established.

Green soil bags are particularly suitable for minor erosion repair and embankment strengthening. They are not intended to withstand major wave action, storm surges, or severe river erosion and shall not be used as standalone protection in such environments.

### *5.7.3 Construction and Planting*

Bioengineering works shall be scheduled to coincide with the early part of the wet season, typically between April and June or July, to ensure adequate soil moisture for plant establishment. Planting shall not be undertaken late in the wet season, as insufficient root development may occur before the onset of dry conditions.

Slopes shall be properly prepared prior to planting, including trimming to the design profile and removal of loose material. Newly planted areas shall be protected from grazing, trampling, and uncontrolled access. Where rainfall does not occur within 24 hours of planting, supplemental watering shall be provided.

Regular inspection and maintenance shall be carried out to ensure uniform vegetation cover, prevent the formation of animal paths or erosion gullies, and replace failed plants as necessary. Bioengineering alone is not suitable for deep-seated slope failures, areas with uncontrolled groundwater pressure, or locations subject to severe hydraulic forces. Inadequate drainage, inappropriate species selection, or lack of maintenance will significantly reduce effectiveness. These limitations shall be clearly recognized during design and implementation.

## 5.8 Roadside vegetation

*Figure 70 - Roadside vegetation*

This section provides guidance on how to plan, implement and monitor vegetation activities along the LGED roads without compromising road longevity and safety. The Tree Plantation and Conservation and Tree Resource Distribution Activities Implementation Manual under LGED (2003) recognizes LGED playing a leading role in contributing to social and economic development through roadside tree plantation. The guidance from this manual is incorporated in this section.

Roadside vegetation is any vegetation growing along the roads. Planting trees, shrubs and grasses along the road can create a productive asset and serve many objectives, all of which contribute to the well-being of the population along the road, the quality of the environment, as well as the quality and durability of the road. Roadside vegetation can also alleviate the negative effects of roads on the local environment, such as pollution, noise, fine dust, erosion of roadsides and gully formation. Bangladesh has already made significant progress with roadside tree planting, applying the Social Forestry Rules. According to an informal estimate, 30% of rural roads are lined with managed roadside vegetation. This is a good achievement, but it also means that there is still considerable scope for expansion, besides improving on existing vegetation.

In developing roadside vegetation, it is important to be cognizant of the main preferred functions – and adjust the design and vegetation selection to this. The tables below can be used to guide the priorities for the different roads and road sections. In some road sections, dust control or soundproofing may be most important; in other areas, productive use is more relevant. Elsewhere, beautification and giving the area a special identity through roadside vegetation may be the main objective. Road safety is always a major concern on every road.

| # | Key points |
|---|---|
| **1** | Plan roadside vegetation with the full scope of potential benefits in mind, to optimize them. |
| **2** | Address ownership and community management as a precondition, making use of the Social Forestry Rules. |
| **3** | Build in adequate time and community consultation to secure the roadside verges for common beneficial use. |
| **4** | Prevent and manage unplanned roadside plantation, which can have negative impacts including road safety, moisturizing, and shading of pavement. |

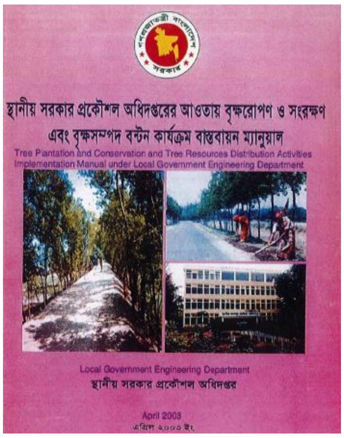



*Figure 71 - Road side tree planting guidelines 2003*

*Table 43 - Functions and applications of roadside vegetation*

| Function | Application |
|---|---|
| **Sound proofing** | - Vegetation close to the road will reduce sound pollution.<br>- Dense, layered planting, multi-row vegetation is most effective.<br>- Combine ground vegetation with shrubs and larger trees.<br>- Evergreen is preferred. |
| **Flood and typhoon protection** | - Tree plantations serve as obstructions against cyclone wind speed and surge velocity, especially when multiple rows of trees and shrubs are preferred to withstand these destructive forces.<br>- Deep and firmly rooted trees and shrubs are preferred as they are better able to withstand the heavy cyclone forces.<br>- Trees with open canopies and without heavy limb branches are preferred to prevent damage from uprooting and branches falling off.<br>- Ideally, trees are regularly checked and older and diseased trees removed. |
| **Promoting biodiversity** | - Create a variety of habitats, integrate rocks, logs, and mini-wetlands in the roadside vegetation.<br>- Connecting to landscape hedges to create biological corridors.<br>- Selective mowing and removal of biomass to enhance plant species diversity.<br>- Avoid mowing in flowering or breeding season, leave some strips totally unmowed. |
| **Carbon sequestration** | - Use native, fast-growing, and long-lived tree species suited to local conditions.<br>- Use deep-rooted perennials, grasses, and legumes to increase soil carbon. |
| **Road safety** | - Roadside greenery in general improves driver alertness and tranquility – and encourages responsible traffic behavior.<br>- Preference is for low-growing shrubs and groundcovers near road edges and light-canopy trees set back from the road, allowing regular visual breaks<br>- Avoid tree planting in high-speed sections (>60 kilometers/hour).<br>- Support visibility (no tree planting in inner bends).<br>- Glaring can be avoided by planting dense evergreen trees the in direction of the rising or setting sun.<br>- Irregular and varied spaced planting can avoid speeding behavior. |

| | |
|---|---|
| **Beautification and comfort** | - Provide shade and space where there is much pedestrian movement.<br>- Consider iconic trees for beautification and local identity. |
| **Avoiding interference** | - Do not grow high trees near electricity lines.<br>- Avoid root penetration in culverts. |

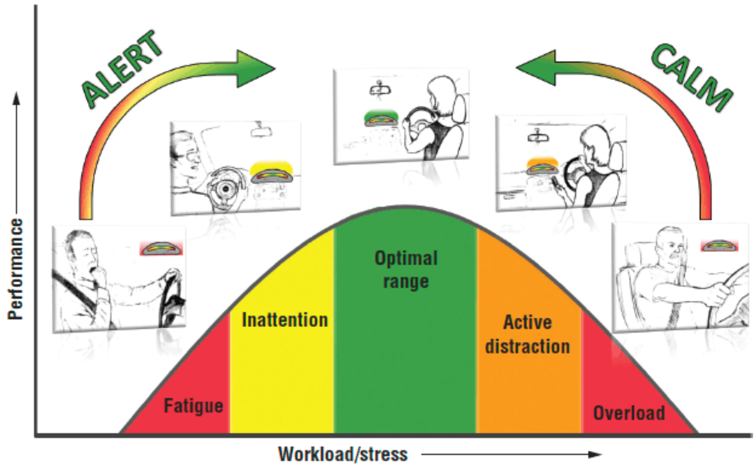



*Figure 72 - Alertness*

### *5.8.1 Choosing the location*

**Avoiding no-go areas**

There is much scope to expand the location of the roadside vegetation. There are, however, also no-go areas, where roadside vegetation should not be considered: close to public utilities or where vegetation affects visibility or creates collision risks (discussed below). The distance to electric poles and electricity lines should be considered as well, to avoid the trees coming into contact with electric wires. A distance of 3-4 meters from low tension lines and 7-8 m from the poles is recommended to avoid interference. Very high trees are avoided in the vicinity of electricity lines.

**Avoiding collision risks**

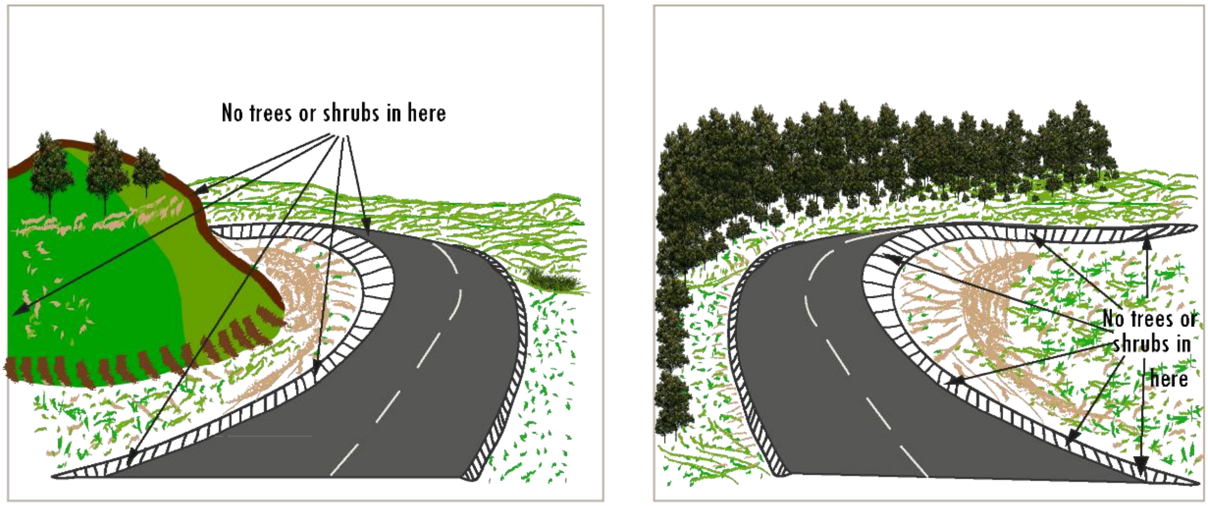
A very important factor to consider when designing roadside plantations is to minimize the risk of vehicle-tree collisions. Trees can be the cause of fatalities during accidents, in particular in high-speed zones (Budzynsky et al, 2016), where they may be avoided or placed behind a crash barrier. Tree planting should avoid high-speed zones, and a safe distance should be kept at medium-speed sections (see table 7.1). If a road is upgraded, it may be necessary to cut down trees to ensure safety. The following safe distances are recommended, derived from the World Bank Guideline of Green Roads for Water and Climate Resilience, originally based on guidelines adopted from Australia.

