LATIN AMERICA CONSERVATION COUNCIL

A Guide to Good Practices for **Environmentally Friendly Roads**

Juan D. Quintero

We are about to witness a rapid growth in road building, with at least 25 million kilometers of new roads built by 2050. Nine-tenths of these roads will be in developing countries—in areas that harbor some of the planet's most irreplaceable refuges for biodiversity.

The Amazon Rainforest (NASA)

Cover photo: Highway in Central Forest Spine, Malaysia

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Foreword

Henry M. Paulson, Jr.

Co-Chair, Latin America Conservation Council
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In developed parts of the world, we tend to take our roads for granted. But in Latin America, where populations and economies are growing, there is a shortage of roads to move goods and people. The countries in Latin America are responding to this shortage as are developing countries across the globe.

As this *Guide to Good Practices* describes, we are about to witness a rapid growth in road building, with at least 25 million kilometers of new roads built by 2050. Nine-tenths of these roads will be in developing countries—in areas that harbor some of the planet's most irreplaceable refuges for biodiversity. Roads boost economies, but they can also damage and destroy natural ecosystems that provide vital services for life on Earth.

As a lifelong conservationist, I care deeply about preserving our planet's wild natural beauty and biodiversity. I've also spent much of my life focused on financial issues, and I value economic growth and progress. To me, it's imperative that growth and conservation go hand-in-hand. As global citizens, we share our world's limited natural resources and have a responsibility to act as good environmental stewards.

So how should we manage this collision of environmental protection and economic needs? This *Guide* rightly concludes that clear rules are needed to first avoid, then minimize, and finally offset any unavoidable environmental impacts—in that order. While licensing and environmental impact assessment policies are in place in most Latin American countries, it is no secret that these policies are not always sufficiently clear or well applied, nor are existing tools and technologies adequately used to reduce environmental impacts.

This *Guide* is part of an effort to provide sound, science-based information and advice on building practices for road construction. It documents good practices of roads built in a thoughtful, reduced-impact way, which, unfortunately, tends to be the exception. It promotes a more holistic, life-cycle approach to addressing impacts on nature, which is needed to break from the reactive, ***ad hoc*** approach that characterizes business as usual nowadays. Surprisingly, no manual to better road building has existed; this *Guide* aims to begin to fill that gap.

In 2010 I worked with The Nature Conservancy to bring together like-minded public and private leaders to form the Latin America Conservation Council (LACC). The council is committed to bringing attention to science-based solutions for sustainable growth in Latin America and beyond. LACC members sponsored this Guide to provide a clearinghouse for approaches and technologies to build more environmentally friendly roads, with fewer impacts on nature. The LACC calls for designing "*smart infrastructure*," striving for no-net-loss of "natural capital."

This *Guide to Good Practices* ultimately is about changing behavior and making it easier for government officials, builders, and others to design and build better roads, anticipating issues upfront that can cause delays and cost overruns on the back end. Doing so should be viewed as good business as well as good for the planet—an investment now in a more sustainable future that balances development and conservation for people and nature.

Acknowledgments

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The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of the LACC members or TNC.

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Acronyms

CFS	Central Forest Spine (Malaysia)
CIA	cumulative impact assessment
EIA	environmental impact assessment
EMP	environmental management plan
ER	engineer's representative
ET	engineer team
GIS	geographic information system
IBAT	Integrated Biodiversity Assessment Tool for Business
MODIS	Moderate-resolution Imaging Spectroradiometer
MSE	mechanically stabilized earth
NPP	National Physical Plan (Malaysia)
RAC	rubberized asphalt concrete
REA	regional environmental assessment
RES®	Road Energy Systems
ROW	right-of-way
SEA	strategic environmental assessment
TBTRA	Terminal Blend Tire Rubber Asphalt
TOR	terms of reference
VEC	valued ecosystem component
VMS	variable message signs
VOC	volatile organic compound


Wildlife overpass. Photo: Thinkstock.com

Chapter 1
Introduction

Roads and Development

Infrastructure and the services it provides significantly affect national economies and people's quality of life. In today's global economy, transport infrastructure is vital for promoting trade, commerce, and investments. Transport infrastructure and services—particularly roads—play an important role in economic and social development, having such positive impacts as providing people with access to health facilities, markets, schools, and employment. Roads are essential lifelines of a country, providing connectivity and access to goods and services. In rural areas, roads are even more critical for women and children, providing increased income and access to education and health services. In Peru, rural road projects raised women's income by 14%, girls' primary school attendance by 7%, and the number of visits by women and children to health centers by 55% (IDB 2014).

The Twenty-First Century will see an unprecedented expansion of roads, with at least 25 million kilometers of new roads anticipated by 2050 (Laurance *et al*. 2014). Nine-tenths of these new roads will be in developing nations, which sustain many of the planet's most biologically rich and environmentally important ecosystems (Laurance *et al*. 2015). While roads are critical for economic development, these ecosystems and the services they provide are vital for sustaining life. Roads are key drivers of land use change and deforestation, threatening biodiversity. In Latin America and the Caribbean, commercial agriculture facilitated by transportation networks is a leading driver of deforestation (Watkins 2014). The challenge is for road development to proceed without having detrimental effects on the environment and local communities.

Globally, it is estimated that each year there is a USD 1 trillion funding shortfall for infrastructure projects. To bridge this gap, there is a strong push for sustainable development, in which economic prosperity is shared broadly and achieved without compromising natural capital. Sustainable development is meant to include and balance social, economic, and environmental (and increasingly climate change) needs and benefits (World Bank 2001). The Millennium Development Goals have acted as a tool to galvanize the efforts of the international community toward creating an enabling environment for development.

In Latin America and the Caribbean, it is estimated that investments of around 5% of gross domestic product (an amount equivalent to USD 250 billion in 2010) are required in infrastructure over a long period to close the gap between present services and projected demand (IDB 2014). As countries attempt to meet demands, there is an urgent need for everyone involved—governments, funding agencies, and the private sector—to embrace sustainability and integrate it at every step. Without this, the price of infrastructure development may be environmentally, socially, and economically very high—a price that future generations will certainly have to bear.

The best environmental practices are gaining traction worldwide in many sectors. Yet a comprehensive review of best practice guidelines for roads revealed some surprising gaps, as well as areas that are very well documented. Typically, the management of individual project activities is well documented, such as construction management or conducting environmental assessments, and an extensive literature exists on the environmental impacts of roads on wildlife. This good practices Guide (henceforth called 'the Guide') focuses on the neglected area of integrating environmental considerations throughout the project cycle—from planning to implementation and maintenance—rather than addressing the impacts in a piecemeal manner, as currently practiced. By increasing awareness of and access to these best practices, this Guide should encourage government authorities, practitioners, and industry to adopt them not as an extra burden that increases costs but as an upfront investment in minimizing unpredictable delays and conflicts—and ultimately as an investment in a sustainable future that balances development and conservation for people and nature.

The Roads Guide: What It Is and What It Is Not

The purpose of this Guide is to present an approach for incorporating environmental issues into road conception and execution to promote a new era of more environmentally friendly and subsequently sustainable road projects. The Guide looks into the issues of bridging the gap between concepts and practical implementation. It emphasizes the mainstreaming of environmental aspects throughout the project cycle from planning and design to construction, operation, and maintenance (and decommissioning)[1] and integration of the Mitigation Hierarchy. Lessons learned from both good and bad practices illustrate the complexities associated with integrating environmental considerations into road development. Although it is acknowledged that environmental and social issues are intertwined, complex social issues such as indigenous people, physical cultural resources, resettlement, gender, child labor, and so on are not addressed here. Only social issues related to environmental concerns during construction, such as noise, workers' camps, and safety, are covered.

Recognizing the broad range of different terms used in road development across the region, the Guide also aims to construct a common vocabulary of terms to facilitate dialogue across sectors. Although it focuses primarily on Latin America, examples from other regions of the world are also provided to illustrate good practices. The Guide benefits from the existing wealth of information available through publications and the professional experience of experts working on road projects globally.

The primary audiences of this Guide are individuals involved in the planning, design, construction, operation, maintenance, and decommissioning of road infrastructure, including environmental specialists. The Guide is meant to be read by government

[1] Decommissioning is generally applicable to forest roads or access roads to other infrastructure projects only.

departments such as highway department and environmental permitting agencies, by environmental practitioners and consultants, and by contractors and other organizations involved in roads development and environmental assessments. It will also be useful for stakeholders like nongovernmental organizations that are interested and involved in developing environmental friendly roads and seeking to balance development and conservation needs.

Using the Guide

The Guide is based on the project cycle. Following this introductory chapter, Chapter 2 provides an overview of basic road concepts to familiarize the reader with the standard terminology relating to road development. This includes road classification systems, road typology, the different agencies involved in road development, and the road project cycle. Chapter 3 discusses the environmental impacts associated with road development, including those in sensitive areas.

Chapter 4 details the best practices to be followed at each stage of the project cycle to integrate environmental considerations. The Mitigation Hierarchy is introduced as a concept that can be applied throughout the project cycle to avoid, minimize, rehabilitate, and compensate for environmental impacts. Chapter 5 focuses on sensitive areas. While measures described in Chapter 4 are applicable in sensitive areas, more attention needs to be paid in sensitive areas, developing site-specific solutions.

The final chapter in the Guide introduces innovative new technologies that can promote environmental sustainability. This includes environmental friendly products and construction technologies as well as software tools. Although brand names are purposefully not included, please note that the Guide does include reference to some innovative technologies developed by Latin America Conservation Council members. This is not meant as a commercial endorsement but instead is an effort to encourage the reader to stay up-to-date and consider new technologies in an ongoing fashion. The people and landscapes of Latin America deserve nothing less.

The final chapter in the Guide introduces new construction technologies, products and software tools developed with the aim to promote environmental sustainability. Although brand names are purposefully not included, please note that the Guide does include references to some products and technologies developed by Latin America Conservation Council members. This is an effort to encourage the reader to stay up-to-date and consider new technologies in an ongoing fashion, mitigate the environmental impact of projects and foster conservation benefits. The people and landscapes of Latin America deserve nothing less.


Freeways || highways
Arterials
major
minor
rural
urban
Collectors
Local roads
low volume
paved
unpaved

Chapter 2
Basic Road Concepts

Road Classification

Some countries classify roads as urban or rural; others classify them according to the administrative jurisdiction or the number of vehicles/day, speeds, topography or terrain crossed, number of lanes, restricted access, connectivity, and so on. However, the most common way to classify a road system is according to its functions and capabilities.

Freeways or highways are paved dual carriageways with three or more lanes in each direction that have limited access. They provide largely uninterrupted travel, often using partial or full access control, and are designed for high speeds. Freeways do not have level crossings, intersections, traffic lights, or roundabouts. Some have collector/distributor lanes or interchanges that further reduce the number of access ramps that directly interface with the freeway.

Arterials are major through-roads that are expected to carry large volumes of traffic. They are large, divided roads that can have intersections, level crossings, traffic lights, or roundabouts. Arterials are often divided into major or minor and rural or urban. They are generally paved. **Collectors**, as the name suggests, collect traffic from local roads and distribute it to arterials. **Local roads** have the lowest speed limits and carry low volumes of traffic. In some areas, local roads may be unpaved and can be urban or rural.

Typology of Roads Works

The term "road works" includes construction of new roads, upgrading of roads, improvements to road specifications, rehabilitation of existing deteriorated roads, and maintenance on existing roads (see Table 1).

Table 1. Typology of Roads Works

Typology	Description	Typical works involved
Construction of New Roads	This involves developing road works with new alignments. It requires the acquisition of land for the entire stretch. It may include new road works, bypasses, and realignment.	Major earthworks like construction of drainages, sediment and erosion control structures, land stabilization structures, viaducts, bridges, tunnels, etc.
Upgrades of Roads	This involves changing road category (e.g., seasonal to all-weather, secondary to primary). Land acquisition may be needed in most cases.	▶ Adding new lanes (2 to 4, 4 to 6, etc.). ▶ Changing road surface (from gravel to pavement, for example). ▶ Widening intersections. ▶ Improving traffic signs, shoulders, and drainages.
Improvements	This involves works to improve the road specifications. Most of the work is done on the existing platform or right-of-way (ROW). Additional land acquisition may be needed in specific locations.	▶ Widening lanes and shoulders. ▶ Adding extra lanes in steep inclines. ▶ Improving curves and the vertical and/or horizontal alignment. ▶ Strengthening bridges. ▶ Improving traffic signs, shoulders, and drainages.
Rehabilitation	This involves works on existing deteriorated roads to bring them to previous/original conditions. All the work is done on the existing platform/right-of-way. No additional land acquisition is needed.	▶ Improving drainage, slopes, embankments, and other structures. ▶ Strengthening pavements. ▶ Complete resurfacing. ▶ Recuperating civil works. ▶ Improving traffic signs and shoulders.
Maintenance	This involves works on existing roads to maintain the road conditions. All the work is done on the existing platform/right-of-way.	▶ Routine works such as patching potholes or clearing drains conducted regularly. ▶ Periodic works such as resurfacing, line-marking, bridge maintenance. ▶ Special works such as repairing landslides and washouts.

Agencies Involved

A number of agencies and actors are involved—from road planning to operations. These agencies range from the national level to provincial and district authorities, depending upon the type of roads. The role of the key actors is presented in Table 2.

Table 2. Key Actors Involved in the Road Development Process

Actor	Role	Role in Developing Environmentally Friendly Roads
Planning Agency/Sector Ministry	Establishes national priority and criteria for the selection of road networks and corridors.	Carrying out strategic environmental assessments (SEAs) and considering them while planning development objectives.
Road Agency	Selects the alignment, defines specifications for the road, designs the road.	Ensuring avoidance of sensitive areas and applying the Mitigation Hierarchy to minimize impacts, carrying out fragmentation analysis.
Land Use Planning Agency and Agencies Such as Environmental Agencies, Regional Authorities	Carries out land use planning, develops natural resource plans.	Identifying “no-go areas” and areas that require protection and special consideration.
Environmental Agency	Requests environmental impact assessment (EIA) and terms of reference (ToRs) for EIA; issues environmental licenses for the project.	Requesting an analysis of alternatives, considering trade-offs for environmental issues; monitoring compliance with the requirements of the environmental licenses.
Designer	Designs the road based on input from engineers, environmental and social specialists, and other experts.	Ensuring mitigation measures are included in the design.
Environmental Specialist	Conducts EIA, analyses impacts, provides guidance for the design.	Ensuring the Mitigation Hierarchy is incorporated in the project; identifying mitigation and compensation measures.
Contractor	Builds the road based on the engineering design.	Applying best practices and technologies during construction; implementing the environmental management plan.
Supervision Engineer	Carries out the quality control of the construction, monitors it, and supervises the contractor during construction.	Ensuring all mitigation measures are followed and impacts from construction activities are mitigated.
Lending Agency	Maintains oversight.	Ensuring that compliance with environmental safeguards and project cost includes all mitigation and compensation measures.

Road Project Cycle

There are five main stages in the implementation of a road project: planning, pre-design, final design, construction, operation and maintenance as described in this section (see Table 3 for a summary of the key activities). In some cases, there is a decommissioning stage as well. Chapter 4 discusses in detail the best ways to incorporate environmental considerations at each stage.

Planning

The planning process includes the establishment of road policies at national, regional, or local levels; the evaluation of transportation needs; analysis of route vulnerability to natural disasters; and technical, economic, environmental, and financial feasibility analysis. Transport planning takes into account the different transportation modalities and defines the need for roads, establishing the priorities, objectives, and strategy for the road sector. At this stage, the corridor with the least impact is selected.

Pre-Design

At the pre-design stage, even though critical decisions that will affect the environment and surrounding communities have already been made, other important decisions will have to be made to identify the best road alternative within the least-impact corridor. The product at this stage generally includes a description of the proposed project's location and major design features, its potential socio-environmental negative impacts, and a rough description of the measures to be taken to avoid, minimize, and mitigate those impacts or to enhance positive ones. The economic analysis usually takes place in this phase.

Final Design

Once the preferred alternative has been selected, the project moves into the design stage. The product of this stage is a complete set of executive plans, technical specifications for each project component, costs estimates, and the quantities of materials that will be needed during the project's construction. Usually only minor changes to the original project developed during the planning and pre-design stages occur.

Construction

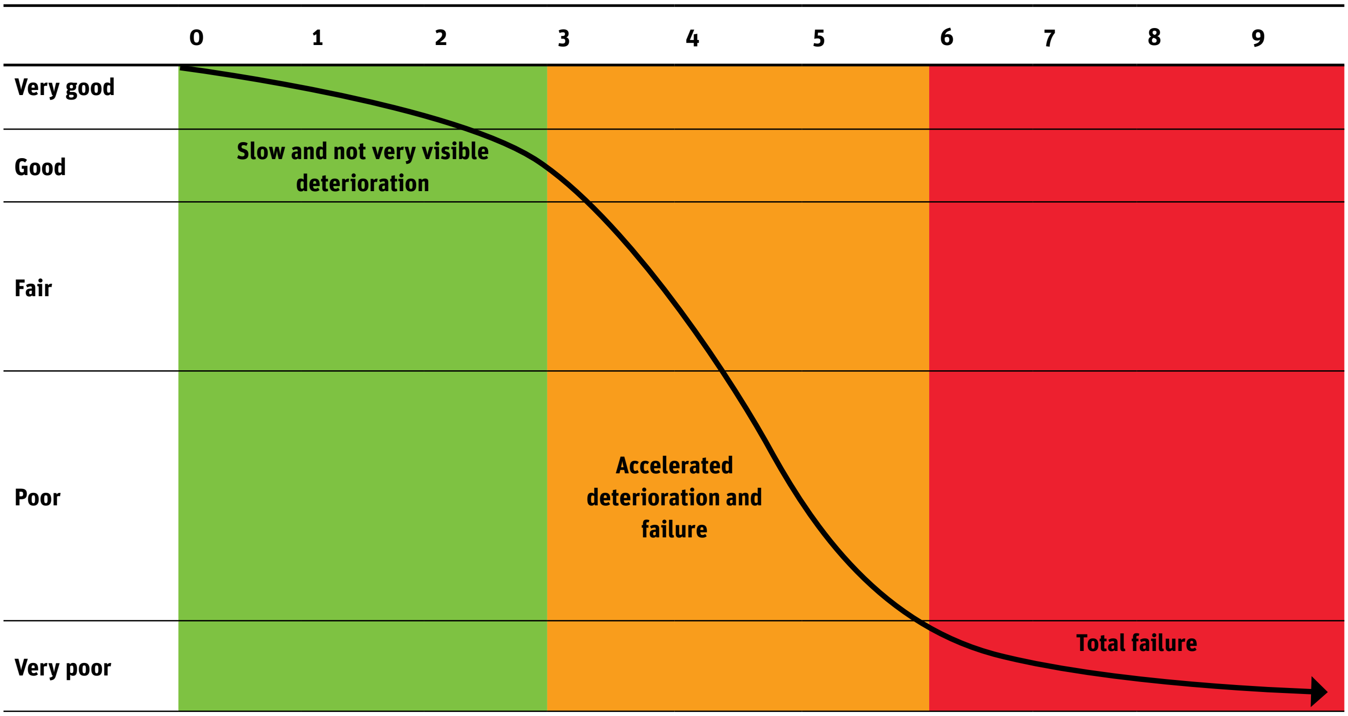
Once the final designs have been completed, construction bid packages are prepared, the bidding process takes place, a contractor is selected, and construction is initiated. In this phase, some adjustments in the design may be necessary (especially when there is a long time between the end of the design phase and the selection of the contractor). Therefore, the continuous involvement of the design team and environmental experts throughout this stage is essential. Construction may be simple or complex and may require a few months to several years. Once construction is completed, the road moves to the operation and maintenance phase.

Operation and Maintenance

During operation, it is necessary to ensure that traffic is moving smoothly and that the road provides the type and service levels desired. Maintenance, divided into routine and periodic, involves works to preserve the road in its original service-level conditions. Postponing road maintenance can result in rapid deterioration of the road and its eventual failure as well as in high direct and indirect costs and an increase in accidents. If road defects are repaired promptly, the cost is usually modest.

Road deterioration is slow at first, practically invisible, and mostly limited to its wear and tear and to minor damages to the pavement and the drainage system (see phase A in Figure 1). If maintenance is not carried out, the road tends to deteriorate faster and its base and foundations can be compromised (phase B). Once the road condition has become very poor, its deterioration tends to decrease as traffic levels drop severely and because there is little left to deteriorate (phase C) (World Bank 2008a).

