INTERNATIONAL DEVELOPMENT IN FOCUS

Green Roads for Water

Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience

Frank van Steenbergen, Fatima Arroyo-Arroyo, Kulwinder Rao, Taye Alemayehu Hulluka, Kifle Woldearegay, and Anastasia Deligianni

WORLD BANK GROUP

INTERNATIONAL DEVELOPMENT IN FOCUS

Green Roads for Water

Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience

FRANK VAN STEENBERGEN, FATIMA ARROYO-ARROYO, KULWINDER RAO,
TAYE ALEMAYEHU HULLUKA, KIFLE WOLDEAREGAY, AND ANASTASIA DELIGIANNI

WORLD BANK GROUP

1818 H Street NW, Washington, DC 20433
Telephone: 202-473-1000; Internet: www.worldbank.org

1 2 3 4 24 23 22 21

ISBN: 978-1-4648-1677-2
DOI: 10.1596/978-1-4648-1677-2

Cover photo: © Patrick Brown/UNICEF/Panos. Used with permission; further permission required for reuse.
Location: Kola, Uvira, South Kivu, Democratic Republic of Congo. Frank (age 10) carries containers of water. Twice a day, he hauls 20 liters of water from a spring to his home. Frank is looked after by his sister and brother-in-law because his mother is severely ill in hospital. Three of Frank's seven siblings have died in the past eight months. His sister, Tantin Sifa, says two of the deaths were caused by "a mystery illness," while the third was a victim of diarrhea.
Cover design: Debra Naylor / Naylor Design Inc.

Contents

Boxes

Figures

Photos

Tables

Acknowledgments

This report was written by a team led by Kulwinder Rao (Lead Transport Specialist) and Fatima Arroyo-Arroyo (Senior Urban Transport Specialist), and comprising consultants from MetaMeta—Frank van Steenbergen, Taye Alemayehu Hulluka, Kifle Woldearegay, Anastasia Deligianni, and Marta Agujetas Perez—as well as Xavier Espinet Alegre (World Bank Transport Specialist) and Aminata Nguitone Dia (World Bank Consultant), under the overall guidance of Nicolas Peltier (Practice Manager) and Aurelio Menendez (Practice Manager) and overall leadership of Franz R. Drees-Gross, Director. The document benefited from useful comments and contributions from Kanta Rigaud (Lead Environment Specialist), Shomik Raj Mehndiratta (Practice Manager), Fiona Collin (Lead Transport Specialist), Chris Bennett (Lead Transport Specialist), Andrew Losos (Senior Transport Specialist), Kenichiro Tachi (Senior Environmental Engineer), Nicolas Desramaut (Senior Environmental Engineer), John Bryant Collier (Senior Environmental Specialist), Joop Stoutjesdijk (Lead Irrigation and Drainage Specialist), Kazi Fateha Ahmed (Environmental Specialist), Justin Runji (Senior Transport Specialist), Brendan Halleman (Vice President Europe and Central Asia of International Road Federation); Josep de Trincheria Gomez (Emergency WASH and Rainwater Harvesting Specialist), Eric Howard (Road Safety Consultant), Ian Greenwood (Road Engineering Consultant), and Damon C. Luciano (Consultant).

We would like to acknowledge th following people for their ideas, insights, contributions, and inspirations: Abraham Abhishek, Khalid A. M. Ahmed, Mohammed Al-Abyad, Khondaker Alinoor, Madiha Kamal Al-Junaid, Michael Anyala, Alemgena Araya, Janeiro Avelino, Alemayehu Ayele, Heinz Bender, Judith de Bruyne, Marlies Batterink, Jelle Beekma, Cecilia Borgia, Robert Bogere, Luwieke Bosma, Annabel Bradbury, Roelof Buffinga, Karen Campbell, Eugenio Cha-verde, Simon Chevalking, Joseph Chibwe, Rudolph Cleveringa, Petter Claesson, Flavia S. Cosoveanu, Fernando Dabo, Messay Daniel Tulu, Fabricio del Rio Valdivia, Jonathan Demenge, Lakew Desta, Ivan G. Ebong, Getachew Engdayehu, Letty Fajardo Vera, David R. Fay, Sean Furey, Timmo Gaasbeek, Diego Garcia-Landarte Puertas, Hilary Galiwango, Maheshwor Ghimire, Russell Gilbert, Jorge Giovanhica, Peter Gitonga, Dr. Berhane Grum, A. M. Aminul Haque, Ibnul Hasan, Nicholas Hawkins, David Hirsch, Jesper Hornberg, Imran Hossain Newton, Nagaraja Rao Harshadeep, Motaher Hossain, Sk. Nurul Islam, Jahidul Islam, Nancy Kadenyi, Bizuneh Kebede, Theophilus M. Kioko, Haftu Kiros, Lenneke Knoop, Julia Komagaeva, Matthijs Kool, Ashok Kumar, Raquel Lauge, James Leather, Cleophas N. Makau, Rowshan Mamtaz, Kebede Manjur, Eng. Benson Masila, Nathaniel Matthews, Abraham Mehari Haile, Derbachew Mezgeb, Bakhodir Mirzaev, Nicholas Mulenga, Charles Mutemo, Jackson W. Muthini, Charles M. Mutuku, Leonard Mutuku, Fred Mwango, Mauricio Navarro, Linda Navis, Erik Nissen-Petersen, Rubina Normahomed, MacPherson Nthara, Lewis W. Nzuki, Godfrey Obura, Elcidio Paruque, Sanmugam A. Prathapar, Frank Radstake, Sadmina Razzaque, Belmiro Rodolfo, Karin Roelofs, Marco Antonio Rodriguez, Deruo Roia, Mark Henry Rubarenzya, Abul Fazal M. Saleh, Sharafaddin A. A. Saleh, Francesco Sambalino, Sundie Silwimba, Irene Simoes, Anika Tahsin, Eulio Tebe, Simon Thuo, Stephen Twomlow, Aksakolov Ukumatsho, Gulkhumor Ukumatshoeva, Marco Vaz dos Anjos, Simone Verkaart, Rodrigo Villegas, Amdom Weldu, Daniel Wiegant, Geoffrey Wilson, Saroj Yakami, and Karma Yangzom.

The team is grateful to its partners who co-funded and supported this work: the Pilot Program for Climate Resilience (PPCR, https://www.climateinvestmentfunds.org), the Global Facility for Disaster Reduction and Recovery (GFDRR, http://www.gfdrr.org), and the Korea Green Growth Trust Fund (KGGTF, http://www.kgreengrowthpartnership.org).

About the Authors

Fatima Arroyo-Arroyo is a Senior Urban Transport Specialist in the Transport Global Practice at the World Bank, based in Dakar. She is also the acting Pillar Lead of Urban Mobility in the Sub-Saharan Africa Transport Policy Program. She supports governments in west and southern Africa to enhance urban mobility and accessibility. Arroyo-Arroyo is an enthusiast of integrating multidisciplinary dimensions in transport projects, such as fragility considerations, climate adaptation, and technology. She leads urban transport projects with a focus on vulnerable groups, nonmotorized transport, public transportation, and the formalization of informal transport operators, especially in fragile environments. Before joining the Africa Region, she supported the urban transport and urban railway agenda in Latin America and East Asia. She holds a master´s degree in civil engineering from École Nationale des Ponts et Chaussées and a master's degree in international business administration from La Universidad Internacional Menéndez Pelayo.

Anastasia Deligianni is an environmental engineer with a master's degree in international land and water management. She has worked in the field of climate resilience worldwide as a volunteer, intern, researcher, and program manager. Her main interest is contributing to the sustainable development and allocation of water resource use in a context of social, economic, and environmental objectives. She holds the position of Program Manager for the Green Roads for Water (GR4W) program at MetaMeta Research, where she coordinates the GR4W activities worldwide and maintains the GR4W Learning Alliance and the GR4W website (www.roadsforwater.org).

Taye Alemayehu Hulluka is Senior Water Resources Management Specialist at MetaMeta Research and Assistant Professor at the Ethiopian Institute of Water Resources, Addis Ababa University. Dr. Taye Hulluka has worked for different organizations in the fields of mineral resources development, water resources management, environment, and integrated land use plan development. He has also worked substantially on the development of institutional frameworks for water management, and he has served as a member of think-tank group for the development of mega-development projects in Ethiopia.

Kulwinder Rao is a Lead Transport Specialist and Global Lead for Fragile and Conflict-Affected Countries in the Transport Global Practice of the World Bank. He is a professional engineer with more than 34 years of experience in highway policy planning, engineering, and project management, including performance-based contracting (PBC) methodologies such as output- and performance-based road contracts and public-private partnerships. His experience includes designing and implementing road concession programs in the state of Punjab, India; leading several large design-and-build infrastructure projects in the Middle East; and development of World Bank-funded projects for PBCs in Bolivia, Botswana, China, India, Liberia, Mozambique, Sri Lanka, and Uganda. Before joining the Bank, he worked at the highest level in road administration in India and held senior management positions in the private sector. He holds a bachelor's of science degree (with honors) in civil engineering from Punjab University, India.

Frank van Steenbergen is the Director of MetaMeta (www.metameta.nl), a 35-person social enterprise dedicated to making a difference in land, water, infrastructure, and agriculture. Dr. van Steenbergen has worked in water resource management and policy change in more than 30 countries over the past 25 years—covering water resource management, groundwater development, agriculture, partnership building, transboundary water management, irrigation, and water harvesting from roads. The primary lesson from this extensive experience is that much more can be done by innovatively combining large investment, better resource management, better water use, and the creation of sustainable economic opportunities. He is Team Leader of the Green Roads for Water program that tries to connect road development with water resources management. His passion is the Honey Museum, a global collection of honey and the artifacts that beekeepers use, the divine combination of nature, well-being and human endeavor, and respect and skill.

Dr. Kifle Woldearegay Woldemariam is an Associate Professor at Mekelle University, Ethiopia, where he specializes in geoengineering. He has been involved in several projects, including the following: (1) site investigations for infrastructural development; (2) study, design, and construction of different water harvesting schemes—such as dams and diversion weirs—in Ethiopia and Rwanda; (3) assessment of the hydrological effects of natural resources management; (4) evaluation of the efficiency and sustainability of small-scale irrigation practices, including surface and groundwater; (5) water harvesting from roads and road catchments; (6) management of aquifer recharge for climate resilience; (7) Hazards and Disasters Management in Africa mainly related to landslides, megagullies, and flooding; and (8) sustainable mountain development for livelihood transformation. Together with MetaMeta, he was awarded the Global Roads Achievement Award in 2015 by the International Roads Federation for the Green Roads for Water Program, when it was rolled out in Tigray, Ethiopia. He has supported the program in several countries as co-team leader for the roads for water projects. His main interest is being in the field and focusing on implementation on the ground and evidence generation through documentation and monitoring.

Executive Summary

ROADS AND WATER: GREEN ROADS FOR WATER AND CLIMATE RESILIENCE

These guidelines discuss the use of roads for beneficial water management. Roads and water are generally seen as enemies, with water responsible for most of the damage to roads, and roads being a major cause of problems such as erosion, waterlogging, flooding, and dust storms. This tension, however, can be reversed. Green Roads for Water and Climate Resilience (also known as "Green Roads" or "roads for water") places roads in the service of water and landscape management and climate resilience without sacrificing or diminishing their transport functions. With global investment in roads of US$1–US$2 trillion per year, plus maintenance costs, widespread adoption of Green Roads approaches can leverage investment at a transformative scale, making road development and maintenance a vital tool for achieving climate resilience, water security, and productive use of natural resources.

The Green Roads approaches presented in these guidelines fall into *adaptive* and *proactive* categories. In the adaptive approach, roads are built in a conventional manner, but water management and landscape protection measures are systematically integrated into the roads construction and maintenance programs. The proactive approach goes further by designing road alignments and structures that serve the primary transport function and are optimized for water management objectives such as water harvesting, flood retention, sedimentation control, and erosion management.

Both the adaptive and proactive approaches yield triple benefits. First, they reduce water-related damage to the roads. Second, they minimize or even reverse adverse impacts of roads on the surrounding landscape, such as flooding, waterlogging, and land degradation. Third, they manage water beneficially, either for the benefit of roadside water users, or by improving the sustainability of water resources, by reducing disaster risks, or through some combination of benefits.

By engaging with roadside communities to understand how they can benefit from road development, Green Roads have an impact on the quality of life through labor-based approaches; using the road to harvest, store, or redirect water; reducing road externalities; or some combination of these benefits.

Green Roads are generally more cost-effective than traditional road resilience measures and produce significant co-benefits through improved management of water resources. In general, the adaptive approaches presented in these guidelines are less costly and have shorter payback periods (sometimes much less than a year), whereas the proactive measures are costlier and often have longer payback periods. Adaptive approaches implemented on a large scale in Ethiopia have been found to have low upfront costs and favorable cost-benefit ratios, paying for themselves fourfold in a single year. Similar cost-benefit ratios have been reported in Bangladesh and Kenya. Proactive approaches, although usually costlier, have the potential to reshape water resources and the landscape in much more profound ways. Additionally, some proactive designs have been found to cost less than conventional and adaptive designs.

The adaptive and proactive Green Roads approaches can be contrasted with the *protective resilience* (or *basic resilience*) approach prevalent in many road agencies today. The protective approach recognizes that climate events are becoming more extreme and prioritizes preservation of the road asset above all else. This approach often results in changes to road specifications and results in costlier designs. For example, protective approaches often call for higher-capacity cross drainage, changes to road materials, or both. Although these "road-hardening" approaches may enable the road to withstand the impact of severe climate events, they often result in more flooding and erosion and hinder beneficial management of water resources. When accounting for all of these impacts, protective or basic resilience often produces less sustainable overall outcomes than Green Roads approaches that manage road water for the benefit of water users and the environment while still preserving the transport function of the road.

The underlying premise of Green Roads is therefore quite simple: designing roads to fit their natural and anthropomorphic contexts, minimize externalities, and balance preservation of the road, water resources, landscape, and soil resources will usually cost less than traditional protective resilience approaches and produce more sustainable overall outcomes.

THE ECONOMIC CASE FOR GREEN ROADS FOR WATER

Green Roads can better manage climate risks to road infrastructure and simultaneously enable sustainable management of water and more productive use of land. Although the costs and benefits vary, Green Roads approaches generally add relatively little to the costs of road programs, can cost less than basic resilience, and can produce benefits far in excess of these additional costs.

Some examples of the economic benefits of the roads-for-water approach can be found in research developed in Ethiopia, Kenya, and Bangladesh:

- The notably large-scale roads for water program implemented under the mass mobilization watershed campaign in Ethiopia is estimated to have produced benefits of US$18,879 per kilometer compared with costs of approximately US$1,800 per kilometer. Including the cost of organizing and developing the program would still only raise the costs to US$3,600 per kilometer. Even then, the roads-for-water approach achieved a fourfold return on investment in the first year. It comes as no surprise that the program has spread quickly through the different regions of Ethiopia.

- Research in Kitui, Kenya, found that an investment of US$400 per kilometer in integrated road-water infrastructure increased farmers' incomes by an average of US$1,000 after one cropping season, a net benefit of 150 percent.
- Green Roads approaches can also produce substantial benefits in wet climates. For instance, hydrological modeling of Polder 26 in coastal Bangladesh shows that improved drainage could potentially produce up to US$3.1 million in net benefits through increased agricultural activity. Green Roads would reduce the depth and duration of waterlogging by 10 days in low-lying areas.

GREEN ROADS APPLIES TO DIVERSE LANDSCAPES AND CLIMATES

These guidelines provide Green Roads strategies for diverse landscapes and climates, including watershed areas, semiarid climates, coastal lowlands, mountainous areas, and floodplains (figure ES.1). For instance, by acting as barriers and drains for rain runoff, roads have a major impact on surface hydrology in semiarid climates. In these contexts, Green Roads can support numerous forms of large-scale water retention and can be a vital means for improving water resource management. Techniques for systematically harvesting water in semiarid areas include floodwater spreaders, flow dividers at culverts, road drifts, or the use of road embankments as storage reservoirs. Green Roads can also foster sustainable water resource management by diverting water to storage systems such as infiltration trenches or farm ponds, and by diverting water to where it is most useful. In pastoral areas, Green Roads can be used to guide water to areas where grass is seeded or natural vegetation regenerated.

Green Roads can also improve watershed management. The choice of road alignment and road slope will influence drainage patterns in the catchment and can be used to increase water storage. The design and placement of culverts and water crossings affects runoff velocity and can be used to minimize erosion and guide water to productive land. Warping dams, road platforms, modified culverts, and various water-harvesting structures are all useful for these contexts.

In coastal lowlands, the Green Roads approach enhances disaster mitigation and flood management. In these regions, roads double as flood protection infrastructure, and flood embankments can also be designed to be used as roads. Cooperation among the responsible organizations in transport, water management, and disaster risk reduction is vital to the optimization of these diverse functions through adoption of joint specifications and development of better-integrated concepts. As the main infrastructure in low-lying areas, roads can also be used to control water levels for productive uses and minimize unintended waterlogging. The guidelines discuss several techniques for optimizing the flood resilience co-benefits of Green Roads, including building higher roads or road levees, ensuring access to flood shelters in flood-prone areas, using excavation material to make nearby roads, making roads submersible in selected areas, evacuation planning, and reinforcement of road embankments.

In mountainous areas, Green Roads approaches pay special attention to protecting and managing the road environment through careful selection of the road alignment and through complementary land and water management measures. Where feasible, road construction in mountainous areas should use mass balance methods whereby material excavated for road construction is reused onsite because this approach mitigates the impacts of construction on the mountain landscape. Special care is also required to create road-water crossings that guide water without damaging the road or adjacent land, which can often provide a further use of the spoil. Development of roads in mountainous areas often opens new springs and seeps. These guidelines also discuss how these water resources can be deliberately managed to provide important new sources of domestic and productive water in a manner that systematically protects springs.

These guidelines present a range of low-cost approaches specifically applicable to unpaved rural roads. Unpaved rural roads constitute more than half of the road network in most countries and are vulnerable to water damage, and therefore deserve special attention. Because unpaved rural roads serve the most remote settlements, are the most vulnerable to damage caused by water, are the least funded, and are the least likely to be repaired, their preservation is vital to the well-being of rural communities. Application of Green Roads approaches to unpaved rural networks can therefore contribute greatly to the overall resilience of the network while also supporting economic development of local communities. These guidelines present a range of techniques that can both protect unpaved roads and make them function as instruments for water management, including water bars, rolling dips, improved side drainage, and infiltration bunds.

Special attention is also needed to systematically incorporate roadside tree planting into road development.[1] Roadside tree planting can mitigate the health hazards posed by dust from unpaved roads and, in addition, has other benefits such as creating productive assets, reducing crop damage, reducing soil erosion, improving visibility, acting as a wind break, providing shade, and sequestrating carbon. Roadside tree planting plans should consider ownership of the road reserve, potential future road widening, the economic value of the tree species, the shape of the tree barrier, root development, road sightlines and road safety, and access to water.

MULTISECTORAL APPROACHES AND CITIZEN ENGAGEMENT ARE VITAL TO GREEN ROADS IMPLEMENTATION

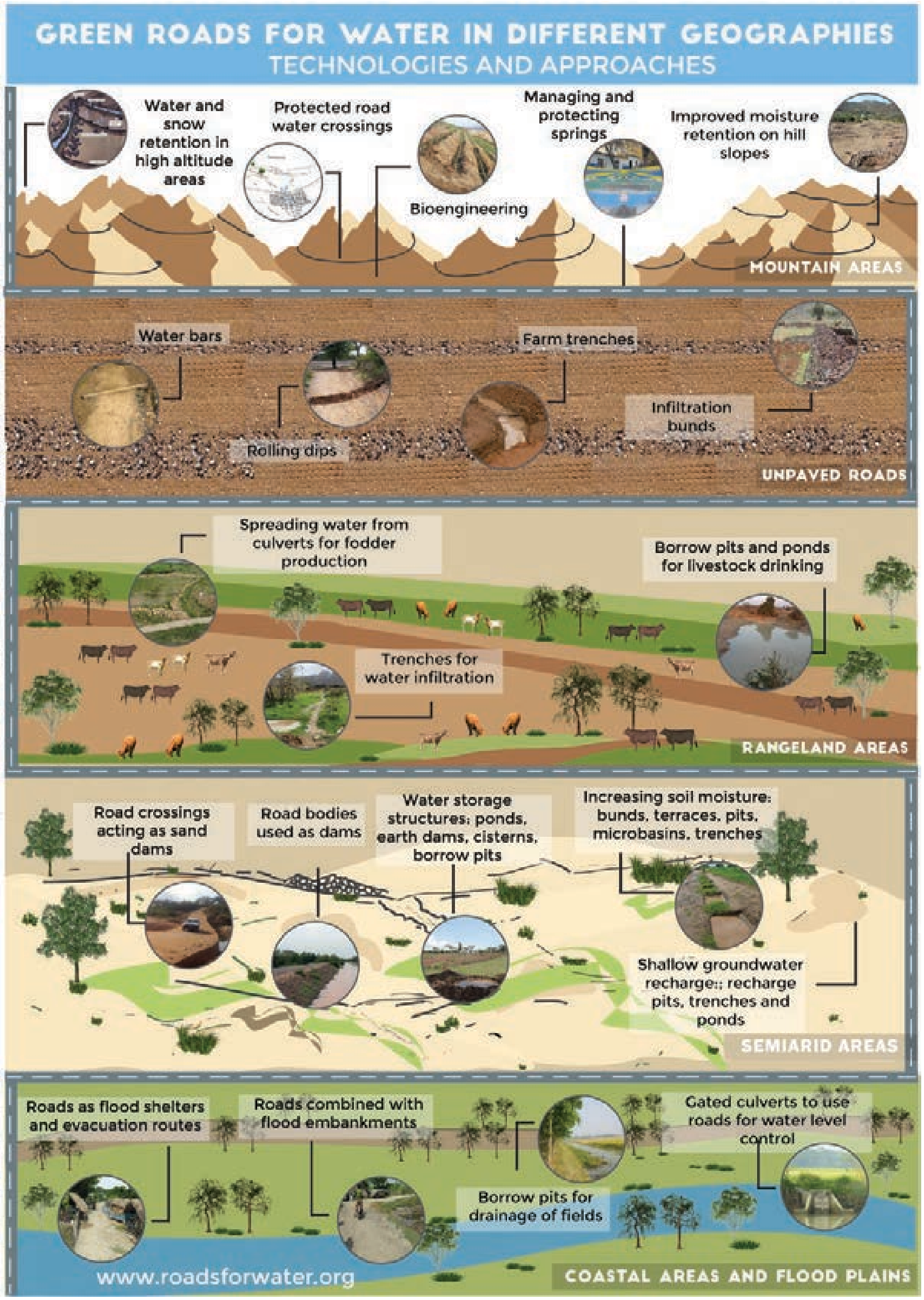
Because Green Roads approaches are cross-sectoral, implementation of Green Roads programs generally requires changes in road sector governance to encourage openness to cooperation and recognition of a multidimensional approach to sustainability, and to promote trust and transparency among a larger group of collaborating stakeholders. Experience in the ongoing Green Roads programs has shown that establishing a cross-sectoral approach is not difficult because there are gains for all parties.

Getting the process started may entail several steps, including fact finding, encouraging diverse agencies to talk, identifying champions, focusing on early implementation, working on different fronts, capacity building, and research into and consolidation of experiences from various working methods.

Adopting adaptive resilience approaches that include modifying road infrastructure with additional, usually low-cost, water-control measures generally requires investment in complementary programs. For instance, training for roadside users and farmers may be vital to maximize benefits. Special green funding arrangements may be required for these supplementary programs. Additionally, because road agencies would generally not be best positioned to

FIGURE ES.1

Green Roads for Water in different geographies: Technologies and approaches



Source: MetaMeta (www.roadsforwater.com).

undertake farmer training, memoranda of understanding are useful to facilitate collaboration between the main sector agencies involved in implementation.

Likewise, proactive resilience approaches pose new challenges that are best met through interagency and cross-sector collaboration. Scaled-up collaboration is critical to developing road infrastructure alignments, concepts, and designs that serve multiple objectives beyond the transport function. Traditional approaches to economy and efficiency may need to be reconsidered in favor of multifunctional investments that can tackle a broader range of challenges more efficiently. This broader approach involves new, integrated designs; training for engineers; modeling for specific challenges; and special green funding arrangements for additional costs. Often, relatively little additional engineering is required, and costs can be shared among cooperating agencies.

Finally, community engagement is at the heart of Green Roads for Water and Climate Resilience. Although communities should be engaged at the earliest stages of any road development program, community engagement plays a stronger role in Green Roads programs that support water resource management and community development. Community engagement for Green Roads helps reveal how the road affects the landscape and environmental quality for the community and how the road can support community goals such as livelihoods. In addition to benefits for the physical environment, a road program can be a major injection into the local economy. Roads improve access to services and economic opportunities, road works offer direct labor and skills development opportunities, and complementary programs can promote sustainable water management and livelihoods. Systematically engaging communities within the reach of the road is vital for optimizing these opportunities and leveraging the benefits of Green Roads at scale. The opportunities for community engagement exist at every step of road development, including conceptualization and planning, design, construction, and maintenance and aftercare. When engaged and supported, communities can be major forces for implementation of Green Roads programs at scale—in the construction of rural roads, in their systematic maintenance, and in undertaking complementary measures.

NOTE

1. Running off the road and colliding with fixed objects, especially tree trunks, is, internationally, one of the most frequent crash types with fatal outcomes. Roadside tree planting may be a critical road safety issue, and much care and knowledge are required to ensure tree plantings do not increase the risk of death and serious injury for vehicle occupants. These guidelines provide some guidance for minimizing these outcomes.

Abbreviations

ANE	National Roads Administration in Mozambique (Administração Nacional de Estradas)
ASA	Articulação Semiárido Brasileiro
DR	design rainfall
GLADIS	Global Land Degradation Information System
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
LCS	labor contracting societies
MoU	memorandum of understanding
PAHs	polycyclic aromatic hydrocarbons
Pb	lead
PRA	Participatory Rural Appraisal
RMGs	road maintenance groups

Setting the Stage for Roads for Water

Introduction

Water is the single largest factor in road damage; as a consequence, it is generally considered the prime enemy of road infrastructure. Water is responsible for 80 percent of damage to unpaved roads (Chinowsky and Arndt 2012) and 30 percent of damage to paved roads. Water management is a critical area of study in the development of roads, and the focus is on managing water to minimize the damage to road infrastructure. Therefore, the impact of roads on their surrounding landscape and surface hydrology is often considered secondary. This lopsided focus translates into significant direct impacts on natural hydrology and landscapes and into missed opportunities to harvest water for communities along the road.

Conventional road design often blocks and changes runoff, interferes with subsurface flows, and changes water patterns. Roads cause erosion, local flooding, and sedimentation. Failure to anticipate how roads will affect natural water flows results in road bodies that act as dams and become primary causes of drainage congestion and waterlogging, disturb wetland hydrology, and prevent fish movement. For instance, transect surveys undertaken along roads in upland Ethiopia and Uganda show that there may be 8–25 flash points—such as local erosion, flooding, sedimentation, or waterlogging—for every 10 kilometers of road.

Ibisch et al. (2016) estimate that, at present, 20 percent of the global land surface is within one kilometer of a road, which is where most people live and where economic activities are concentrated. Given the vast coverage of the road network and its proximity to the human population, ensuring that roads contribute to water management may have the potential to improve water security globally. An estimated one in four people currently depends on groundwater as the primary water source. Yet too few regions maximize the potential for roads to play a positive role in management of water resources, for instance, by directing road water to recharge groundwater or through short-term water storage in roadside ponds. Many examples emerge from a variety of countries; for example, research in Tigray, Ethiopia, finds that road runoff affected 70 percent of roadside farmers, but only 20 percent were making productive use of that runoff (Teweldebrihan 2014). Furthermore, even though roads can play many positive roles managing water in low-lying coastal areas, data from two coastal polders in

Bangladesh show that 60 percent of farmers are affected by impeded drainage caused by roads.

Climate change will compound these challenges. Climate change is likely to exacerbate the frequency and intensity of meteorological phenomena, making it crucial to design roads that are climate resilient and do not hamper, but instead contribute to, water resource management. More frequent and extreme weather events pose new risks to roads, landscapes, and water resources. Uncertainty about the future climate and the high cost of standard approaches to climate resilience make planning for climate resilience far more challenging for road agencies. At the same time, more frequent and extreme droughts are increasing reliance on aquifers, which are becoming depleted in many water-scarce regions.

In this context, the roads-for-water guidelines advocate for a change in the paradigm in the way roads projects are planned and implemented. The guidelines advocate for a more integrated design process with local communities and social, environmental, water, and agriculture sectors to turn around the negative impacts of roads on the surrounding landscape, and simultaneously maximize the beneficial use of roads for water management and climate resilience that can work to the advantage of local communities along the roads.

These guidelines are drawn from field experience and work in professional communities in road development, water management, climate resilience, disaster risk reduction, and environmental, social, and agricultural development. They combine experiences from Bangladesh, Bolivia, China, Ethiopia, Kenya, Liberia, Mozambique, Nepal, Portugal, Sudan, Tajikistan, Uganda, the Republic of Yemen, and Zambia. All these countries have taken initial steps to promote beneficial road-water management.

Specific attention is given to road safety issues, which have traditionally not been understood or have not been responded to for low-volume road construction in all countries, but particularly in low- and middle-income countries. The emergence of Safe System thinking internationally is changing awareness and building recognition of the need for actions to minimize the presence of low-likelihood but high-outcome collision risk conditions given that such conditions lead to substantial numbers of fatalities and serious injuries at the network level.

The audience for these guidelines is diverse. The report targets experts in multiple disciplines who work in the planning and implementation of road projects or who assess the impact of and mitigation measures for road projects, such as civil engineers, planners, and environmental and social specialists. This document is also intended for other communities of practice, such as those who work in flood prevention, landscape restoration, agricultural development, climate resilience, disaster risk reduction, and the environment in general. Another key audience comprises community representatives and nongovernmental organizations in rural areas.

These guidelines are organized into four sections:

- The first section begins with an introductory overview of the general approach of roads for water in chapter 1.
- The second section describes the uses and geographies for roads for water. It starts with a discussion of the key concepts in watershed management (chapter 2), and a discussion of how roads can be used to develop safe domestic water resources in rural areas (chapter 3). Chapters 4 through 6 provide details on various geographies: water-short semiarid areas (chapter 4), low-lying flood-prone areas (chapter 5), and middle- and

high-altitude zones (chapter 6). Each area has its own opportunities, sets of appropriate measures, and dos and don'ts.

- The third section (chapters 7 through 13) concentrates on some of the most important techniques and provides practical details on how to implement them. The following interventions are discussed: the conversion of borrow pits for use as water storage, the use of road drifts, the development of local

TABLE I.1 Geographies, challenges, and techniques

GEOGRAPHY OR TOPIC	PRIME CHALLENGES	TECHNIQUES
Watersheds and catchments (chapter 2)	Water harvesting Erosion control Flood control	Choice of road alignment Culvert placement and design (chapter 2) Road drainage Water-harvesting and erosion-control structures (chapters 8 through 11) Road drift and platforms (chapter 9) Warping dams
Rural water supply (chapter 3)	Source augmentation Water quality	Grass strips and ecological water control Recharge from roads (chapter 2) Surface water storage (chapters 8 and 11) Spring management (chapter 3)
Semiarid areas (chapter 4)	Water harvesting Water retention Erosion control	Floodwater spreaders Flood diversion from culverts Infiltration trenches and other recharge techniques Surface storage including borrow pits and farm ponds Raised road embankments for water retention Road drifts and sand dams (chapter 9)
Coastal areas and floodplains (chapter 5)	Water table control Drainage Water storage Flood protection Flood relief	Road alignment and heights Cross drainage and gated culverts Borrow pits (chapter 8) Fish passages Levees and flood shelters Evacuation routes Low-embankment roads (chapter 11) Submerged roads (chapter 7) Bioengineering and turfing
High- and medium-altitude areas (chapter 6)	Stabilization of mountain areas Spring and stream management	Road alignment and slope Green construction methods Bioengineering Road-water crossings Spring management Land protection measures including drifts (chapter 9) and regreening (chapter 12)
Complementary measures to protect roads from water (chapter 13)	Preventing road structures from being compromised by the proximity to water induced by the application of Green Roads for Water techniques	Impact of water Mitigation measures Roads as dams Recommended practices

water storage, harvesting water from road drainage, and promoting groundwater recharge with unpaved roads and roadside tree planting. Table I.1 presents a summary of the prime challenges, the appropriate techniques for the different geographies, and the corresponding chapters. Chapter 13 provides additional information on how to protect roads from water.

- The fourth section (chapters 14 through 16) discusses how to make Green Roads for Water and Climate Resilience work. Chapter 14 describes the governance arrangements that are conducive to integrating road development, climate resilience, and water management. Chapter 15 describes how to engage roadside communities in the development of effective roads-for-water programs that support community needs and promote livelihood opportunities. Finally, chapter 16 recaps the guidelines with a summary of some of the costs and benefits of roads for water, describes the roads-for-water program in Ethiopia, and provides a preview of other roads-for-water programs.

REFERENCES

Chinowsky, P., and C. Arndt. 2012. "Climate Change and Roads: A Dynamic Stressor–Response Model." *Review of Development Economics 16* (3): 448–62.

Ibisch, P. L., M. T. Hoffmann, S. Kreft, G. Pe'er, V. Kati, L. Biber-Freudenberger, D. A. DellaSala, M. M. Vale, P. R. Hobson, and N. Selva. 2016. "A Global Map of Roadless Areas and Their Conservation Status." *Science* 354 (6318): 1423–27.

Teweldebrihan, M. D. 2014. "Optimizing Intensified Runoff from Roads for Supplemental Irrigation: Tigray Region, Ethiopia." Doctoral dissertation, UNESCO–IHE Delft Institute for Water Education, Delft, the Netherlands.

1 Understanding the Concept and the Potential of Roads for Water

CHANGING THE PARADIGM: CONCEPT AND PRINCIPLES OF ROADS FOR WATER

These guidelines introduce the concept of Green Roads for Water and Climate Resilience (also called “Green Roads” or “roads for water”). This concept seeks to expand the traditional relationship between roads and water toward a more multisectoral approach aimed at mitigating roads’ impact on the environment and benefiting local communities through better water management.

The core idea of roads for water is therefore that the negative impacts of roads on the surrounding landscape can be inverted, and roads can simultaneously become instruments of beneficial water management and climate resilience. Roads and water are generally seen as enemies, with water responsible for most of the damage to roads, and roads being a major cause of problems such as erosion, waterlogging, flooding, and dust storms. This tension, however, can be reversed. Green Roads for Water and Climate Resilience places roads in the service of water, landscape management, and climate resilience without sacrificing or diminishing their transport functions.

The integrated approach to road and water management proposed in these guidelines aims to deliver triple benefits: to reduce road damage, to reduce land degradation, and to improve the beneficial use of water to enhance community resilience. Precisely because of the close connection between roads, surface hydrology, and subsurface hydrology, adopting the right practices can simultaneously reduce the damage water poses to roads and reduce or even reverse the harms roads pose to water resources, soils, and landscapes. This often means fitting the roads within their natural and anthropomorphic contexts in ways that complement surrounding natural hydrology, ecosystems, landscapes, human settlements, and economic activities. Implementation of the Green Roads for Water concept is anchored in the key principles outlined in box 1.1.

Although water management is already a vital aspect of roads, the traditional approach has mainly focused on the resilience of the road infrastructure, with limited focus on the resilience of the landscape and opportunities to enhance resilience for communities through access to water. A strong case can be made for developing roads to be an integral part of the watersheds and

BOX 1.1

Principles of roads for water

Implementation of the Green Roads for Water concept is anchored in key principles:

- *Communities' and users' needs should be a central concern in road planning, design, and implementation.* This principle requires road agencies and others to collaborate with roadside users to understand their needs during the planning, design, and implementation stages of roads-for-water projects. These discussions must take into consideration all possible alternative water-harvesting mechanisms and the purposes to which the harvested water will be placed. Gender is an important consideration in this process: in Ethiopia it was found that women in poor female-headed households are less equipped to prepare their land for road-water harvesting, for instance, because they lack access to animal traction (Demenge et al. 2015).
- *Implementing Green Roads programs requires collaboration among larger and more diverse groups of government institutions.* Changes in road governance that encourage openness to cooperation, multidimensional sustainability, trust, and transparency are vital to undertaking a more open and multidisciplinary approach to road development. Collaboration between road agencies and agencies responsible for agriculture, disaster management, natural resources, or other domains is crucial to leveraging the full benefits of Green Roads. The task of developing road infrastructure alignments, concepts, and designs that serve multiple objectives beyond transport requires new approaches. A new approach that involves interagency collaboration can ensure multifunctional investment formulation to tackle challenges more effectively. This collaborative approach requires integrated plans and designs, capacity building, and special green funding arrangements for additional costs. For instance, agricultural agencies or local authorities may need to play a role in establishing agreements to ensure facilities that harvest and store water are maintained by the roadside users. In low-lying areas, road agencies may need to collaborate closely with those responsible for management of disaster risks and with agricultural agencies to maximize the potential for roads to serve flood control, agricultural, irrigation, and transport functions.
- *Implementing roads-for-water solutions is not necessarily complicated and often requires only basic techniques and manual labor methods.* Controlling the speed of runoff, selectively channelizing or dispersing water, and preserving existing watercourses can be achieved through simple, low-cost solutions, implemented by local low-skill workers, and can create employment or microenterprise opportunities. From an engineering point of view, roads-for-water solutions are no more complex than traditional approaches, but they may require greater collaboration between different stakeholders.
- *Roads-for-water solutions should fit the the landscape and human settlements.* Different livelihood systems have different water-harvesting demands, and different landscapes interact differently with roads. For instance, in many semiarid areas smallholder and household-scale irrigation supplements rainfed systems. If rainfall is sparse or not timely enough, water harvesting from roads could help during periods of scarcity, or water can be added to the buffer capacity. Shallow groundwater extraction and small storage structures could serve this purpose. Finally, commercial farming, which usually comes with the expense of high water demands, can be served by medium- to large-scale surface storage such as borrow pits, earth dams, and ponds.

landscapes in which they are situated. Such an approach can preserve road infrastructure and reduce the maintenance burden, contributing to infrastructure productivity; reduce roads' impacts on the environment; and even enable roads to serve as instruments for beneficial water management and sustainability.

Ideally, all such measures and opportunities should be part of the environmental and social management plans of road investments, not only to address risks but also to make use of opportunities. Green Roads programs can go much farther than addressing localized risks and opportunities, however. Green Roads programs are being implemented as large-scale, cross-sectoral climate adaptation and resilience programs affecting agriculture, water and sanitation, water resource management, and landscape management. These Green Roads programs can restore aquifers and landscapes, manage water supplies to create and enhance livelihoods, and integrate roads with the landscape in ways that improve the climate resilience of infrastructure and maintain beneficial natural systems. Such programs create benefits that accumulate over time, paying long-term dividends to rural economies. The most ambitious among them will open up new economic opportunities and improve prospects for future generations.

The Green Roads for Water concept is applicable to different geographies and climates.

- In *mountainous terrains* Green Roads projects design road alignment and cross drainage to divert water to recharge aquifers in semiarid climates, provide low-cost and effective slope stabilization, and support preservation of ecosystems and national parks.
- In *arid and semiarid areas* roads can be used to harvest water (van Steenbergen et al. 2018) to serve the communities around the road. The water intercepted by road bodies can be guided to recharge areas or surface storage or can be applied directly to the land. With the enormous lengths of roads being built, roads present the main opportunity for water harvesting and water buffer management in many semiarid areas (Salman et al. 2016).
- In *pastoral areas* roads can contribute to management and productivity in several ways. The concentrated runoff from roads can support plantings of native grass species. Similarly, in very dry areas, road runoff can be used to rekindle the roots of useful tree species under farmer-managed natural revegetation programs. Under such programs, dormant tree shoots that come up after a sporadic watering event are systematically pruned, and local tree stands can be maintained in otherwise harsh environments.
- In *wet lowlands* Green Roads for Water can help manage flooding and boost agricultural productivity. Roads in floodplains and coastal areas can play important roles in flood protection and agriculture given that they often double as embankments and provide evacuation routes and flood shelters. Roads and bridges also affect the shallow groundwater tables in low-lying areas and floodplains and can have enormous consequences for land productivity. The way in which a road is built, such as the height of bridge sills and culverts, will have considerable influence on the quality of the wetlands on either side of the road.
- In *desert areas* Green Roads can be used to control sand dune movement or at least not aggravate it. Avoiding aligning the road with the prevailing wind direction limits the wind-tunnel effect that triggers sand motion. Roadside vegetation can also help stabilize newly opened areas.
- Roads may also contribute to protection of *wildlife areas*. Wildlife movement is very much guided by the availability of water. The collection of runoff in designated storage within wildlife parks can support wildlife management and regreening of designated areas of the parks. Water runoff can also be directed to create buffers to curtail encroachment by livestock keepers or farmers.

- In *water catchments* roads can manage water by controlling the speed of runoff, compartmentalizing and mitigating flood runoff (rather than concentrating runoff into fewer tributaries), and influencing the sedimentation process in the catchment. The choice of where to place a road within a catchment and which additional water-management measures to include has a major impact on how the catchment is managed.

THE THREE LEVELS OF PROMOTING RESILIENCE: PROTECTIVE, ADAPTIVE, AND PROACTIVE

Considerable debate is ongoing on the effect of climate change on road infrastructure. The conversation centers on how to manage more intensive runoff, more frequent flood peaks, and rising temperatures. Ebinger and Vandijcke (2015) state that the loss caused by disrupted transport infrastructure can be enormous, and sheltering roads from climate impacts is extremely important to economies. The concern for resilient roads often translates into a *protective resilience* or *basic resilience* approach under which road infrastructure is safeguarded from inclement weather events at any cost (Cervigni et al. 2016; Farrag-Thibault 2014; Douglas et al. 2017; NDF 2014; Transportation Research Board and National Research Council 2008). Under a protective approach to resilience, road infrastructure specifications are adjusted to account for specific climate risks such as temperature rise, higher flood peaks, loss of permafrost, more extreme freeze and thaw cycles, or extreme cold. This approach treats stresses as exogenous and follows traditional methods for engineering roads to withstand environmental stresses.

The first downside of the protective resilience approach is that it often improves the resilience of the road at the expense of the resilience of the natural or human-made environment. For example, protective resilience often calls for protecting the road from higher flood peaks with better cross drainage. Although protecting the road is essential to keeping the economy running, larger cross drainage immediately passes the impact of extreme weather events onto the surrounding area, causing more severe floods, more inundation, and heavier erosion. Because roads often divert water from natural drainage paths and concentrate it, the volume of water passing through the enlarged drain may be far greater than natural flows. Although the road is protected, the landscape around it often suffers even more from the effects of climate change. These impacts may also harm the built environment, such as farmers' fields or downstream settlements.

The second downside is that this protective approach does not use the road's potential to improve water management and the climate resilience of the surrounding area. Not only can improved water management protect the landscape, it may also support nearby communities' livelihoods, access to potable water and sanitation, and water security.

This guideline advocates alternatives to the protective approach that could be called *resilience plus*. The "plus" involves integrating water management into road development and design. This approach adapts or designs roads to fit within the landscape in various ways that allow them to support improved management of water and the local environment, including managing water for the benefit of nearby communities. In most cases, the roads-for-water approach (the resilience plus approach) will reduce road damage from water just as well as the protective approach and will also reduce maintenance—and sometimes even construction—costs (see the section titled "The Benefits and Costs of Roads for Water").

The resilience plus approach is a preferable option compared with the protective or basic approach to climate resilience. By building roads that can serve several purposes beyond transport, and by making these functions part of the design and development of roads, roads can be created that (a) reduce the often substantial collateral damage caused by uncontrolled road water on the landscape around them; (b) are likely to have lower maintenance costs, will often suffer less downtime, and are generally better able to withstand weather effects, including those caused by climate change; and (c) generate substantial benefits through water management, including by harvesting water for beneficial uses. In other words, rather than being a source of landscape degradation, roads can become instruments for climate change resilience.

There are two levels to this resilience plus approach. The first level is *adaptive resilience*. Adaptive resilience makes use of the road infrastructure as it is but adds measures to improve water management. The second level is *proactive resilience*. Proactive resilience goes back to the drawing board and reconsiders all aspects of the road, including the road alignment. The proactive approach calls for designing roads that optimally contribute, within economic parameters, to better land and water management, in addition to allowing for better communication and coordination among stakeholders involved in road design.

These different approaches—*protective resilience*, *adaptive*, and *proactive*—are sometimes complementary. While the first goal of roads for water is to avoid developing roads that introduce new problems (notably through the proactive approach), measures aimed at protective or basic road resilience can be incorporated in and complemented by approaches at the adaptive and proactive levels. Table 1.1 describes the measures applied under these three increasing levels of road resilience for different geographies. Table 1.2 describes how the three levels affect different elements of roads.

THE BENEFITS AND COSTS OF ROADS FOR WATER

With global investment in roads of US$1 trillion to US$2 trillion per year, of which 40 percent is in developing countries, widespread adoption of Green Roads approaches can leverage investment at a transformative scale, making road development and maintenance a vital tool for achieving climate resilience, water security, and productive use of natural resources. Dulac (2013) estimates that 25 million kilometers of paved road-lanes and 335,000 kilometers of rail-track will be added from 2010 to 2050, a 60 percent increase. The estimated cost of this new infrastructure in roads and railroads over four decades is US$45 trillion. Unpaved road networks, which make up the majority of roads in most countries, will also continue to expand, adding to this total. Future growth and upgrading of road networks present considerable opportunities to build in infrastructure productivity from the very beginning.

The economic case for roads for water is based on three key observations from implementation in the field:

- The Green Roads approach provides triple benefits: reduced road maintenance costs, reduced landscape degradation, and improved access to water for productive and consumption uses. Roads for water can not only preserve

TABLE 1.1 Three levels of road resilience in different geographies

	BASIC RESILIENCE: PROTECTIVE KEY OBJECTIVE: PROTECTING ROAD INFRASTRUCTURE	RESILIENCE PLUS 1: ADAPTIVE KEY OBJECTIVE: MAKING THE BEST USE OF, AND ADAPTING TO, HYDROLOGICAL CHANGES INTRODUCED BY THE ROAD	RESILIENCE PLUS 2: PROACTIVE KEY OBJECTIVE: REDESIGNING ROAD INFRASTRUCTURE TO OPTIMIZE THE AREA'S WATER MANAGEMENT AND CLIMATE RESILIENCE, OFTEN TO BENEFIT LIVELIHOODS
Core concepts of Green Roads for Water			
Watersheds and catchments	Protect catchment to protect road infrastructure	Protect catchment to protect road infrastructure; revise drainage location to reserve natural hydrology	Plan road alignment and drainage structures in support of catchment management by preserving natural hydrology and potentially enabling floodwater retention
Domestic water collection and use	Road provides no domestic water benefits	Adapt existing roads to enable safe collection and storage of domestic water resources	Design new roads to maximize collection of safe domestic water and other co-benefits
Application to different geographies			
Semiarid areas	Catchment measures reduce water damage to roads	Use runoff guided from roads for recharge and storage; upper catchment protection	Design roads and cross-drainage facilities to collect runoff and guide to recharge area
Watersheds and catchments	Protect catchment to protect road infrastructure	Protect catchment to protect road infrastructure	Plan road alignment and drainage structures in support of catchment management
Coastal areas and floodplains	Increase height of flood embankments to deal with higher floods	Use gated structures on village roads to manage water levels	Consider low embankment roads with controlled floodways; develop road levees in flood-prone areas In cases of extraordinarily high risks of erosion and flooding, especially in coastal lowlands, consider managed retreat, relocation, realignment (purposeful, coordinated movement of people, buildings, and infrastructure away from risks) to address existing and future risks
High- and medium-altitude areas	Have safe road-water crossing and protection measures; have adequate road drainage Consider shifting road alignment to higher areas; train mountain rivers to reduce exposure of roads to mountain floods	Use water-retention and land-management measures suitable to mountain areas to stabilize mountain catchment and retain moisture and snowmelt; systematically manage springs and seeps	Use cut-and-fill instead of cut-and-throw methods; observe maximum slope and gentle alignments; combine roads with additional water storage and drift for torrent stabilization
Desert areas	Not applicable	Use road runoff for revegetation and dune stabilization Develop small roadside oases by taking road runoff to depression areas	Limit impact on sand dune formation by ensuring road is not aligned with prevailing wind

Source: MetaMeta, (www.roadsforwater.org).

TABLE 1.2 Three levels of road resilience for different road elements

	BASIC RESILIENCE: PROTECTIVE KEY OBJECTIVE: PROTECTING ROAD INFRASTRUCTURE	RESILIENCE PLUS 1: ADAPTIVE KEY OBJECTIVE: MAKING THE BEST USE OF, AND ADAPTING TO, HYDROLOGICAL CHANGES INTRODUCED BY THE ROAD	RESILIENCE PLUS 2: PROACTIVE KEY OBJECTIVE: REDESIGNING ROAD INFRASTRUCTURE TO OPTIMIZE THE AREA'S WATER MANAGEMENT AND CLIMATE RESILIENCE, OFTEN TO BENEFIT LIVELIHOODS
Bridges	Increase dimensions to accommodate flood peaks and prevent flood congestion; deepen abutments	Integrate bridge crossing into catchment management to reduce riverbed siltation and mitigate flood peaks	Use bridge sills for controlled drainage and wetland management; consider drifts instead of bridges to stabilize riverbeds
Drifts	Use higher spillways and larger aprons to accommodate peak floods	Use drifts and small fords to stabilize erosive streams	Use nonculvert drifts for water retention, river stabilization, and floodwater spreading
Paved roads	Increase capacity of road drainage; reinforce drainage infrastructure; build more weatherproof road surfaces, impermeable pavements, and embankments	Manage catchments to retain water and control erosive runoff to reduce risk to infrastructure	Consider changed alignment and cross drainage for water storage and recharge
Unpaved roads	Increase cross drainage and protect road surface with additional layers of aggregate	Manage catchments to retain water and control erosive runoff to reduce risk to infrastructure; protect road surface with water bars, dips, and infiltration bunds	Include basic drainage for water harvesting as part of road development; take measures to manage subsurface flows; protect catchments
Roadside slopes	Adjust critical slopes	Implement bioengineering and vetiver planting for productive use	Implement bioengineering and vetiver planting for productive use
Drainage structures	Increase dimensions to accommodate larger flood peaks	Implement gated control and water spreading from culverts and drains	Place culverts to optimize drainage pattern for water harvesting
Borrow pits	Not applicable	Systematically convert borrow pits for storage, seepage, or recharge	Plan new borrow pits to optimize storage functions after conversion
Roadside vegetation	Not applicable	Systematically promote roadside planting for sequestration and better dust control and microclimate	Systematically promote roadside planting for sequestration and better dust control and microclimate

Source: MetaMeta, (www.roadsforwater.org).

critical resources but can also directly improve agricultural productivity and employ local people in road works that might otherwise rely on heavy equipment and skilled workers from distant communities.

- The additional cost of integrated road-water management is a small fraction of the overall outlays for road investment or road repair and maintenance, typically adding less than 5 percent to the cost of road investments. This cost may be financed from climate funding top-ups for road infrastructure programs.
- The cost of roads for water for building climate-resilient roads that work with the landscape to harvest water and manage floods is generally lower than the cost of adopting new design specifications called for by the basic resilience approach to climate resilience.

Green Roads can better manage climate risks to road infrastructure and simultaneously enable sustainable management of water and more productive use of land. Although the costs and benefits vary, Green Roads approaches balance the different environmental priorities, and impacts of road development generally add relatively little to the costs of road programs, can cost less than basic resilience, and can produce benefits far in excess of these additional costs. See box 1.2.

The costs and benefits of the investment in the roads-for-water approach to climate resilience should be contrasted with the basic resilience approach.

BOX 1.2

Examples of benefits and costs of roads for water around the world

Numerous examples show that the roads-for-water approach to climate resilience often produces benefits far in excess of costs, in addition to improving the climate resilience of the roads:

- One notably large-scale Green Roads program, the Green Roads for Water program implemented under the mass mobilization watershed campaign in Ethiopia, is estimated to have produced benefits of US$18,879 per kilometer compared with costs of approximately US$1,800 per kilometer. Including the cost of organizing and developing the program would raise the costs to US$3,600 per kilometer. Even then, the roads-for-water approach achieved a fourfold return on investment in the first year. It comes as no surprise that the program has spread quickly through the various regions of Ethiopia. The water retention measures implemented in Ethiopia comprise simple earthworks-based interventions such as floodwater spreaders, roadside water ponds, and infiltration trenches. These measures do not require additional engineering, but it is sometimes necessary to incorporate safety measures such as offsets or barriers to prevent vehicles that unintentionally leave the carriageway from entering these ponds and ditches. Many of these approaches are explained in chapter 4. These are a minimum but cost-effective package. Monitoring data from Ethiopia's roads-for-water program and from other sources has been used for the cost-benefit calculations. Chapter 15 presents further details of this program.
- In Kenya, road-water harvesting measures were promoted in the semiarid counties of Kitui and Machakos and adopted by farmers. The initial average investments for the road-water diversion and the land preparation (leveling, terracing) were low, on average US$421 per farmer. This amount was recouped in less than a year, with average benefits of US$1,048 (Kadenyi and Kioko 2019). These benefits accrued in the subsequent years as well. The benefits were particularly high in areas with a short rainy season (because the rainfall is gentler and a large portion of the runoff can be controlled) and in drought years (with 30 percent fewer adopting farmers affected than non-adopting farmers suffering from droughts).
- In Bangladesh, development of water control structures using culverts (see chapter 5) is a low-cost adaptive resilience measure and can range from the use of a simple sheet iron gate on a pipe culvert to a fully gated structure. A sheet iron gate may have almost no upfront cost, whereas a gated structure may cost up to US$700 but can manage water over several hectares of land. Furthermore, hydrological modeling of Polder 26 in coastal Bangladesh shows that improved drainage could potentially produce up to US$3.1 million in net benefits through increased agricultural activity. Green Roads would reduce the depth and duration of waterlogging (by 10 days in low-lying areas). If waterlogging were to be completely removed, farmers could multicrop boro or aman rice, vegetables, watermelon, and sesame, increasing agricultural productivity by 300 percent. If boro rice could be cultivated without waterlogging, the net benefit would be 270 million taka (US$3.1 million).

This more conventional approach to developing resilient roads is described, for instance, by NDF (2014) and Cervigni et al. (2016).

In the conventional basic resilience approach, road infrastructure design specifications are adjusted to make a road better withstand adverse weather effects. This approach may quickly drive up the cost of improving the road's climate resilience. For example, to deal with more intense rainfalls, culverts may be adapted so that they can handle larger volumes of water, with a cost of about US$31,000–US$45,000 per kilometer. In addition, basic resilience measures such as larger cross drainage and higher and stronger road embankments exacerbate the harmful environmental impacts of roads such as uncontrolled flooding, erosion, sedimentation, and waterlogging. Basic resilience approaches may preserve the road in times of heavier weather but will cost far more to construct and do far more damage to the surrounding landscape.

In contrast, the roads-for-water approach—the adaptive and proactive approaches—proposed in these guidelines is therefore a "low risk, high reward" approach to road development, delivering the triple benefits of less road damage, less land degradation, and more beneficial use of water. This approach can be the basis for entire road sector–climate retrofitting projects and for campaigns to promote implementation of roads-for-water measures by farmers and other roadside landowners. Such campaigns consist of motivation, capacity building, and coordination, following the example of the Ethiopia programs. Coordination is essential to ensure that the integrity of the roads is respected and safeguarded, and that the benefits of water use are spread wisely, not only to those immediately adjacent to the roads.

The threshold to begin adaptive approaches is low. The costs in Ethiopia were about US$1,800 per kilometer. Other figures come from Kenya, where research conducted in the Kitui area found that an investment of US$400 per kilometer in integrated road-water infrastructure increased farmers' incomes by an average of US$1,000 after one cropping season, a net benefit of 150 percent (box 1.2). Similarly, Green Roads approaches can also produce substantial benefits in wet climates. For instance, hydrological modeling of Polder 26 in coastal Bangladesh shows that improved drainage could potentially produce up to US$3.1 million net benefits through increased agricultural activity. Green Roads would reduce the depth and duration of waterlogging (by 10 days in low-lying areas).

The proactive approach is associated with new road development programs or major rehabilitation and emphasizes "building roads right from the beginning" to be instruments for climate resilience, landscape management, and water management. The cost of proactive measures is not necessarily much higher (as the example of nonvented road drifts in chapter 9 shows). Even then, integrating roads with the environment around them may be much more cost-effective than merely defending the road against water and climate change. Through roads for water, multiple environmental threats can be tackled as part of the same agenda of inclusive, resilient, and green growth. There is, moreover, scope to deploy creative approaches on new roads with the development of roadside tree planting (chapter 12) or planting local forests along roadsides, offsetting part of the carbon emissions of the indispensable but increasing traffic.

Although the costs and benefits of roads-for-water programs depend upon the context, the roads-for-water program in Ethiopia is considered for comparison in table 1.3. The Ethiopian example was selected for two main reasons. First, it is one of best documented cases of the use of roads for climate resilience

TABLE 1.3 Comparison of costs and benefits of road resilience approaches

	NO CLIMATE RESILIENCE INTERVENTIONS	GREEN ROADS FOR WATER (ETHIOPIA)[a]	PROTECTIVE RESILIENCE[b]
Costs per kilometer			
Intervention costs:			
Paved roads	US$0.00	US$1,800	US$45,000
Unpaved roads	US$0.00	US$1,800	US$31,200
Benefits per kilometer			
1. Resilience dividend			
Routine maintenance	Costs increase substantially across the network because of climate change impacts that damage the road over the years	Cost savings per year: Paved: US$1,100 Unpaved: US$2,200	Cost savings are generally comparable to those from the roads-for-water technique
Periodic maintenance	Costs increase substantially across the network	Cost savings: Paved: US$3,400 Unpaved: US$1,870	Cost savings are generally comparable to those from the roads-for-water technique
Reduced damage from erosion	Erosion from peak weather events is not mitigated	US$2,675	Erosion often worsens down-stream from protected roads, sometimes severely
Reduced damage from flooding	Flood impacts typically not mitigated upstream or downstream of roads	US$1,762	Road is protected; Flood damage often worsens downstream of improved roads
Reduced damage from sedimentation	Higher levels of sedimentation	US$180	Higher levels of sedimentation, sometimes severe
2. Unlocking economic potential			
Reduced impact from climate change	Climate impacts not mitigated	US$550	Climate impacts are not mitigated and may be exacerbated
Duration of road closures or downtime	More road closures and downtime	US$3,800	Generally comparable to those from the roads-for-water technique
3. Co-benefits			
Beneficial use of water harvested by the road	No opportunities to harvest water beneficially	US$4,500	Opportunities to use water beneficially are forgone

Source: MetaMeta, (www.roadsforwater.org).
a. Benefits from the roads-for-water program in Ethiopia (Demenge et al. 2015). The benefits in this column are on annual basis and are expected to be delivered every year (after the rainy season).
b. Cost of protective resilience for paved roads is based on the estimated prices for new planned investments of 796 kilometers of multicountry roads under the Program for Infrastructure and Development in Africa (Cervigni et al. 2016).

around the world, and second, it is a large-scale program that permits the measurement of impact and better links causality to benefits.