*Table 44 Roadside vegetation distance and road safety measures (Source: VicRoads Tree Planting Policy 2015)*

| Speed zone | Road safety measures | |
|---|---|---|
| **40km/h** | The impact force during accidents is unlikely to exceed human tolerances, so no specific mitigation is needed. | |
| **50km/h** | A minimum lateral distance from the road edge of 1 m should be maintained to reduce incidental interaction between vehicles and trees. | |
| **60km/h** | Intersections | At least 10 m beyond intersection on the approach and departure side. |
| | Driveways | At least 3 m between driveway and tree. |
| | Lane merge locations | 3.6 m lateral distance from road edge. |
| | Curves | 3.6 m lateral distance from road edge for gentle curves; a barrier should be placed on moderate 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 without crash barriers are not suitable. |

**Improving visibility**

Roadside tree planting can improve road visibility, but it can also obstruct views. This should be considered in the selection of sites. Placing trees in bends should be done with care. 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 – i.e., the outer bends - will enhance visibility and alert drivers to curves in the roads. At intersections or exits, no trees should be planted. Overgrown trees are a particular problem, and care should be taken not to plant trees with horizontal crowns.




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 73- Tree planting and road visibility*

**Choosing the location: reducing glare effects**

Roadside regreening can also contribute to road safety by reducing the risk of glare – the blinding of drivers by the low-rising or setting sun. As Bangladesh is close to the equator, the sun is at a low angle for relatively short periods in the day; it is still useful to reduce the risk of glare with roadside vegetation. This is served with relatively dense foliage at critical sections that creates effective shade and light filtration. Also, it is better to stagger the planting of trees rather than aligning them perfectly, so as to avoid the 'sun-flicker' effect between trees or from gaps in the vegetation. The location where glare is to be avoided can be determined by a simple glare analysis – observing where the sun is low on the horizon (0-15 degrees) in the early morning or evening, taking into account the surrounding landscape and buildings as well: these may block or redirect the glare. The most critical area will be on eastern (sunrise) and western facing (sunset) sections of roads, or areas on top of a hill where glare can certainly appear. Glare is especially to be avoided close to road intersections or pedestrian areas.

**Choosing the location: improving scenic outlook**

Vegetation should also be planned to improve the scenic outlook and create vistas. The recommendation is to use the vegetation as a 'frame', using taller trees at the sides to draw the eye toward a beautiful view and using low shrubs or grasses/ ground cover in the line of sight, as in a picture frame. In general, also to break the monotony and avoid a feeling of being boxed in, deliberate "windows" or "gaps" in vegetation should be created at designated viewpoints, for instance, at road curves or points of interest.

**Distance from road edge**

The minimum distance for roadside tree planting depends on the road type and the tree species. In general, the busier the road, the larger the distance between the road edge and the plantation. This is related to road safety, as discussed above, but also on the use of the road verge for roadside activities, walking, parking, or traffic diversion. In general, the following minimum distances are recommended. In case trees are planted with a wide canopy, a larger minimum distance may be observed. Moreover, the vegetation must not obstruct driver visibility, traffic signs, or the approach to junctions.

*Table 45 - Distances from road edge*

| Type of Road | Minimum Distance from Road Edge (m) |
|---|---|
| Village / Rural Roads | 1.5 – 2.0 meters |
| District Roads | 3.0 – 4.0 meters |
| State Highways | 5.0 – 7.0 meters |
| National Highways | 10.0 – 15.0 meters (clear zone) |

### *5.8.2 Roadside vegetation design*

**Single or multiple rows**

Single-row plantations are considered when space is limited. One or two plantations are cost-effective options but require a uniform and high survival rate. Their functionality is more limited, but land value or land ownership may narrow the space available for roadside vegetation: a narrow strip may be all there is. However, when possible, it is preferable to have plantations of several rows to protect a larger area. This will serve several functions: noise reduction, dust trapping, biodiversity, and carbon sequestration

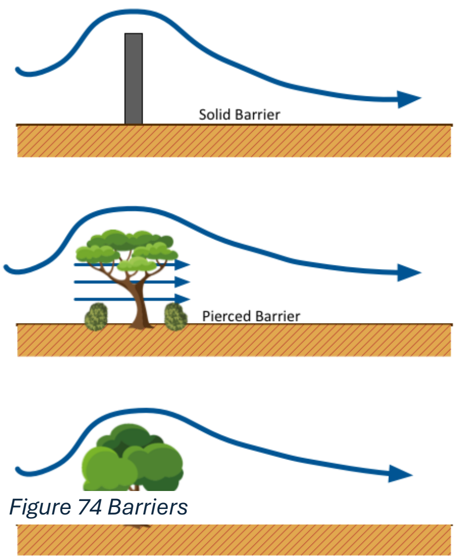


*Figure 74 Barriers*

**Spacing density and porosity**

The selection of species will determine the plant spacing, i.e., the distance between the different shrubs and trees. Shrubs, for instance, grow at 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 (> 15-meter height) are planted 9-12 m apart, medium-sized trees (10–15-meter height) 6-9 meter apart, and smaller trees (< 10-meter height) 4-6 meter apart. Larger shrubs are planted 2.5-4 meters apart, and lower shrubs are placed 1.5-2.5 meters apart. The shrubs can form the undergrowth of the tree planting.

The spacing and the number of rows will determine the porosity of the vegetation. Where dust is an issue, sufficient porosity is recommended so that the vegetation traps the dust. If the vegetation is too dense, the wind will lift the dust over the roadside vegetation, and no dust will be left behind in the vegetation. The figure above shows different types of roadside plantations. The best effect on dust control is from porous barriers. Porous plantations allow a large part of the air flow to go through them. Dust will be trapped better because there is more contact with the leaves of the trees and shrubs. To accomplish a good degree of porosity, plantations should be approximately 5-20 meters wide, consisting of tall trees with a shrub layer underneath. The capture of dust 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 to solid barriers, all dust will 'leap' over the barrier and little will be intercepted.

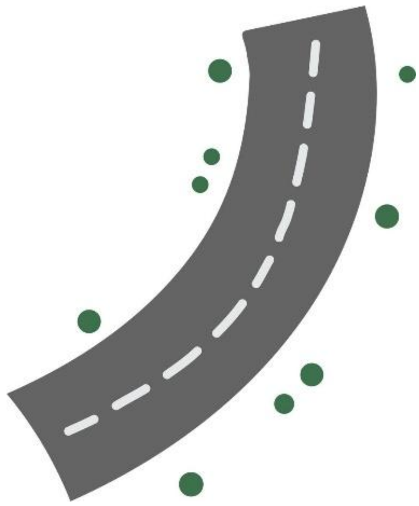


*Figure 75 - Curves*

**Irregular or regular distance**
The consensus is that road greenery has a soothing effect on drivers – and improves their alertness and tranquility, which contributes to road safety. Science has proven that exposure to visual greenery improves cortisol levels in the human brain.

So whilst roadside vegetation improves alertness, it is also important to avoid monotony. At straight road sections, variation is useful: long rows of trees in flat areas are likely to increase drowsiness. What is recommended is to have sections with regularly spaced trees, alternated with open vistas and short sections with irregularly spaced trees. In critical sections, such as bends, planting trees at irregular distances is recommended, as this creates a feeling of unexpectedness

**Connection with hedges and local forests**
Roadside vegetation can be combined with perpendicular hedges and low 'stepping stone' vegetation to connect fragmented habitats, enhancing ecological connectivity and promoting biodiversity. By having uninterrupted roadside vegetation connected with hedges, agroforestry belts, and local forests in the area around the roads, an ecological corridor network can be created with species moving over a large area - providing shelter, food, and protection from predators. It is a powerful conservation strategy that prevents habitat isolation and supports species migration, breeding, and feeding. Small mammals, including bats, birds, and insects, will be able to move freely. This is not a matter of ecology only because such biodiversity also may have a positive effect on the surrounding farm areas as well: pollination, control of pests, and improved soil life. This function is best achieved in relatively wide roadside vegetation with ample undergrowth of shrubs and grasses.

### *5.8.3 Planting on roadside bunds*

In Bangladesh a large proportion of the roads are placed on embankments, so as to prevent the roads from being flooded during monsoon rainfall. The design of the embankments brings special requirements for the roadside vegetation. It is recommended to have a graded plantation on these bunds, as follows:

*Figure 76 - Vetiver grass stabilizing embankments*

- Organic matter producing grasses, such as daincha, arahar, or mulberry trees are planted the on upper half of the road embankment
- Deep rooted trees, like betel nut, tamarind, coconut palm, data palm are planted in the lower half of the embankment
- If the embankment is structurally weak, embankments may also be stabilized by mini terracing and the use of vetiver grass. The embankment protection by roadside vegetation may be complemented with clay cladding, especially when the road bodies are made of sandy silt, silty sand, or non-plastic silt.
- If the embankment is in danger of flooding, then special protective grasses are important, such as ikar, binna grass, and jajnabati.