Figure 1. Road Condition Over Time



Source: World Bank 2008a.

Road maintenance can be divided in three categories:

- ***Routine maintenance:*** Works undertaken each year, such as verge cutting and culvert cleaning, patching holes, etc.
- ***Periodic maintenance:*** Activities undertaken at intervals of several years (usually three to five) to preserve the structural integrity of the road or to enable it to carry increased axle loadings; works include resurfacing, line marking, overlay, and pavement reconstruction (patching and batching).
- ***Special maintenance works:*** Activities that cannot be estimated with any certainty in advance, including, among others, emergency works to repair landslides and washouts that result in the road being cut or made impassable; winter maintenance works of snow removal or salting are also included under this heading.

Decommissioning

Road decommissioning is carried out only for forest roads and access roads constructed for other projects. It encompasses activities that result in the stabilization of unneeded roads and their restoration to a more natural state. It consists of blocking the entrance to the road, revegetation, removing bridges, removing fills and cuts, establishing drainage ways and removing unstable shoulders, and full obliteration recontouring and restoring natural slopes. Road decommissioning is useful for reducing chronic sediment delivery, restoring hillslope hydrology, and reducing impacts to aquatic, riparian, and terrestrial ecosystems of roads crossings (Napper undated).

Table 3. Summary of the Different Stages of the Road Project Cycle

Stage	Description of Activity
Planning	National, regional, and local governments identify transportation needs and programs to be built within financial constraints.
Pre-Design	The road project is more clearly defined. Alternative locations and design features are developed and the alignment is selected.
Design	The final design is prepared, focusing on minimizing and avoiding environmental impacts.
Construction	Bidding documents are prepared and the contractor is selected.
Operation and Maintenance	Works to allow safe vehicular movement and maintain the road in working condition.
Decommissioning	Restoration of the environment around an unneeded road to a more natural state.

Typical Road Construction Sequence

The construction of a road generally follows a pre-established sequence. However, this sequence may vary according to the characteristics of each road project and the country where it is developed. Each stage has different environmental and social impacts, which should be minimized or avoided from the start of construction. A typical sequence involves the following steps: pre-construction, surveying and stalking, clearing and grubbing, constructing access roads, removing obstructions, excavating, sub-grading and grading, paving, re-vegetating and restorating disturbed areas, and equipment for traffic control. A summary of the road sequence and related construction activities and environmental activities is presented in Appendix 1 (Quintero 2012a).

Chapter 3
Environmental Impacts of Road Infrastructure

Road development can affect terrestrial and aquatic ecosystems in a number of ways. Typical impacts to the wildlife and surrounding environment include habitat fragmentation and modification, restriction of animal movements, injury and mortality of wildlife species, soil erosion and hydrological alterations, environmental contamination, and human colonization-induced disturbances (Rajvanshi *et al.* 2001). Impacts on wildlife and ecosystems are more pronounced in sensitive areas.

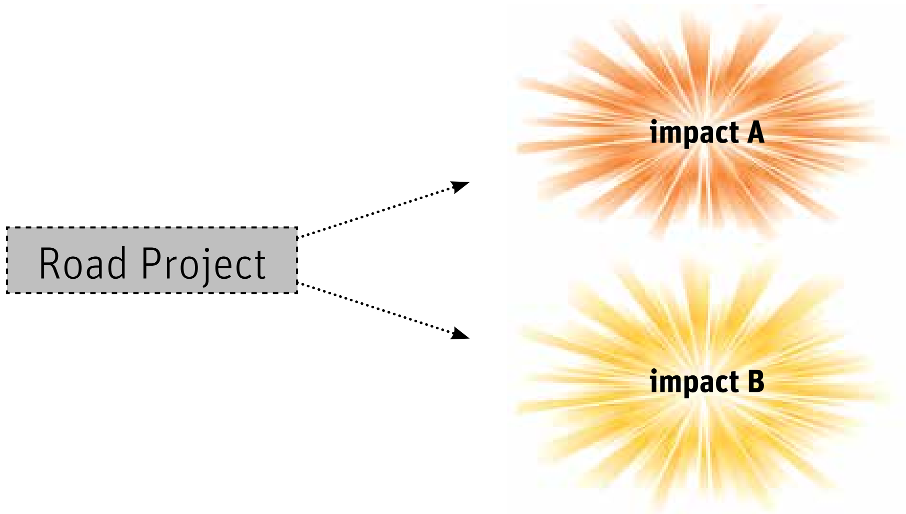
It is estimated that highways can require more than 10 hectares (ha) of land per kilometer of road. As a large part of that surface is metaled/sealed, it is lost as a natural habitat. Though provincial and local roads occupy less area per kilometer, they account for a major part of the total road network, so the combined effect of road construction on natural habitats can be substantial (Seiler and Folkeson 2006). While land taken for road construction is tangible, the influence of the road itself on the surrounding wildlife, vegetation, hydrology, and landscape is difficult to estimate but can be significant, contributing more to the overall loss and degradation of habitat than the road itself.

The impacts can be categorized into three broad categories: direct, indirect, and cumulative.

Direct Impacts

The direct impacts are the primary effects of activities associated with road construction and operation. They are usually easy to anticipate due to the straightforward cause-and-effect relationship with the road works (Rajvanshi *et al.* 2001) (see Figure 2).

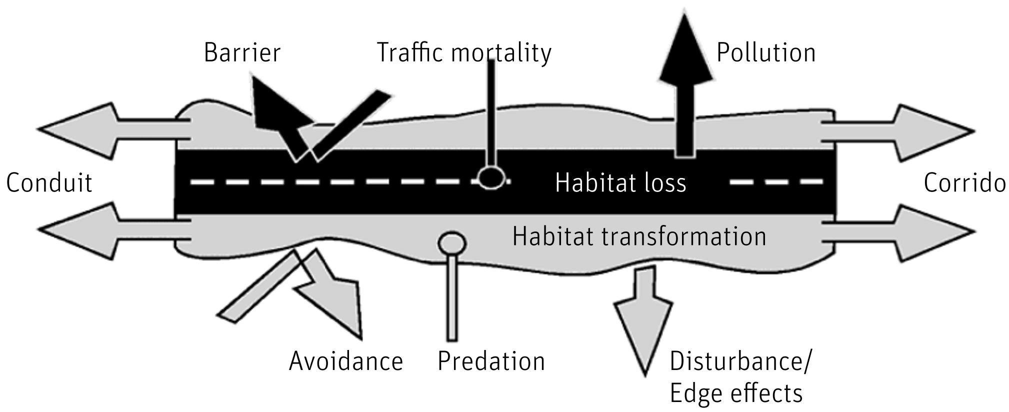
Figure 2. Direct Impact from Road Development



Direct effects on wildlife include roads acting as barriers due to the presence of bare road surfaces, alteration of roadside habitats, and the creation a variety of emissions and disturbances such as noise, dust, headlight illumination, and pollutants in the soil and vegetation (Rajvanshi *et al*. 2001). The natural movement of animals (to forage, find mates, seek shelter, reach breeding sites, and participate in social interactions) gets restricted, and many animals prefer to avoid roads (see Figure 3).

To Note: Wide highways with high volumes of traffic create the highest levels of direct ecological disturbance and present the greatest barriers to wildlife.

Figure 3. Direct Ecological Effects of Roads on Wildlife



Source: Seiler 2001.

Pollution levels are typically high during construction. Noise from construction equipment and traffic noise during operation influences animal behavior, altering activity patterns, and it can increase heart rate and stress. Higher concentration of heavy metals as well as petroleum and other products close to the road edges brings about changes to the local biodiversity and can influence animal behavior. For example, increased concentrations of some pollutants like salt (used to prevent road-freezing) near roadsides can attract large mammals, increasing the risk of vehicular collision (Trombulak and Frissell 2000).

Mortality due to vehicular collisions is well documented. Animal-vehicle collision, which is also a traffic safety issue, occurs frequently when the road network blocks animal migration routes or access to food or water (biological corridors). Animals that are attracted to roads or that need to cross them are more vulnerable. Such species include, among others, reptiles that are drawn to sun-warmed asphalt, roadside grazers such as deer, predators looking for food, and migrating amphibians (Trombulak and Frissell 2000; Rajvanshi *et al*. 2001). Though the number of wildlife individuals killed due to road-related casualties may be few in an absolute sense, roadkills can lead to local population extinctions and affect the population dynamics for threatened or endangered species. The number of collisions generally increases with traffic intensity, animal activity, and such factors as day and time of the year, drivers awareness, and integration of the road into the landscape (Seiler and Folkeson 2006). Bird casualties can also be significant. Roads close to or crossing wetlands can result in a high density and diversity of birds being forced to fly across roads, thus increasing the risk of mortality due to traffic accidents. At the same time, large birds such as raptors and owls are attracted to the grassy road verges to prey on the small mammal and songbird populations that concentrate there (Iuell *et al*. 2003).

Poor construction practices can lead to impacts such as erosion, sedimentation, and alteration of drainage patterns (see Box 1). Removal of vegetation or gravel material from borrow pits is also a direct effect of road construction.

Box 1. Erosion and Sedimentation

A severe direct effect of road construction is erosion and sedimentation, as often vegetation is removed, natural drainage pathways are altered, and stable topsoil aggregates are stripped away as part of the grading process. Construction activities can cause and accelerate erosion by exposing large areas of soil to rain and running water. If runoff is not properly controlled and treated, it can lead to sedimentation of nearby watercourses and degradation of fish and wildlife habitat. Climate, soil type, topography, and vegetation all influence the extent of erosion. Slope stability can be upset by the creation of road cuts or embankments. Excessive steepness of cut slopes, deficiency of drainage, modification of water flows, and excessive slope loading can result in landslides. The cost of addressing impacts of erosion and sedimentation once they have occurred can be quite significant (GGHACA 2006).

Unstable slopes leading to erosion and landslides

Indirect Impacts

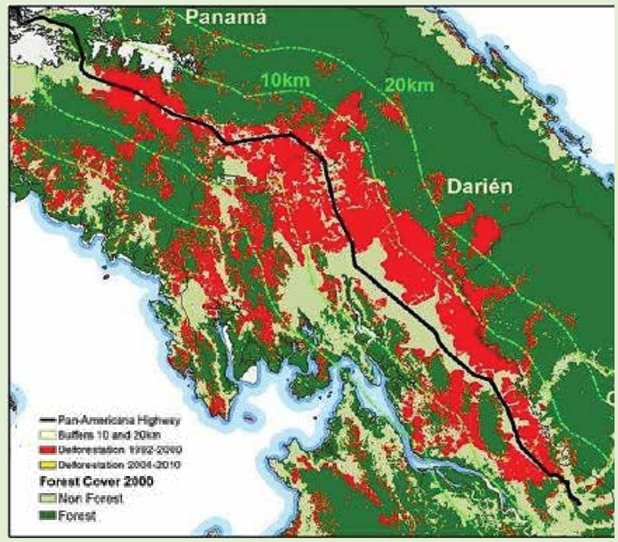
Indirect impacts are usually a result of human activities associated with infrastructure construction or improvement (Ledec and Posas 2003). They are the consequences of direct impacts (see Figure 4). Illegal collection of natural resources, land use changes that may lead to habitat degradation or even destruction, and downstream hydrological effects are typical indirect impacts that can have significant consequences for the surrounding environment and ecosystems. Illegal collection of natural resources, including illegal logging and poaching, can lead to species decline. Further expansion of roads in and around natural habitats is likely to increase linking areas that were once inaccessible to market networks.

To Note: Indirect impacts tend to be both more serious and more difficult to control and measure than direct impacts.

Figure 4. Indirect Impacts from Road Development

Source: Walker and Johnston 1999.

Box 2. Pan-American Highway, Panamá



The Pan-American Highway is located in the Darien province of Panama at the eastern end of the country, and its length is approximately 262 km. There are more than 10 protected areas with important ecological functions located in a 30 km of buffer around the road. Habitat monitoring indicated that habitat loss is greater closest to the road and that the majority of habitat change occurred in the 1990s, directly after road construction. Deforestation from 2004 to 2011 was less than 10% of the 1990s' levels.

Between 1992 and 2000 there was an alarming loss of 7% of the total national forest cover in Panama, which is equivalent to 497,306 ha. This deforestation was localized mostly in the provinces of Panama and Darien and close to the road. The impacts occurred mainly in the direct influence area of the road (0–10 km). The Darien province lost 24% of its forests, and Panama lost 23%. Most of this deforestation occurred in mixed native forest in order to create new cropland areas.

Source: Argote *et al.* 2012.

In addition, construction and maintenance activities can alter downstream hydrological processes and geomorphologic conditions. For example, road construction may involve channel relocation, the obstruction of wetland (affecting flood prevention), and construction of embankments, drains, cuts, and fills that can negatively influence local hydrology. Poorly planned activities can lead to erosion and sedimentation in water bodies. Further, erosion impacts of roads facilitate gully development below their drainage structures (e.g., culverts, water bars, rolling dips) and eventually lead to channel extension, diversion of existing stream channels, and the increase of drainage density (Quintero 2012b). These impacts can, over time, damage the natural aquatic conditions, affecting aquatic species reproduction, life span of downstream infrastructure (e.g., reservoirs and bridges), and change water supply systems relying on ecosystems of natural habitats (Elliot, Foltz, and Luce 1997).

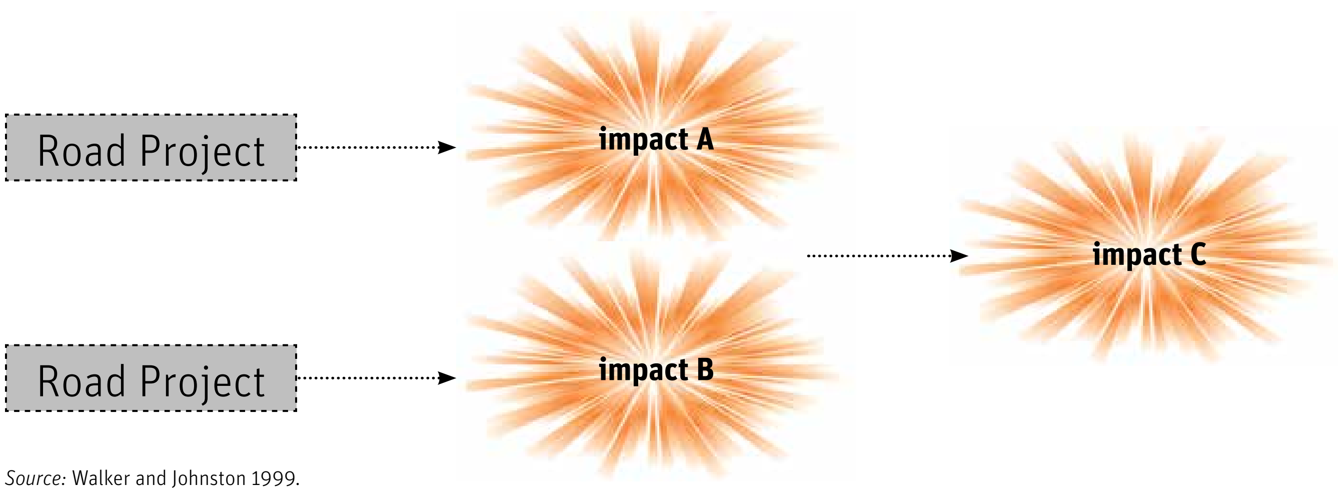
Road development often accelerates land use changes, resulting in permanent habitat loss (see Box 2). Natural habitats may be transformed into areas for agriculture, mining, aquaculture, human settlement, and other industrial purposes as roads improve opportunities for economic exploitation of resources in these areas (Quintero 2012b). It is estimated that commercial agriculture is one of the most important drivers (68%) of deforestation and that logging and timber extraction account for more than 70% of the forest degradation in Latin America and in the Caribbean (Hosonuma *et al.* 2012). Road development—particularly highway development—can inadvertently lead to increased commerce and shops near towns and rest stops, attracting large numbers of people. These areas ultimately grow into zones of urbanization (Rajvanshi *et al.* 2001).

Cumulative Impacts

> **To Note:** Multiple and successive environmental and social impacts from existing developments, combined with the potential incremental impacts from proposed future developments, may result in cumulative impacts that would not be captured by the analysis of a stand-alone development.

Cumulative impacts are changes in the environment that are caused by an action in combination with other past, present, and future actions (Hegmann *et al.* 1999). Cumulative impacts are contextual and encompass a broad spectrum of impacts at different spatial and temporal scales. Cumulative impacts can occur because a series of projects of the same type that are being developed or because of multiple projects within the same area (IFC 2013) (see Figure 5). Cumulative impacts can take place due to a single impact occurring many times over a project period, for example blasting during construction; multiple interrelated impacts occurring in the same period, such as roads that induce competition for resources, redefine home range boundaries, and induce stress among animals simultaneously, or multiple unrelated direct and indirect impacts, such as a barrier effect, human colonization, and habitat contamination (Rajvanshi *et al.* 2001). In all cases, individual impacts cannot be considered in isolation but rather as components of the more serious cumulative effects. Cumulative impacts can also be described as additive (the sum of all impacts), synergistic (impacts that interact to produce an impact greater than the sum of individual impacts), or antagonistic (impacts that counteract each other, reducing the overall impact) (Morris and Therivel 1995). Cumulative impacts may last for many years beyond the life of the project that caused the effects.

Figure 5. Cumulative Impact from Road Development



Source: Walker and Johnston 1999.

Cumulative impacts can also take place when numerous actions occur during a brief a period of time within a limited area. A threshold may be exceeded and the environment may not be able to recover to pre-disturbance conditions. Also each new action can induce further actions, adding to the cumulative effects already occurring (Hegmann *et al.* 1999).

Problems with Habitat Fragmentation and Modification

> **To Note:** Fragmentation of large wildlife habitat areas into smaller patches is one of the most significant effects associated with road works.

Fragmentation is the process of breaking contiguous blocks into smaller isolated blocks. All species require a minimum habitat to maintain their populations. Road construction leads to habitat modifications and creates barriers between habitat blocks, affecting the threshold for many species as smaller patches may be unviable for their survival—leading to local population extinctions (Somerset Highways 2005; Quintero 2012b). Fragmentation can reduce the gene flow between members of a once contiguous population of either fauna and flora (for example, migration for breeding, pollination), reduce species richness, and change composition and function of entire communities (Frankham, Ballou, and Briscoe 2002; Haddad *et al.* 2015). The loss of area, increase in isolation, and greater exposure to human land uses along fragment edges initiate long-term changes to the structure and function of the remaining fragments (Haddad *et al.* 2015).

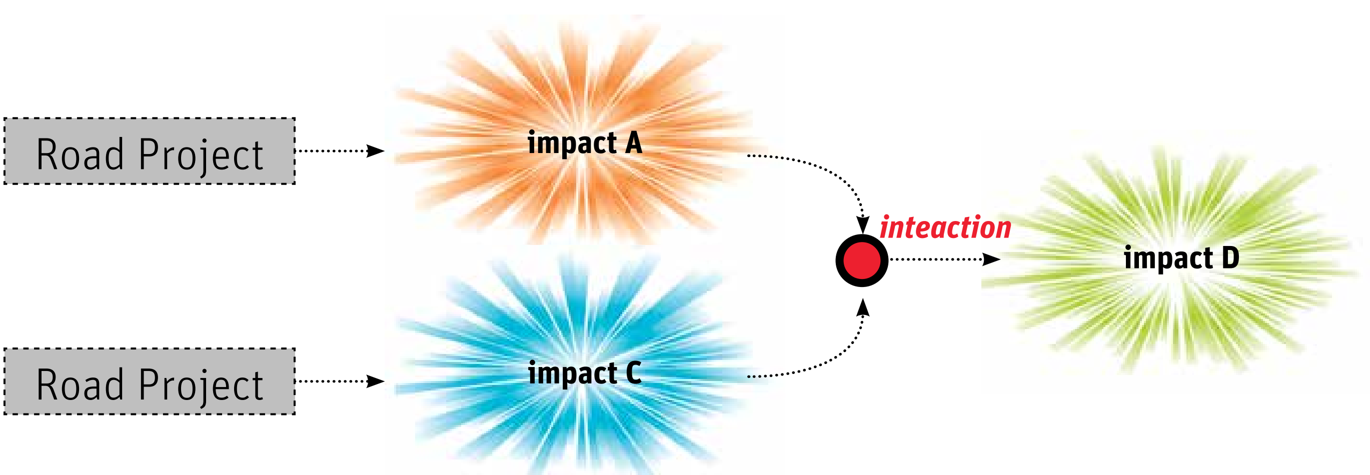
A single road can turn a habitat area into isolated units, while a network of new roads can effectively reduce a contiguous habitat area to a large number of discrete patches. As roads act as barriers to movements and dispersal, more edge habitat is created and edge effects penetrate more into habitats. These processes can, in turn, contribute to more habitat loss as the numbers of individuals of particular species change. Isolation of populations generally leads to their decline and eventual demise, to the detriment of the ecosystem. The nature of habitats is itself changed by the creation of new ecotones (where cleared areas and forests meet) along new patch borders (Rajvanshi *et al.* 2001).