The comparison of the costs and benefits of the roads-for-water approach in Ethiopia with other approaches points out its significant benefits while additional costs per kilometer are reduced.

Furthermore, several adaptive and proactive resilience measures may even reduce construction costs.

- Borrow pits may be reused for permanent water storage rather than backfilled, which is often done with low-quality soil material (see chapter 8). This is a considerable cost-saving measure and it creates a local water resource almost for free, especially when site-selection criteria and safety measures are considered in upfront planning (van Steenbergen 2017).

- Roads in flood-prone areas may be built with lower embankments and equipped with controlled overflow “floodway” structures instead of high embankments (see chapter 7). This reduces costs enormously because the expenditure on the embankments is considerably less, and roads do not wash out in unpredictable locations.
- Culvert-less, “nonvented” drifts may be used as road crossings. Such drifts cost the same as road drifts with culverts but prevent the scouring of rivers and encourage the buildup of sand-water storage immediately upstream of the drift, effectively combining the function of a road crossing with that of a sand dam (Neal 2012). Based on a calculation of costs and benefits, Excellent Development (2018) estimates that maintenance costs on culvert-less drifts are only 13 percent of the maintenance costs of vented drifts.
- Water levels in the coastal lowlands, such as the polders in Bangladesh (see chapter 5), may be managed. The only option for doing so is to make use of the road network in these areas, expand it wisely, and equip it with appropriate cross-drainage structures.
- Road embankments may be used for water storage, as in countries as diverse as Burkina Faso, Portugal, Turkmenistan, Uganda, and the Republic of Yemen. Because road embankments are a sunk cost, reservoirs can be developed with comparatively minimal additional expense.
- Low-cost measures, such as drainage dips, water bars, and infiltration bunds, may be used on unpaved roads to guide water to productive uses and prevent the kind of damage to those roads that is usually not repaired (see chapter 10).

ROAD SAFETY CONSIDERATIONS

Numerous issues must be carefully considered in the design, construction, and ongoing maintenance and rehabilitation of roads, many of which cannot be fully addressed in these guidelines. Road safety requirements are among the many issues that are not fully addressed but deserve mention.

Attention to the road context is a first-order principle in road safety. Certain environments call for lower vehicle operating speeds, whereas others can be adapted to mitigate some of the risks posed by higher operating speeds, enabling faster movement. In general terms, measures to reduce speed are necessary in villages and towns and in other contexts in which nonmotorized road users are frequently in close proximity to high-speed traffic. Higher travel speeds can be accommodated more easily in rural areas where these risk factors are not present. In these environments, roadside trees and structures pose significant and often underappreciated risks to vehicle occupants. Road-safety decision-making also requires proactive identification of risks. For instance, operation and maintenance of certain road-water management facilities may also introduce people to high-risk areas of the roadside.

In addition, motor vehicle operators often underestimate road-safety risks and overestimate their capacity to manage those risks. This overconfidence often results in higher and less safe operating speeds. For instance, removal of roadside objects may give vehicle operators a greater feeling of safety, resulting in higher speeds that are not suitable for the road surface conditions. Road user psychology therefore adds significant complexity to the challenge of designing safer roads. Because the road user is unlikely to fully appreciate the risk posed by any individual safety deficiency in a given context, the road engineer must consider how all aspects of the road and roadside will affect safety.

Indeed, as a new awareness of what makes a road fit for safe travel has emerged among the road design profession internationally, much of the guidance that had informed past design standards has been questioned. Substantial revision is taking place. This shift in thinking is reflected in the UN Decade of Action 2011–2020 and the Safe System approach, which emphasizes prevention of serious injuries and fatalities by building road infrastructure that is forgiving of road users' mistakes. Preference is given to creating conditions that reduce the likelihood that a road user would make an error that could result in a serious collision. The new thinking also accepts that road user error will inevitably occur and strongly favors road designs that are forgiving so these errors are less likely to cause serious injury or death. Examples include maintaining good shoulder conditions so that unintentional encroachment into the shoulder does not result in an immediate loss of control that could have unpredictable outcomes, and establishing a median barrier to prevent errant vehicles from crossing over the carriageway into oncoming traffic.

A complete summary of the Safe System approach to providing safer road infrastructure is beyond the scope of these guidelines. However, many traditional approaches to the use and management of roads and roadsides have been found to reflect a lack of awareness of conditions that pose a risk to the lives of road users. The impact of these shortcomings on safety outcomes at the network level is often substantial.

Identification of risk factors for the crash types that are most likely to result in fatal and serious injury outcomes is vital to prevention. These guidelines highlight the most common types of fatal and serious injury crashes experienced on the world's roads in the contexts that are the focus of this report. The most important collision risks in relation to existing and new roads in low- and middle-income country contexts fall into three categories.

- (a) *Run off road crashes.* Vehicles can hit fixed objects, including manmade roadside structures and trees—which may pose conflicts with the greening agenda. Vehicles may also encounter uneven roadside terrain and vertical or near-vertical drops at the roadside, such as dry ditches and ponds. Water bodies adjacent to the roadside might also be encountered.
- (b) *Unsafe waterflows over roads.* It is vital to consider the consequences of unsafe water flows over roads and how to minimize loss of life in those circumstances. Roads that incorporate floodways must protect pedestrians and other nonmotorized road users as far as is possible from actual floodwater flows. Pedestrians and other nonmotorized road users traveling along or crossing roads in the vicinity of floodways are at a heightened risk of being involved in collisions with vehicles. It is often possible for motor vehicles to traverse floodwater flows that would easily sweep other road users into the current.
- (c) *Safe road operation during construction.* Many road safety issues must be fully considered during construction of a road to ensure safe conditions for road users and road construction workers.

REFERENCES

Cervigni, R., A. M. Losos, J. L. Neumann, and P. Chinowsky. 2016. *Enhancing the Climate Resilience of Africa's Infrastructure: The Roads and Bridges Sector*. Africa Development Forum series. Washington, DC: World Bank. doi: 10.1596/978-1-4648-0466-3.

Demenge, J., R. Alba, K. Welle, K. Manjur, A. Addisu, L. Mehta, and K. Woldearegay. 2015. "Multifunctional Roads: The Potential Effects of Combined Roads and Water Harvesting Infrastructure on Livelihood and Poverty in Ethiopia." *Journal of Infrastructure Development* 7 (2): 165–80. https://doi.org/10.1177/0974930615609482.

Douglas, E., J. Jacobs, K. Hayhoe, L. Silka, J. Daniel, et al. 2017. "Progress and Challenges in Incorporating Climate Change Information into Transportation Research and Design." *Journal of Infrastructure Systems* 23 (4): 04017018.

Dulac, J. 2013. *Global Land Transport Infrastructure Requirements: Estimating Road and Railway Infrastructure Capacity and Costs to 2050*. Paris: International Energy Agency.

Ebinger, J. O., and N. Vandijcke. 2015. *Moving toward Climate Resilient Transport: The World Bank's Experience from Building Adaptation into Programs*. Washington, DC: World Bank.

Excellent Development. 2018. "Rural Road Crossings: A Vehicle for Water Investment in Drylands." https://www.excellentdevelopment.com/sand-dam-road-crossing-brochure.

Farrag-Thibault, A. 2014. "Climate Change: Implications for Transport." Business for Social Responsibility and University of Cambridge, United Kingdom. http://www.bsr.org/reports/BSR-Cambridge-Climate-Change-Implications-for-Transport.pdf.

Hebson, C. 2015. "Adapting Large Culvert Design Policy for Climate Change." Presentation at ICNet DOT Workshop, University of New Hampshire, Durham, NH, April 30. http://theicnet.org/wp-content/uploads/2015/08/2015-06-Hebson-DOT-Culvert.pdf.

Kadenyi, N., and T. Kioko. 2019. "Socio-Economic Effects and Impacts of Road Run-Off Harvesting in Arid and Semi-Arid Lands for Climate Resilience with Road Water Management." MetaMeta Research, Hertogenbosch, the Netherlands.

Neal, I. 2012. "The Potential of Sand Dam Road Crossings." *Dams and Reservoirs* 22 (3–4): 129–43.

NDF (Nordic Development Fund). 2014. "Climate Resilient Roads: Cambodia Rural Roads Improvement Project: Results from Climate Change Adaptation."

Salman, M., L. Bunclark, M. AbuKhalaf, C. Borgia, L. Guarnieri, O. Hoffmann, F. Sambalino, F. V. van Steenbergen, and F. Lebdi. 2016. *Strengthening Agricultural Water Efficiency and Productivity on the African and Global Level: Status, Performance and Scope Assessment of Water Harvesting in Uganda, Burkina Faso and Morocco*. Rome: FAO.

Transportation Research Board and National Research Council. 2008. *Potential Impacts of Climate Change on U.S. Transportation: Special Report 290*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12179.

van Steenbergen, F. V. 2017. "Road-Side Borrow Pits as Ponds for Off-Season Small-Scale Irrigation." Hamburg University of Applied Sciences, Hamburg, Germany.

van Steenbergen, F., K. Woldearegay, M. Agujetas Perez, K. Manjur, and M. A. Al-Abyadh. 2018. "Roads: Instruments for Rainwater Harvesting, Food Security and Climate Resilience in Arid and Semiarid Areas." In *Rainwater-Smart Agriculture in Arid and Semi-Arid Areas*, edited by Walter Leal Filho and Josep de Trincheria Gomez. Cham, Switzerland: Springer International Publishing.

II Geographies and Uses

2 Roads for Watershed Management

KEY MESSAGES AND KEY TECHNIQUES

Key messages

- Roads affect watersheds by concentrating and accelerating runoff, interrupting subsurface flows, and increasing hydrological connectivity. As a result, road development has often contributed to watershed deterioration such as flooding, gullying, and erosion.
- Modest changes can enable roads to be used to retain water in a watershed and stabilize areas that are prone to erosion.

Key techniques

- Some of the more important techniques for managing roads' impacts on watersheds are choice of road alignment and slope (this chapter), the design and placement of culverts to divide and slow runoff (this chapter and chapter 10), and carefully designing the road-drainage system and appurtenant structures to avoid erosive velocities and guide water to productive land (this chapter).
- Important structures include road surfaces and templates (chapter 9), warping dams (this chapter) and a variety of water-harvesting and erosion control structures (chapters 8 through 11).

OBJECTIVE

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

A study based on the Global Land Degradation Information System (GLADIS) survey (Bai et al. 2008) also establishes that land degradation was on the increase in the 1991–2008 period and affected one-quarter of global land area. However, this global survey painted a mixed picture. Land quality has been declining in parts of the world—24 percent of the global land surface, in fact—but in 16 percent, land quality has improved. The challenge of managing watersheds is enormous and should not be underestimated, but it is possible to reverse the tide and improve the quality of our natural resources.

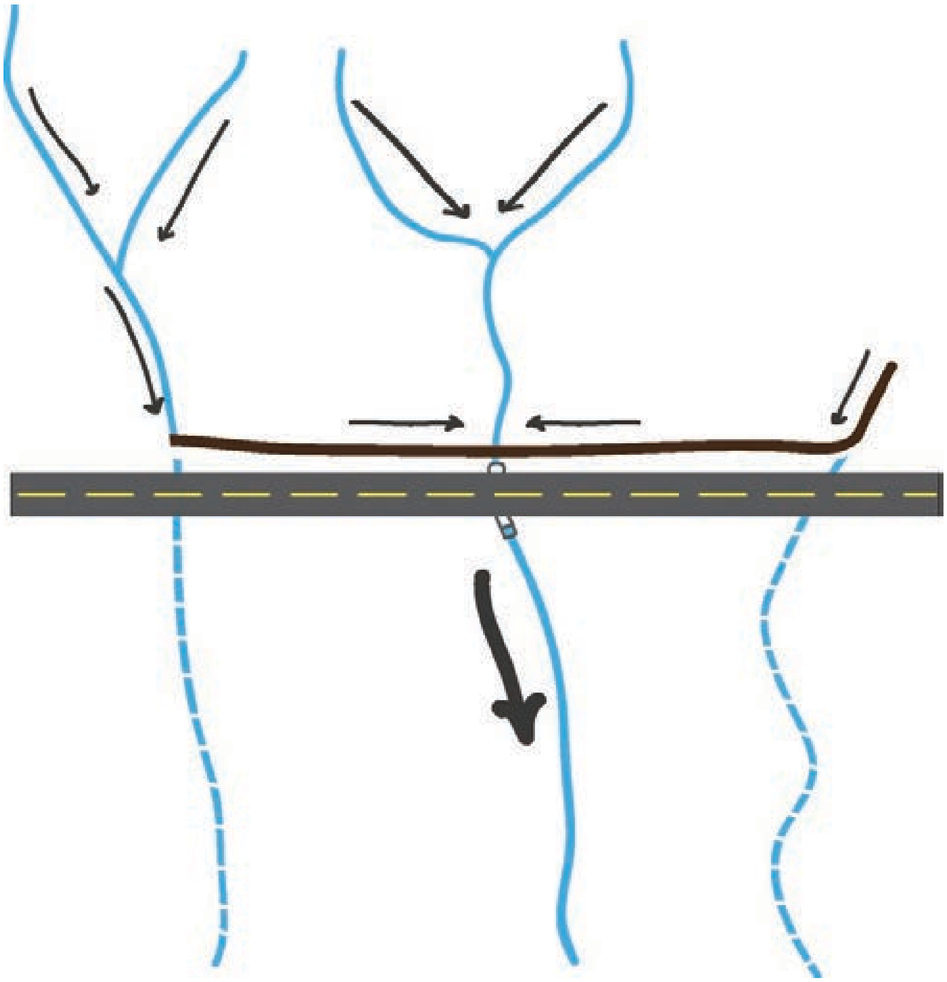
This chapter discusses the opportunities for roads to contribute to watershed management rather than—as is often the case—causing the deterioration of watersheds. Construction of a road typically changes the drainage pattern of entire areas. Surface runoff is blocked by road embankments and is typically concentrated in a smaller number of streams and drains within the watershed. The road network also acts as an additional drainage network in the watershed, increasing the catchment's drainage efficiency and allowing water to drain from the watershed more quickly. Thus, runoff volumes are substantially higher in the natural drains that receive concentrated runoff flows from the road drainage, whereas the flow in other natural drains is diminished (figure 2.1). The first group of streams will carry higher volumes of water, which may create more floods and generate erosion and scouring flows that were previously unusual. In streams that are blocked, downslope erosion will cease, and some areas may dry out. The overall levels of sedimentation in water bodies will generally increase, however. Wemple, Jones, and Grant (1996) estimate that 57 percent of the road length in two watersheds in Oregon functions as flow paths, with some road segments draining directly into streams and others through newly created gullies. As discussed in this chapter, road alignments will differ in their hydrological connectivity.

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

Equally, a road made *in fill* can create an impervious roadbed (figure 2.2), and it will affect the presence of shallow groundwater. In this case, shallow groundwater movement is blocked, creating wet or moist conditions upstream of the road and possibly drying land and wells downstream.

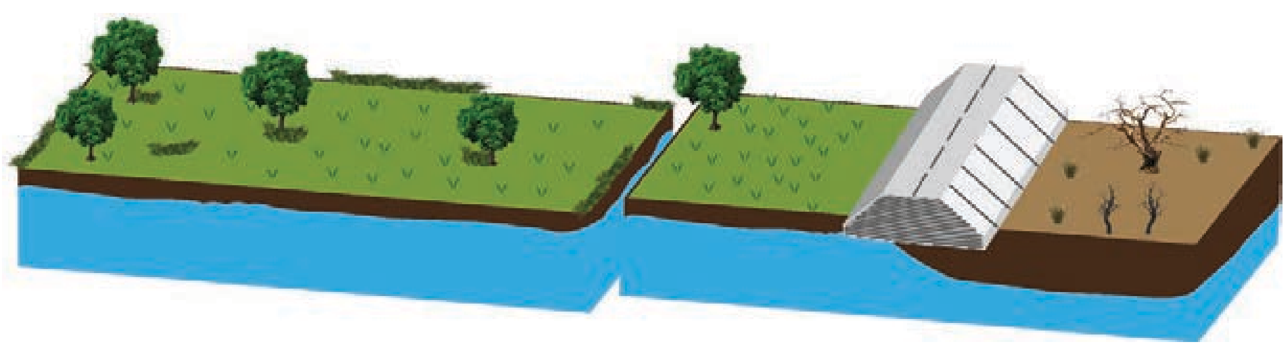
The combined impact of roads on runoff patterns risks substantial damage to landscapes, including erosion, sedimentation, flooding, waterlogging, and desiccation. This degradation of the catchment may ultimately turn against the road itself: roads in degraded landscapes are more vulnerable to damage by stream erosion, uncontrolled flooding, rockfalls, or landslides. The two-way impact can be immediate and spectacular, as when gullies developing from culverts regress and take the road with them, or when heavy scour in drains along the road undermines the road itself. Photos 2.1 and 2.2 are examples of inadequate road drainage's playing havoc with roads.

FIGURE 2.1
Changed runoff patterns



Source: MetaMeta, (www.roadsforwater.org).

FIGURE 2.2
Before (left) and after (right): Road in fill blocking subsurface streams, causing wetting upflow and drying downflow



Source: MetaMeta, (www.roadsforwater.org).

PHOTO 2.1

Erosion from culvert undermining road, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 2.2

Erosion caused by surface water flows redirected by a road

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

OPPORTUNITIES

All the negative effects described in the previous section can be inverted. Roads, rather than being the nemesis, can contribute to watershed improvement. Changes in hydrological processes can be used to better manage the watershed, both by reducing the risk of damage and by optimizing positive impacts on water availability, vegetation cover, and economic activities.

This chapter discusses how roads can become beneficial instruments for watershed management and outlines several recommended practices in road development and maintenance. Key principles guiding such approaches are similar to those discussed elsewhere in these guidelines, namely, road development should use road infrastructure and ancillary measures to decrease the speed of water flows, guide water to appropriate areas, increase infiltration, improve retention of subsurface water, mitigate erosion hot spots, and control sedimentation.

The impact of measures on and along the road can be further enhanced by supporting the development of vegetation that can help retain soils and soil moisture, slow runoff flows, and reduce the chance of flooding and erosion. Roadside plantings can also clean water that runs over the road, improving water supply. Water channeled from roads can be used to increase vegetation cover, water new plantings, or support tree regeneration or roadside tree planting.

RECOMMENDED PRACTICES

This section provides broad principles for aligning rural road development and watershed management. Several relevant practices are discussed in greater detail in separate chapters of these guidelines. This chapter discusses the following practices:

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

Choosing the location and slope of the road

The location of a road in a catchment has a major impact on the volume of water that can be captured by the road bodies and the sediment that is generated and intercepted. Table 2.1 shows general considerations for locating roads within a catchment. Table 2.2 outlines further principles for optimizing the impact of roads on watersheds.

Temmink (2015) undertook modeling of a watershed in Ethiopia using an existing 21 kilometer road to assess the impacts of various potential road locations. The modeling looked at the natural state and the location of the road using alternative alignments, different slopes, and various culvert strategies (that is, different densities of culvert placement). The results of this analysis show the importance of well-considered selection of road alignment on water-harvesting potential, erosion, and road scouring:

- Road alignment has a major impact on water-harvesting potential. Placing a road lower on the slope and selecting a slope generating higher runoff volumes can increase the amount of water diverted by the road and its culverts by a factor of seven.
- As a general rule, "road alignments should be set at toe-slopes, where cross slope is between 5 to 40 percent gradient, making it easier to drain" (Zeedyk 2006). If roads are developed higher on the slope, they will fail to catch a large part of the runoff; if set too low, drainage will be more difficult and road flooding can occur.

TABLE 2.1 Socioeconomic, morphological, and environmental criteria for the location of new roads

ROAD CONTEXT	ROAD LOCATION CRITERIA
Socioeconomic considerations	
Short connection	Give preference to the shortest connection between centers of activity.
Property	Locate roads appropriate distances from valuable property or land uses that would be negatively affected.
Morphological considerations	
River crossings	When following a rivercourse, minimize the number of crossings.
Mountainous areas	Avoid high fills and deep cuts, and avoid or at least minimize hairpin bends.
Mid-slope areas	Avoid alignments along long, steep areas of mountainsides and sloping areas.
Rise and fall	In general, give preference to gradual climbing and descending; avoid unnecessary rising and falling.
Sunny areas	Give preference to sunny areas to reduce potential damage from soil moisture.
Ridges	On smooth hill ridges, it may be preferable not to change runoff patterns because of the potential for unpredictable shifts in erosion patterns.
Foot of the slope	Expect high runoff pulses, especially in semiarid environments where rainfall intensity and runoff rates tend to be higher.
Environmental considerations	
Forests	Prevent avoidable destruction of forests and tree plantings.
Pristine areas	Do not enter pristine areas, areas with unique ecological value, or areas with high conservation value.
Marshlands	Avoid marshlands or other low-lying areas with poor drainage.
Erosion	Avoid areas that are highly susceptible to erosion.
Unstable slopes	Avoid areas with unstable slopes.
Flood levels	Stay above acceptable flood levels and stay away from areas with flooding risk.
Secondary effects	Be aware that roads catalyze the concentration of economic activities (villages, gas stations, and so on) that are often detrimental to sensitive habitats and ecosystems.

Source: MetaMeta, (www.roadsforwater.org).

TABLE 2.2 Additional catchment management criteria related to road construction

Location on hillside	Consider placing the road uphill, mid-hill, or downhill to balance the upstream road catchment and downstream water-use areas.
Rain slope	In semiarid areas, place the road on hillsides with more rain to capture more runoff for productive use.
Compartmentalization of flood runoff	Use roads to compartmentalize and slow runoff, especially in areas that are highly susceptible to flooding and deep erosion.
Slopes, curves	Provide sufficient curves and breaks on the slope. A steeper road straight up a slope is likely to act as a drainage collector. If numerous minor drains are collated by a new road, the road will impose a new drainage pattern on the landscape. This effect can happen particularly on hilltops where drainage patterns are usually not well-defined. Care is required to alternate slopes and curves.
Bends	Bends are exit points for water running along the road surface. Care must be taken to ensure that runoff on road bends is used productively and does not cause undue erosion.
Roads in cut	Avoid constructing roads level with or lower than adjacent land, because such roads attract runoff and can become the main drainage route. Unpaved roads built atop soft material are at risk of lowering over time from erosion and wear and tear of the road surface. When the road is level with the land, construction of permanent water bars and rolling dips is recommended to prevent erosion of the road surface.
Groundwater	Consider the interaction between construction methods (both in cut or in fill) and shallow groundwater tables, and plan mitigation measures such as additional cross drainage or permeable road embankments. Alternatively, roads constructed in fill may secure shallow wells upslope from the road.

Source: MetaMeta, (www.roadsforwater.org).

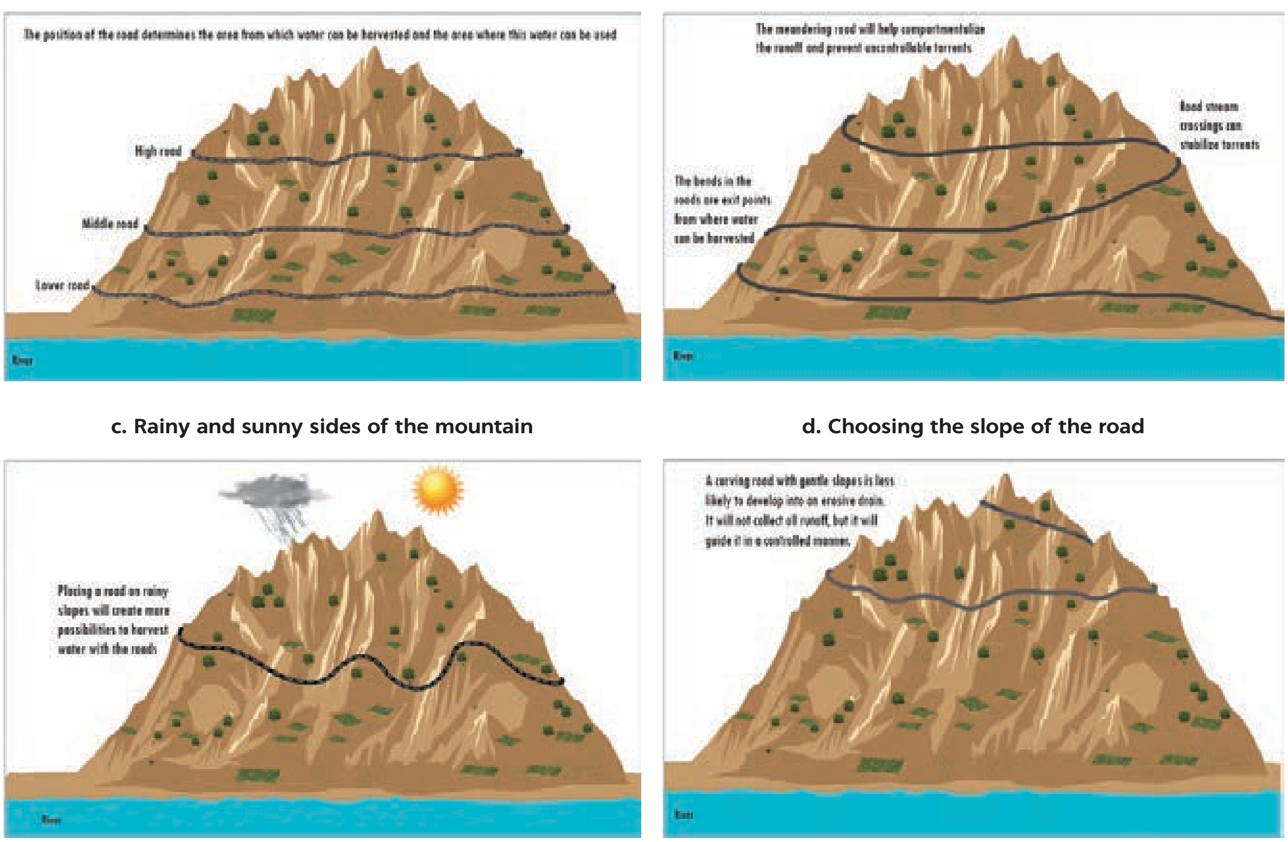
- In the Northern Hemisphere, roads facing south will dry up more quickly, whereas those facing north will take more time to dry. However, soils facing north are deeper, thus facilitating road construction and maintenance work.
- Road construction typically increases erosion by at least 10 percent compared with the natural catchment. The increase is usually greater, that is, ranging from 12 percent to 40 percent (Bryan and Schnabel 1994; Luce et al. 2001; Megahan, Wilson, and Monsen 2001; Wemple 2013).[1] This effect can be nearly halved with better road location and culvert placement. The key measures to control erosion include (1) raising the road embankment, (2) avoiding the most sensitive and erosion-prone areas, (3) adjusting culvert size, (4) having culverts drain into stable or reinforced waterways, and (5) in steep areas, providing an adequate number of bends in the road to reduce the slope of the road and the risk of the road's transforming into a new drain.
- The scouring of unpaved road surfaces is also greatly affected by the choice of road alignment, especially the road's length and slope. Avoiding long, steep slopes and placing adequate cross drainage can reduce scouring significantly (see chapter 10), contributing to road durability and reducing sediment deposition in the watershed.

Because roads create opportunities to retain water in the watershed and can help prevent erosion with appropriate measures, additional criteria should be considered, as presented in figure 2.3.

FIGURE 2.3

Road alignments for better watershed management

a. Placing the road high-, mid-, or low-hill **b. Choosing road alignment**



Source: MetaMeta, (www.roadsforwater.org).

Designing the road-drainage system

Road-drainage systems are always a major intervention in watershed hydrology. If a road is equipped with a proper drainage system, the system will collect water along the road and remove it from the road body. This process will protect the road surface, especially of unsealed roads, and make the water available for productive use. Typically, the *raison d'être* of road-drainage systems is to preserve the roads and prevent runoff from interfering with road operations. At the same time, roads are large water-harvesting systems and should be managed accordingly. When not designed and managed well, road drainage commonly causes uncontrolled flooding and erosion that affect the road body, neighboring land, and the environment. It is also a missed opportunity for water harvesting for productive purposes.

The runoff is preferably "given back" to the land through water harvesting and the diversion of water to farmland, to rangeland, or for forest development. The road network and its drainage should have limited hydrological connectivity (that is, road drainage should not divert large volumes of water to watercourses, nor should water from minor watercourses be redirected by road drainage). A high level of connectivity, such as would arise if road drains redirected drainage into streams, increases the speed with which water drains from the watershed. Heightened hydrological connectivity of this kind along a road network will concentrate water volumes, amplify flood peaks, reduce infiltration, and reduce groundwater recharge. Rather than connecting road drains to streams in the watershed, road drainage should run into vegetation, bunds, farm fields, or pastures. This approach will also reduce sediment deposition in the streams.

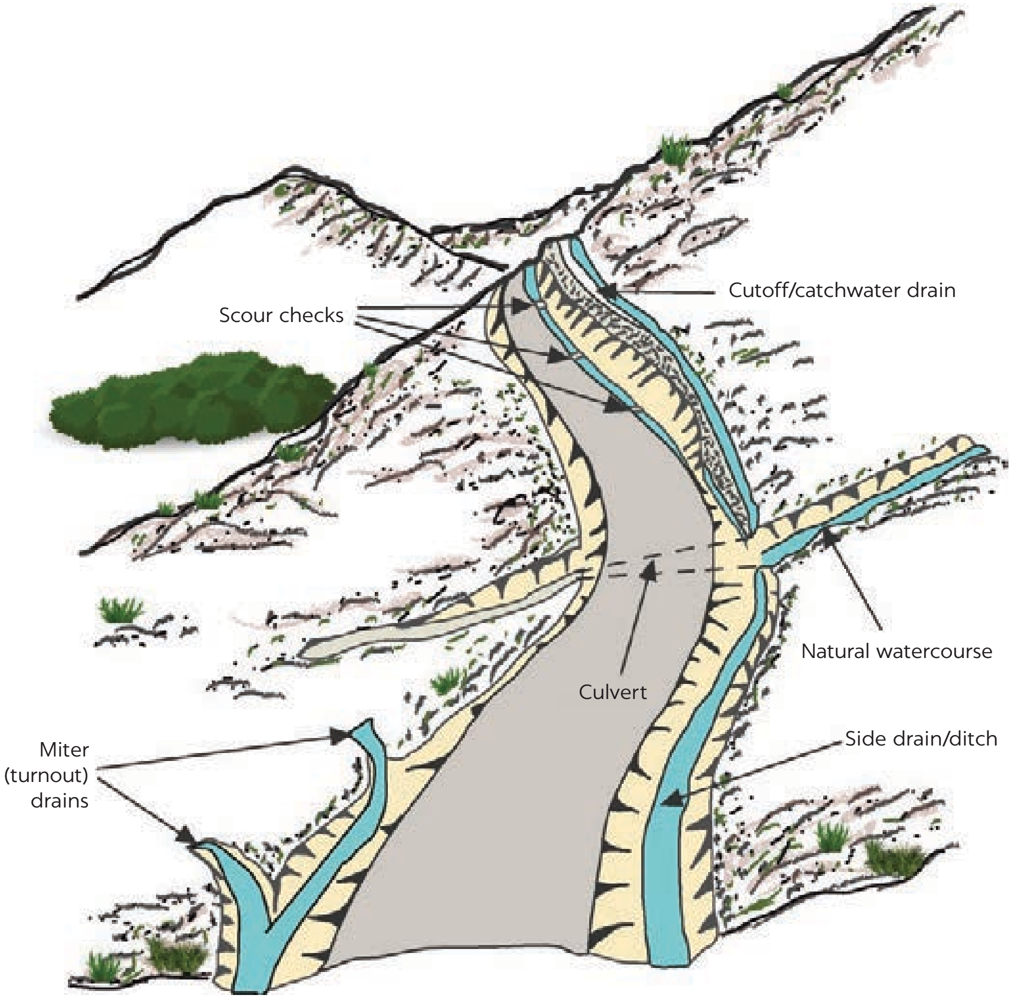
A simple test of the adequacy of a road-drainage system is whether the drainage system can redirect peak runoff volumes while also making runoff water available for reuse. A good drainage system can prevent road scour or erosion along road drains and waterways if drains are properly aligned or alternatively protected with erosion-control measures. Especially when the road material is highly erodible, it is important to have road drainage that will protect the road from water running on it (figure 2.4). If the road is not protected, rills and scour tracks will be created on the road, and the fine grades in the road body will be washed out. The road itself may increasingly develop into a natural gully (see photo 2.3).

When in place, the road-drainage system can consist of (1) cutoff drains that shield the road from uphill runoff; (2) side drains that channel the water along the road; (3) culverts, pipes, and bridges that take water across the road body; and (4) mitered (turnout) drains that divert water to the land adjacent to the road. The road template itself is also an important part of road-drainage design. Road runoff can be influenced by shaping the road surface, such as by tilting the road surface downhill or establishing a crown shape that guides water to the side of the road from the middle section. Figure 2.5 illustrates several such road templates. Depending on the road material, there is a risk that such purposely shaped road surfaces may be worn down by traffic and rainfall.

Certain drainage features are relevant to unpaved roads, which tend to have less-developed drainage systems. Water bars and rolling drainage dips that remove water from the road surface directly to the adjacent land are beneficial for controlling water flows over road surfaces and managing discharge. Construction of infiltration bunds that run parallel to the road is another important measure for diverting water from unpaved roads that lack

FIGURE 2.4

Road-drainage system as an asset for road protection, watershed management, and water harvesting



Source: MetaMeta, (www.roadsforwater.org).

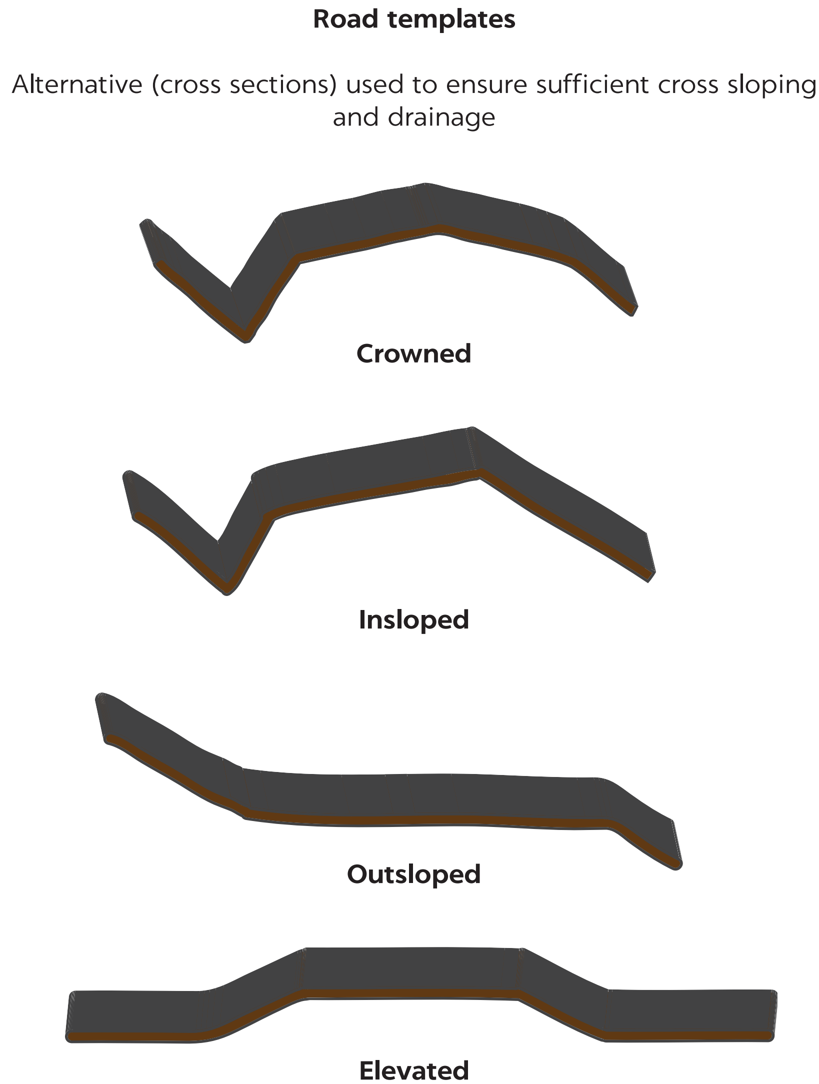
PHOTO 2.3

Large gullies caused by poor road-drainage systems in Tajikistan

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

FIGURE 2.5

Various road cross-sectional profile templates



Source: MetaMeta, (www.roadsforwater.org).

well-developed drainage systems. Infiltration bunds can be formed from stone lines and slow the road runoff and help it infiltrate (see chapter 10).

Table 2.3 presents numerous opportunities for using road-drainage systems for beneficial watershed management.

Culverts and other cross-drainage structures along a road body are among the most important considerations when designing for beneficial water management. The number and location of these structures determine the opportunities to collect water, retain moisture, and control erosion and sedimentation. Cross-drainage structures are commonly placed in line with existing natural drainage paths such as gullies and small streams. These locations allow water from the upper catchment to pass underneath roads and connect these watercourses directly to the downstream portion of the catchment. Despite their importance, the number of cross-drainage structures is often minimized for reasons of cost, resulting in concentration of naturally distributed runoff water at fewer drainage points. This practice contradicts one of the key general principles of beneficial

TABLE 2.3 Recommended practices for road-drainage systems and water harvesting

OBJECTIVE	APPLICABLE DRAINAGE PRACTICE
Systematically collect and divert runoff	The road-drainage system is a mechanism for effectively collecting and diverting all water that is gathered around the road. If adequately designed, it can help "harvest" a large part of the runoff from the catchment uphill of the road and avoid waterlogging upstream of the road. The road-drainage system should generally have sufficient capacity to remove the peak runoff volume quickly enough to facilitate transit.
Dispose of runoff in areas where it can be used beneficially	Road-drainage water should not be disposed of in areas where it creates damage or where it serves no useful purpose; rather, it should be led to agricultural areas, tree plantings, rangeland, recharge areas, or ponds. It is also important that road-drainage water (including the sediment and other particles it carries) not be directly discharged into streams where it will create turbidity and cause stream sedimentation.
Have an adequate number of outlets from the drainage system	It is important to have adequate outlets from the road-drainage system; these outlets should distribute the water over a wide area rather than accumulating water flows too voluminous to be handled from a limited number of outlet points. In a few cases, however, on steeper and erodible slopes where gullies develop below each cross-drainage structure, runoff should be concentrated at fewer points that lead to well-reinforced waterways. This approach helps optimize resources invested in waterway stabilization on steeper terrain.
Reduce the hydrological connectivity of the road network	To minimize the road's contribution to hydrological connectivity, runoff collected from road drainage should be diverted or distributed to vegetative bunds, pasture, or farmland and should not be allowed to quickly discharge into local streams and drains. This recommendation prevents the rapid buildup of flood peaks after rainfall in the watershed.
Harvest sediment from road-drainage systems	Road-drainage systems can also be used to collect sediment. This objective requires the side-drain slope to be broken with drop structures such as scour checks. Sediment will be deposited in the flat sections and can then be collected and used as building material, particularly if collected near towns. Sand harvesting from road drains can be an important job opportunity.

Source: MetaMeta, (www.roadsforwater.org).

water management in watersheds: that roads should not contribute to hydrological connectivity.

Culverts are important elements in road-water management. Culverts that discharge water in an uncontrolled manner can be a major source of damage, but culverts can also guide the runoff from the catchment to places where it is used beneficially. Culvert design, including bed sill and some of the ancillary structures, can also help control erosion. There are a number of important recommended practices:

- Culverts should be placed on drainage lines. As obvious as it sounds, culverts are often incorrectly located during the road design and construction process.
- An adequate number of culverts should be built. Distorting natural drainage patterns by reducing the number of cross-drainage points is likely to create highly erosive runoff, flooding, or both.
- Culverts should be installed close to productive land, storage ponds, and recharge areas. When necessary, they should be equipped with diversion canals that direct runoff water to benefit areas and structures such as ponds or infiltration trenches.
- The upstream side of culverts must be designed properly and include any protection measures (Berhe 2018) to guide water through the culvert at a controlled velocity. These measures may comprise the following:
  - Widened intake channels to slow the runoff passing through the culvert
  - Protection of the intake channels with riprap or vegetation to prevent erosion

- Proper design and protection measures on the downstream sides of culverts depend upon the soils and slope immediately downstream but may include the following:
  - V-shaped floodwater spreaders (see photo 2.4)
  - Check dams and stepped drop structures
  - Riprap protection
  - Diversion channels to take runoff to benefiting areas, storage, or recharge structures
- Proper design of the culvert is required, particularly in steep, erodible streams. The lower sill of the culvert can be raised and help stabilize the stream and prevent further scouring out of the stream.

Planning water-harvesting and erosion control measures along with roads

Rural roads' contribution to erosion is well documented and can be clearly seen in roadside gullies, landslides,[2] and the presence of road aggregates washed from the surface of unpaved roads. Measures to control and prevent erosion should be part of road construction and maintenance. The following important measures are discussed in this chapter as well as in chapter 10: well-placed road alignments (slope, bends, and drainage system), check dams, infiltration bunds, rolling dips and water bars, reinforced culverts, and water spreaders.

The road represents a change in the natural topography, opening fresh slopes that may be protected by several mechanical and biological measures. These erosion-control measures must be introduced simultaneously with the road's development to keep erosion from occuring.

There are several methods for biological treatment. The two most popular are bioengineering and the use of stabilizing plants, in particular vetiver grasses (*Chrysopogon zizanioides*). Bioengineering is the use of plants for slope stabilization and runoff control. It involves using plant parts such as

PHOTO 2.4
V-shaped floodwater spreader

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

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).

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 millimeters to more than 5,000 millimeters 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. Although common in some countries, several proven uses of vetiver have not been introduced in many other countries where they could make a significant contribution. The same applies for bioengineering. Although some countries (for example, Nepal) are very proactive in bioengineering, it is relatively unknown in other countries.

There are other ways that roads can contribute positively to erosion control in watersheds, including stabilizing erosive streams with small road fords or drifts, controlling erosive areas with embankment roads, and combining warping dams with roads.

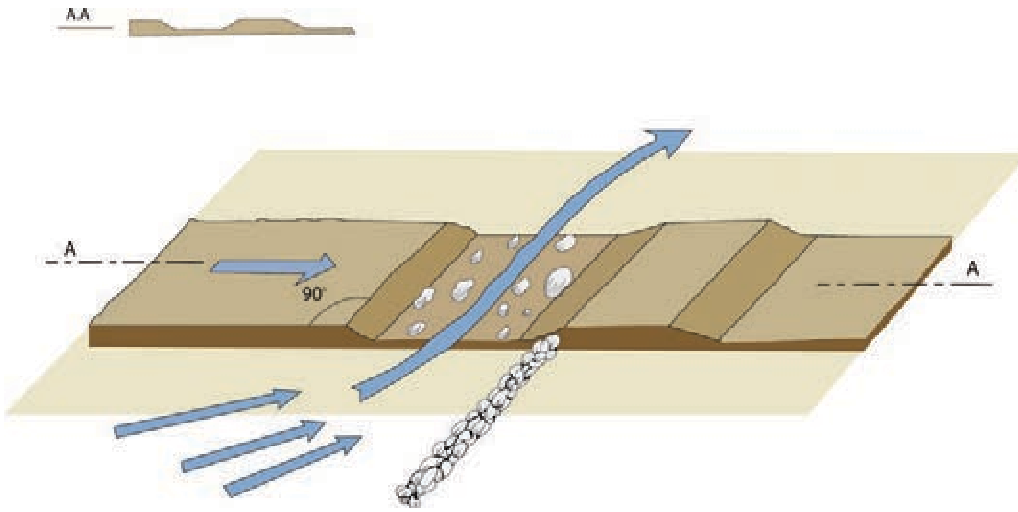
Stabilizing Streams with Road Platforms

Road platforms or small fords may be placed at erosive stream crossings to stabilize them. These structures will retain the streambed material and allow water to spread over the breadth of the road body before it is discharged downstream, which will make stream flows much gentler. If such road platforms are raised on the uphill side, they can help stabilize the stream and even build up a small sandy layer in the streambed that can act as water storage and connect to the aquifer surrounding the stream. Chapter 9 discusses the principle of such road drift's acting as sand dams in greater detail. If a riverbed is filled with a thick layer of sand gravel, the river can feed the groundwater adjacent to it. Building a series of such stabilizing structures on a stream at different road crossings is the preferred option. Small sand dams may be added in some cases. Note that such structures can have a significant adverse impact on aquatic life in the stream, and that the design of any structure within a stream or river should be carefully considered to balance all concerns.

Fords may be straight with a dip or depressed section (see figure 2.6) that will divert the runoff from the road surface and guide the water from the stream. The ford may also be parabolic in shape, mainly to facilitate natural streams overpassing the road. The advantage of parabolic fords is that they spread the water over a larger width of the riverbed, causing less damage to the streambed and stopping whatever rutting that may appear in the riverbed. The fords also hold the bed material in place. A further advantage of such stream crossings is that they do not become clogged. The key disadvantage of fords is that the road may not be passable during short-term floods; fords are therefore most appropriate on low-volume roads.

FIGURE 2.6

Road ford with longitudinal slope to allow the crossing of a natural stream with a permanent rolling dip added to divert water from the road surface



Source: © Masila Benson Muteti, Regional Manager at Kenya Rural Roads Authority. Used with permission. Further permission required for reuse.
Note: The rolling dip is constructed with concrete, masonry, or rocks (Bender 2009).

Controlling Erosive Areas with Embankment Roads

Roads that cross unstable and highly erosive landscapes can be developed to reduce the land-degradation process. Runoff should be concentrated in the more stable streams; cross drainage should not be placed on the steepest or most erodible sections in a watershed.

Erosion can sometimes be controlled in some highly erosive drainage lines by simply not installing culverts or by installing them with high sills. The runoff will disperse and fill the stream along the uphill side of the road, which can help control the specific erosion hot spot.

Capturing Eroded Soils with Roads in Combination with Warping Dams

Warping dams are relatively high retaining structures constructed to capture soil in highly erodible landscapes. Warping dams slow water flows, allowing sediment to settle on the upstream side of the dam; over time the accumulating sediment creates stable and fertile terrace land from which runoff water can be better managed. Once the land area is filled up, the watercourses can be channeled. Roads can be combined with such warping dams. Warping dams were used extensively to restore land in China's Loess Plateau (Li, Du, and Liu 2016), where the landscape was heavily degraded. Hillsides were treated with a range of measures, and valleys were blocked off with warping dams, creating fertile new land where there had been heavy erosion.

NOTES

1. When a catchment is heavily eroded, the road's additional impact on sedimentation is proportionally less; in fact, roads can help mitigate some of the erosion. Therefore, in relatively pristine watersheds a road's contribution to the sedimentation process is proportionally higher but may be lower in absolute numbers.
2. Because there is an extensive and rich literature on preventing landslides during road development, this subject is not addressed in these guidelines.

REFERENCES

Bai, Z. G., D. L. Dent, L. Olsson, and M. E. Schaepman. 2008. "Global Assessment of Land Degradation and Improvement: Identification by Remote Sensing." Report 2008/01, ISRIC, World Soil Information, Wageningen.

Bender, H. 2009. "Pistes rurales et mésures antierosives. Recommendations techniques." Bender Associates, Saarbrücken, Germany.

Bryan, R. B., and S. Schnabel. 1994. "Estimation of Sedimentation Rates in the Chemeron Reservoir." *Advances in Geoecology* 42: 231–48.

Devkota, S., K. Sudmeier-Rieux, I. Penna, S. Eberle, M. Jaboyedoff, A. Adhikari, and R. Khanal. 2014. *Community-Based Bio-Engineering for Eco-Safe Roadsides in Nepal*. Lausanne: University of Lausanne, International Union for Conservation of Nature, Nepal, and Department of Soil Conservation and Watershed Management, Government of Nepal.

Greenfield, J. C. 2008. *The Vetiver System for Soil and Water Conservation*. The Vetiver Network International.

Ibisch, P. L., M. T. Hoffmann, S. Kreft, G. Pe'er, V. Kati, L. Biber-Freudenberger, D. A. DellaSala, M. M. Vale, P. R. Hobson, and N. Selva. 2016. "A Global Map of Roadless Areas and Their Conservation Status." *Science* 354 (6318): 1423–27.

IPBES (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). 2018. "Summary for Policymakers of the Assessment Report on Land Degradation and Restoration of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services." Edited by R. Scholes, L. Montanarella, A. Brainich, N. Barger, B. ten Brink, M. Cantele, B. Erasmus, et al. IPBES Secretariat, Bonn, Germany.

Li, Y., G. Du, and Y. Liu. 2016. "Transforming the Loess Plateau of China." *Frontiers of Agricultural Science and Engineering* 3 (3): 181–85. https://doi.org/10.15302/J-FASE-2016110.

Luce, C. H., B. E. Rieman, D. B. Jason, J. L. Clayton, J. G. King, and T. A. Black. 2001. "Incorporating Aquatic Ecology into Decisions on Prioritization of Roads Decommissioning." *Water Resource Impact* 3 (3): 8–14.

Megahan, W. F., M. Wilson, and B. S. Monsen. 2001. "Sediment Production from Granitic Cutslopes on Forest Roads in Idaho, USA." *Earth Surface Processes and Landforms* 26: 153–63.

Pinners, Elise. n.d. "Vetiver System Bio-Engineering in Semiarid Areas: How to Establish and Maintain Hedges." Director TVNI, Director Green Cycle Consultancy Ltd.

Temmink, T. 2015. "From a Problem towards Potential: Improving Rural Road Design in Drylands, a Modelling Case Study for a Catchment in the Tigray Region, Ethiopia." MSc thesis, Utrecht University.

Wemple, B. C. 2013. "Assessing the Effects of Unpaved Roads on Lake Champlain Water Quality." New England Interstate Water Pollution Control Commission, Lake Champlain Basin Program, Lowell, MA.

Wemple, B. C., J. A. Jones, and G. E. Grant. 1996. "Channel Network Extension by Logging Roads in Two Basins, Western Cascades, Oregon." *Journal of the American Water Resources Association* 32 (6): 1195–207.

Zeedyk, B. 2006. *A Good Road Lies Easy on the Land: Water Harvesting from Low-Standard Rural Roads*. Santa Fe, NM: The Quivira Coalition; Zeedyk Ecological Consulting, LLC; The Rio Puerco Management Committee – Watershed Initiative; and the New Mexico Environment Department – Surface Water Quality Bureau.

3 Rural Roads and Water Supply

KEY MESSAGES AND KEY TECHNIQUES

Key messages

- Road surfaces carry harmful heavy metals, polycyclic aromatic hydrocarbons (PAHs), and salts, which will affect water quality.
- Most water harvested with roads, however, originates from the entire catchment, not from the road surface, and is not affected by contamination from road surfaces.
- Water harvested with the roads improves water supply by augmenting water resources through recharge and by feeding surface storage.
- Depending on geology, road development may also help develop new springs and seeps.

Key techniques

- Road water can be collected in cisterns and ponds (this chapter and chapter 11) or fed into recharge structures (chapter 2).
- Springs along roads should be protected and, in some cases, even have their outflow managed (chapter 6).
- Grass strips can reduce pollution loads (this chapter).

OBJECTIVE

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

OPPORTUNITIES

This chapter discusses several opportunities for using roads to improve rural water supply, especially to increase access to drinking water.

- Road-water harvesting can recharge groundwater, and the development of shallow tube wells can serve to replenish drinking water.
- Water harvesting using road bodies can feed surface drinking water systems, but care should be taken to ensure acceptable water quality.
- Protecting and managing springs opened by road construction can provide a safe and reliable source of water (see chapter 6).

Domestic water quality is always a concern, particularly when road surfaces and intensively traveled highways are used to collect drinking water. Such runoff is not typically used as domestic water, however. Water collected from roads generally originates from the entire catchment, whereas water coming directly from road surfaces plays only a minor role. Moreover, most water would be harvested with low-volume unpaved roads, owing to their dominance in rural areas. Precautions are necessary when water harvesting is undertaken near intensively used highways because of the higher risk of pollutants in the water.

The potential that water captured in road-water harvesting may have high contaminant loads associated with road traffic, especially in the case of intensively used highways, is a legitimate concern. Surface and groundwater would then be susceptible to pollution from road runoff. Surface waters are particularly vulnerable because they are directly exposed to the contaminants. Pollution of groundwater tends to occur gradually given that some of the contaminants are intercepted before reaching the aquifer system, but the cleanup process is difficult and expensive.

Common contaminants in highway runoff are heavy metals, inorganic salts, aromatic hydrocarbons, and solids from the road surface that result from regular highway operation and maintenance activities (FHWA 2016). In addition, road surface runoff may contain grease, oil, rust, and rubber particles from vehicle wear and tear. These materials are often washed off the highway during rainstorms. Heavy metals such as lead, zinc, iron, chromium, cadmium, nickel, and copper generally undergo physical, chemical, and biological transformations as they reach adjacent ecosystems. They are either taken up by plants or animals or are adsorbed by clay particles, or they settle as bottom sediments that could leach metals depending on the condition and sensitivity of the receiving water.

Low pH levels (less than 7) trigger metal solubility and leaching (Hanes, Zelazny, and Blaster 1970). However, copper, iron, chromium, and nickel leaching are limited in natural waters where aerobic conditions are maintained (Granato, Church, and Stone 1995). Heavy metals from highway runoff are not necessarily toxic; the toxicity of water is determined by the form of metal and its availability to organisms. For instance, ionic copper is more harmful to aquatic organisms than elemental copper (Yousef et al. 1985). Similarly, ionic zinc and cadmium cause greater harm to aquatic life than their base forms.

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

Table 3.1 provides typical concentrations of pollutants in road runoff in intensively used road sections (more than 10,000 vehicles a day).

Initial runoff during a rainstorm event usually has a much higher concentration of pollutants. The highest pollution level is in the “first flush.” It is assumed that up to 70 percent of the pollution load is associated with sediments because much of the oil adheres to such fine particles. The typical pollution levels, as in table 3.1, can be compared with the acceptable levels (available from WHO), with the main area of concern being the concentration of lead (Pb).

Deicing salts is an additional category of pollutants and can be a problem in temperate and cold climates. The most common salts used are sodium chloride, magnesium chloride, calcium chloride, and special mixtures. Their harmful effects may be reduced by careful application. Different types of cold weather conditions (sleet, ice, light snow, heavy snow, compacted snow, ice rain) require different applications of deicing agents and methods, such as pre-wetting. Also, better understanding the nature of road surfaces and their responses to different cold weather conditions enables effective road treatment with minimal road salts. Brick roads and wooden bridges, for instance, are much more prone to freezing than tarmac or earthen roads. Careful application of road salts yields a double benefit: less stress on local water resources and financial savings for deicing operations.

Several strategies can be used to prevent or reduce water contamination from road surfaces. These approaches are particularly important when harvesting water close to intensively used pollution-risk hot spots. The first strategy should be to revisit the road specifications: some PAHs, for instance, originate from the material chosen for road construction. Coal tar–based pavement sealants are a notorious source of PAHs (Valentyne et al. 2018). The second strategy is to avoid use of this category of road runoff, particularly near intensively used highways. To avoid accidental pollution, the safe removal of contaminated water from road drains can be considered. For example, very strict care is taken that no highway runoff will recharge the aquifer systems close to the world-famous mineral water resources in Vittel, France. All such road runoff water is collected and disposed of away from recharge zones. A third strategy is to improve road operations, particularly deicing operations.

TABLE 3.1 Typical concentrations of pollutants in highway runoff (milligrams per liter)

CONTAMINANT	TSS	COD	TOTAL N	TOTAL P	Cd	Cu	Pb	Zn[a]	PAH
Typical concentration (mg/L)	200	100	2	0.5	0.0015	0.1	0.03	0.5	0.003
WHO norm (mg/L)	n.a.	n.a.	n.a.	n.a.	0.003	2	0.01	n.a.	n.a.

Sources: BUWAL 1996; Dierkes 1999; Heinzmann 1993; Krauth and Klein 1982; ÖWAV 2002; Pfeifer 1998; US EPA 1983; WHO 2017.
Note: Cd = cadmium; COD = chemical oxygen demand; Cu = copper; mg/L = milligrams per liter; N = nitrogen; n.a. = not applicable; P = phosphorus; PAH = polycyclic aromatic hydrocarbons; Pb = lead; TSS = total suspended solid; WHO = World Health Organization; Zn = Zinc.
a. No health-based guideline values are proposed for zinc (Zn). It is assumed that drinking water seldom contains Zn concentrations greater than 0.1 mg/L.

Natural remediation methods offer a fourth approach to reducing the risk of water contamination from intensively used highways (Wilson 1999). Roadside vegetation, particularly grass strips or vegetated drainage channels, is one example of this approach. These interventions can improve the quality of water in two ways: by absorbing pollutants from water and by separating pollutants from the release of sediment. The effects of vegetation on contaminant removal depend on environmental conditions, the number and type of plants, and the nature and chemical structure of pollutants.