### *5.8.4 Combining water harvesting and tree planting*

Along roads, there are substantial opportunities to harvest water, as discussed in the previous chapters. This can be combined with tree planting. Small diversion channels can be constructed to slowly divert surface flow from the roadside drainage system toward the tree seedlings. These diversion structures can be combined with small storage structures around the trees to retain this water for the tree or small depressions (swales) that feed the rootzone of the vegetation. Also, smaller bushes and grasses can 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.

### *5.8.5 Vegetation programs and ownership*

**Implementing roadside vegetation programs**

It is a precondition that ownership and community management of the rural roads are addressed, making use of the Social Forestry Rules. It is recommended to build in adequate time in road planning to secure the roadside verges for common beneficial use and to sharpen the guidelines on roadside vegetation.

**Land ownership**

Before developing roadside vegetation, the land ownership along the road should be established. Roadside plantations are often established within the so-called ‘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 Bangladesh, the Roads and Highways Department is the owner of much of the road verge. For LGED, this is different: the land adjacent to the road is often owned by individual families or communities. The planting of roadside vegetation needs to be done in close consultation with the roadside communities and land users. The Social Forestry Rules have applied.

**Social forestry**

The key characteristics of social forestry program are summarized below.

- To use the road embankments and protect the roads from encroachment, social forestry groups are given custody of designated sections of the road embankments. The Forestry Department, with these SFGs, clears the road embankments and plants a mixture of trees. Forest Department invests in a first rotation of trees, provides necessary convening and technical expertise, and engages and organizes local communities for roadside tree planting.
- The SFGs take care of the road sections under a tripartite agreement they sign with the Forest Department, the LGED that owns the roadside land and the local government, the Union Parishad. Each community participant (family) enters a 10-year MoU with the Forest Department, which details the participant’s credentials, a particular section of right of way, tree species for planting, management plan, conditions for harvesting and benefits sharing.
- Under this agreement, the SFGs have the usufruct of the roadside forestry, i.e., the tree twigs and branches, obtained from pruning, thinning, and other maintenance of the plantations. Besides, the SFGs are allowed some cropping of, for instance, papaya, ladyfingers or pigeon peas.
- The Forest Department harvests the trees (usually after a 10-year rotation period), sells the timber at auctions, and shares sell proceeds with the beneficiaries according to the Social Forestry Rule 2004. Here is the formula: Forest Department: 10%, LGED): 20%, Social Forestry Group: 55%, Union Parishad: 5%, and Tree Farming Fund 10% (for new planting after the first rotation).

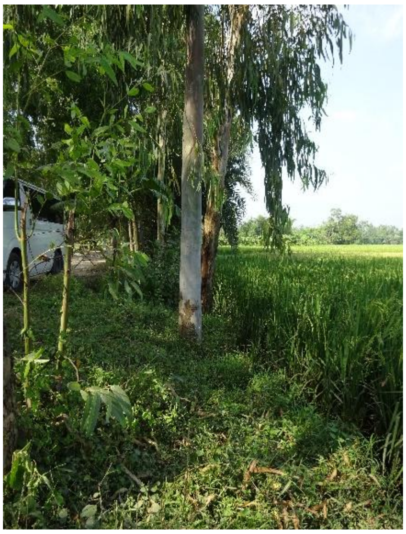


*Figure 77 - Well-managed and vegetated shoulder*

- After the trees are harvested at the instigation of the Forest Department, a new cycle starts. In the meantime, the Social Forestry Groups protect the roadsides against encroachment by shops and houses, as is common on most other roads.

### *5.8.6 Operational considerations*

**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.

**Practicalities of planting**

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.
- Sites with established animal paths should not be considered, as protection of the 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-growing nursery
- Time of planting: Between July 1st and mid-August.
- Planting sites shall be at a reasonable distance from farmlands as well as from the edge of the road. The effect of the shade on crops (direction of the sun) will be taken into account when deciding the location.
- Distances between seedlings.
- Care and maintenance: Keep soil weed-free, protect from cows/goats, irrigation if needed, control of pests and diseases.

**Eliminating weeds**

The survival and growth of tree seedlings depend on the fast reestablishment of their root system. Competition from the roots of other plants growing in the area will hinder the reestablishment of the 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. It is not recommended to add materials (compost, manure, or other soil) to the soil unless it is of very poor quality. If that is the case, it is best to incorporate a maximum of 25% 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 meters. Soil shattering involves pulling one tooth, or a set of teeth, at various depths through the soil to break up the compaction by the roadsides.

Top soiling should be done when possible. It involves the removal, storage, and application of topsoil material to provide a suitable growing medium for vegetation. Top soiling 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 buried with excavated material, such as fill slopes. When possible, laboratory tests and field surveys should be carried out 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. They should be one hand wide and one hand deep. 45 by 45 cm deep and preferably be excavated two weeks ahead of the actual planting. Fertilizer or cow dung can be added to the planting holes immediately after excavation. Planting should be done after two weeks, preferably in the afternoon.

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, 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.

**Watering**
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 to 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 irrigations are 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.

**Selecting seedling**
Seedling quality will influence the amount of care that the seedling needs. Quality seedlings are available from public and private sources. Tree seedlings should measure at least one meter in length. Healthy seedlings grow new roots faster and can access deeper soil moisture. Poor-quality seedlings develop roots slowly and therefore require more frequent irrigation. Also, the seedlings have to adapt to a new location, where, in the nursery, they have been watered daily; they now have to 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.

**Maintenance**
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 the necessary resources and

arrangements for maintenance should be made 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.

Given the highly distributed nature of roadside tree planting, local management is generally best. Three other factors that contribute to effective management are: (1) restrictions on the free movement of cattle and ruminants; (2) clearly assigned ownership and usufruct rights to the roadside plantation; and (3) the ability to economically use the plantations, even if it means harvesting and replanting.

**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. There are several materials that can be used as mulches, 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-elevation sites, it is important to apply a mulch that will last more than one year. Materials with the highest durability are the 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 especially recommended for hot and dry sites and sites 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**.

Regular pruning is important for safety and canopy optimization. It is important to develop well-spaced structural branches early in the life of a tree. Branches that are growing 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. Though it is advisable to examine the trees yearly and do pruning or cutting of branches for reshaping, if necessary. Uncontrolled growth of trees and shrubs could cause problems for vehicles, such as reduced sight distance, 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**

In free-grazing areas and places subject to damage, fencing will be necessary. Social fencing is sometimes considered a better 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 as these plantations often cross several districts.

There are a range of methods to protect seedlings, which include 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 since they block the sunlight, impeding plant growth. Individual trees can be fenced by surrounding them with wood sticks made with small branches from nearby trees.

Plastic netting can be installed to protect seedlings from browsing animals over each seedling. The netting acts as a barrier to the foraging of 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. The 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 after planting as possible 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 it is still growing inside the shelter, the seedling will not be capable of supporting itself. Tree shelters are more effective than other methods, but they are also more costly.

## 5.9 Selecting roadside vegetation

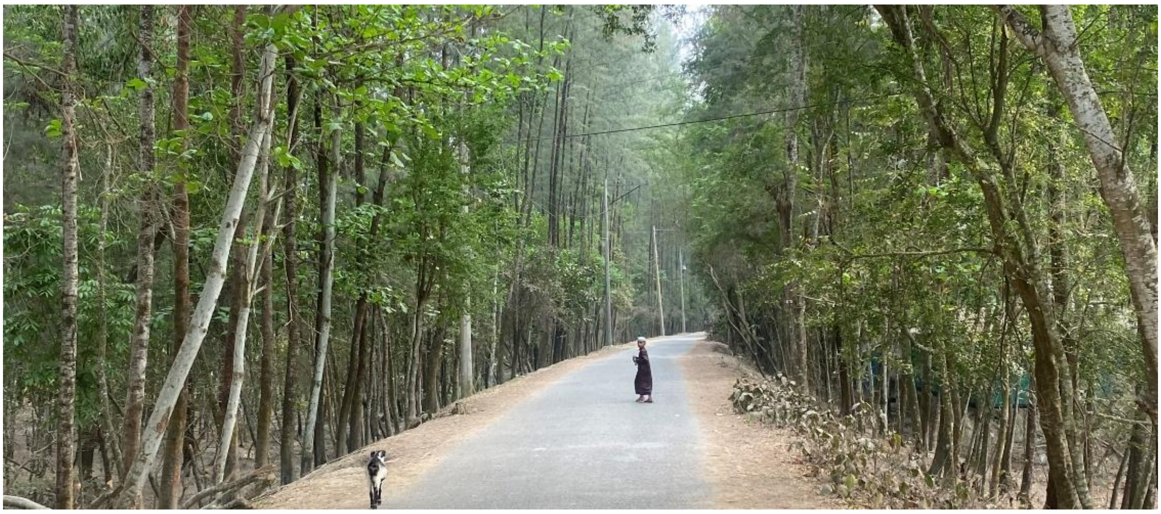


*Figure 78 - Roadside vegetation*

| # | Key points in selecting roadside vegetation |
|---|---|
| 1 | A mix of trees, shrubs and grasses for a full range of benefits that vegetation can provide. |
| 2 | Decide on the importance of different qualities and select species accordingly: carbon sequestration, timber value, non-timber value, pollution abatement, noise reduction, soil improvement, wind break, biodiversity harbour, shading effect, esthetic value, and reduced storm exposure. |
| 3 | Look at suitability for the concerned hotspot region: the Coastal Zone, the Barind and Drought Prone Areas, the Haor and Flash Flood Areas, the Chattogram Hill Tracts, and the Flood Plains and Estuaries |

In general, plants selected to vegetate roadsides must be able to resist harsh conditions because the land adjacent to the road is often degraded. Selection should be in line with local soil and climate conditions. The figure on the right gives the preferred species for different soils in Bangladesh. In the black soil, no acacia trees can be planted, for instance. Instead, gamma, chapalish, teak and mahagony are suitable trees for black soils. Khaiya acacia, keora and golpata can be planted in coastal areas.