Studies by Haddad *et al.* (2015) indicate that while fragmentation does have detrimental outcomes, it can also lead to unexpected surges in abundance of some species, although not the original species, depending upon local conditions. Further studies based on latest technologies and scientific information are required to fully understand the effect of fragmentation on species diversity. However, it is clear that habitat fragmentation by transport networks and consequential secondary developments have become one of the most serious global threats to biological diversity. It is estimated that the effects of fragmentation can be prevalent even up to or sometimes greater than a distance 1,000m from the road surface.

Impact Interactions

The potential effect of the reactions between impacts—whether between the impacts of just one project or between the impacts of other projects in the area—is also an important factor to consider (see Figure 6). The resulting impact can be more severe than the individual impact. For example, two major developments being built adjacent to one another and during overlapping time periods can have many interactive impacts, such as from land use changes to construction and operational noise (Walker and Johnston 1999). The interaction between specific project impacts is a result of the direct, indirect, and cumulative impacts of the project, while the interaction between several projects is cumulative (Morris and Therivel 1995). The impacts arising from the interactions can be long-term and can continue during the operation of the projects. The relationship between the different impacts is complex, and it is often difficult to distinguish between impacts—particularly indirect, induced, and cumulative ones. Table 4 shows the nature and scale of the different impacts.

Figure 6. Impact Interaction from Road Development



Source: Walker and Johnston 1999.

The interaction due to various environmental issues or threats such as fragmentation and climate change also has to be considered. While fragmentation and climate change both affect species habitat directly, the indirect effect of both factors on species interactions can have implications on the structure and functioning of species communities (Klapwijk and Lewis undated). Range shifts due to both climate change and fragmentation can alter the composition and structure of ecological food webs, ultimately affecting survival of the species.

Table 4. Relationship between Impact Types

	Direct Impacts	Indirect Impacts	Cumulative Impacts
Cause	Due to project activities	Due to project activities but occur later or farther away than direct impacts	Caused by the project activities in combination with pre-existing conditions and the actions of other activities
Time Frame	Present	Present and future	Past, present, and future
Range of Effect	Within and closely adjacent to the project limits	Within and near the geographic area where the project may influence direct changes	Multiple areas; each specific resource has its own range within which its condition may be affected

Source: Adapted from TxDOT 2009.

Potential Impacts of Roads in Sensitive Areas

In environmentally sensitive areas, impacts and the resulting interactions can be more severe. Typically, sensitive areas are those that have specific environmental characteristics needing protection and that are sensitive to environmental and sociocultural impacts caused by road development (MPW 2008). The potential impacts on a number of sensitive areas are presented in Table 5, and the impacts on water bodies, forests, and caves—some of the most commonly encountered sensitive areas in road development projects—are described further here.

Water Bodies

Building roads through water bodies such as streams can affect the movement of aquatic animals and can isolate and divide populations. Crossing a natural drainage network can change the natural flow of surface water and cause flooding or increase the speed of streams, causing erosion and sedimentation downstream. Soil excavation will normally lower the water table, while filling can frequently increase the water table in the surrounding areas. Water quality can be degraded, and groundwater contamination can occur. Roads passing near or sometimes through mangroves and wetlands areas can cause severe and rapid destruction of the ecosystem by interfering with the natural flushing and creating a saline imbalance, leading to mass mortality of all organisms unable to tolerate new salinity levels (see Box 3).

Box 3. The Ciénaga-Barranquilla Highway, Colombia

The Ciénaga-Barranquilla highway cuts across the Ciénaga Grande de Santa Marta, which encompasses mangrove forests, dry forests, pastureland, plantations, subsistence agriculture, and marine wetlands over thousands of kilometers of Colombia's Caribbean coast. It is a rich source of seafood for the local communities and for coastal and inland cities.

Construction of the Ciénaga-Barranquilla highway cut off all but one of the natural connections between the lagoon complex and the ocean, changing the hydrology of the wetland complex. This resulted in substantial mangrove mortality (nearly 70%), affecting fish populations that depended on the mangroves. In about the 10 years between the 1980s and 1990s, fish biomass declined by about 70%. By 2005 there was a 41% decrease in catch volume compared with a decade earlier, and local fishers experienced a 35% decrease in income.

The impact on the hydrology was not only due to road construction but also from the cumulative effects of infrastructure and economic development near and upstream of the Ciénaga Grande de Santa Marta. Roads and dam construction on the Magdalena River along with expansion of plantations and cattle ranching contributed to reduced freshwater flows, an increase in sedimentation, and increased nutrient pollution in the waterways, lagoons, and wetlands.

Source: Mandle, Griffin, and Goldstein 2014.

Forest Areas

Road development in forest areas has the potential to cause impacts to the physical and biological components of the environment (MPW 2008).

- New road construction in forest areas reduces forest coverage and causes other adverse impacts, such as reduced vegetation coverage and wildlife habitats, and can induce impacts on physical or biological components (see Box 4).
- During the operation phase, a road that passes through or is adjacent to a forest area has the potential to facilitate resource extraction such as illegal logging, mining, and fisheries and wildlife trade.
- Apart from illegal logging, forest squatting and the illegal collection and destruction of protected flora and fauna by local communities may also take place. Forest squatting by the local communities may occur since forests are a valuable income source for isolated and vulnerable communities and a useful land resource for those who require additional lands for income generation, especially small-scale farmers or farm workers. This use and squatting will significantly hamper the conservation functions of forests.
- The existence of new roads in forest areas can likely stimulate change of land use along the road corridor through the establishment of spontaneous settlements and other uses.
- The existence of roads in forest areas may cause ecosystem fragmentation in the forests concerned. In addition, road traffic may disturb wildlife, including protected species.

Box 4. Habitat Loss: Trans-Chaco Highway, Paraguay

Habitat status in the country was monitored every 16 days from 1 January 2004 until 31 December 2010. Cumulative habitat loss during the seven years analyzed was determined to be 1,767,163 ha nationwide, equivalent to an annual rate of 252,452 ha/year. The most affected ecoregion was the Dry Chaco, which registered 93% of the deforestation.

The Trans-Chaco highway is approximately 736 km long, extending from the boundaries between Bolivia and Paraguay. An increase in deforestation within a buffer area of 20–50 km from the road was observed, with the network of secondary roads branching out from the Trans-Chaco contributing to the increased habitat loss. It is estimated that about 650,000 ha were lost in a 50 km buffer since 2004. High rates of conversion show that the road can be considered an enabling force, easing access to remote areas and having a considerable negative impact within its area of influence.

The Trans-Chaco Road is about 150 km from the Defensores del Chaco National Park and does not have a direct influence on deforestation around the park's borders. Nevertheless, deforestation from the road that connects Mariscal and Estigarriba and from the secondary roads in the area are putting an alarming amount of pressure on this and other protected areas. The main drivers of change are the indiscriminate conversion of forest to pasture or agricultural land influenced by high commodity prices, land colonization, and a near absence of land use control. Over time, barring drastic changes in conservation policies or implementation of land use policies, deforestation will continue its progress toward the protected areas.

Average pre-road deforestation rate: 23,000 ha

Average post-road deforestation rate: 97,000 ha

Source: Argote *et al.* 2012; Reymondin *et al.* 2013.

Caves

Roads can increase unregulated or illegal access to caves, causing disturbance to and destruction of the local flora and fauna. Road works can affect the natural drainage pattern of the caves, affecting the cave hydrology. Changes in cave airflow patterns, modifications to cave microclimates, and the introduction of foreign bodies into caves can take place.

Table 5. Sensitive Areas and Potential Impacts

Sensitive Area	Potential Impacts
Forests	▶ Fragmentation ▶ Conversion/change in land use ▶ Deforestation/logging ▶ Reduction in species diversity ▶ Effect on endemic species ▶ Effect on threatened and endangered species ▶ Cumulative impacts
Aquatic Habitat (swamps, ponds, marshes, lakes, streams, wetlands)	▶ Draining wetlands ▶ Waterlogging (permanent, seasonal) ▶ Algal bloom ▶ Degradation, such as damming for water storage, irrigation, or recreation ▶ Direct disturbance (activities close to the wetland) ▶ Loss of biodiversity ▶ Pollution ▶ Fragmentation of aquatic habitats
Coral Reefs	▶ Pollution ▶ Destruction ▶ Loss of critical habitat for reef fish ▶ Coral bleaching ▶ Algal bloom ▶ Local extinction of species ▶ Loss of tourism ▶ Coastal erosion ▶ Sedimentation
Coastal and Riparian	▶ Clearance ▶ Fishing ▶ Cutting (for wood or charcoal) ▶ Hydrological changes like fragmentation of aquatic habitats ▶ Pollution ▶ Solid waste ▶ Trampling ▶ Sediment runoff
Grasslands	▶ Degradation ▶ Conversion/ranching ▶ Reduction in species diversity ▶ Effect on endemic species ▶ Effect on threatened and endangered species
Caves	▶ Increased access to caves ▶ Altered airflow ▶ Destruction ▶ Loss of endemic flora and fauna ▶ Pollution/leaching of chemicals ▶ Changes to surrounding land use ▶ Change in cave hydrology
Deserts	▶ Degradation ▶ Introduction of invasive species ▶ Exploitation of cacti and reptiles ▶ Loss of endemic flora and fauna
Savanna	▶ Desertification and infertile soil ▶ Poaching
Mountain	▶ Impacts on fragile plant communities

Identifying Impacts during the Project Cycle

Impacts are typically more pronounced and visible in the construction and operational stages. In the planning stage there are no activities onsite that can lead to physical changes to the surrounding environment at the project site. During this stage, care has to be taken to first avoid and then minimize and mitigate impacts. Site selection, analyzing fragmentation effects and location in relation to sensitive areas is key to avoiding impacts. During the pre-design stage, impacts are also minimum and may occur during alignment selection due to land titling, developing access roads, or soil investigations that can require some land clearing. Detailed descriptions of the potential impacts caused by activities undertaken during construction, operation, and maintenance phases are given in Table 6.

Table 6. Potential Environmental and Social Impacts during Construction, Operation, and Maintenance

Activity	Potential Impacts
Construction Workforce	▶ Construction of new building camps. ▶ Increased demand for infrastructure and utilities. ▶ Tensions between outside workers and local communities. ▶ Theft; drug and alcohol abuse. ▶ Affected living standard and income of local residents due to occupation of farmland. ▶ Market distortion due to temporary inputs to local economy. ▶ Unemployment of local labor. ▶ Disruption to livelihoods, cultural activities, and well-being of locals. ▶ Competition for employment with locals.
Workers' Camp and Site Installation	▶ Generation of significant volumes of wastewater and solid waste. ▶ Stockpiling of waste and illegal dumping. ▶ Contamination of land, surface water, and groundwater caused by spillage and leakage from storage of hazardous materials including petroleum products, chemicals, hazardous substances, or hazardous wastes. ▶ Watercourses and agricultural land can be easily contaminated with wastewater and solid wastes.
Erosion and Sedimentation	Roadbed and side slopes digging, roadbed filling, road surface paving, bridge foundation treatment, materials stack, concrete plants, construction machinery operation, etc. can: ▶ Destroy surface vegetation. ▶ Aggravate soil erosion. ▶ Weaken soil conservation capacity. ▶ Temporarily change water flow patterns.
Emissions and Dust (Air Quality)	Sources of air pollution during construction that can be a nuisance and cause health problems are: ▶ Fugitive dust emissions due to exposure of slope surface, uncovered stockpiling area, earth moving and excavation activities. ▶ Dust emission due to blasting. ▶ Dust from vehicles and unpaved roads. ▶ Wind blow during transportation of material by vehicles and when transporting on unpaved access roads. ▶ Gases emissions from batching plants and concrete mixing stations. ▶ Gases emissions during pavement of road surface by asphalt plant. ▶ Air pollutant emissions from exhaust of construction plant and vehicles such as CO, CO_2, NO_x, and SO_2. ▶ Air pollution problems during the operation phase are: ▶ Exhaust from vehicles (e.g. CO, NOx) that may deteriorate air quality in tunnel and at nearby sensitive receptor locations. ▶ Gases emissions during road maintenance and resurfacing of road (e.g. asphalt plant).

Activity	Potential Impacts
Noise and Vibration	Disturbances to livelihoods and damage to structures can be caused by: ▶ Operation of various equipment during construction (air compressors, concrete mixers, powered mechanical equipment, bulldozers, excavators, etc). ▶ Vehicles transporting materials within construction site and beyond the construction boundary. ▶ Piling activities during construction of foundations/piers. ▶ Ventilation systems during tunnel construction. ▶ Blasting and vibration during tunnel construction. During the operation phase, noise may be generated by: ▶ Traffic from road and vehicle horns. ▶ Service areas and car parking areas. ▶ Construction plant during road maintenance.
Earthworks, Fill Slopes, Cuts, Borrow Pits, Quarries, Disposal Sites, Stockpiles	▶ Loss of topsoil affecting productive land. ▶ Land instability from incorrect earth removal or unstable deposition of spoil, leading to landslides or erosion events. ▶ Discharge of sediments into watercourses, agricultural lands, drainages, and irrigation canals. ▶ Erosion of riverbanks, slopes, and productive land. ▶ Noise and vibration. ▶ Dust emissions affecting health. ▶ Disturbances or damage to physical cultural resources. ▶ Damage to agricultural land and native vegetation. ▶ Visual impacts.
Disposal of Debris, Demolition of Structures	▶ Damage of local forest areas, contamination of drainage watercourses, and impacts on land by improper disposition of construction and vehicle waste. ▶ Injury of workers and the general population by falling debris and flying objects.
Construction of Tunnels	▶ Large-scale moving activities that may generate lots of waste. ▶ Soil erosion. ▶ Blasting may cause noise and vibration, landslides, impacts on workers, nearby communities, and animals. ▶ Dust and gases caused by heavy machinery and construction equipment may affect the health of workers. ▶ Wastewater produced during tunnel construction may pollute downstream water bodies if not properly treated. ▶ Traffic safety in the tunnel.
Clearing of Construction Areas	Large-scale moving activities, disturbance of soil profile, and removal of vegetation can result in: ▶ Soil erosion and visual impact. ▶ Loss of productive plots/trees affecting livelihoods and habitat. ▶ Loss of habitat and vegetation for animals. ▶ Discharging sediment and vegetation material into watercourses, affecting in-stream habitat. ▶ Discharging sediment and vegetation material into agricultural lands and irrigation canals.
Landscape, Visual Impacts, and Site Restoration	Landscape and visual impacts during construction can result from: ▶ Poor/inadequate aesthetic design and landscaping design of the proposed road structures. ▶ Poorly implemented temporary mitigation measures and slope protection measures during excavation and slope work. After completion of construction and before operation of the project, landscape and visual impact may occur because of: ▶ Lack of appropriate compensatory planting at the end of construction for non-native species. ▶ Planting of species visually incompatible to the background environment. ▶ Lack of proper maintenance/watering of newly planted vegetation during the post-construction period. ▶ Lack of proper restoration of cleared areas, such as borrow pits, stockpiles and disposal areas, construction camp areas, areas under bridges, and any areas occupied temporarily.

Activity	Potential Impacts
Water Quality	Pollution of watercourses, groundwater, natural habitats, and productive land caused by: ▶ Wastewater generated from construction equipment (e.g., uncontrolled release of bentonite from tunnel drilling machine). ▶ Wastewater from bored piling locations. ▶ Resuspension of bottom sediment and mud caused by cut-trench river crossings and construction of bridge foundation within rivers. ▶ Soil erosion/flush away from uncovered stockpiling locations, uncovered excavation sites, and unprotected slope surface during adverse weather conditions. ▶ Uncontrolled surface water runoff carrying sediment-laden discharges directly into natural water bodies such as streams, fish ponds, rivers, and local irrigation channels. ▶ Domestic sewage generated by construction workers, such as kitchen, shower, campsite, etc. Main water quality issues during operation phase are: ▶ Wastewater generated during routine road surface cleaning and surface runoff from road surface during heavy rain falls. ▶ Pollution of nearby water body due to vehicle accidents leaking fuel, hydraulic oil, toxic materials, or dangerous goods. ▶ Wastewater discharge from service areas, car parking, and toll stations.
Solid Waste, Hazardous and Chemical Waste	Damage to local forest areas, pollution of drainage watercourses and natural habitats, and impact on agricultural land caused by: ▶ Surplus excavated materials requiring disposal due to earth-moving activities and slope cutting. ▶ Disposal of used wooden boards for trenching works, scaffolding steel material, site hoarding, packaging materials, containers of fuel, lubricant, and paint. ▶ Waste generated by demolition of existing houses/buildings affected by the project or breaking of existing concrete surface. ▶ Domestic solid waste generated by construction workers, construction campsite, kitchen, toiletries. ▶ Improper disposition of hazardous wastes such as waste oil, spent lubricant, solvents, and contaminated materials resulting from leakage of oil and fuel. ▶ Improper handling and storage of hazardous and chemical substances and construction materials.
Work in Watercourses	▶ Discharges of sediment into watercourses affecting in-stream habitat. ▶ Changes in habitat as a result of modifications to river bed and banks. ▶ Erosion of river banks. ▶ Introduction of invasive species. ▶ Aquatic connectivity issues like changing watercourse paths, blocking fish passage and affecting in-stream habitat. ▶ Discharges of oil and fuel to watercourses, affecting water quality.
Ecological Considerations (Fauna and Flora)	▶ Destruction of native vegetation and land outside proposed working areas. ▶ Damage of forest areas. ▶ Loss of habitat and vegetation for animals due to site clearance. ▶ Destruction or disturbance of aquatic life due to works in rivers. ▶ Aquatic connectivity impaired. ▶ Land occupation at ecological sensitive areas. ▶ Damage of forests and waterways adjacent to camps and work areas. ▶ Illegal hunting of wild animals by construction workers. ▶ Lack of reconstruction of lost habitats and recreation of diverse ecosystems. Impacts during operation phase include: ▶ Traffic noise and lighting can force wildlife to leave their natural habitats. ▶ Lack of evaluation of the success of recreation of habitat and identification of further measures to improve ecological conditions. ▶ Traffic accidents with wildlife crossing the expressway.

Activity	Potential Impacts
Construction Site Safety	▶ Risk associated with working in an enclosed environment such as inadequate ventilation and fire fighting within tunnel/tunnel shaft. ▶ Seepage of water into tunnel during the tunnel construction. ▶ Collapse within tunnel when drilling through geologically unstable ground layers. ▶ Risk of falling objects and unstable working platform. ▶ Risk associated with blasting and fire. ▶ Risk associated with equipment and traffic movements, on and off the construction sites.
Traffic Management	▶ Traffic congestion during construction due to the increase of heavy traffic (of the construction itself and from traffic detours) in high traffic avenues and exit ramps, community roads. ▶ Degradation of local roads due to heavy equipment machinery and traffic detours. ▶ Pedestrian safety, especially for schoolchildren during construction. ▶ Increase in traffic accidents.
Access and Linking Roads	▶ Increased noise, dust, and air pollutants caused by construction vehicles that will use existing local and provincial roads. ▶ Pedestrian safety, especially for children and pupils. ▶ Additional vehicles used for transportation of materials may cause traffic jams and accidents in existing access roads. ▶ Newly developed access roads may affect water quality, destroy existing vegetation cover, cause changes in the landform in certain areas, affect and create bare surface more prone to erosion.
Community Relations	▶ Lack of communication and consultation with local communities can lead to an opposition to a road project, delays in the construction process, increased costs, and unsatisfactory solutions.
Health Issues	▶ Spread of disease due to poor housekeeping and accumulation of domestic waste within the construction site. ▶ Stagnant water may result in mosquitoes breeding. ▶ Unsafe sex conduct could bring HIV/AIDS risk to the local communities. ▶ Illnesses brought by outside construction workers.
Cultural Aspects	▶ Cultural sites and heritage relics could be affected by roads.