Vegetated channels along roads slow water runoff, trap sediment, and enhance infiltration. They are little artificial wetlands, engineered and planted to slow the flow of stormwater runoff. The goal is to expose the dirty water to plants and soil, which absorb toxic metals, filter out water-clouding sediment, and neutralize noxious germs. According to the United States Department of Agriculture Natural Resources Conservation Service,[1] if properly installed and maintained, plants and soil have the capacity to do the following:

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

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

RECOMMENDED PRACTICES

Road-water harvesting for groundwater recharge

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

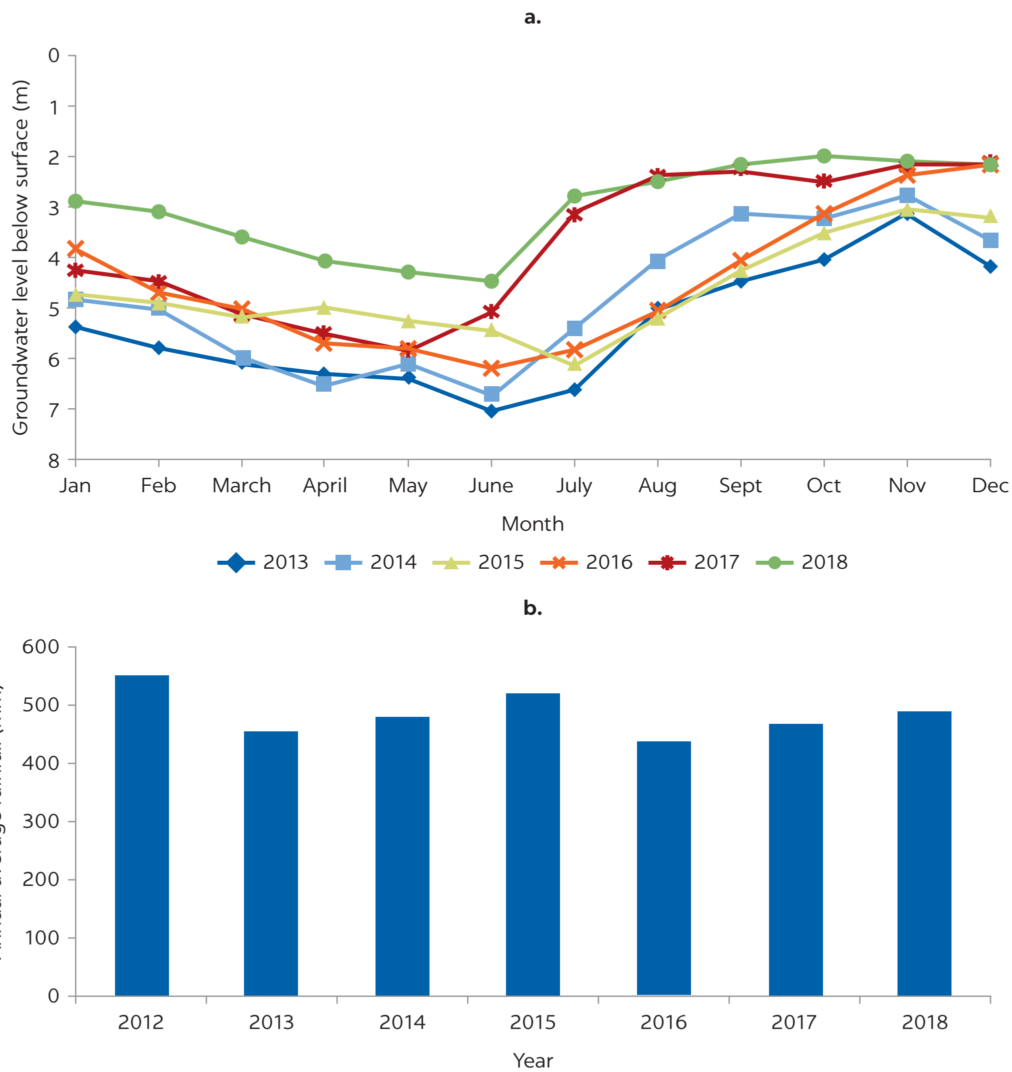
Roads can be used for groundwater recharge using several techniques (see chapter 4). Water from roadside drainage can be diverted to percolation ponds, trenches, and swales (van Steenbergen et al. 2018) or spread over recharge zones. In recharge zones, runoff collected by a road body infiltrates through comparatively porous, unconsolidated, or fractured material such as sand, fractured basalt, and old glacier deposits. The recharge zone is situated on top of the receiving water-bearing layer or aquifer. This water can then be extracted with existing or new hand-dug wells or shallow or deep tube wells, depending on the geology and the depth of the groundwater.

Recharge by infiltration takes advantage of the natural treatment processes that occur when water moves through soil. Thus, groundwater quality will very likely be substantially improved compared with initial runoff quality and will have become more suitable for household purposes (hygiene and sanitation) or as stock water, although further treatment may be necessary for it to be used as drinking water.

Results from groundwater monitoring undertaken in Ethiopia reveal an increase in groundwater levels following the implementation of road-water management techniques for groundwater recharge (figure 3.1). Infiltration systems designed for groundwater recharge require permeable soils (sandy loams, sands, and gravels) with relatively high infiltration rates. By storing water in aquifers, evaporation losses are reduced compared with surface water storage. There are also indications that the intense recharge of

FIGURE 3.1

Change in groundwater levels in an area with groundwater recharge from road water, Tigray, Ethiopia



Source: Kifle et al. 2019.

Note: (a) Groundwater fluctuation in Freweign area, Tigray, Ethiopia. The well is located downstream of a borrow pit converted into a percolation pond. The borrow pit was converted into a pond in July 2014, and monitoring was done for the period 2013–2018. Three additional water storage ponds were constructed at the end of 2016 for groundwater recharge purpose. (b) Rainfall distribution for Freweign area for 2012–18. m = meters; mm = millimeters.

groundwater by a large range of measures, including through water harvesting with roads, can improve groundwater quality by diluting natural contaminants. Woldearegay, Tamene, and van Steenbergen (forthcoming) find that total dissolved salt levels decreased over a 15-year period in well-managed catchments in Tigray, Ethiopia, from 730 milligrams per liter in 1991 to 534 milligrams per liter in 2016 after the rainy season, as in Abreha we Atsbeha, for instance.

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

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

The most important parameters for groundwater recharge of relatively unpolluted water (that is, without PAHs; see box 3.1) are suspended solids content, total dissolved solids, bottom of form (total dissolved salt) content, and the concentrations of main cations such as calcium, magnesium, and sodium. When there are too many suspended solids, it is recommended that sediment or silt traps be installed to avoid clogging. If the water is meant to be extracted for drinking supply, the main water quality parameters to consider are microorganisms, trace-inorganic chemicals, and anthropogenic organic chemicals. Soils generally act as natural filters that reduce the concentration of pollutants caused by physical, chemical, and microbiological processes. In these processes, suspended solids are filtered out; biodegradable organic compounds are decomposed; microorganisms are adsorbed, strained out, or die; nitrogen concentrations are reduced by denitrification; synthetic organic compounds are adsorbed or biodegraded; and phosphorous, fluoride, and heavy metals are adsorbed, precipitated, or immobilized. The extent to which soil can remove pathogens depends on several factors, including the physical, chemical, and biological characteristics of the soil; the size and nature of the organism; and environmental conditions such as temperature. The largest organisms, such as protozoa and helminths, are removed effectively by filtration unless the soil contains large pores. Bacteria are also filtered, although viruses may be too small to be filtered by most soil pores (National Research Council 1994).

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

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

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

Road-water harvesting for surface storage

Water from culverts and roadside drains can be diverted to surface water storage points, such as cisterns or ponds. In limestone areas, communities in the Republic of Yemen have developed water cisterns along roads (photo 3.1). The water cisterns are filled by rainfall events, though the events are scarce. Apart from storing water, the cisterns double as cold stores. The water from the cisterns is used for livestock watering in dry periods. Roadside cisterns may have reinforced covers to reduce evaporation and to prevent humans and livestock from falling into the tanks.

In the Republic of Yemen, the first runoff after a long dry spell is often not allowed to enter the cistern because this "first flush" water is contaminated and carries too much dust and sediment. Road water collected in the roadside drainage ditch channel is typically managed by two small porter stones installed across the trapezoidal ditch channel. Mud, sand, or a piece of cloth are used to block the "gate" and divert water to the cistern. During the first flushes and later—after the cistern is filled—these temporary checks are removed. Some roadside cisterns include sediment-trapping facilities, using overflow structures and skimming the cleaner top layer of water. When designing cisterns, there are two major issues to consider: type and amount of storage, and contaminant removal.

Boxes 3.1, 3.2, and 3.3 provide examples of water cisterns used for household purposes that benefit many smallholder farmers in India, Brazil, and China, respectively.

PHOTO 3.1

Examples of roadside cisterns in the Republic of Yemen

Source: © Mohammed A. Al-Abyadh, Road Maintenance Fund, Ministry of Public Works and Highways, Sana'a, Republic of Yemen. Used with the permission of Mohammed A. Al-Abyadh. Further permission required for reuse.

BOX 3.1

Taanka or water cistern in Rajasthan, India

A taanka is a traditional rainwater harvesting technique used in the Thar Desert region of Rajasthan, India (see photo B3.1.1). A taanka is a cylindrical underground rainwater storage cistern, wherein rainwater from rooftops, a courtyard, or a natural or artificially prepared catchment flows into the paved underground pit through filtered inlets constructed on the external wall of the structure. It can potentially be used for road-runoff harvesting by diverting water from culverts. The average water storage capacity of a taanka is about 20,000 liters. Materials used for constructing them can vary from stones to bare soil, or cement or lime with *Ziziphus nummularia* thorns.

Components of a taanka include the following:

- *Circular catchment*. The catchment is 15–25 meters in diameter, paved with locally available *murrum* (stone fragments) sloping toward silt catchers.
- *Silt catcher*. Inlets into the underground tank are lined to prevent sand and suspended material from entering along with rainwater and are covered by an iron-mesh guard to prevent birds and rodents from entering the tank.

(box continues next page)

Box 3.1, *continued*

- *Storage tank*. A circular pit measuring 3 × 3.3 meters holds up to 25,000 liters of water, with a 60 × 60 centimeter opening at the top from which people draw water.
- *Outlets*. Covered vents measuring 30 × 30 centimeters allow excess water to be released.

PHOTO B3.1.1
Taanka or water cistern in Rajasthan, India

Source: Milkmen437 at English Wikipedia, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons.

BOX 3.2

One Million Cisterns program in Brazil

In the semiarid region of Brazil, 1.2 million cisterns were built between 2003 and 2016, benefiting 4.5 million people. The program was implemented through partnership agreements with Articulação Semiárido Brasileiro (ASA), a network of more than 3,000 civil society organizations, state and municipal governments, and other stakeholders. Financing came through the federal budget. To support the ASA's actions, the Association Program One Million Cisterns was established in 2002 with the Ministry of Finance as a public interest civil society organization.

(box continues next page)

Box 3.2, *continued*

The Cisterns Program has four components:

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

BOX 3.3

Cistern program in Hezhang County, China

After the severe floods of 2010 in China, 12,804 water tanks were installed to provide drinking water to 53,833 farmers in Hezhang County, China. These cisterns, or water tanks, are filled with rainwater. The water from these tanks can be used by the household (for drinking, cooking, and washing) and for livestock watering. Farmers save considerable travel time formerly required to fill water bottles and baskets. Each farmer pays only US$155 for a cellar to have water for domestic and livestock use (Meng 2011). Since the 1990s, modern rainwater-harvesting systems have been built extensively for household use and agriculture with the government's support. The rainwater catchment includes a concrete yard, roof, earth, and asphalt road surface. The water storage tanks are made from concrete or red clay and have a capacity of 20–30 cubic meters (Jiang, Li, and Ma 2013).

Using springs opened by road construction

When roads cross hilly areas and the road is constructed with deep cuts, the excavation may open up springs and seeps in mountain aquifers or in saturated soil layers (see "Changing the Mountain Environment" in chapter 6). These newly opened springs can damage cut slopes and erode land. However, they could also provide a safe water supply source (García-Landarte Puertas et al. 2014). To ensure that water quality is not threatened and that roads are not damaged, springs need to be protected.

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

- Understand the nature of the spring.
- Ensure that the spring is not a stream that has gone underground and is reemerging.
- Ensure that the source and the collection area are not likely to be polluted by surface runoff.
- Check that there are no latrines within 30 meters, particularly upstream of the spring.

- Fence the area around the spring tank to prevent pollution.
- Make sure that if the spring is to be connected to a piped water system, it is on higher ground than the area to be supplied so that the water will flow with gravity.
- Take care that the spring tank is not built on swampy ground or on land that is subject to erosion or flooding, and that the flow from the protected spring will not cause erosion or damage the road.
- Develop a collecting structure to collect the water from the spring.

Protecting the catchment of the spring and the spring head from pollution is crucial, as is arranging for the spring water to be delivered at an appropriate height so that water falls with gravity directly into a container. An inspection of the ground upstream of the spring is essential to ensure that pollution does not pose a danger or, if it does, to identify measures to prevent it.

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

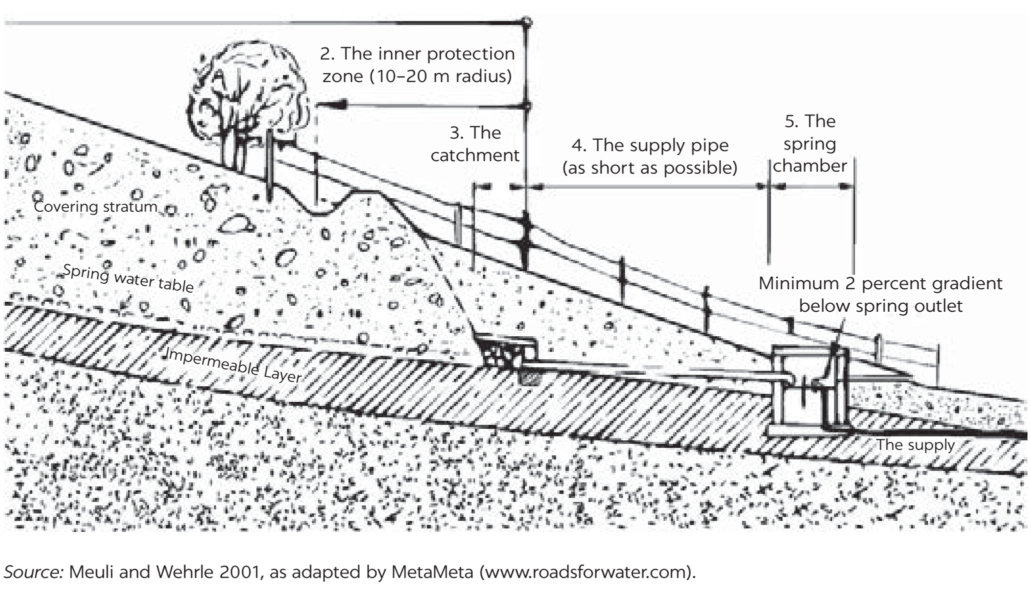
Springs can be protected by installing a spring tapping, a spring box, and a drainage system. Moreover, a surface water drainage ditch should be dug above and around the spring area to keep surface water runoff from polluting the source. If the area around a spring intake is unstable or exposed to erosion,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

Protection boxes (figure 3.2) for newly opened springs collect the spring water, which can either be diverted to infiltration structures (such as soakways) or used directly in storage structures such as open ponds or cisterns. Estimating the spring's flow rate is important for properly determining the dimensions of the collection tanks and creating spillover structures.

FIGURE 3.2

Spring protection area

1. The intake area or extended protection zone (100–150 m)



Source: Meuli and Wehrle 2001, as adapted by MetaMeta (www.roadsforwater.com).

Box 3.4 describes the advantages of protecting springs.

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

Figure 3.3 illustrates the stages in the construction of a spring collection chamber.

Stage one:

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

Stage two:

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

Stage three:

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

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

Spring Flow Rates

Seasonal rainfall variations influence spring yield. Seasonality should be studied when designing the spring system to ensure that enough water will be available during the dry period of the year. To determine the reliable yield of a spring, the spring's flow must be measured at the end of the rainy season. A flow of greater than 0.1 liter per second can fill a 20-liter container in just over three minutes, which is sufficient for many uses. If the flow is less than 0.1 liter per second,

BOX 3.4

Advantages and disadvantages of spring protection schemes

Advantages

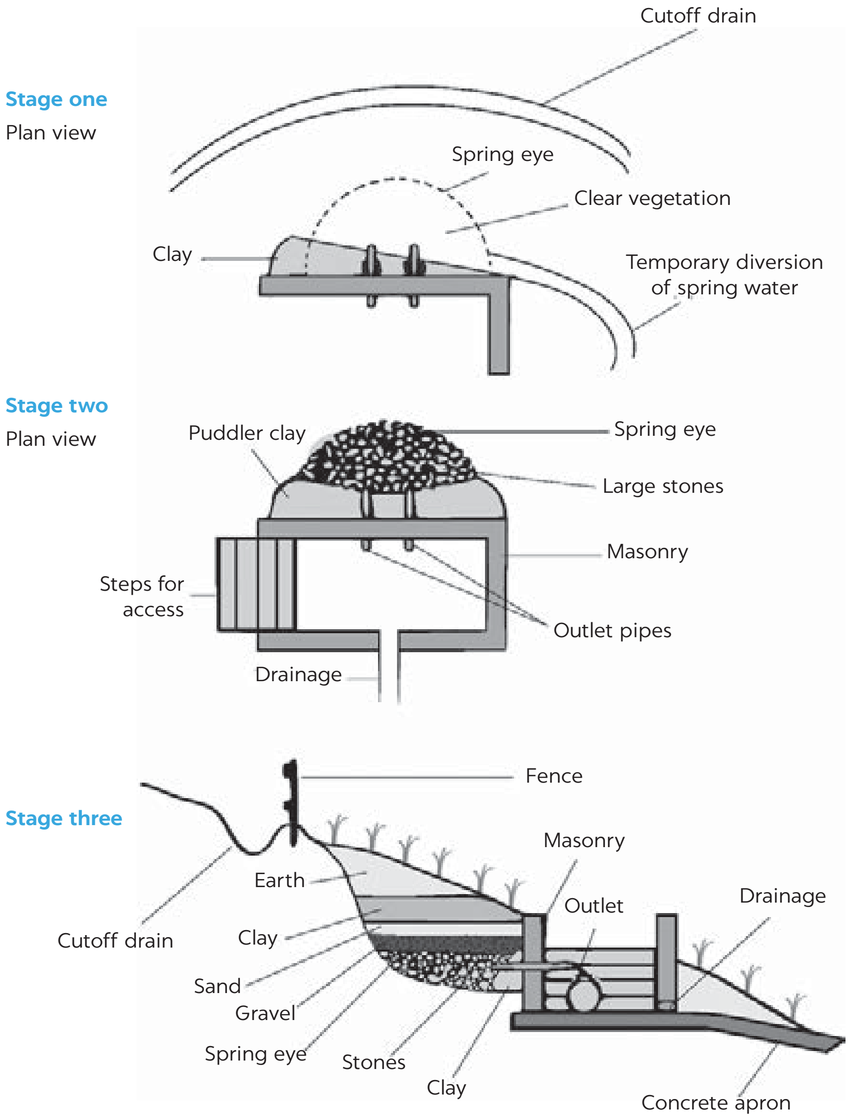
- Water coming naturally to the surface limits need for pumping
- Low maintenance and operating costs
- Can be a high-yielding source of good quality; no need for treatment

Disadvantages

- Yield can diminish or dry up during extreme drought periods
- Regular maintenance is needed around the spring head to prevent pollution

Source: WaterAid 2013.

FIGURE 3.3
Stages in spring construction



Source: MetaMeta (www.roadsforwater.com).

a storage tank can be installed to enable the flow from the spring to accumulate throughout the day. If the flow is 0.5 liters per second or more, the spring would be suitable for supplying multiple outlets or a piped gravity scheme. The choice between an open or closed (with tank) distribution system depends on the spring's capacity and the demand. When the demand is higher than the spring flow, a closed circuit with a storage tank should be installed. When the demand is lower than the spring flow, an open circuit without a tank is recommended.

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

- The distance between the catchment and the spring chamber should be as short as possible to reduce the chance of pipe blockage.
- The pipe must be laid as straight as possible and without vertical bends to prevent blockage.

- To prevent sediment buildup, the minimum supply pipe gradient from the catchment to the spring chamber should be 3 percent.
- It is recommended that an overflow pipe 5–10 centimeters higher than the supply pipe be installed.

Operation and Maintenance

Frequent maintenance of the spring area by a local caretaker and adequate operation by the community are necessary to ensure long-term usability of a spring (Bruni and Spuhler 2018).

The tasks of the caretaker should involve the following:

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

See photos 3.2–3.4 for illustrations of roadside springs.

PHOTO 3.2

Roadside spring with inadequate collection reservoir, Sardinia, Italy

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.
Note: Collection reservoir is too small, with overflow water damaging the road.

PHOTO 3.3

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

Source: © Kifle et al. 2019. Used with the permission of Kifle et al. Further permission required for reuse.

PHOTO 3.4

Roadside spring in Klotten, Germany

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

NOTE

1. "Buffer Strips: Common Sense Conservation" (https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/home/?cid=nrcs143_023568).

REFERENCES

Al-Abyadh, M. A. 2017. "War Environmental Impact along Roads in Yemen." Sustainable Pavement Design and Management, Greening Road Projects. 5th IRF Middle East Regional Congress and Exhibition, Dubai, UAE, October 29–31.

Bruni, M., and D. Spuhler. 2018. "Water Source Protection | SSWM." Sustainable Sanitation and Water Management Toolbox website. https://www.sswm.info/sswm-university-course/module-4-sustainable-water-supply/further-resources-water-sources-hardware/water-source-protection.

BUWAL. 1996. *Gewässerschutzmassnahmen beim Strassenbau: Grundlagenbericht*. Zurich: Ernst Basler und Partner.

Dierkes, C. 1999. Verhalten von Schwermetallen im Regenabfluss von Verkehrsflächen bei der Versickerung über poröse Deckbeläge. Forum Siedlungswasserwirtschaft und Abfallwirtschaft Universität GH Essen, Heft 14.

FHWA (Federal Highway Administration). 2016. "Is Highway Runoff a Serious Problem?" FHWA Environmental Technology Brief, Publication FHWA-RD-98-079, Office of Infrastructure R&D, Turner-Fairbank Highway Research Center, McLean, VA. https://www.fhwa.dot.gov/publications/research/infrastructure/structures/98079/runoff.cfm.

García-Landarte Puertas, D. K., L. Woldearegay, M. Mehta, M. van Beusekom, M. Agujetas, and F. van Steenbergen. 2014. "Roads for Water: The Unused Potential." *Waterlines* 33 (2): 120–38.

Granato, G. E., P. E. Church, and V. J. Stone. 1995. "Mobilization of Major and Trace Constituents of Highway Runoff in Groundwater Potentially Caused by Deicing Chemical Migration." Highway Research Record No. 1483, Highway Research Board, Washington, DC.

Hanes, R. E., L. W. Zelazny, and R. E. Blaster. 1970. "Effects of Deicing Salts on Water Quality and Biota." National Cooperative Highway Research Program No. 91, Highway Research Board, Washington, DC.

Heinzmann, B. 1993. Beschaffenheit und weitergehende Aufbereitung von städtischen Regenabflüssen. Fortschritt-Berichte Reihe 15, Nr.113, VDI Verlag, Düsseldorf.

Jiang, Z., X. Li, and Y. Ma. 2013. "Water and Energy Conservation of Rainwater Harvesting System in the Loess Plateau of China." *Journal of Integrative Agriculture* 12 (8): 1389–95.

Kifle, W., G. Berhane, A. Taye, M. Kebede, and A. P. Marta. 2019. "Practices and Hydrological Effects of Road Water Harvesting in Northern Ethiopia: Towards Design of Multi-Functional Infrastructures." *Momona Ethiopian Journal of Science* 11 (2): 159–86.

Krauth, K. H., and H. Klein. 1982. Untersuchung über die Beschaffenheit des Oberflächenwassers von Bundesautobahnen, Teil II: Untersuchungen an der BAB-A6. Schriftenreihe Forschung Straßenbau und Straßenverkehrstechnik, BMV, Heft 363.

Meng, J. 2011. "Cisterns Secure Drinking Water in SW China." People's Daily Online, August 8. http://en.people.cn/90882/7562987.html.

Morschel, J., D. Fox, and J.-F. Bruno. 2004. "Limiting Sediment Deposition on Roadways: Topographic Controls on Vulnerable Roads and Cost Analysis of Planting Grass Buffer Strips." *Environmental Science and Policy* 7 (1): 39–45.

Meuli, C., and K. Wehrle. 2001. *Spring Catchment*. Gallen, Switzerland: SKAT, Swiss Centre for Development Cooperation in Technology and Management.

National Research Council. 1994. *Ground Water Recharge Using Waters of Impaired Quality*. Washington, DC: National Academies Press. https://www.nap.edu/read/4780/chapter/4#36.

NSW Agriculture. 2003. *Roads and Salinity*. Sydney: Department of Infrastructure, Planning and Natural Resources.

ÖWAV. 2002. Regelblatt 35 – "Behandlung von Niederschlagswässern," Regeln des österreichischen Wasser- und Abfallwirtschaftsverbandes, Österreichisches Normungsinstitut.

Pfeifer, R. 1998. Schmutzstoffrück halt durch chemisch-physikalische Regenwasserbehandlung im Trennsystem22. Schriftenreihe des Institutes für Siedlungswasserwirtschaft Universität Karlsruhe, Band 92, Verlag Oldenbourg, München.

Pritchard, O. G., S. H. Hallett, and T. S. Farewell. 2015. "Soil Geo-Hazard Mapping for Improved Asset Management of UK Local Roads." *Natural Hazards and Earth System Sciences* 15 (9): 2079–90.

US EPA (United States Environmental Protection Agency). 1983. "Results of the Nationwide Urban Runoff Program." Final Report, Water Planning Division, Washington, DC.

Valentyne, A., K. Crawford, T. Cook, and P. D. Mathewson. 2018. "Polycyclic Aromatic Hydrocarbon Contamination and Source Profiling in Watersheds Serving Three Small Wisconsin, USA Cities." *Science of the Total Environment* 627 (June): 1453–63.

van Steenbergen, F., K. Woldearegay, M. Agujetas Perez, K. Manjur, and M. A. Al-Abyadh. 2018. "Roads: Instruments for Rainwater Harvesting, Food Security and Climate Resilience in Arid and Semiarid Areas." In *Rainwater-Smart Agriculture in Arid and Semi-Arid Areas*, edited by Walter Leal Filho and Josep de Trincheria Gomez. Cham, Switzerland: Springer International Publishing.

WaterAid. 2013. "Protection of Spring Sources." Technical Brief. WaterAid.

WHO (World Health Organization). 2003. "Polynuclear Aromatic Hydrocarbons in Drinking Water: Background Document for Development of WHO Guidelines for Drinking-Water Quality." WHO/SDE/WSH/03.04/59, World Health Organization, Geneva.

WHO (World Health Organization). 2014. *Investing in Water and Sanitation: Increasing Access, Reducing Inequalities*. Geneva: World Health Organization.

WHO (World Health Organization). 2017. *Guidelines for Drinking Water Quality*. Fourth Edition incorporating the first addendum. Geneva: World Health Organization.

Wilson, P. J. 1999. "Pollution from Highway Runoff: The Highways Agency Approach." SCI Lecture Papers Series, Highways Agency, London.

Woldearegay, K., L. Tamene, and F. van Steenbergen. Forthcoming. "Groundwater Recharge through Landscape Restoration and Surface Water Harvesting for Climate Resilience: The Case of Tekeze River Basin, Northern Ethiopia."

Yousef, Y. A., H. H. Harper, L. P. Wiseman, and J. M. Bateman. 1985. "Consequential Species of Heavy Metals in Highway Runoff." *Transportation Research Record* 1017: 56–62.

4 Roads for Water Harvesting in Semiarid Areas

KEY MESSAGES AND KEY TECHNIQUES

Key messages

- Traditional road designs often change surface hydrology in semiarid areas in ways that cause extensive erosion, flooding, and sedimentation and expose the road bodies to considerable damage.
- Because roads act as barriers and drains for rain runoff, they can also be used for large-scale water harvesting, which can boost community livelihoods and water security at a potentially large scale.

Key techniques

- Several techniques can be undertaken to make use of road infrastructure to systematically divert or retain water in semiarid areas, including floodwater spreaders, flow dividers at culverts, and road drifts or the development of road embankments that serve as storage reservoirs.
- Road drainage can be connected to water storage, such as infiltration trenches, converted borrow pits (chapter 8), or farm ponds (chapter 11).

OBJECTIVE

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

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

This chapter advocates for systematically optimizing the effect of roads on moisture and water in semiarid areas and for combining water harvesting and road building as much as possible. The sheer magnitude of road programs makes them a powerful asset for retaining water in semiarid areas (photo 4.1). Moreover, as discussed in the first chapter, beneficial road-water management is a triple win because in semiarid areas it can also contribute to reduced damage to roads.

OPPORTUNITIES

If a road map were to be overlaid on a soil moisture map, strong correlations would likely appear. Because roads influence surface and subsurface flows, the moisture in a landscape can be significantly affected by the location of roads and how those roads are constructed. Roads can block surface and subsurface flows, creating moist stretches upstream of the road and dry patches downstream. Road drifts in riverbeds, if properly constructed, may retain subsurface flows and spread floods, again enriching the moisture in the area. Conversely, erosion from culverts and road drainage may create gullies that deplete the moisture around them.

PHOTO 4.1

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Road infrastructure can be used to harvest water and redistribute runoff to areas where it can play a beneficial role. A road can act either as an embankment that guides water or as a drain that channels rainwater. These functions can be used to systematically enhance water management. The amount of water that can be harvested depends on the rainfall pattern, the catchment area enclosed by the road, and the land use and soil characteristics within the catchment area. For a road to act as a water-harvesting mechanism, the road-drainage mechanism needs to be well developed, which can be achieved by locating the road on an elevated embankment and constructing an appropriate system of side drains or cross drains, or by integrating suitable drainage structures into the road surface such as water bars and rolling dips. (Rolling dips are suitable for unpaved roads and are described in chapter 10.)

Table 4.1 presents order-of-magnitude estimates of the volume of water (in cubic meters) that can be harvested from 1 kilometer of road equipped with drainage facilities designed for intensive water harvesting.

The challenge is not only to capture the rainfall runoff, but also to store it for later use. Runoff in the landscape that is guided by road infrastructure can be stored in three different ways (see figure 4.1):

- 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

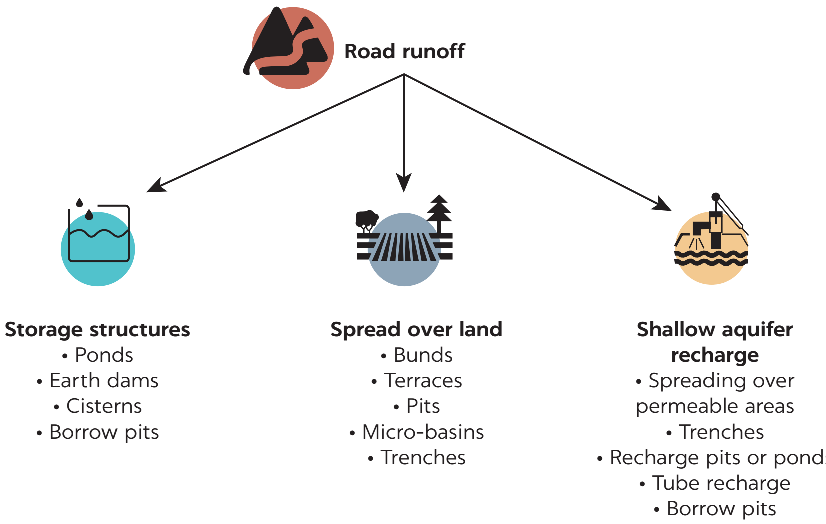
Some of the differences between these storage methods are summarized below. In semiarid climates, all three storage methods can usually be used simultaneously. In many cases, road-water harvesting can be part of larger watershed improvement programs that deploy a broad range of methods to capture and store runoff, with road-water management being a part of this process (see box 4.1).

TABLE 4.1 Volume of water that can be harvested from 1 kilometer of road

	HARVESTED WATER VOLUME (CUBIC METERS)								
	350 MILLIMETERS ANNUAL RAINFALL			500 MILLIMETERS ANNUAL RAINFALL			700 MILLIMETERS ANNUAL RAINFALL		
Catchment area (hectares)	Runoff coefficient			Runoff coefficient			Runoff coefficient		
	10%	20%	30%	10%	20%	30%	10%	20%	30%
10	3,500	7,000	10,500	5,000	10,000	15,000	7,000	14,000	21,000
15	5,250	10,500	15,750	7,500	15,000	22,500	10,500	21,000	31,500
20	7,000	14,000	21,000	10,000	20,000	30,000	14,000	28,000	42,000
30	10,500	21,000	31,500	15,000	30,000	45,000	21,000	42,000	63,000
50	17,500	35,000	52,500	25,000	50,000	75,000	35,000	70,000	105,000
100	35,000	70,000	105,000	50,000	100,000	150,000	70,000	140,000	210,000
500	175,000	350,000	525,000	250,000	500,000	750,000	350,000	700,000	1,050,000

Source: MetaMeta, (www.roadsforwater.org).
Note: This table presents the approximate volume of water that can be harvested for a given design rainfall, runoff coefficient, and catchment area. The design rainfall for water-harvesting structures is usually the minimum level of rainfall with a 67 percent probability of occurrence based on seasonal rainfall records for at least 30 years (see "Design and Layout of Roadside Farm Ponds" in chapter 11 for how to calculate design rainfall). Each of the design rainfalls is assumed to have three different runoff coefficients (10 percent, 20 percent, and 30 percent). The table presents simplified estimates and does not rely on measurements of actual runoff, the intensity of individual rainfall events, the shape of the catchment, or losses on the way to the storage point.

FIGURE 4.1
Water runoff



Source: MetaMeta (www.roadsforwater.com).

BOX 4.1

Road-water harvesting campaigns in Ethiopia: Mobilizing millions to increase resilience

The annual mass mobilization campaigns in Ethiopia (photo B4.1.1) mobilize millions of people to work on soil and water conservation and water harvesting. The main goal of mass mobilizations is to reverse severe land degradation and retain water runoff in the landscape. Activities undertaken during the mass mobilization are mostly carried out on cultivated lands. The 2016–17 road and hillside water-harvesting campaign in Amhara Region involved 1,450,000 persons and benefited 751,000 people. In Tigray, 1,306,000 persons were involved and 409,000 directly benefited.

The campaign requires extensive coordination but is largely planned at the local level, including by landowners. The target area is defined by administrative and watershed boundaries. The regional, *woreda* (district), and *kebele* (subdistrict) administrators, specialists, and development agents coordinate work planning and implementation. Planning and measurement are conducted by land users themselves. Implementation plans are later discussed with the communities.

To carry out the work, men, women, and youth contribute 20–30 days of free labor during the February–April slack labor season. The approach involves organizing land users in development teams of 20–30 members, which are further divided into work teams of 5 members. Women and men participate equally in the work groups and as team leaders. At the end of each day, each work group evaluates its activities and discusses plans for the coming days.

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

The hydrological and socioeconomic impact of these technologies has been measured since 2015. Monitoring data have shown an increase of 1.2–2.0 meters in groundwater levels during the dry period.

(box continues next page)

Box 4.1, *continued*

PHOTO B4.1.1

Road-water harvesting as part of the mass mobilization campaign in Amhara, Ethiopia, 2018

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Soil moisture next to the road has increased up to 100 percent in some cases, and farm productivity has risen by 35 percent on average. Moreover, the campaign has produced the added benefits of protecting roads from erosion, limiting flooding and sedimentation, and drastically reducing damage to the landscape.

Detailed data collection has enabled analysis of costs and benefits. The road-water harvesting measures are estimated to cost US$1,800 per kilometer and to produce benefits of US$16,879 per kilometer. These benefits include reduced downtime and road maintenance, reduced damage from erosion, reduced flooding and waterlogging, and beneficial use of harvested water.

- The storage capacity of surface reservoirs such as ponds and borrow pits is limited to the size of the basin, but the water is readily available at the surface. Surface storage systems also suffer losses from evaporation. Chapters 8 and 11 describe the development of borrow pits and ponds.
- In contrast, much greater quantities of water can be stored in the soil, in shallow aquifers, or both, provided that the geology of the area is suitable. The water storage capacity of soil varies according to the soil texture. Table 4.2 compares the storage capacity of different soils.

TABLE 4.2 Available water in different soils in the Abyan Delta, Republic of Yemen

SOIL TEXTURAL CLASS	AVAILABLE WATER IN 1 METER SOIL DEPTH (MILLIMETERS)
Loamy sand	39
Sandy loam	83
Silt loam	163
Clay loam	170
Silty clay loam	202

Source: van Steenbergen et al. 2010.

- The infiltration characteristics and the capacity of shallow aquifers to store water differs with the type of geological formation, the soil crust, and the type of rainfall (heavier rainfall means more infiltration).
- The recharge capacity of shallow aquifers can be enhanced by techniques that accelerate runoff infiltration such as infiltration trenches or infiltration ponds, tube recharge (called *bhungroo* in India), or well recharge. These techniques are presented in more detail later in this chapter.
- Techniques such as mulching or deep plowing may be used to preserve moisture in the soil profile and ensure its availability in the growing season (van Steenbergen et al. 2010). Chapter 11 on roadside farm ponds describes this technique.
- Shallow aquifer storage has several advantages over surface water storage. For instance, shallow aquifer water is available for a long time (whereas surface storage systems are depleted over time because of evaporation) and can be accessed on demand, making it suitable for precision uses. The disadvantage of shallow aquifer storage is that the water must be pumped up, but there are many low-cost solutions to this challenge. Very shallow groundwater is therefore among the optimal storage options; low-cost centrifugal pumps or solar pumps have the suction required to lift water up to 10 meters, making smallholder irrigation possible as a route from poverty to prosperity.
- Sediment in surface runoff is an important consideration in water-storage systems. Surface storage reservoirs gradually fill up with this sediment and need to be cleaned. In contrast, sediment generally does not need to be cleaned from soil moisture storage or shallow groundwater recharge systems. In fact, silt often improves the soil structure and is a rich source of micronutrients. Whereas sediment is a problem in surface storage, it can be an asset for soil moisture storage strategies. In the case of groundwater recharge, fine sediment such as clay may also pose a problem because it may seal the soil surface and reduce the infiltration capacity of the underlying shallow aquifer. This sealing may be prevented by regular plowing or by the action of soil (rain worms, sow bugs, or termites) that tends to take fine sediment down from the surface and mix it with lower soil layers.

GENERAL PRINCIPLES

A few general principles underlie water harvesting in semiarid regions. The first of these is that runoff is preferably intensively managed throughout the entire water catchment. A large proportion of the runoff in a catchment can be retained by implementing several water conservation techniques—such as retention ponds, soak pits, infiltration galleries, terraces, and eyebrows—throughout the watershed. In untreated areas, approximately 8–12 percent of the runoff is retained, but intensive water harvesting can double or triple this proportion, potentially exceeding 30 percent of the runoff. Harvesting larger amounts of water can also reduce the volume of potentially destructive stormwater in the lower part of the watershed. Intensive water retention can store a large amount of water and can change the water cycle of large areas by affecting water availability for crops and soil processes that accelerate natural fertilization, and by creating microclimates that are more conducive to vegetation and agriculture, thus reducing the risks of drought and water scarcity. Moreover, intensive catchment treatment that includes systematic use of all road-water harvesting opportunities can bring sedimentation under.

The second principle for water harvesting is to slow down runoff by guiding water to level land and spreading it. Water runoff loses its erosive nature at slower speeds, and sediments can settle. Reducing the speed of runoff also enables water infiltration to increase. Installing check dams, guiding water from steep slopes, building terraces and furrow ditches, and other techniques can be used to slow water runoff speeds. As more stormwater infiltrates the soil, less water must be managed as surface runoff.

Third, water users' needs should be the central concern in water harvesting. The priorities of roadside users need to be discussed during the planning, design, and implementation stages of water-harvesting projects. These discussions must take into consideration all possible alternative water-harvesting mechanisms and the purposes to which the harvested water will be put. An example of water harvesting use is shown in the below picture (photo 4.2). For instance, gender is

PHOTO 4.2

Fodder grown from road culvert water, South Gondar, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

an important consideration in this process: in Ethiopia it was found that women in poor, female-headed households are less equipped to prepare their land for road-water harvesting, for instance, because they lack access to animal traction (Demenge et al. 2015). Additionally, different livelihood systems also have different water-harvesting demands. For instance, in many semiarid areas, smallholder or household-scale irrigation supplements rainfed systems. If rainfall is scarce or not sufficiently timely, water harvesting from roads could help during periods of scarcity, or water can be added to the buffer capacity. Shallow groundwater extraction and small storage structures could serve this purpose. Pastoralist communities' need for grazing lands is best served by water-harvesting techniques that spread sheetflows over extended areas. Finally, commercial farming, which usually has high water demands, can be served by medium- to large-scale surface storage such as borrow pits, earth dams, and ponds.

The final general principle is that the sustainability of road-water harvesting structures needs to be ensured. Some earthwork structures will need regular repair. Water users will need to establish routines for inspecting the water management systems periodically (after each rainy season) and modify or improve the systems as required to address impacts such as erosion or overflowing, and remediate any health, safety, and environmental concerns. Water-harvesting systems must include adequate measures to prevent mosquito breeding and waterborne diseases arising in standing water (see chapter 8).

ROAD SAFETY PRINCIPLES

Vehicles, running off the road and hitting fixed objects is a major source of road fatalities on all kinds of roads, and especially on rural and interurban roads. Whether vehicles leave the carriageway because of driver impairment (by alcohol or other substances), fatigue, or distraction, the presence of structures, existing trees, or intentionally planted trees can increase the risks of fatality or serious injury for vehicle occupants. Culvert endwalls, bridge endposts, water-diversion structures, or any other structure above the ground surface on the roadside can increase these road safety risks. Errant vehicles also pose a risk to nonmotorized road users who may be maintaining or operating roadside water-harvesting systems. These risks are important considerations in rural and interurban roads.

The appropriate strategies for reducing these risks depend upon the surrounding context. Travel speeds should be lower when roads pass through settlements, but it is often very difficult to coax drivers into reducing their speeds. Appropriate safety barriers can protect vehicle occupants from collisions with roadside structures or trees and protect people on the roadside from being struck by errant vehicles. The roadside structures can also sometimes be constructed at or below ground level. Certain kinds of structures, including trenches, including structures for water management, could be constructed a substantial distance away from the carriageway without reducing their efficiency to prevent cars from sinking into them.

Travel speeds on the carriageway will dictate the "clear zone" (for example, lateral offset) distance to any introduced object on rural roads. Clear zone requirements for any roadside object are substantial if future collisions are to be avoided, and more recent analysis (Doecke and Woolley 2010) shows that the necessary clear zone may be well in excess of traditional offset requirements (for example, see the American Association of State Highway and Transportation

Officials). There is also a need to provide, as much as possible, roadside surfaces that enable errant vehicles leaving the carriageway to safely navigate these areas and come to a halt without overturning or hitting other objects.

Vertical or very steep drops of more than 150 millimeters at the edge of the carriageway need to be avoided in construction of roads. Formed shoulders or hardstanding areas of 1.0–1.5 meters' width should be provided at the edge of the carriageway, with gently sloping embankments beyond these hardstanding or recovery areas. Alternatively, barriers to prevent vehicles leaving the carriageway and overturning on the roadside will be necessary.

It is also necessary to consider the consequences of unsafe water flows over roads and how to minimize loss of life in those circumstances.

Unsafe water flows over roads

Water flows over roads pose specific safety challenges, including the prevention of collisions between vehicles and nonmotorized road users who are traveling along or crossing roads in the vicinity of floodways, and the protection of pedestrians as much as possible from floodwater flows on floodways. Precautionary measures are vital to such facilities, such as the following:

- Following engineering guidance in designing measures that protect pedestrians crossing roads in times of flooding from impact with vehicles
- Reducing the likelihood of pedestrians drowning while attempting to cross floodways at high flow periods by providing marker posts showing the water flow depth and providing clear signage warning pedestrians against crossing when water depths exceed 75 millimeters

TECHNIQUES FOR ROAD-WATER HARVESTING

A range of techniques can be used for harvesting water from roads in semiarid areas, as shown in table 4.3; there are also different types of storage. The choice of water-harvesting techniques in semiarid areas will depend upon topography, subsurface conditions and soils, climate, and the economics of potential land uses near the road. For instance, in sloped areas it is easier to collect and store water by making use of drainage patterns created by the natural topography. In contrast, flat areas offer more opportunities to spread water over large areas but face greater challenges related to waterlogging and sedimentation. This section discusses the main water-harvesting techniques.

Floodwater spreaders along road surfaces

Water can be harvested directly from the road pavement. This approach offers limited water collection potential compared with the broader repertoire of road-water-harvesting techniques that focus on harvesting water corralled by road embankments and drainage systems.

A well-graded and compacted surface will generate a conspicuous amount of runoff water. Asphalt-paved roads have a rainwater collection efficiency (runoff coefficient) of 0.65 to 0.75 (ERA 2011). For an unpaved road, the runoff coefficient varies more, from 0.25–0.30 in semiarid areas to 0.80 during heavy storms. This means that if yearly rainfall is 500 millimeters, then 325–375 cubic meters

TABLE 4.3 Water-harvesting techniques from roads and applicable storage

HARVESTING TECHNIQUE	SURFACE STORAGE	SOIL MOISTURE STORAGE	SHALLOW GROUNDWATER RECHARGE
Floodwater spreaders along road surfaces		✓	
Flood diversions from culverts and road drainage		✓	✓
Infiltration structures fed from road drainage			✓
Cascading irrigation from road drainage			
Surface storage fed from road drainage (borrow pits, ponds, and cisterns)	✓		✓
Road bodies used as dams for water storage	✓		
Raised road embankments with raised culverts	✓	✓	✓
Road crossings used as sand dams or as water-spreading structures		✓	✓

Source: MetaMeta (www.roadsforwater.com).

of water may be collected from a 20–50 meter stretch of paved road. In humid or subhumid areas, the runoff coefficient from unpaved roads is higher because of the frequent rain and higher soil moisture. Runoff generated by the road surface can be diverted directly to farmland, recharge areas, or storage ponds through the use of drainage techniques.

A common technique is to have a series of floodwater spreaders alongside paved road surfaces.[1] These spreaders will guide the runoff from the road surface to farmland immediately adjacent to the road and contribute to greater soil moisture. They consist of low (30 centimeter) curved structures made of local material that can be used for collection. They are inexpensive to build but need to be rebuilt annually.

Water collected from paved road surfaces may have a high proportion of hydrocarbons and other pollutants from traffic, which makes the use of water from the road surface generally unsuitable for human or animal consumption. The degree of pollution is a function of traffic intensity and rainfall levels and frequency. For example, measurements along a paved highway section in Ethiopia were unable detect the presence of oil or grease (Woldearegay 2016). Nevertheless, direct road-water harvesting should be avoided in areas with heavy traffic: the pollution from hydrocarbons and oils may prohibit the reuse of road water. Chapter 3 addresses use of road surface runoff in greater detail.

Flow diversions from culverts and road drainage

Most of the water collected through road-water harvesting consists of surface runoff from the landscape adjacent to roads, not just the road surface. Road embankments and drainage systems collect and divert this water to a limited number of culverts. This approach epitomizes how road development changes drainage patterns across landscapes. Concentrating runoff and directing it through culverts will always create a risk of erosion downstream of the culverts. Gullies so created may even "creep" upstream and destroy the road body. Therefore, one of the key principles of road-water harvesting is that runoff should be diverted away from the culverts in ways that protect downstream land and make beneficial use of water.

Applying the principles of road-water harvesting also requires that the dimensions and appurtenant structures of road culverts be optimized during design. Research on 15 culverts by Berhe (2018) along the Freweyni–Hawzien–Abreha We Atsbeha road in Tigray (Ethiopia) found that design changes could reduce erosion by 15 percent and increase water-harvesting potential by 25 percent. Table 4.4 summarizes these modifications.

Various kinds of auxiliary structures may also be constructed to gently divert flow from culverts to where water will be used or conserved. These structures may be constructed of a range of materials with different alignments, widths, and heights. V-shaped flood diverters are typically most appropriate because they dissipate energy from the culvert runoff (photo 4.3 and figure 4.2). If the flow from the culvert comes at a low velocity, a diversion structure will be adequate. The structures should also be placed at a reasonable distance of at least three meters from the culvert outlets to avoid creating sedimentation inside the culvert.

Flows from culverts on steep slopes have high scouring potential. These conditions are ideally addressed with energy dissipaters located a safe distance from the culvert outlet (to avoid creating full flow conditions inside the culvert barrel). The flow diversion structure should then be placed next to the energy dissipater.

TABLE 4.4 Culvert design changes along Freweyni–Hawzien–Abreha We Atsbeha road in Tigray, Ethiopia

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

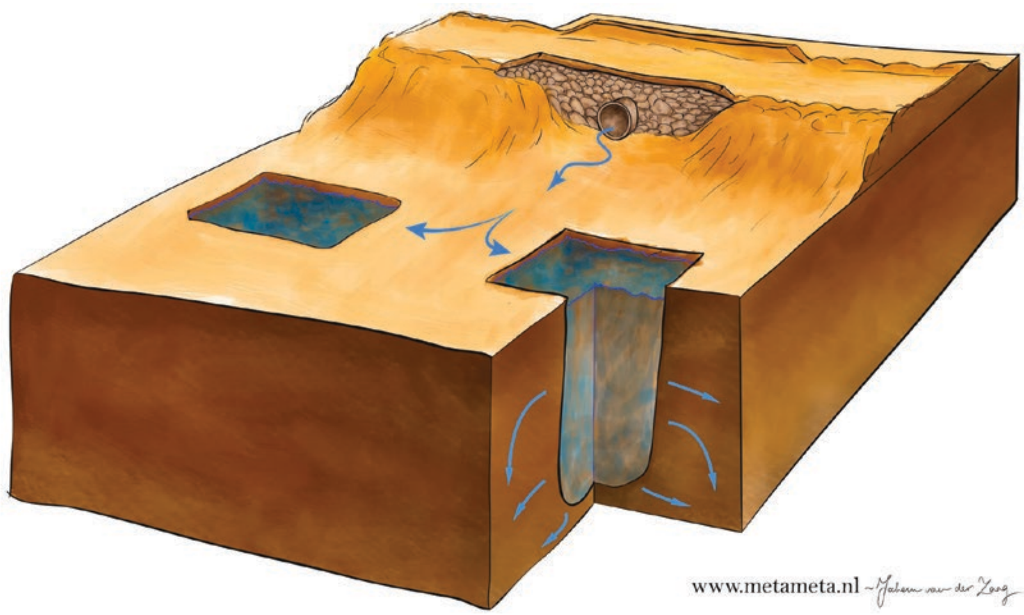
Source: Berhe 2018.

PHOTO 4.3

V-shaped diversion structures constructed from soil and stone to spread water from culverts, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

FIGURE 4.2
V-shaped diversion structure constructed from soil and stone to spread water from culvert, Ethiopia



Source: MetaMeta (www.roadsforwater.com).

Infiltration structures fed from road drainage

The purpose of cross drains and side drains is to evacuate water away from road structures. Although the drains are often placed without consideration of the opportunities for water use or storage, modest earthworks can ensure this water is used. Water from road drains, either culverts or lead-out ditches (or mitered drains), can be guided directly to groundwater recharge structures. Most common are infiltration trenches, recharge wells, and infiltration ponds, as shown in photos 4.4, 4.5, and 4.6.

Infiltration trenches are popular in Ethiopia and have contributed to rising groundwater levels. For instance, wells are currently usable in several areas where groundwater was not previously present. Infiltration trenches consist of a chain of individual percolation ponds with water overflowing from one pond to the next. Constructing chains of ponds in steep terrain limits scour by allowing water to overflow from one pond to the next in the trench. Typical dimensions for a single percolation pond in a trench are 1.5 meters long by 0.4 meter wide by 0.5 meter deep. The infiltration trenches should be placed at a safe distance of at least 20 meters from the road body on the downhill side to keep them from soaking the soil and affecting the road subgrade. Alternatively, the infiltration trench is led away from the road body, as shown in photo 4.3.

It is imperative that infiltration trenches be located far enough from the edge of the road to avoid being a safety hazard and to avoid causing constant soaking of the road subgrade. Photo 4.7 provides an example of an infiltration trench that is located too close to the road.

PHOTO 4.4

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 4.5

Collecting road water for groundwater recharge: Recharge well, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 4.6

Abandoned borrow pit, Mozambique

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 4.7

Infiltration trench located too close to the roadside, Malawi

Source: © Macpherson Nthara. Used with the permission of Macpherson Nthara/MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Directing Water to Retaining Ponds/Ditches Bodies at the Roadside

Runoff can also be guided to recharge wells or percolation ponds, which collect the water for recharge into shallow aquifers. In some cases, these bodies may be abandoned dug wells or out-of-use borrow pits. It is important that these recharge structures penetrate a water-bearing layer with good transmissivity (ability to convey water) and spare storage capacity (not saturated). Such conditions are easily found in most semiarid areas.

Excavation of drainage ditches or ponds adjacent to the road carriageway often results in unsafe roadside conditions for a vehicle leaving the carriageway. If excavated treatments are needed for conveying or storing water, they should be located well away from the carriageway (usually more than 20 meters or more if possible, depending on the travel speeds on the road) and if not, road users should be protected by appropriate safety barriers.

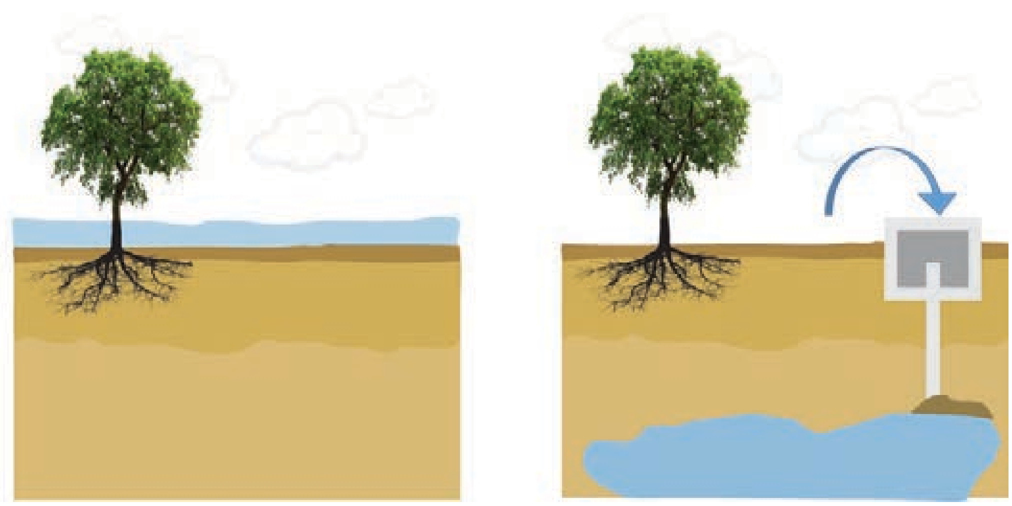
Special tube recharge wells, or *bhungroo* as they are called in Gujarat, India, are a further, sophisticated means of improving infiltration (figure 4.3). These recharge wells collect excess water during the rainy period and are best situated in areas that are temporarily inundated. The land is slightly tilted toward the recharge well, so that it "feeds" the well with water. The bhungroo are equipped with small cemented collection structures measuring 1.5 by 2.0 meters. The top of the recharge pipe sticks out of the bottom of the collection unit to prevent the entry of sediment and dirt. The recharge pipes are between 30 meters and 100 meters deep, and between 10 centimeters and 15 centimeters in diameter. They should penetrate into a sandy layer within this depth; a slotted screen is placed at the top of the pipe to limit debris ingress.

Cascading irrigation fed from road drainage

Water from road drainage can also be applied directly to the land through a single, leveled ditch located at the top of a field from which water spills evenly into the field downstream, preferably by furrows. This approach prevents water from the road-drainage system from immediately submerging the crop

FIGURE 4.3

Tube recharge well (bhungroo) collecting excess water for recharge



Without bhungroo **With bhungroo**

Source: MetaMeta (www.roadsforwater.com).

and causing damage. The field must have a very even, continuous gentle slope to avoid erosion and water ponding. A variation on this technique is used in relatively level humid areas, where a single road ditch is used in two ways: during rainy periods as a drainage ditch collecting excess water, and during dry periods as the source of supplementary irrigation.

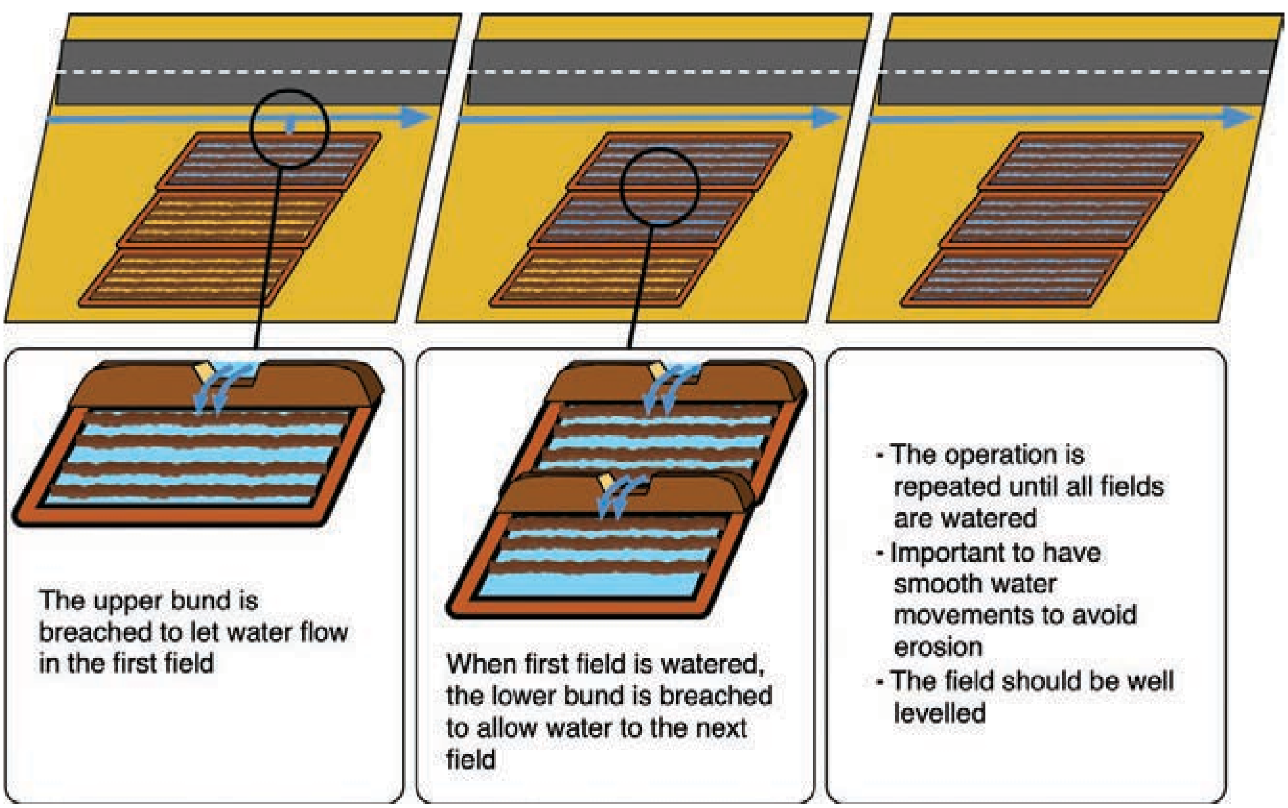
In a more elaborate system, the water collected from the road can serve a cascade of fields (figure 4.4). The fields are divided into subbasins. Water is allowed in the uppermost basin. Once a field is filled, its retaining bund is breached to allow water to enter the next field downslope. This system is commonly used to grow rice in slightly undulating areas.