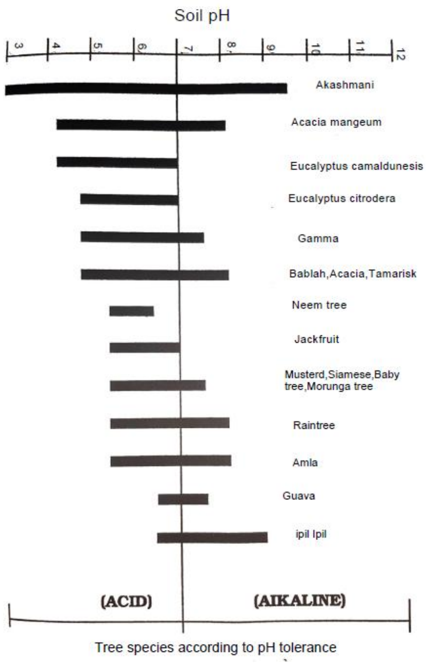



*Figure 79- Species suitable for acid and alkaline soils*

Native species are preferred since they are adapted to local conditions and there is no risk of them becoming invasive. The choice of species is based on the objectives of the plantation (economic or environmental) and the space available. Multipurpose trees (fruit, fodder, timber, fuel wood species) can be incorporated to provide economic benefits. The Tree Plantation and Conservation Manual of 2003 proposes a distribution of 50% forest trees, 30% fruit trees, 20% medicinal trees.

Below are the general criteria for selecting species:

- Tree species should preferably be evergreen or remain green for most of the year.
- Tree species should not be broad-rooted, as tree roots may penetrate the road surface.

Tree species should be deep-rooted to resist the force of wind power and drought stress.

- Tree species should have crown architecture with more horizontal than vertical extension so as not to interfere with traffic and other functions.
- Tree and grass species should be tolerant to seasonal drought, insect, and pest attacks.
- Thorny plants are to be avoided as they may cause tire punctures.
- Tree and grass species should never be invasive.
- Tree species should preferably be fast-growing.
- Tree species should preferably have one or more of social and economic values such as medicinal, food, fuel wood, feed and bee-fodder.
- In case tree species are edible by livestock, fencing in the growing stages is needed to protect the tree and enable it to mature.

| Tree Species | Flood Plains and Estuaries | Coastal Zone | Haor and Flash Flood Areas | Chattogram Hill Tracts | Barind and Drought Prone Areas | Storm-proof (wind-firmness) | Area | Stable Root System | Time to Maturity / End of Life | Height at Maintenance | Carbon Sequestration | Timber Value | Non-Timber Value | Windbreak Value | Shading Value | Biodiversity Harbour | Pollution Absorption | Dust Trapping | Sound Proofing | Esthetic Value | Soil Improvement | Other Benefits | Area Type |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Shorea robusta (Sal) | No | No | No | No | Yes | Moderate – Strong trunk but tall sail; mixed wind performance | Central/Northern Sal forests | Deep taproot, good for stability | 15–20 yrs / up to 100 yrs | 15–20m | High | High (furniture) | Resin, leaf plates | Moderate | Moderate | Supports birds, mammals, insects | Moderate | High | Moderate | Moderate | Adds organic matter | Cultural, ecological forest species | Forest |
| Heritiera fomes (Sundari) | No | Yes | No | No | No | Moderate – Stilt roots help, but canopy exposed in cyclones | Sundarbans, coastal | Stilt roots, saline-tolerant | 15 yrs / 70–100 yrs | 15–20m | Very High | High | Medicinal, tannin | High | Low | Nurseries for fish, birds, reptiles | High (heavy metals) | Moderate | Moderate | Low | Stabilizes coastal soils | Salt-tolerant, rare mangrove species | Forest |
| Barringtonia acutangula (Hijol) | Yes | No | Yes | No | No | Moderate – Grows in waterlogged areas; crown moderate | Haors, wetlands | Deep-rooted, flood-tolerant | 10–15 yrs / 50 yrs | 8–12m | Moderate | Low | Flowers used locally | Low | Moderate | Attracts wetland birds, bees | High (nutrient filter) | High | Moderate | High (beautiful flowers) | Water purification, shade plant | Flood-resilient | Wetland |
| Artocarpus heterophyllus (Jackfruit) | No | No | No | Yes | Yes | No – Heavy fruit and broad crown increase wind damage | Nationwide | Deep-rooted, pavement-friendly | 7–10 yrs / 40 yrs | 10–15m | High | Medium | High-value fruit | Moderate | High | Habitat for insects, squirrels | Moderate | Moderate | Low | High (massive foliage) | Enriches soil with leaf litter | Widely cultivated and loved species | Homestead/Agricultural |
| Melocanna baccifera (Bamboo) | Yes | No | No | Yes | Yes | Yes – Flexible culms; narrow profile; good wind resilience | Hills, rural areas | Fibrous root binds soil on slopes | 3–5 yrs / 10–15 yrs | 5–10m | High (fast growth) | High (construction) | Crafts, shoots, fencing | Moderate | Moderate | Understory wildlife shelter | Moderate | High | Moderate | Moderate | Prevents erosion | Renewable, grows fast | Homestead/Agricultural |
| Aegle marmelos (Bael) | Yes | No | No | Yes | Yes | Yes – Compact crown; strong wood; deep rooting | Dry areas, homesteads | Taproot, drought-resistant | 8–10 yrs / 50 yrs | 8–10m | Moderate | Low | Fruits, medicinal uses | Moderate | Moderate | Attracts bees, birds | High | Moderate | Moderate | High (fragrant flowers) | Improves soil with organic matter | Sacred in culture, pest repellent | Homestead |
| Albizia lebbeck | Yes | No | No | Yes | Yes | No – Wide, spreading canopy; limb failure in storms | Urban, roadsides | Spreading roots, nitrogen fixer | 4–5 yrs / 30 yrs | 10–15m | Moderate | Moderate | Shade, fodder, medicine | High | High | Insect and bird-attracting | Moderate | High | High | High | Nitrogen fixing | Reduces urban heat island effect | Urban |
| Azadirachta indica (Neem) | Yes | No | No | Yes | Yes | Yes – Moderately narrow crown; wind-firm, deep rooting | Urban, rural | Deep-rooted, low maintenance | 3–5 yrs / 40 yrs | 10–15m | Moderate | Low | Medicinal, pest repellent | Moderate | Moderate | Habitat for beneficial insects | High (air purifying) | Moderate | High | Moderate | Adds leaf litter to soil | Mosquito repellent, antifungal | Urban |
| Acacia auriculiformis | Yes | Yes | No | Yes | Yes | Yes – Used as windbreak; strong, fibrous roots | Roadside, degraded lands | Fibrous roots, soil stabilizer | 4–6 yrs / 30 yrs | 10–12m | Moderate | Medium | Pods, firewood, gum | Moderate | Moderate | Shelter for birds | Moderate | Moderate | High | Moderate | Nitrogen fixer | Wind-resistant, erosion control | Degraded/Upland |
| Ficus religiosa (Peepal) | Yes | No | No | Yes | Yes | No – Very wide canopy; heavy lateral limbs | Urban, sacred groves | Deep roots, pavement-safe | 10–15 yrs / >100 yrs | 20–30m | High | Low | Shade, cultural | Moderate | High | Hosts birds, insects, epiphytes | Moderate | High | High | High (sacred fig) | Improves microhabitat | Cultural significance, oxygen release | Urban/Sacred |
| Terminalia arjuna | Yes | No | Yes | Yes | No | Yes – Riverbank species with strong anchorage | Riverbanks, flood zones | Strong roots for erosion control | 10 yrs / 70 yrs | 15–20m | High | Moderate | Bark (medicinal) | Moderate | Moderate | Bird nesting, bees | High | Moderate | High | High | Improves bank soil | Flood-control, medicinal | Riparian |
| Dalbergia sissoo (Sheesham) | Yes | No | Yes | No | Yes | No – Brittle branches under strong winds | Plains, agroforestry | Taproot, strong wood | 10 yrs / 60 yrs | 15–20m | High | High | Fuelwood, shade | Moderate | Moderate | Hosts insects, birds | Moderate | Moderate | Moderate | Moderate | Fixes nitrogen | Agroforestry value | Agroforestry |
| Syzygium cumini (Jamun) | Yes | No | Yes | Yes | Yes | Moderate – Dense wood but rounded crown | Lowlands, homesteads | Deep-rooted, fruit-bearing | 6–8 yrs / 50 yrs | 10–15m | Moderate | Low | Fruits, medicine | Low | High | Birds, bats | Moderate | Moderate | Moderate | High (fruit tree) | Leaf litter | Food source | Homestead |
| Moringa oleifera | Yes | No | No | Yes | Yes | Yes – Slender crown; flexible branches | Homesteads, dry zones | Light roots, fast-growing | 2–3 yrs / 20 yrs | 8–10m | Moderate | Low | Nutrient-rich leaves | Low | Moderate | Bees, insects | High | Moderate | Moderate | High | Improves nutrition | Climate-resilient, food security | Homestead |
| Dipterocarpus turbinatus | No | No | No | Yes | No | No – Tall emergent with windthrow risk in cyclones | Chittagong Hill Tracts | Deep taproot, stabilizing | 15 yrs / 80 yrs | 25–30m | Very High | High | Resin, medicinal | Moderate | Low | Birds, insects | Moderate | Moderate | Moderate | Moderate | Enriches forest soil | Supports evergreen forest biodiversity | Hill Forest |
| Terminalia bellirica | Yes | No | No | Yes | Yes | No – Large, spreading crown | Dry forests, homesteads | Strong root, drought-tolerant | 8–10 yrs / 60 yrs | 15–20m | High | Moderate | Medicinal fruits | Low | Moderate | Birds, bees | Moderate | Moderate | Moderate | Moderate | Improves dry soil | Used in Ayurveda, traditional uses | Dry Forest |
| Saccharum spontaneum | Yes | Yes | Yes | No | No | Yes – Grass with flexible stems | Floodplains, riverbanks | Fibrous roots, soil binder | 1–2 yrs / 3 yrs | 1–2m | Low | None | Fodder, erosion control | Low | Low | Hosts small wildlife | Low | Moderate | Low | Moderate | Prevents river erosion | Native grass, quick regeneration | Floodplain/Grassland |
| Swietenia macrophylla (Mahogany) | Yes | No | No | Yes | Yes | Yes – Dense wood; generally wind-firm when well-rooted | Hill plantations | Taproot, invasive risk | 10 yrs / 60 yrs | 20–30m | High | Very High | Shade | Moderate | Moderate | Limited biodiversity support | Moderate | High | Moderate | Moderate | Minimal soil benefit | High-value timber, ecological concern | Plantation |
| Areca catechu (Betel Nut) | Yes | Yes | No | No | No | Moderate – bends but crown may snap. | Coastal, homesteads | Fibrous roots, fairly stable | 7–8 yrs / 60–100 yrs | 15-20m | Moderate | Moderate | Nuts, fronds | Low | Moderate | Attracks polinators, | Moderate | Moderate | Low | High (tall, | Adds organic leaf litter | Valuable cash crop | Homestead/Agricultural |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | and fibers | | | bees, insects | | | | graceful palm) | | and cultural plant | |
| Palmyra palm | Yes | Yes | No | No | Yes | High – deep-rooted and wind-firm. | Rural landscapes | Deep anchorage | 14-15 yrs / 60 yrs | 25-30m | Moderate | Moderate | Fruit, sap, leaves | Moderat e | High | Attracks wildife, supports local fauna | Moderate | Moderat e | Moderat e | High (majesti c palm) | Stabilizes coastal soils | Products support rural livelihoods | Homestead/Agricult ural |