At times it may be difficult to clearly distinguish between the different types of impacts, particularly indirect and cumulative impacts, as cumulative impacts are those of a similar nature but of greater intensity. As an example, Table 7 presents potential direct impacts on wildlife and their corresponding indirect and cumulative impacts during the project cycle.

It is clear that infrastructure planning must be carried out at the landscape level to capture all possible impacts from the local and regional perspectives, integrating economic, social, and environmental issues. Maintaining habitat connectivity is essential for the survival of many wildlife populations. When the impact is below a critical threshold, populations may be sustained, but beyond this threshold, even small changes to the environment may cause unexpected and irreversible effects (such as the extinction of local populations). The larger the spatial scale concerned, the longer the time lag until effects may be detectable. This underscores the need for fragmentation analysis and cumulative impacts assessments (see Chapter 4).

Table 7. Potential Impacts on Wildlife

Project Activity	Typically Most Important Direct Impacts	Indirect Impacts	Cumulative Impacts
Planning and Pre-Design Stage			
Siting of project	▶ Potential impacts due to improper site selection	▶ Influx of people to areas where roads may be built to avail monetary compensation	▶ Pressure on natural resources
Design Stage			
Promoting good practices such as wildlife crossings, erosion control measures, signage, runoff control, etc.	▶ Minimum impact on flora and fauna		
Land acquisition	▶ Displacement of people	▶ Pressure on forest resources if people move to forest areas	▶ Decrease in wildlife and non-timber forest resources
Construction Stage			
Clearing of vegetation	▶ Loss or degradation of habitat	▶ Reduction in of habitat use	Decline in wildlife population and diversity
Right-of-way clearing	▶ Loss or degradation of habitat	▶ Reduction in structural diversity, increase in isolation of habitats	▶ Reduction in population size and integrity
Construction and operation of roads	▶ Barrier to dispersal ▶ Construction related impacts—noise, dust, pollution, traffic and safety, waste, erosion	▶ Disproportionate use of habitats ▶ Disturbance to wildlife populations	▶ Competition for resources and redefined boundaries of home range ▶ Increased stress
Road construction on unstable land	▶ Soil erosion	▶ Siltation of water bodies	▶ Degradation of aquatic habitat, species decline
Construction activities, blasting and vehicle movement	▶ Stress on animals	▶ Changes in behavioral responses and physiological disorders in animals	▶ Increased mortality; reduced fertility
Construction of temporary access roads for quarries	▶ Facilitation of public access	▶ Eventual acceptance of road as permanent features	▶ Colonization stimulating road-habitat conversion
Road construction in mountain ecosystems	▶ Barriers to vertical migration and dispersal of species	▶ Subdivision of populations in previously connected habitats	▶ Threat to endemic character of the mountain ecosystem
Road construction in coastal areas	▶ Alteration of tidal flushing cycle in mangroves and salt marshes	▶ Increased or decreased salinity	▶ Changes in habitat quality and species composition
Road alignment through wildlife habitat	▶ Increased access to pristine wildlife habitat areas	▶ Unplanned development ▶ Poaching	▶ Decline in habitat quality, species decline

Project Activity	Typically Most Important Direct Impacts	Indirect Impacts	Cumulative Impacts
Channel relocation **Crossing of water courses**	▶ Alteration direction of water flow ▶ Interruption of fish movement	▶ Degradation of wetland dependent on flooding ▶ Diminished ground water recharge ▶ Increased flow in receiving streams ▶ Diminishing fish stock	▶ Threats to conservation of some wetland species ▶ Localized drought, decline in productivity ▶ Reduced habitat suitability for some species, affecting species composition ▶ Loss of migratory fish in the watershed
Maintenance Stage			
Mowing of roadsides	▶ Changes in vegetation composition	▶ Fluctuations in small mammal density due to discontinuity with adjacent wooded habitats	▶ Alteration of trophic dynamics, ecosystem change
Application of herbicides to control vegetation along roadways	▶ Transportation of chemicals to water bodies	Changes in wetland characteristic	▶ Loss of habitat niche for dependent species and population decline
Application of salt for de-icing	▶ Transportation of salt to water bodies ▶ Damage to plants–"leaf burn"	▶ Increased sodium and chloride in water bodies, disturbance to the circulation of water	▶ Depletion of oxygen levels affecting survival of some aquatic species
Dust raised during operation and construction	▶ Dust deposition on vegetation, interference with photosynthesis	▶ Reduced primary productivity	▶ Reduction of food sources, species decline
Traffic	▶ Disturbance to wildlife species of road verges	▶ Changes in activity patterns leading to habitat use more during night ▶ Abandonment of habitat, migration to others	▶ Competition for resources with nocturnal animals, decline of certain species ▶ Overuse of other habitat areas, eventual decline of some species
Increase in traffic volume	▶ Increased roadkills	▶ Decline in populations	▶ Change to trophic dynamics and species composition

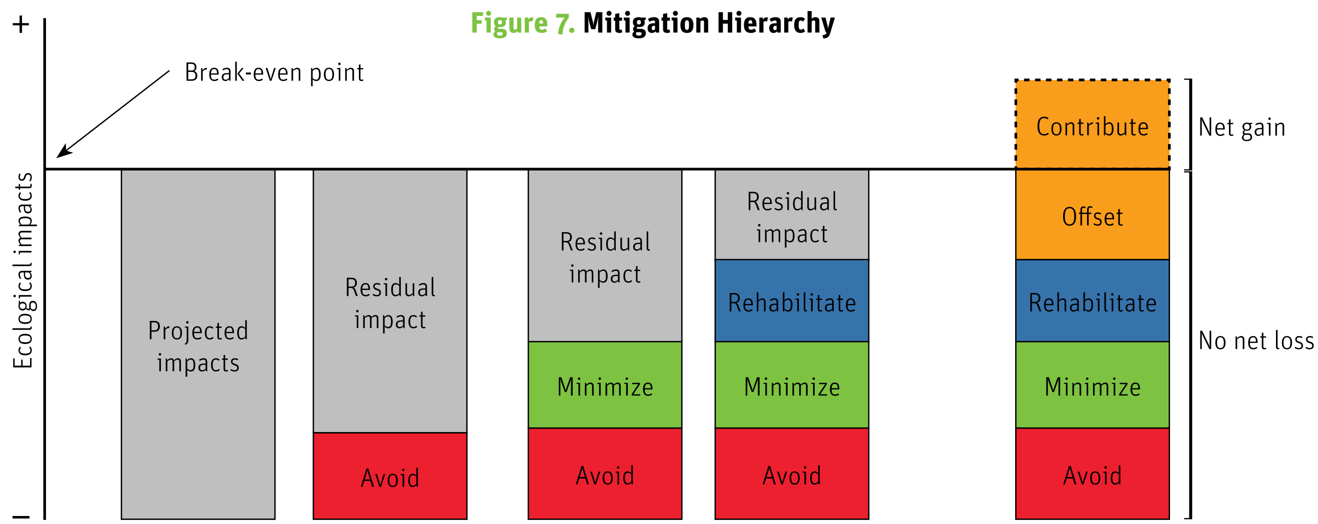
Source: Adapted from Rajvanshi *et al.* 2001.

Chapter 4
Application of Good Environmental Practices

From planning to operation, all stages of the project cycle require an assessment of the impacts of decisions made on the environment and communities. Impacts are caused by biological and physical changes associated with the project. Therefore, understanding the nature and extent of these changes is required if these impacts are to be adequately predicted. Properly addressing the issues improves project management and environmental decision-making.

To fully integrate environmental considerations into road development, a systematic approach is required. Ideally, projects should first avoid, then minimize, then restore, and finally—when the previous options are exhausted—offset their impact to achieve no net loss in biodiversity (BBOP 2009; PricewaterhouseCoopers 2010). This is known as the Mitigation Hierarchy, as depicted in Figure 7 (Quintero *et al.* 2010). Applying the Mitigation Hierarchy can help to ensure environmental management.

Figure 7. Mitigation Hierarchy



Source: Adapted from BBOP 2009; PricewaterhouseCoopers 2010.

Avoidance: To prevent impact to sensitive areas by excluding them from consideration for project siting. This is the preferred option taken to avoid creating impacts from the outset and a useful concept for land use and infrastructure planners.[2] This should be the foremost option especially in sensitive areas and infrastructure in “No go areas” should be avoided.

Minimize: To reduce potential impact through activities that protect biodiversity and ecosystem function. It includes, as far as it is practically feasible, measures that need to be taken to reduce the duration, intensity, or extent of impacts that cannot be completely avoided.

[2] The “no-build option” can be included under avoidance.

Rehabilitate: To leave affected areas (where the impacts could not be completely avoided or minimized) in similar or better conditions as those that were verified prior to the execution of the project's activities.

Compensate/Offset: Measures taken to compensate, through offsets or other means, any residual significant adverse impacts that cannot be avoided, minimized, and/or rehabilitated or restored, in order to achieve no net loss or a net gain of biodiversity.

The Mitigation Hierarchy is aligned with stages of the project life cycle—from planning to construction and operation. Beyond reduced or positive impacts to the environment, the hierarchy provides an approach for integrated development, with expected results in reducing transactions costs for infrastructure development. At every stage, it is vital that environmental agencies and experts work in coordination with road planners and designers. Solutions that are acceptable from an environmental, safety, and engineering design perspective should be developed.

Good practices can be implemented at every stage to mitigate environmental impacts. These are depicted in Table 8 in line with the Mitigation Hierarchy.

Table 8. Incorporating Environmental Considerations into the Project Cycle

Project Cycle/ Mitigation Hierarchy	Upstream Planning	Pre-Design	Design Stage	Construction	Operation & Maintenance
Avoid	▶ Upstream identification of environmental issues–strategic, multisectoral, and regional environmental assessments; cumulative impact assessments ▶ Land use planning incorporating environmental considerations ▶ Analysis of alternative programs/projects ▶ Identification of 'No go areas'	Screening: ▶ Identifying nature and magnitude of impacts ▶ Identifying natural habitat and social components ▶ Careful site selection	▶ Project design balancing engineering techniques and technologies with environmental issues ▶ Protect areas at the project site with important biodiversity values	▶ Good construction practices ▶ Timing construction activities to account for patterns of species behavior (e.g., breeding, migration) or ecosystem functions	▶ Regular, timely maintenance
Minimize	▶ Community involvement ▶ Climate change adaptation measures ▶ Interagency collaboration	Screening scoping: ▶ Analysis of alternatives ▶ Identification of scope of EIA study ▶ Community involvement	▶ Collection of baseline data ▶ Species-specific surveys ▶ Identifying all impacts ▶ Community involvement ▶ Project design incorporating environmental issues ▶ Wildlife structures	▶ Good construction practices ▶ Use of latest innovative construction technologies ▶ Costed mitigation measures as part of bidding documents ▶ Monitoring	▶ Regular monitoring ▶ Routine maintenance practices ▶ Community involvement

Project Cycle/ Mitigation Hierarchy	Upstream Planning	Pre-Design	Design Stage	Construction	Operation & Maintenance
Rehabilitate			▶ Developing targeted measures such as proper drainage structures ▶ Community involvement	▶ Good construction practices ▶ Costed mitigation measures as part of bidding documents ▶ Monitoring	
Compensate			▶ Compensation plan–creating new protected areas, supporting existing protected areas, long term conservation of private reserves ▶ Restoring biodiversity values, or enhancing or creating new habitat	▶ Compensation plan–creating new protected areas or supporting existing protected areas, long term conservation of private reserves ▶ Restoring biodiversity values, or enhancing or creating new habitat	

Upstream Planning

Planning is the first phase of the transportation decision-making process. At this stage, planning is carried out to meet transport needs. It is vital to start considering the environmental consequences of any policy, project, or program that is addressing transportation deficiencies. As far as possible, the transportation planning process should use all available information on ecological resources to anticipate the potential consequences of transportation plans on the environment and on society. An analysis of alternate modes of transportation should be carried out based on strategic assessments. This Guide however, does not discuss upstream multimodal transportation planning.

To Note: Spatial planning at the landscape level—using technology, data, and available tools—can eliminate sites (avoidance) from potential development on the basis of the sensitivities of biodiversity or ecosystem (Hayes *et al.* 2015).

The density and configuration of the road network across landscapes are important aspects to consider in terms of the scale and intensity of the road's impact on wildlife (van der Ree, Smith, and Grilo 2015). At this stage, broad implications on the environment of design parameters, such as type of road surface, radius of curvature, types of curves, mass curve, design speeds, breaking distances, and so on, should be considered.

As specific projects are not yet defined, the planning efforts should be informed by strategic studies such as sector environmental assessments or regional environmental assessments (REAs) and cumulative impact assessments (CIAs) so as to rule out certain solutions that may meet the development objectives but that do so at an unacceptable or high level of environmental degradation (WSDOT 2010). If such assessments have not been carried out, then—depending upon the nature of roads works under consideration (such as highways development or road network planning in a region)—it may be necessary to conduct these studies. An environmental cost-benefit analyses should inform the decision-making process. Based on all available information, the least impact corridor should be selected, minimizing environmental and social impacts with economic benefits. Priorities identified at the national level feed into regional and subnational plans. Currently in Latin America, these tools are not widely used to inform decision-making and are mostly used when multilaterals are involved. Most environmental assessment systems in Latin America do not require SEAs, REAs, or CIAs (except in Chile, the Dominican Republic, Panama, Guatemala, Colombia, and Peru, which do have SEA laws).

Strategic Studies for Early Impact Identification

Strategic studies, such as sectoral environmental assessments and regional environmental assessments, provide the context for lower levels of planning and decision-making (DEAT 2004). These assessments reduce the likelihood of conducting feasibility studies for projects that may not be environmentally sustainable by ensuring that project proposals are set within a policy framework that has already been subject to environmental scrutiny (Quintero *et al*. 2010). This also saves resources spent on project preparation.The environmental assessments provide vital information that can feed into the overall planning process (DEAT 2004). The responsibility for SEAs varies between countries. Sometimes it's carried out by the planning agency; other times, by the sectoral agencies. SEAs should include:

- A description of the current environmental situation in the sector/region.
- An environmental analysis, including consideration of cumulative effects and fragmentation.
- An analysis of the environmental costs and benefits of alternative investment options and strategies.
- A mitigation strategy for eliminating or reducing effects to acceptable levels.
- A plan for improving environmental management in the sector.
- An environmental monitoring plan.

The Mocoa-Puerto Asis By-Pass Road in Colombia serves as a good example of the application of SEA. The use of strategic planning and a regional biodiversity conservation approach in this project are considered an important step to a more biodiversity-friendly road infrastructure development in Colombia. Some regional planning efforts that included protected areas and biodiversity corridors based on SEAs were introduced in the project design. This 46.5 km road, located in the southern region of Putumayo, cuts through sensitive natural habitats in a geologically unstable area. The project proposes to expand a forest reserve, create a biodiversity corridor based on landscape and territorial planning, and support biodiversity conservation programs.

Cumulative Impact Assessment

This may be a part of the strategic assessments or may be independent studies. It should inform the planning process by providing information on the following (IFC 2013):

- All valued ecosystem components (VECs) (including both environmental and social aspects) that may be affected by the development under evaluation and an assessment of selected VECs.
- All other existing and reasonably anticipated and/or planned and potentially induced developments, as well as natural environmental and external social drivers that could affect the selected VECs.
- Assessment and/or estimation of the future condition of selected VECs.
- Avoidance and minimization, in accordance with the Mitigation Hierarchy, of the development's impact on the VECs.
- Monitoring and management of risks to VEC viability or sustainability over the life span of either the development or its effects, whichever lasts longer.
- Project-related monitoring data.

Boundaries for the analysis should encompass the geographic and temporal extent of impacts (from other past, present, and predictable future developments) that influence VEC conditions throughout the time period during which project impacts will occur. This scope is likely to extend beyond a project's direct area of influence (IFC 2013).

Role of Land Use and Natural Resource Planning

To Note: Land-use planning plays an important role in managing the risks of infrastructure projects by guaranteeing an upstream implementation of the avoidance principle and providing a framework for mitigation and compensation.

Data from land use plans and natural resource plans, focusing on environmental priorities such as protection of watersheds, biological corridors, and sensitive areas, can facilitate decision-making (see Box 5). "No-go areas," where road network development would be significantly detrimental to the environment, can be identified. Recent literature refers to environmental restriction analysis as a tool for determining these areas. Not all impacts can be mitigated, and not all mitigation measures are equally effective (van der Ree, Smith, and Grilo 2015). Using landscape habitat connectivity models and models mapping environmental priorities allow for a more integrated road strategy, taking into account different land management practices and habitat conservation concerns. For example, if a road is identified to be passing through a migratory route, then alternative routes may be considered during the transportation planning process, thereby not only protecting the migratory route and the wildlife but also avoiding controversy at the individual project stage (NRC 2005).

Box 5. Mainstreaming Conservation into Planning

To mainstream conservation into development, Malaysia has adopted a national spatial planning strategy as stipulated in the National Physical Plan (NPP) 2005. The NPP sets a spatial framework for sustainable development and delineates important conservation areas for biodiversity and conservation. The Central Forest Spine (CFS) is a major conservation landscape in this plan. The CFS consists of three forest complexes harboring the tiger populations and has been identified as a priority for conservation. Incorporating CFS into the NPP will allow for tiger conservation, promoting the protection of biodiversity-rich core areas that are interconnected by a system of large forest blocks where ecologically sound land use is practiced. The NPP sets guidelines for land use and development. Thus, the tiger/biodiversity conservation areas are very clearly defined and integrated into national, state, and local plans. Any alienation of land for development projects has to be referred to the Department of Town and Country Planning, which consults the NPP.

Source: Samsudin 2010.

At the individual project level, potential environmental effects can be evaluated by screening for sensitive areas such as wetlands, areas with species of concern, and so on. Using a geographic information system (GIS) and other mapping techniques, potential impacts can be identified and appropriate alignment selected to avoid creating impacts from the onset.

Interagency Collaboration

Road planning should include inputs from other relevant agencies such as those responsible for natural resource planning, watershed planning, or land use planning to ensure the proposed projects or plans will not adversely affect the environment but will complement the land use of the area. All agencies need to work together (see Box 6). Linking the plans can help to identify natural resources that should receive special consideration of avoidance and minimization strategies, identify ways for transportation projects to contribute to environmental enhancement as part of future project planning and implementation, and provide direction for the location and design of compensatory mitigation sites so that these sites can help to maximize benefits by supporting larger conservation objectives (NRC 2005).

Box 6. Road Planning to Construction

National development plans establish the priority for road infrastructure. For example, roads may be prioritized for connecting industrial areas to ports such as in Colombia, or national integration and regional integration may be a priority. The national priority informs the road corridor planning carried out by the planning agency or sector ministry. Environmental considerations should be incorporated at this stage of planning, possibly through SEA or REAs. After this upstream planning, the road agency selects the road alignment informed by an analysis of alternatives and proceeds with the road design. In parallel, land use planning and natural resource-use planning take place at the national and provincial level. The road agency should consult and collaborate with the different agencies to ensure that the road alignment selected is compatible with the land use plans and that development does not lead to adverse environmental effects. Once the design is finalized, the road moves to the construction stage. It may be built by the government agencies or contracted to the private sector.

Climate Change

Climate change adds new complexity to infrastructure planning and implementation. The frequency of natural disasters and their costs have risen dramatically globally. For example, the Latin American and Caribbean region has the highest average economic damages from disasters in the world (0.18% of gross domestic product per event) (Watkins 2014). Weather events such as storms, extreme precipitation, and extreme temperatures pose a costly risk to roads in terms of degradation, necessary maintenance, and potential decrease in life span due to climatic impacts (Schweikert *et al.* 2014).

As transport infrastructure has a long economic life, the costs and benefits pertaining to climate change, including emissions from vehicles and the risk of damage from disasters such as flooding and landslides, have to be a part of the calculation in evaluating infrastructure investment options (Fardoust, Kim, and Sepúlveda 2010). Some weather events could be exacerbated under future climate change, thus increasing risks and negatively affecting road performance like safety, reliability, and cost efficiency. To manage greenhouse gas emissions, transportation planners may consider reducing the use of fossil fuels and increasing vehicular efficiency, among other options. Various climate change prediction models are available, and by analyzing different scenarios into road planning, the potential impact that roads can have on greenhouse gas emissions as well as the effect that changes to the weather pattern may have on roads can be determined. Including climate change implications in transportation planning is critical for protecting future investments in infrastructure. Climate change is a complex issue and an increasingly important one that needs to be factored into planning and development. The issues of addressing climate change during road development is beyond the scope of this Guide. However as an example, possible climate change management measures that can be considered when designing the road are provided in Table 9 in the section on the Design Stage.