Alternatively, water can also be routed to a series of planting pits that are connected to each other by ditches (figure 4.5). Once a pit is filled, water continues to the next pit. This system is typically used to grow high-value trees. These three systems all require a degree of control at the point of water intake; not all road-drainage water is necessarily used.

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

Road runoff can also be collected in surface storage such as small ponds, dams, borrow pits, or cisterns. Borrow pits can be systematically used as recharge, storage, or seepage ponds. These pits are excavations of source materials—sand, gravel, soil—for road construction and are usually located very near the road itself. The planned "second life" of borrow pits is discussed in chapter 8.

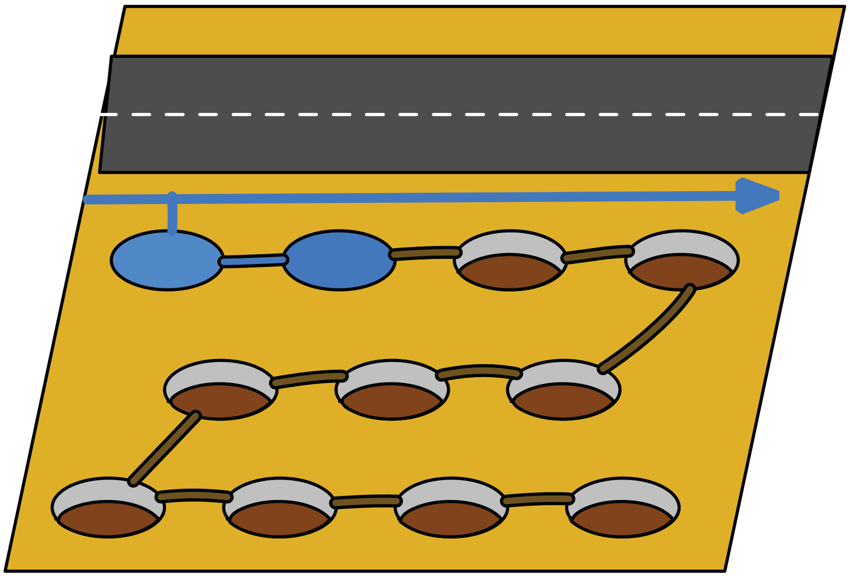
FIGURE 4.4
Cascading irrigation sequence



Source: MetaMeta (www.roadsforwater.com).

FIGURE 4.5

Road runoff directed to interconnected soaking pits



Source: MetaMeta (www.roadsforwater.com).

Another option is development of ponds for road-water storage, as discussed in detail in chapter 11. Cisterns or covered storage can also be used to protect the water from external pollutants and to reduce evaporation. Because of their greater cost, cisterns are used for domestic water or high-value productive use (see chapter 3).

Road bodies used as dams

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

- Dam walls creating storage by blocking valleys,
- Side embankments of reservoirs (photos 4.8 and 4.9), or
- Guide bunds channeling water to storage ponds.

When roads double as dam walls or side embankments, some concern about their safety is warranted. All safety measures related to dams would apply to ensure the safety of these structures. These measures include regular inspection of seepage and cracks, provision of spillways and emergency escapes, and protection from damage by livestock or rodents. Furthermore, as noted in chapter 13, if appropriate mitigation measures are not implemented during the construction and operation of the road, the long-term soakage of a clay embankment can lead to the loss of bearing capacity of the road itself, causing the road to fail prematurely.

Storage reservoirs must also function safely to ensure the road itself is not undermined by the impact of seepage on subgrades. Ensuring safe functioning may require special side protection through clay sealing, riprap, or geotextiles. Protecting road users from leaving the road carriageway and encountering the water body is also necessary.

PHOTO 4.8

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 4.9

Lightly armored road embankment for storing water, Burkina Faso

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.
Note: Safety barriers should be present to prevent errant vehicles from entering the body of water.

Raised road embankments with raised culverts

One variation on the use of road embankments for water storage is the use of raised road embankments with raised culverts. A raised embankment placed in the drainage path or in a depression area will retain water runoff, which can then be used in surface storage, for recharge, or to improve soil moisture. This technique is demonstrated in photo 4.10. This approach can improve grazing areas or wetlands. The culverts in these road sections are raised, and storage capacity is a function of the enclosed area and the height difference between culverts and ground level.

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

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

Depending on the depth of the riverbed, fords will also slow subsurface flows and retain groundwater upstream. Wells or infiltration galleries can then be constructed to gain access to the water retained upstream of the ford. This capacity

PHOTO 4.10

Raised road embankment and raised culverts creating local wetland in Kotomor, Agago (northern region, Uganda)

Source: © Aidenvironment. Used with the permission of Aidenvironment. Further permission required for reuse.

to store and retain shallow groundwater is highly relevant in arid regions and improves water access and availability. Chapter 9 provides a detailed description of the use of road drifts and similar approaches.

A closely related technique is to use water-spreading weirs combined with river road crossings. These structures have been developed with considerable success in several Sahelian countries, including Niger (photo 4.11). Water-spreading weirs route temporary floods out of dry riverbeds to inundate surrounding areas. The water-spreading weir serves as the main river crossing; roads connecting to the weir or river crossing further spread the floodwater. In this way, the combination of the river crossing with embanked roads leading to it acts as a large flood spreader (figure 4.6). Drop structures and cross drainage are added to the water-spreading weirs to ensure their stability. Arid and semi-arid environments are thus regreened with forest and grass species (GIZ and KfW 2013).

Embankments without safety barriers (and without a water body below the slope) should have trafficable slopes to allow for an errant vehicle leaving the carriageway. Embankment side slopes should not be steeper than two units horizontal to one unit vertical.

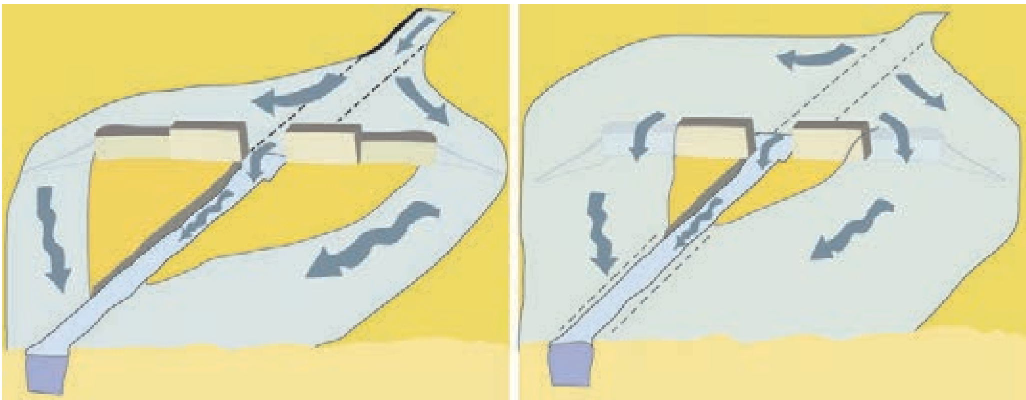
PHOTO 4.11

Water-spreading weir, Ethiopia

Source: © GIZ-SDR Project (Heinz Bender). Used with the permission of GIZ-SDR Project. Further permission required for reuse.

FIGURE 4.6

Water can be directed around and over water-spreading weirs, depending on water depth



Source: MetaMeta (www.roadsforwater.com).

NOTE

1. Low earthen structures less than 150 millimeters in height at 3–5 meters offset from the edge of the carriageway are preferred. Taller structures should be placed a safe distance (15–20 meters) away from the edge of the carriageway.

REFERENCES

Berhe, A. W. 2018. "Improving the Design of Road Hydraulic Structures for Water Harvesting: The Case of Freweyni–Hawzien–Abraha–We–Atsbeha Road, Tigray, Ethiopia." Doctoral dissertation, Mekelle University, Mekelle, Ethiopia.

Demenge, J., R. Alba, K. Welle, K. Manjur, A. Addisu, L. Mehta, and K. Woldearegay. 2015. "Multifunctional Roads: The Potential Effects of Combined Roads and Water Harvesting Infrastructure on Poverty in Ethiopia." *Journal of Infrastructure Development* 7 (2): 165–80.

Doecke, S., and J. Woolley. 2010. "Effective Use of Clear Zones and Barriers in a Safe Systems Context." Presented at the Australasian Road Safety Research, Policing, and Education Conference, Centre for Automotive Safety Research, The University of Adelaide, Australia.

ERA (Ethiopian Roads Authority). 2011. *Design Manual for Low Volume Roads, Part E*. Addis Ababa, Ethiopia: Ethiopian Roads Authority.

GIZ and KfW. 2013. *Water-Spreading Weirs for the Development of Degraded Dry River Valleys: Experience from the Sahel*. Eschborn: Deutsche Gesellschaft für Internationale Zusammenarbeit.

Salman, M., L. Bunclark, M. AbuKhalaf, C. Borgia, L. Guarnieri, O. Hoffmann, F. Sambalino, F. V. van Steenbergen, and F. Lebdi. 2016. *Strengthening Agricultural Water Efficiency and Productivity on the African and Global Level: Status, Performance and Scope Assessment of Water Harvesting in Uganda, Burkina Faso and Morocco*. Rome: FAO.

van Steenbergen, F., P. Lawrence, A. Mehari Haile, J. M. Faures, and M. Salman. 2010. "Guidelines on Spate Irrigation," Irrigation and Drainage Paper 46, Food and Agriculture Organization, Rome.

Woldearegay, K. 2016. "Short Communication: Quality of Water from Roads; the Case of Freweign-Hawzien-Abreha." Unpublished.

5 Roads for Water in Coastal Lowlands

KEY MESSAGES AND MAIN TECHNIQUES

Key messages

- In coastal lowlands, roads serve as flood protection infrastructure and vice versa; in such cases, cooperation between the responsible organizations in transport, water management, and disaster risk reduction is vital to optimize the various functions and co-benefits. Cooperation includes joint specifications and better-integrated concepts.
- Roads also have a major impact on water management in coastal lowlands, and commonly cause waterlogging.
- Because roads are the main infrastructure in these low-lying areas, they can also be used to control water levels for productive uses.
- Such measures contribute to the longevity of the lowland road network.

Main techniques

- The main ways to optimize the interface between roads and flood resilience are building higher roads or road levees to control water and provide flood shelters in flood-prone areas, creating floodwater storage, using excavation material to make local roads, using low embankment roads in selected areas (chapter 11), evacuation planning, and turfing of embankment slopes.
- The main methods for improving the contribution of roads to water management in coastal lowlands are choosing road alignments that compartmentalize high- and lowlands, providing adequate cross drainage to retain and release water, using gated culverts for water level control, making use of borrow pits for drainage and water storage (chapters 7 and 8), and using roads for land accretion.

OBJECTIVE

This chapter discusses the systematic integration of road development with productive water management and improved flood resilience in low-lying coastal delta areas. It is based on work in Bangladesh but also refers to other countries. Integrated planning and management of roads, cross-drainage structures, and flood embankments is a powerful strategy for enhancing climate resilience, reducing flood-disaster risks, increasing agricultural production, and ensuring the durability and reliability of road infrastructure in coastal areas.

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

Because of their location, coastal systems are among the most productive but are also one of the most threatened (Dayton et al. 2005). These regions are at the forefront of climate change and face major risks from sea-level rise, storm surges, floods, changing rainfall patterns, coastal erosion, and tsunamis. Furthermore, coastal lowlands also face pressure from changing river regimes, evolving sedimentation patterns in coastal deltas, and land subsidence (World Bank 2008). In some coastal lowland areas, these changes may have greater impacts than those caused by climate change. Land subsidence in the Ganges Delta, for instance, is estimated to be 18 millimeters per year (Brammer 2014), which is much more than expected global sea-level rise, projected to be 1–2 millimeters per year (Church et al. 2001).

Roads have a significant influence on the development of coastal areas. Because they are often combined with permanent embankments, roads may influence the duration and extent of inundations and the dynamics of flooding in coastal deltas (photo 5.1). Roads also fragment the landscape and interrupt the natural flow of water and the movement of sediments and nutrients important for biological diversity, fertile agriculture, and fisheries (Douven, Goichot, and Verheij 2009). Douven et al. (2012) argue that a *resilience approach* rather than a *resistance approach* often works better in coastal areas. A resilience approach consists of managing the road infrastructure along with the surrounding landscape, adapting to the broad opportunities of the area rather than reclaiming and protecting as much land as possible, and accepting risks while building in mechanisms to deal with these risks. The resilience strategy aims to minimize the consequences of floods while maintaining natural floodplain dynamics as much as possible. In contrast, the resistance strategy aims to prevent and regulate floods and has a major impact on natural floodplain dynamics (Douven, Goichot, and Verheij 2009).

OPPORTUNITIES

Roads, water management, and flood protection are strongly connected in low-lying coastal areas, but this connection is usually not systematically operationalized, which results in a major missed opportunity and, in many cases, creates substantial drainage-related problems.

There is considerable scope for an integrated approach in which roads can become instruments for water management and flood resilience in coastal areas. The three main opportunities are (a) roads that contribute to improved agricultural water management, (b) roads combined with flood embankments, and (c) roads that serve more systematically as temporary flood shelters and evacuation routes. These opportunities are discussed below.

Roads for improved water management within low-lying coastal areas

Roads, bridges, culverts, and gates strongly influence water flows, water distribution, and water levels in low-lying areas. Networks of internal roads, including small village roads and pathways, divide areas into compartments with relatively higher and lower lands. In this way, road infrastructure may impede drainage and create waterlogging, affecting land use and the soil's capacity to absorb rain during high rainfall events. Cross-drainage structures (bridges, culverts or gated culverts, and pipes) are often insufficient or too narrow, and obstruct water flows. Likewise, bridge sills may be too high, impede drainage, and cause waterlogging.

Although the impact of roads on area hydrology is often a neglected aspect of road design, roads can be powerful instruments for better regulating water levels in fields, contributing to improved agricultural production. If properly fine-tuned, roads in low-lying coastal regions can create areas with both low and high water levels and thus allow more varied, multiple-cropping agricultural practices. At present, road alignments are generally not selected with adequate consideration for catchment hydrology. As mentioned, water-crossing structures may have inadequate dimensions, be incorrectly located or absent, and are rarely provided with systems of gates that enable active management of water levels, such as storing and releasing water between different sections of low-lying coastal areas. At the same time, new roads designed without attention to required drainage are often quickly damaged by erosion and subsidence. In summary, combining road development with water management brings multiple benefits, including less waterlogging, less road damage, improved agricultural production, and improved overall livelihoods of local communities.

Roads combined with flood embankments

Roads and flood embankments are strongly linked. Many flood embankments are also used as roads, with the top of the embankment serving as a subgrade for the road pavement. In turn, some roads function as embankments of rivers, channels, and canals. Sometimes these transport and flood protection functions are mismatched, such as when a paved road is developed on an embankment that has not yet reached its safe and climate-proof level. In these cases, the embankment height cannot easily be increased because of the road. In some instances, the height of an existing embankment is reduced to enable construction of a wider road that better serves the structure's transport functions. In addition, roads tend to compact embankment bodies. This compacting force often makes the embankment stronger but also may cause subsidence of the embankment body; where roads increase the risk of subsidence, they also threaten the essential flood protection function of an embankment. The construction of bridges in the flood embankment may also either weaken or strengthen the flood protection functions. These problems are best addressed by merging road and embankment development and reconceiving roads and embankments as an integrated concept, which involves adopting standards for embankments that include criteria to accommodate future roads. Both facilities will be stronger and better serve their intended functions.

Roads more systematically serve as temporary flood shelters and evacuation routes

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

RECOMMENDED BEST PRACTICES

This section discusses best practices for road development in coastal lowlands (figure 5.1). The three main opportunities are to enhance the overall climate resilience of low-lying areas, boost agricultural and fishery production, and better preserve road bodies, thereby reducing long-term costs. The road design process in low-lying coastal areas should ideally enable development of roads that contribute to systematic management of overall drainage through control structures and provide sufficient capacity for water storage and removal. The functioning of water-related infrastructure can make a major contribution to agricultural productivity and the sustainability of all infrastructure, not just roads.

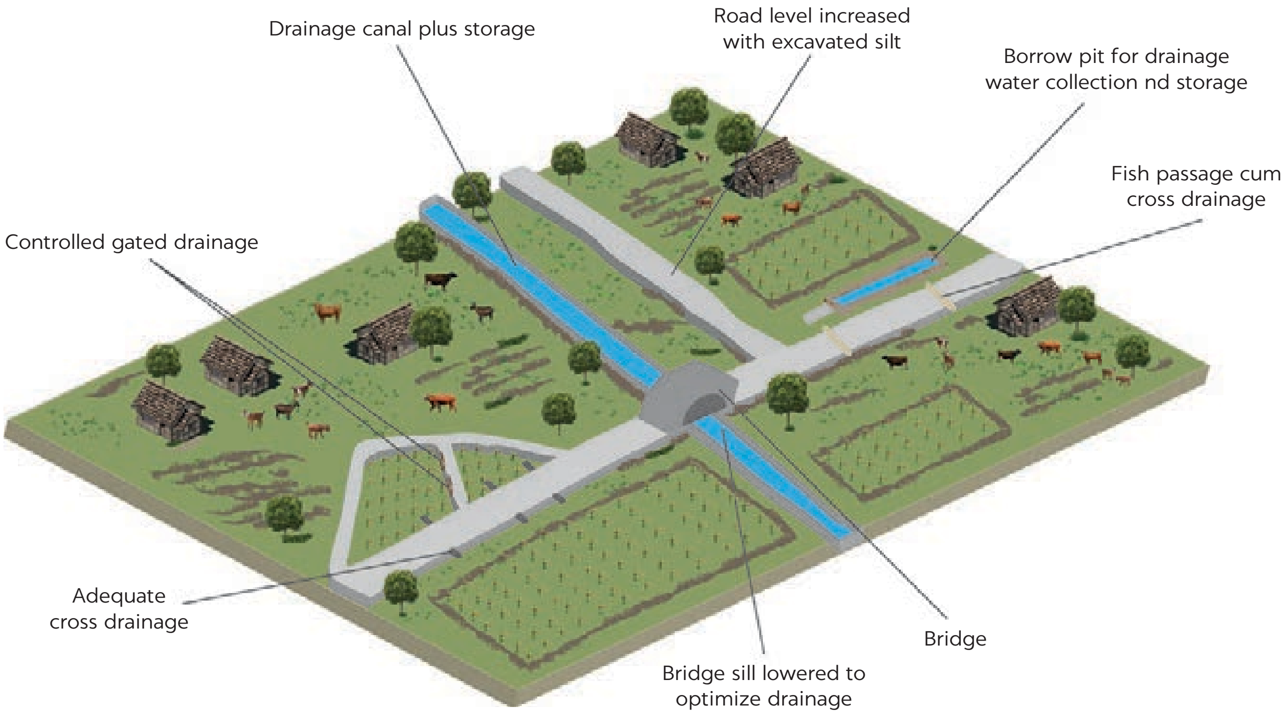
Roads for water management in low-lying coastal areas

Coastal areas are typically major suppliers of agricultural produce because of their proximity to urban centers and because the availability of land and moisture are generally conducive to farming. Managing water levels in extensive low-lying flat areas of coastal regions can be a significant challenge. Roads can play a major role: they are usually the only infrastructure present in low-lying areas that can be used to control water levels. Table 5.1 outlines several practices that leverage roads for water management in these contexts.

The effect of roads on surface hydrology is often not adequately accounted for during road development, particularly for smaller roads and footpaths. Except for major highways, local road management agencies and institutions do not typically conduct hydrological surveys to support development of new roads. The criteria often used in the design of village roads are mainly based on traffic, public demand, land availability, and socioeconomic connectivity (access to markets and surrounding villages). These practices result in road damage from seepage (photo 5.2) and waterlogging around roads (photo 5.3), and opportunities for improved productive water management are missed.

The basic hydrological considerations when developing roads in low-lying coastal areas are flood drainage, stream channels and topography, afflux, debris properties, scour risk, road alignment, soil conditions, and fish movement (Queensland, Department of Transport and Main Roads 2015). If a hydrological survey is not possible because of resource constraints, local

FIGURE 5.1
Recommended best practices in coastal lowland areas



Source: MetaMeta (www.roadsforwater.com).

TABLE 5.1 Improved practices in low-lying coastal areas

DESIGN CONCERN	RECOMMENDED PRACTICE
Alignment selection	Plan roads and paths to more systematically serve as boundaries that separate high-, middle-, and lowlands in low-lying coastal areas.
Cross-drainage locations	Integrate cross drainage at the inception of the road development process, including dimensioning and placing culverts and pipes in accordance with the hydrological catchments, especially in polders.
Cross-drainage control measures	Use gated culverts and pipes to turn these road structures into instruments for water-level control.
Wildlife and habitat preservation	Ensure fish passages in areas where there are wild fish.
Construction processes	Convert roadside borrow pits to serve as drainage ditches and to provide critical dry peak or dry season irrigation or use for fisheries.
Sedimentation control	In low-lying areas, consider the possible effect of roads on sediment retention. Roads can be used to trap sediment and allow land to rise gradually to deal with river water-level rise.
Lowland water storage	Excavate ponds and canals to create adequate storage for the dry season and reuse the sediment for building road embankments or flood levees (photo 5.1).

Source: World Bank.

community groups could undertake landscape mapping. Such mapping could include location of the road, current land use on either side, the micro-relief of the area, the location of cross-drainage structures (culverts, pipes, and bridges) and the need for gates, and water retention and drainage requirements for agriculture and aquaculture.

PHOTO 5.1

Road created with excavation material from drainage canal in coastal Bangladesh

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 5.2

Water seepage from river (left) caused road collapse

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

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

Roads redefine the surface hydrology of low-lying coastal regions, changing drainage patterns and compartmentalizing areas. To the extent possible, roads can be proactively designed to follow contour lines and compartmentalize

PHOTO 5.3
Waterlogging in Bangladesh

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

farmland into high-, middle-, and lowlands. Each level of land will have its own best usage and cropping pattern, and the road will contribute to optimizing the productive use of the land.

A suitably detailed digital elevation model can be used for this purpose if available, but it is unusual to have digital elevation models that capture the micro-elevation in coastal areas, which may range from 50 centimeters to 150 centimeters. If no digital elevation model is available, systematic discussion with local organizations and governments may enable road agencies to plan and design roads that divide areas into high-, middle-, and lowlands and choose appropriate cross-drainage locations and structures.

The compartmentalization of land at different levels can also be used to slow peak rainfall runoff by storing it behind the polder 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. Water can be retained longer in higher areas that may serve as storage for lower areas or be used for the cultivation of rice and shrimp in the wet season. It should be noted that overflow of water over an embankment may cause scouring of the foot or side of it, which can lead to the erosion for which controlled overflow from a designated overflow point and controlled cross-drainage structures are recommended.

Integrate drainage structures in the initial road design

Although drainage structures (culverts and pipes) should typically be incorporated in the overall road design, unfortunately they are not always included. In some situations, the requirement for and location of culverts or pipes are determined after road damage occurs from seepage or when waterlogging occurs. Adequate consideration for drainage water management rarely takes place. Rather than using such an ad hoc approach, drainage requirements are better determined when the road or pathway is first constructed. A ready-reckoner “gap rule” may be used, especially for community roads. This rule is used in Bangladesh, for instance. It describes the recommended length (in meters) of drainage openings (bridges, culverts, and pipes) per kilometer of road (table 5.2). The rule accounts for the type of road and its geographic location. Specific rules for a region need to reflect the rainfall patterns experienced in that area.

The following steps are recommended for determining the location and type of cross-drainage structures:

- Observe natural drainage patterns and place cross-drainage structures along natural drainage paths.
- Discuss the need for drainage of higher-elevation areas and the opportunities to discharge the excess water.
- Consider the potential benefits of installing controlled cross-drainage structures (see next section) in those locations. Consider pipes or culverts with gates if flow needs to be constricted or water levels need to be controlled. If water must always move freely, a bridge is preferred for larger crossings.

Use gated culverts or crossings to retain and control water

Gated water-crossing structures (photo 5.4), particularly on box culverts and pipes, help control water levels in conjunction with road infrastructure and are especially useful inside polders.[1] These relatively simple devices can control water levels in a large area. They also enable management of the water level in the upstream area for rice cultivation, for instance, by opening or closing the gate. For example, upstream areas can be drained when fertilizers and other agricultural inputs need to be applied. In this way, controlled cross drainage from roads goes hand-in-hand with the cultivation of high-yielding varieties. An example of the use of gated culverts to boost rice agricultural yield is presented in box 5.1.

Gates on cross-drainage structures can also be used to manage water storage upstream of the roads, for instance, for dry season cultivation or for aquaculture. In this case, it may be useful to provide additional protection to the road structure to prevent it from being affected by the high water levels (refer to chapter 13).

Gates should be provided at specific locations based on local discussion and agreement about how to control drainage; manage water levels in fields, canals, and ponds; and increase water availability for different purposes (irrigation, fisheries, and households). The gates may be made of wood or iron, but an

TABLE 5.2 Minimum cross-drainage opening (meters per kilometer of road) for Bangladesh lowlands

	GEOGRAPHIC LOCATION		
ROAD TYPE	SWAMPY	HILLY	PLAIN
Secondary and tertiary roads	10–15	7–15	6–10

Source: LGED 2005.

PHOTO 5.4
Gated culvert in Bangladesh

Source: MetaMeta (www.roadsforwater.com).

important consideration is that they should be theft- and tamper-proof. Local discussion should also create clarity on the rules and responsibilities for operating the gates.

The following are recommended practices for gates on cross-drainage structures:

- For box culverts, provide an internal slot or external railing for stop logs or gates.
- For pipe culverts with superstructures, provide a hook or railing to attach the gate.

Especially where there is more than a 0.5-meter difference between upstream and downstream land, scour protection may be provided with vegetation or small stone pitching on both the upstream section and the downstream flow path. This measure will prevent damage from water gushing through once upstream water is released.

Ensure fish passage

Roads also have an impact on the movement of wild fish in low-lying areas. The road should not obstruct fish migration routes, and bridges should be placed in accordance with major migration routes. Culverts have relatively small openings and are less suitable for maintaining fish migration routes. Therefore, bridges are preferred to minimize impact on fish ecology (Douven, Goichot, and Verheij 2009). Nevertheless, culverts and pipes are the main

BOX 5.1

Controlling rice cultivation with dual-purpose culverts in Liberia

Lowland rice cultivation is common in Liberia. Roads in several areas have disturbed the hydrology, but in other cases clever dual-purpose road culverts have been established to regulate water flows for rice cultivation (photo B5.1.1). The road culverts act as a micro-dam and a bridge to cross a small river. They have two outlets: a higher, larger one (60 centimeters wide) in use during the high rain season, allowing more water to pass, and a smaller one (12 centimeters wide) for the dry season to allow a controlled flow to the irrigated rice field on the downstream side. The small pipe directs the water to the irrigation canal built on the downstream side. The canal intake on the culvert is gated and can be opened or closed depending on requirements.

PHOTO B5.1.1

Road culvert in Liberia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

passages for fish and other aquatic animals in wetland areas. Several considerations apply if culverts are used as fish passages.

- The flow velocity through the culvert should not be greater than the swimming capabilities of the fish. In general, a very gentle slope through the culvert should be provided to ensure unrestricted fish movement.
- The outlet of the culvert should not have a vertical drop that makes it difficult for fish to swim or leap out or up.

- The water level in the culvert should not fall below the minimum required to enable fish movement, at least during the fish movement season. Standing shallow water in the culvert or pipe will help fish cross.
- There should be no debris or sediment accumulation in the culvert or pipe that causes physical blockage or increased turbulence preventing movement of fish across the culvert.

Use borrow pits for multiple functions

Borrow pits (photo 5.5) are excavations performed to collect materials—sand, gravel, soil—for road construction and maintenance. They are typically located parallel to the road. For instance, the standard criteria for borrow pits in Bangladesh (LGED 2004) are as follows: the depth should not exceed 1.5 meters, and the width of the embankment's side berm to the edge of the borrow pit should be 3–10 meters.

Borrow pits will fill with water during the monsoon season, assuming the soil is sufficiently impermeable and the water table sufficiently high. Borrow pits serve several useful functions:

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

In most instances, roadside borrow pits should not be backfilled but instead their location and dimensions should be discussed with the users and owners of the land where they are located, preferably under the guidance of local community groups. The location of borrow pits in low-lying areas should follow several considerations, including clear ownership of land and future borrow pits, definition of future functions, and ability to landscape the borrow pit and make it safe.

Borrow pit excavation and use for water storage beside the road carriageway creates a serious roadside hazard for run-off-road incidents. Photo 5.6 illustrates unsafe conditions for most contexts. The risk of reaching the pond in a run-off-road incident is somewhat high because the carriageway has a sealed surface and therefore provides for higher vehicle travel speeds. Borrow pits would ideally be placed farther from the road, and the road embankment slopes would ideally have been constructed with an even and somewhat gentler pitch to ensure errant vehicles remain upright and controlled. The presence of bicycles and fields in the foreground and buildings in the background suggests this is a populated farming area and a high-risk context for vehicle-pedestrian collisions, and measures to reduce vehicle operating speeds are highly desirable.

Photo 5.7 illustrates a context with varying run-off-road collision risk conditions. Smaller trunk diameter shrubs in the foreground do not pose a safety risk, whereas shrubs that grow to a trunk diameter greater than 75 millimeters and trees (shown in the background) would be considered to pose a safety risk when located within the recommended clear area. A setback of 20 or more meters from the road carriageway will alleviate the run-off-road risk where travel speeds do not exceed 50 kilometers per hour, but will still increase the potential for a severe crash outcome compared with the no-intervention option.

PHOTO 5.5

Roadside borrow pit for rice drainage and fishery in Bangladesh

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 5.6

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Use roads to raise lands

Roads in low-lying areas can be used to capture sediment to increase the land level on one side to gradually deal with river water-level rise. This practice now occurs by chance but can be managed better. The impact can be noticeable. For instance, in Polder 2, Shatkira, Bangladesh, the ground level has increased 15 centimeters on the upstream side since the road was built in 2000. The higher ground is less prone to flooding and waterlogging, and farmers can grow a wider variety of dry-season crops. The land rise (75 millimeters per year) in this area is higher than the combined sea-level rise (4–8 millimeters per year) and land subsidence. Roads can be used to trap sediment in selected low-lying coastal areas as part of polder-level road planning, informed by hydrological mapping. This technique would require the following steps:

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

Reuse the excavation material from canals to increase road levels

The internal drainage in low-lying areas often consists of a network of canals, usually the original coastal creeks. These canals are multifunctional: they remove excess water when required but also serve as water storage or are used for aquaculture (photo 5.7).

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

PHOTO 5.7
Siltation of Khals causing drainage congestion and waterlogging in Bangladesh

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Roads combined with flood embankments

In addition to serving a flood protection role, flood embankments are also used for transportation in coastal areas. In turn, some newly developed roads in coastal areas double as flood embankments. Because a variety of organizations may be involved (road departments, disaster risk reduction departments, water departments), it is important to harmonize design criteria for roads and embankments, such as widths, side slopes, and heights. Similarly, planning for the development of roads and embankments should be coordinated among agencies responsible for the diverse functions that embankments serve. For example, integration of embankment and road design concepts and standards should account for traffic functions as well as flood safety, without compromising either. Table 5.3 and figure 5.2 offer an overview of recommended improved practices in this field.

Synchronized criteria for embankment roads

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

In addition, the development of new design criteria for embankments and roads should be based on future climate scenarios. Specifications for standard crest width for a given road hierarchy, embankment height based on a return flood period that reflects the hierarchy of the road and the property it protects, side slope protection, and the size and number of drainage structures may need to be adjusted to account for climate change. Road and water management organizations should work together and establish common standard criteria for embankment and road design, including who pays for what portion of costs should the water management requirements increase the design costs over those required for transportation functions.

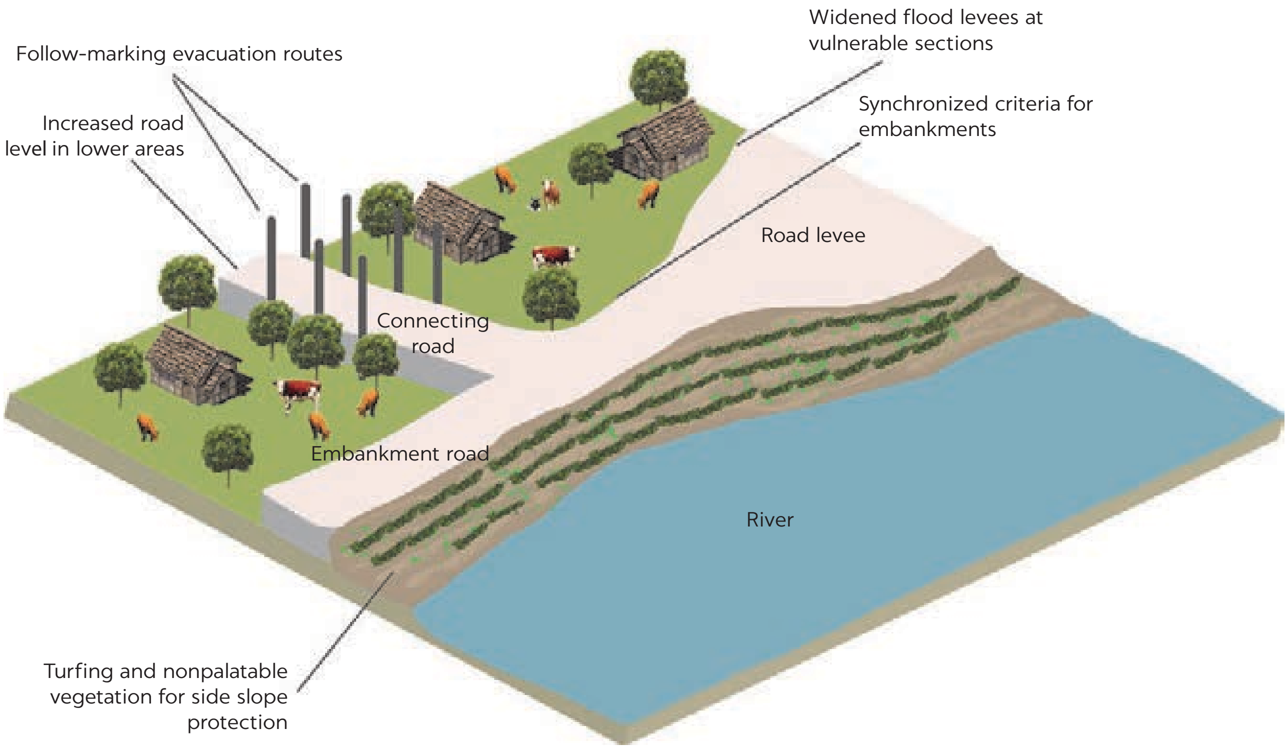
TABLE 5.3 Recommended practices for roads as flood embankments

CHALLENGE	RECOMMENDED PRACTICE
Integrating road and embankment concept	Synchronize criteria for flood embankment heights, widths, and slopes in line with climate change scenarios.
Investment planning and timing	Coordinate development of embankment raising and road development.
Erosion	Use turfing or vegetation with nonpalatable crops such as vetiver for side slope protection.

Source: MetaMeta (www.roadsforwater.com).

FIGURE 5.2

Diagram of recommended practices for roads combined with flood embankments



Source: MetaMeta (www.roadsforwater.com).

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

The development of roads and embankments is not always coordinated in practice. Road and water organizations should come to agreements on what is required in advance of road construction. Because the crest width and the side slope prescribed by water organizations is binding, the budget for road development should include provisions for raising (and widening) road embankments to safe levels as well as for road pavement and subgrades. When developing a road on an existing embankment, the effect of compaction of the existing embankment should also be accommodated. If a road is constructed on an embankment that is not yet at prescribed standards, the pavement should be considered temporary and may be demolished to be rebuilt after the embankment is raised.

Use of turfing or vegetation for side slope protection

Measures to protect side slopes should be incorporated in the initial design of roads or embankment roads and the berms of the embankments (Islam 2000). Local vegetation (grass and shrubs, but not trees) should be used to protect the side slope of roads, particularly embankment roads. Suitable grass species such as vetiver can be planted at 0.3 meter by 0.3 meter spacing, mixed with *Ipomoea*, *Nypa*, *Typha*, and *Pandanus* (Islam 2000). Vegetation on the berm slopes is a barrier against runoff and erosion. Slope protection with grass increases the stability of the slope and decreases road erosion, leading to road stability and flood resistance (box 5.2). Turfing can be combined with the use of jute or coir netting to prevent soil erosion (photo 5.8).

Species should be selected in consultation with the local community. Land in coastal areas is often at a premium and is heavily contested. The use of side slopes and the protection of newly planted vegetation should be discussed with the local government to determine who can use the side embankment, who is responsible for guarding the side slope, and how this agreement is to be supervised and enforced. Grass vegetation should be evenly spread and well maintained, including grass cutting in some cases, and no animal paths (which can cause gullies) should be allowed to develop because they can undermine the embankment. On the other hand, if the vegetation is evenly spread, hoof action of animals may compact and strengthen the embankment.

Coastal-area embankment roads in tropical regions may be protected by a 50–200 meter wide belt of mangrove or by nonmangrove species planted at staggered intervals. This practice may also decrease the impacts of storm surges and the tidal effect (Islam 2000). Mangroves retain nutrients in their roots, increasing soil stability and keeping up with sea-level rise (Alongi 2008). Moreover, mangroves act as a buffer against strong winds and the cyclone tidal effect.

Roads as temporary flood shelters and evacuation routes

Roads play an important role in flood disaster response. Because of their higher elevation, they serve as emergency flood shelters and provide evacuation routes. Emergency shelters have been constructed in many communities, but because these shelters are often unable to accommodate the entire population in an affected area, roads are a possible complement to typhoon shelters and other flood-response measures. Several good practices can better connect road development and emergency responses in coastal areas (see table 5.4).

Prioritize the development of roads that connect to emergency shelters

Connecting communities to designated emergency shelters, such as that in photo 5.9, should be one of the priority considerations in developing road systems. The road network development plan for a coastal polder should be designed in such a way that it is possible for humans (especially women, children, and disabled people) and livestock to reach safety in a short distance. Road development should also be part of disaster risk management planning, so that road investment plans and disaster management facility plans can be integrated.

Prioritize the development of roads in the lowest areas

Roads also provide important functions during floods, serving as safe shelters during and immediately after floods. These functions should be

BOX 5.2

Repairing embankments using Green Soil Bags

The Green Soil Bag is a recent and innovative method for preparing or repairing embankments. The Green Soil Bag is a unique tool developed to block water like a traditional hessian sack. The major advantage of the Green Soil Bag over traditional sandbags is that it is fully biodegradable and filled with a mixture of grass seeds and rich earth. The seeds will germinate, depending on the temperature, and grow outward through the jute. For the first one and a half years, the bag itself will ensure stability in the dike or embankment. Later, the bag will be digested, and the emergent grass net will overtake its soil retention function, blocking erosion by rooting into the subsoil. Dutch water boards use this smart and simple invention to strengthen their levees and harvest the grass. Green Soil Bags were designed to repair dikes and flood defenses, increasing their height. The Green Soil Bag was also introduced under a pilot project in Gondamari, Bangladesh, where local communities were very enthusiastic about evidence of good initial results (photo B5.2.1).

PHOTO B5.2.1

Green Soil Bags used to build levees in Kalapara, Bangladesh

Source: © The Vetiver Network. Used with permission. Further permission required for reuse.

systematically strengthened. In designing new roads, priority may be assigned to the road sections in the lowest part of an area to raise them to at least design specifications (to withstand a 1-in-20-year flood plus 0.3 meter additional freeboard). Where possible, excavation material from local canals may be used.

PHOTO 5.8

Use of turfing combined with jute netting

Source: © The Vetiver Network. Used with permission. Further permission required for reuse.

TABLE 5.4 **Recommended practices for roads as flood shelters and evacuation routes**

	RECOMMENDED PRACTICE
Road alignment	Prioritize the development and heightening of roads leading to designated emergency shelters.
Polders	Create heightened road bodies in low-lying areas of the polder to create safe routes and safe temporary shelters during flood events and refuge areas in the post-flood scenario.
Embankment and flood protection	Create levees along vulnerable sections of the roads to protect roads and embankments and create flood and post-flood shelters for humans and livestock.
Evacuation	Plan evacuation routes using road infrastructure.

Source: MetaMeta (www.roadsforwater.com).

Consider levees along roads to temporarily accommodate flood-affected persons

In addition to raising the roads in the lowest sections of low-lying coastal areas, levees may be created along internal roads and along specific embankment sections. These levees can shelter people and livestock during floods and high-water events. These higher sections should be created in especially high-risk areas using the remaining silt from the excavation of canals, ponds, or rivers. Such sections along the roads could provide the opportunity to temporarily accommodate flood victims (people, cattle, and goods) until their homes have been rehabilitated (photo 5.10). Levees should be spaced at strategic distances so that they are accessible throughout flood-prone areas, placing them along more exposed sections of flood embankments so they can serve as additional reinforcements. The same may also be done for the area outside the embankments. Finally, use of these levees should be regulated by local governments to prevent the undesired permanent occupation of flood shelters.

Plans for emergency facilities should be based on estimates of the number of people and livestock that will depend on them during floods. As a rule of thumb, the minimum space needed for a person to take shelter lying down is 1.5 square meters. Although that is sufficient space over the short term, 3.5 square meters of covered area is more appropriate for longer-term emergency space (Red Cross 2013). An average household in Bangladesh, for instance, has 4.6 members

PHOTO 5.9

Cyclone shelter, Bangladesh

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 5.10

Embankment used as a temporary flood shelter

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

(Begum 2004). A family can therefore be assumed to need a shelter area of approximately 15–16 square meters. For livestock, a space of 2–4 meters per head would suffice. Therefore, 85 people can take shelter (without livestock) on a longitudinal section of a 100-meter embankment with a width of 3 meters. If there are multiple areas of 300 square meters in specific locations along an embankment, the number of people who would benefit from temporary shelter is proportionally higher.

Such levees should be protected by stabilizing their embankments with hedges, vetiver, and other grasses on their slopes and toes to protect them from erosion (Islam 2000).

Plan and mark evacuation routes

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

- Mapping population centers;
- Mapping road networks and looking at the above-ground level of roads;
- Mapping for floods, inundation risk, and escape routes (figure 5.3) (WMO and GWP 2011);
- Putting in place flood signs (boards, poles) along the roads as part of evacuation-route planning, especially in areas that are easily inundated; the aim is for escape routes to remain visible during emergencies (Photo 5.11) (WMO and GWP 2011); and
- Raising awareness so that a large share of the population is familiar with evacuation routes.

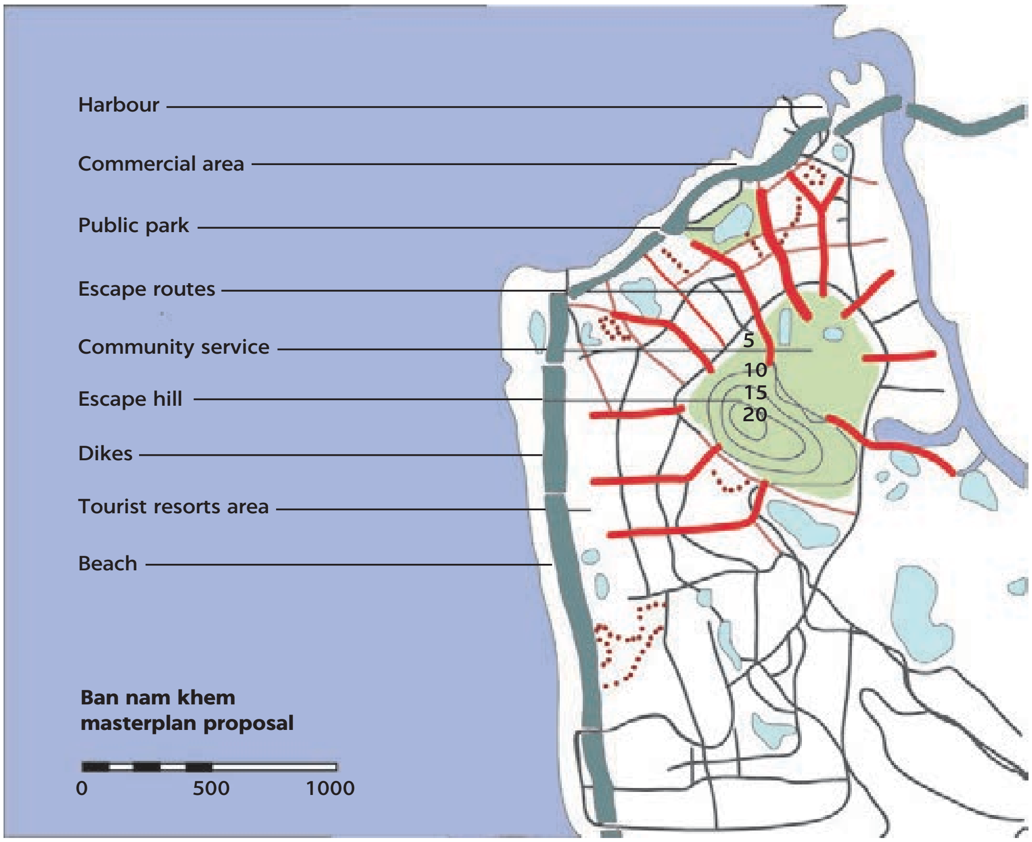
Managed retreat, relocation, realignment

In some areas with extraordinarily high risks of erosion and flooding, especially in coastal lowlands, managed retreat, relocation, and realignment (purposeful, coordinated movement of people, buildings, and infrastructure away from risks) can be considered as a cost-effective and feasible solution to address present and future risks.

Although this approach has not been broadly implemented because of the difficulty of building consensus, there are some examples in the recovery and reconstruction of communities after devastating disasters (such as the "Build Back Better" program after the Great East Japan Earthquake and Tsunami of 2011).

FIGURE 5.3

Flood escape route map, Thailand



Source: MetaMeta (www.roadsforwater.com).

NOTE

1. This practice is not recommended for roads that serve as flood embankments (see section "Roads Combined with Flood Embankments").

REFERENCES

Alongi, D. M. 2008. "Mangrove Forests: Resilience, Protection from Tsunamis, and Responses to Global Climate Change." *Estuarine, Coastal and Shelf Science* 76 (1): 1–13. https://doi.org/10.1016/J.ECSS.2007.08.024.

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.

Brammer, H. 2014. "Bangladesh's Dynamic Coastal Regions and Sea-Level Rise." *Climate Risk Management* 1: 51–62. https://doi.org/10.1016/j.crm.2013.10.001.

Church, J. A., J. Gregory, P. Huybrechts, M. Kuhn, K. Lambeck, M. Nhuan, and P. L. Woodworth. 2001. "Changes in Sea Level." In *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel*, 639–94. Cambridge, UK, and New York: Cambridge University Press.

Dayton, P., S. Curran, A. Kitchingman, M. Wilson, A. Catenazzi, J. Restrepo, and L. Dan Ling Tang. 2005. "Coastal Systems." In *Ecosystems and Human Well-being: Current State and Trends*, Volume 1, 513–49. Washington, DC: Island Press. https://www.millenniumassessment.org/documents/document.288.aspx.pdf.

Douven, W., J. Buurman, L. Beevers, H. Verheij, M. Goichot, N. A. Nguyen, and H. M. Ngoc. 2012. "Resistance versus Resilience Approaches in Road Planning and Design in Delta Areas: Mekong Floodplains in Cambodia and Vietnam." *Journal of Environmental Planning and Management* 55 (10): 1289–310. https://doi.org/10.1080/09640568.2011.644848.

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." Delft Cluster. https://repository.tudelft.nl/islandora/object/uuid%3Abe31676b-5563-43e0-91e0-f68298e16c0c.

Haque, U., M. Hashizume, K. N. Kolivras, H. J. Overgaard, B. Das, and T. Yamamoto. 2012. "Reduced Death Rates from Cyclones in Bangladesh: What More Needs to Be Done?" *Bulletin of the World Health Organization* 90 (2): 150–56. https://doi.org/10.2471/BLT.11.088302.

Islam, M. N. 2000. "Embankment Erosion Control: Towards Cheap and Simple Practical Solutions for Bangladesh." Coastal Embankment Rehabilitation Project, South Khulshi, Chittagong, Bangladesh. http://prvn.rdpb.go.th/files/CP-3-1.PDF.

LGED (Local Government Engineering Department). 2005. "Road Design Standards, Rural Roads." LGED and Japan International Cooperation Agency.

Queensland, Department of Transport and Main Roads. 2015. *Road Drainage Manual - July 2015 edition*. Queensland: Department of Transport and Main Roads. https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications/Road-drainage-manual.aspx.

Red Cross. 2013. *Mozambique: Community Shelter Guidelines*. Maputo: Mozambique Red Cross.

WMO and GWP (World Meteorological Organization and Global Water Partnership). 2011. "Flood Emergency Planning: A Tool for Integrated Flood Management." APFM Technical Document No. 16, Flood Management Tools Series, WMO. https://reliefweb.int/sites/reliefweb.int/files/resources/Tool_16_Flood_Emergency_Management.pdf.

World Bank. 2008. "Adaptation to Climate Change in Coastal Areas of the ECA Region: A Contribution to the Umbrella Report on Adaptation to Climate Change in ECA." Washington, DC, World Bank.

6 Roads for Water in Mountain Areas

KEY MESSAGES AND MAIN TECHNIQUES

Key messages

- Selection of road alignment and slope and provision of adequate water crossings are critical for the longevity of the road and to minimize harmful effects of the road on the surrounding environment.
- Given the climate vulnerability of medium- and high-altitude areas, it is important to safeguard road environments in these settings with measures that reduce the risk of disturbance while also improving the areas' productive value.

Main techniques

- The mass balance method should be considered for the development of new mountain roads.
- Water-road environments can be managed through the main techniques of spring capture, reinforced road-water crossings (see also chapters 9 and 10), and bioengineering.

OBJECTIVE

Many high-altitude and middle-altitude areas are at the forefront of climate change. Much of the attention is placed on their medium- and long-term contribution as water towers, safeguarding the future water supply of minor and major rivers that originate from them. Climate change comes in several forms in high mountain regions: higher summer temperatures or more frequent, short-duration warm spells; more rainfall but less snow; more wet snow and less dry snow. These changes often unsettle the precarious balance in mountain regions, causing glacier retreat, more frequent landslides, and the emergence of temporary lakes. They also cause mountain areas to become drier in the long run as snow melt becomes a less reliable source of moisture.

The trajectory of climate change appears to vary between different high- and medium-altitude areas. Lutz et al. (2014) describe various trends in different parts of the Himalayan region, the world's foremost water tower. Most Himalayan glaciers are losing mass, often on the order of 23–56 percent, with significant repercussions for the water security of high-altitude areas. Within the Himalayas, the exception is the Karakoram range, where glaciers are stable and are sometimes gaining mass (Bolch et al. 2012). In general, because of glacier melt, water availability will increase until 2050 but decrease between 2050 and 2100 (Immerzeel, Pellicciotti, and Bierkens 2013). Adaptation to seasonal shifts, changed water availability, and extreme events, such as flooding, are new challenges in the mountain regions.

Road development in mountain regions presents many engineering, logistical, and financial challenges (photo 6.1). If done carelessly, the development of roads in these areas can have a heavy negative impact on the surrounding environment and undermine climate resilience. Road development can change runoff patterns and cause areas to further dry out. It can transform the face of mountain regions, leaving behind huge erosion scars and accelerating the rate of sedimentation.

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

This chapter first discusses the impact of roads on mountain environments. It then discusses investments in roads to make them instruments for resilience in their mountain environments and the additional measures to be considered in

PHOTO 6.1

A mountain environment

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

bolstering the mountain road environment. Road protection and landscape management should be combined to reinforce one another.

CHANGING THE MOUNTAIN ENVIRONMENT

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

A third effect on hydrology is that opening a road cut in hilly terrain also opens fresh mountainsides and increases the air-surface exposure of the hill slope (photos 6.2 and 6.3), which will dry out the hill slopes, particularly when the slopes are freshly cut. Moreover, a gully effect occurs, with soil moisture moving toward the road cut, where it constantly evaporates. Unless the side

PHOTO 6.2

Increased air-surface exposure of hill slope

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 6.3

Interrupted subsurface flow caused by road openings along Mugu Humla Road, West Nepal

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

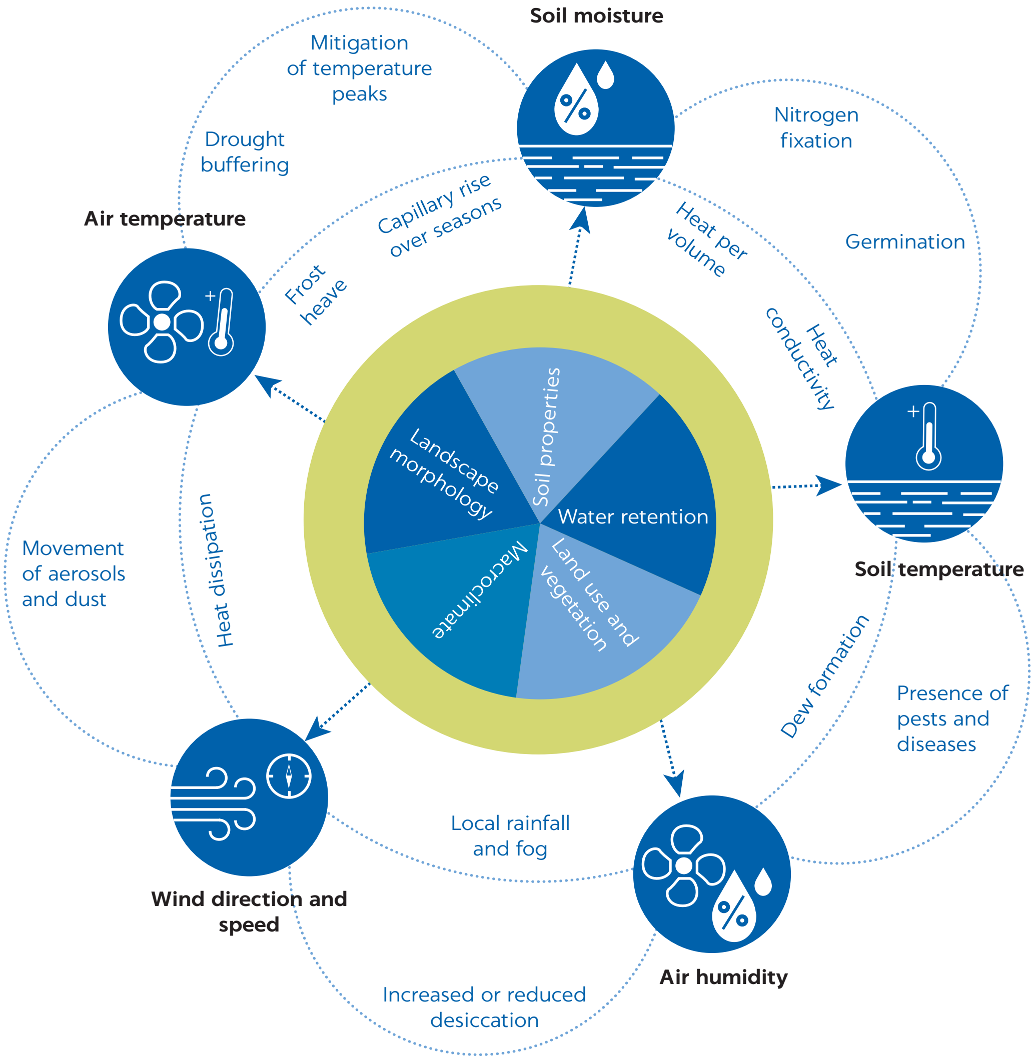
slope is covered again with vegetation, it may lead to "bleeding" of the subsurface moisture, drying up hillsides.

Fourth, the construction of roads will also increase the so-called hydrological connectivity of the watershed. Hydrological connectivity describes the degree to which hydrological elements of a landscape are interconnected. The higher the connectivity, the faster the rainfall runoff, causing peak flows in the rivers to emerge early and be more pronounced (Meng, Wu, and Allan 2013). Chapter 2 further describes this phenomenon. Road development generally accelerates runoff, making new connections and concentrating flows in a smaller number of drainage lines.

Furthermore, the opening of roads in steep mountain terrain exerts a large impact on the microclimate (see figure 6.1) of roadside areas. This impact can be observed, for instance, when forest areas are traversed. The impact on the microclimate is caused by the changed hydrology and the greater exposure of the mountain slopes to sun and wind and reduced tree canopy once roads open up the roadside environment. The general effect will be for the area surrounding the mountain road to dry. Such drier road environments and reduced soil moisture affect soil temperatures (more heat exposure) and microbiology. When soils are less moist, microbial action in the soil decreases, which will, for instance, reduce the capacity to fix nitrogen, with repercussions for vegetative growth. Gradual drying, an increase in daytime temperature, and a lowering of night

FIGURE 6.1

Interlinked components of a microclimate



Source: MetaMeta (www.roadsforwater.com).

temperature also occur. These changes may also affect local rainfall patterns and the occurrence of dew, which is an important source of moisture for vegetation. To minimize these impacts, measures should be taken to retain moisture and regreen the area.

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

IMPROVING THE MOUNTAIN ROAD

Several considerations are essential to developing mountain roads that contribute to resilience and that can withstand shocks and stresses:

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

Choosing the road alignment and design carefully

The choice of road alignment and design goes a long way toward ensuring sustainability of the road and its contribution to the resilience of the landscape. A first important consideration in selecting the road alignment is that it should not disturb runoff patterns. The high speed of runoff on steep slopes commonly found in mountain regions can create havoc for sometimes unstable slopes. Several considerations come into play in choosing an alignment that reduces runoff, but in particular, observing reasonable longitudinal slopes is crucial. The Nepal Rural Road Standards, for instance, use 7 percent as the ruling gradient (for a maximum distance of 300 meters). The recommended limiting longitudinal gradient in mountain roads is 10 percent. Beyond this limit, the road will act as a drain, collecting water during rainfall events, resulting in extensive rutting to an unpaved road surface, and requiring careful design and construction of side drains to prevent erosion. Such steep, rutted, and often slippery roads are dangerous for vehicles, and are sometimes impossible to pass. They also alter the drainage pattern of the mountain slopes. Choosing gentler slopes has cost implications because the length of the road will increase and there will be more bends. However, these costs are recovered through road functionality and reduced damage to the surrounding landscape.