## 6. Looking ahead

The Guidelines on Green Roads for Water (GR4W) address major opportunities in connecting road infrastructure with water management. When this integrated approach is applied, roads can serve not only as transport corridors but also as instruments for water management and enhanced flood and climate resilience.

Combining road development with water management offers the potential for multiple benefits. These include reduced waterlogging and water scarcity, better flood management, improved access to services and facilities, enhanced agricultural and aquacultural productivity, more effective watershed management, and improved livelihood opportunities for local communities and more. The very extensive road network of LGED presents an opportunity and a huge responsibility!

A systematic, not piecemeal, approach is required – with assessments of the entire road network, as part of regular road planning and asset management. Annex 1 gives a tool to do this. At the same time, work processes can be fine-tuned towards these opportunities – strong coordination with other departments and local government, systematic community engagement, locally-led development, and better processes in planning and budgeting. Annex 2 also identifies different bottlenecks to be addressed and introduces better working practices.

The shift from conventional road development to green roads is already widely recognized as essential. Green Roads for Water form a core component of this transition, integrating road infrastructure with land and water management, biodiversity conservation, climate resilience, and disaster risk reduction, as outlined in these Guidelines. Beyond water-related benefits, green roads also promote responsible material sourcing, local job creation, decarbonization, and overall improvements in quality of life.

Implementing green roads programs therefore represents not a marginal adjustment, but a major systemic transformation in how roads are planned, built, and managed - one that positions road infrastructure as a driver of sustainable development, resilience, and inclusive growth.

## References


Abhishek, A., Borgia, C., Manjur, K., van Steenbergen, F., & Vera, L. F. (2020, April). Gender mainstreaming in rural road construction/usage in Ethiopia: impact and implications. In *Proceedings of the Institution of Civil Engineers-Transport* (Vol. 173, No. 2, pp. 122-131). Thomas Telford Ltd.

Alongi, Daniel M. 2008. "Mangrove Forests: Resilience, Protection from Tsunamis, and Responses to Global Climate Change." *Estuarine, Coastal and Shelf Science* 76(1): 1–13. https://www.sciencedirect.com/science/article/pii/S0272771407003915 (April 18, 2018).

Barkat, Abul et al. 2007. 1207 *Towards a Feasible*.

Begum, M. 2004. "Factors Affecting Family Size in Rural Bangladesh." *Bangladesh Medical Research Council bulletin* 30(3): 115–24. http://www.ncbi.nlm.nih.gov/pubmed/16240982 (March 19, 2018).

Cross Red. 2013. "Community Shelter Guidelines in Mozambique."

CSIR-CRRI. 2013. *Guidelines for Planning and Construction of Roads in Cyclone Prone Areas*. New Delhi. https://www.slideshare.net/phanis9/guidelines-for-planning-and-construction-of-roads-in-cyclone-prone-areas (September 20, 2017).

Douven, W., M. Goichot, and H. Verheij. 2009. "Roads and Floods: Best Practice Guidelines for the Integrated Planning and Design of Economically Sound and Environmentally Friendly Roads in the Mekong Floodplains of Cambodia and Viet Nam: Synthesis Report." https://repository.tudelft.nl/islandora/object/uuid%3Abe31676b-5563-43e0-91e0-f68298e16c0c (April 17, 2018).

Dung, Le Viet, Le Thanh Phong, Luu Thai Danh, and Paul Truong. "Vetiver System for Wave and Current Erosion Control in the Mekong Delta, Vietnam." http://www.vetiver.org/VVN_wave and current.pdf (September 7, 2017).

Haque, Ubydul et al. 2012. "Reduced Death Rates from Cyclones in Bangladesh: What More Needs to Be Done?" *Bulletin of the World Health Organization* 90(2): 150–56. http://www.who.int/entity/bulletin/volumes/90/2/11-088302.pdf (March 19, 2018).

Hasan, Shaikh Shamim, Xiangzheng Deng, Zhihui Li, and Dongdong Chen. 2017. "Projections of Future Land Use in Bangladesh under the Background of Baseline, Ecological Protection and Economic Development." *Sustainability (Switzerland)* 9(4).

Howell, J. 2008. Study of Road Embankment Erosion and Protection *No Title*. https://assets.publishing.service.gov.uk/media/57a08bb7ed915d3cfd000ebc/Seacap19-TP6.pdf.

Islam, Md Nazrul. 2000. "EMBANKMENT EROSION CONTROL: TOWARDS CHEAP AND SIMPLE PRACTICAL SOLUTIONS FOR BANGLADESH." http://prvn.rdpb.go.th/files/CP-3-1.PDF (September 27, 2017).

Kalam, Azad Abul, and Kenichi Matsushima. 2016. "International Conference on Transport and Road Research." In Dhaka. https://assets.publishing.service.gov.uk/media/57a09dcced915d622c001bbb/61280-AzadAKMatsushimaK-2016-SustainableSlopeProtectionSolution-ICTRR2016Paper-ReCAP-v20160316.pdf (August 10, 2017).

LGED. 2005. Road Desing Standards, Rural Road *Web Copy*.

LGED, Local Government Engineering Department. 2010. "Planning Guidelines for Rural Road Master Plan ( Guideline on GIS Application for Rural Road Development ）."

Ministry of Environment, Forest and Climate Change, Government of the People's Republic of Bangladesh. (2022). *National Adaptation Plan of Bangladesh (2023-2050)*

Momtaz, Salim. 2015. "Social Impact Assessment in Bangladesh : A Critical Review of the Recent Developments." (October 2010).

Queensland, Department of Transport and Main Roads; 2015. *Road Drainage Manual - July 2015 Edition*. corporateName=Department of Transport and Main Roads;

jurisdiction=Queensland; sector=government. https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-drainage-manual.aspx (February 27, 2018).
Schiechtl, Hugo M., and R. (Roland) Stern. 1997. *Water Bioengineering Techniques : For Watercourse, Bank and Shoreline Protection*. Blackwell Science. http://trove.nla.gov.au/work/15620281?q&versionId=46375464 (September 7, 2017).
Shariful Islam, Mohammad. 2013. "Study on Growth of Vetiver Grass in Tropical Region for Slope Protection." *International Journal of Geomate* (December 2013). http://geomatejournal.com/sites/default/files/articles/729-734-3163-shariful-Dec-2013.pdf.
Smith, E. R. 2006. *Floodway Design Guide*.
Van Steenbergen, Franciscus Wilhelmus Maria; Arroyo Arroyo, Fatima; Rao, Kulwinder Singh; Hulluka, Taye Alemayehu; Woldemariam, Kifle Woldearegay; Deligianni, Anastasia.
*Green Roads for Water : Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience (English).* International Development in Focus Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/102951623742853259
WMO & GWP. 2011. "FLOOD EMERGENCY PLANNING A Tool for Integrated Flood Management." https://reliefweb.int/sites/reliefweb.int/files/resources/Tool_16_Flood_Emergency_Management.pdf (March 20, 2018).