Models for Impact Prediction

Development of transportation infrastructure is one of the causes of changes to land use and land cover, contributing to deforestation and loss of biodiversity. As discussed in Chapter 3, road development can lead to indirect, induced, and cumulative impacts. While planning infrastructure, an analysis of these potential impacts and their interactions can help in understanding the changes to land use and in particular deforestation of natural forests and the resulting impacts on biodiversity. Several models using various techniques are available to analyze changes to land use and land cover, capturing the interactions between anthropogenic and natural systems in space and time (Seifert-Granzin 2013).

Based on the need, the appropriate mode for analysis and scenarios should be selected in the respective country, area, or project boundaries. Remotely sensed data with coarse spatial resolution, such as the Advanced Very High Resolution

Radiometer and the Moderate-resolution Imaging Spectroradiometer (MODIS), are commonly used over large areas, such as the national, continental, climate zone, or global scale. As most deforestation occurs at subpixel scales, data can prove inadequate for directly and precisely estimating deforestation. In such cases high spatial resolution data, such as Landsat data, allow for more accurate quantification of deforestation areas (Zhu 2014). Infrequent repeat coverage, frequent cloud cover, and data costs can hamper mapping approaches with Landsat data for monitoring long-time deforestation over large regions. Thus, researchers often adopt sample-based methodologies to estimate deforestation with higher spatial resolution imagery.

Some widely used and established models and tools include Terra-i, Databasin, the Integrated Biodiversity Assessment Tool for Business (IBAT), Forest Watch, and Imazon (see Chapter 6 of descriptions). The tools can prove useful while planning road development. By plotting proposed projects within these models, the area of influence can be visualized with respect to the natural environment, and potential impacts can be identified based on different scenarios. This can benefit in site selection and identifying "no-go areas."

Pre-Design Stage

Environmental analysis conducted in this stage is meant to inform alignment selection and the preparation of preliminary road design. During this stage, an initial screening to determine whether a full EIA is required. If it is, then scoping of the project is the following step, which would lead to the baseline study.

Screening for Impacts

Screening is conducted to establish the need for the project, identify environmental issues, categorize the project, and decide whether an EIA is needed. Local communities know the area the best and are a great resource for on-the-ground knowledge. They should be involved in alignment selection, providing input for analysis of alternatives to ensure local interests are integrated into the road design. For example, in the Prime Minister Rural Roads Program in India, representatives of local communities walk the entire stretch of the proposed road so that their concerns can be taken into account. Where the community feels that a culturally sacred place, a heritage site, or an important seasonal water body will be affected by the road, an alternative route is found.

Information that should be gathered and analyzed during screening includes the following (Rajvanshi *et al.* 2001; Tsunokawa and Hoban 1997):

- Scale and location of the project, including maps showing the location of the project in relation to natural habitats and sensitive areas. Tools such as IBAT or Databasin can be useful in identifying sensitive areas.
- A description of the main components of the project.
- A list of potentially affected natural habitat components, including natural habitat types, vegetation, types and distribution, and key species of conservation concern according to the International Union for Conservation of Nature, the Convention on International Trade in Endangered Species of Wild Fauna and Flora, and local official lists; lists of endemic species; preliminary distribution and abundance information about key species and their habitats, migratory pathways, breeding and spawning areas (when applicable), and local threats to natural habitats.[3] (Table 12 at the end of Chapter 4 provides a list of components to screen for in sensitive areas.)

[3] The International Union for Conservation of Nature's Red List of Threatened Species categorizes the conservation status of plant and animal species globally. The Convention on International Trade in Endangered Species of Wild Fauna and Flora lists species that require protection from overexploitation.

- Nature and magnitude of potential impacts including:
  - Irreversible destruction or degradation of natural habitats.
  - Absolute quantity of natural habitat affected.
  - Potential for cumulative impacts.
  - Potential indirect (induced) and direct impacts.
  - Impacts on ecosystem services (see Box 7).
- Environmental category of the project.

Box 7. Ecosystem Services and Roads

Incorporating ecosystem services into the roads project cycle can enhance the sustainability of roads and benefit road users while at the same time avoiding unintended negative consequences to surrounding communities. Ecosystem services are the benefits that people derive from nature that support and fulfill human life, such as providing food, clean air, and water purification. Taking such ecosystem services into account during planning, design, and construction and then monitoring the impacts can lead to roads that are economically, socially, and environmentally sound. For example, protecting wetlands adjacent to and upstream of a road can prevent flooding of the road. On the other hand, if the wetlands were degraded or paved over, this could compromise the flood regulation service, putting the road, its users, and surrounding communities at greater risk and resulting in more frequent and costlier repairs when flood damages occur.

Ecosystem services relevant to roads include flood protection, coastal storm protection, erosion control, landslide **prevention, water quality regulation, air quality regulation, carbon sequestration, and storage for climate regulation.**

Source: Mandle, Griffin, and Goldstein 2014.

Scoping

Scoping is a process used to define what can and cannot be accomplished during a particular environmental study and to determine the level of detail needed in the environmental assessment within existing budget and time constraints. In this stage, key environmental issues and potential impacts that require further study are identified, and ToRs for the EIA study are prepared. Participatory stakeholder consultations are important, including with relevant regulatory agencies to inform them about the project and to receive inputs and concerns, feeding into the design process. Scoping should include the following (Rajvanshi *et al.* 2001; Tsunokawa and Hoban 1997):

- The geographic boundary of the study in relation to possible impacts or areas of influence, including maps and images.
- A plan for public involvement.
- Possible alternatives, considering all environmental components including sensitive areas and ecosystem services (see Box 8).
- Requirements for the collection of baseline data and other information, such as on valued ecosystem components.
- The skills and human resources needed to undertake the environmental assessment.
- Time constraints and time horizons of the study (that is, project time limits and how far into the future to predict project effects).
- Existing information sources, gaps, and constraints on methodology.

Box 8. Impacts on Natural Habitats: Key Input to Alignment Selection

For the Hubei Yiba Highway in China, three corridors were evaluated to select the most environmentally and socially benign alignment. The selected corridor has the lowest overall impact on environmental and cultural resources. The analysis of alternatives included optimizing the alignment where possible to minimize waste. The water quality of the Guanzhang drinking water reservoir was protected by shifting the alignment away from the Guanzhang watershed. The design was modified to reduce visual impacts on the Xiaofeng, Shennonglia, and Gaolan scenic areas. The final alignment minimizes the impacts to sensitive resources and the Three Gorges National Geological Park.

Design Stage

During this phase, much of the design work and environmental analysis and documentation requirements for a project should be completed, and the process of obtaining licenses and permits often begins. Most environmental analysis is usually done in tandem with project design, and a redesign to address an environmental issue is common (WSDOT 2010). Context-sensitive design should be developed to avoid and minimize adverse environmental effects. This requires the use of creative engineering solutions and techniques. For example, increasing the slope along the sides of a roadway to minimize wetland fill or an assessment of availability of local materials suitable for road construction can help reduce the use of virgin excavated materials. Equally important is to design roads with the premise of minimizing the volume of waste materials and pollution and of identifying users of excess useable material to avoid potentially costly alternative disposal options (IRF 2013). Additionally, climate resilience to withstand changing conditions, such as an increase in temperatures and flooding, has to be factored into the road design (see Table 9).

Table 9. Climate Change Risk Management Options for Roads

Climate Change Risk Management Option	How the Hazard Is Addressed	Implementation Feasibility
Sea level rise and flooding: Damage to facilities, such as roads, bridges, bridge piers, and culverts, from high flows and sediment transport; possible roadway erosion through undermining		
Move roads further inland	Moves roads out of flood zone	Difficult to implement
Install barriers to route floodwaters away from roads	Protects roads from floodwaters	Moderately easy to implement
Elevate roads using new land or by raising level	Moves roads, bridges above expected sea level	Moderately easy to difficult to implement
Develop alternative critical transportation paths	Provides resilience for events that occur infrequently (such as very high tides)	Moderately easy to implement
Improve levees along major rivers	Reduces flooding of roads near rivers	Ranges from moderately easy to difficult to implement, depending on levee size
Upgrade pumping systems to handle higher runoff for low areas and underpasses	Reduces impact of flooding	Easy to implement
Install walls to route floodwaters away from roads	Prevents flooding	Moderately easy to difficult to implement
Enhance infiltration systems such as using porous pavement or bioretention ponds	Reduces flooding	Moderately easy to difficult to implement; requires capacity (maintenance)
Install raised roads with rock-filled drainage ditches along the sides to increase infiltration	Reduces flooding of roads	Easy to implement
Armor bridge piers and culverts	Reduces impacts of floods and high sediment loads	Easy to implement

Climate Change Risk Management Option	How the Hazard Is Addressed	Implementation Feasibility
Storm surge		
Use modular sea walls and flood walls along roads	Routes floodwater away	Moderately difficult to implement
Install pumping systems for low areas and underpasses	Reduces flooding	Easy to implement
Extreme temperatures damage to pavement by buckling or asphalt softening		
Increase maintenance for pavement surface	Covers spots where asphalt melted	Easy to implement
Install concrete pavement to avoid problems with asphalt	Reduces holes in pavement	Easy to implement

Key to Implementation Feasibility:

Easy = Relatively straightforward to implement, provides long-term benefits, has no adverse secondary impacts.

Moderately easy = Minimal demands on capacity (staffing, funding, and maintenance capabilities); option is not expected to result in significant social or environmental impacts.

Moderately difficult = Intermediate-scale efforts required to implement; option could require further assessment of environmental and social impacts, additional regulatory requirements, or capacity and technical expertise.

Difficult = Major effort would be needed to implement; option could result in adverse environment/social impacts or could require significant expenditures, capacity, technical expertise, political will, or legal authority.

Source: Adapted from IDB 2015.

The design stage is one of the most important phases in the project cycle, as during this stage the EIA and other environmental studies must be completed. The environmental report should be drafted after analyzing environmental issues, comparing alternative alignments, developing management measures, consulting with agencies regarding any required permits, and making a determination about the significance of any unmitigated environmental impacts. The key issues that a good environmental impact assessment should cover are described in this section.

Baseline Data

Baseline data are collected to determine the biodiversity values occurring at a site, their current condition, and trends before a project commences (Gullison *et al.* 2015). The baseline information should allow for a clear understanding of the environment's behavior, especially of those components considered vulnerable to the actions that are going to be performed during implementation. The process should include relevant experts and stakeholders. The biodiversity baseline study supports the assessment of impacts and risks of a project, application of the Mitigation Hierarchy, and design of the long-term biodiversity monitoring program (if one is required) (Gullison *et al.* 2015).

EIA reports should provide baseline data on biodiversity in the project area and its area of influence relevant to its local, regional, national, and international importance; its use by local communities; its functional roles (e.g., in terms of resource yields or production, population trends of key species); and the application and impacts of national policy. Primary data may be gathered through direct methods (e.g., transect sampling) or indirect methods such as anecdotal information from hunters or fishers on species caught (Duke and Aycrigg 2000). To predict the project's impact upon natural habitats, relevant data should be generated on the following:

- The status of biodiversity and natural resources and its uses and threats, including both scientific and indigenous knowledge.
- Ecosystem functions and values, including the extent to which environmental thresholds or critical levels are being approached.

Baseline data should include:

- An overall picture of existing conditions and trends, including ongoing and proposed development activities in the study area (see Box 9).
- The types of habitats that might be affected, covering both terrestrial and aquatic habitats (surface water/water quality, floodplain, groundwater).
- Data on the natural and surrounding environment, such as:
  - Air quality
  - Soil characteristics
  - Plants and animals—threatened and endangered species, migratory species, locally important species
  - Land use—population/land use, shorelines, wild and scenic rivers, wetlands, farmlands, public lands, and forest lands, historic and cultural resources, social and economic issues, including relocation and aesthetics and visual quality
  - Public services and utilities
  - Sensitive areas, such as forests, protected areas, biological corridors, important bird areas, etc.
  - Fish species composition and abundance above and below road crossing project site before any development
  - Fish, amphibians, water quality, inundated area, for any road project in proximity to wetlands, streams
  - Ecosystem services
- Issues raised during consultations with concerned parties and potentially affected communities.
- Information pertaining to additional biodiversity studies, if undertaken.

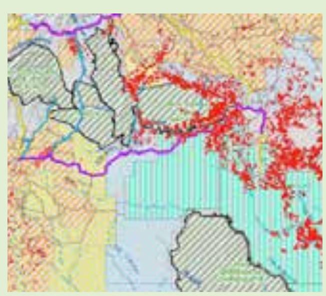
The baseline study can be revisited after a project has commenced due to additional requirements placed on an existing project or a project modification or expansion requiring environmental analysis (Gullison *et al.* 2015).

Box 9. Early Identification of Cumulative Impacts

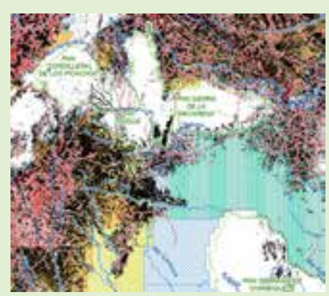
The Puerto Rico–San Jose del Guaviare La Macarena Road in Colombia is planned in an ecologically unique zone that is the meeting point for the flora and fauna of the Amazon, Orinoco, and Andes regions. The region has a high level of biodiversity with numerous endemic and rare species. The road would interfere and disturb the ecological connectivity between La Macarena and Chirbiquete National Parks, thus interrupting the connections between the Andes and Amazon ecosystems. Maps that analyze the current state of the area of influence and its sensitivities have been developed. Extensive studies have been undertaken, supported by overlying the visual maps, to understand the pressures faced by the ecologically sensitive area. Some of the maps generated include deforestation rates during 10 years, potential for hydrocarbons and mines, and pressures due to cultivation of illegal substances. Based on the environmental analysis, solutions to maintain connectivity and the free movement of animals are being developed.

A. The Macarena Road

B. Hydrocarbon areas in relation to the road



C. Illegal cultivation with A and B



D. Deforestation pressure overlaid with maps A, B and C

Source: Rodrigo Botero 2014.

Assessing Impacts

The nature and significance of all possible impacts should be assessed. The intrinsic, utility, functional, and structural values of biodiversity and natural habitats should be considered. Consideration should also be given to the potential significance of impacts on the composition, structure, and function of biodiversity and sensitive areas at the landscape, habitat/ecosystem, species/population, and gene (where applicable) levels (Duke and Aycrigg 2000). Impact assessment should, among other factors, include:

- The impacts on biodiversity, ecosystem services, and natural habitats, including sensitive areas and other important areas like biological corridors, local communities.
- Assessment of possible impacts for each project stage: pre-construction, construction, operations/maintenance, and decommissioning.
- Description of the nature and magnitude of impacts assessed—this includes the degree of severity such as major, moderate, and low or reversible.
- More rigorous analysis of major and irreversible impacts.
- Identification and analysis of direct and indirect (including induced) impacts using a systematic methodology (such as matrices, checklists, expert judgment, extensive consultations).
- Cumulative impact analysis.
- Analysis of impact interactions.
- Analysis of impacts as a deviation from baseline conditions (the difference between conditions expected if development were not to proceed and those expected as a consequence of it).
- Duration of impacts (long-term or short-term).
- Economic valuation of environmental costs and benefits, including utility and functional values of the species, habitats, and ecosystems affected (including their economic importance) in a local, regional, or national context.
- Assessment of the possibility of accidents during construction and of operations that might affect natural habitats or biodiversity and that might require special precautionary measures.

Management Measures

Management measures are proposed based on the baseline data and impacts identified. The environmental assessment should recommend options for eliminating, reducing to acceptable levels, or mitigating environmental impacts. This should include information regarding:

- Measures to control both adverse impacts and enhance project benefits.
- Measures for all significant impacts; wherever possible, these measures should be defined in practical terms (e.g., costs, needs, and timetable).
- Issues concerning the integrity of natural habitats and ecosystems and maintenance of their functions.
- Measures to deal with issues affecting the ecosystems outside the project boundaries.
- Measures to avoid and minimize impacts before prescribing mitigation activities.
- Any residual or unmitigated impacts and a justification why these impacts cannot be mitigated.
- Compensation/offset plan for residual impacts that cannot be mitigated.
- If all concerned parties and institutions accept the compensation, confirmation that they are willing and committed to implement it.
- Effectiveness of mitigation measures.
- An implementation schedule, along with cost estimates, a financing plan, and institutional responsibilities for mitigation measures.

Examples of typical measures incorporating the Mitigation Hierarchy are given in Box 10.

Box 10. Typical Mitigation Measures

- Full site protection through project relocation or redesign (avoidance)
- Strategic habitat retention (minimization)
- Restricted conversion or modification (minimization)
- Measures to minimize ecological damage (minimization)
- Post-development restoration works (compensation)
- Ex-situ measures, such as captive breeding, plant seed banking (compensation)
- Translocation and/or reintroduction of species (compensation)
- Restoration of degraded habitats (enhancement)
- Redesign and upgrading culverts (Minimization and enhancement)
- Establishment and maintenance of ecologically similar protected area of suitable size and integrity (enhancement or offset)

Source: Duke and Aycrigg 2000.

Environmental Management Plan

The environmental management plan (EMP) should outline the management, monitoring, and institutional measures and the implementation schedule for a project to avoid or control adverse impacts. The EMP should also describe the actions needed to implement the latter measures and should include the following:

- A list of all project-related activities and impacts, organized by development stage (planning, construction, operation, and decommissioning).
- Management measures for relevant impacts.
- A monitoring program indicating the linkages between impacts identified in the EIA report, indicators to be measured, methods to be used, sampling locations, frequency of measurements, detection limits (where appropriate), and a definition of thresholds that will signal the need for corrective actions.
- A list of regulatory agencies involved in the implementation of the EMP and their responsibilities.
- Specific remedial and monitoring measures given for construction and operation activities and impacts, stressing the use of best engineering practices, using local materials as far as possible, managing drainage issues, etc.; these should be presented in consultation with the road designers.
- Consideration of important ecological aspects such as species-area relationships, protected area design, viability of species populations, and connectivity of habitats, where applicable.
- The timing, frequency, location, and duration of monitoring measures specified in an implementation schedule.
- Reporting schedule, including discussion of what to submit, to whom, and when as well as cost estimates and sources of funding for both one-time costs and recurring expenses for EMP implementation.
- Procedures to provide information on the progress and results of mitigation and monitoring measures.
- Institutional arrangements for implementing the measures.
- Training needs and schedule for training, including identifying potential trainers.
- Inclusion of costs of mitigation measures in the project's financing and mechanisms to ensure that adequate recurrent cost financing is incorporated into the project implementation.

- Compensation measures for impacts that cannot be minimized or mitigated.
- Landscaping plan to improve visual aesthetics.

The cumulative impact assessment should produce a mitigation plan, which is similar in structure as the EMP but which addresses the cumulative impacts. All measures or activities included in the EMP need to be fully budgeted and have a clear definition of institutional responsibilities (JICA 2013). A schedule for these activities tailored to the project planning, construction, and operation stages needs to be prepared. Moreover, these activities should be integrated in the project activities as a whole.

As a good practice, the project's EMP should be budgeted and included in the bidding documents to ensure that the contractor will implement it. The design phase usually ends when the project's bidding process has ended and the construction contract has been awarded to a specific contractor.

Construction Stage

Prior to beginning construction, the contractor should submit an environmental and social management implementation plan based on his construction methodologies, work program, and type and number of construction plants that will be used. The implementation plan should demonstrate compliance with the environmental and social requirements established in the bidding documents and should be enhanced by the contractor's works practices, implementation procedures, and programs.

Collaboration between the design and environmental team should continue during construction, where the environmental supervision engineer can timely identify any environmental issue that may arise and propose measures to address it.

Engineering Techniques Integrating Environmental Consideration

Using innovative products and processes can improve infrastructure construction sustainability. This involves using alternative materials and processes, using high-performance and value-added products, minimizing the use of natural resources, minimizing waste, recycling, reusing, and optimizing economic resources (Bustamante and Montoliu 2014). Further, improving existing practices such as using warm mixed asphalt rather than traditional asphalt mixes or using alternative materials for pavement construction where appropriate (such as biopolymers or biobinders) can eliminate the use of hazardous substances and reduce greenhouse gas emissions as well as reduce energy consumption (Bustamante and Montoliu 2014). Chapter 6 describes in more detail new and innovative technologies and products that can be used during road construction to improve efficiency and minimize pollution, thereby reducing the environmental impacts generated during construction.