Road drainage is a second critical concern in the choice of road alignment. The Green Roads criteria developed in 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 embankment's becoming soaked, causing subsequent loss of strength and carrying capacity. Furthermore, if there is a risk of freezing, as there often is in mountainous conditions, water flow across the road can lead to formation of very dangerous ice conditions. In such cases, all efforts to avoid water moving across the road surface should be considered.

A third factor in selecting road alignment is to keep a safe elevation and distance from existing streams and rivers. A safe distance could prevent the road from becoming inundated or damaged by floods in such rivers and streams and reduce road runoff discharge into these watercourses. The road layout should be aligned with the current and predicted hydrological situation. An analysis of current hydrological data and future scenarios can inform this decision.

Choosing appropriate construction methods

A variety of methods can be chosen to develop mountain roads. The cut and fill method used in several programs in Nepal is worth considering. A central element of this approach is "mass balancing," that is, minimizing waste mountain material. In mass balancing, the spoil that becomes available from cutting the road is used to make the downslope toe of the road. This approach has two main advantages. First, reusing the spoil in making the downslope toe significantly reduces the amount of unused spoil. Second, there is less cutting of the mountain slope because the new road width is created both by cutting the mountain slope and adding the downslope toe. Compared with other methods, the height of the road cut is decreased, and thus the risk of erosion, instability, and drying out of the hillside are also decreased. The roads are ideally developed over a period of three to four years, allowing the road to settle and consolidate before it is further widened. The preferred construction method is labor based, creating employment and skills but also allowing for careful handling of the construction process. Box 6.1 describes the Green Roads cut and fill method.

Instead of the labor-based approach, machine-based approaches are often used in road construction to save cost and time. In the machine-based approach, a "cut and throw" method is used, whereby the upper hill slope is excavated and the excavation material, rather than being used for the downslope toe, is dumped downhill. A modified hybrid method may be used, whereby roads are opened by trained excavator operators. Labor groups may undertake remedial work, such as the development of slope protections, breast walls, and general road clearance. There is, however, a marked difference between the labor-based cut and fill approach and the hybrid mechanical approach, as captured in table 6.1. In general, the faster turnaround time and the lower costs of the hybrid mechanical method come at the cost of more environmental damage, less reuse of the spoil, less attention to springs, and a loss of labor opportunities. The labor-based approach is preferable for roads-for-water programs. The remediation measures described in the subsequent sections of this chapter are even more urgent when the mechanized approach is adopted.

Including protected road-water crossings

When a mountain road is opened, many new road-water crossings are created over regular streams and over torrents that only flow during the rainy season and often descend onto the road body. Unless abatement measures are taken, these interrupted streams and torrents will damage the road surface by their erosive force and create extensive wet road sections that are easily damaged by traffic impact. Erosion may easily extend to the land alongside the road. Techniques to reduce damage from these water crossings include causeways, dissipation blocks, check dams, infiltration bunds, and down-road protection. Many of these measures can make use of the spoil and rubble that become available when a road is constructed.

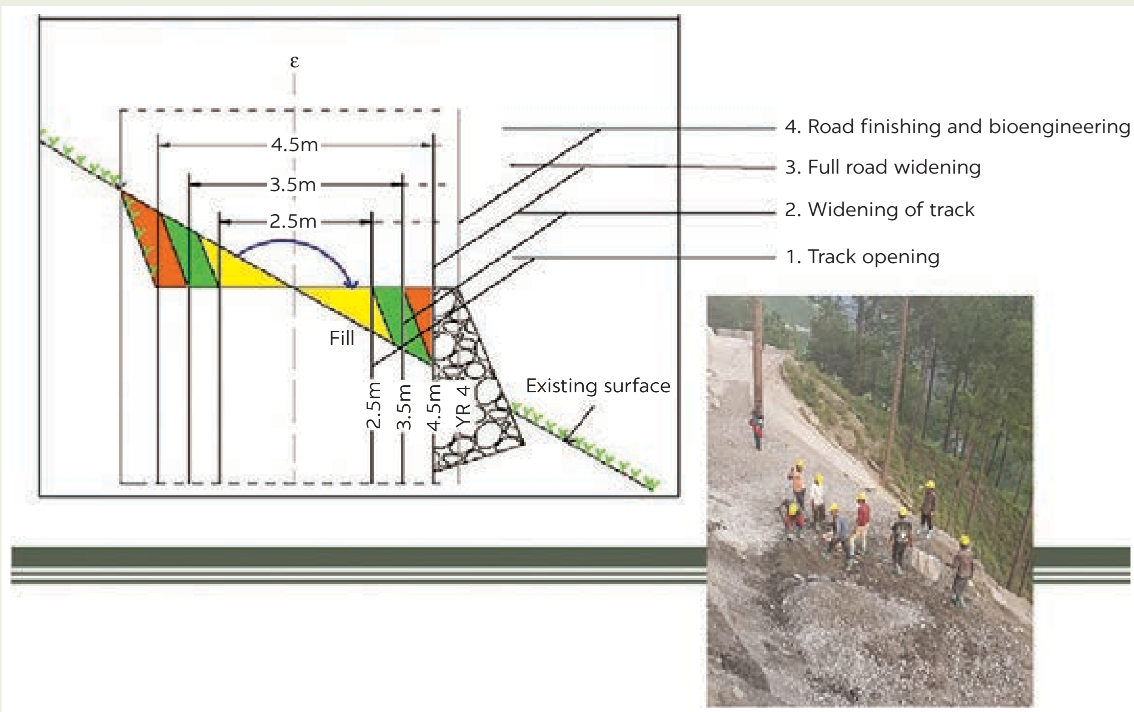
BOX 6.1

Green Roads cut and fill method explained

Construction of the road in phases

A two-stage survey is conducted during the cut and fill method. The first stage of the survey takes place before the track opening at the beginning of year 1. This stage includes a preliminary survey, a feasibility study, and a detailed survey. Doing this helps to fix the alignment of a road but also helps to locate important and sensitive issues along the road alignment such as water sources, streams, and settlements. After the finalization of the survey report, the contract is prepared for the road construction.

- Year 1: 2.5-meter track opening allowing one rainy season for natural compaction after track opening
- Year 2: Track opening to 3.5 meters allowing another season for natural compaction
- Year 3: 3.5 meters to full width (4.5 meters)
- Year 4: Road finalization and bioengineering



- From year 2, vertical phase-wise construction of structures is carried out on a yearly basis to allow for natural compaction.
- The backside of the structure is backfilled with granular soil that is compacted in layer-wise fashion every 15 centimeters.
- Subsurface drainage is provided for walls that are 5 meters or greater in height.
- The stage 2 survey is performed after the track is opened. During the stage 2 survey, the watercourse discharge on ravines and the catchment area will be better known, and structures can then be designed accordingly.
- Drains are provided in sections with gradients greater than 7 percent and in waterlogged areas and paddy fields. In the road sections without drains, a 5 percent outward slope is maintained to drain off surface water.
- Geotextile is used along the back of retaining walls to prevent loss of fine particles from the backfill mass, thus barring sinkhole or cavity formation in the backfill.

Source: MetaMeta (www.roadsforwater.com).

TABLE 6.1 Comparison of labor-based and mechanical approaches to mountain road construction

PARAMETERS	LABOR-INTENSIVE CUT AND FILL METHOD	MECHANIZED CUT AND THROW METHOD
Slope exposure	Shorter side slopes	Higher side slopes (up to 40 percent higher)
Loss of land	Estimated savings of 6,320 square meters of land per kilometer over conventional cut and throw methods[a]	Much land, including productive land, lost
Slope stability	More stable	Disturbance because of mechanical action, which needs remedial measures
Road surface stability	Natural stabilization and compaction of road surface related to phased approach	Opening entire width of the road at once creates less stability
Spoil composition	Smaller and more uniform rocks	Mixed, including large boulders
Spoil displacement	Reuse of 86 percent of spoils inside fill[b]	Much excess spoil
Spring management	Possibility of spring handling	Larger disturbance of springs and seeps
Reuse of soil	Possible	Impossible
Labor creation	Approximately 25,000 labor days per kilometer	Approximately 10,000 days per kilometer, if proper aftercare and finishing built in; if not, considerably less
Indicative costs	US$260,000 per kilometer	US$160,000 per kilometer[c]
Construction time	3–4 years	1 year

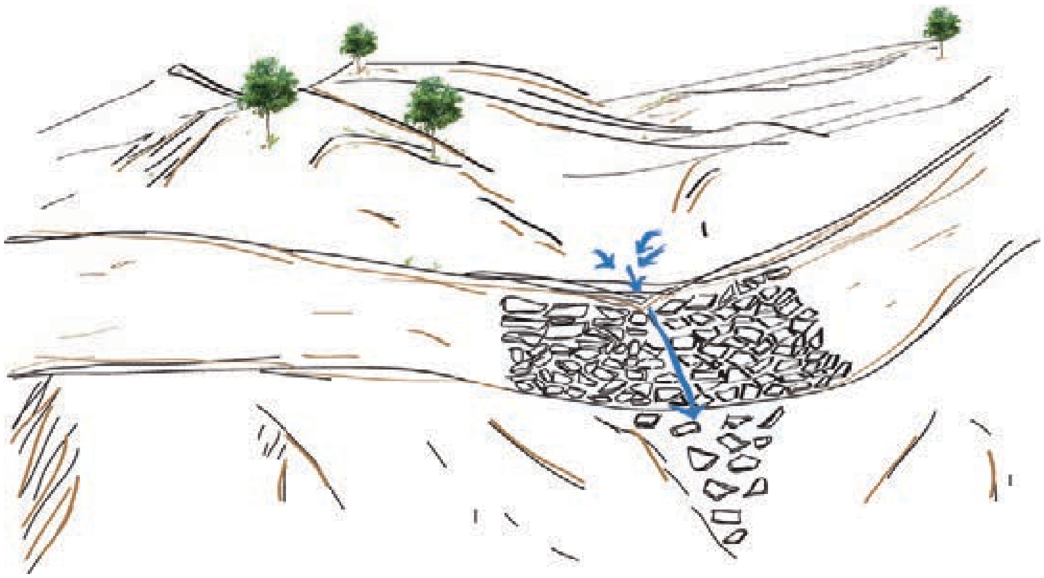
Source: MetaMeta (www.roadsforwater.com).
Note:
a. Phuyal, Stamper, and Acharya (2008) quoted in Mulmi (2009).
b. Phuyal, Stamper, and Acharya (2008) studied 7,900 cross sections of 286 kilometers of hill roads in different regions. The study established that by adopting a mass balancing approach to green roads, 3,345–2,900 cubic meters of spoil can be reused for side slope filling per kilometer of new road construction. The remaining 445 cubic meters of the spoil can be used along roads to improve the longitudinal gradient or for water retention or water protection measures.
c. This is an initial estimate. The final cost per kilometer of the hybrid mechanized approach will decrease by a further 25–30 percent of the estimate because the filling work is reduced by two-thirds as per the experience of work in Bama village of Mugu district in Nepal (van Steenbergen and Yakami 2019).

Tilted Causeways

Roads are often traversed by several mountain streams. At these places, causeways should be made of flat stones. Like the entire road, causeways are tilted at a slight angle (maximum 4–5 degrees[1]) toward the downhill side to facilitate drainage of the water from the stream (figure 6.2). This is a good practice because it ensures the use of local material and provides structures that are easy to maintain. A depression can be made in the middle of the causeway to improve and guide the removal of water. This depression should be modest: if the causeway has a width of 25 meters, the lowered section should be 25–50 centimeters. The depression should be at a maximum 5-degree angle so it does not interfere with the road's trafficability. Where the road water exits the tilted causeway, it may be useful to armor the downstream part of the stream. Using a tilted causeway on sloped terrain has several benefits:

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

FIGURE 6.2
Tilted causeways



Source: MetaMeta (www.roadsforwater.com).

Reinforced Causeways (Drifts) at Ephemeral Stream Crossings

Where roads cross the dry bed of ephemeral streams, reinforced causeways or drifts may be used. In addition to their function as traffic conduits, they help stabilize the unstable gravelly streambeds in mountain environments. Drifts may also help retain water in the sand and gravel of the riverbed. Chapter 9 describes the application of such nonvented drifts in semiarid areas. In mountain areas, the drift may be reinforced beyond normal specifications to enable it to withstand the pressure of torrential flows and the impact of rolling boulders. The drift should not be equipped with culverts. Along with the body of the drift itself, the drift consists of the approach road, the upstream protection of the stream, and the downstream apron. Because of the heavy natural armoring of mountain streams, they may not need downstream aprons.

Dissipation Blocks

Use of dissipation blocks is recommended where a minor stream descends onto the road (figure 6.3). The block may be created by stacking up stones and rocks that become available when a mountain road is opened. If placed where the streams and torrents hit the road, these stockpiled stone blocks will dissipate the force of the water flows. This measure comes at no extra cost because the stone blocks are stockpiled for use in future repairs yet are often placed off-stream. The blocks are best placed 30–40 centimeters away from the side slope. Flat stones may be placed between the torrent coming from the hill slope and the dissipation block to break the velocity impact of the descending water. The stockpiled stones will further baffle the force of the mountain stream. A small depressed section may be created in the road body, like a mini-causeway, to guide the streamwater across the road. A barrier to protect vehicle occupants from collision with the block would be required.

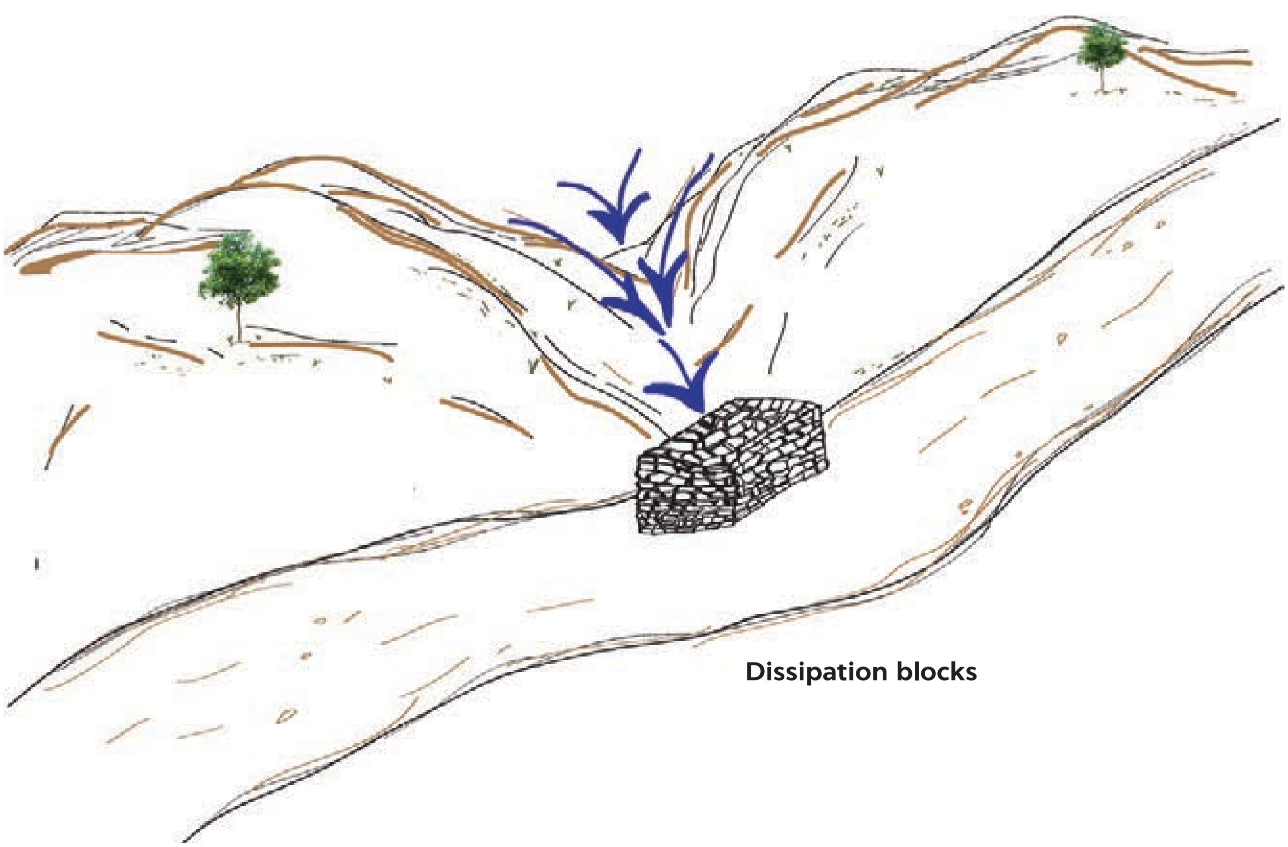
Check Dams and Downstream Protection

In accented terrain, most streams will flow at high velocity. The development of a road section creates chutes that can cause considerable damage to the road surface and side slopes. Placing check dams in the upstream section of these road streams reduces the velocity of water crossing the road. Again, spare stone material from the construction of the road may be used to build up small check dams upstream. The excess material may also be used to armor the down-road part of the stream by placing some stones there. This technique will prevent damage from erosion to the landscape and avoid upward gully development that could affect the road body. The general criteria[2] for check dams are as follows:

- Spacing between check dams = height × 1.2/slope of stream in decimals
- Side key of check dams, 0.7–1.0 meter each side
- Bottom key and foundation, 0.5-meter deep
- Height of check dams, 1 meter (maximum excluding foundation)
- Stone face vertical-to-horizontal ratio, between one to three and one to five
- Spillway (preferably in trapezoidal shape) width, 0.75–1.00 meter; depth or freeboard, 0.25 meter
- Using rock rubble for apron immediately downstream: length 1 meter and width 0.5 meter

FIGURE 6.3

Dissipation block placement on the road



Source: MetaMeta (www.roadsforwater.com).

Infiltration Roadside Bunds

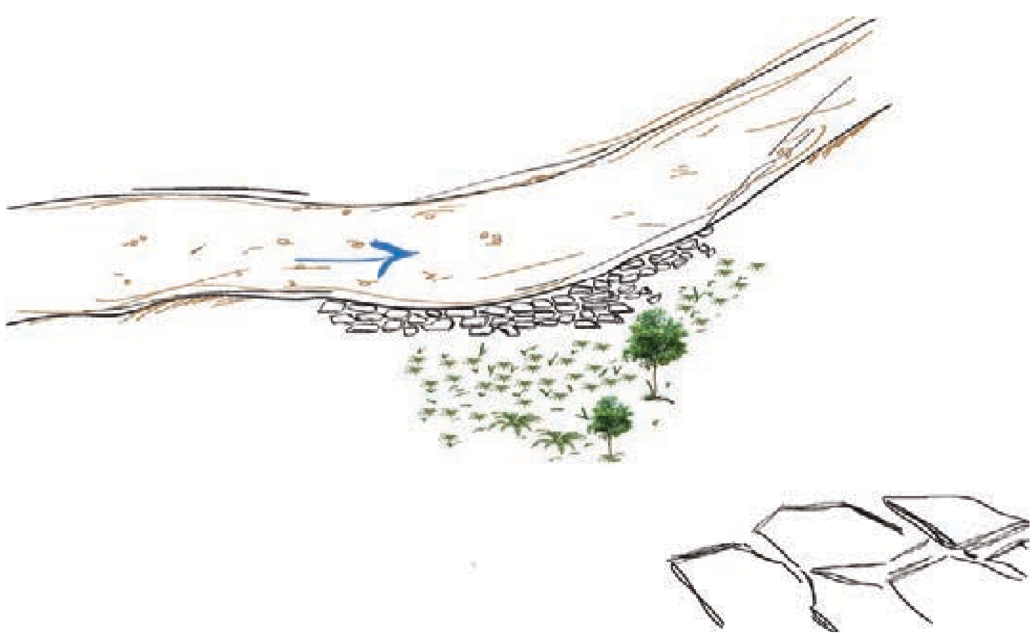
During the monsoon, fine material from unpaved roads is washed into adjoining agricultural land, causing loss or damage to crops, often forcing farmers to replant. A good practice in mountain roads is to use an outward-sloping road crown to drain water evenly from the road to the adjacent land. The slopes preferably have a maximum inclination of 5 percent to prevent runoff from traversing the road surface. Even so, a certain amount of concentrated flow along road sections is unavoidable, particularly in sloping road sections. To prevent this flow, infiltration bunds in downslope road reserves can be used in areas where road water is expected to wash into agricultural land (figure 6.4).

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

Managing roadside mountain springs and seeps

In mountain areas, the development of roads—either though the removal of unconsolidated material or the cutting of rock formations—will affect the occurrence of seeps and springs. 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.

FIGURE 6.4
Infiltration bunds



Source: MetaMeta (www.roadsforwater.com).

TABLE 6.2 Effect of road development on different types of springs

SPRING TYPE	DESCRIPTION	EFFECT OF ROAD DEVELOPMENT
Springs with concentrated discharge (through one or more orifices)		
Fracture spring	Faults, fractures, and cleavage in semipermeable and permeable formations connected with a water source (seepage, flow, shallow or deep aquifer)	Road development may expose the spring; rock cutting may change the location of the orifices, either blocking old or creating new ones.
Contact spring	Permeable layer overlays an impermeable layer, forcing water to come out, often in a line of springs	Road may distort the outflow of the spring, causing orifices to be blocked or new ones to be created; highly dependent on geological faulting.
Fault spring	As a result of geotectonic movement, a permeable layer is moved on top of an impermeable layer	Road may distort the outflow of the spring, causing orifices to be blocked or new ones to be created; highly dependent on geological faulting.
Depression spring	The groundwater table reaches the surface in topographical low point	Road may create new depression springs where the roads are made in cut, or it may create dry existing springs by lowering the groundwater table.
Karst spring	Relatively large flow from large openings, typically in karst areas where water erodes the calcium formation	Roads may expose new springs and expose new cavities.
Springs with diffuse discharge		
Seep	Diffuse direct discharge of water, usually from soils or unconsolidated sediments (sand or gravel)	Road development may create many seeps, especially where roads are developed in areas with deep soil profiles.
Secondary springs	Water issued from a primary spring that is typically covered by debris or rock fall	Road development may expose springs or change the outlet, particularly where unconsolidated material is removed.

Source: MetaMeta (www.roadsforwater.com).

Table 6.2 shows the effect of the opening of a new road alignment on different spring types. The development of roads may distort existing springs but may also create new ones. Given the importance of springs for domestic water supply or agricultural use, the management of mountain springs in road development should be an integral part of road construction. Springs and seeps are also main sources of road damage (photo 6.4), either by affecting the road surface directly or by creating minor depressions in the roads that grow during the monsoon and cause uncontrolled and erosive runoff from road bodies.

There are several types of springs. Geomorphology, rock type, and tectonic history determine the type of spring that occurs. Two broad categories are springs with concentrated discharge through one or more clear orifices, and springs with more diffuse discharge. Table 6.2 shows the effect of road development on the different types of springs.

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

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. Table 6.3 suggests methods for managing different types of springs in different circumstances.

PHOTO 6.4

Road surface damage caused by seep created by a road opening, Mugu, Nepal

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

TABLE 6.3 Recommended practices for spring management along roads

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

Source: MetaMeta (www.roadsforwater.com).

By controlling the outflow of springs, water can be better retained in the area. Equipping the orifice of a spring with a gated outlet and even a tap makes it possible, in some cases (especially karst springs or fracture springs), to store spring water in the mountain aquifer and prolong its availability.

Bioengineering

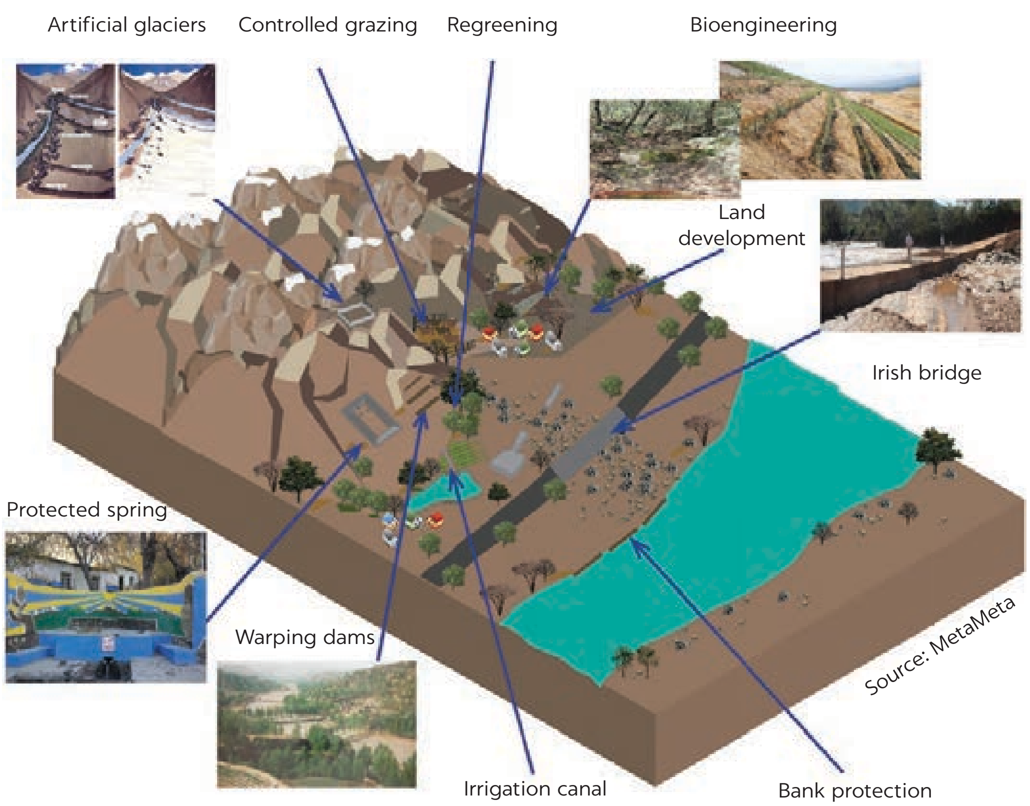
Bioengineering encompasses a range of vegetative measures to stabilize slopes along mountain roads. Vetiver is commonly used for this purpose. Because of its deep strong roots and high survival rate, vetiver rows have been applied widely on steep, erosion-prone slopes. Vegetative measures combined with structural measures are used along road sections in steep areas, as in Nepal. Native plants that are known to adapt well to the 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. Additional measures are often used to further protect and reinforce slopes, such as brushwood mattresses, fascine bundles, timber crib walls, or riprap in selected sections.

Improving the mountain road environment

Mountain areas are highly challenging for road connections at any time. To create resilience in these areas, both the roads and the demanding environment in which they are located (see the section titled "Changing the Mountain Environment") must be addressed in concert. Safeguarding the road environment will protect the road and create a large productive asset. The purpose is to create a more stable and productive environment, making better use of the opportunities that exist in high- and middle-altitude areas. Measures to better retain moisture and to build up, enhance, and protect land, while ensuring safe roadside conditions, include the following (see figure 6.5):

FIGURE 6.5

Integrated road-landscape management measures to be considered in mountain areas



Source: MetaMeta (www.roadsforwater.com).

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

Land-Use Planning

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

Water and Snow Retention and Storage

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

More water storage may be created, as in other roads-for-water programs, with special farm ponds or converted borrow pits or by using road bodies to create reservoirs (see photo 6.5). Check dams and irrigation diversion channels can also be used to decrease the amount of water streaming down and delay peak floods. Check dams also provide an additional source of water that can be used in summer when seasonal streams and springs dry up. However, these infrastructure projects should be carefully planned so as not to increase the risk of floods and mudslides for populations downstream. Other measures such as reforested areas and livestock enclosures will also increase water retention in the soil.

PHOTO 6.5
Farm pond in high-altitude Nepal

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

FIGURE 6.6
Snowshed in Alpine environment

Source: MetaMeta (www.roadsforwater.com).

Artificial Glaciers

The development of artificial glaciers is an ingenious technique first developed by local engineers in Ladakh (North India). The principle consists of diverting water from glacial streams through canals and pipes (up to 4 kilometers long) to shaded, colder, and flatter areas, where the difference in temperature and lower velocity of water will cause the water to refreeze. When the meltwater reaches the artificial glacier site, it is spread and contained by retaining walls of stones or concrete built in series (see figure 6.7). The artificial glaciers may be up to 2 kilometers in length and 2.5 meters in depth. The water is stored there during the entire winter and melts in spring when solar radiation and temperatures increase. Artificial glaciers have several advantages for agriculture and road infrastructure:

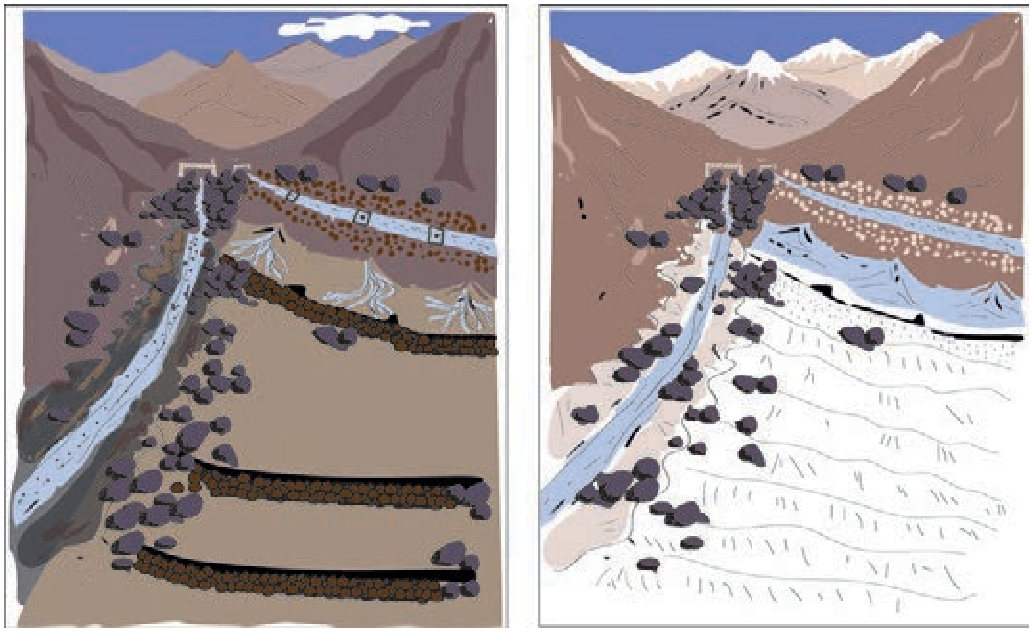
- They make water available before higher glaciers start melting, enabling farmers to begin cultivating earlier in the season.
- They reduce the amount of meltwater lost from the high-altitude area.
- They reduce peak floods, erosion, and damage to infrastructure.

Land Development with Meltwater

Intense sedimentation in young mountain areas may lead, for instance, to a reduction in downstream reservoir capacity. However, sedimentation is not necessarily a hazard: it can be an asset as well. It helps build or renew soils, creating new land and plugging gullies and depressions. “Warping” techniques can be used to trap sediment for beneficial use. Warping entails building up land with moisture-rich soil along rivers and streams. This process can be accomplished by letting turbid water flood onto agricultural land so that its suspended sediments form a layer before the water is allowed to flow away. Roads can also be used to

FIGURE 6.7

Technique for creating artificial glaciers in mountain areas



Source: MetaMeta (www.roadsforwater.com).

BOX 6.2

Warping dams

Warping dams are typically up to 5 meters high, but they can be shorter as well. The development of a warping dam consists of two stages: the land development stage and the consolidation and management stage. The land development stage takes several years (on average three to five years, but sometimes more than 10 years). By then, a warping dam will have collected enough sediment for farming to begin. When the warping dam is filled with sediment, stabilization is necessary through the creation of controlled water overflow structures. These structures can be created by changing the existing spillways into a circular shape, redesigning the top of the shaft as a spillway, constructing a side spillway, or designing an earth dam as an overflow dam (van Steenbergen et al. 2011).

guide such meltwater. In this way, poor soils are enriched with fertile fine silt (or warp) or by trapping sediment behind warping dams built on gullies or steep valleys to intercept sediments and thereby create new land terraces (see box 6.2).

Improved Moisture Retention on Hill Slopes

The changes that come with road construction are described in the section titled "Changing the Mountain Environment" and include opened hill slopes and exposure of the earth to more sunlight and wind. These changes add up to a severe impact on the microclimate that could affect forest stands or the quality of the pasture. The impact on the microclimate will be less water retention, resulting in a loss of moisture, an increase in temperature, and more desiccating effects.

The loss of moisture should be counterbalanced by measures that improve the capacity of the road-affected area to retain moisture, which will also reduce the risk of erosion and degradation of forest hill slopes and contribute to regreening of the affected area, including potentially compensating for removal of trees during road construction. Large quantities of spoil (rocks and boulders) from road construction provide the material for implementation of these measures. Use of eyebrow terraces or half-moons and stone strips or rock bunds is recommended for steep mountain slopes. Eyebrows are small, semicircular, stone-faced structures that open in the direction of the runoff (photo 6.6). They can be built on steep slopes, usually with a maximum preferred slope of 50 percent, yet steeper gradients are possible, especially when rainfall is not torrential. On a slope, the steepest sections should be avoided, and the eyebrows may be constructed in the gentler sections.

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

Making Better Use of Excavated Soil

Soils are removed when roads are constructed. The construction of a 3.5-meter-wide section of road for 1 kilometer with a soil depth of 30 centimeters would

PHOTO 6.6

Eyebrow terraces on mildly sloping land, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

yield 1,050 cubic meters of soil. The soil removed during construction is a valuable asset in land development and in regreening hillsides. These hillsides are often deforested and stripped of vegetation during the road-building process. This damage can be remediated by replanting trees on hill slopes in combination with building eyebrow terraces and stone strips. This approach slows runoff while facilitating regreening.

Controlled Grazing

Uncontrolled grazing can be a major cause of land degradation in medium- and high-altitude areas. Measures to reverse this trend and restore pastures include area enclosures, better pasture management, and, in some cases, reducing herd sizes.

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

Grazing areas may be further enhanced by the spreading of floodwater or meltwater. When water is flowing in mountain streams, it can be diverted to grazing areas that are short of moisture, which will also reduce the risk of downstream floods because the water is spread over a large area. Care should be taken to avoid interference with existing downstream water uses.

Regreening

In several mountain areas, the demand for fuel wood and timber has had a severe impact on stands of trees and shrubs. Regreening will stabilize slopes, help retain water, and even change the microclimate by achieving shorter precipitation cycles. Regreening involves a series of measures: land use planning and controlled grazing are often prerequisites for successful revegetation. Regreening campaigns may provide incentives to mountain communities or forest enterprises to plant and safeguard new tree stands. Alternative arrangements can be powerful too, such as farmer-managed natural revegetation (whereby natural tree sprouts are protected and nourished), farmer-owned timber or fuel wood plantings, and agroforestry farms or roadside tree plantings (see chapter 12).

NOTES

1. According to the Nepal Rural Road Standard, the maximum cross slope differs for different road types: for an earthen road, 5 percent; for a gravel road, 4 percent; and for a bituminous seal coat road, 3 percent.
2. Based on DSCWM (2016) and Desta et al. (2005).

REFERENCES

Bolch, T., A. Kulkarni, A. Kääb, C. Huggel, F. Paul, J. G. Cogley, and M. Stoffel. 2012. "The State and Fate of Himalayan Glaciers." *Science* 336 (6079): 310–14.

Desta, L., V. Carucci, A. Wendem-Agenehu, and Y. Abebe. 2005. "Community-Based Participatory Watershed Development: A Guideline." Ministry of Agriculture and Rural Development, Addis Ababa, Ethiopia.

DSCWM (Department of Soil Conservation and Watershed Management. 2016. "Guideline on Landslide Treatment and Mitigation." Department of Soil Conservation and Watershed Management, Kathmandu, Nepal.

Immerzeel, W. W., F. Pellicciotti, and M. F. P. Bierkens. 2013. "Rising River Flows throughout the Twenty-First Century in Two Himalayan Glacierized Watersheds." *Nature Geoscience* 6 (9): 742–45. https://doi.org/10.1038/ngeo1896.

Lutz, A. F., W. W. Immerzeel, A. B. Shrestha, and M. F. P. Bierkens. 2014. "Consistent Increase in High Asia's Runoff Due to Increasing Glacier Melt and Precipitation." *Nature Climate Change* 4 (7): 587–92. https://doi.org/10.1038/nclimate2237.

Meng, Z., J. S. Wu, and C. J. Allan. 2013. "Hydrologic Connectivity for Highway Runoff Analysis at Watershed Scale." *Journal of Water Management Modeling*. https://doi.org/10.14796/JWMM.R246-02.

Mulmi, A. D. 2009. "Green Road Approach in Rural Road Construction for the Sustainable Development of Nepal." *Journal of Sustainable Development* 2 (3): 149–65.

Phuyal, D., K. Stamper, and M. S. Acharya. 2008. "Green Road Approach: An Appropriate Method of Hill Road Construction in Nepal for the Preservation of Mountain Environment and Landscape." Paper presented at the XIII International Interdisciplinary Conference "Unicity, Uniformity and Universality in the Identification of the Landscape and Cultural Mosaic," Aquileia-UD, Italy, September.

RAP 3 (Rural Access Program Phase 3). 2018. "Climate Resilience Audit of Maure-Kailasmandu District Road Bajura." Rural Access Programme Phase 3, Lalitpur, Nepal.

van Steenbergen, F., A. Tuinhof, L. Knoop, and J. Kauffman. 2011. "Transforming Landscapes, Transforming Lives: The Business of Sustainable Water Buffer Management." 3R Water Secretariat, Wageningen, the Netherlands. https://www.researchgate.net/publication/254833306_Transforming_landscapes_transforming_lives_the_business_of_sustainable_water_buffer_management.

van Steenbergen, F., and S. Yakami. 2019. "Making Roads Work for Water: Scoping Study for Mugu District." Report to RAP 3. MetaMeta Research, Hertogenbosch, the Netherlands.

7 Roads in Floodplains

KEY MESSAGES AND MAIN TECHNIQUES

Key messages

- Roads have a major impact on floodplain hydrology: they often bisect 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.

Main techniques

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

OBJECTIVE

Floodplains are among the highest-potential areas for agriculture in the world, bringing together many different functions. A cautious estimate is that floodplains constitute 50 million hectares of land globally, much of which is relatively pristine. Floodplains are also vulnerable to relatively minor changes in hydrology: changes in the water supply upstream or changes in the morphology of the floodplain itself can have drastic effects.

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

A road passing through a low-lying floodplain alters the movement of water within the floodplain and with it the wetland ecosystem and flood-based

PHOTO 7.1

Dry and wet sides of road in Gambela floodplain, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

livelihoods, including fisheries, rangeland, flood-recession agriculture, and flood-rise agriculture. This impact is particularly true when the road is constructed on a high, impermeable embankment. This type of road acts as a barrier that divides the floodplain into wet and dry zones (photo 7.1). The wet zone on the upstream side will have floodwater spreading along the road embankment. In the dry zone, on the downstream side of the embankment, floodwater will be obstructed from entering. It is important to take this effect into account because it can be used to plan land use in floodplain areas. Furthermore, cross-drainage structures on these roads can have particularly pronounced effects on water management. The objective of this chapter is to discuss the opportunities and recommended practices in constructing roads in floodplains.

OPPORTUNITIES

The opportunities for using roads to manage floodplains differ with the type of floodplain and its predominant use. In relatively dry floodplain areas, floodwater can, for instance, be stored in the upstream zone for use in the dry season. In wetter floodplains, the road will create wetter conditions in the upstream areas, affecting the local ecology and creating conditions conducive to the cultivation of submerged crops such as rice and sugarcane. The possible effects of road construction on land submergence and silt deposition must also be considered: a road or bridge in a floodplain that blocks the movement of floodwater can cause land levels to rise (photo 7.2). Competing interests of upstream and downstream communities on either side of the road can lead to conflicts.

PHOTO 7.2

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Road development in low-lying floodplains will depend on several decisions:

- The preferred land use and wetland functions in the floodplain area
- The objective of the road, and whether it should be passable under all circumstances
- The financial resources available for the road's development

In general, either of two key strategies can be followed when developing infrastructure in floodplains: the *resistance strategy* and the *resilience strategy* (Beevers et al. 2012). The resistance strategy, in principle, aims at preventing and regulating floods, whereas the resilience strategy aims at minimizing the consequences of floods while maintaining natural floodplain dynamics as much as possible. Typically, the resistance strategy will overcome the risk of floods to the road and traffic by providing ample freeboard, which protects against all flooding. The road will be designed to withstand adverse situations without necessarily considering the road's potential adverse effects on the surrounding area. The resilience strategy, on the other hand, considers the best possible road alignment while carefully siting water crossings (at the bottom of sag curves) to minimize flood damage and ponding on the road surface. The resilience strategy calls for provision of flow-through and flow-over relief structures.

RECOMMENDED PRACTICES AND PREFERRED OPTIONS

Once the overall strategy for road development in floodplains is clear, several specific decisions must be made:

- Selection of the location and height of the road embankment
- Consideration of the use of controlled overflow sections
- Provision of adequate cross drainage and subsurface flow capacity
- Control of the upstream water level with cross-drainage structures
- Ensuring fish passage

Location and height of road embankments and controlled overflow sections

The location of the road and height of the road embankments are critically important decisions when developing roads in flood-prone areas.

The location of the raised road embankment will divide the floodplain, with one side of the embankment free from inundation and the other side exposed. Although people living downstream of the road will not face flood hazards, they will also not have access to beneficial uses of floodwater for fisheries, grazing areas, and farming using residual moisture after a flood recedes. Those living upstream of the road will face greater risk of floods during the rainy season because the flow is restricted to only part of the original floodplain. Considerable care is necessary to manage these impacts when siting roads in floodplains.

A second crucial decision is whether to opt for high or low road embankments. High-embankment roads that restrict floodplains are sometimes prone to breaches during peak flood periods. During extreme floods, the road can be overtopped, and damage can occur in an uncontrolled manner. The resulting damage is often severe and may disrupt traffic movement for an extended period. Damage to road embankments can be substantial, not only because of breaches. Debris and silt may accumulate on and along road embankments, and repairs to road shoulders may be necessary. In addition, the stability of stream channels in low-lying floodplains is uncertain; the debris and silt deposited by floods may cause channels to shift and, in general, change the floodplain's morphology.

Low-embankment roads are an alternative to high-embankment roads. Low-embankment roads can be designed to allow overflowing, or to route floodwater through designated sections called floodways (photo 7.3). These designated overflow areas make it possible to lower the height of the road embankment along its entire length, resulting in considerable cost savings. Overflow embankment sections, or floodways, 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.

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

- The depth of flow over the embankment should be inversely related to the width of the embankment's overflow section. Deep flow over the road can interfere with transport. Therefore, the overflow depth should be kept to a minimum.
- The upstream and downstream faces of the embankment should be blanketed with impermeable material such as stone masonry or concrete lining.
- During the design of the top of the road surface, the scouring effect of the overtopping flow should be considered, and a material that protects the road

PHOTO 7.3

Floodway, Sado Plain, Portugal

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

base from saturation should be selected: rigid pavement (ford or vented ford) is a good option.
- The downstream side of the embankment and its toe need protection from scouring by the overflowing water. A toe apron, stilling basin, downstream pool, or stone riprap are good alternatives for this purpose.
- The downstream side should be well aerated to avoid subatmospheric pressure. Flow splitters should be positioned at the top edge of the downstream face of the embankment.
- Trees on either side of the floodway can provide further protection against scouring by overflowing water.
- The overflow should be guided to areas where it serves beneficial purposes: groundwater recharge areas, grazing land, or a wetland.

One disadvantage of floodways is that overtopping renders a section of the road unusable during flood events. This lack of access causes inconvenience, 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.

Adequate cross drainage and subsurface flow capacity

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

Culverts

Culverts can provide cross drainage for both surface and shallow subsurface flows. Partly buried culverts will convey both surface and subsurface flows. They will also mitigate slow flooding events. The common embedment depth for partly submerged round culverts is 40 percent. Culverts that only carry surface flows will be placed above ground level.

The number of culverts is critical. Given the slow flow of water in a floodplain, multiple culverts are required. The culverts balance the amounts of water on either side of the road. They rarely flow at capacity but are required for unusual events. The dimension of the culverts is a second consideration. For a seasonally fluctuating wetland, such as a floodplain, the amounts of water passing through for part of the year will be high; thus, large culverts are required. Table 7.1 indicates the preferred spacing and dimension of culverts.

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

A special consideration for placing culverts in floodplains and wetland conditions is that the underlying soil may not have much bearing capacity, and reinforcement may be required. The most common of the various ways to provide reinforcement are as follows:

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

TABLE 7.1 Road culvert spacing and dimensions for floodplains

	STAGNANT	SLOW LATERAL FLOW	FAST LATERAL FLOW
Culvert spacing	Widely spaced	Mid- to widely spaced	Closely spaced
Maximum culvert spacing on a permanent road (meters)	200	150	100
Maximum culvert spacing on a temporary road (meters)	250	200	150
Culvert diameter (millimeters)	250–500	500–800	greater than 800

Source: Partington et al. 2016.
Note: Necessary culvert spacing and culvert diameter largely depend on the topography, rainfall, and runoff characteristics. The values in the table are guide values that require location-specific calculation.

French Mattresses

An alternative to providing cross drainage using culverts is to provide permeable sections. These sections typically consist of coarse clean rock enveloped in geotextile or a local alternative material and are known as "French mattresses" or "rock sandwiches." They have added value over culverts in several instances (Penn State University 2013):

- Where water saturation risks destabilizing the road base (also between two culverts)
- Where a bidirectional flow of water through the road base should be allowed
- For preventing gully erosion that may occur downstream of a culvert in areas with considerable slope by making it possible to disperse flows
- To help preserve wetlands by releasing water more gradually than culverts, which may lower wetland water levels

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

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

French mattresses are constructed using the following steps:

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

Controlling upstream water levels with cross-drainage structures

Road cross-drainage structures also control upstream water levels in floodplains. An important consideration is the height of the bed sills in bridges and culverts, because they will effectively determine the water level in the upstream section of the road (photo 7.4). Because these bed sills define the level of the main drainage outlet, they effectively determine the water level in a very large area, which

PHOTO 7.4
Bridge sill determining water level in upstream floodplain, Mozambique

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

creates the conditions for wetland development, ensuring adequate water levels for submerged or aquatic crops such as rice or sugarcane. Bed sills of bridges and culverts are an important factor in the drainage and waterlogging of large floodplain areas.

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

To manage water levels on the land for these productive uses, gates may be provided on the culverts (photo 7.5). Gates make it possible to either raise the water level or drain the land. The placement of such gates should be determined in close cooperation with the land users. Assessing the effect of impounding water upstream on the integrity of the road body is also important. Reinforcement may be provided, if required. Generally, the preferred type of gate is the stop log with wooden planks sliding in a railing. These wooden logs can be maintained by the land users and will be less prone to theft and vandalism than permanent gates.

Ensuring fish passage

Culverts in wetland areas are the main passage for fish and other aquatic animals. Several considerations apply if culverts are used as fish passages, as outlined in "Roads for Water Management in Low-Lying Coastal Areas" in chapter 5.

PHOTO 7.5

Water in canal controlled by gates on the culvert, Uganda

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

ALTERNATIVE ROAD OPTION IN FLOODPLAINS: SUBMERSIBLE ROADS

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

To provide downstream protection of a horizontal submersible track, an opening of 10–15 centimeters wide is set every 3–4 meters to drain the road (Bender 2009). These roads are inundated during the flooding season but facilitate 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.

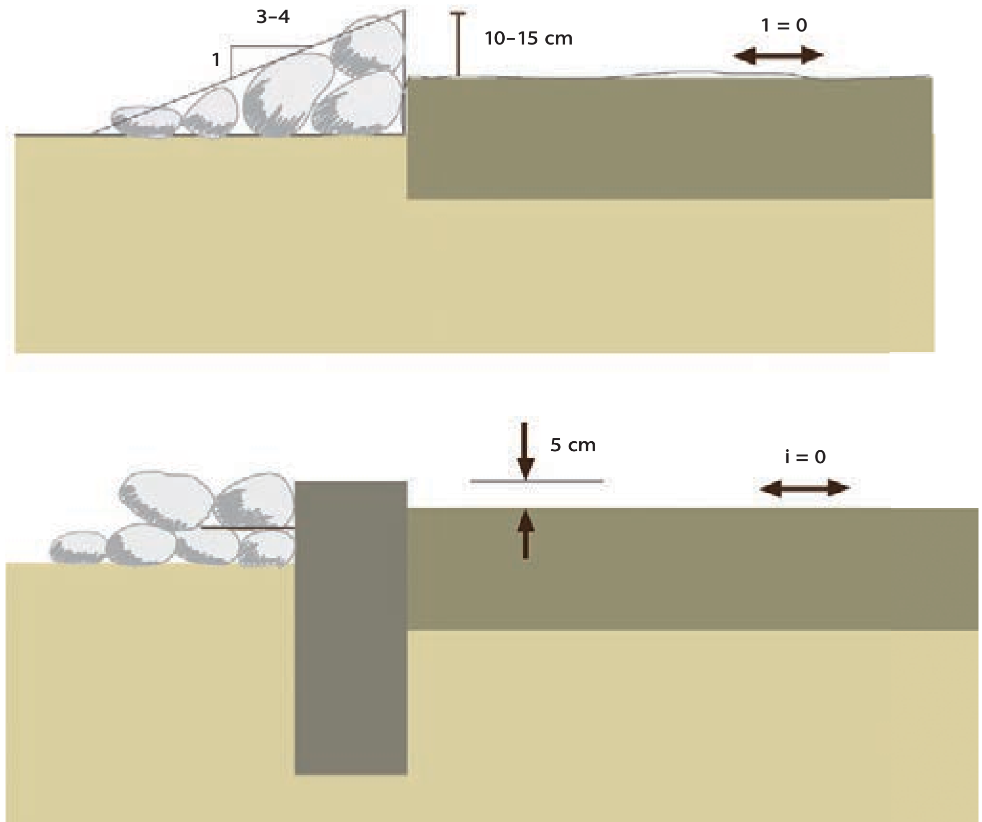
The following requirements apply for submersible roads (figure 7.1):

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

To avoid prolonged flooded conditions after a flood, it is possible to make one or two parts of the road 5–20 centimeters below the lower level of the ground.

FIGURE 7.1

Submersible road criteria



Source: MetaMeta (www.roadsforwater.com).

REFERENCES

Beevers, L., W. Douven, H. Lazuardi, and H. Verheij. 2012. "Cumulative Impacts of Road Developments in Floodplains." *Transportation Research Part D* 17 (2012): 398–404.

Partington, M., C. Gillies, B. Gingras, C. Smith, and J. Morisette. 2016. *Resource Roads and Wetlands: A Guide for Planning, Construction and Maintenance*. Special Publication SP-530E. Pointe-Clire, QC: FPInnovations.

Penn State University. 2013. "Technical Bulletin: French Mattress." Penn State University, University Park, PA.

III Techniques

8 Borrow Pits

KEY MESSAGES AND MAIN APPLICATION

Key messages

- Borrow pits can be used as future water storage (rather than being backfilled).
- This future use can be simplified by appropriate planning of borrow pit size, location, and entry points.
- Borrow pits can be further upgraded with proper protection, entrance control, landscaping, and (if necessary) lining.

Main application

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

OBJECTIVE

This chapter provides guidance on the systematic conversion of borrow pits to water-storage structures. Borrow pits provide the source material for the construction of road embankments. Depending on the local area, the source material can be gravel or aggregates, silica sands, laterite sands, and calcite. Once no longer in use for the mining of road construction material, borrow pits can become key assets for local water supply (photo 8.1). Rather than backfilling the pits or leaving them unattended, the borrow pits may be systematically converted into storage structures to serve as sources of irrigation or livestock water. In areas where there is no alternative, borrow pits may even become sources of domestic water. In some areas, borrow pits have been landscaped into attractive recreation areas and urban lakes. This chapter discusses the opportunities for converting borrow pits and the recommended practices for planning and implementation.

PHOTO 8.1

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

OPPORTUNITIES

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

- The pit can be connected to a water source.
- The pit is located in an area of water shortage.
- The pit is close to domestic, livestock, or irrigation water users.

Borrow pits may be used for water supply in three ways:

- *Water retention*. The borrow pit is used for direct storage of runoff water. In such cases the pit should have a relatively impermeable bed to prevent stored water from leaking away.
- *Infiltration ponds*. In this case, the water that is collected infiltrates and feeds the shallow groundwater. Such borrow pits should have relatively permeable beds to facilitate groundwater recharge. They may even be supplied by excess water from nearby streams diverted or pumped into the converted borrow pit. (See box 8.1.)
- *Seepage ponds*. Borrow pits can serve as seepage ponds in areas with high groundwater levels, such as the floodplains of major rivers (photo 8.2). In this case, the pits will fill constantly with groundwater seeping from adjacent areas and provide an almost permanent water source.

PHOTO 8.2

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

BOX 8.1

Converting a gravel pit into an infiltration structure in Italy

Coastal areas of southern Tuscany, Italy, face increasing water stress from construction of upstream storage dams and extensive use of wells to cultivate high-value vegetables. Because gravel quarrying was previously common and lightly regulated, gravel operations frequently closed without the gravel pits' being refilled. These pits provided an opportunity to recharge local groundwater supplies. To achieve this goal, a gravel pit close to Forni was deepened and transformed into an infiltration structure aimed at replenishing local groundwater resources. The excavated pit was split in two: a relatively small sediment pond and a larger infiltration basin that received the overflow of clean water from the sediment pond (photo B8.1.1). The choice of pond location and the deepening of the infiltration basin were designed to tilt the groundwater recharge away from the Cornia River to reduce the risk that the new water lens underneath the gravel pit might feed back into the river instead of recharging local aquifers.

The infiltration structure is fed by an intake from the Cornia River equipped with a pumping unit. The pumping unit typically operates 75 percent of the time. The pump automatically ceases if the river level falls below the minimum flow thresholds, set for environmental reasons. The pump also stops during flood events when the river water carries iron, nitrate, and excessive sediment. Fully automated measurement of water quality ensures appropriate management of water quality risks. The structure recharges water at a rate of 65 liters per second. A piezometer around the

(box continues next page)

Box 8.1, *continued*

PHOTO B8.1.1

Gravel pit converted into infiltration structure, Tuscany, Italy

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

infiltration pond detected an 80 centimeter increase in groundwater level in the first month of operation.

The investment in the pond was US$360,000, and it created storage capacity of 200,000 cubic meters. At a unit cost of US$1.80 per cubic meter, the cost of the facility is very affordable compared with surface storage dams. Instrumentation accounted for 40 percent of the cost. It may be possible to replicate this concept on other abandoned gravel pits at an even lower cost. It is conceivable that in the future such structures may be used to produce and sell water, and that the structures could be operated by remote control.

RECOMMENDED PRACTICES

The reuse of borrow pits as water ponds needs to be approached systematically, from the planning of these pits to their development, conversion, and aftercare. The following elements should be considered and are addressed in the remainder of this chapter:

- Siting of borrow pits
- Designing, shaping, and protection of borrow pits

- Addressing safety issues
- Reducing excessive water losses
- Reducing the risk of sedimentation

Siting of borrow pits

Siting of borrow pits is primarily guided by the availability of source material for road construction, proximity to the road, and arrangements for acquiring borrow sites. Future use for water storage should be considered as a secondary factor when choosing the locations of borrow pits. When several potential sites are available that meet the primary objectives of a borrow pit, the following considerations should be used if the borrow pit is later to be transformed into a water-storage structure:

- The borrow pits should be close to areas where people reside or where there is interest in irrigation (photo 8.3). Care should be taken to balance different possible uses. In some pastoralist areas, for example, there are concerns that converted borrow pits may attract nonpastoralists and create conflict. In general, the location of water resources should be planned carefully, for instance, by considering rangeland potential so as not to create an imbalance between grazing area and livestock numbers.[1]
- Siting often involves a choice between one relatively large borrow pit or several smaller pits. More but smaller borrow pits are often preferable in areas with dense populations because more localized storage capacity will be created. A larger borrow pit may be a more secure source of irrigation water, particularly if combined with water-saving measures (van Steenbergen 2017).
- In general, local drainage patterns should be carefully considered and borrow pits should be positioned optimally so that they can capture surface water flows, optimize their contribution to recharge, or collect seepage flows.

PHOTO 8.3

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

- o The ideal location of a borrow pit in dry, sloping areas is often on the downslope of the road where culverts and other road-drainage structures can easily supply runoff. In contrast, there are fewer opportunities to direct road-drain flows into borrow pits built on an upslope from the road drain. More and flatter land for productive use is often located on the downslope side of a road.
- o In areas with high groundwater tables where seepage flows can supply water, borrow pits are best located on the river side of roads, where groundwater stocks are more secure. The local population can be consulted to identify where groundwater availability is reliable.
- o In communities where animals are not fenced in, borrow pits should be located far enough from the road to discourage animals from congregating on the road or immediately adjacent to it.

Size and shape of borrow pits

The size and shape of converted borrow pits affect their function. The size and shape are largely determined by the availability of material for excavation and by the way excavators and dump trucks operate. Borrow pits should be excavated well clear of the carriageway, and a 20-meter minimum offset is suggested. A greater offset distance should be provided for higher volume roads. Borrow pits often have irregular shapes, and the original pits should be modified and properly landscaped as part of the transition to their new function as water-storage facilities. This modification is preferably done by deploying the earthmoving equipment of the operator or contractor that excavated the borrow pits.

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

- *Safety*. Modify or remove potentially dangerous heaps and sides.
- *Stability*. Ensure stable slopes (see box 8.2).
- *Shape*. The converted borrow pit's shape should be designed to optimize storage. A convex shape is preferable for unlined borrow pits that are converted

BOX 8.2

Slope of the converted borrow pit

The preferred slope of a converted borrow pit in combination with a pond depends on, among other factors, the type of soil. The ANE (National Roads Administration in Mozambique) Environmental Guidelines prescribe a minimum slope of 1.0:4.0. The material of the borrow pits may necessitate much gentler slopes. As a rule of thumb, the following values can be used:

- Clay loam 1.0:5.0 – 2.0:1.0
- Sandy loam 2.0:1.0 – 2.5:1.0
- Sand 3.0:1.0

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

$$Y = 100CI/A,$$

where

Y = average slope (percent)
C = total contour length (centimeters)
I = contour interval (centimeters)
A = drainage area (square centimeters)

Preferably, the slope will be gentle and regular.

into storage ponds. Convex pits are ideal for water storage because they have the most favorable ratio of water-storage volume to potentially permeable surface area at the pit bottom. They are also inherently more stable than ponds with odd and square angles. Lined ponds are preferably trapezoidal. A trapezoidal shape is preferred for pits lined with geotextile because the geotextile can be more easily installed. If many borrow pits in a certain area are to be lined with geotextile, standard dimensions should be used for the converted borrow pits to reduce costs by allowing linings to be stitched together before being shipped to the installation site.