# Annex 1: Identification and prioritization guide

The following guide is meant to identify and prioritize GR4W measures. With the questions on the list the main areas where GR4W need to be implemented can be assessed and the most. This can be integrated in regular maintenance program or programs that invest in the upgrading or new construction of roads in Bangladesh.

It is recommended that district engineering teams use this list to identify the priority road sections where measures can be taken to build back better existing roads and have new roads align with the different green road opportunities, whilst ensuring better connectivity.

This is done on the basis of field records, insights from field engineers, transect survey (i.e systematically drive-throughs of the road network) and consultations with local government and communities.

Worksheet 1 identifies the main road sections where interventions are needed – to reduce persistent maintenance challenges and to create better water management along and with the road.  This identification and prioritization than leads to Worksheet 2 to 7, where respectively potential measures are identified to:

- Address maintenance problems (workheet 2)
- Address water logging (worksheet 3)
- Address water scarcity (worksheet 4)
- Manage road side springs (worksheet 5)
- Extend road side vegetation (worksheet 6)
- Support local fisheries (worksheet 7).

*Table 46 - Worksheet 1*

| **Priority list** | | | | | | |
|---|---|---|---|---|---|---|
| **Opportunity to improve** | Which area | Specific road sections | Description | Severity from score 1-5. (5 is high) | Can be addressed in maintenance program score 1-5 | **Follow up assessm ent list. Go to:** |
| **Are there road section with repeated maintenance problems** | | | | | | **Work Sheet 2** |
| pavement | | | | | | |
| embankment | | | | | | |
| cross drainage | | | | | | |
| bridges | | | | | | |
| combination | | | | | | |
| | | | | | | |
| **Are there areas with water logging related to road development** | | | | | | **Work Sheet 3** |
| Are there areas with fast silting up drains | | | | | | |
| Are there areas where road infrastructure steers flooding | | | | | | |
| Are there problematic bridges (siltation, scouring, flooding) | | | | | | |
| Are there areas with disturbed riverbeds related to bridges | | | | | | |
| Are there road section that are regularly flooded | | | | | | |
| Which areas are most exposed to typhoons and devastative flooding | | | | | | |
| Which areas are transitioning to high yielding among paddy | | | | | | |
| Are there unprotected river facing/sea facing roads? | | | | | | |

| | | | | | | |
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| | | | | | | |
| **Which areas are affected by water scarcity** | | | | | | **Work Sheet 4** |
| Is there sourcing of sand and gravel from vulnerable rivers | | | | | | |
| Are there borrow pits or borrow strips, are they used | | | | | | |
| | | | | | | |
| **Are there new roadside springs - what is their condition** | | | | | | **Work Sheet 5** |
| Are there areas with marked decline in springs | | | | | | |
| Are there areas that suffer from severe erosion | | | | | | |
| Are there areas in danger of landslide | | | | | | |
| | | | | | | |
| **What is the situation with regards roadside vegetation** | | | | | | **Work Sheet 6** |
| Well covered areas (>30%) | | | | | | |
| Scantily covered areas (,<10%) | | | | | | |
| Areas with potential for improvement | | | | | | |
| | | | | | | |
| | | | | | | |
| | | | | | | |
| **Are there reports of fish population going down/ changing** | | | | | | **Work Sheet 7** |
| Is this related to road development | | | | | | |
| Are there report of other effect on biodiversity? | | | | | | |

*Table 47 - Worksheet 2*

| Are there road section with repeated maintenance problems | Describe | Improvement to consider |
|---|---|---|
| unpaved road top | rutting, slips, holes | Rolling dip/ water bar; side protection |
| pavement | potholes, wearing, root damage, | revisit roadside tree planting, avoid flooding, prolonger inundation |
| embankment | slips, encroachments, side flood day | better protection, vegetative, armoring combination, infiltration stones |
| cross drainage | leakage, blockage, bypassing, overtipping | better inlets/outlets, redimensioning, additional cross drainage, provide gates, |
| bridges | damage to approach, pavement, pillars, failure, bypassing | protection with NBS, reconsider sill/ width/ height, or total replacement |
| combination | | |

| **On the basis of:** |
|---|
| Detailed discussion with field staff |
| Inspection of records |
| Community discussion |
| Field visit/ transect survey |

*Table 48 - Worksheet 3*

| Issue | Description | Improvement to consider |
|---|---|---|
| Are there areas with water logging related to road development | Seasonality, overall condition of area, situation of rivers, capacity of cross drainage, silted up/blocked, , other impediment like bridge sills | Additional cross drainage capacity, height of cross drainage, location, clearing |
| Are there areas with fast silting up drains | Reasons for silting up, effects , stagnation, design errors (for instance capacity/ dimension of the drain, quality of silt | Reuse of silt for road construction, remove road or bridge related blockages |
| Are there areas where road infrastructure steers flooding | Type of effect (haors, or riverine flood), effect on/from sedimentation of waterways and drains, beneficial compartmentalization effects | Study on effect of an roads |
| Are there problematic bridges (siltation, scouring, flooding) | Nature of problems, assessment of reasons | Revisit bridge construction, redimensioning |
| Are there areas with disturbed riverbeds related to bridges | Assess history, bridge width, piers, current and original width of the river | Revisit bridge construction, redimensioning, remove most important bottlenecks |
| Are there road section that are regularly flooded | Origin/ background of flooding, effect on road body, relation with cross drainage | Look at compartmentalization, height of roads and cross drainage, overall drainage, and storm water situation |
| Which areas are most exposed to typhoons and devastative flooding | Effect of typhoons in general and effect on road network, function of roads during evacuation and relief for humans and livestock | Raising roads, making wide sections, side slope protection |
| Which areas are transitioning to high yielding among paddy | Prevalence of new high yielding among rice varieties, other requirement for controlled irrigation | Gated culverts, additional minor roads |
| Are there unprotected river facing/sea facing roads? | Vulnerable breach sections, controllable sections (limited options in case of shifting rivers) | Raising, resectioning, NBS/ bioengineering, protection with sandbags and vegetation, armoring, use of geotextile, etc. |
| | | |

| **On the basis of:** |
|---|
| Detailed discussion with field staff |
| Inspection of records |
| Community discussion |
| Field visit/ transect survey |

*Table 49 - Worksheet 4*

| Water scarcity | | |
|---|---|---|
| **Issue** | **Description** | **Improvement to consider** |
| Which areas are affected by water scarcity | Seasonality, situation during rain situation, current use of cross drainage water, scope for storage with road body, effect of cross drainage on flooding patterns | Different water harvesting options, guiding road water drainage, creating storage with road bodies, culverts and bridges |
| Is there sourcing of sand and gravel from vulnerable rivers | Current situation with respect to sand depletion, enforcement, alternative sources, use of manufactured sand, experience with alternative road designs | Alternative sourcing, sand harvesting/ skimming, manufactured sand |
| Are there borrow pits or borrow strips, are they used | Current situation, current use, effect on recharge, future planning, ownership situation | Conversion of borrow pits, consider lining with geotextile, proper allocation, proper design off |
| Can we create storage in local rivers and drains | Local streams that can be used for storage, without disrupting the sediment bed (avoid tidal rivers) | Bandara cum bridges, gated culverts, raised bridge sills |

| **On the basis of:** |
|---|
| Detailed discussion with field staff |
| Inspection of records |
| Community discussion |
| Field visit/ transect survey |

*Table 50 - Worksheet 5*

| Issue | Descriptions | Improvements to consider |
| --- | --- | --- |
| Are there new roadside springs - what is their condition | Type of springs or seeps, location, season ability, current use or non-use, damage to road or hillside | Spring protection, enhanced recharge and spring shed improvement |
| Are there areas with marked decline in springs | Reported drying or decline springs, different contributing factors | |
| Are there areas that suffer from severe erosion | Most vulnerable areas, reasons, records | |
| Are there areas in danger of landslides/slips/ mudflows | | Bioengineering measures, NBS |

| **On the basis of:** |
| --- |
| Detailed discussion with field staff |
| Inspection of records |
| Community discussion |
| Field visit/ transect survey |

*Table 51 - Worksheet 6*

| | Describe | Opportunities |
|---|---|---|
| **What is the situation with regards roadside vegetation** | | |
| Well covered areas (>30%) | | |
| Scantily covered areas (,<10%) | | |
| **What would be main benefit if covered with vegetation?** | | Proper planning and tree selection |
| productive use | | |
| erosion control | | |
| dust control | | |
| noise control | | |
| beautification | | |
| road visibility | | |
| road protection | | |
| **What is current situation with road verges?** | | Assess feasibility and start discussion with local government |
| ownership | | |
| current use | | |

Areas with potential for improvement

*Table 52 - Worksheet 7*

| **Are there reports of fish population going down/ changing** | **Describe** | **Improvement to consider** |
|---|---|---|
| Is this related to road development/ cross drainage | Are there obstructions | Modify / increase culverts |
| | Are there interrupted flows | Better connection to water |
| | Are their high velocity culverts | Modify culverts, use stones inside culvert to create slow flow areas |
| | Other possible disruptions | Discuss solutions locally |
| Are there report of other effect on biodiversity like high roadkills | Investigate causes and effects | Underpasses, overpasses, changes in vegetation |
| Are there opportunities to improved bird and bat population | | Nesting cage under bridges |

| **On the basis of:** |
|---|
| Detailed discussion with field staff |
| Inspection of records |
| Community discussion |
| Field visit/ transect survey |

*Table 53 - Worksheet 7*

| Maintenance Record | Case | Date |
|---|---|---|
| | | ....-....-...... |
| | | ....-....-...... |
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| | | ....-....-...... |

# Annex 2: Planning and budgetting processes

As part of the assessment current procedures and working methods were reviewed. Improvements were identified, discussed below.