During construction, it is usually a better option to use locally available construction materials (as long as they meet the specification requirements), as well as local resources, labor, and skills. Using local materials can be cost-effective and can minimize the air, noise, and dust pollution created by hauling materials from long distances. Creative engineering solutions and/or techniques for the use of materials may be required. In areas such the Amazon, with deficits in aggregates, it could be beneficial to use stabilization techniques using lime or cement for the construction of the pavement layers, thereby also reducing the need to transport materials. In mountainous areas, for example, as a good engineering practice to minimize environmental impacts, a careful study of the layout and compensation of land analyzing the size of the cuts and embankments, walls, and other containment structures should be carried out (use of the road's mass curve). The Latin American region has seen an excessive use of slope cutting solutions rather than containment walls, perhaps since the latter requires greater analysis, more field testing, and engineering calculations, although it can be a more sustainable solution.

Throughout the construction stage, measures to minimize environmental impacts should be taken; Box 11 presents the minimum requirements for good environmental management. Some of these issues are discussed further in this section.

Box 11. Environmental Management

During construction, all activities such as workers' camp installation, works carried out in the road corridor, borrow pits and tunnels, and ecological works should take potential environmental impacts into account. The contractor should follow provisions of the EMP and work with the supervision engineer and environmental team throughout. The following environmental specifications should be included in the bidding documents.

a. Work Safety, Camp and Site Installation
- Workforce
- Environmental Training and Awareness
- Construction Site Safety
- Camp and Site Installation
- Wastewater
- Solid Waste
- Hazardous and Chemical Waste
- Use and Storage of Material Handling
- Maintenance of Construction Equipment

b. Road Corridor
- Clearing of Construction Areas
- Erosion and Sedimentation
- Earthworks, Cuts and Fill Slopes
- Air Quality
- Noise and Vibration
- Traffic Management

c. Stockpiles, Borrow Pits, and Tunnels
- Stockpiles and Borrow Pits
- Tunnels

d. Ecological Considerations
- Landscape, Visual Impacts, and Restoration
- Scenic Spots and Sensitive Areas
- Environmental Emergency Procedures

Erosion and slope stabilization—green corridors: Plant cover and natural vegetative residue protect the soil from the impact of wind and water, slowing runoff and enhancing infiltration of water. During road construction, trees and plants are removed, the natural drainage pathways are altered, and stable topsoil aggregates are stripped away as part of the grading process, exposing the soil surface to the elements causing soil erosion (GGHACA 2006).

To Note: Drainage and erosion control should be incorporated into the project design, and an erosion and sediment control plan should be in place before any earthmoving activity occurs.

Erosion control methods include planting grasses using vetiver grass, planting shrubs, stepped slopes, riprap, crib walls, grindwork, wooden barricades, geotextiles, and retaining walls (see Figure 8) (Tsunokawa and Hoban 1997). Slope stabilization can be carried out using simpler techniques such as planting vegetation or using sophisticated techniques such as retaining walls in more complex situations.

Figure 8. Slope Stabilization and Erosion Control Methods

Earth-reinforced systems, reinforced soils, geosynthetic confined soils, geosynthetic reinforced soils, or mechanically stabilized earth (MSE) walls offer an economical and effective alternative to traditional gravity type structures for most wall heights and applications. Soil-reinforced structures include welded wire walls, geotextile reinforced walls, modular block walls, tire-faced walls, concrete face panel walls, timber walls, lightweight wood, or sawdust walls reinforced with geosynthetics (Keller *et al.* 2011). The least expensive type of MSE wall is a geotextile wall in which the geosynthetic is used for reinforcement as well as wrapping the material around the face (see Figure 9). An emulsion spray, or a more durable facing such as gunite, can be added to the geotextile to prevent degradation when exposed to the sun (see Figure 10). A geotextile stabilized with carbon black helps minimize degradation.

Figure 9. Design Drawings of a Geotextile Wall

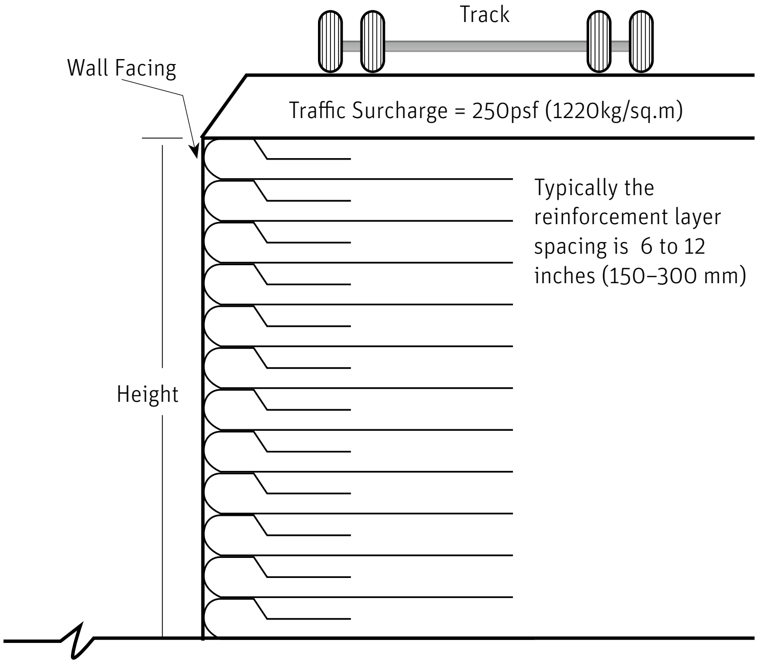


Figure 10. Geotextile Wall Supporting Roadway Prism

Drainage: Good drainage planning, placement, and construction is important for erosion and sediment control. Road drainage systems can be helpful in retaining more water in dry areas (channeling water into aquifers) or in taking away unhealthy standing water. The drainage structures should be based on design flow (such as a storm event) as well as site characteristics and environmental considerations such as fisheries. Every structure has a flow capacity, which should not be exceeded. Examples of drainage structures are given in Figure 11.

Figure 11. Drainage Structures

Managing pollution—sediment and dust control and waste management. Water pollution, particularly from sediments, is an issue during construction when a large amount of soil is disturbed and exposed to erosive forces. Especially problematic areas include water-crossing sites, such as bridges and culverts, and tunnel-drilling sites. A high sediment load can create problems downstream. Measures to prevent water pollution include avoiding alignments that are susceptible to erosion, such as those crossing steep slopes; minimizing the number of water crossings wherever possible; using only clean fill materials around watercourses, such as quarried rock containing no fine soil; and leaving buffer zones of undisturbed vegetation (width increased in proportion to slope) between road sites and bodies of water. In addition, mitigative measures such as controlling the flow water, using settling basins/sedimentation tanks (see Figure 12), paving dirt and gravel roads, and using water treatment can be carried out (Tsunokawa and Hoban 1997).

Figure 12. Multiple Stage Sedimentation Tank

Air pollution through dust generation and vehicular movement and noise pollution from construction activities like blasting or operation of heavy machinery are common during construction. Watering constructions sites frequently and covering vehicles transporting materials can control air pollution (see Figure 13). Using well-maintained and "silenced" equipment, operating within existing noise control regulations, and limiting work hours near residential areas can control noise pollution.

Figure 13. Controlling Dust

Significant amounts of solid and liquid waste can be generated from large road projects. Uncontrolled and untreated, these wastes can become a major source of pollution, disrupting the ecosystem and contributing to local (and sometimes much broader) health problems. It is estimated that construction crews on larger projects that exceed 1,000 people at any one time may generate up to 60,000 liters per day of liquid wastes (sewage) and up to 3,000 kilograms of solid waste (Tsunokawa and Hoban 1997).

Pollution from chemical products can also occur and can be controlled by following the recommended procedures for containing and confining their use (e.g., bitumen production) (see Figure 14).

Figure 14. Proper Management of Chemicals

Quarries and Borrow Areas: These provide materials for road construction, and if the sites are not properly selected and rehabilitated, construction can have significant impacts on soils, water, and the natural environment. This can include erosion and siltation, air quality and noise impacts during their use, as well as visual and aesthetic intrusion. Quarries and large borrow sites should be restored (see Figure 15) and can be landscaped and developed for a variety of natural, economic, or recreational uses (Tsunokawa and Hoban 1997).

Figure 15. Restoration of Borrow Areas

Workers' Camp Management: Several issues are of concern at workers' camps, especially for larger road projects involving migrant workers or a large number of workers living together. These include waste disposal (including sewage), transmission of diseases within the camp and to neighboring communities, water sources and pollution, and illegal activities such as hunting, safety, and sanitation.

Good housekeeping rules—such as providing trash receptacles, cleaning septic tanks, and ensuring that the lifestyles of construction workers do not have any negative impacts on the social and economic welfare of nearby communities—are essential (see Figure 16).

Figure 16. Waste Management

Trash Receptacles

Improper Water and Waste Disposal

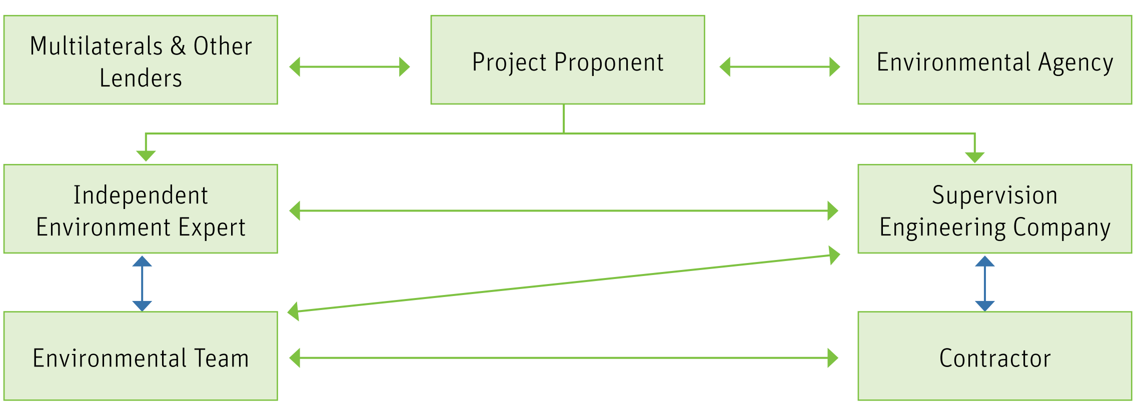
Channel for Treated Sewage Effluent

Roles and Responsibilities

For the EMP to be successful, the active involvement of all entities—the project proponent, environmental agency, the engineer's representative (ER), the environmental engineer team (ET), any contractors, an independent environmental expert, and multilaterals or other lenders—is essential.

There should be a clear organizational structure and line of communication with respect to environmental protection and reporting requirements. A typical organizational chart for implementation is shown in Figure 17.

Figure 17. Typical Organizational Structure during Construction



A summary of the responsibilities of all entities is presented in Table 10.

Table 10. Responsibilities for Environmental Management

Key Actors	Overarching Responsibilities
Project Proponent	Develops a project-specific EMP based on the findings of the EIA process and the requirements on mitigation measures and control mechanism. The project-specific EMP should form part of the project contract specifications. Project proponent has final responsibility for environmental performance of the project during both construction and operational phases. Employs an engineer's representative as its representative to oversee the project works.
Environment Agency	Monitors compliance with EIA requirements and environmental license requirements.
Supervision Engineering Company/Engineers Environmental Representative	Oversees the construction works of the project and monitors the works undertaken by contractors and the environmental team of the contractor in order to ensure compliance with the specifications and contractual requirements.
Environmental Team Established by the Contractor	Implements and manages the EMP program and the required environmental monitoring works.
Contractor	Complies with relevant environmental legislative requirements; works within the scope of contractual requirements and other tender conditions; participates in the joint site inspections undertaken by the ET and undertakes any corrective actions instructed by the ER and/or the independent expert; provides and updates information to the ET regarding works activities that may contribute to the generation of adverse environmental impacts; stops construction activities that generate adverse impacts upon receiving instructions from the ER or the independent expert; adheres to the procedures for carrying out complaint investigation.
Independent Environmental Expert	Checks, reviews, verifies, and validates the overall environmental performance of the project through regular audits, inspections, and reviews of project submissions.
Multilaterals and Other Lenders	Oversees the project works, carries out regular audits, reviews project submissions and the results of audits undertaken by the independent environment expert and ensures that the project is implemented according to the contract specifications and complies with internal policies and procedures.

Source: Atkins 2007.

To minimize the impacts on the environment during the construction of roads, environmental supervision is essential. This can be carried out as part of the engineering supervision or by an independent environmental team. Independent environmental supervision is recommended to ensure compliance with all EMP provisions, particularly in sensitive areas.

During supervision inspection, monitoring and supervision of construction of all road, bridge, and tunnel works and ensuring compliance with the EMP or any other environmental mitigation measures developed as well as with project technical specifications and contract documents should be carried out.

Regular site inspections to review the status of environmental protection measures and the effectiveness of environmental mitigation measures as well as project environmental performance is required. When required, the supervision engineer should recommend alternatives with the least environmental impact.

Monitoring parameters, location, and the frequency of monitoring provided in the EMP should be followed and, if necessary, changes should be made. Monitoring should be carried out by qualified experts and samples should be handled and analyzed appropriately.

Environmental Training

The success of the environmental assessment processes and the implementation of the mitigation measures depends on the awareness of environmental issues by all involved at all stages of the project. Environmental training is necessary for the environmental specialists working on studies, mitigation plans, and supervision. It is also essential for the staff of the road agencies, technical specialists, contractors, consultants, and anyone else involved in the development of the road (Tsunokawa and Hoban 1997).

Training needs assessments should be part of all specific studies or assessments that are carried out during the road cycle. Training needs at the sector level should include planning tools and strategic assessment methodologies. Environmental assessments should identify training needs for EMP implementation. The training content should be tailored to meet the needs of each group. The training time and frequency will differ for each group. For example, training for managers can be carried out during one or two days while that of supervision engineers should continue for one or two years or for the duration of construction, covering a range of topics such as technical methods and procedures, an introduction to ecology, and guidelines for organization and management.

Training should be conducted by qualified specialists consisting of experts specializing in the natural environment and highway professionals who already have field experience with environmental assessment and road project procedures (Tsunokawa and Hoban 1997). During construction, training of workers and technical staff is usually carried out by the supervision engineer.

Operation and Maintenance Stage

The operation and maintenance of roads, highways, bridges, and tunnels involves inspection, routine and season-specific maintenance, and repair of not only the road and bridge structures but also the right-of-way where drainage facilities are located. During operation, emission of greenhouse gases contributing to climate change is a matter of concern. (Managing emissions is a national issue and part of the broader national planning process and climate change strategy; it is beyond the scope of this Guide and as a result is not discussed here.)

Other issues that require monitoring during operation include effects on local biodiversity, water and noise pollution, soil, waste, and safety. Regular monitoring during the operation phase of a road is necessary to ensure that provisions made during the design and construction phases are valid and effective. Monitoring measures specified in the EMP should be followed and modifications made if necessary. Monitoring of drainage and storm water quality and the removal of surface water or hazardous spills should be carried out. Local flora should be protected and replanted where needed. The use of animal crossings and the number of roadkills should be monitored to check the effectiveness of the animal crossing structures and to maintain safe driving conditions. Camera traps or motion sensors can be used to determine the species and frequency of use of the animal crossings. In sensitive areas or areas with high biodiversity, regular patrolling, possibly in coordination with forest agencies, should be carried out to deter poaching, hunting, and other illegal wildlife activities. Monitoring during operation can identify potential problems that may arise and require fixing (maintenance) to minimize environmental impacts and extend the life span of the road surface and associated infrastructure. Key areas that should be monitored include the following:

- Road pavement and right-of-way
  - Road surface and ROW should be free from obstructions, litter, debris, and roadkill.
  - Potholes should be nonexistent or their amount and size should be below a certain minimum.
  - Vegetation in the right-of-way should not exceed a specified height.
  - No trees should obstruct traffic or visibility or pose a safety hazard.
  - Slopes should be free of loose material and should be stabilized using vegetative measures.

- Drainage system
  - Culverts should be free of debris and sediment or up to a maximum percentage of the cross-section.
  - Surface drainage structures should correct cross-section and sediment or be up to a maximum percentage.
  - Riverbeds should be clear for a certain distance from the edges of the road.
- Road works
  - Retaining walls should be structurally sound.
  - Bridge structures should be structurally sound and free of litter and debris.
  - Tunnels should be structurally sound and free of litter and debris.
  - Wildlife crossing structures should be structurally sound and free of litter and debris.
- Road signaling and safety measures
  - Traffic signs, road signs, and road markers should be complete, clean, and clearly visible.
  - Guardrails and bridge railings should be clean, painted, and clearly visible.

Maintenance as a Key Factor in Road Sustainability

Typically, once roads have been built—having gone through the planning, design, and construction process involving large amounts of resources and time—they are then neglected, with only occasional emergency repairs. Once the roads degrade over time (see Chapter 2, Figure 1), the cycle of rehabilitation or reconstruction starts, and once again substantial resources, time, and effort are required to bring the road to its original or useable form. This vicious cycle of construction, degradation, and rehabilitation can be avoided if attention is paid to road maintenance. Maintenance can prolong the life of existing roads, thereby saving time and resources that may otherwise be spent on planning and rehabilitation or reconstruction works. It is estimated that if defects are neglected, an entire road section may fail completely, requiring full reconstruction at three times or more the cost, on average, of maintenance costs (Burningham and Stankevich 2005). Preventive maintenance (avoiding damage to the road and preventing traffic accidents), complemented by timely corrective maintenance (repairing the road), is the most cost-effective path. Maintenance is also essential for the safety of the road. Roads in poor condition can lead to accidents.

As maintenance activities are carried out on the existing platform and are meant to ensure that all associated structures are functioning, such as drains and culverts, impacts to the environment are minimal and may even be avoided (see Figure 18). For instance, blocked drains can lead to water accumulation, affecting the road surface and becoming breeding sites for mosquitoes. If slips or landslides occur, these sites can be easily identified and slope protection works can be carried out, preventing accidents and extending the life of the road. Thus, through regular maintenance the long-term sustainability of the road and associated features can be guaranteed.

Figure 18. Maintenance Activities

Culvert before and after maintenance activities

Road before and after maintenance activities (debris cleaning)

As with other road construction activities, maintenance works can have environmental impacts but on a smaller scale. Impacts can include erosion, disturbance to water flow, chemical pollution, disturbance to traffic, and noise, as discussed earlier. Most of the mitigation measures during construction are applicable during the maintenance phase.

Key Activities

Routine maintenance activities involve clearing and minor repairs to the road pavement, road shoulder, and road reserve to ensure adequate visibility and normal vehicle transit and clearing and minor repairs to the drainage system to ensure the safe conveyance and disposal of runoff water and the free flow of watercourses (World Bank 2008a). Table 11 provides a description of the main routine maintenance activities under these groups. The various components that require maintenance are:

- Road surface: This involves clearing the road surface; removing minor landslides; repairing and sealing cracks, joints, rills, and ruts; patching potholes in pavement and shoulders.
- Right-of-way: This involves clearing the ROW; cutting grass and brush; trimming, cutting, and removing trees; removing loose material from slopes; stabilizing slopes.
- Drainage system: This involves clearing and repairing culverts and inlets; clearing and repairing side drains, channels, and other surface drainage structures; clearing small waterways.
- Road works: This involves repairing retaining walls, cleaning and repairing bridge structures.
- Road signaling and safety measures: This involves cleaning, painting, and maintaining traffic signs, road markers, guardrails, bridge railings, and tunnel structures and removing obstacles in the right-of-way.