- *Depth.* Increasing borrow pit depth can reduce evaporation. A depth of 7 meters or more is preferred. Depth is an important consideration when borrow pits depend on surface runoff and are not constantly recharged from shallow groundwater seepage. Depth is particularly relevant to conserving water through hot, dry periods when evaporation from borrow pits is high. Deep borrow pits are also likely to cross through several layers of rock and soil with different hydraulic properties. If water retention is the primary goal, the borrow pit should not extend below the impermeable layer.
- *Access.* Different water users will use the borrow pit, so the shape should include an access ramp. Access may need to be provided to people or trucks. According to current guidelines in Mozambique, borrow pits are to be provided with single-access roads to allow for better control. Truck ramps can be easily modified to provide safe access for livestock and people. It is advisable to stone pitch the ramp to enhance its stability against cattle trampling, when possible.
- *Contamination reduction.* Special levees can be installed with small pumps to lift water out of the borrow pit. Although not ideal, special water troughs for livestock, or subponds, fences, or trenches, can also be installed to prevent livestock from coming into direct contact with the water to reduce the risk of contamination.
- *Spillway facilities.* Room for a spillway is recommended, especially in sloping terrain. As borrow pits collect water, they may spill over once they are filled, such as after a heavy rainstorm. It is important to consider a spillway that can release excess water to a natural drain in the layout of the pit. In some cases, the borrow pit will be large enough in comparison with its catchment area that no spillway is required because it is unlikely to fill.
- *Inlet reinforcement.* Inflowing water often causes erosion and structural damage at the inlet-reservoir interface. Water dropping from the inlet into the storage structure can easily carve out borrow pit walls and quickly trigger gully formation upstream of the water drop. Stone pitching, steps, and masonry can be used to reinforce the inlet.

The following factors should be considered with respect to the size of the borrow pit:

- The size of the borrow pit and its use for domestic purposes, irrigation, or livestock are closely related. Borrow pits often serve as a source of water where there is no alternative and so should have enough capacity to provide water over a large part of the dry period. In some areas the pits may fill several times a year, depending on the rainfall pattern; in other areas the borrow pits may only fill once or twice a year, so large borrow pits are needed.

- When converting abandoned borrow pits into water-storage ponds, good assessments of the runoff in the area and the required usage are critical. Expected runoff can be calculated with the simplified rational method (see box 8.3).
- A borrow pit that primarily serves to recharge groundwater should be large enough to accommodate a large part of the runoff (with scope for some water to escape through spillways or other overflow structures into the feeder canal).

Ensuring the safety of the converted borrow pit

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

- People, especially children, and animals may fall into the borrow pit. It is possible that animals will drown and pollute the water, making the water unusable for the intended purpose.

BOX 8.3

Calculating the size of converted borrow pits: Supply and demand

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

To determine the supply, it is necessary to take the following steps:

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

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

   with P being the probability of occurrence, m the rank, and N the number of observations. Plot the probability against the amount of rainfall for each season.
3. From the obtained curve, determine the rainfall with a 67 percent probability of occurrence (probability of occurring twice every three years).
4. Multiply the catchment area's obtained rainfall by the runoff rate (0.1 for permeable soils, 0.9 for paved roads). In this way it is possible to roughly estimate the amount of runoff reaching the borrow pit.

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

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

where
V = volume of water to meet local needs (cubic meters)
I = water volume to meet irrigation needs (cubic meters)
E = water losses due to evaporation (cubic meters)
S = water losses due to seepage (cubic meters)
H = domestic water demand (cubic meters)
L = livestock demand (cubic meters)

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

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

- The water may become contaminated and become a source of mosquito breeding.
- The water from the borrow pit may become unsafe for consumption.

The group of people who manage a borrow pit should cooperate closely to undertake several measures to improve its safety:

- *Install fencing.* The borrow pit may be fenced, either with plant material or by excavating trenches. Fencing reduces the risk of people or animals straying into the storage pond. Tree fencing may also contribute to reduced evaporation from the pond surface. In some cases, the selection of trees may contribute to reducing the incidence of malaria.
- *Reduce the incidence of vector-borne diseases, particularly malaria.* Shallow ponds often become breeding habitats for mosquitos. Vector breeding is considerably less in deeper water. The pond can also be actively managed so that the water has enough movement to deter mosquito breeding. Introducing larvae-eating fish species to the pond can also reduce the risk of mosquito infestation. Tilapia (*Oreochromis niloticus*) are particularly effective (known to remove more than 90 percent of the larvae) and are a commercially attractive source of protein. The management of vegetation around the borrow pit and the removal of small water-filled depressions can also reduce mosquito breeding. Some trees are known to repel malaria mosquitos (for example, the olon tree, *Zanthoxylum heitzii*, which is native to Central Africa). Several still-experimental methods may control mosquitoes as well, such as the use of vegetable oil with white colorant. The colorant reduces evaporation losses (because it reflects sunlight), and the oil makes it more difficult for mosquitos to land on the water.
- *Safeguard water quality.* Hand pumps and sand filters can be installed to help safeguard water quality. Some areas have no source of water other than the borrow pit. Borrow pits are open-surface water bodies, however, and do not provide safe water for direct human consumption. This limitation can be overcome by placing a hand pump and sand filter on the borrow pit, or by household treatment of the water. It is essential to safeguard the quality of the borrow pit by segregating the area where livestock are drinking.

Reducing excessive seepage

A significant share of water can disappear from seepage when borrow pits are used for surface storage rather than as infiltration or seepage ponds. In areas with fine sediment, seepage may cease to be a factor over time as fine material seals the bed of the pond. In addition, some low-cost measures can be used to reduce seepage from ponds:

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

The measures above may be insufficient in areas with permeable soils. Lining with geotextile may be necessary to reduce seepage and make the borrow pit suitable for storage (photo 8.4). Polyethylene, butyl rubber, and vinyl membranes are commonly used for pond lining. The recommended practices include the following:

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

Several kinds of geomembranes are available on the market, with different benefits and drawbacks. See table 8.1.

PHOTO 8.4
Borrow pit lined with geotextile, Mozambique

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

TABLE 8.1 Geotextile materials for reservoir lining

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

Sources: BTL Liners - Geomembrane Systems, n.d., "What's the Best Material for Pond Liners: A Side-by-Side Comparison," https://www.btlliners.com/best-material-for-pond-liners/, retrieved January 26, 2021; Pond Informer, June 18, 2019, "Comparison of Different Pond Liner Materials (Which Is Best?)," https://pondinformer.com/pond-liner-material-guide/.
Note: EPDM = ethylene polypropylene diene monomer; PVC = polyvinyl chloride; RPE = reinforced polyethylene; UV = ultraviolet.

Reducing the risk of sedimentation

The lifetime of a borrow pit converted into a water-storage pond may be shortened if it is regularly filled with sediment-rich water flows. Several measures are recommended to prolong its life:

- Locate borrow pits in areas with protected watersheds and low silt content in the runoff that feeds the borrow pits. This approach may not always be possible, but the health of the catchment may be a consideration in siting the borrow pit.
- If well-protected watersheds are unavailable, use vegetation plantings to mitigate silting from the most critical sediment runoff areas.
- Take steps to trap sediments before they reach the converted borrow pits. Install sediment traps or employ vegetative measures.
- Maintain sediment traps and vegetative measures that can fill up quickly. The sand in the sediment traps can sometimes be repurposed for use as building material or agricultural soil and may be harvested and sold.

Borrow pit management

Converted borrow pits need to be well managed, including by undertaking the following activities:

- Regulate use of the borrow pit, particularly in times of scarcity.
- Avoid contamination that makes the water unfit for use.
- Undertake basic maintenance and protection, such as protecting vegetation, cleaning sand traps, controlling entrance by livestock, and performing periodic desiltation.

Regularizing future ownership of borrow pits in combination with storage facilities is essential. The land used for digging the borrow pits may have been privately owned at one time, so it is important that ownership of the borrow pit be settled and that the original landowner be compensated.

A local committee or local government should look after the water source and attend to its access, protection, and maintenance. To the extent possible, management committees should be linked to a legitimate local government, and ad hoc management committees should be avoided.

If a committee is in place, it can also mobilize the resources to conduct maintenance work. A local committee can raise funds through several avenues, such as charging for use of the converted borrow pit or dividing the maintenance work among users who each take care of a section of the pond.

NOTE

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

REFERENCE

van Steenbergen, F. V. 2017. "Road-Side Borrow Pits as Ponds for Off-Season Small-Scale Irrigation." Hamburg University of Applied Sciences, Hamburg, Germany. https://roadsforwater.org/wp-content/uploads/2017/06/Technical-Sheet_BPs.pdf.

9 Road Drifts

KEY MESSAGES AND MAIN APPLICATIONS

Key messages

- Road drifts can be used to build up water storage in sandy dry riverbeds, which will help build up moisture in the sand deposited upstream of the drift in a manner similar to sand dams.
- The road drift should not include a culvert; the center of the drift should be lowered and there should be adequate spillover capacity.
- Road drifts can also be used to stabilize ephemeral riverbeds.
- A series of road drifts and sand dams may be planned in dry rivers.

Main applications

- Nonvented road drifts can create water storage in semiarid areas and prevent rivers from braiding.
- Nonvented drifts can also be used in mountain areas to prevent the erosion of mountain streams and road-water crossings.

OBJECTIVE

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

OPPORTUNITIES

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

Moreover, the transport of water in the riverbed reduces evaporation and minimizes water losses. The water quality in the riverbed is usually improved because the riverbed material acts as a sand filter.[1] In the absence of other reliable sources, the water from the dry river, accessed through scoop holes, infiltration galleries, or wells, serves as a source of domestic water or as water for livestock or irrigation. In addition, the subsurface flow in an ephemeral river recharges shallow groundwater. By constructing a well upstream of the river, people can extract this water more conveniently.

The importance of these rivers is evident, especially in arid and semiarid areas where a single river flood may be the only source of water for an entire year. The lack of alternative water sources is all the more reason to harness these rivers in the best manner possible and increase their water-retaining capacity. This goal can be accomplished using dual-purpose road drifts. On low-volume roads, road drifts are more economical and are preferred to conventional bridges across expansive dry rivers with occasional floods (photo 9.1). The drifts may not

PHOTO 9.1

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

Source: © Paul van Koppen. Used with the permission of Paul van Koppen, kopconsult. Further permission required for reuse.

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

RECOMMENDED PRACTICE: RIVER CROSSINGS AS SAND DAMS AND BED STABILIZERS

Road drifts not only serve as river crossings but should also function as sand dams and riverbed stabilizers. Nonvented drifts[2] can act both as low-volume traffic conduits and as water-retaining structures. They help capture and store floodwater and retain it for future use. Unlike vented drifts, nonvented drifts are not equipped with culverts. Drifts provide good opportunities to retain water from ephemeral rivers because they act as sand dams (see box 9.1).

It is important that these dry river crossings have *no* vents (culverts). Because of the absence of culverts in the drift, coarse sand and gravel will accumulate in the riverbed upstream of the drift, which creates a small man-made aquifer of sand and water. Coarse sand and gravel have large pore spaces between their grains; these spaces can account for up to 35 percent of total sand volume.

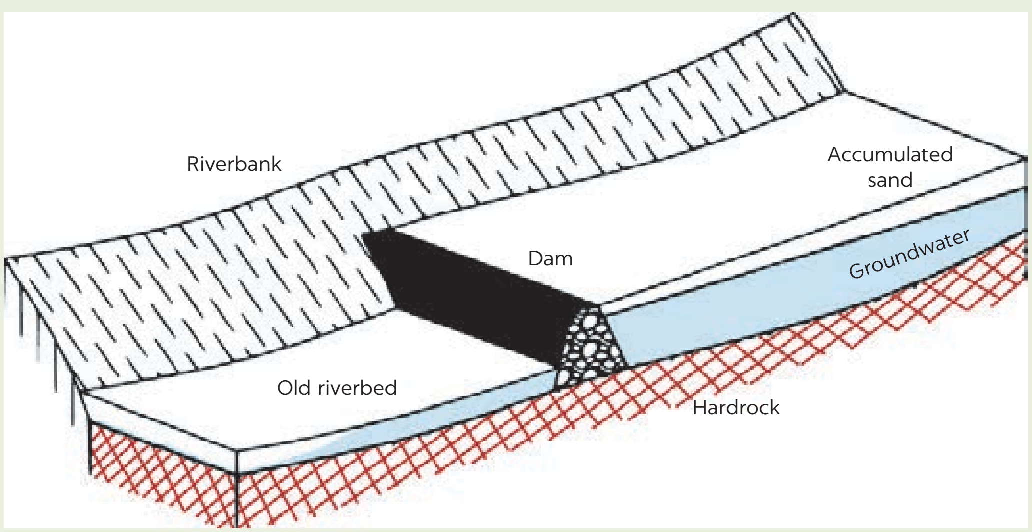
BOX 9.1

Sand dams

Sand dams reinforce what sandy rivers are already doing: storing water in the sand. A retaining wall across the riverbed enables the accumulation of sand upstream, increasing its water storage capacity and water retention (figure B9.1.1).

FIGURE B9.1.1

The principle of a sand dam: Accumulating coarse sand upstream of the dam or culvert



Source: MetaMeta (www.roadsforwater.com).

This means that up to 35 percent of the volume of sand and gravel can be used to store water. Thus, a nonvented drift builds on the natural capacity of a sandy riverbed (photo 9.2). The newly deposited material will store floodwater and make it available during the dry season. The water retained in the riverbed will also connect to and feed aquifers on the banks of the river. The extent of this effect depends on local topography and geology.

Water-retaining sand dams come at no additional cost. In fact, they are even cheaper than the alternative option, that is, vented drifts equipped with culverts. The exact cost of nonvented drifts depends on their height, which also determines their capacity to retain water (table 9.1).

Nonvented drifts also provide other water management benefits. The first is stabilization of the upstream riverbed. Depending on the lay of the land, nonvented drifts make it possible to use gravity upstream of the drift to divert water from the riverbed. Water can be diverted from perennial flows or short-term floods or spates. Diversion of water from rutted and incised riverbeds is difficult, but water can be diverted more easily if the riverbed is first stabilized and smooth.

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

One potential way to make nonvented drifts passable during flood events is to add a vented drift at the top of the embankment. (Figure 9.1 shows an example

PHOTO 9.2

Road drift on a small river near Kitui, Kenya

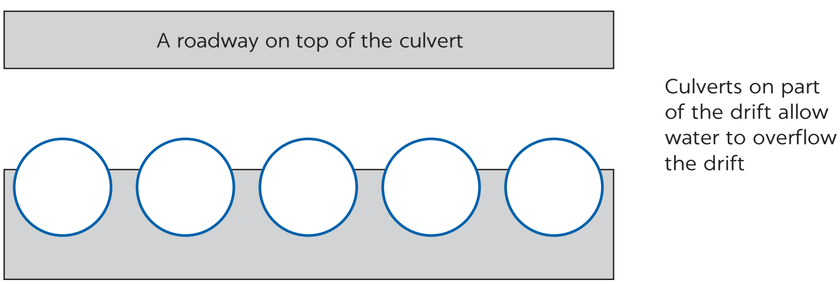
Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

TABLE 9.1 Drift construction costs in Makueni County, Kenya, 2015

DRIFT TYPE	CONSTRUCTION COST (US$ PER METER)
Large drift, foundations excavated at maximum depth of 1.5 meters and elevated 0.3 meters above the existing sandy riverbed.	1,240
Large drift, constructed on bedrock, elevated 0.5–1.2 meters above the existing riverbed.	760
Small drift, constructed on normal, ordinary river channels. Little or no elevation above the existing riverbed level. Depth 0.5–1.0 meter.	475
Small drift (road slabs), constructed on bedrock or swampy plains. Little or no elevation above the existing riverbed level. Maximum depth 0.5 meter.	330

Source: "Road Crossings for Water Harvesting in Seasonal Rivers: Non-Vented Drifts as Sand Dams," http://spate-irrigation.org/wp-content/uploads/2017/10/PN31Road-crossings-WH-Seasonal-rivers.pdf.

FIGURE 9.1
Sandwich drift to ensure passability



Source: MetaMeta (www.roadsforwater.com).

of a sandwich drift that allows water flows in case of flooding.) Analysis of traffic volumes is required to determine whether this option would be economical and necessary. Because floods in these ephemeral rivers are mostly limited to a few days a year, nonvented drifts are suited to low-volume routes. For high-volume roads, the suitability of this combination of structures can be better assessed on a case-by-case basis.

Siting of a nonvented drift

Several requirements are associated with appropriate sites for nonvented drifts on dry riverbeds. The first is to select a narrow, shallow section of the dry river. Narrow sections are preferred to save material and labor costs. A geophysical survey at the riverbed to measure the depth of sand sediment on top of a rock or subsurface formation is a critical part of the process. The best location for a nonvented drift has shallow sand depth, narrow width, and low riverbanks, and is not on a river bend.

A second requirement is to select sandy or gravelly rivers. Fluvial flow will be stored in the space between loose sand particles and gravel in the riverbed and will make the water easy to retrieve while reducing evaporation.

Ephemeral rivers that predominantly carry clay or silt are not suitable for a nonvented drift or sand dam because the fine material will not hold much extractable water.

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

Fourth, the socioeconomic potential of a nonvented drift needs to be considered, including the presence of population, farmland, and the scope for nonagricultural activities. For instance, brickmaking is a rewarding rural economic activity that can be boosted by the presence of water.

Fifth, development of a series of structures in a dry river is the favored method. Preferably, a series of nonvented drifts and other structures (weirs and sand dams) are built in a dry river, helping to regulate the flow, stabilize the river, and improve floodwater retention across the entire river. None of these structures can be fully connected (as in a cutoff weir) to the river's bedrock to avoid blocking subsurface flow to the downstream areas, depriving those living there.

Finally, an estimate of the sediment load that comes in with a flood must be made. Enough coarse sand and gravel must be accumulated to prevent fine particles from being stored upstream of the retaining wall. Fine particles diminish the storage capacity of sand-retaining structures. Walls that are too high trap silt and fine particles, reducing the potential water storage.

Design of nonvented drifts

A nonvented road drift consists of several elements: the body of the drift, the approach road, the upstream protection of the stream, and the downstream apron. The main points with respect to the design of nonvented drifts are presented below:

- Expand the drifts by 5–10 meters on either side of the riverbank, depending on the width of the river.
- Extend the approach above the experienced flood level to prevent damage when floods are high.
- In sandy riverbeds, anchor the structure at 1.5 meters below the existing riverbed level; in rocky riverbeds, the foundations should be laid on the bedrock.
- Foundations should have a minimum width of 500 millimeters and a construction depth of 250 millimeters.
- The top slab, on which traffic passes, should have a constructed thickness of at least 150–200 millimeters, depending on traffic volume and load.
- The drift should be filled with hardcore material and compacted to a maximum depth of 1 meter on sandy riverbeds and 0.6 meter on rock riverbeds.
- The foundations, walls, and slab should be rigidly tied together to prevent the drift from being washed away by floodwaters.
- The width of the roadway slab should vary between 3 meters and 5 meters, depending on the anticipated type and volume of traffic.

- The drift should extend a maximum of 1 meter above the existing riverbed, which is sufficient to ensure that sand and water accumulate upstream of the drift.
- Gabions should be installed at the foundation of the drift on the downstream side to prevent the foundation from being undermined by overflowing floodwater.
- The drift should have a curvature toward the center of the river to ensure that the water concentrates in the middle of the river, minimizing erosion along the riverbank
- The elevation of the drift and the walls above the riverbed determine the additional material deposited and the amount of water retained. Coarse material is deposited in the riverbed, while finer material is washed off the drift and walls to downstream areas of the river. The deposits accumulate over several years. The height of the drift can be increased in stages so that mainly coarse material is deposited each year.

Measures to prevent failure

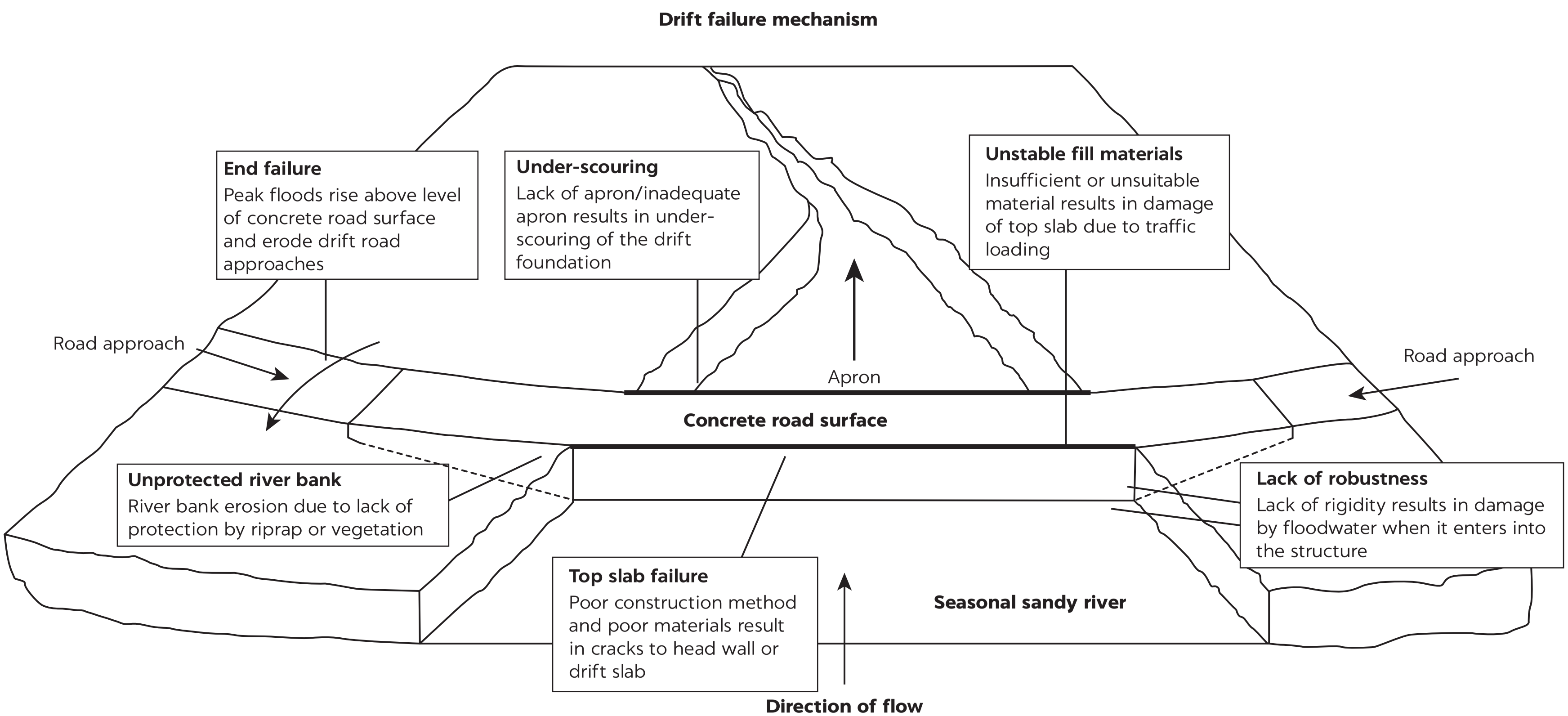
The constructed drift is an investment that provides livelihoods for communities. Therefore, it is important to prevent structural failure and washing away by floodwater. Figure 9.2 illustrates the possible causes of drift failure that should be considered during design and construction. Measures to prevent failure include the following:

Body of the drift. The top slab of the drift should be adequately supported to avoid collapse under traffic load and to create mass resistance so as not to be washed away by floodwater. Fill material of adequate strength should be placed in the structure to give it firm resistance to floodwater. The fill material also ensures adequate resistance to traffic load. Rock fill is typically recommended, with a minimum depth of 1 meter underneath the top slab in sand riverbeds and 0.6 meter in drifts constructed on rock riverbeds (see figure 9.3).

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

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

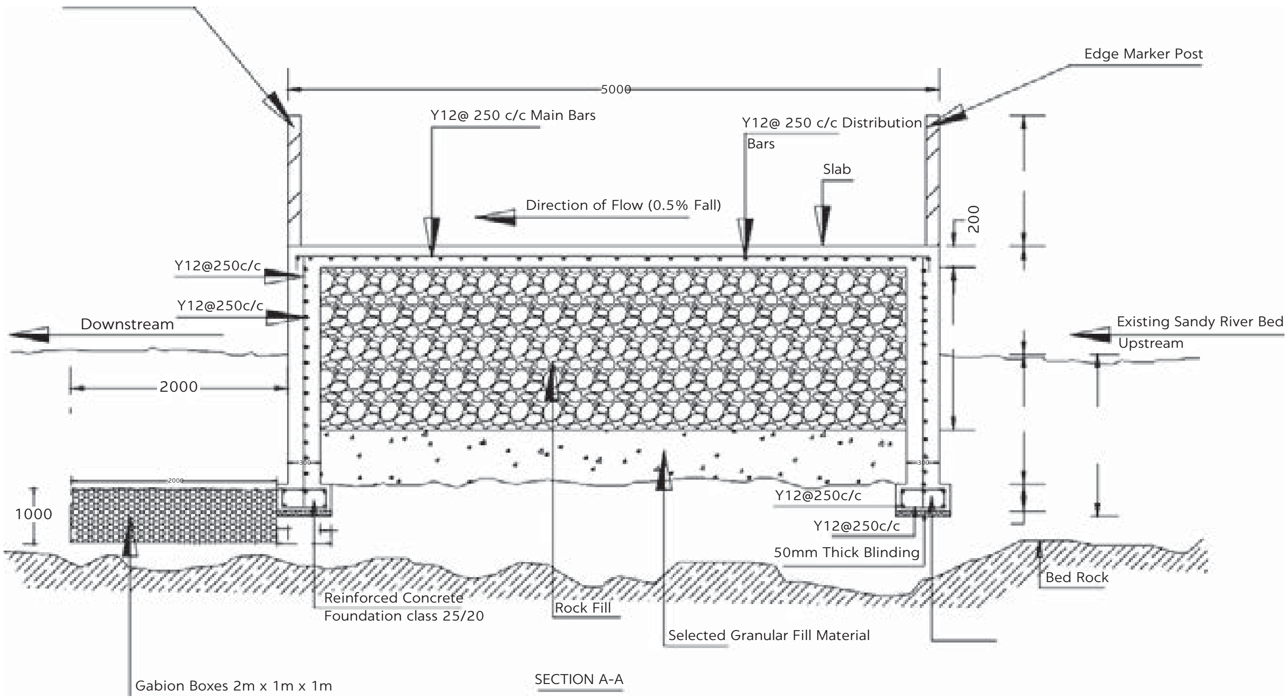
FIGURE 9.2
Overview of nonvented drift with preventable failure features



Source: MetaMeta (www.roadsforwater.com).

FIGURE 9.3

Drift construction in sand river bed: General section of nonvented drift with design considerations



Source: ©Masila Benson Muteti, Kenya Rural Roads Authority (KeRRA) Regional Manager. Used with permission. Further permission required for reuse.
Note: Y12@250c/c = placing reinforced bars of size Y12 placed at 250mm center to center. This is to reinforce a structural wall to increase its strength. c/c = center to center.

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

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

CONSTRUCTION

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

- Drifts should be constructed with reinforced concrete with twisted Y12 steel bars in a single layer spaced at 250 millimeters center to center.

- Structural concrete should be class 25/20 and blinding concrete should be class 15/20, with 1.0:1.5:3.0 and 1.0:3.0:6.0 ratios of cement, fine aggregates, and coarse aggregates, respectively. The concrete should be mixed well in the concrete mixer and compacted in place using a poker vibrator.
- The water-to-cement ratio should be well controlled. Ideally, the water should be half the amount of cement in the mix.
- The concrete design mix should be prepared by a qualified engineer and tested to meet the required strength before application. Well-compacted rock fill should be placed up to a minimum depth of 1 meter to give the drift sufficient mass.

NOTES

1. Sand is a very suitable water filter. It removes many pollutants, even though it cannot guarantee drinking water quality.
2. Various terms are used for drifts, including fords, low causeways, and Irish bridges.

REFERENCES

Excellent Development. 2018. "Rural Road Crossings: A Vehicle for Water Investment in Drylands." https://www.excellentdevelopment.com/sand-dam-road-crossing-brochure.

Global Resilience Partnership. 2017. "Road Crossings for Water Harvesting in Seasonal Rivers: Non-Vented Drifts as Sand Dams." Practical Note 31, Global Resilience Partnership. http://roadsforwater.org/wp-content/uploads/2017/10/PN_31_Road-Crossings-for-Water-Harvesting_SF.pdf.

10 Water Harvesting and Drainage from Unpaved Roads

KEY MESSAGES AND MAIN APPLICATIONS

Key messages

- Most damage to unpaved roads, as much as 80 percent, is caused by rain runoff.
- Unpaved road surfaces are a major cause of sedimentation (up to 35 percent, excluding gullies) in mountain catchments.
- Damage can be minimized when water is systematically directed to the land rather than running along the road surface.
- Directing water requires design considerations in unpaved road alignments—regular slope reversal, avoidance of sunken roads, and inclusion of basic road drainage.
- Several additional measures preserve unpaved roads, enable water harvesting, and reduce erosion, such as water bars, rolling dips, and infiltration bunds.

Main applications

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

OBJECTIVE

This chapter discusses basic measures that reduce water damage to unpaved roads by guiding water away from road surfaces to locations where it can be used productively or for recharge. These measures are particularly important for the preservation of unpaved roads. For instance, water is responsible for approximately 80 percent of damage to unpaved roads (photos 10.1 and 10.2). Unpaved roads are also usually built to much lower standards than paved roads and are commonly not equipped with drainage systems beyond an earthen longitudinal drain and culverts. In addition, maintenance funding for lower-tier roads is often chronically insufficient in developing countries, and delays to repairs can have major impacts on connectivity and welfare, particularly in

PHOTO 10.1

Water damage in action on an unpaved road with gully at the end of the slope, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 10.2

Roads constructed with highly erodible red sand washed away in each major runoff event, Mozambique

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

remote areas. Finally, unpaved roads are often constructed with highly erodible material because of lack of suitable natural resources. The rutting of these roads is an important road safety issue. Preventive measures that reduce degradation of the unpaved part of the road network are therefore extremely important.

OPPORTUNITIES

Preventing damage to unpaved roads by combining adequate road drainage with water harvesting is essential. More than 75 percent of the roads in many countries are unpaved. Unpaved roads are the largest single intervention in the rural landscape. As discussed in chapter 2, they are also one of the main contributors to the sediment in a catchment, ranging from 12 percent to 40 percent, according to the literature. Several studies on forestry development in the United States establish that road development, more than logging, accelerates sedimentation in local streams: roads start to behave as tributaries of the streams, "creating a more efficient sediment delivery system" (Castro and Reckendorf 1995). Practices that keep the sediment out of the stream, such as vegetation buffers, are bypassed and sometimes even destroyed during the construction of rural roads.

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

High sediment loads in water have other effects as well. Turbidity affects much aquatic life, such as by reducing the spawning of fish (Noss 1992). Higher sediment loads have an optical effect by blocking light penetration and slowing biological activity. Many fish, such as salmonids, spawn in the gravelly bed load of a river, placing their eggs at different depths (Castro and Reckendorf 1995). These eggs require fresh, fast-flowing water. However, medium-textured sediment that is suspended in water at medium speeds will settle and clog spawning grounds. The same issue can affect benthic organisms. The effect of sediment loads also depends on the type of stream: in fast-flowing streams, much of the additional sediment may be carried farther along, but in streams with lower gradients, the riverbed morphology will change much more under the impact of sedimentation. The composition of the sediment, that is, its size and shape, is also an important variable; flat particles (such as clays) are more likely to form a relatively immobile film on the riverbed.

During construction of new unpaved rural roads, there are several guidelines for reducing sediment release and improving capacity to harvest and recharge water. The positive measures are usually low cost and will help preserve the integrity of the road. This chapter discusses three Green Roads measures that help preserve unpaved roads:

- Avoid road alignments that include long and steep slopes without drainage facilities.
- Use basic road-surface drainage mechanisms, such as a series of rolling dips (small depressions with a small bump) or water bars (small slanted humps) to divert water from the road surface to the land for productive use.
- Use infiltration bunds to slow downside erosion from the roads and promote recharge.

RECOMMENDED PRACTICES

Planning road alignments for adequate drainage and water management

Much of the damage sustained by unpaved roads can be prevented. The main requirement is to stop water from running along the unpaved road surface at high speed, because this action erodes the road surface. This erosion initially removes fine material but later removes small stones and gravel, eventually removing a large part of the road material. Some measures for reducing the speed of water on the road surface include ensuring there is adequate crossfall to drain the water directly to the edge of the road, alternating the longitudinal slope of the road (that is, ensuring that extended lengths of road do not slope in the same direction along which runoff accumulates), incorporating bends that allow runoff to evacuate the road surface, and establishing a basic road-drainage system using the low-cost measures discussed in this chapter.

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

- As water depth on the road surface increases, the relative surface tension decreases, resulting in higher runoff velocity.
- As flow velocity increases, sheer force "plucks" larger particles from the road surface.
- When the velocity of the runoff on the unpaved road surface doubles, the volume of sediment that can be moved increases fourfold.
- When the velocity of runoff is doubled, the size of particles that the runoff can transport increases eightfold.

Much of the eroded material will be deposited downstream, clogging drains and covering fields. Some of this sediment will travel farther downstream, reducing the capacity of downstream storage. In some cases, however, the nuisance can be turned into an asset with sand being harvested as a business opportunity (see box 10.1).

BOX 10.1

Creating youth employment with sand harvesting

Local governments in Ethiopia issue temporary sand-mining permits to organized groups of youth (with equal numbers of males and females). The permits are part of a very successful small business incubation program and could be considered for expansion to other countries.

Over the course of one year of sand mining, the group of youths is expected to retain the profit from sand harvesting for use as seed capital for future business activities. Each youth saves about US$850 from sand mining, and the government lends each one an additional $3,400. In total, each member may establish his or her own new business with about US$4,250. This employment opportunity has resulted in better local government regulation of sand and gravel mining, an activity that had previously been captured by local thugs.

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

The primary means of avoiding erosion of the surface is ensuring there is adequate crossfall on the road so that water has the shortest drainage path from the center of the road to the side drain, thereby reducing the volume of water traveling along the road surface and in turn reducing the risk of erosion.

In locations where maintenance of unpaved roads is lacking and the crossfall is likely to be severely jeopardized, the longitudinal profile can mitigate some of the risks of erosion. In such cases, the longitudinal grade of an unpaved road should range from 4 percent to 10 percent, with frequent grade reversals. Natural drainage is ensured if the road reverses grade every 60–100 meters (Zeedyk 2006). Water naturally exits the roadway at every grade reversal. According to Napper (2008), the most important recommendations are as follows:

- Try to reverse the slope of the road and avoid long, uniform stretches.
- Where possible, use crowned or outsloped (tilted) road templates, or both, to drain the water immediately to the side of the road, although such templates are sensitive to wear and tear.
- Use rolling drainage dips and water bars to remove water from the road surface (see section titled "Use Basic Road-Surface Drainage") at designated places where the water can be used productively.
- Space drainage features at greater distances on fine-grained and erosive soils or cover the most vulnerable sections with at least 10 centimeters of coarse aggregate.
- Place a well-vegetated buffer zone or a row of stones (an infiltration bund) at the edge of the road to disperse flow, reduce runoff velocity, and collect sediment from road runoff (section titled "Use Infiltration Bunds to Control Erosion and Enhance Recharge").
- Avoid creating long, entrenched road sections; ensure evacuation of water to either side of the road. Avoid gradual degradation that causes an unpaved road to sink and become a drain.
- Where subsurface flow is considerable, provide side drains to collect this flow and reuse it. Alternatively, provide permeable fills and French mattresses close to saturated water pockets. Another option is to provide full road-drainage systems with side drains and cross culverts. Such well-developed drainage systems will not only protect the road but will also help to more systematically collect and harvest water from around the road.
- Maintain a vegetative cover around the road to increase roughness and reduce erosion. Where vegetation is removed (by road construction), sedimentation may increase up to sevenfold.
- To establish self-cleaning drains, ditches and the road surface must have a slope equal to or greater than the contributing source of sediment. The faster the water, the more sediment it can transport (at an increasing rate).
- On very steep hill slopes (greater than 35 percent), develop internal drains that guide water away from steep cut slopes and intercept subsurface flows to keep them from causing severe erosion on the downward fill slope.
- Ensure that diversion of streams at stream road crossings is controlled at times of high flow.

Care is required to connect drainage from unpaved roads to land where it can be used productively. Water can be used for farming, particularly for building up soil moisture ahead of planting or for direct use during the growing season. In this case, the use of farm trenches is preferred; the runoff is guided to the farm and directly irrigates the root zone (photo 10.3; box 10.2). Trenches are preferred to using runoff on the land, where it may damage the crop.

PHOTO 10.3

Farm trenches in Kenya: Road-drainage water serving the root zone

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

BOX 10.2

Connecting drainage cuts to farm trenches in Mozambique

In the absence of a developed road-drainage system along most roads in Mozambique, drainage cuts are often found on the sides of paved and unpaved roads (photo B10.1.1). These cuts remove water from the road surface and are usually made by a road grader during construction or maintenance. The drainage cuts, also called *sanjas*, are often closely spaced, typically 100 meters or less apart. At present, these drainage cuts end in the road reserve and do not serve farmland, although they could be adapted for this purpose.

To help direct water to farmland for productive use, sanjas can be lengthened. Connecting the sanjas through trenches to farmland would make more moisture available for crops and would carry water directly to plant roots. This approach should enable a 20 percent increase in yields and make it possible to grow other, more profitable crops. The practice of using road cuts to water farmland is common, as in Kenya.

Recommended practices in making trenches that connect drainage cuts to farms include the following:

- In consultation with the farm owner, extend the drainage trench beyond the center of the farm. If the land is terraced, the trench should follow the terraces.
- Make the trench approximately 50 centimeters deep.
- The ideal width of a trench is about 40 centimeters; a relatively narrow and deep trench will preserve the most moisture. Some crops, such as bananas, require wider trenches.
- The trench should ideally be rectangular.

(box continues next page)

Box 10.2, *continued*

- Make sure the water from the road flows naturally to the land by placing the inlet at a position that makes best use of the slope.
- Make gentle curves in the trench to minimize erosion.
- Make sure the trench is not too steep, that is, less than 3 degrees. If the trench is too steep, it will erode easily.
- The main trench can branch into side trenches. The drainage trench can feed a farm pond (discussed in chapter 11), in which case a silt trap should be installed before the pond entrance to catch the sediment in the trench water.
- Plant grasses and small trees on the banks to strengthen the trenches and prevent collapse.
- If there is heavy rain, the entrance to the fields should be closed with an earthen heap to prevent overflow of the road to the agricultural land.

PHOTO B10.1.1

Sanjas in Mozambique

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Use basic road surface drainage

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

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

FIGURE 10.1
Water bar in place

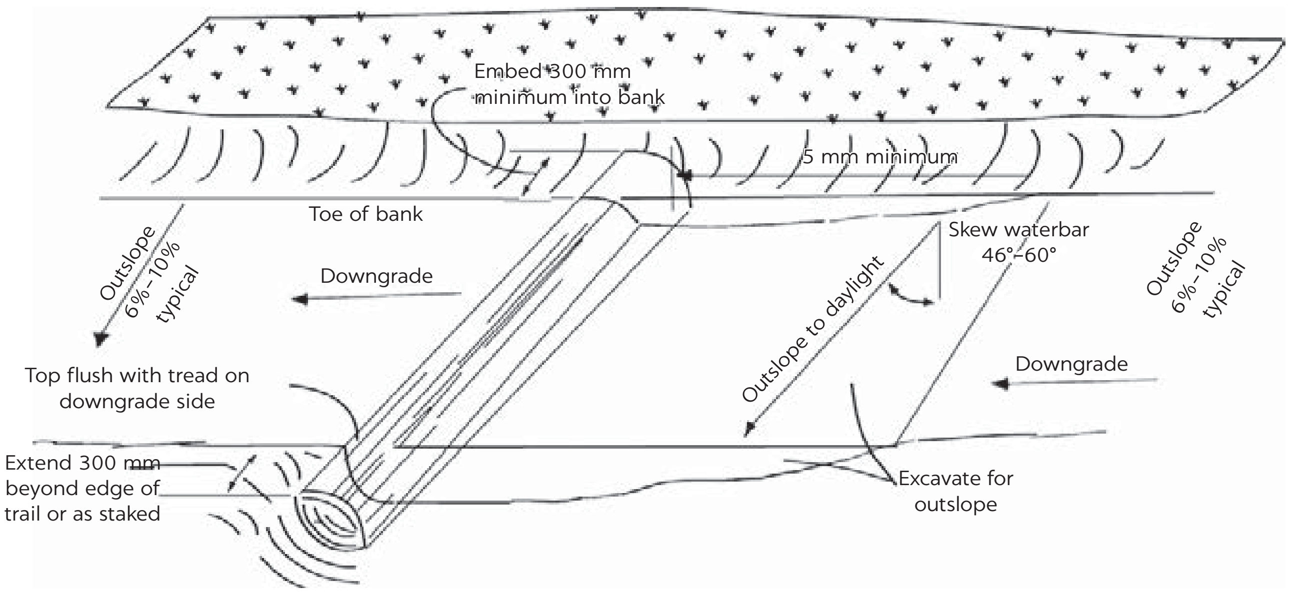
Source: MetaMeta (www.roadsforwater.com).

The specifications for water bars are as follows:

- The water bar should be positioned at an angle to the road direction, preferably between 45 and 60 degrees. Water bars placed at less than a 45-degree angle to the road direction are prone to clogging.
- Typically, water bars have a height of 75–150 millimeters and a width of 0.3–1.0 meter (see figure 10.1).
- Water bars may be made of soil, but in very loose soil they can be made of reinforced material: rock, timber, or precast concrete. Prefabricated water bar structures must be embedded into the road body to a depth equal to two-thirds of the structure height (see figure 10.2).
- The number of water bars needed to achieve optimal erosion and runoff control depends on the slope or road grade. The greater the slope, the less space there should be between water bars. Spacing may be further reduced along highly erodible roads with many aggregates of less than 2 millimeters in particle diameter (see table 10.1).
- The outer extremes of the water bar need to be extended at least 300 millimeters beyond the road tread.
- The outflow end should remain open to avoid accumulation and preferably lead to land where the water will be used for farming or pasture. The runoff should not flow directly to a stream.
- The outslope of the road must be between 6 and 10 degrees.

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

FIGURE 10.2
Rock water bar specifications



Source: MetaMeta (www.roadsforwater.com).

TABLE 10.1 Spacing of water bars

ROAD GRADE (%)	GENERAL SPACE BETWEEN WATER BARS (METERS)	SPACE BETWEEN WATER BARS IN HIGHLY ERODIBLE ROADS (METERS)
2	75	45
5	40	25
10	25	15
15	18	11
20	14	9
25	12	7
30	10	6

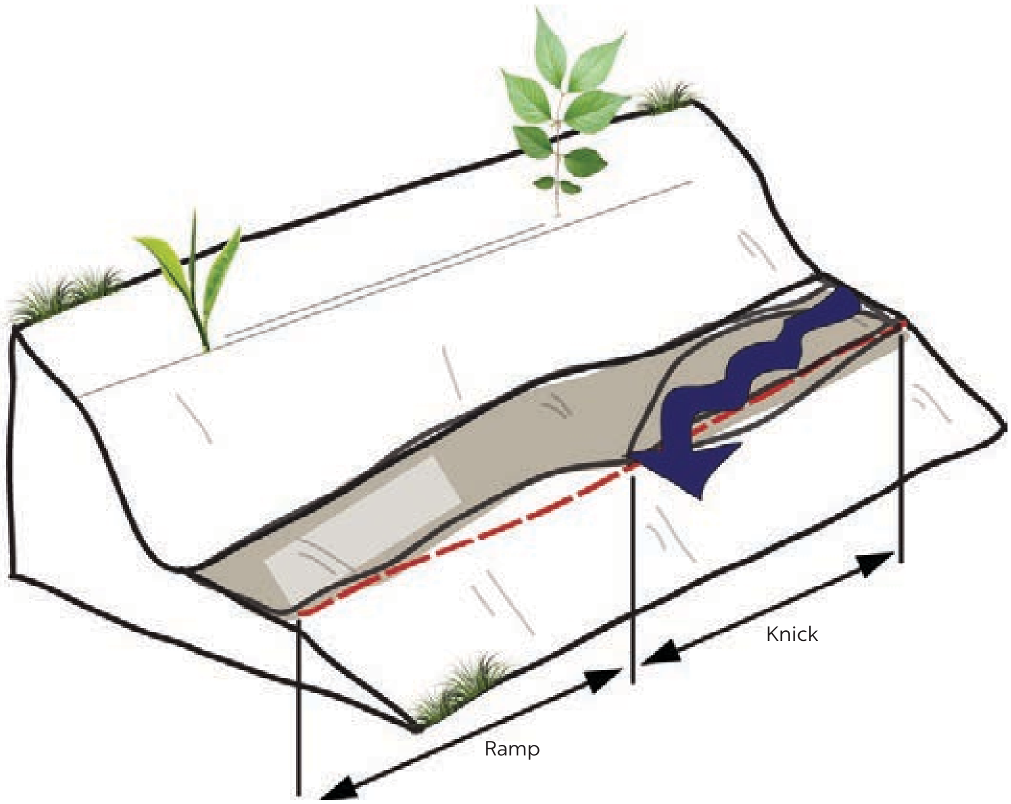
Source: Based on Packer 1967.

Rolling dips (figure 10.3) are the most reliable cross drains for low-standard roads. They collect surface runoff from the roadway or road ditch and direct the flow across and away from the roadway. Their main features are as follows:

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

FIGURE 10.3

Rolling drainage dip in low-volume road



Source: MetaMeta (www.roadsforwater.com).

Use infiltration bunds to control erosion and enhance recharge

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

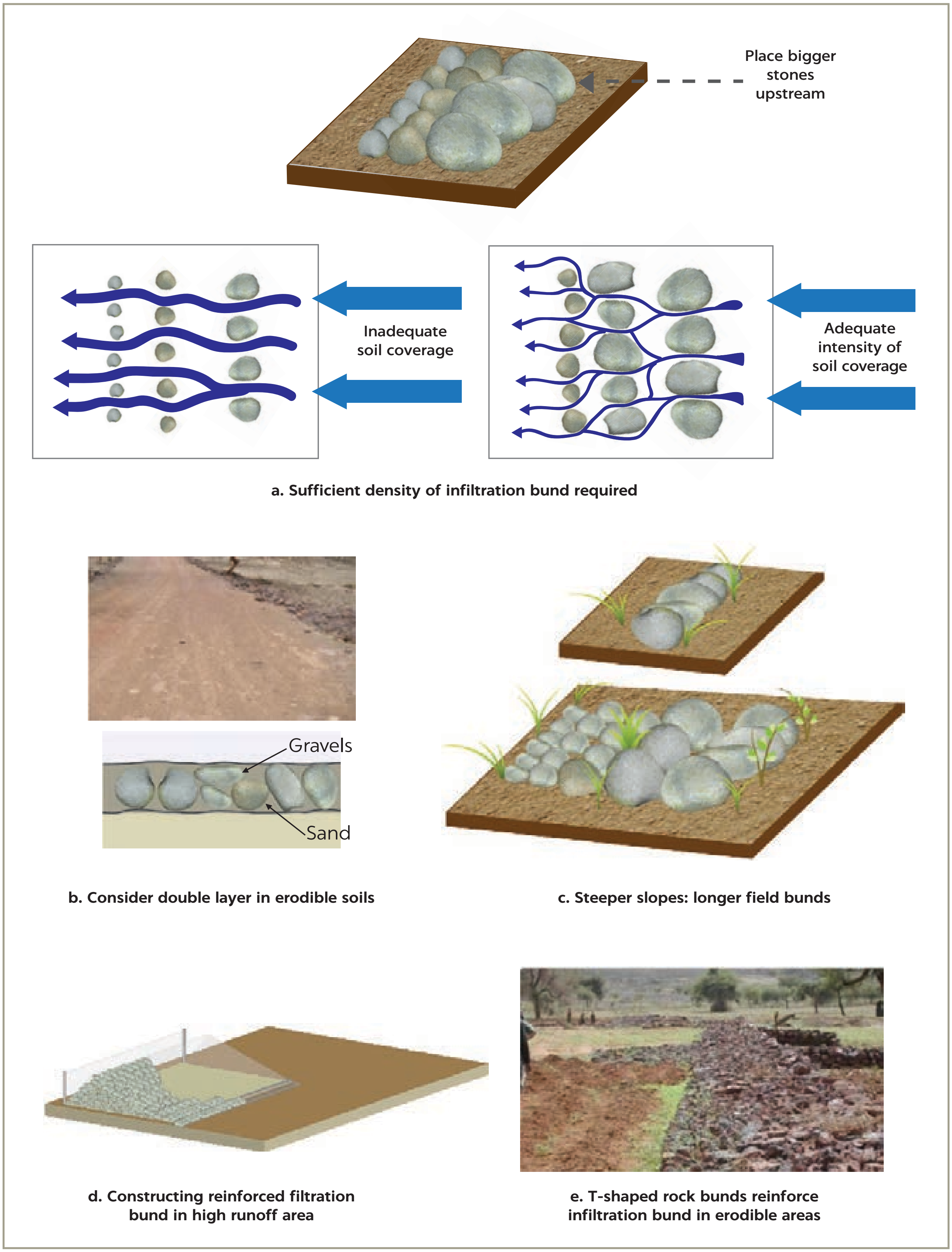
Several measures may be considered to curtail this erosion. Trees, shrubs, and grasses may be planted along rural road alignments to reduce the erosive effect of runoff from the road template. Such measures are particularly useful if no side drain is provided and the road template is outsloped or crowned. This scenario is discussed in chapter 12, which deals with roadside vegetation.

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

The following recommendations for infiltration bunds are based on Bender (2009). Figure 10.4 illustrates key features of these techniques.

FIGURE 10.4

Best practices for development of roadside infiltration bunds



a. Sufficient density of infiltration bund required

b. Consider double layer in erodible soils

c. Steeper slopes: longer field bunds

d. Constructing reinforced filtration bund in high runoff area

e. T-shaped rock bunds reinforce infiltration bund in erodible areas

Source: MetaMeta (www.roadsforwater.com).

- Rock infiltration bunds are best placed within 3 meters of the road border.
- The stones in the rock infiltration bunds should be placed at sufficient density to disperse the water and prevent erosion; if too few stones are used for the incoming water flow, the water will not slow down and the bund will not work.
- Large stones should be placed upstream.
- A single layer of stones is sufficient in moderately erodible road slopes, but good compaction is critical. An initial compaction under dry conditions followed by a second compaction under wet conditions is recommended. A double layer of stones may be used in highly erodible soils.
- The infiltration bund should have a thickness of 15 centimeters in terrains with medium sediment transport capacity. This thickness can be increased in areas with higher transport capacity. Wider infiltration bunds with larger head stones or a second bund are recommended for loamy soils, vertisols, and areas with concentrated runoff.
- Uphill masonry protection of infiltration bunds may be necessary in areas with highly erodible, very soft loamy soils, concentrated runoff, and long-standing water. A T-shape layout may also be considered.

REFERENCES

Bender, H. 2009. "Pistes rurales et mésures antierosives. Recommendations techniques." Bender Associates, Saarbrücken, Germany.

Castro, J., and F. Reckendorf. 1995. "Effects of Sediment on the Aquatic Environment: Potential NRCS Actions to Improve Aquatic Habitat." Working Paper 6, Natural Resources Conservation Service, Department of Geosciences, Oregon State University, Corvallis, OR. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/?cid=nrcs143_014201.

Napper, C. 2008. "Soil and Water Road-Condition Index - Desk Reference." San Dimas Technology and Development Center of the Forest Service, United States Department of Agriculture, Los Angeles, CA. https://www.fs.fed.us/t-d/pubs/pdf/08771807.pdf.

Noss, R. F. 1992. "Issues of Scale in Conservation Biology." In *Conservation Biology: The Theory and Practice of Nature Conservation Preservation and Management,* edited by P. L. Fiedler, 239–50. Boston, MA: Springer.

Packer, P. E. 1967. "Criteria for Designing and Locating Logging Roads to Control Sediment." *Forest Science* 13 (1): 2–18.

Zeedyk, B. 2006. *A Good Road Lies Easy on the Land… Water Harvesting from Low-Standard Rural Roads.* Santa Fe, NM: The Quivira Coalition; Zeedyk Ecological Consulting, LLC; The Rio Puerco Management Committee – Watershed Initiative; and the New Mexico Environment Department – Surface Water Quality Bureau.

11 Roadside Farm Ponds

KEY MESSAGE AND KEY APPLICATION

Key message

- Roadside ponds can be important sources of water. Safety, catchment characteristics, soil characteristics, lining, capacity, sediment interception, and disease control all need to be taken into account in careful planning.

Key application

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

OBJECTIVE

A common method for harvesting water is to direct the runoff guided by the road body and road-drainage systems into farm ponds. These ponds can store water for additional irrigation, livestock water, or domestic water use. They can sustain high-value agriculture (see box 11.1) or enable the raising of livestock. Roadside ponds are common in many countries, but they are not widespread everywhere. In many areas they could be connected to roadside drainage cuts or miter drains. The objective of this chapter is to discuss the development of these ponds, the opportunities they provide, and the recommended practices.

OPPORTUNITIES

Farm ponds are dug-out structures with a definite shape and size, and with proper inlets and outlets for collecting the surface runoff flowing from a small catchment or part of a catchment, including the water guided by road bodies (photo 11.1). The water leading to farm ponds can come from the roadside drainage system or its culverts or can be guided by road embankments. As described in box 11.1, farm ponds can receive water from several sources.

BOX 11.1

Growing grapes with road water in Bolivia

Grape production is the main cash crop for the majority of farmers residing immediately south of Tarija, Bolivia. Grape farmers rely mostly on reservoirs for irrigation water. However, water distribution does not meet the ever-growing demand. High erosion rates are also decreasing the storage capacity. Some farmers near roads are successfully experimenting with road-water harvesting. Among the many means of storing road water, one of the most common is the use of water-harvesting ponds, known locally as *atajados* (photo B11.1.1).

Usage of water associated with the San Jacinto Dam provides one example. Piped water running along the road is distributed at long and irregular intervals. The atajados help buffer water and redistribute it. The small farm ponds were initially built as storage infrastructure, with the intention of storing water during fallow periods. This approach gave farmers the freedom to apply water to their fields at the most convenient times. With growing water demand and dwindling supply, the atajados assumed a dual role. While still storing water from the piped water system, they also began to collect road runoff to compensate for the intermittent water supply.

PHOTO B11.1.1

Water-harvesting ponds or atajados used for grape production, Bolivia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 11.1

Developing a roadside pond in Kenya

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Farm ponds are one of the most important kinds of rainwater-harvesting structures. In general, water leaving an area without serving the needs of that area can be considered a lost opportunity. Farm ponds can be systematically developed to capture concentrated runoff along road sections rather than letting the runoff play havoc with the areas surrounding the road or even undermine the road body itself. Systematic development of farm ponds is an important method for capturing this road-guided runoff.

Farm ponds may be used for irrigation (full or supplementary; photos 11.2 and 11.3) and livestock watering. With treatment they can also be used for domestic applications. In addition, ponds can be used for recharging groundwater, catchment protection (that is, soil erosion control), ecosystem and biodiversity conservation and rehabilitation, and recreation.

The primary application of farm ponds is in dry lands where they can be a critical source of additional water. Farm ponds can also be used in wet areas for irrigation and livestock watering during dry spells.

RECOMMENDED PRACTICES

This section discusses the recommended practices with respect to farm-pond planning, design and layout, and construction.

PHOTO 11.2

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

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

PHOTO 11.3

Farmer extracting water with a diesel pump

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Planning of farm ponds

Farm ponds are developed in different types of catchments. The nature, size, and slope of the catchments differ, and different types of farm ponds are possible. Three factors must be considered in the siting of farm ponds: soil type, topography, and catchment size.

Soil Types

The soils associated with construction of a roadside farm pond should preferably have low hydraulic conductivity with minimum seepage and percolation so that water can be retained in the pond for long periods. Soils with low infiltration rates are most suitable for pond construction. Table 11.1 shows the infiltration rate of different soils. Clay and clay-loam soils have good potential for rainwater harvesting in unlined ponds, and ponds constructed of these soils suffer minimal seepage losses. Runoff water is naturally captured in ponds and depressions in such areas. Soils for pond construction should meet the following criteria:

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

When geotextile liners are considered, standardizing the dimensions of the ponds is useful so that the geotextile lining can be prepared in advance rather than being made on site, which is more laborious and cumbersome.

Soils having outcrops and stones must be avoided when digging farm ponds. The soil profile depth should ideally be investigated before digging the pond to avoid wasting significant effort. Good soils extending to a depth greater than 1 meter that are free of stones and have low pH, low electrical conductivity, and low groundwater level should be selected for the farm-pond site. Other soils may introduce difficulties. Peat soils have special problems because they are usually very acidic and need copious liming to yield usable water. Soils rich in limestone create problems of precipitating phosphate and iron.

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

TABLE 11.1 Infiltration rates of different soils

SOIL TYPE	INFILTRATION RATE (MILLIMETERS/HOUR)
Sand	> 30
Sandy loam	30–20
Silty loam	20–10
Clay loam	10–5
Clay	< 5

Source: Savva and Frenken 2002.

Topography

Topography is an important consideration in planning farm ponds because it can affect the following:

- The size, shape, and depth of a pond
- Dam or pond embankment height
- The speed and intensity of runoff into the pond
- The simplicity or complexity of pond design and construction and thus cost
- Safety issues

The topographic features of the farm catchment vary from place to place. In general, the land proposed for pond construction must accommodate a minimum amount of excavation to achieve an economical storage capacity. A narrow, deep pond will have a much smaller evaporation loss than a broad, shallow reservoir. If the land has some slope, the pond does not need to be excavated; a “u”-shaped bund can be used to create the pond. The road body itself can be part of the pond wall in some cases.