## 2.1 Improving processes in planning and budgeting

The following changes were assessed to improve the planning and development of new roads.

**Planning roads with due cognizance of the natural topography and hydrology.** When roads are planned, including smaller roads and paths, the local topography should be observed. Large parts of Bangladesh have very low gradients. In these areas roads are very vulnerable to floods. At the same time, the roads can be used to manage the floods.

It is, hence, important to plan the roads so that they can for instance compartmentalize areas, which helps in flood management, or follow the contours so that roads and (gated) culverts can help the water level management. The same is true in the haors where even slightly elevated submersible roads can help to control flood recession and contribute to prolonged soil moisture. The compartmentalization at different levels can also help to slow peak rainfall runoff by storing it behind the road embankments before it overflows onto the next stretch of land. This process slows the velocity of water, reduces erosion and siltation, and leads to more groundwater recharge, and can ensure that areas that areas that need to remain dry, remain dry. Water can be retained longer in relatively higher areas that may serve as storage for lower areas or be used for the cultivation of rice or for aquaculture in the wet season. It should be noted that overflow of water over an embankment may cause scouring and erosion. In these circumstance, controlled overflows from a designated overflow point and controlled cross-drainage structures are recommended.

**Make use of opportunities in land use planning**. Ideally the development of roads is part of land and water use planning. In several projects this process has started for instance in the development of polder plans under several programs. The interest in such local and spatial plans was positive as it allowed a larger perspective to be developed and shared by different parties operating in the same area. It would for instance ensure road development and upgrading aligns with topography and hydrology.

There are also legal openings. Flood control zone can be specified by referring to the boundaries of the mouza (village) map. Delineation of flood-free zones is of utmost importance in planning the road network. According to Article 25 of the Bangladesh Water Act, the Economic Commission may *declare any wetland as a flood control zone to ensure easy passage of the flow of flood water. To protect flood control zones, the Executive Committee may impose prohibitions or conditions on any activity that obstructs or diverts the water flow through such zones.* The BWDB should delineate this flood-free zone and this should be aligned in the planning/upgrading of road networks.

Current practice is that land grabbing and encroachment in the flood-free zones are a constant threat in Bangladesh, and land zoning is affected by this. Though there are several provisions that make it possible to start the process, further commitment/enforcement from the national government would be helpful.

**Construct all roads with cross drainage from the beginning**. A practice was observed whereby roads are constructed without (sufficient) cross drainage in the first place – sometimes caused by funding constraints.

The next step is then to wait for problems to occur, which may then be solved subsequently by the placement of culverts and bridges that were omitted earlier. It is understood that this is done as the initial budget may not suffice for the investment in the new road and cross drainage structures. However, in the meantime, huge losses are incurred to the adjacent farms as the land becomes waterlogged. This loss is a multiple of the investment in the delayed cross drainage. It is recommended to always construct all roads with cross drainage from the beginning. It is also recommended to prioritize investment in improved cross drainage over the construction or upgrading of roads.

**Mainstream roadside vegetation**. The benefits of roadside vegetation are multiple if done well. These benefits concern the stabilization of the road shoulders, their productive use, road safety, pollution control, improved local climate and the management of biodiversity. At present, a rough estimate is that 30% of the rural roads are forested, whereas the others are barren. This proportion should go up, and special programs may be started along existing roads. Whereas in the major roads, owned by the RHD, the road verges are owned by the RHD, this is not the case with the roads under LGED. It is a precondition that ownership and community management of the rural roads are addressed, making use of the Social Forestry Rules. It is recommended to build in adequate time in road planning to secure the roadside verges for common beneficial use and to sharpen the guidelines on roadside vegetation.

**Changing the choices in construction material.** When considering climate resilience and improved water management in a more holistic manner, it should also be considered that roads have an enormous footprint in the extraction of construction materials, equivalent to 30-40% of all construction materials. In Asia, in fact, the demand for construction materials increased by 64% over the last decade, whereas globally, this was 17%. There is a huge need to reduce this (carbon) footprint to mitigate climate change and reach targets including those of the Paris Agreement in 2015.

**Budgeting.** For each of the above-mentioned topics (adequate planning roads of with due cognizance of the natural topography and hydrology, making use of opportunities in land use planning, directly including cross drainage, mainstreaming roadside vegetation, and changing preferred construction material), budgeting is an important factor to consider. Too often, it is observed that actual design and construction are not aligned with the long-term importance of the road infrastructure in a changing climate. Increasingly working with a 'life cycle' approach, whereby long-term reliability of the infrastructure is served, and overall maintenance costs are reduced, albeit at maybe higher initial investment costs, is a promising avenue for improved budgeting. This finding is not only relevant for road infrastructure, but also for water infrastructure of Bangladesh (van Steenbergen et al., 2023). Additionally, incorporating circular economy principles in material selection and project design can help close resource loops, reduce waste, and enhance the sustainability of road infrastructure throughout its life cycle.

## 2.2 Preparation and implementation

Several factors affect the smooth preparation and implementation of integrated green road development. The following changes are assessed to affect the preparation and implementation of road construction.

**Addressing the availability of land for roads and road shoulders**. A recurrent complaint is that there is inadequate space for the road shoulders. Given the high population density and the intense land use, acquiring land for road development is a tedious process. The availability of land is required to make sure that roadside slope design can be as per design for the soil type of type of road. For roads that are likely to be upgraded, a wider road shoulder is preferred. The acquisition of the road verges may require a longer period in road development. At present the ownership of the road shoulders on extensive lengths of LGED roads is unclear. Land has been made available for the road construction to go ahead, but the status and ownership of the land is unclear. It is recommended that better processes are considered that allow better control over the road shoulders.

Gaining ownership of the road and road shoulder through land acquisition processes is furthermore challenged due to the huge cost considerations, especially when looking at the total length of rural roads. However, gradually ownership of land up to shoulder and side slopes has been transferring from the current owners to the Government through land survey and settlement process conducted by the Department of Land Records and Survey under Ministry of Land. Nevertheless, that transferring process is lengthy and time consuming.

**Reviewing the sourcing of material from borrow pits**. Borrow pits ideally have a dual function, sourcing material for road construction and maintenance, but also serving as a place for water storage, collecting excess water and making it available in times of stress. This requires careful consideration of where the borrow pits are placed, who owns them, and who will later operate them. A common practice is to use strips of land along the roads, collecting excess water from fields. Another practice is for borrow pits to be converted for water storage and fish cultivations. Ideally, this is planned in the road process. Apart from the excavation of borrow pits, sourcing of earthwork material, also for the widening of roads, is increasingly done through dredging of silt and sands from adjacent rivers and canals. In parallel to this development, the extent to which borrow pits are present and developed, has been shrinking.

**Timing of road development/improvement activities.** Insufficient road quality may occur as roads are developed or improved during the rainy season when working conditions are challenging. Execution of works in the monsoon season happens mainly due to poor planning, late procurement process and compulsion obligation prior to closing of projects. Construction is often delayed in the rainy season, which hampers the construction process. In such cases, compaction of the road may become a challenge as the soil is saturated with water, reducing the stability and sustainability of the structure.

It is proposed to fund road development and upgrading outside the monsoon season by considering multi-year projects. In this regard it is promising that the online Integrated Budget and Accounting System (iBAS) has been introduced in Bangladesh, which disburses funds on a quarterly basis taking away the problems that come up with annual disbursements. This helps to realise LGED's intention to have planning, designing, budgeting, and procurement done in the monsoon season, followed by implementation of the works soon after the monsoon. iBAS in principle is making fund disbursement more efficient in public spending: funds availability has become possible year-round. It also allows for easier multi-year funding, which has earlier been practiced by LGED in several cases of maintenance programming and project planning.

## 2.3 Coordination

Coordination with multiple stakeholders is essential for the integrated development of roads. The following critical issues were observed to improve coordination in road development, upgrading and maintenance.

**Strengthen coordination between LGED and water organizations (BWDB (for roads cum embankments owned by BWDB), WARPO, WMOs).** This is particularly critical where the road is combined with flood management functions and the long-term development of the road, the carpeting of roads, its height and the slope protection should be aligned with flood protection functions. When LGED paves an embankment, height and width are not always according to the standard road design criteria. This may also lead to the carpeting of an embankment before it is raised to safe standard levels. Moreover, the quality of carpeting of embankment roads is sometimes not adequate. This results in rapid degradation of the road and later also leads to the deterioration of the embankment

Lack of communication between BWDB and LGED may result in extended time needed by BWDB to approve LGED's plans for developing an embankment road.. The coordination mechanism between LGED and BWDB, only relevant for roads cum embankments owned by BWDB, was in place through a signed MoU between LGED and BWDB at the central level for paving BWDB embankment. Local-level officials, in many cases, were not authorized to sign the MoU. This mechanism may be strengthened by establishing coordination committees at the district level with, more authority given to local-level officials.