Table 11. Routine Maintenance Activities

Activity	Description
Road inspection and clearing	Inspection of the road to assess whether any urgent issues need to be dealt with and clearing any loose material or obstructions.
Removing landslides up to 10 m^3	Clearing landslides smaller than 10 m3 from the road pavement, shoulder, and the drainage ditches to allow normal vehicle transit and proper drainage.
Clearing drainage ditches	Clearing the side ditches and other drainage ditches of sediment and other material that may obstruct the free flow of water in order to ensure proper drainage and the protection of the road.
Clearing culverts	Clearing sediment and other material that may obstruct the free flow of water in the culverts to ensure proper drainage and the protection of the road.
Clearing bridges	Clearing boulders, branches, and other material that may obstruct the free flow of water below the bridges in order to ensure proper drainage and the protection of the road.
Clearing the road reserve	Cutting vegetation that grows in the road reserve and impedes visibility, restricts normal traffic, or damages the road, drainage system, or other road works, as well as the collection of garbage.
Repairing the road shoulder	Filling up and compacting the road shoulder to the height of the road surface in order to avoid damage to vehicles and to ensure that the road pavement is not undermined.
Sealing cracks and joints	Removing loose material from cracks and joints and sealing them with bitumen to avoid water entering and causing more severe damage to the road.
Repairing potholes	Filling small potholes with compacted asphalt to restore the uniform pavement surface and allow normal vehicle transit.
Removing loose material from slopes	Removal of stones and loose soil from the slopes above the road to avoid having them fall on the road or cause landslides, which could damage the road or vehicles.
Repairing retaining walls	Replacement of loose stones in the retaining wall and clearing of the weep holes to allow proper drainage and avoid having the wall collapse.

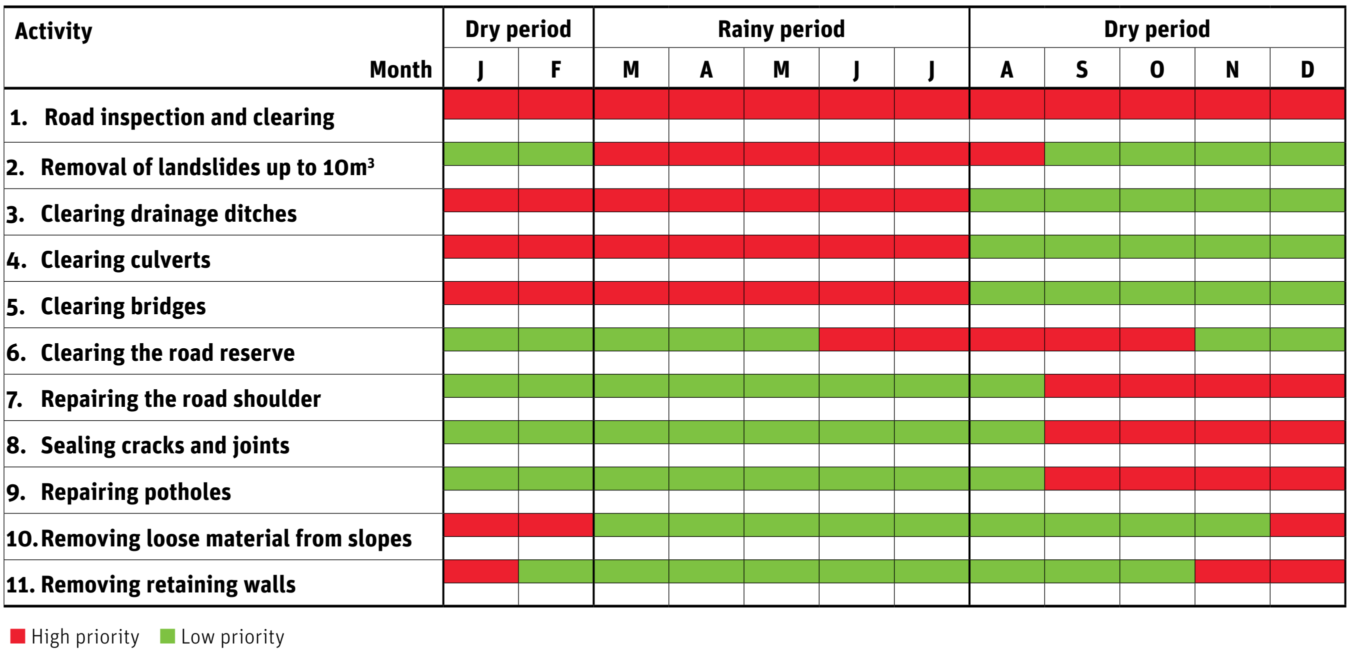
Source: World Bank 2008a.

Maintenance Schedule

The agency responsible for the maintenance works should be identified. This varies between countries and municipalities. Common models include a central maintenance department in the road agency, outsourcing individual roads and network of roads to contractors, association of townships that buy equipment and maintain maintenance crew and rotate service, rehabilitation and maintenance contracts, microenterprises in local communities, and maintenance teams in municipalities or townships.

Maintenance activities should be planned during the course of the year, taking into account the season and the need and frequency of the activity. For example, clearing of the drainage structures should be carried out before the rainy season starts and for the duration of the season, ensuring that the drains allow the free flow of runoff water. Figure 19 gives an example of a maintenance schedule plan.

Figure 19. Maintenance Schedule for Roads



Community Involvement

Local communities can play a significant role in maintenance activities (see Box 12). In some countries, such as Peru or Colombia, local communities are involved through microenterprises. Creation of microenterprises for labor-based routine road maintenance, both of the paved network and the unpaved network, complemented by periodic maintenance (generally equipment-based) every few years, ensures sustainability of the roads.

Local communities, either through microenterprises or through other forms of contracts, use labor-based methods and hand tools in carrying out different activities aimed at improving and maintaining a stretch of the road. Experience from Latin America shows that the contracting of microenterprises for routine road maintenance has improved road conditions throughout the year as well as extended the life span of the roads, thus reducing transport costs and travel times and increasing economic activities and incomes (World Bank 2008b).

Box 12. Experiences from Latin America

Data on roads receiving routine maintenance in Peru showed that transport costs had been reduced by more than 20%, traffic had increased by more than 100%, and transport times had been halved.

In Honduras, the Department of Maintenance employed 5,208 people in the execution of maintenance activities by force account, resulting in low levels of efficiency and 74% of the budget being spent on salaries. With the introduction of the microenterprise-based routine maintenance system as part of the Road Fund, the required personnel was reduced to 700 people and the coverage was greatly increased. Whereas in the former Department of Maintenance each employee was on average responsible for 2.6 km of roads, each employee of the Road Fund is responsible for 368 km of roads.

Source: World Bank 2008b.

Table 12. Components to Screen for in Sensitive Areas

Sensitive Area	Components
Forests	▶ Type of vegetation ▶ Flora and fauna, including threatened and endangered species ▶ Migratory routes/corridors ▶ Aerial pathways ▶ Breeding grounds and feeding areas ▶ Water bodies, aquatic habitat ▶ Fish species ▶ Commercial fishing ▶ Hunting ▶ Poaching ▶ Planned conservation areas
Aquatic Habitat **(Swamps, ponds, marshes, lakes, streams, wetlands)**	▶ Birds ▶ Aquatic fauna–fish and other species ▶ Breeding area
Coral Reefs	▶ Fish species/diversity ▶ Coral species ▶ Threatened/endangered coral and fish species ▶ Invertebrate species
Coastal and Riparian	▶ Bird species including breeding birds ▶ Fish species ▶ Mangrove tree species ▶ Fauna species like mammals ▶ Marine biodiversity ▶ Invertebrates like oysters, crabs, shrimp
Grasslands	▶ Type of vegetation ▶ Flora and fauna, including threatened and endangered species ▶ Migratory routes/corridors ▶ Aerial pathways ▶ Breeding grounds and feeding areas ▶ Water bodies, aquatic habitat ▶ Feeding areas
Caves	▶ Type of invertebrates ▶ Threatened and endangered species ▶ Presence of fossils ▶ Type of rock
Deserts	▶ Type of invertebrates ▶ Flora and fauna, including threatened and endangered species
Savanna	▶ Desertification and infertile soil ▶ Poaching
Mountain and Alpine	▶ Endemic plant and key animal species
Cultural Site	▶ Type and size of cultural site ▶ Type of vegetation around the site ▶ Access to the site
Productive Lands	▶ Nature of land use ▶ Presence of any infrastructure such as for irrigation ▶ Water bodies

Sensitive areas are those that have specific environmental characteristics needing protection and that are susceptible to environmental and sociocultural impacts caused by road development

Chapter 5
Technical Solutions for Roads in Sensitive Areas

Sensitive areas are those that have specific environmental characteristics needing protection and that are susceptible to environmental and sociocultural impacts caused by road development (MPW 2008). Impacts in sensitive areas can be more severe than elsewhere. As a good practice, construction in sensitive areas—particularly those where impacts may cause severe irreparable damages to the environment, such as in mangroves—should be avoided (see Box 13). Even if roads are not located in sensitive areas, proximity to such areas can potentially have impacts in the areas themselves. It is difficult and likely impossible in some locations to control the effects of human activities after roads are built, such as increased land clearing and development, the migration and movement of people, and increased hunting or poaching (van der Ree, Smith, and Grilo 2015).

Box 13. Irreversible Impacts to Sensitive Habitats: Ciénaga-Barranquilla Highway, Colombia

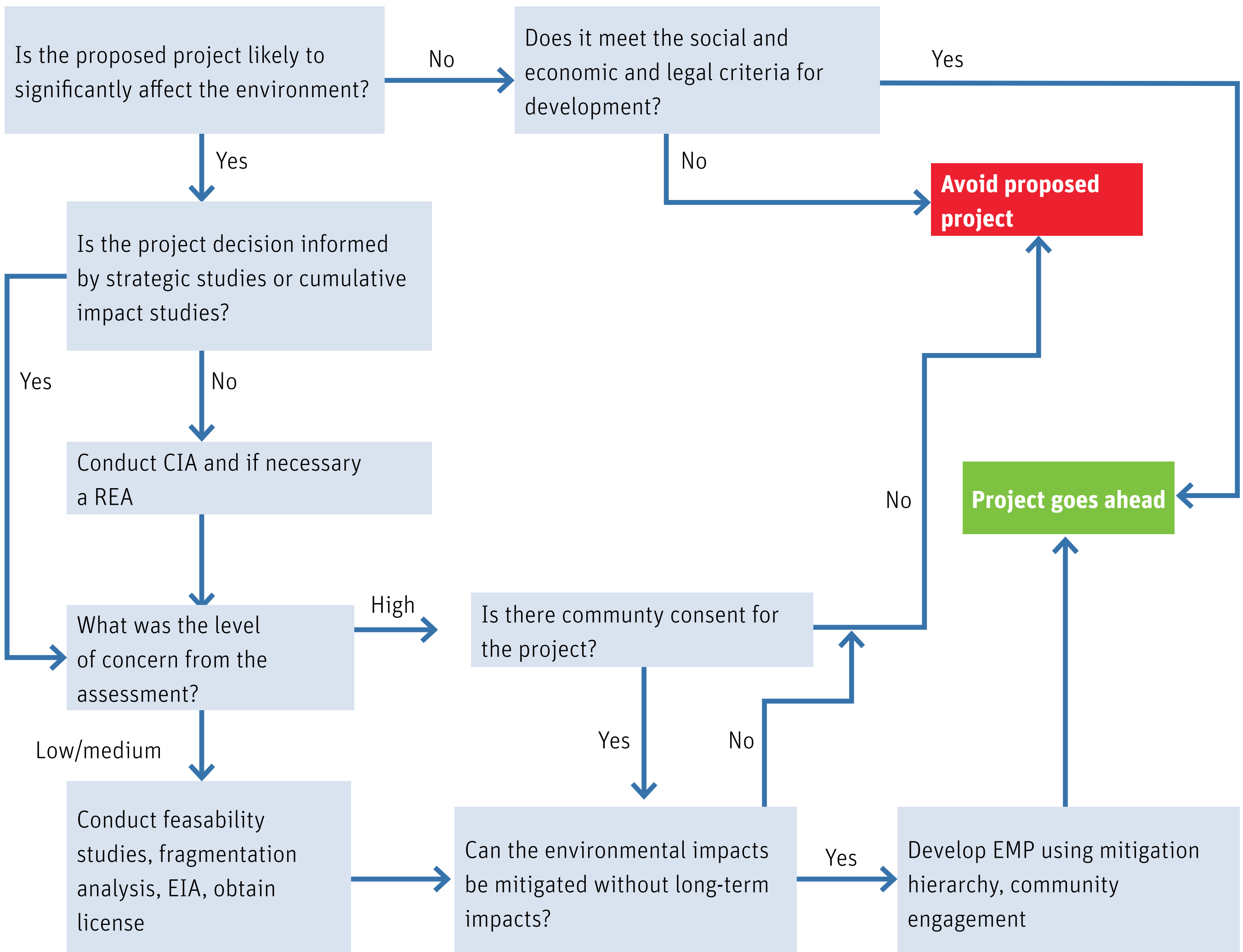
Ciénaga-Barranquilla Highway, cutting across the Ciénaga Grande de Santa Marta, affected the hydrology of the wetland complex, resulting in substantial mangrove mortality (nearly 70%) and fish populations declines. In the 40 years following the construction of this highway, the natural habitat was drastically modified partly as a direct effect of the road as well as the cumulative effects of other development on hydrology and salinity. The road also opened up access to the mangroves for commercial wood extraction, accelerating their decline.

The PROCIENAGA was launched in 1992 with the aim of restoring the natural hydrological flows by reestablishing connections between the ocean and the lagoon that were blocked during highway construction as well as connections between the lagoon and Magdalena River. In the 18 years of effort after the project ended, the restored connections were not properly maintained and as a result the wetland filled with sediment, renewing fish mortality and mangrove dieback. In 2005 the government introduced an environmental tax to the highway toll to support dredging and other maintenance activities. Even after all the efforts, erosion of the road continues, and additional work is required to restore the natural environment.

Source: Mandle, Griffin, and Goldstein 2014.

Adequate due diligence should be conducted and a rigorous methodology such as that depicted in Figure 20 should be used to reach the decision of going ahead in a sensitive area. If indeed the decision is made to go ahead, then in addition to the good practices presented in Chapter 5, specific mitigation measures should be used such as discussed here. Caution should be exercised when planning protection measures in sensitive areas and, depending on the nature of impact in a sensitive area, the mitigation measure may need to be tailored. An example is planning animal crossings. An overpass may be suitable for ungulates such as deer and antelopes, while an underpass may be more suitable for large predators that do not like to be exposed, such as jaguars.

Figure 20. Decision-Making Process



Minimizing Impacts

The sensitive areas more commonly encountered during road construction are protected areas, water bodies, and caves. Specific mitigation measures that can be taken at such locations are described in this section, while Table 13 presents some typical mitigation measure relevant to these areas.

Table 13. Main Environmental Impacts and Typical Mitigation Measures

Type Of Impact	Typical Mitigation Measures
Clearing of vegetation: ▶ Loss of habitat ▶ Habitat disruption or fragmentation ▶ Edge effects	▶ Clearing should avoid domino effect (tree fall longitudinally to ROW) ▶ Rescue of sensitive species of flora and fauna ▶ Selective or salvage logging for commercial timber species ▶ Reforestation/landscaping along ROW ▶ ROW can be used as biodiversity corridor connecting different areas
Road acts as a barrier: ▶ Obstruction to migratory movements ▶ Obstruction of local fauna	▶ Fauna crossings; multiple species fauna crossings are most effective ▶ Improved design of bridges, culverts to act as fauna crossings ▶ Viaducts in sensitive areas for fauna movement ▶ Canopy crossings in rural roads
Road works (earth movements, cuts, excavation/filling, etc.) cause erosion that: ▶ Degrades water quality ▶ Affects aquatic life	▶ Slope stabilization and revegetation of slopes ▶ Restoration of affected areas ▶ Restoration/revegetation of quarries, borrow pits, and disposal sites
Wetland, river, and stream diversion and crossings or works near them: ▶ Affects hydrological balance ▶ Unbalanced salinity in mangrove wetlands ▶ Barrier effect to movement of aquatic life	▶ Culverts and drains properly designed and placed ▶ Multiple culverts in wetland areas ▶ Long bridges/viaducts to cross wetland areas ▶ Buffer zones of undisturbed vegetation left between roads and watercourses
Roads provide access to remote areas and sensitive areas: ▶ During construction, from workforce and camps ▶ For settlers, bringing deforestation, illegal use of natural resources, and changes in land use	▶ Camp and construction environmental specifications ▶ Environmental supervision of construction ▶ Codes of conduct for workers ▶ Limitation of work access to sensitive areas
Increased traffic along roads leads to: ▶ Road kills ▶ Noise effects on fauna	▶ Fauna crossings ▶ Fauna fences ▶ Fauna signs ▶ Traffic speed control ▶ Limitations on night traffic ▶ Special measures in protected areas

Protected Areas (Forests)

Road works in or around protected areas pose significant risks and challenges. Most national parks are designated as such because of their ecological significance or recreational value and are set aside for their protection and preservation. It is always preferable to avoid the construction of a road for through-traffic across a national park or other protected area. In cases where major roads must go through parks and conflicts between road users and the natural environment are anticipated, various mitigation measures that might not ordinarily be justified may be implemented. Box 14 presents the findings of a study from Southeast Asia on how to minimize impacts of road development on endangered mammals. Special measures for road works in protected areas include the following:

- Enactment and enforcement of laws prohibiting hunting, transport of hazardous substances, and removal of plant materials from the park.
- Inspection of the contents of vehicles entering the park to discourage importation of potentially hazardous cargo, such as livestock, when there is reason to believe that disease spread may be an issue—and inspection of vehicles leaving the park, for poached animals and plant materials.
- Educational measures aimed at informing the travelling public about why they should not feed wildlife, remove plants, litter, etc., and to instill a general appreciation of the desirability of conservation.
- Implementation of traffic control measures such as volume restrictions, visible signage, lower speed limits (especially at night), and bans on vehicles stopping while crossing the park.
- Provision of rest areas with garbage cans and toilet facilities to discourage indiscriminate stopping along the roadside and littering.
- Use of design features such as deep ditches, narrow shoulders, and barriers to discourage roadside stops.
- Prohibiting camps, quarries, borrow pits, and disposal sites within park boundaries.

Box 14. Lessons from Southeast Asia

Based on a study identifying specific roads threatening endangered mammals in Southeast Asia, the authors proposed mitigation measures to limit road impacts in the region:

- Maintaining and improving forest connectivity on either side of existing roads (e.g., underpasses, overpasses, road signs, and culverts).
- Increasing enforcement effort along existing roads through habitats of endangered species.
- Minimizing threats from logging roads via sustainable forest management regimes.
- Resolving land rights and tenure prior to road construction.
- Increasing engagement with road development agencies in conservation planning.
- Integrating road planning across relevant government agencies.
- Conducting projections of economic and biodiversity loss prior to road development.
- Exploring compensation schemes that can minimize the need for or impact of proposed roads.
- Auditing environmental and social impact assessments.
- Raising public awareness of environmental impacts of road projects.

Source: Clements *et al.* 2014.

Water Bodies

Roads can lead to surface or groundwater flow modification as well as to a degradation in quality. Changes in water flows can affect the hydrology, restrict movement of fish and other organisms, affect river/steam continuity and alter the habitat of flora and fauna. Sensitive areas should be avoided; where this is not feasible, priority should be given to route alternatives with minimum disturbance to the aquatic ecosystem. In the Belize Road Sector Project, a road under the program crossed a wetland area. Rather than long embankments, the project included numerous culverts that allowed a more natural (and not concentrated) flow of water between the left and right hand sides of the road (see Figure 21).

Special measures to protect water bodies include the following:

- Avoiding alignments that are susceptible to erosion, such as those crossing steep slopes.
- Minimizing the number of water crossings wherever possible.
- Using only clean fill materials around watercourses, such as quarried rock containing no fine soil.
- Leaving buffer zones of undisturbed vegetation (width increased in proportion to slope) between road sites and bodies of water.
- Paving sections of dirt and gravel roads that are prone to erosion near water bodies to reduce the amount of sediment produced.
- Installing and maintaining temporary erosion and sedimentation controls along the ROWs where construction activities disturb soils near watercourses.
- Maintaining the flow of the water body through proper placement and appropriate size of culverts.
- Using wider bridge spans and reducing or eliminating in-water piers help to limit effects on aquatic systems.
- Designing bridges and culverts with hydraulic characteristics that allow aquatic organisms to pass through them in both directions, as appropriate to different life stages.