Drainage or Catchment Area

The drainage or catchment area that produces runoff for farm-pond storage plays an important role in farm-pond planning. Road construction has a major impact on a catchment’s drainage, given that the road infrastructure often reshapes the catchment. Roads generally tend to combine smaller subcatchments and bundle runoff into a limited number of drainage canals, which effectively enlarges the source area of the pond.

Draining excessively large source areas into large ponds should be avoided, particularly if rainfall is concentrated in a short period (for example, if 80 percent of annual rainfall occurs in less than two months). These large ponds will require larger levees and have greater construction costs. More important, oversized source areas increase the risk of washouts and flushing; additionally, large ponds may require spillways and other water-control structures and are difficult to manage. A lower-cost alternative may be to connect a cascade of ponds, where water overflows from one storage pond into the next. If rainfall and runoff are more evenly distributed over the year, ponds can be smaller.

The pond must be filled at least once in the season so that farmers can use the water for critical irrigation and other applications during dry spells. Depending on the rainfall pattern, a pond may be filled several times a year, increasing its effectiveness as a water-storage facility. Oversized ponds and ponds serving small catchment areas may not fill adequately and may not offer adequate water supply during extended periods of hot, dry weather.

See box 11.2 for a summary of pond site requirements.

Design and layout of roadside farm ponds

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

Pond Capacity

The design capacity of a roadside farm pond depends on the purpose for which water is needed and the amount of inflow that can be expected in a given period.

BOX 11.2

Siting of a roadside farm pond

The following factors should be taken into account when siting farm ponds.

- Selection of the farm-pond site depends on local soil conditions, area topography, drainage capacity, infiltration, and rainfall pattern and distribution.
- Identification of natural depressions where rainwater or runoff either flows or accumulates during the rainy season may aid planning.
- A good pond site will have level topography that provides for economical construction, soil with enough clay to retain the water, and an adequate water supply.
- Deep clay soils are best for lining ponds because they minimize leakage. Because a pond is simply a depression for holding water, the sides and bottom must be composed of a soil that minimizes seepage.
- Coarse-textured sandy soils should be avoided because they are highly permeable, and water will drain through them. If seepage is believed to be high, pond walls can be plastered with clayey soil and compacted or lined with plastic.
- Sites with underlying strata of sand, gravel, limestone, shale, or fractured rock at a shallow depth may also result in high leakage and seepage losses and should be avoided unless they are sealed with clayey soil. Peat soils have special problems because they are usually highly acidic and need substantial liming.
- Farm ponds should be located where the area topography creates a road catchment from which sufficient runoff can be collected and redirected toward the farm pond by gravity. Whether the ponds can be supplied with water must be verified: the road embankment guides water either from road drains or culverts or from the runoff in drainage cuts. Water may be collected from the bends, low points, water bars, and rolling dips of unpaved roads.
- For more solid construction and greater compaction of embankments, soils having a wide range of grain sizes are preferable to soils with relatively uniform particle size.
- The choice of pond sites should balance economics, accessibility, and safety. A pond that provides the largest volume of water with the least amount of landfill offers the most economical construction. Liability is also an important consideration in pond site selection. The potential impacts of pond or dam failure should be assessed carefully, especially if failure could cause loss of life or injury.
- Siting should ensure that polluted or contaminated water is not harvested into farm ponds.
- Provision must be made for a pipe and emergency spillway, if necessary. The runoff flow patterns from these structures must be considered when locating the pond or pit and placing the spoil.

Source: Based on Nissen-Petersen 2006.

The pond's capacity should enable it to supply enough water to meet the demand from crops, integrated farming systems, or other uses for which it is constructed. An economical pond is not oversized relative to either water storage needs or water yield from the catchment.

The seasonal water yield can be estimated using past historical weather data (that is, mean annual, mean seasonal, or certain probability-based rainfall [in millimeters] multiplied by a runoff coefficient, which is usually between 0.1 and 0.3, and multiplied by catchment area). Conservatively, at least 20 percent of seasonal rainfall can be expected to run off black soils, and at least 10 percent can be expected to run off red soils, with mild to medium slopes. Where historical weather data are not available, rainfall analysis must be undertaken before estimating the catchment water yield.

Storage losses such as seepage and percolation will also influence the pond's storage capacity. Table 11.2 presents natural soil-type seepage losses.

The type of soil in the catchment area helps determine siltation and will affect the pond's storage capacity over time. A 5–10 percent provision should be made for the loss of storage capacity caused by silting.

Estimating water demand. Water-demand estimation is central to the design of farm ponds. Demand estimation is one of the factors determining the choice of pond capacity. The following formulas can be used to estimate water demand for irrigation, livestock, and human needs.

$$\mathrm{Ir} = \frac{10 \times \mathrm{ETcrop} \times \mathrm{Ca}}{\mathrm{Ef}}$$

Ir = Irrigation water requirements in cubic meters for the entire dry period
ETcrop = Crop water requirement in millimeters during the dry period
Ca = Area irrigated with water from the reservoir in hectares
Ef = Overall water application efficiency

$$\mathrm{WL} = \frac{\mathrm{NL} \times \mathrm{AC} \times \mathrm{T}}{1{,}000}$$

WL = Water needed for livestock during the entire dry period in cubic meters
NL = Number of animals to be watered from the reservoir
AC = Average rate of water consumption in liters per animal per day (ranging between 25 and 60 liters/animal/day)
T = Duration of the dry period in days

$$\mathrm{Wd} = \frac{\mathrm{Po} \times \mathrm{Dc} \times \mathrm{T}}{1{,}000}$$

Wd = Domestic water supply during the dry period in cubic meters
Po = Number of users of the reservoir
Dc = Average rate of water consumption in liters per person per day (average of 40 liters/person/day in Eastern Africa)
T = Duration of the dry period in days

Rainfall analysis. Rainfall is one of the most critical hydrological input parameters for the design of farm ponds. Its distribution varies both spatially and temporally in semiarid and humid regions of a country. The quantity of surface runoff depends mainly on rainfall characteristics such as intensity, frequency, and duration.

TABLE 11.2 Natural soil-type seepage losses

SOIL TYPE	SEEPAGE LOSS (MILLIMETERS/DAY)
Sand	25.0–250.0
Sandy loam	13.0–76.0
Loam	3.0–20.0
Clayey loam	2.5–15.0
Loamy clay	0.25–5.0
Clay	1.25–10.0

Source: FAO 1981.

- Frequent rains mean that the pond may fill up several times during the year, which will make it possible to have a smaller (and less costly) pond. The timing of rainfall and the expected pond levels should be considered in relation to the timing of when pond-water users will need to draw on the stored water.
- Intense rainfalls that far exceed the infiltration capacity of catchment area soils will produce more runoff than low-intensity rainfall events, even if low-intensity events have much longer duration.

Rainfall analysis is particularly critical for optimal economic design of farm ponds. Although using long-term rainfall data is the best way to estimate rainfall for pond design, these data are often not available. Without these data, rainfall must be estimated based on probability analysis.

"Design rainfall" (DR) is defined as the total amount of rain during the cropping season at or above which the catchment area will provide enough runoff to meet the crop's water requirements. If the actual rainfall in the cropping season is less than the DR, the pond will not store the desired volume of water. If the actual rainfall exceeds the DR, surplus runoff may cause damage to the structures (runoff will exceed the pond's storage capacity). Timing is important: the creation of storage, that is, the development of ponds, will transfer water from peak periods to periods of scarcity.

The DR is calculated using probability analysis. The DR is a minimum level of rainfall with a specified probability of occurrence. Suppose a 67 percent probability is chosen: this probability indicates that the seasonal rainfall has a two-thirds chance of reaching or exceeding the DR in a given year. It also means the seasonal rainfall may be expected to reach or exceed the DR during only two out of three years; in this case, the pond would probably only fulfill the water users' needs two years out of every three years. The higher the selected probability, the greater the likelihood that runoff levels into the farm ponds will meet or exceed the design level and the water user will have enough water. Selecting a low probability means the pond will be larger and will cost more to construct. It may capture and store more water during exceptionally wet years, but it will be oversized and will only partially fill during years with average rainfall.

Pond Layout

Once the capacity of the roadside farm pond has been determined, the layout of the pond can be prepared, including its shape, dimensions (depth and side slopes), and any additional structures.

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

Square and rectangular ponds can be created by digging the pond itself, by closing the surrounding area with well-compacted levees, or by a combination of these two approaches. Ponds of this type (square or rectangular) are recommended and easily constructed, particularly in areas with flat topography. An excavated pond is often built on level terrain and its depth is achieved solely by excavation. An excavated pond is relatively safe from flood damage, requires little maintenance, and can be built to expose a minimum water surface area in relation to volume, which is beneficial in areas with high evaporation loss and limited water supply.

Depth and side slope of farm pond. The depth of a pond is generally determined by soil depth, type of material excavated, and type of equipment used. Pond depth is the most important dimension among the three. In semi-arid regions, evaporation losses can be reduced by storing the same volume of water in a deeper pond because a smaller exposed surface area of the pond reduces losses from evaporation. Seepage losses increase with pond depth, however. When ponds are constructed using manual labor, any increase in depth beyond 3.5–4.0 meters becomes uneconomical. Lifting water from depths greater than 3.5–4.0 meters is also less economical and more difficult to do with hand-operated lifting devices. Pond depths of 2.5–3.5 meters may generally be the most suitable.

The pond's side slope is based on the angle of repose of the material excavated. This angle varies with the type of soil. In most cases, side slopes of 1.0:1.0 to 1.5:1.0 are recommended for practical purposes. Based on practical experience, selected side slopes should generally be no steeper than the natural angle of repose of the material. Table 11.3 presents the recommended side slopes for different soils.

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

Additional features. Important ancillary features of farm ponds include the following:

- *Inlet protection*. If surface water enters the pond in a natural or excavated channel, the side slope of the pond must be protected from erosion.
- *Spillways*. A spillway is an important feature of a pond. It is designed to accommodate the removal of excess runoff in a controlled manner. The spillway must be reinforced with stone pitching, concrete, or, at a minimum, grasses. The spillway should be located some distance from the road embankment so that it does not undermine the road-pond embankment.
- *Silt traps*. The runoff from the road embankment will carry significant quantities of sediment. Unless this sediment is either removed regularly or intercepted before it reaches the pond, it will fill the pond and prematurely end the pond's economic life (box 11.3). The runoff is best routed across a vegetated area, which will intercept a large part of the sediment. A silt trap will further remove sediment. A silt trap consists of a small settling basin where the sediment is trapped and then removed.
- *Fencing*. Roadside ponds may be fenced, preferably by native tree species that do not have root systems that will penetrate the pond. The fencing will help regulate access to the pond and provide shelter from wind and thus reduce evaporation from the pond.

TABLE 11.3 Suitable pond side slopes for different soils

SOIL TYPE	SLOPE (HORIZONTAL:VERTICAL)
Clay	1.0:1.0
Clay loam	1.5:1.0
Sandy loam	2.0:1.0
Sandy	3.0:1.0

Source: Kumar et al. 2020.

BOX 11.3

Controlling sedimentation and contamination

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

- *Sediment traps.* The best way to reduce the immediate inflow of sediment into the pond is to route runoff through an area with vegetation. This area can be grasses, wild vegetation, or cultivated plants, for instance, banana trees. Sediment can also be removed from ponds by hand or by using pits that trap the sediment.
- *Drainage area.* Land under permanent cover of trees or grasses is the most desirable drainage area. If such land is not available, consider treating the watershed with proper soil-conservation practices to control erosion before constructing the pond, or include silt traps as part of the pond design.
- *Removal of contamination.* Generally, catchments must be selected in such a way that contaminated drainage from farmsteads, feedlots, sewage lines, dumps, industrial and urban sites, and similar areas does not reach the pond. Similarly, runoff from intensively used road segments, which can carry hydrocarbons, rubber, and oils, must not be allowed to enter farm ponds.

Constructing the roadside farm pond

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

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

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

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

When landowners develop ponds, they often use manual labor or tractor-pulled wheeled scrapers. An alternative method for developing ponds is to make use of animal traction with the help of scoops (photo 11.4). This method is uncommon but has great potential.

The following are the main recommendations for using animal traction for farm-pond construction:

- For animal digging, use staged ramps and construct the pond in layers.
- The area to be excavated should be softened by plowing to a depth of 20–30 centimeters, which can be done by an ox-drawn plow attached to one or two oxen pairs using normal yokes. The space should be planned to enable the animals to turn easily.
- The softened soil should be removed with the ox scoop. To load the scoop, the operators simply raise the handles of the device to augment the incidental angle between the soil and the scoop. The forward movement of the animals will do the rest. Once the scoop is loaded, the handles are lowered again, and the scoop is pulled until the disposal area is reached. To offload the soil, the operators raise the handles until the scoop topples together with its load. These scoops are not usually available but can be made in local workshops.
- Excavated soil needs to be properly disposed of and is commonly used to build a berm around the pond. It is important to compact the berm to avoid erosion problems. A simple roll compactor can be built with second-hand bearings, scrap metal, and an old oil drum. The drum is filled with sand and rotates as the oxen pull it.

PHOTO 11.4

Developing a roadside pond with oxen scoop and compactor, Tanzania

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

REFERENCES

FAO (Food and Agriculture Organization). 1981. "Estimates of Water Requirements." In *Training Manual on Fishery*. Rome: FAO. http://www.fao.org/fishery/static/FAO_Training/FAO_Training/General/x6705e/x6705e02.htm#84s, accessed October 28, 2018.

Kumar, A., H. Hansraj, S. Kumari, R. Kumar, A. Prakash Anurag, and B. Krishna. 2020. "Method of Farm Pond Construction for Improving Livelihood of the Small Farmers." *Food and Scientific Reports*, Vol. 1: 36–38. https://www.researchgate.net/publication/338991006_Method_of_farm_pond_construction_for_improving_livelihood_of_the_small_farmers.

Nissen-Petersen, E. 2006. "Water from Roads. A Handbook for Engineers and Technicians on Harvesting Rainwater from Roads." ASAL Consultants Ltd. for the Danish International Development Assistance (Danida) in Kenya. http://www.waterforaridland.com/Books/Water%20from%20roads.pdf.

Savva, A. P., and K. Frenken. 2002. *Irrigation Manual: Planning, Development, Monitoring and Evaluation of Irrigated Agriculture*. Volume II, Module 7. Harare: Food and Agriculture Organization of the United Nations.

12 Roadside Tree Planting

KEY MESSAGES AND KEY APPLICATIONS

Key messages

- Dust from unpaved roads is an overlooked but major health hazard.
- Roadside tree planting has many co-benefits beyond dust control, such as creation of productive assets, reduced crop damage, reduced soil erosion, improved visibility, and provision of wind breaks, shade, carbon sequestration, and beautification.
- Some key considerations for planning roadside tree planting are ownership of road reserve, plans for future road widening, economic value of the tree species, shape of the tree barrier, root development, road sightlines, road safety, and access to water.

Key applications

- Given the multiple benefits of roadside tree planting, it is surprising that it is not more widespread. Its application extends to almost all geographies.
- Roadside tree planting and roadside forests can offset part of the carbon dioxide emissions that come from new roads.

OBJECTIVE

This chapter provides guidance on how to plan, implement, and monitor roadside vegetation activities without compromising road longevity and safety. Roadside vegetation is any vegetation growing along the roads. Planting trees, shrubs, and grasses along the road can create a productive asset and can alleviate the negative effects of roads on the local environment.

Roadside trees can help mitigate negative effects such as erosion, loss of fertile soils, gully formation that undermines road foundations, heavy dust, wind-related desiccation, and more. Dust lifted by vehicles, especially along unpaved roads (photo 12.1), has a direct effect on the health of people and

PHOTO 12.1

Road dust: A source of health and other problems

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

livestock living near the roads and on crop production. In a survey conducted in Ethiopia, close to 44 percent of the respondents said that the occurrence of dust had increased after road construction (Agujetas Perez, Tegebu, and van Steenbergen 2016). Road dust is composed of coarse particles that can worsen heart- or lung-related conditions when inhaled through the nose and mouth (Greening 2011). High levels of dust can cause skin irritation and disease, eye irritation, shortness of breath, chronic obstructive pulmonary disease, asthma, interstitial lung disease, lung fibrosis, lung emphysema, and increased risk of lung and skin cancer (Krzyżanowski, Kuna-Dibbert, Schneider 2005). The human body can handle particles larger than 10 microns, but smaller particles pose greater health risks (Nordstrom and Hotta 2004). Dust can have a physical and chemical impact on crops and can reduce yields. In the survey in Ethiopia cited above, 11 percent of respondents recorded such a decline (Agujetas Perez, Tegebu, and van Steenbergen 2016). Dust from unpaved roads settles on the flowers of crops, impeding them from producing fruit. Moreover, dust affects photosynthesis, respiration, and transpiration and therefore interferes with plant growth (Leghari and Zaidi 2013). Dust on plants can smother the leaves, block stomata, and obstruct photosynthetic activities (Rahul and Jain 2014).

Careful assessment of road safety risks is essential before designing roadside tree-planting programs. Trees can pose a significant risk of death and serious injury to occupants of vehicles that run off the carriageway unintentionally and strike trees at travel speeds as slow as 30 kilometers an hour. This type of crash is high risk in outcome severity and is one of the most likely causes of death for vehicle occupants on the world's roads.

OPPORTUNITIES

The scope for roadside planting is enormous. Roadside vegetation has multiple benefits (see box 12.1), including creating barriers against road dust. Trees and shrubs especially can trap the dust with their leaves, minimizing the amount of dust reaching farms and houses. There is little research on how effectively roadside tree lines intercept dust; however, Maher et al. (2013) indicate that roadside tree planting can reduce particulate matter by more than 50 percent, and even more if the leaves are hairy. Moreover, trees provide shade and contribute to beautification. Beautification is a significant service because large numbers of people walk along the roadside in many countries.

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

Furthermore, roadside plantings will not only check deterioration of roads and the environment but will also create productive assets for local communities. Productive benefits can be derived from the direct benefits of trees—such as timber and fruit harvesting—and by their acting as windbreaks that reduce desiccation and wind erosion.

As noted earlier in these guidelines, any tree planting where trunks will achieve a diameter greater than 75 millimeters in due course should be located a substantial distance from the edge of the road (probably a minimum of more than 20 meters from the carriageway, and farther where travel speeds are greater than 50 kilometers an hour). Provided that safe sightlines are maintained, shrubs with full-grown diameters of less than 75 millimeters can be used nearer to roads because they pose much less risk to the health of vehicle occupants. Where planting already exists or planting closer to the carriageway is considered necessary, appropriate safety barriers are required to protect vehicle occupants from crashes into tree trunks.

BOX 12.1

Advantages of roadside vegetation

Roadside vegetation offers a number of positive attributes.

- Removes dust and other pollutants from the air, protecting crops, roadside communities, and livestock
- Reduces soil erosion; holds soils in place
- Creates wind breaks to reduce desiccation and wind erosion
- Enhances flood control by slowing and absorbing road runoff
- Provides carbon dioxide sequestration
- Produces direct benefits, such as timber, fodder, fuelwood, fruits, pollinator habitat
- Provides shade and keeps the road cool for road users
- Beautifies roadsides
- Improves visibility
- Can be used to guide road speed

RECOMMENDED PRACTICES

Despite its considerable benefits, roadside vegetation is generally not an integral aspect of road development and management. India is a notable exception; it launched the Green Highways Policy in 2015. This policy includes a provision to set aside 1 percent of all road investments for a roadside tree development fund.

As outlined in this section, roadside tree planting must be carried out in accordance with good road safety engineering principles and should not introduce unacceptable risk of death and serious injury from vehicle collisions with tree trunks located too close to the carriageway where adequate barrier protection is not provided.[1] Roadside tree planting undertaken in this manner should be systematically integrated into all road-building programs, in particular for unpaved roads. Roadside vegetation should be planned in detail as part of road development programs, showing the main objectives of the roadside vegetation (dust control, beautification, improved visibility, erosion control, and so on) and the preferred plantings for different roadside stretches. Site characteristics, such as rock content, soil depth, accessibility, steepness of slopes, and access to water resources, as well as road visibility, expected speeds, and impact risks, need to be assessed. Tree species should be chosen that will provide economic and environmental benefits, and local communities should be actively engaged in management of plantings (photo 12.2). The remainder of this chapter discusses recommended practices for developing roadside vegetation.

PHOTO 12.2
Roadside tree-planting campaign in Amhara, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

SITE SELECTION

Site selection for roadside vegetation should account for land ownership, the practicalities of roadside planting, and road user visibility and safety.

Land ownership

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

Practicalities of planting

Several considerations will aid planting of roadside vegetation and increase tree survival rates. The following criteria should be taken into account when selecting sites for roadside planting:

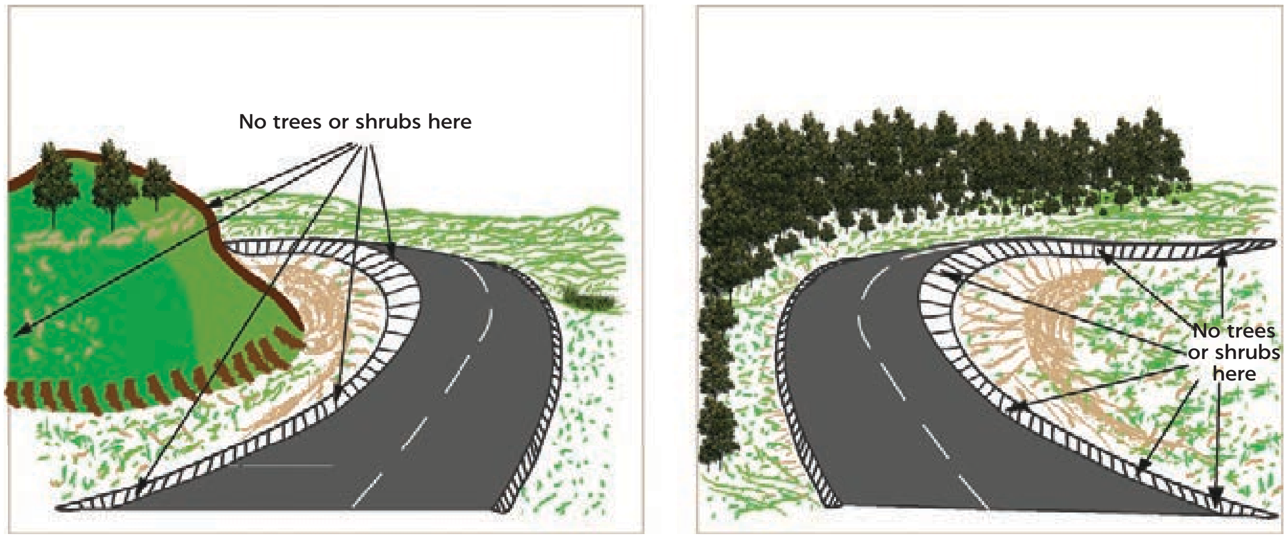
- Planting sites should have access to water sources, which may include water harvested from the roadside.
- Sites with established animal paths should not be chosen because protecting saplings will be difficult.
- Sites with nearby households engaged in farming or other activities should have priority.
- Sites should preferably have easy access to a tree nursery.
- Nearby communities should have a positive attitude toward the benefits of the plantings (firewood, fruits, beekeeping).
- Planting sites must be a reasonable distance from farmlands as well as from the edge of the road. The effect of shade on crops (sun direction) must be considered when choosing locations.

Visibility

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

Care should be taken when placing trees on bends. In general, no trees or shrubs should be planted on the inside of cut slopes around curves, nor should trees or shrubs be planted on the inside curve of an embanked road. However, trees planted on the opposite of these positions will enhance visibility and alert drivers to curves in the roads. No trees should be planted at intersections

FIGURE 12.1
Tree planting and road visibility



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

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

Source: MetaMeta (www.roadsforwater.com).

or exits. Overgrown trees are a particular problem and care should be taken not to plant trees with horizontal crowns.

Road safety

Road safety is an extremely important factor when designing roadside plantings. Trees can contribute to fatalities in run-off-road collisions, particularly in high-speed zones (Budzynski et al. 2016). Trees are one of the major factors in deaths on rural roads in many countries (photo 12.3).

Tree planting should not compromise road safety. Tree planting should not be undertaken in high-speed zones and should be kept a safe distance from the carriageway in medium-speed road segments (see table 12.1). If a road is upgraded, trees may need to be cut down to ensure safety. A minimum 20-meter offset is required for all speed zones above 40 kilometers an hour. Regardless of the speed zone specified, the actual mean speed of travel for any new road cannot be known in advance. Run-off-road crashes have high-severity outcomes and are among the most unforgiving types of collisions.

Distance to electricity lines

Contact between trees and electrical wires and poles should be prevented. A lateral distance of 8 meters from the utility wires should be maintained to minimize interference. Very tall trees should not be planted in the vicinity of electricity lines in rural areas.

PHOTO 12.3

Roadside tree planting in Bangladesh under the Social Forestry Program, having covered 73,000 kilometers of roads and benefited 700,000 persons

Source: Andrew Zankharenka. Used with permission. Further permission required for reuse.

TABLE 12.1 Roadside vegetation and road safety measures

SPEED ZONE	ROAD SAFETY MITIGATION METHOD	
40 km/h	The impact force is unlikely to exceed human tolerances, so no specific mitigation is needed. However, it would be beneficial to have a minimum lateral offset of 1 m between edge of lone/curb face to mature front face of tree.	
50 km/h	A minimum lateral distance from the road edge of 1.5 m of lateral offset between edge of lone/curb face to mature front face of tree should be maintained to reduce incidental interaction between vehicles and trees.	
60 km/h	**Intersections**	at least 10 m beyond intersection on the approach and departure side
	Driveways	at least 3 m between edge of lone/curb face to mature front face of tree
	Lane merge locations	3.6 m between edge of lane/curb face to mature front face of tree
	Curves	3.6 m between edge of lane/curb face to mature front face of tree for gentle curves; barrier for moderate/tight curves
70-100 km/h	The impact force is highly likely to exceed human tolerances and trees are not beneficial in these scenarios. Safety barriers are the most appropriate mitigation (wire rape safety barrier, guard rail or other approved safety barrier that is suitable in high-speed environments)	

Source: MetaMeta, (www.roadsforwater.org).

SPECIES SELECTION

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

The main criteria for selecting species are as follows:

- Tree species should be evergreen or remain green for most of the year.
- Species should be fast growing.
- Tree species should not be broad-rooted because tree roots may penetrate the road surface.
- Tree species should have crown architecture with a more horizontal than vertical extension.
- Tree and grass species should be tolerant of seasonal drought and insects and pests.
- Tree species should be deep-rooted to resist wind and drought stresses; deep-rooted trees are also strongly preferred because they are less likely to damage the road.
- Thorny plants are to be avoided because they may cause tire punctures.
- Tree and grass species should never be invasive.
- Tree species should have one or more aspects of social and economic value, such as medicinal, food, fuelwood, feed, or shade.
- If tree species are edible by livestock, fencing is needed in the growing stages to protect the tree and enable it to mature.
- Tall-growing trees should not be selected for planting beneath power lines.
- Trees that do not grow large-diameter trunks can be given preference because they pose less risk to errant vehicles.

SITE PREPARATION

Tree-planting sites must be prepared properly, including elimination of weeds, preparation of the soil, and the use of planting pits.

Eliminating weeds

The survival and growth of tree seedlings depends on the quick reestablishment of their root systems. Competition from the roots of other plants growing in the area will hinder this process. Along with directly competing with the emerging roots of seedlings, the roots of weeds and grasses can also release chemicals that impede the growth of other plants. Therefore, weeds and all other vegetation should be removed from the planting site.

Preparing the soil

The soil must be prepared to facilitate growth of seedlings. The soil must be loose enough and have adequate pore space to allow roots to penetrate and absorb sufficient water and oxygen. In many instances, the highly compacted soils that often result from roadside construction do not have suitable characteristics for tree planting. Moreover, people and animals tend to walk along the roadsides, compacting the soils even more. Adding materials (compost, manure, or other soil) is not recommended unless the existing soil is of very poor quality. If existing soil quality is very poor, the volume of organic matter added to it should not exceed 25 percent of the planting bed. Ultimately, it is better to select plants that can tolerate existing conditions than to improve a large area of soil to suit less well-adapted species.

Several actions can be undertaken to loosen the soil and make it suitable for planting. Tilling 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 meter. Soil shattering involves pulling one tine, or a set of tines, through the soil at various depths to break up compaction by the roadside.

Topsoiling should be undertaken when possible. Topsoiling involves the removal, storage, and reapplication of topsoil material to provide a suitable growing medium for vegetation. Topsoiling increases nutrient availability, water-holding capacity, and microbial activity for the planting. Topsoil should only be removed from areas that will be excavated, are highly compacted, or are buried under excavated material, such as fill slopes. When possible, laboratory tests and field surveys should be conducted to determine topsoil quality. Topsoil with high salinity, very high or very low pH, or any other condition that may obstruct plant growth should be avoided. Removal and collection of topsoil is best done when soils are relatively dry to avoid soil compaction. The depth of topsoil application depends on the amount available. Deeper topsoil generally will result in a more productive site.

Preparing planting holes

Use of planting holes improves newly planted trees' chances of survival. Planting holes should be dug vertically rather than perpendicular to the ground surface. Preferably, the planting hole should be 5–7 centimeters deeper than the total length of the root system, and at least as wide as the root system. Species that can be rooted from cuttings can be planted deeper given that portions of the stem will root when buried. The roots of the seedlings should not be forced into the planting hole, nor damaged or broken during planting. After placing the plant in the hole, excavated soil should be placed firmly around the root system so that there is no loose soil or air pockets around the root plug. The root system must not be damaged during this operation.

DESIGN OF ROADSIDE VEGETATIVE BARRIERS

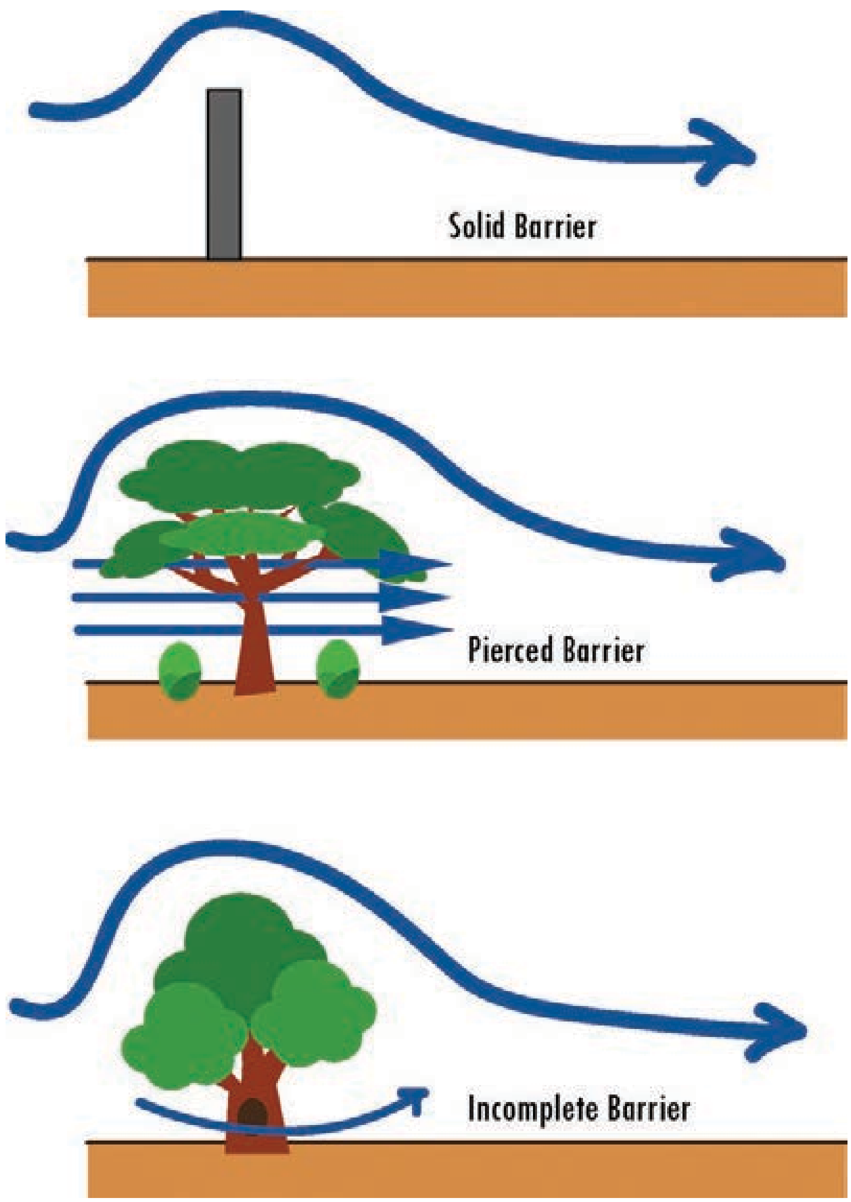
Several decisions must be made when designing roadside vegetative barriers, specifically the combination of trees and shrubs, the porosity of the barrier, and the number of tree lines.

The selection of species will determine plant spacing, that is, the distance between the different shrubs and trees. Shrubs, for instance, grow at a much closer spacing than trees, which should be taken into account when determining the combination of species to be planted. The general guidance for row plantings is that larger trees are planted 3–5 meters apart, larger shrubs 2.5–4.0 meters apart, and smaller shrubs 1.5–2.5 meters apart. Single-row plantings should only be used on higher-value land and where space is limited. When possible, it is preferable to have plantings of two to four rows to protect a larger area. One- and two-row plantings are cost-effective options but require a uniform and high survival rate.

Figure 12.2 illustrates different types of roadside plantings. Porous barriers have the most beneficial impact on dust control. Dust capture is enhanced by

FIGURE 12.2

Roadside tree barriers and dust movement



Source: MetaMeta (www.roadsforwater.com).

turbulence in the planting caused by the presence of irregularities such as branches, leaves, and complex leaf structures. The more irregularities the structure contains, the more dust and pollutants will be trapped. In comparison, almost all dust will "leap" over solid barriers, and little will be intercepted. Porous plantings allow a large part of the airflow to traverse the planting. Dust will be trapped better because there is more contact with the leaves of the trees and shrubs. To achieve a good degree of porosity, plantings should be approximately 5–20 meters wide and consist of tall trees with a bush layer underneath.

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

COMBINING WATER HARVESTING AND TREE PLANTING

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

Network of shallow trenches

A network of shallow trenches can be made along the road to route road runoff over a large area, water trees, and even create small roadside forests (photo 12.4). Trenches together with single-line roadside tree plantings can sequester carbon and offset some of the negative effects of road development.

Micro-catchment water harvesting

Micro-catchment water harvesting is one method used to collect surface runoff from a small catchment area into the root zone of an adjacent infiltration basin. This basin can be used for plants. Micro-catchments are alterations of the topography that direct rainfall runoff to plants. They are simple and inexpensive and provide many advantages over alternative irrigation schemes. Micro-catchment techniques are more effective on slopes not exceeding a 7–8 percent gradient. The optimal size of the micro-catchment depends on the site characteristics and the size of the seedlings.

A semicircular bund (also known as an eyebrow or demilune) is a stone structure that contains a water-soaking pit and a planting pit (photo 12.5 and figure 12.3). Semicircular bunds are commonly used on steep land (such as grades greater than 50 percent).

PHOTO 12.4

Network of trenches for roadside tree planting, Uzbekistan

Source: © Jonathan Demenge. Used with the permission of Jonathan Demenge. Further permission required for reuse.

Infiltration trenches

Infiltration trenches are large, deep pits that protect cultivated land from flooding and erosion while recharging groundwater (figure 12.4). Road runoff can be channeled to infiltration trenches where water will percolate. These infiltration trenches will increase the soil moisture of the adjacent area. Trees can be planted next to the trenches such that the roots of the seedlings benefit from the increased soil moisture. Grass strips can be planted at the edges to protect the holes of these infiltration trenches.

Swales

A swale is a broad, shallow channel (natural or man-made) designed to promote infiltration and reduce the flow velocity of runoff (photo 12.6). Its main purpose is to slow, spread, and infiltrate runoff. Swales are appropriate for harvesting road runoff and intercepting silty or contaminated runoff. Swales are never compacted or sealed because their main purpose is groundwater recharge. In fact, swale soils can be loosened to increase recharge and infiltration rates. They also provide an opportunity for tree planting because of the soil moisture increase along and around the swales.

Contour stone bunds

Contour bunds (figure 12.5) are designed to collect enough water to recharge soils and provide water for plant growth during the dry season. They also protect soils from erosion during peak rain events. Design criteria for determining the

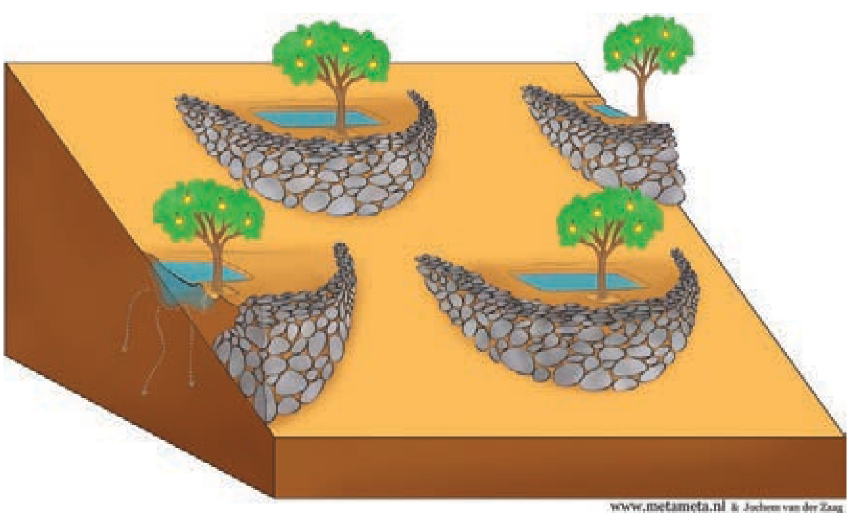
PHOTO 12.5

Communities building stone eyebrows at the roadside to catch runoff and support the growth of tree seedlings, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

FIGURE 12.3

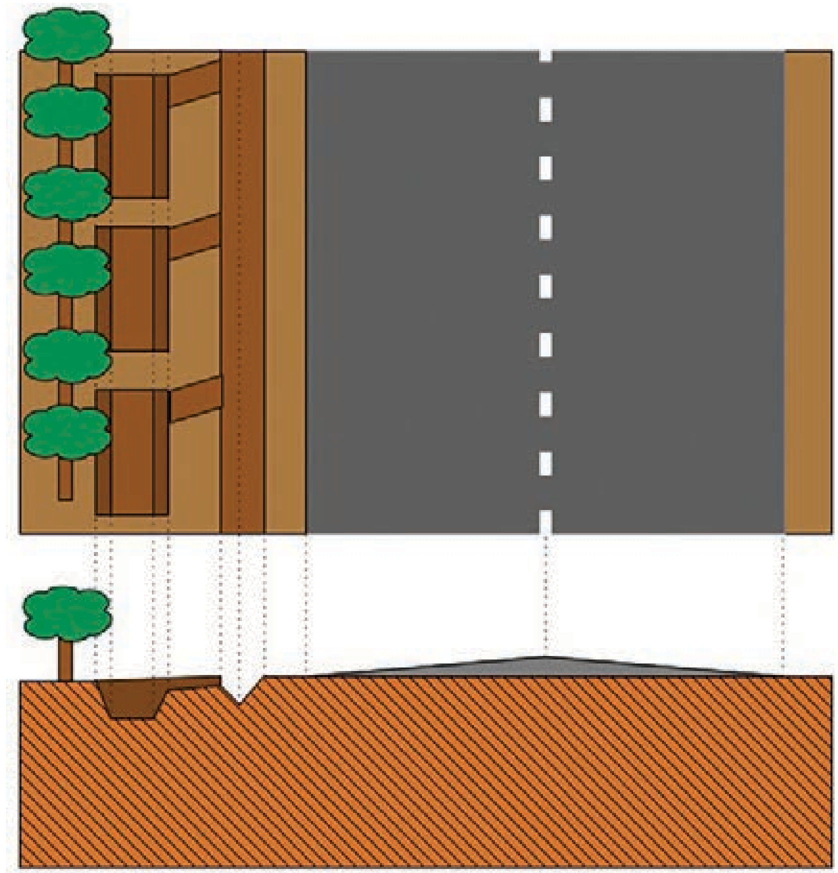
Diagram of a semicircular bund



Source: MetaMeta (www.roadsforwater.com).

FIGURE 12.4

Infiltration trenches collecting road runoff to enhance the growth of seedlings



Source: MetaMeta (www.roadsforwater.com).

PHOTO 12.6

Swale with overflow option along road in the Netherlands

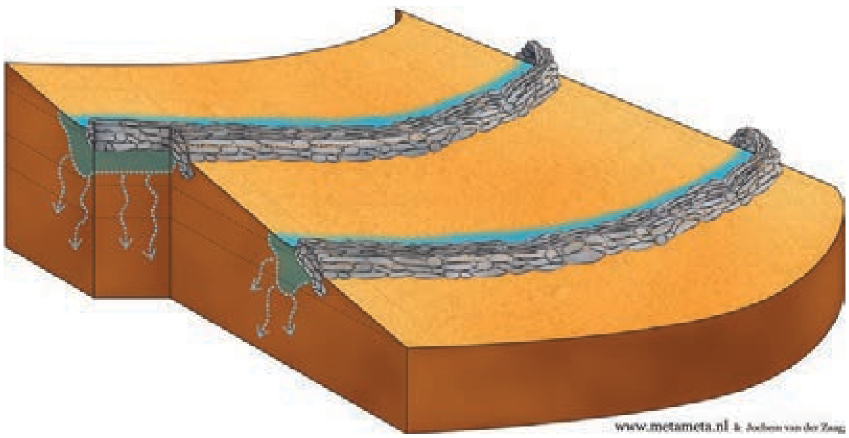
Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

distance between bunds include slope gradient, rainfall intensities, and infiltration rates. In very dry areas, trees can be grown above the bund; in more humid areas, it is better to plant them on the downside to minimize the risk of waterlogging.

Planting pockets

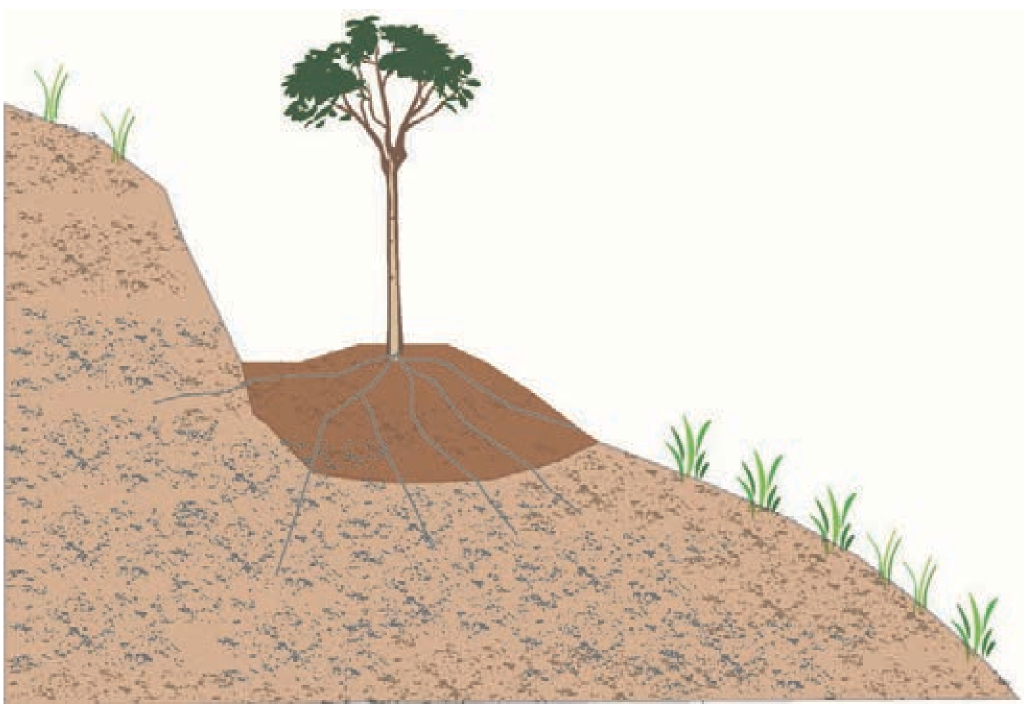
When terraces are filled with growing media (topsoil or amended subsoil) and planted, they become "planting pockets," akin to planting holes. Planting pockets, illustrated in figure 12.6, must have adequate soil depth to store the intercepted runoff and allow the establishment of planted seedlings. The surface of the planting pocket should be in-sloped to capture water and sediment, and the face of the pocket should be protected from surface erosion.

FIGURE 12.5
Stone bunds



Source: MetaMeta (www.roadsforwater.com).

FIGURE 12.6
Planting pockets



Source: MetaMeta (www.roadsforwater.com).

Use of polymers to increase survival rates

Trees are at their most vulnerable just after transplanting. A prolonged drought can cause saplings to die or to become stunted and twisted. Polymers placed in the root zone of the saplings will ensure they have more secure access to moisture. One effective method is the use of water pads; in this application, the polymer water pads are held in place by wedging them between jute and brown paper.

CONCLUSIONS

Safety considerations and maintenance of the trees are the most important considerations for the establishment of roadside plantings, which require careful planning and preparation. To ensure the effort and expense of planting is not wasted, the resources and arrangements necessary to maintain the trees and keep them alive should be confirmed 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. In general, only the number of trees that can be ensured to survive and thrive should be planted.

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

Seedling quality will influence the amount of water needed. Healthy seedlings grow new roots faster and can access deeper soil moisture. Poor-quality seedlings develop roots slowly and must be irrigated more frequently. Seedlings must adapt to the new location, as well—in the nursery they were watered daily, but now they must be hardened to sustain their new environment. To help them adapt and survive over time under harsh conditions, the amount and frequency of watering should be reduced until the tree has fully adapted and can survive on its own.

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

Because roadside plantings require care, plans for their maintenance and management must be identified (box 12.2). Numerous methods can work. The question is not so much which method is best, but whether there is a clear arrangement in place. Given that roadside tree plantings are often dispersed across a large area, arrangements for local management are generally most successful. Three additional factors that contribute to effective management are (a) restrictions to the free movement of cattle and ruminants, (b) clearly assigned ownership and usufruct rights to the roadside planting, and (c) the ability to economically use the plantings, even if it means harvesting and replanting.

BOX 12.2

Roadside vegetation maintenance practices

The following techniques are applied to protect roadside vegetation.

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

On sites where vegetation is expected to take several years to establish, such as arid or high-elevation sites, mulch that will last more than one year should be applied. Materials with the highest durability include 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 those with competing vegetation but is less important on sites with less potential for competing vegetation to become established during the first several years after planting. Mulching is also less critical on sites with low evapotranspiration rates or high rainfall.

Pruning. Well-spaced structural branches should be developed early in the life of a tree. Branches that grow close together when trees are young will grow into each other with age and will be unable to develop their full structural strength. Once the structural branches have been established, little pruning should be needed. It is advisable to examine the trees yearly and prune or cut branches for reshaping, if necessary. Uncontrolled growth of trees and shrubs could cause problems for vehicles, such as reduced sight distance and vehicle damage or personal injury. Trees also need to be pruned to remove dangerous hanging branches or to prevent lower branches from blocking a path or obstructing visibility.

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

A range of methods can be used to protect seedlings, including rigid and nonrigid netting, fencing, and animal repellents. Fencing materials that allow enough sunlight for photosynthesis are preferred. Stone or brick fences are not advisable because they block sunlight and impede plant growth. Individual trees can be fenced by surrounding them with sticks made from small branches from nearby trees.

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

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

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

- Paying local caretakers based on the survival rate and health of the roadside vegetation
- Sharing tree ownership between caretakers and investors, whereby investors annually compensate the tree caretaker for his or her efforts; upon tree maturity, proceeds are shared

NOTE

1. In some countries the most common crash type leading to fatalities is run-off-road hit fixed object, usually trees. Increasing exposure to this very high-risk crash type needs to be avoided as a high priority.

REFERENCES

Agujetas Perez, M., F. N. Tegebu, and F. van Steenbergen. 2016. "Roadside Planting in Ethiopia: Turning a Problem into an Opportunity." *Sustainability in Environment* 1 (2): 98–115. www.scholink.org/ojs/index.php/se.

Budzynski, M., K. Jamroz, L. Jelinski, and M. Antoniuk. 2016. "Why Are Trees Still Such a Major Hazard to Drivers in Poland?" *Transportation Research Procedia* 14: 4150–59. https://doi.org/10.1016/j.trpro.2016.05.386.

Greening, T. 2011. *Quantifying the Impacts of Vehicle-Generated Dust: A Comprehensive Approach*. Transport Research Support Program. Washington, DC: World Bank.

Hagen, L., and E. Skidmore. 1971. "Windbreak Drag as Influenced by Porosity." *Transactions of the ASAE* 14 (3): 464–65.

Krzyżanowski, M., B. Kuna-Dibbert, and J. Schneider. 2005. *Health Effects of Transport-Related Air Pollution*. Copenhagen: Regional Office for Europe of the World Health Organization.

Leghari, S. K., and M. A. Zaidi. 2013. "Effect of Air Pollution on the Leaf Morphology of Common Plant Species of Quetta City." *Pakistan Journal of Botany* 45 (S1): 447–54.

Nordstrom, K. F., and S. Hotta. 2004. "Wind Erosion in the USA: A Review of Problems, Solutions and Prospects." *Geoderma* 121: 157–67.

Rahul, J., and M. K. Jain. 2014. "An Investigation in to the Impact of Particulate Matter on Vegetation along the National Highway: A Review." *Research Journal of Environmental Sciences* 8 (7): 356–72.

VicRoads (Roads Corporation of Victoria). 2015. "Tree Planting Policy." VicRoads, Victoria, Australia. https://202020vision.com.au/media/41974/vicroads-tree-planting-policy.pdf.

13 Protecting Roads from Water

KEY MESSAGES AND KEY TECHNIQUE

Key messages

- Water is a major factor in the deterioration of roads, and traditional road design aims to keep the road embankment dry by moving water away from the road.
- If roads are to be used to manage the flow of water, the risk of damage to the road must be mitigated through careful design.
- Mitigation measures can enable roads to be used to manage water without introducing significant detriments to the road.

Key technique

- The type of issue to which the roads-for-water approach may expose a section of road should be identified, and the appropriate mitigation measures should be implemented.

OBJECTIVES

Although these guidelines focus on the ability to use road infrastructure to control and harvest water for nonroad purposes, it is important to remember that water is widely recognized as one of the—if not the—biggest causes of road deterioration. Roads suffer damage from water in the following ways:

- Fast-moving water flowing alongside the road, either in unprotected earth drains or free flowing along the side of the road embankment, can erode the shoulder and the road embankment's lateral support.
- Fast-moving water flowing across the road surface may peel off the road's seal layer (especially if a surface treatment is applied) and deposit it into the downstream environment, resulting in damage to the road and the environment. Subsequent water damage may erode the road's basecourse layer.
- Long-term saturation of the road subgrade and subbase layers (particularly those with higher proportions of clay content) will result in the road's loss of

structural bearing capacity. This is a serious concern if heavy loading occurs during the period of saturation.

This chapter explores these issues further and provides some basic guidance on how to mitigate the risks so that the road is protected from water damage while the benefits of using the road to control water are achieved.

IMPACT OF WATER

The impact of water events (rain, snow melt, or otherwise) on road infrastructure can be considered in simple terms, as described in table 13.1. Within this context, a short-duration event is one wherein the road is not subject to water long enough for the water to ingress into the road structure beneath the traffic loading zone. The rate at which water moves through gravelly or sandy materials will naturally be much higher than through clay materials, owing to their relatively higher permeability. The duration of an event is therefore defined in the context of the materials that are exposed to inundation (table 13.1).

For a well-compacted clay-based subgrade, the rate of water infiltration will often be less than 5 millimeters per hour. For granular basecourse materials, the rate of water infiltration is in the vicinity of several meters per hour. For water to cause damage to the road, the water must penetrate to the key zone of influence located under the wheel paths. Given the much higher rate of water ingress via granular layers, it is reasonable to assume that if the water rises above the transition point between the clay and granular layers for a period of more than an hour, water entering through the permeable upper layers will make contact with the underlying clay layer in the area of the wheel path (that is, water would travel horizontally through the highly permeable gravel layers, and then down into the clay layers below). Conversely, if the water is only deep enough to contact the clay layers, significant water ingress under the wheel paths occurs only after one or two days.

If water soaks the clay subgrades under the wheel path, the road must not be exposed to heavy traffic until the subgrades have had adequate opportunity to

TABLE 13.1 Key concerns for road damage from water-based events

	SHORT-DURATION EVENT	LONG-DURATION EVENT (SOAKAGE IS CONSTRAINED TO CLAY LAYERS FOR MORE THAN 1 DAY, OR GRANULAR LAYERS ARE SOAKED FOR MORE THAN 1 HOUR)
Fast-moving water	• Erosion of unprotected earth drains • Limited erosion of unprotected side of embankment • Stripping of surface dressing layer from road if road is overtopped (especially if surfacing is old and brittle)	• Extensive erosion of side drains • Extensive erosion of embankments • High likelihood of stripping of surface dressing layer if road is overtopped • Loss of bearing capacity of road structure • Accelerated pavement aging if road is subject to heavy traffic before drying out
Slow-moving water	• Limited damage to road structure	• Loss of bearing capacity of road structure • Accelerated pavement aging if road is subject to heavy traffic before drying out

Source: World Bank.

drain; otherwise, permanent damage to the road may occur. In keeping with the rule of thumb outlined above, assuming the water did not reach the more permeable granular (upper) layers, if the clay embankment is soaked for a period of 24 hours or more, it is safe to assume that water may have reached the critical zone under the wheel path and the road must dry out before it can be exposed to heavy traffic. In such cases, water should be allowed to drain from the road for the same length of time that the temporary water had been allowed to soak the embankment. Therefore, following a 30-hour soaking, the road would need to drain for 30 hours after the temporary water recedes before it should be exposed to heavy traffic.

Conversely, when water can enter much more quickly via the granular layers and soak down into the clay layers, the time for the road to become soaked is much shorter (by a factor of 50–100 depending on material properties) than the time for it to drain. In this case, a rule of thumb is that for each hour that water soaked through the granular layers, the road should be given two to four days after the water has receded.

MITIGATION MEASURES

Because these guidelines are focused on using the road to manage water, mitigation measures such as raising the road, installing additional culverts, or similar actions are not considered in detail in this section. Instead, the mitigation measures in table 13.2 focus on methods that will enable the road to experience the least (or no) damage while still offering the benefits of the

TABLE 13.2 Mitigation measures

ISSUE	POTENTIAL MITIGATION MEASURES
Erosion of earth water channel by fast-moving flows emanating from outside the road embankment	• Line earth channel with rock riprap • Construct a concrete “u” drain on steep slopes • Install check dams to break up flow • Use geoengineered (planted) solution • Construct earth channel in a zigzag formation to lengthen the drain and thereby reduce the gradient
Erosion of side of embankment by floodwaters	• Install rock riprap on side of embankment • Use geoengineered (planted) protection of embankment
Erosion of surface of the road owing to water moving across it	• Ensure the surface is maintained well • Use concrete or similar durable surfacing • Alter road cross-slope, such that the water is deepest at the upside of the flooding to reduce the speed of water flowing across the surface, with the maximum speed occurring as the water exits the pavement • Raise the pavement out of the flood zone • Increase the size of the drainage structures to reduce flooding
Softening of embankment under the wheel path	• Increase depth of gravel layers to reduce the loading stress on more water-sensitive subgrade or clay embankment • Close road during periods of inundation, and keep road closed until embankment has dried out • Use a concrete pavement to spread the load over a greater area

Source: World Bank.

roads-for-water approach. The purpose of the table is not to determine what solution should be used, but rather to let the reader be reassured that technical solutions are available to mitigate risks when adopting the roads-for-water concepts outlined elsewhere in these guidelines.

ROADS AS DAMS

Of all the roads-for-water interventions outlined in these guidelines, use of the road as a dam wall to constrain water over the medium or long term poses the greatest risk of damage to the road. In such cases, damming raises the risk that the road will fail by introducing the horizontal forces of the water (especially if the height of water being retained is significant) and by potentially softening the embankment, thereby reducing the load-carrying capacity of the road.

Roads are not typically designed to dam water, so a road intended for this purpose must be carefully designed to have sufficient lateral strength. To mitigate the risk of damage from water penetration, the road embankment design should include highly permeable wick drains and a horizontal drainage layer. A very low-permeability layer should be used to create the dam wall. This low-permeability layer may be composed of some combination of clays and artificial geotextile-type (PVC, rubber, or similar) liners, depending on what natural materials are available. Side protection (riprap or something similar) may also be required to prevent erosion of the impermeable layer.

RECOMMENDED PRACTICES

Although the design of roads to avoid the presence of water is standard engineering practice, the roads-for-water approach means that segregating water from the road itself is not always possible or desirable. In these instances, the road authority will need to adapt designs to ensure the potential impacts of water coexisting with the road are appropriately mitigated.

This chapter touches briefly on a number of the key issues that can arise under the roads-for-water approach, and in each case suggests mitigation measures that the designer may wish to consider to manage or eliminate those concerns. The key message of these guidelines is that standard road design practice may not be appropriate for the roads-for-water approach; however, the impact of water can be readily managed by considered (and often relatively inexpensive) modifications to standard designs.

IV Management

14 Making It Work: Governance for Green Roads for Water

KEY MESSAGES

- In *adaptive resilience*, the existing road infrastructure is adapted to optimize its contribution to water management and climate resilience. This strategy involves additional, usually low-cost, water control measures and requires complementary programs such as training for roadside users and farmers, special green funding arrangements for supplementary programs, and memoranda of understanding between main sector departments.
- In *proactive resilience*, road alignments and designs are chosen for their ability to serve multiple objectives beyond transport. Proactive resilience requires multifunctional investment formulation, new integrated designs, training for engineers, modeling for specific challenges, and special green funding arrangements for additional costs.
- Trust, integrity, cooperation with other sectors, focus on sustainability, and community engagement are key values in Green Roads programs.
- Initiating a roads-for-water approach may entail different steps, including fact-finding, getting sectors to talk, identifying champions, early implementation, working on different fronts, capacity building, and research into and implementation of new working methods.