It is proposed that embankment paving plans are streamlined and that design heights for embankments and embankment roads adopted by LGED and BWDB are harmonised, following the BWDB guidelines. The road templates and construction materials used for pavement should also comply to the minimum requirements in the LGED guidelines. Before starting the implementation, LGED should wait until BWDB reshapes the embankment in accordance with the guidelines' specifications. Afterwards, BWDB can give clearance (No objection certificate-NOC) to LGED to pave the embankment. Monitoring by BWDB is needed for embankment roads implemented by LGED.

**Improve coordination between LGED, LGIs and local communities in road construction, upgrading and maintenance.** LGED should involve local communities in the whole process (survey and implementation) of road improvement and cross-drainage structures. Local people are the users of the infrastructure, and their participation in the whole process is essential for them to understand the connection between road and water management. Moreover, it is a way to validate the collected data and address land acquisition challenges. The engagement should be done systematically, meaning that the discussions are open and representative, preferably with the engagement of LGIs. Discussion should be with the different stakeholder groups (farmers, fishermen, business people, teachers, among others) and use participatory planning techniques such as joint mapping.

Under various programs, Water Management Organizations have come into existence in the water systems in Bangladesh., including the Water Management Cooperative Societies, promoted under LGED. Other WMOs are registered either under the Participatory Water Management Rules of 2014. These WMOs have a significant role to play in improved water management, flood defence, and flood response. The different organizations working with these WMOs should be encouraged to strengthen their activities in this field, and special service providers should be encouraged to work with WMOs in improved water management. There need to be regulations that encourage the WMGs/WMCA to follow and accomplish O&M guidelines related to their responsibilities (filling potholes, rat holes, side slope protection, clearing culverts of garbage).

**Cooperation between LGED and NGOs.** Some rural roads are constructed by NGOs. It is recommended to ensure effective cooperation among government offices (LGED, UP) and NGOs working on a rural road and water construction/improvement and maintenance, as well as cross drainage structures, and that improved design guidelines are followed by these actors as well if needed taking help of experienced design engineers.

**Strengthen coordination between LGED and DDM.** Some rural roads and bridges are being improved/constructed by another GoB agency, namely the Department of Disaster Management (DDM). However, coordination between the LGED and DDM remains limited. Strengthening inter-agency collaboration could also help ensure that rural road infrastructure better supports disaster management objectives. Additionally, roads built by DDM are often of lower quality (often earthen roads) compared to those constructed by LGED, resulting in LGED frequently having to upgrade or rehabilitate DDM-constructed segments. Improved coordination and communication between the two agencies could enhance the overall efficiency, quality, and effectiveness of infrastructure development efforts.

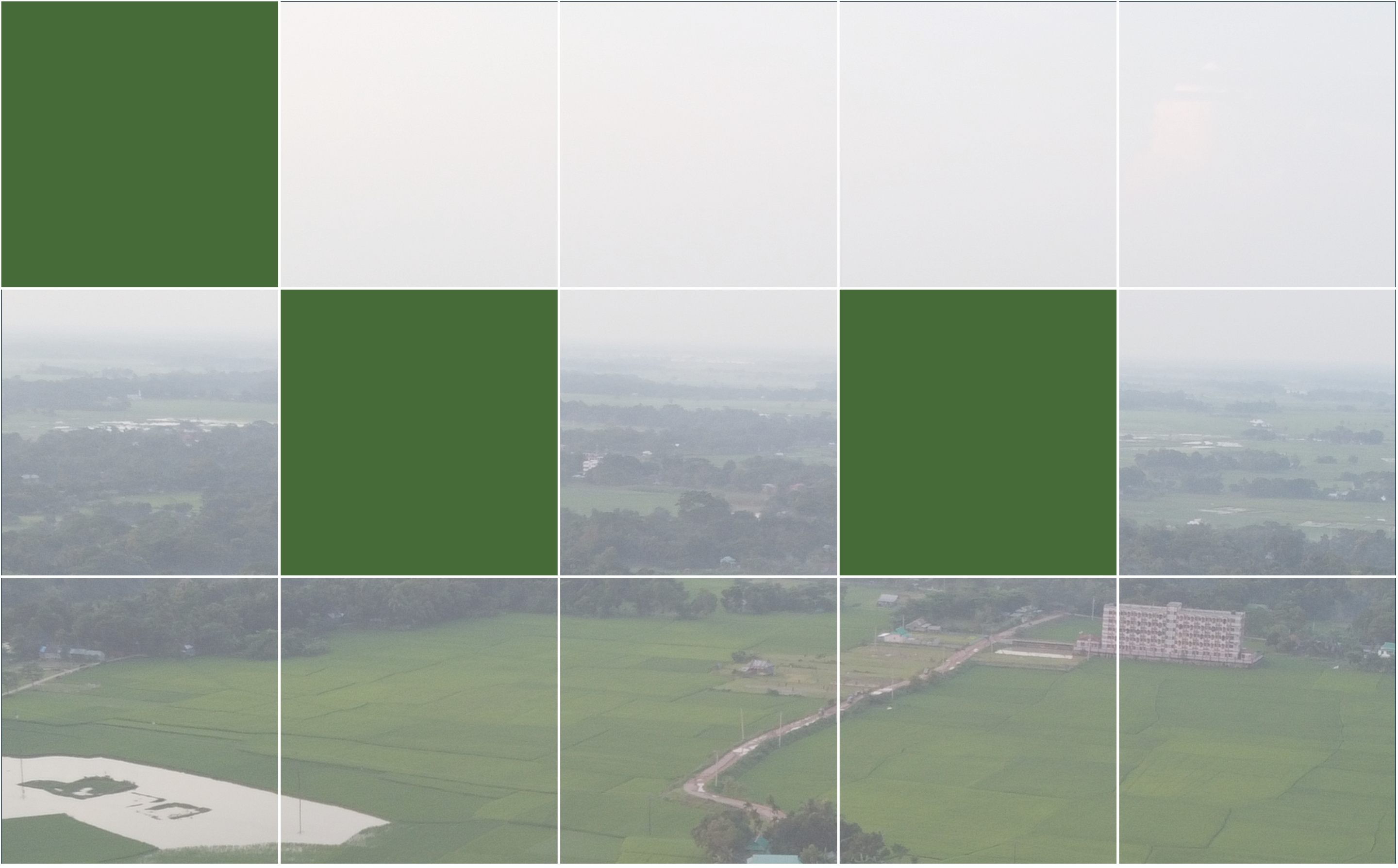
**Vetting of bridge and culvert design by BWDB in sensitive areas**. A special case where (inter-agency) coordination is required concerns the vetting of bridge and culvert design. The construction of bridges and culverts can interfere with the hydrology of the areas upstream and downstream. There are several critical interfaces. The first is the drainage congestion that occurs when bridges and culverts are under-dimensioned or where bridge sills and culverts are placed too high above the bed level of the river or khal. This will pond up the water and lead to drainage congestion, affecting the productivity of the land and leading also to unhealthy conditions related to the stagnant water. A special case is that of tidal rivers. When bridges across these tidal rivers are constructed too narrow, the sediment balance in these tidal rivers is affected, leading to a dramatic shifting of sediment loads in these rivers, affecting the normal drainage in large areas. The result can be devastating – with the productive use of large areas negatively affected. It is proposed that the design of bridges follow adjusted guidelines to avoid drainage congestion (bridge sills) or river sedimentation (narrow bridges) and that bridges and culverts are vetted by the engineering staff of the BWDB. A special water and sedimentation checklist may be developed for this purpose.

## 2.4 Aftercare and asset management

The management of the enormous portfolio of road assets by the LGED, in excess of 300,000 kilometre provides many benefits to optimize road development and water management. The following are the recommendations to improve aftercare and asset management and improve the functions of Green Roads for Water Management.

**Engage local community organizations in maintenance and avoiding disruption**. Roads and related drainage structures need very regular maintenance for their upkeep and also to ensure unhampered water flow. Currently, many pipes, culverts, and sluice openings are silted, damaged, or blocked .The high amount of sediments deposited through runoff is often related to the inconsiderate location of the road and drainage structures. Furthermore, local communities also obstruct the drainage structures for aquaculture or to create retention areas for irrigation. Thus, the khal's capacity to store water decreases due to siltation, leading to drainage congestion. The Bangladesh Water Act stipulates that no one can stop, obstruct, or divert water flow without permission. If this happens, the Executive Committee (EC) of WARPO may impose any restriction by issuing a protection order. It is recommended that local communities, especially where formalized in a WMO, are explicitly made responsible for these small but vital repairs.

**Consider engaging Labour Contracting Societies (LCS) on long-term basis in road maintenance**. Unlike in other countries, there is no permanent arrangement for local road maintenance. There is a long history of engaging LCS on relatively smaller, labour-intensive works, but this is almost always on one-time contracts. LCS should be engaged in this in multi-year contracts. Currently, earthen roads are mainly constructed/maintained by the PIO (project implementation office). Surveys are carried out to identify the road problems, which are repaired based on the available funds. However, more effort is needed at the local level for routine maintenance of roads and water structures. Routine maintenance should include the same tasks as the LCS have, i.e., ensure side slope, repair holes, drain water puddles, remove bushes and plants, remove vegetation that block the culverts or pipes, remove vegetation that damages roads, clean debris of outlet/inlet, turf on the side slope, and stockpile dry land on the side of the road for the monsoon.



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