OBJECTIVES

Using roads for water management is a new practice for many road agencies. Introducing this new practice requires more than mastering new techniques for road design, construction, and maintenance. Establishing road programs that support water management generally requires changes to governance, as well. The overarching change is that road development and water management will be intimately linked in all aspects of road planning, construction, and maintenance programs. The outcome of this linking is that both water management objectives and transport objectives are taken into account in the choice of road alignments and designs, as described in the section titled “The Three Levels of Promoting Resilience: Protective, Adaptive, and Proactive” in chapter 1. Considering these dual objectives ideally involves several adjustments to working methods, including methods for preparatory surveys (see appendix A), physical design, budgeting, and community engagement (see chapter 15). None of these changes is insurmountable or complicated; they just need to be implemented.

This chapter describes common challenges in road sector governance, impediments to implementing Green Roads programs, and the directions in which governance should move to be more responsive to the opportunities that Green Roads for Water offers. As noted, using roads as instruments for water management and climate resilience (including more reliable road transport functions) requires different methods of working. This chapter focuses directly on this change, sharing the experiences of different countries where the roads-for-water practice is being introduced. The chapter discusses different methods that may be used to introduce the change.

GOVERNANCE FOR ROADS FOR WATER

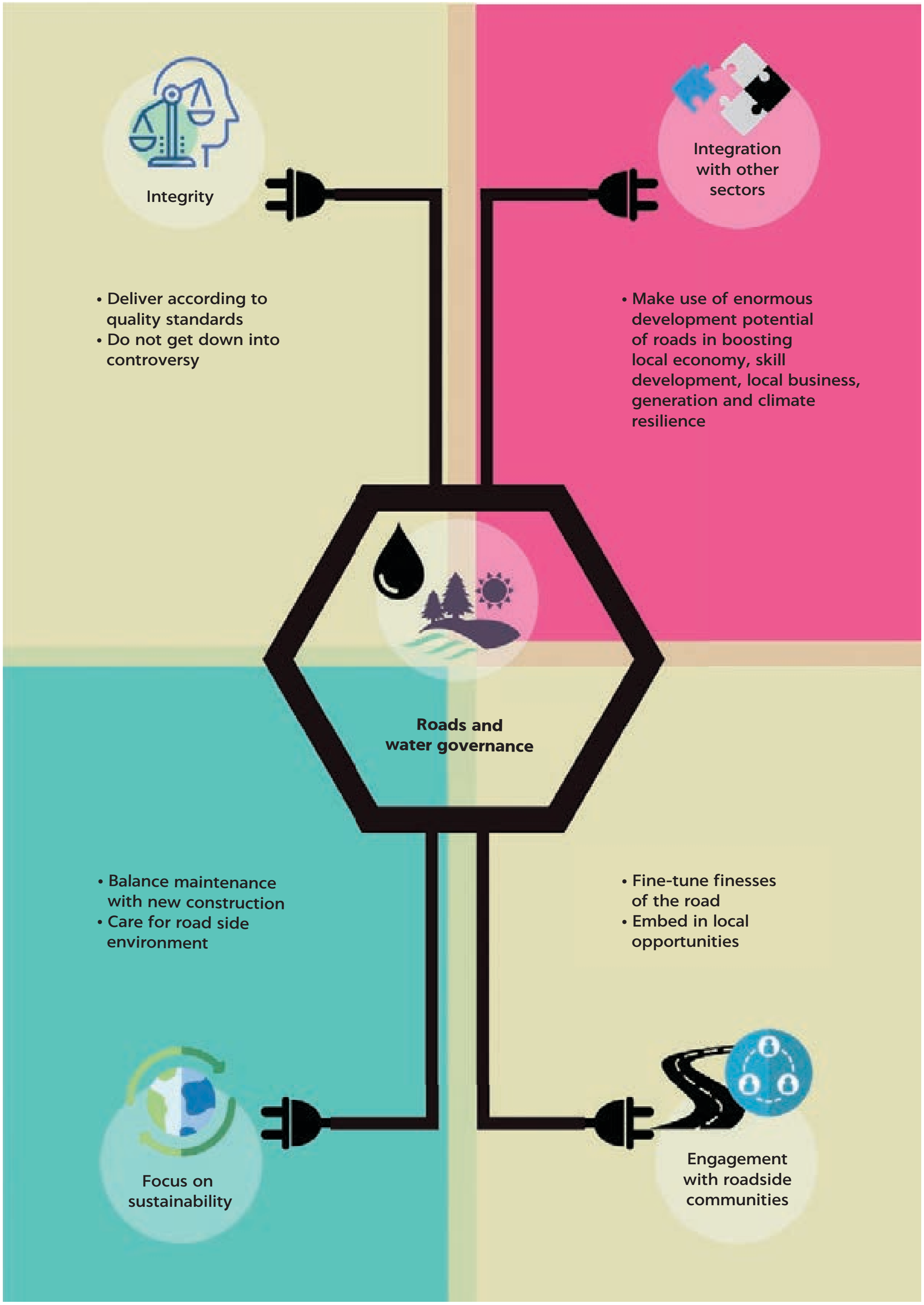
Several key factors can accelerate uptake of new practices in the road sector, from the integration of beneficial water management in road development and maintenance to the promotion of economic opportunities that road development can bring (see figure 14.1).

The first factor is integrity. Integrity is vital to maintaining high working standards and creating a culture of accountability and transparency. Mismanagement often results in failure to follow critical specifications, which can lead to the rapid deterioration of infrastructure. Large amounts of money are moved around in the road sector, and mismanagement or corruption scandals affect road agencies in many countries. When sector leadership is compromised by scandals, instability can more easily emerge in the management of a road organization, reducing the agency's effectiveness and capacity to adopt new practices and meet higher standards for quality. The shadow of corruption and tolerance of mismanagement can be as damaging as corruption itself.

A second challenge is that road agencies are generally not well integrated with other sectors. This point is difficult to quantify but has been observed in the roads-for-water programs of various countries. For example, the road sector often operates in isolation, frequently with different legislation covering the road sector and the water sector. Road sector institutions often have very limited awareness of the positive impacts that roads could have on water management and climate resilience. Furthermore, legislation that requires road institutions to provide a "safe, resilient, and efficient" (or similarly worded) road network is often interpreted as constraining opportunities to use road sector funds for roads-for-water measures. As an example, road development projects often have consent conditions imposed on borrow pits to restore the area to its condition before the road development, which precludes retaining them for water management. The consent conditions under which road development projects are undertaken typically only apply to the road reserve and do not provide a legal means for the contractor to undertake works outside the road reserve that would lead to better water management—beyond that needed to protect the road. Improving cooperation between and alignment of the water and roads sectors will in many cases require changes to the legislation governing the two sectors' key institutions as well as changes in attitudes within both sets of organizations. This new collaborative approach was applied when implementing the Bangladesh Roads for Water project as illustrated in photo 14.1.

FIGURE 14.1

Improved governance for Green Roads for Water



Source: MetaMeta (www.roadsforwater.com).

PHOTO 14.1

A large range of stakeholders discussing the integration of roads and footpaths for better management of drainage and water levels in low-lying polder areas, Bangladesh

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

Finally, pressure to meet political priorities is a major cause of mismanagement in road sector institutions. In response to such pressures, road institutions often prioritize constructing new infrastructure over critical issues of functionality and maintenance; this approach is not only detrimental to the existing infrastructure but also results in quality problems for new infrastructure. For example, road agencies have sometimes deliberately underspecified road designs to satisfy unrealistic timelines and budgets, resulting in roads with serious defects such as unsustainable gradients or grossly insufficient drainage, thus reducing the road's useful life and wreaking havoc on the environment and communities around the road. Additionally, maintenance of rural roads is heavily underfunded almost everywhere. In the worst case, the poor condition of remote rural roads is entirely ignored in favor of new construction. A broader focus on road and water sustainability may help address these challenges given that a focus on the quality of the roads and the environment necessarily involves raising the standard of care in road programs.

IMPROVED WORKING METHODS FOR ROADS FOR WATER

Many road sector institutions will need to scale up their engagement with other stakeholders and institutions as they attempt to implement roads-for-water programs. Each of the three resilience approaches has different implications for the stakeholders involved. If the sole objective is to protect the road (*protective resilience*) against climate change with, for instance, better pavements or larger cross drainage, then the main stakeholders are the road users and the road authorities.

However, if the objective is expanded to include water-harvesting measures and to make secondary use of the road body for water management (*resilience plus 1*, or *adaptive resilience*), then agricultural and water authorities are also main players and local community involvement must increase, with road authorities leading the process. However, if road infrastructure is critically assessed and designed to serve different functions (*resilience plus 2, or proactive resilience*)—transport, water management, disaster preparedness, and climate resilience—then multiple stakeholders, including roadside communities, water and agricultural agencies, environmental authorities, disaster management agencies, relevant nongovernmental organizations, and potentially others, must collaborate closely throughout the entire process.

Table 14.1 describes the activities and changed working methods under each of the resilience approaches. In the protective "basic" approach, road designs are changed—requiring higher specifications and costs—and catchment programs may be initiated along the most vulnerable road sections. In the adaptive

TABLE 14.1 Working methods in the three resilience approaches

RESILIENCE APPROACH	ACTIVITIES	MAIN STAKEHOLDERS	CHANGED WORKING METHODS
Protective Basic resilience: *Protect the road*	• New specifications for cross drainage and road surface • Catchment management for road protection	Road authorities; some coordination with land management authorities	• Increased construction budgets • Catchment protection program
Adaptive Resilience plus 1: *Make the best use of the road*	• Train farmers and implementers on road-water management techniques • Integrate roads for water in existing catchment management programs • Make complementary investments in roads-for-water measures • Combine road maintenance arrangements with water management measures	Key stakeholders work in a complementary fashion: • Agriculture authorities • Water authorities • Disaster risk reduction authorities	• Complementary programs • Training for roadside users and farmers • Special green funding arrangements for supplementary programs • Memorandum of understanding between main sector departments (roads, water, disaster risk management)
Proactive Resilience plus 2: *Modify the design and function of the road*	• Changes to legislation covering road authorities, water management authorities, and perhaps others • Changes to road building and watershed management guidelines • Creation of task forces within main government departments (roads, water, and agriculture) • Creation of interministerial steering committee • Incorporate in main country policies and programs (green growth, climate resilience, agricultural growth) • Include the approach in university curriculum • Work with main infrastructure funders	Key stakeholders work hand in hand: • Road authorities • Agriculture authorities • Water authorities • Environmental authorities • Disaster preparedness authorities • Infrastructure investors	• Develop new program goals and criteria • Multifunctional investment formulation • New integrated designs and guidelines • Training for engineers and experts in all related sectors • Modeling for specific geographies • Special green funding arrangements for additional costs • Intersectoral task forces • Interministerial steering committees to ensure programs have necessary support from the top down

Source: MetaMeta (www.roadsforwater.com).

approach, farmers and agricultural or water organizations undertake complementary measures around the road infrastructure. Implementation of adaptive approaches involves a range of coordinated activities. Some examples include sensitization of related authorities in agriculture, water resources, environment, and disaster risk reduction; training for farmers and others involved in implementation; special additional funding arrangements; and memoranda of understanding between road authorities and others.

The Kenya Roads Board and Water Sector Trust Fund have signed a memorandum of understanding (MoU) to formalize their roles in implementing an adaptive resilience approach; the MoU is a funding arrangement whereby the Trust Fund will pay the costs associated with storage ponds.

In a proactive resilience approach (resilience plus 2), the different sectors work together even more closely. Because proactive resilience conceptualizes road projects as multifunctional assets, road development is not the responsibility only of road authorities but is shared and discussed with many others. This approach requires new working methods that can account for different considerations early in the road development process. (Annex 14A provides recommended terms of reference for teams working on this approach.) Over time, new practices are tested and captured in new guidelines and new design recommendations. The interministerial committee on roads for water established in Uganda is an example of this wider cooperation.

GETTING THE PROCESS GOING

The roads-for-water management concept has been introduced in a variety of countries. Although interest is widespread, the speed of uptake varies, partly because of the different overall governance systems in different countries, as discussed in the section "Governance for Roads for Water." Key divergences include the management culture of the organizations most motivated to implement roads for water and the level of decentralization or centralization of the critical institutions.

Uptake in Ethiopia, for instance, was fast. A large lever existed and could be used—the Watershed Programs, orchestrated by the Regional Bureaus of Agriculture. These programs mobilized large numbers of people every year in the lean season (see the section titled "Examples of Community Engagement at Scale" in chapter 15). Water-harvesting measures were systematically integrated into this program and large-scale adaptive resilience measures were quickly implemented. Moreover, there is a strong "can do" mentality in Ethiopia. The regional governments quickly took ownership of the concept of roads for water and incorporated it into their five-year plans.

This scenario may be compared with Kenya, where decentralization under the 2013 constitutional amendment placed substantial budgetary resources under the control of the 47 counties, including the responsibility to build and maintain rural roads. Under decentralization, the Kenya Rural Roads Authority made the transition from a commanding role to an advisory one. Introducing a new practice across Kenya now requires a larger number of decisions to be made in each county. Kenya does not have campaigns equivalent to the watershed programs found in Ethiopia, so there is no single mechanism for introducing the additional water-harvesting measures, even at the county level.

It is therefore important to understand the driving forces in the roads and water sectors and to assess the best opportunities for introducing Green Roads for Water into practice: Are there organizations with large "leverage" in the sense that they can provide incentives to motivate many other important actors across the country? How are responsibilities distributed between the central government and local governments for different categories of roads? What is the distribution of construction and maintenance roles? Are roads maintained? Are there private sector players (such as toll-road operators)? What are the main opportunities for improving road quality or water management, and what are the pain points? How politicized is road development? Are there coordinating arrangements between the road sector and the water, environment, climate, or disaster risk reduction sectors? How does the road sector score in climate or resilience funding?

Experience introducing roads-for-water activities in various countries has provided valuable lessons:

- *Get people to talk*. The road sector and other sectors have often never communicated, and bringing the different perspectives together can generate much appreciation and many fertile ideas (photo 14.2).
- *Do basic fact-finding in a region or a country to define the opportunities and provide an anchoring point*. Basic fact-finding should improve the

PHOTO 14.2

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

Source: © Macpherson Nthara/MetaMeta (www.roadsforwater.com). Used with the permission of Macpherson Nthara/MetaMeta (www.roadsforwater.com). Further permission required for reuse.

understanding of the driving forces noted above and of the win-win opportunities of Green Roads for Water. It is also important to cast a wide net when sharing the results of this fact-finding. Brief the main organizations related to roads, water, and land management but also involve associations and civil society groups that may own the program in various additional ways.

- *Find champions*. Highly motivated individuals often have surprisingly large convening power and the ability to convince others. These individuals could be within government, within funding agencies, or independent experts. Their influence can fast-track uptake of roads-for-water programs, particularly if they are working for organizations that have a great deal of leverage.
- *Move forward with early implementation*. Almost all Green Roads for Water measures are "no regret" in the sense that they hardly can do any wrong; in the worst case they may not be very effective. Many opportunities to introduce Green Roads for Water (especially opportunities in the adaptive resilience category) require limited additional funding and can be done using local initiative. Preparation of flow dividers and spreaders, clever use of road spoil (chapter 4), gating of road culverts (chapter 5), and conversion of borrow pits (chapter 8) do not require extensive preparation and can be undertaken very quickly to start the change.
- *Do not get mired in pilots*. There is pressure with innovative approaches to first test them and demonstrate them in pilots. Pilots are not advised. There is a large risk of getting stuck in such pilots—they take a long time to complete and even longer to prove their points. Pilots are also always contextual: what works in one place does not necessarily work elsewhere, so their capacity to convince is limited. Pilots run the risk of dissipating momentum rather than building it.
- *Work on different fronts*. It is important not to focus on a single activity in introducing the new approach, but to work on multiple fronts—engaging with champions, providing motivational training, undertaking early adaptation projects, and documenting and broadcasting results so that different experiences reinforce one another.
- *Capacity building and research should support immediate action*. Capacity building and research are useful but slow drivers. They help engage future generations of experts, but they do not usually create momentum. When training, motivational events are more important in the early stage—to create enthusiasm and interest and to connect with people who have introduced roads-for-water programs in their own areas.
- *Consolidate in due time*. At first, it is important to get the programs moving and to look for early adoption. At a later stage, the learning needs to be consolidated in guidelines and new designs, supplemented by good practices from other areas, and supported by new ways of working where possible (see also the section titled "Governance for Roads for Water").

ANNEX 14A. SAMPLE SUPPLEMENTAL TERMS OF REFERENCE FOR ROAD PROGRAMS

The paragraphs below contain text that can be inserted into contracts:

Road infrastructure has a major influence on the immediately adjacent environment. There is a genuine risk that this influence is negative, as in erosion, flooding, waterlogging, sedimentation, or even sand dune movement. Yet this influence can also be inverted; roads should contribute to better environmental management, beneficial water management, and climate resilience.[1] These approaches may often reduce road asset management costs and the risk of road disruption.

The consultants shall investigate and report on the potential beneficial contributions of roads to environmental management and water use, and identify measures required to use the potential of roads-for-water management to benefit communities.

In fulfillment of their assignment, the consultants shall (a) take the above general considerations into account in the general conduct of their inquiries, reporting, recommendations, and designs; and (b) consider and report on the following three areas, in particular:

(1) Identify measures in road and bridge infrastructure designs that can optimize roads' contribution to the environment and water resource management, access to water, and climate resilience. This can be the placing of culverts and road drainage so as to optimize runoff patterns for water harvesting, the optimizing of road embankment heights and overflow structures for flood management, the systematic conversion of borrow pits for water storage, the development of road drifts that retain and store water in the riverbed, the use of road embankments as dam walls for water storage, the gating of road culverts for the control of water level, the inclusion of water bars and rolling dips in feeder roads to divert water to surrounding fields and prevent road erosion, the inclusion of flood shelters in road infrastructure, and the aligning of road routes to control sand dune movement and to optimize recharge and water-harvesting areas.

(2) Identify (and appraise) measures that would enable roads and bridges to contribute to sustainable environmental management and beneficial water use. These measures can include additional activities to channel water from road drainage for use in water harvesting; roadside tree planting, improving range- or pasture-lands, or beneficial bioengineering programs; measures that reduce the risk of erosion, stabilize fragile environments, maintain natural hydrology, and minimize hydrological integration; and others.

(3) Identify (and appraise) the additional institutional activities required to better integrate beneficial water management and proactive environmental management into road programs. These activities may be in the form of modification to manuals and guidelines, changed budgeting systems or improved consultation and coordination processes, revised maintenance arrangements, special workshops and training, or pilot activities or modeling.

NOTE

1. For resource material, see www.roadsforwater.org.

15 Making It Work: Community Engagement

KEY MESSAGES

- Roads are at the heart of inclusive development: Roads stimulate growth in transport services and logistics companies, which is vital to building value chains; roads improve access to services and economic opportunities; road development offers direct labor and skills development opportunities, and can be an injection into the local economy; roads stimulate local business by creating new business opportunities; and roads' impact on the physical environment can be managed in beneficial ways.
- Optimizing these opportunities requires engaging communities within the reach of the road, their representatives, and other directly concerned parties.
- Engagement should be meaningful but will differ according to the stage of road development—conceptualization and planning, design, construction, maintenance, and aftercare.
- Communities can be a major force in the implementation of roads and Green Roads programs at scale—in the construction of rural roads, in their systematic maintenance, and in undertaking additional adaptive Green Roads for Water measures.

OBJECTIVE

Community engagement is essential to developing roads that are positive instruments for socioeconomic development and livelihoods, environmental rehabilitation, and climate resilience. Unfortunately, the road sector typically does not undertake extensive community engagement like some other sectors do, which is unfortunate because development of roads programs alongside those who are directly affected could bring about enormous benefits beyond transport. Roads are the backbone of local value chains and provide vital access to services. They present opportunities for better work, skills development, water and environmental management, and business development. Green Roads that promote climate resilience can also be the basis for creating many more livelihood opportunities than traditional roads. Community engagement is critical to identifying which opportunities are appropriate for individual communities.

The importance of stakeholder engagement and information disclosure is also highlighted in the Environmental and Social Framework of the World Bank (2017). To improve the process of engagement and consultation, the Environmental and Social Framework proposes a documented approach to (a) stakeholder identification and analysis, (b) planning how the engagement with stakeholders will take place, (c) disclosure of information, (d) consultation with stakeholders, (e) addressing and responding to grievances, and (f) reporting to stakeholders.

This chapter first discusses the scope for community engagement in different dimensions of Green Roads for Water development. It then discusses the practicalities of community engagement in different stages of road development. Finally, the chapter provides examples and takes lessons from three large-scale community engagement programs in Ethiopia, Bangladesh, and Nepal.

SCOPE FOR COMMUNITY ENGAGEMENT

The impact of roads programs is easily underestimated. Around the world today, local economies provide insufficient opportunities for vulnerable groups and youth to develop the skills, knowledge, assets, and experiences that will enable them to thrive in the productive peaks of their lives. Although it is commonly understood that roads provide access to new services and jobs, appreciation of the positive role roads can play in improving access to—and management of—water resources and preserving and protecting the landscape and pristine areas is lacking. When these opportunities are managed carefully, roads programs can create new livelihood opportunities for communities and simultaneously connect those communities to the outside world. Even today, roads are one of the main ways by which ideas and aspirations are spread and transform lives.

For these reasons, roads are vitally important to supporting local economies and creating opportunities for future generations. Meeting the needs of youth is among the biggest challenges faced by rural communities around the world (box 15.1). The vast differences in how rural communities manage their land and water resources have enormous impacts on the opportunities available to youth,

BOX 15.1

Sand harvesting by groups of young people

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

vulnerable groups, and future generations. Unless measures are in place to build resilience, climate change will exacerbate these differences, and many opportunities to improve livelihoods could be permanently lost. When local economies offer insufficient opportunities, many more people will inevitably fall into poverty or worse.

These guidelines argue that roads programs themselves are one resource, like water and the land, that can be managed to directly support livelihoods, connectivity, and resilience. The enormous sums expended on roads can support communities in many ways: through labor-based roads works to support incomes; through programs that encourage workers to save and invest earnings in new livelihoods that are supported by the road, such as acquiring cattle or farming equipment; by introducing new agricultural and aquaculture techniques that use road-water management to enhance farm incomes; by storing water for later use; by managing water flows to enhance rangeland and reduce the harms from flooding; and by enhancing the climate resilience of the roads and natural landscape that communities depend upon.

Because roads programs can shape every corner of a country, they have tremendous potential to bring about positive change. But road agencies and their staff must first better understand the opportunities that roads and transport can bring. Once road agencies develop this appreciation, they can reorient from the limited task of putting infrastructure into place toward a focus on engaging communities more deeply to achieve the full range of beneficial impacts that roads programs could have. Table 15.1 outlines this transformation.

All this amounts to a new vision of rural roads as development vectors, as breakthroughs for change, and as instruments for inclusive climate resilience and green growth. Roads should be seen as more than transport lines: they are engines for change and diverse and inclusive local development. Recognizing and investing in all the opportunities that road development presents (including transport, credit, water and trees, and business skills and visions), roads programs can bring tremendous change and opportunity to people's doorsteps.

TABLE 15.1 The scope for community engagement under different roads programs

PROGRAM	ROADS PROGRAM OBJECTIVES	COMMUNITY ENGAGEMENT OPPORTUNITIES
Traditional roads programs	Install roads and protect them from water and climate events	Limited to slight modification of the design; waterlogging and other harms are often resolved only after emerging, if at all
Adaptive or proactive resilience	Integrate roads into the landscape; balance resilience of roads and other natural resources; preserve land and water resources for community use; protect natural and pristine areas	Identify water management opportunities and challenges; determine road alignments for proactive measures; select water-harvesting, storage, and cross-drainage measures that protect resources and enhance livelihoods; train farmers and others to use the road-water management system to boost their livelihoods; establish systems for communities to manage assets such as farm ponds
Adaptive or proactive resilience *plus* a focus on livelihoods	The same as adaptive or proactive roads programs, *plus* integrate program support for livelihood opportunities, local business development, and farmers	The same as for adaptive or proactive resilience, *plus* creating mechanisms to facilitate hiring of local laborers for road works when works are mechanized; enhancing livelihood opportunities through labor-based works; combining labor opportunities with programs that encourage workers to save earnings and invest in assets that enhance their livelihoods after the road is completed; identifying other local needs such as transport services, small logistic parks where produce can be processed and packaged for higher value sale, or other ways to support the local economy

Source: World Bank.

- *Roads open up access for marketing of rural goods and services.* Market access is enhanced when road development is paired with access to local transport services. Local transport can range from carts, bikes, and motorbikes to taxis, small buses, and trucks. Roads can also lead to development of "cooperative aggregators" that help farmers access tools, seed, and fertilizer to enhance farm productivity and help ensure farmers have ready buyers for produce. The combination of roads and transport services can be transformative for rural economies. For instance, agriculture amounts to 15 percent of the gross domestic product of Sub-Saharan Africa, but many farmers lack access to roads and cannot easily sell produce to nearby urban areas. Processing, packaging, and transporting produce is often vital to boosting farmers' incomes. Reliable transport infrastructure and services can open up whole areas and increase their competitiveness.
- *Road development and road maintenance can create direct labor opportunities.* Local labor employment can be a "shot in the arm" for the local economy. There are many examples of labor-based approaches that serve this objective. The labor-based cut and fill method used in Nepal (see box 6.1), for instance, creates 26,000 labor days per kilometer, helps introduce safety procedures and equal pay for women, and is a best environmental practice. Road development may be designed to create labor opportunities for the most vulnerable and for youth. Once people have money in hand, they will spend it locally, and a multiplier of local expenditures and transactions may start to work.
- *Roads programs can directly support development of new livelihood opportunities.* An even stronger case can be made for roads programs that support development of new livelihood opportunities that can be sustained after the road works are completed. For example, laborers may have incentives to reinvest earnings into farm equipment, livestock, or other productive assets that leverage improved access to transport and water resources resulting from the roads program. Roads programs will ideally support sustained, long-term improvement in rural livelihoods.
- *Road development also boosts the development of local business.* Roadside stalls, bars, and hairdressers often benefit immediately, but businesses that support local livelihoods also tend to emerge over time. The initial boost to the local economy eventually supports new businesses such as hardware shops, repairers, agro-vet dealers, storage facilities, financial services, transport service providers, and others (photo 15.1). This second wave of development often depends on building a critical mass of economic activity locally. In Ethiopia, one study found that 77 percent of businesses emerged only after road development (Nega and Hussein 2016). Roads programs can further invest in local production and services by systematically sourcing through local businesses, by stimulating local value chains, and by promoting more business development in areas made newly accessible by roads.
- *Road development can change the physical environment for the better.* A survey of 162 households living within 2.5 kilometers of a road in Tigray, Ethiopia, found that 49 percent complained that the dust affected health and crop production (see the section titled "Objective" in chapter 12); 41 percent complained that floods from the roads affected their houses and cropland, 34 percent had witnessed erosion, 21 percent had seen some sediment deposits in their land, and 9 percent complained of waterlogging in some sections along the road. Environmental impacts of roads are thus significant

PHOTO 15.1

Roadside service providers in Kenya

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

and should be systematically harnessed to benefit communities. Demenge et al. (2015) list many positive impacts of roads, including “improved physical assets (road, irrigated land, new land under cultivation, ponds); livelihoods diversification (sale of water, commercial agriculture, raising fish, increased demand for labor); reduced vulnerability (seasonal water availability reduced, climate change resilience); and saved time in transport/travelling/irrigation/chores” (Demenge et al. 2015, 176).

In service of these ambitions, much of the community engagement work for Green Roads focuses on solving day-to-day problems. Community engagement can help identify where to locate farm ponds so that farmers may access water more easily and uncover means for communities to maintain such assets. Community engagement should address local concerns, such as identifying water and landscape management challenges, asking whether transport services meet community needs, and detecting road safety concerns. Community consultation can help identify the roads program’s goals. Not every community is interested in labor-based road works, but such programs should be considered where there is a surplus of ready labor or where road works can be completed in the local slow season.

COMMUNITY ENGAGEMENT METHODS

To make full use of the opportunities of Green Roads, road agencies should include community engagement in all stages of road development, including conceptualization, design, implementation, and aftercare (figure 15.1). To make use of the potential for roads as development vectors, community engagement

FIGURE 15.1

Different stages in community engagement

Source: MetaMeta (www.roadsforwater.com).

should not be limited to the finalization of road infrastructure but should also look toward enhanced connectivity and road use, the economic development roads can trigger, and the beneficial use of roads for water and other environmental functions (box 15.2). If performed well, community engagement will also enhance local ownership and create an interface between the road-implementing organizations and the people living in the area where the work takes place, including through their representative organizations. At present, such positive partnerships do not occur in many instances, leading to discontent; disputes and litigation over land, labor, and compensation; and frustration about the collateral damage caused by road development. This conflict slows down work and adds to costs, and opportunities to align with local knowledge and priorities are missed.

General guidance

Community engagement should be approached thoughtfully and cautiously, avoiding a number of misconceptions. The first misconception is that community engagement is a "good" without clarity about the objectives, mechanisms, and rules of engagement. Community engagement should be well thought through and planned—similar to how engineering works are planned. Engagement should include clear programs for facilitators and experts. Without specific objectives, there is a significant risk that the conversation will shift to unrelated topics or expectations will be raised that the road agency might undertake actions that it could not realistically carry out. When the conversation

BOX 15.2

Roads and green development corridors

Community engagement is essential to making full use of the opportunities of road development for beneficial road-water management and for optimizing the impact of roads on the access to services, creation of labor opportunities, development of local skills, and boosting of local economies.

One goal of community engagement is to optimize the scope for local initiative and entrepreneurship around the development of Green Roads. Thoughtful community involvement should be undertaken throughout the different stages of road development and maintenance, and stereotype assumptions based on the composition of communities should be avoided.

meanders too much, community members may feel the process is not effective or may not understand its goals.

The second misconception is that local contributions in labor, land, or in kind automatically create "ownership" that ensures sustainability of the infrastructure. Merely participating in a program designed and directed by others does not create local ownership. Rather, ownership is better generated by actions that shift some organizing power to the communities or make resources available to support local initiatives. For instance, road agencies can work directly with communities to codevelop opportunities in local employment, economic development, climate resilience, and water management. Opportunities to engage communities and develop joint programs around roads are plentiful, and community engagement should not be limited to physical contributions.

A third pitfall is to assume "the community" exists. It is important to be aware of the diversity among the people concerned, their cultural practices and inhibitions, the imbalances in power and access between them, and their diverse interests and needs. Such an awareness can help avoid "engaging with the wrong people" in a manner that overlooks the needs of others or, at worst, unwittingly becoming a force for exclusion or repression.

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. An understanding of these community dynamics is essential to ensuring that community engagement is effective. 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.

Community engagement methods

Several different methods can be used to improve understanding of the social relations in the community and people's perceptions. Box 15.3 describes the well-being method. This method focuses on understanding the opportunities and issues from the life priorities of the persons directly concerned. A related technique is participatory rural appraisal, which engages group discussion

BOX 15.3

Well-being method: How to develop a connection between the interviewed person and the interviewer

Step 1: Common human interest

The first stage concerns the establishment of common human interest. As humans, a few areas touch us all deeply, whatever our background: our health, our autonomy and security, and the future of our children. Sharing and discussing our experiences in relation to these issues is one way to establish a personal connection. Some questions that can be asked at this stage include the following:

- How is your health, and what are your concerns?
- How do you see the life and future of your children?
- Do you feel safe and secure?
- Can you manage with your income?
- How do you feel from day to day?
- What risks do you see for your family?

Not all questions need to be asked; what is important is the natural flow of the conversation and the understanding that is jointly developing. It is good to have this conversation as equals and to exchange experiences, with the interviewer or visitor's comparing his or her own life with that of the interviewee and also encouraging mutual questions. This step establishes a human connection and triggers thinking about what is important for one's self and the choices one is making.

Step 2: Reflections

Following the common human interest stage, more reflective questions can be asked. These questions encourage light analysis of the interviewee's situation and that of others and provide mutual and often unexpected holistic insight. Examples of such reflective questions include the following:

- How are things done?
- How do people help each other?
- How is your relationship with members of your family?
- How is your relationship with your neighbors?
- How do you look at things in your life; how do you look at others; how do you look at yourself?
- What are your roles, and are you content with them?
- Would you say that people help each other?
- Do you think things will be different in the future?

The interviewer can also ask for examples and relate to what is in the house or immediate environment to illustrate the points. What is important is to listen empathetically to what is being said, which will often generate new perspectives and understandings of priorities. It will help the interviewer understand what is driving the interviewee, how decisions are made, and what boundary constraints exist.

Step 3: Thematic discussions

From these two stages, the interviewer can move to topics that originally triggered the learning visit (for example, a road construction program, mobility and access, and environmental concerns) and that the interviewer wants to understand better. These topics can be raised in a conversational way to see how they relate to the person's well-being. By this time there should be a good, deep understanding of each other's lives, and the thematic questions can relate to these interests. It is best to use a checklist that the interviewer has memorized or can quickly glance at.

around mapping, preparation of timelines, transect walks, and priority setting. Appendix A describes the participatory rural appraisal technique.

Community engagement process

Community engagement should ideally take place in the various stages of road development and should cover its wider ramifications: the development of infrastructure, its usage and transport functions, promotion of related economic opportunities and services, and development of Green Roads for Water.

The type of engagement changes with the different stages of road development. The decisions made in the early stage of conceptualizing and planning concern where to build the road, the specifications, and the contractual arrangements. At this stage, the road agency must interact with the local government and representative interest groups, such as associations of traders, transporters, or farmers. Decisions will focus on the impact of the road alignment and the main specifications of these groups' needs. For instance, in a lowland area, the community may have particular interests that could help the road agency decide between construction of a low embankment road with a designated spillover versus a high embankment road. Or stakeholders may be concerned about optimizing water management in extremely flat terrain (see box 15.4). The conceptualization stage is also the time to discuss the interconnections with transport and the development of economic opportunities, such as measures to stimulate local business as part of road development or the designation of road reserves and land for economic activities along the road. Agro-processing and aggregating centers are one such example. The increased value of such designated lands can make an important contribution to the economic viability of the road.

BOX 15.4

Using modeling to plan the road network in coastal areas in Bangladesh

The road agency, local government, and key stakeholders worked together to plan the future of a polder. The first step in this exercise was to map the polder's current road network and the likely future road network. The mapping exercise and community discussions identified a large number of bottlenecks where existing roads impeded drainage, substantially harming farm production and contributing to the spread of vector-borne diseases. The drainage patterns could be traced with the help of a detailed digital elevation model. The juxtaposition of drainage and the current and future road network helped to (a) locate the most important cross-drainage works (bridges and culverts) and define the required bed sills; (b) calculate the amount of water that could be stored in the lower part of the polder with the help of road embankments; (c) identify the higher- and lower-lying areas of the polder, and explore the possibility of placing the road on the boundary lines so as to compartmentalize the areas and improve dry-season water control using gated culverts and pipes; and (d) identify the more flood-prone areas that could experience flood relief from development of roads at higher elevations. These models were constructed with inputs from various local stakeholders and then were discussed so as to become part of district infrastructure plans.

Source: MetaMeta (www.roadsforwater.com) and Bangladesh University of Engineering and Technology (https://roadsforwater.org/wp-content /uploads/2018/09/FInal-Draft-poster-Nepal-workshop.pdf).

After the planning stage, more specific details about the design of the road will be put in place (Airey and Wattam 1998). At this stage, representative groups and local government may still play a role, but structured discussions with roadside communities will be important, too. Such discussions need to have an official character, with the persons speaking mandated to do so and the results of the discussion recorded. The nature of the consultation should be clarified, specifically, whether it is informational, binding, or something in between. Community expectations regarding what suggestions are practical to follow up on and what recommendations cannot be accommodated must be managed.

Engaging local communities in these early stages of road development will add considerable value to the later stages. The road agency will gain a detailed understanding of the geographic terrain and local priorities. This information will set the stage for implementation through land release, work arrangements, and sourcing of building materials, such as planning the location of borrow pits with an eye to their later reuse as water storage (chapter 8). This is also the time to discuss and agree on roadside tree planting, including the location, species, and modalities. As much as possible, planning of complementary social, economic, and road-water management measures should be placed in the hands of those who will remain in charge of those activities after the road is developed, not just the road agency. This process requires cooperation with agricultural and water management bureaus, business promotion organizations, educational and health service providers, and transport agencies. If key players are absent, it may be possible to engage the right institutions in discussions about whether they could step up their engagement. For road-water management measures, this is also the stage at which to discuss operation and ownership of the additional water resources, for example, determining to whom the water will be distributed and how facilities such as gated culverts, roadside dams, or overflow structures will be operated and maintained. Discussion with agricultural cooperatives and agricultural bureaus may help ensure the roads program and other programs complement each other productively.

The next stage is implementation. This stage offers considerable opportunities for local employment, skills development, and business development. Paved roads may be constructed by young contractors, as was done in Ethiopia. Groups of university graduates were supported with training, credit, and access to heavy equipment, and took on local road-building contracts. This activity helped build capacity in the construction industry locally and nationally. For unpaved roads, the work can be allocated to local contracting groups, as was done with the Labor Contracting Societies in Bangladesh (see the section titled “Examples of Community Engagement at Scale”). The quality of work and entrepreneurship of these groups has often been remarkable, particularly because they were formed mainly of landless and marginal labor living below the poverty line. The engagement of such groups in basic road building has had an enormous impact on poverty alleviation, encouraging group members to use their earnings to acquire productive assets. Road construction also provides other economic opportunities, such as operation of community borrow pits and quarries and development of support services to the road construction companies and workers (shops, restaurants, and so on). The money spent in the local economy can boost further economic activity. At this stage, additional road-water management measures can be implemented, either individually or as part of community efforts, such as the mass mobilization campaigns in Ethiopia.

Aftercare of roads is the final stage. In this stage, the road agency again interacts with local groups, nongovernmental organizations, local government, agricultural bureaus, and possibly special interest groups, such as transporter organizations. After the roads are constructed, more road-water management measures can be developed based on emerging needs and opportunities. This is also the stage at which effort must focus on maximizing the economic impact of roads by promoting transport services and facilitating business opportunities through the development of local value chains. For instance, improved processing and marketing of produce may help boost livelihoods of local producers. Table 15.2 provides a snapshot of the opportunities and the interstices for community engagement in different stages of road development and in the different areas of impact. The next section discusses a few programs in which community engagement in road development was undertaken on a large scale.

As has been mentioned throughout these guidelines, the maintenance of unpaved roads is a critical challenge because funding levels are almost always inadequate. Coordination of road maintenance and road-water management activities can help narrow the gap between road maintenance needs and funding levels. Approaches include creating road maintenance groups (RMGs) to undertake maintenance (as in Nepal, see the section titled "Nepal: Involving Road Maintenance Groups in Mountain Road Maintenance"), or individuals maintaining designated road sections and the water-harvesting opportunities contained therein.

EXAMPLES OF COMMUNITY ENGAGEMENT AT SCALE

Community engagement is often organized on a project basis but can easily reach scale as part of a national system. This section discusses three examples of nationwide systems for community engagement in road development and maintenance: the roads-for-water activities in Ethiopia, which are part of a large watershed movement; the engagement with labor contracting societies (LCSs) in road development in Bangladesh; and road maintenance groups in Nepal.

Ethiopia: Implementing roads-for-water activities at scale

Soil and water conservation programs have been in place for many years in Ethiopia. Road-water harvesting has been included in the repertoire of measures considered in local planning processes since 2014.

Soil and water conservation "watershed" programs have been in place in Ethiopia even longer, since the 1990s. Several techniques were introduced over the years, including afforestation, gully control, and stone bunds. The earlier programs were often associated with food-for-work programs, and the main purpose was sometimes the creation of work opportunities rather than to build lasting productive land and water assets. The geographic coverage was substantial, however. The central focus was to reduce erosion by trapping and retaining sediment. Despite the scale and effort, results were often unsatisfactory because of a lack of effective community engagement and a limited sense of responsibility for the newly created assets.

The program was thoroughly revived and reoriented in 2007. Particularly from 2009 onward, a new thrust in soil and water conservation was introduced in different regions in Ethiopia. The new impetus had several elements.

TABLE 15.2 How to engage communities in road development

STAGE OF ROAD DEVELOPMENT	COMMUNITY ENGAGEMENT	INFRASTRUCTURE FEATURES	INFRASTRUCTURE USAGE	RELATED ECONOMIC OPPORTUNITIES	RELATED ENVIRONMENTAL SERVICES
Conceptualization and planning	Local government Representative interest groups Stakeholder dialogue	Road alignment selection Decisions on type of contract and construction method	Choice of supporting transport measures	Choice of type of economic opportunities to promote Decisions on use of road reserves Special economic zones	Major choices on multifunctionality Road alignment to optimize environmental functions specific to local opportunities
Design and preparation	Community discussion Local government Participatory methods Consultation with other parties	Design of roads and water crossings and additional measures Freeing up land for road and road reserves Community contracts Agreement on interface in participation	Design to accommodate specific transport	Freeing up land for side activities Roadside tree planting concessions	Identification of measures and locations for road-water management Consultation on location of road drainage structures Consultation on location of water-harvesting structures and borrow pits
Construction of road and water infrastructure	Community groups Local government Participatory methods	Community road construction groups Start-up contractors Community contributions in land and labor Complaint-handling mechanisms	n.a.	Community concessions "Start-up" contractors Training in income-generating activities Additional provisions	Community and individual development of roadside water management infrastructure
Maintenance and continuing care	Community groups Local government	Community road maintenance groups or contracting societies	Community road safety measures	Roadside tree planting	Maintenance and rebuilding of water structures assigned to individuals as part of their responsibility

Source: MetaMeta, (www.roadsforwater.org).
Note: n.a. = not applicable.

First, soil and water conservation would focus on both cultivated and uncultivated land. The farmers who farm the land should primarily conserve the cultivated land, and watersheds should be conserved by public mobilization. Compared with the more scattered intervention in earlier years, the new approach helped create a density of interventions that ensured a systemic change in the landscape. Second, in addition to erosion control, the new approach placed more emphasis on harvesting water and retaining moisture. In practice, this meant using several new techniques. For instance, in low-rainfall zones infiltration ditches were added to the stone bunds so that more water was used for recharge, and storage ponds were added to the trench measures.

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

The amount of work that can be done this way is enormous. In contrast to earlier initiatives, the program was very popular (photo 15.2). The starting point was local planning, and the results were significant. The work was usually accompanied by festive events such as rallies and meetings. By concentrating on one section of a watershed at a time, and not spreading resources too thin, the program organized intensive efforts and usually produced quickly noticeable results.

In addition to the collective work, farmers also invested substantially in their own land improvement (leveling, terracing, soil improvement), and in some places developed wells. Local planning and implementation—something that was missing from earlier efforts—has been one key to the program's success. Capacity building consisted of the following:

- The regional Bureau of Agriculture provided training and planning support to the districts (*woredas*).
- Woredas provided training and support to village clusters.
- Village clusters (in coordination with woreda representatives) offered training to farmers at subcatchments.
- Local experts and farmer-leaders made a watershed plan for each watershed.
- Groups of five farmers worked together and combined their efforts in groups of 25. The location of the water storage and drainage structures was planned locally, with farmers setting out stakes

The strong, locally driven initiative was a break from the previous soil and water conservation efforts. In previous programs, people mainly participated to receive food for survival, and often were unaware of the impact that soil and water conservation activities could achieve. Implementation at scale also meant rapid environmental changes, as evidenced by the reemergence of springs, the regulation of local flows, and the growth of indigenous trees. These results fueled the

PHOTO 15.2

Community mobilization for road-water harvesting in Amhara, Ethiopia

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

program's momentum. The program led to a "success breeds success" effect as improved access to water encouraged experimentation with new crops (fruit trees) and new land management methods.

The roads-for-water activities were implemented in Tigray beginning in 2014 and spread to other states in Ethiopia beginning in 2015 (in particular, the states of Amhara, Oromia, and Southern Nations, Nationalities, and People's Region). The measures consisted of floodwater spreaders from road surfaces, flow dividers at culverts, infiltration trenches parallel to or perpendicular to road alignments, and storage ponds and recharge ponds supplied by the runoff guided by road bodies. These measures quickly gained in popularity and, beginning in 2016, accounted for 25 percent of all the measures undertaken under the watershed campaigns. About 1,670,000 people were involved in the campaigns from 2016–2018. Based on a full 40-day engagement per person (Yaron 2018), this is equivalent to mobilizing 66.8 million labor days.

Bangladesh: Labor contracting societies working on road development

Labor contracting societies (LCSs) were developed in Bangladesh in the 1980s. LCSs were intended to create labor opportunities for landless and marginal farmers (owning less than 0.2 hectares) in the construction and maintenance of small infrastructure. To facilitate this form of community engagement, the

Public Procurement Act, 2008, and Public Procurement Rule, 2008, endorsed "direct contracts" with LCSs. The concept is to bypass conventional works-contracting methods to facilitate the involvement of local people so that low-income individuals can benefit directly from development projects. The LCSs are usually groups of 50 ultra-poor and landless farmers, either male or female, for whom this income opportunity is very important. A public procurement entity, such as the Local Government Engineering Department in the case of local roads, has a legal mandate to enter into such contracts with groups of local people to help alleviate poverty.

The LCS groups are largely self-selected and present themselves directly to the contract-issuing authority. The criteria for membership are age (18–50 years), fitness, local residence, and interest in joining the LCS. Each group has an executive committee. Remuneration is sufficient to provide an attractive opportunity for the poorest in the lean agricultural season. The work to be done under LCSs is identified by the contracting authority through a prework assessment. Next, a work order is prepared for the LCS based on the estimated volume of work. The standard rates for construction work apply as determined periodically for every region of the country. The payment to the LCS is made in the same manner as for other contractors, that is, an advance payment followed by installments. The final payment is based on a postwork assessment in which the actual volume of work is calculated. A security deposit is also taken from the LCS, which is paid back when all work under the contract has been completed. Payment is made to the bank account of the LCS, from which individual members are paid based on their contribution to the work.

Large volumes of work have been completed under several LCS programs in Bangladesh, and the LCS formula has placed money in the hands of the poor who have typically used the money to acquire household economic assets, such as cows or goats for fattening. In road building, equipment was also made available that facilitated the work and enhanced its quality, such as compact rollers and wheelbarrows.

Smooth implementation of LCS activities hinges on several factors:

- Transparent and objective selection of landless and marginal farmers as group members
- Prevention of contract capture by local contractors who then engage outside labor and mechanical equipment
- Timely issuance of work orders so that work can be comfortably undertaken outside the monsoon season or the peak season for agricultural labor demand
- Accurate prework assessments that prevent major postwork discrepancies that could lead to payment deductions, which are likely to disturb relationships among the LCS members
- Smooth handling of all payments, including the return of the security deposit

Nepal: Involving road maintenance groups in mountain road maintenance

Since about 2005, Nepal has undertaken an ambitious road-building program that raised its road coverage above the average of neighboring countries. To ensure the sustainability of these roads, which are often in very challenging terrain, RMGs were formed in several parts of the country (photo 15.3). The functioning of these groups is formalized in several guidelines. RMG activities

PHOTO 15.3

Road maintenance group using work safety measures, Nepal

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

include maintenance tasks that can be carried out by unskilled workers using basic hand tools. The main objective of the RMGs is to ensure the proper functioning of the roads and reduce damage to the roads by maintaining the road-protection measures, particularly the drainage systems and support walls. The RMGs are also responsible for routine maintenance, specifically repairing minor damage to preempt further deterioration of the road. Their activities include clearing culverts, clearing and cutting vegetation on roadsides and drainage structures, and clearing drainage ditches and landslides. They carry out specific minor maintenance aimed at creating basic road-protection structures to prevent damage to the road. Some of these activities could also include the road-water management techniques presented in previous chapters of these guidelines, such as creating side drains that divert water to farmland, building stone-paved water crossings to prevent erosion, and protecting slopes by planting vegetation.

A “length worker” system is used for the rural road network, whereby groups of workers are engaged to maintain the entire road. Rather than having one person work on a dedicated stretch of road, as is common in many countries, the RMGs can allocate their members according to need, allowing them to spend more time on road sections that present more problems. When the RMGs allocate their resources efficiently, they alleviate administrative challenges in contracting, supervision, planning, and inspection, which is particularly convenient on unpaved rural roads, where maintenance is often cumbersome. The RMG model is used for all routine road maintenance activities, but also for recurring and specific maintenance and for emergency maintenance that does not require skilled labor, specific equipment, or special materials.

An RMG's size depends on the length of road, required work input, and estimated number of person-days to be used by RMG members each year. The required number of person-days depends on the characteristics of the road (condition, topography, road surface type, traffic levels, and existing road protection structures). An example of the work norm used in Nepal is provided in table 15.3.

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

- The workers must be older than 18 years.
- Workers must be physically and mentally able to do road maintenance.
- Workers must live near the road to be maintained (to reduce travel time).
- The candidates must be unemployed or employed less than 25 percent of their time.
- The poorest and most marginalized people of the community are given priority.
- Preference is given to female candidates: the groups should comprise at least 33 percent women, but can be composed entirely of women.
- At least 40 percent of the group must be from disadvantaged groups.

Once the selection of members is finalized, the RMG is registered with the local government. The RMG should also elect group representatives, particularly a general chairperson and a treasurer. Individual bank accounts are opened for each member of the RMG for the payment of wages. The local government is responsible for payment to each member based on their monthly performance

TABLE 15.3 Example of work norms for road maintenance groups in Nepal

ROAD TYPE	APPROXIMATE INPUT LEVEL (PERSON-DAYS PER KILOMETER PER YEAR)
Tarmac road	
Road in good-to-fair condition in dry season, that is, road is passable by normal car at minimum road design speed (20 and 40 kilometers per hour for hill and the Terai region, respectively)	65
Road in poor condition in dry season, that is, road is passable by normal car only at less than road design speed (20 and 40 kilometers per hour, respectively)	104
Earthen or gravel roads	
Road in good-to-fair condition in dry season, that is, road is passable by normal car at minimum road design speed (20 and 40 kilometers per hour for hill and Terai region, respectively)	80
Road in poor condition in dry season, that is, road is passable by 4×4 bus, truck or tractor, or normal car only at less than road design speed (less than 20 and 40 kilometers per hour for hill and Terai region, respectively)	104
Road in poor condition in dry season, that is, road is only passable by 4×4 bus, truck, or tractor, and requires heavy maintenance	156

Source: DOLIDAR 2016.

and certification by the oversight team. Alternatively, a bank account is opened in the name of the RMG with at least two representatives nominated from among the RMG members, which prevents mismanagement of payments and secures timely payment.

Before the works begin, training is provided on technical issues to be addressed under the maintenance contract (what road deterioration is; how, when, and where to implement the different maintenance activities; how to do the work; what tools to use; and so on), as well as on the managerial aspects of the maintenance contract (how to work effectively, how to distribute the work activities, how to plan, how to supervise, how payments are made, what documents need to be presented).

Once the members have been trained, the RMG can sign the maintenance contract. RMGs are paid according to performance, based on the condition of the various road sections. Because it is not possible to maintain the entire section of road at one time, RMGs are expected to prepare monthly work plans to determine which road elements and on which sections of the road the performance-based system is to be applied. Frequent inspection of the work plan and work at the road is necessary to ensure the plan addresses the appropriate road segments and road conditions. Inspection forms a basis for payment to the RMGs. Inspection, supervision, and monitoring work is carried out on a weekly basis by technicians or engineers from the district development committee or district technical offices of the project or program.

District rates are used for payments to unskilled labor. There are two methods of payment: either each RMG member is paid directly into his or her personal bank account, or the RMG is paid and assumes responsibility for paying each member according to attendance. In the latter case, the local government regularly monitors payment distribution. There are also allowances for tool maintenance, safety equipment, transport, and for expenditures made by the RMGs' chairpersons, treasurers, and other officers.

CONCLUSIONS

There is considerable scope for community engagement in the introduction of the roads-for-water approach to ensure that the community is aware of the broader benefits that road development can bring. Identification of the correct community engagement methods requires careful thought and advance planning. In effective community engagement, the devil is in the operational details as much as it is in the overall remit.

Community engagement in road development must be carefully organized. In many instances, if the interface is inadequate, interactions are defined by litigation and complaints. Given the opportunities for roads to work as development vectors, including having Green Roads for Water or having roads at the center of development corridors, systematic community engagement is a must.

REFERENCES

Airey, T., and M. Wattam. 1998. "Community Participation in Road Maintenance." ASIST Bulletin No. 7, July 1998: 3–4.

Demenge, J., R. Alba, K. Welle, K. Manjur, A. Addisu, L. Mehta, and K. Woldearegay. 2015. "Multifunctional Roads: The Potential Effects of Combined Roads and Water Harvesting

Infrastructure on Livelihood and Poverty in Ethiopia." *Journal of Infrastructure Development* 7 (2): 165–80. https://doi.org/10.1177/0974930615609482.

DOLIDAR (Department of Local Infrastructure Development and Agricultural Roads). 2016. Road Maintenance Groups (RMG). https://rapnepal.com/sites/default/files/file_documents/rmg_guidelines_0.pdf.

Nega, F., and E. Hussein. 2016. *Quantifying the Road Influence Zone on Socio-Economic Development in Rural Tigray, Ethiopia*. Working Paper 03/16. Addis Ababa: The Horn Economic and Social Policy Institute. https://media.africaportal.org/documents/road_influence_zone_.pdf.

World Bank. 2017. *World Bank Environmental and Social Framework*. Washington, DC: World Bank.

Yaron, G. 2018. "Exploring the Cost-Benefit of Roads for Water in Ethiopia." Itad, Hove, United Kingdom. http://roadsforwater.org/wp-content/uploads/2019/01/GRP-CBA-Case-Study-FINAL.pdf.

APPENDIX A

Participatory Rural Appraisal

Participatory rural appraisal (PRA) techniques are social research methods used to rapidly assess community circumstances in the field. These techniques require trained facilitators and substantial investments to be effective. They aim to enhance the analysis and decision-making power of the participating community. PRAs can be used in program design, implementation, and monitoring and evaluation. The activities described in this appendix are usually carried out in small focus groups. They are best carried out in the local language with a diverse sample of the local community and without the presence of outsiders. Focus group discussions should be hosted by a combination of social scientists and sector specialists from relevant agencies (roads, water, environment, or agriculture, depending on the community's needs). This appendix describes the main methods in carrying out a PRA.

MAPPING

Community mapping (photo A.1) is used to collect information from the community about the location of resources and land uses that might not be obvious from observation alone. This process may help explain how community members view their situation and where they see opportunities and constraints. This method is more effective when undertaken in a small group, preferably representing both women and men, working to produce a large sketch map of the area in which they live. In the context of road-water harvesting, important features to be mapped include the following:

- *Main objects and topography in the landscape* such as roads, villages, churches and mosques, big trees, and rocks. These features will help the community and the practitioner to read the map.
- *Water resources.* Use different symbols to represent different types, different uses, and availability during the year. If necessary, also describe the water quality.
- *Soil moisture.* Depict the areas where soil moisture is depleted faster and where plants stay greener for longer.
- *Accessibility.* Draw all paths that people use to move around.
- *Hot spots.* Note places where there are special road issues related to water.

PHOTO A.1

Making a community map

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

TRANSECT WALK

Transect walks (photo A.2) are systematic walks through a selected area from one side to the opposite side. During the walk the field worker observes the landscape and local practices while at the same time interacting with participating community members.

A transect walk is a valuable tool because it allows community members to look at their area from an innovative point of view. The participants can stop during the walk and discuss what they are seeing around them. The participants can even decide to stop at fixed intervals (for instance, every 100 meters) to make observations. Observing the area in this way helps participants visualize processes that need to be understood to plan and implement road-water harvesting measures. During the exercise, one of the field workers will prepare a sketch of changes that could take place in different locations of the area investigated.

TIMELINE

The field worker will construct a timeline based on observations and discussions. This timeline helps create a context for how the current circumstances emerged and establishes trends that may point to future outcomes. The walk organizer can pose questions about important issues, such as the main economic activities, means of transport, population settlements, and others. Important events can be useful for creating a timeline; for instance, asking participants what the road condition was at the time of the last

PHOTO A.2

Transect walk

Source: © MetaMeta (www.roadsforwater.com). Used with the permission of MetaMeta (www.roadsforwater.com). Further permission required for reuse.

election may elicit more accurate results than asking what the road condition was two years ago. The creation of these timelines helps to develop a collective understanding of past and current trends.

RANKING

In the ranking or scoring exercise, community members are asked to list their water needs priorities. This practice simply involves asking participants to score (vote for) the different items discussed during the walk based on importance. Community concerns can be ordered according to the items that got the most (or the least) votes, which helps communities prioritize solutions and challenges.

ECO-AUDIT

Environmental Benefits Statement

The World Bank Group is committed to reducing its environmental footprint. In support of this commitment, we leverage electronic publishing options and print-on-demand technology, which is located in regional hubs worldwide. Together, these initiatives enable print runs to be lowered and shipping distances decreased, resulting in reduced paper consumption, chemical use, greenhouse gas emissions, and waste.

We follow the recommended standards for paper use set by the Green Press Initiative. The majority of our books are printed on Forest Stewardship Council (FSC)–certified paper, with nearly all containing 50–100 percent recycled content. The recycled fiber in our book paper is either unbleached or bleached using totally chlorine-free (TCF), processed chlorine–free (PCF), or enhanced elemental chlorine–free (EECF) processes.

More information about the Bank's environmental philosophy can be found at http://www.worldbank.org/corporateresponsibility.

green press INITIATIVE

Roads and water are generally seen as enemies, with water responsible for most of the damage to roads, and roads being a major cause of problems such as erosion, waterlogging, flooding, and dust storms. This tension, however, can be reversed. The concept of Green Roads for Water (also known as "Green Roads" or "roads for water") places roads in the service of water and landscape management and climate resilience without sacrificing or diminishing their transport functions. With global investment in roads of US$1–US$2 trillion per year, plus maintenance costs, the widespread adoption of Green Roads approaches can leverage investment at a transformative scale, making road development and maintenance a vital tool for achieving climate resilience, water security, and productive use of natural resources.

Green Roads for Water: Guidelines for Road Infrastructure in Support of Water Management and Climate Resilience provides strategies to use roads for beneficial water management tailored to diverse landscapes and climates, including watershed areas, semiarid climates, coastal lowlands, mountainous areas, and floodplains. The underlying premise of Green Roads is therefore quite simple: designing roads to fit their natural and anthropomorphic contexts; minimize externalities; and balance preservation of the road, water resources, landscape, and soil resources will usually cost less than traditional protective resilience approaches and will produce more sustainable overall outcomes.

Korea Green Growth Trust Fund

CIF CLIMATE INVESTMENT FUNDS

GFDRR Global Facility for Disaster Reduction and Recovery

WORLD BANK GROUP

ISBN 978-1-4648-1677-2

SKU 211677