Figure 21. Maintaining the Flow of Water

Caves/Karst Areas

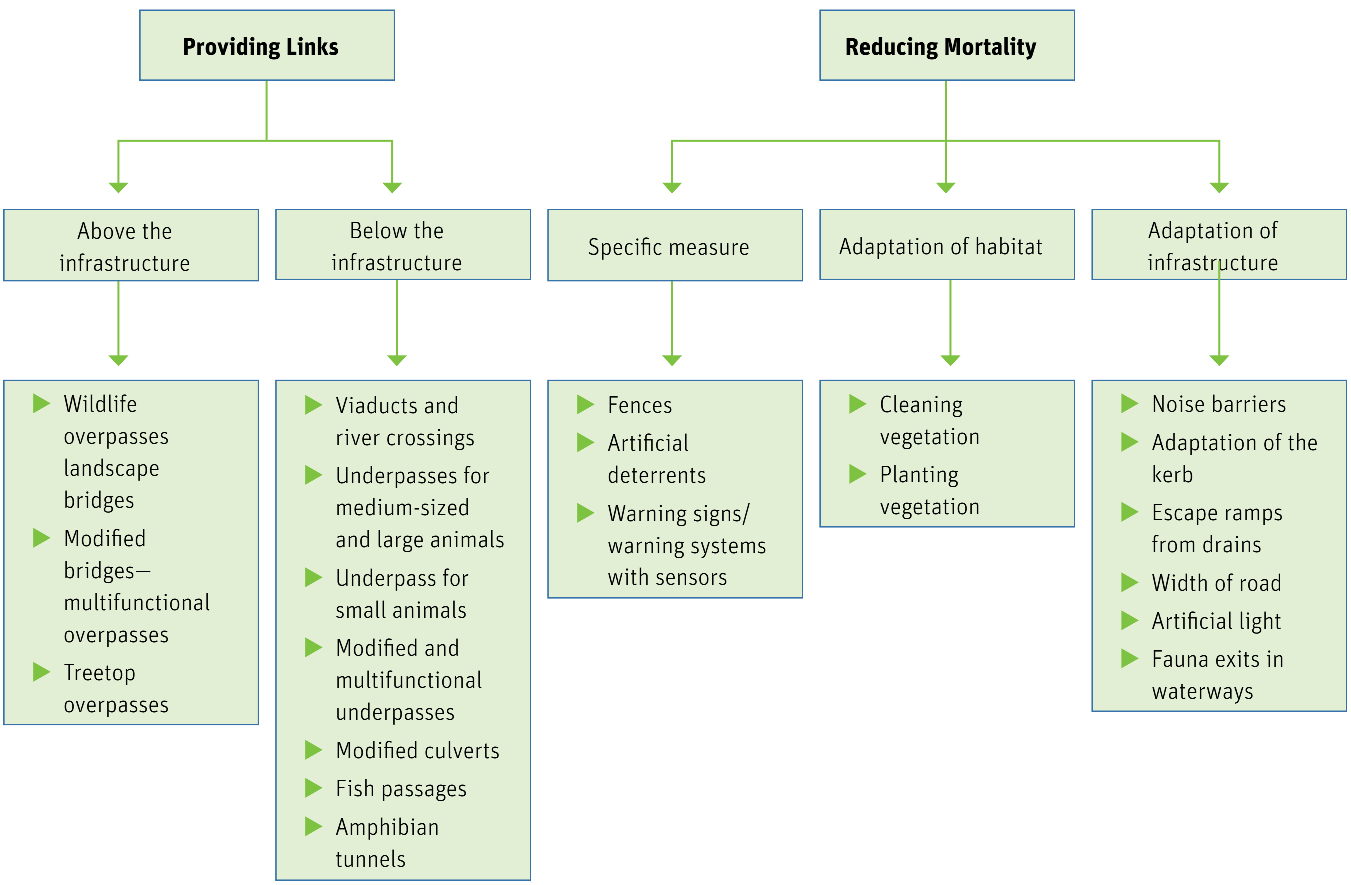
Road construction in karst areas poses sensitive challenges given the presence of caves. Usually, little is known of cave biodiversity, so cave-specific surveys are needed to identify their significance. The Environmental Management Plan should include specific mitigation measures for these cases, such as installing a grill in the culvert at the entrance to prevent human access but allow the passage of bats and not impede the flow of water, protecting the watershed of the cave to prevent groundwater pollution, and installing silt fences and filter strips to prevent runoff of sediments from construction sites into sinkholes.

Engineering Solutions

Fauna Protection

Habitat modification, including fragmentation, is one of the major causes of environmental degradation, particularly in sensitive areas. Measures can be taken to directly provide links between habitats severed by infrastructure, such as wildlife crossing structures or fauna passages, along with measures that aim to improve road safety and reduce the impact of traffic on animal populations by reducing traffic-related mortality. Mitigating impacts can involve a combination of these. Fences work well in combination with fauna passages to compensate for their barrier effect and to channel fauna toward the passage (Iuell *et al.* 2003). Depending on the purpose of the mitigation measure and wildlife present in the area, various methods can minimize the effects of roads (see Figure 22). However, it should be noted that the inclusion of mitigation measures in a proposed road project does not automatically mean that all effects will have been mitigated and that the project should proceed. For example, the likelihood of crossing structures effectively permitting the annual migration of hundreds of thousands of mammals in the Serengeti is extremely low (van der Ree, Smith, and Grilo 2015). Avoidance or "no-go" areas are often the best option in sensitive areas.

Figure 22. Measures to Mitigate Habitat Impacts on Wildlife

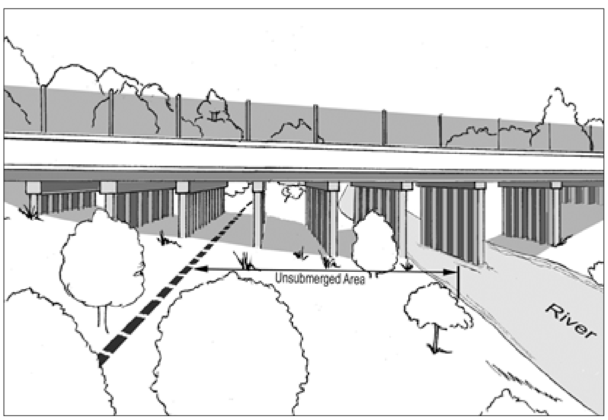


Source: Iuell *et al.* 2003.

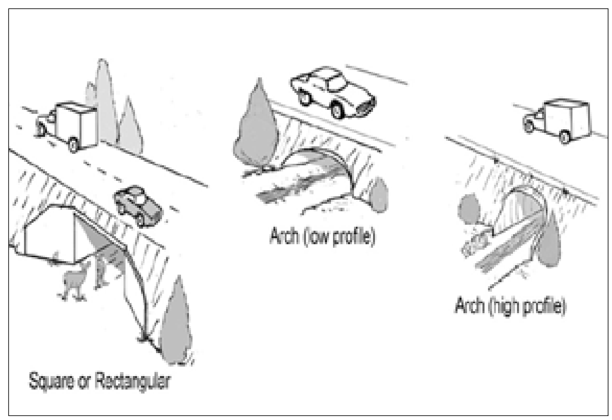
At important crossing points, animal tunnels or bridges can be used to reduce collision rates, especially for protected or endangered species. The use of culverts, bridges, and tunnels or other hydraulic structures can be used for fauna crossings (see Figures 23 and 24). For instance, the use of tunnel-viaduct-tunnel schemes in the Yiba Highway Project in China minimizes the impacts on the movement of local fauna. Species-specific fauna crossings can be expensive and should be used only at a few locations where they are both justified by the importance of the animal population and the crossing route. Imposing vehicle speed limits and traffic calming measures such as speed bumps, where possible, can reduce vehicle-animal collisions. The intention is to lower the vehicle speeds to minimize fatalities (Gleeson and Gleeson 2012).

The crossing structure has to be built such that animals are able to use them. Suitable habitat for species should occur on both sides of the crossing structure at both local and landscape scales. On a local scale, vegetative cover should be present near entrances to give animals security and to reduce the negative effects of lighting and noise. As pointed out by Clevenger and Waltho (2005), crossing structures will only be as effective as the land and resource management strategies around them. Further, at least one structure should be built within an individual's home range. For example, as reptiles, small mammals, and amphibians typically have small home ranges, culverts should be installed at intervals of about 150–300 meters (Beier *et al.* 2008).

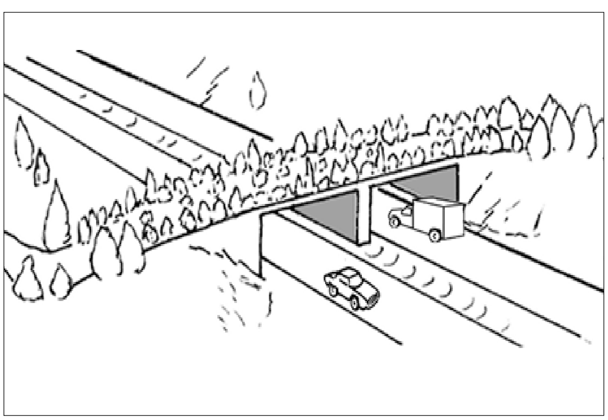
Figure 23. Schemes for Fauna Crossings—Enhanced Culverts and Bridges



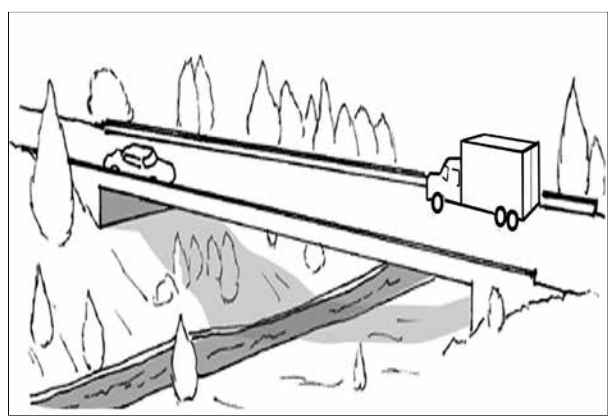
Enhanced Bridge



Enhanced Box Culverts



Fauna Overpass



Water Crossing

Source: Keller and Sherar 2003.

Figure 24. Wildlife-Friendly Structures

50m wide wildlife overpass, Canada

Viaducts in sensitive areas in Yiba Highway, China

Eco-bridges developed as part of wildlife corridors in Malaysia

Impacts on aquatic systems from road construction can be further minimized by proper design of stream crossings and box culverts.[4] Figure 25 illustrates the right and wrong placement of box culvert on a stream crossing. Improving stream crossings to ensure the movement of aquatic organisms can result in many social, environmental and economic benefits, ranging from improved water quality to reduced mental health impacts for people and avoided property damage following major storms. Advantages of road stream crossing are given in Table 14 (Levine 2013).

Figure 25. Proper Box Culvert Placement for Aquatic Connectivity

Aquatic System Fragmentation

Proper Placement of Culvert

[4] See the additional readings section for references on design solutions for maintaining aquatic connectivity.

Table 14. Benefits of Fauna Friendly Stream Crossings

Type of Impact	Outcomes
Social	▶ Improved safety and mobility ▶ Avoided physical and mental health impacts ▶ Enhanced river-related recreation
Environmental	▶ Healthier populations of fish and wildlife ▶ Improved river habitat for in-stream and river dependent species ▶ Decreased erosion of stream banks ▶ Improved water quality ▶ Avoided water quality impacts from storm-related failure
Economic	▶ Avoided flood repair costs: – Repair of damaged infrastructure – Repair and replacement of damaged property – Travel delays – Lost business income from road closures – Local jobs for contractors – Avoided costs to repair environmental degradation (e.g., water quality)

Signs indicating the presence of fauna are a cost-effective means of lowering road strikes. Signs serve as a warning to the general public and to workers during construction and operation. They alert people with the need to reduce speed while passing areas with wildlife activity. The design and placement of the signs can influence behavior. The signs should be placed where they can be clearly seen and give motorists time to react, particularly in areas where fauna crossings occur. Methods to enhance the effectiveness of fauna signs include the following (Gleeson and Gleeson 2012) (and see Figure 26):

- Adding a speed limit.
- Adding flashing lights.
- Using fiber optics to display speed limits or flashing lights when triggered by an animal.
- Making signs physically larger.
- Adding diamond reflecting material.
- Using portable rather than permanent signs so that they can be used at the most relevant times, which is beneficial for seasonally migratory animals.

Figure 26. Fauna Signage

Figure 27. Slope Stabilization, Landscaping, Reforestation

Flora Protection

Restoration of vegetation can be applied as part of slope stabilization measures, preferably using local species, and this can provide animals with shelters as well as landscaping benefits to the road (see Figure 27). Highway projects financed by the World Bank in China include extensive stabilization and landscaping measures, creating green corridors along the ROW. The effectiveness of flora and fauna measures and their relative costs are presented in Table 15.

Table 15. Indicative Comparison of Mitigative Measures for Protecting Flora and Fauna

Measure	Effectiveness	Costs
Vegetative protection fence	Medium protection; excellent integration into the landscape	Low cost, requires maintenance
Artificial fence	Good protection of animals and drivers but can inhibit animal movements	Comparable to vegetation fence
Animal overpass	Very effective where warranted	Expensive; same as normal overpass

Source: Tsunokawa and Hoban 1997.

Compensating for Impacts

Through compensation measures, the road project can offset or even positively contribute to environmental quality. The aim is that the total quality of the environment within an area shall not be reduced because of road construction. Compensation measures can take one of two approaches:

To Note: Compensation should be a last resort, after all avoidance, minimization, and restoration options have been exhausted.

- Replace a function at the same place as the damaged one. For example:
  - Plant trees as replacements for those cut down during construction.
  - Rehabilitate and recultivate abandoned gravel pits in the vicinity of the road project to offset other negative impacts in the environment.

  - Increase existing wetland or improve the quality of existing wetlands if other wetlands are negatively affected.
- Replace functions at another place:
  - Plant trees elsewhere if trees have to be cut down during construction.
  - Construct a developed and serviced parking area to attract tourists to certain places.
  - Create awareness about places of cultural interests nearby if the road project has affected a cultural heritage area significantly.
  - Financial compensation

Perhaps the most common compensation measure in road projects is the reforestation of the right-of-way or reforestation in designated areas along the road. Ecological restoration of borrow pits and disposal sites are also compensation measures. For instance, quarries restored as wetlands can become an ideal habitat for waterfowl in the area. Revegetated disposal sites can house small local fauna.

Compensatory measures should primarily provide value equivalent to what was damaged at the same place and should secondarily provide other environmental value to another place. The measure should, however, always be connected with the negative impacts that have been identified. Furthermore, the measure should be designed so that it is the affected party that benefits from the compensation. How compensatory measures are carried out therefore depends on what is to be compensated, for whom, and the goal of the measure.

Countries such as Colombia and Peru are now mandating compensatory measures. In Colombia, in 2012, a new policy was established that require planned development projects to offset residual biodiversity impacts by restoring or protecting an equivalent habitat elsewhere. The new regulation is based on two key principles: no net loss and ecological equivalence. Furthermore, it establishes offset ratios that range from 1:4 to 1:10. Biodiversity offset plans have to be presented to the environmental agencies up to one year after the environmental permit has been awarded (Sarmiento 2013). Compensation scheme for aquatic ecosystems is being developed as well. The Peruvian Payments for Ecosystem Services Law (Ley de Mecanismos de Retribución por Servicios Ecosistémicos) sets out a framework for compensation for ecosystem services between land stewards and beneficiaries, including civil society, businesses, and municipal governments. The law promotes, regulates and supervises payment mechanisms for ecosystem services arising from voluntary agreements that establish conservation actions, recovery and sustainable use (PES law - Ley Nº 30215). The PES Law recognizes contractual freedom for the contributors and beneficiaries to agree on the PES scheme to be implemented.

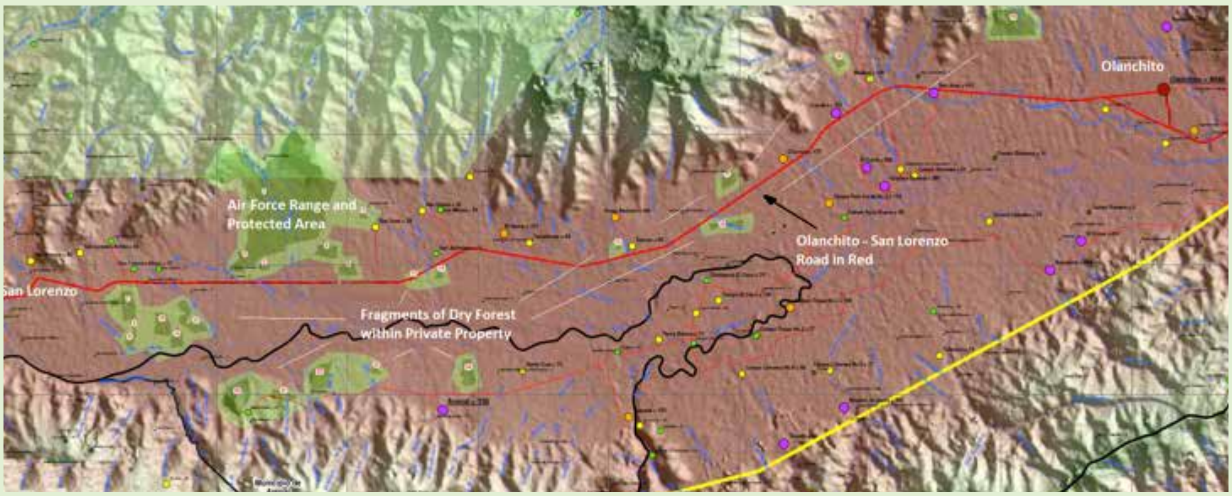
In special cases, compensation measures include compensatory reserves, long term conservation in private reserves or strengthening the protection of existing ones. For example, the Honduras Road Development Project includes the establishment of a system of protected fragments of very dry forest that house the endangered Honduras hummingbird and other sensitive species. The Colombia Mocoa–San Francisco road includes the expansion Forest Reserve and the establishment of a biodiversity corridor between two ecological systems in the country (see Box 15).

Adequate budget for the establishment of compensatory reserves is critical and should be included in the project costs. The timing of implementation is also critical as well as the strengthening of local capacity for implementation. The most important aspect of compensation is guaranteeing the long-term sustainability of the compensation measures. Projects need to include strategies for long-term financing. For example, in the Honduras Road Project, the payments to landowners are limited by the amount of available funds during 10 years. After that, there is no guarantee that the protected area scheme will be sustainable unless other sources of financing are identified. Some road projects going through protected areas allocate a percentage of the tolls to the management of protected areas as a form of sustainable funding source.

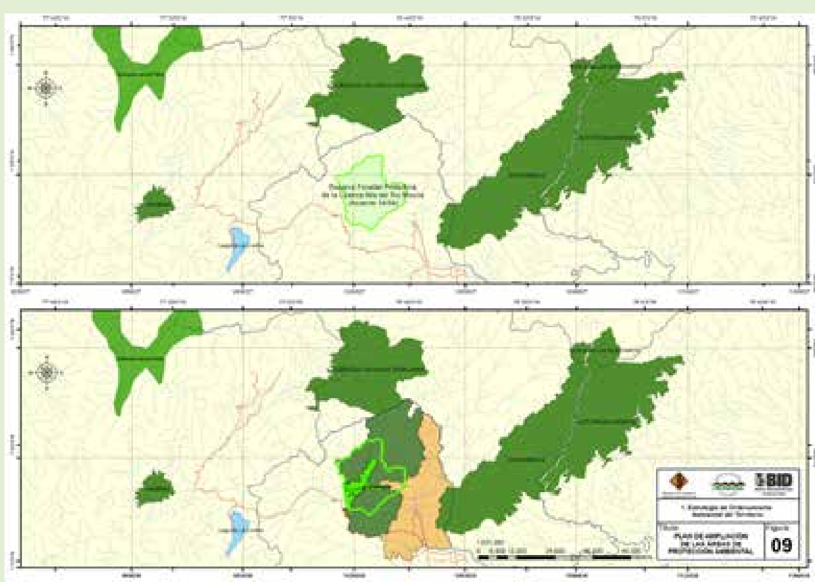
In some countries such as Brazil, the law requires every development project that is determined to have significant environmental impacts to financially support the establishment or maintenance of a conservation unit in the area of project influence. The compensation amount varies as a function of the intensity of undesirable effects upto 0.5% of the project cost (without environmental mitigation cost and taxes). The money is used to create and maintain protected areas (Young 2005). The methodology of determining the compensation is based on impacts on biodiversity, interference with

Box 15. Compensatory Reserves in Two Road Projects

The San Lorenzo–Olanchito area is critical to the survival of the Honduran Emerald Hummingbird and a critically threatened reptile, the black jamo, as well as at least 12 endemic plant species, 9 of which are exclusive to the Aguan Valley. The current habitat is a highly fragmented, with patches of dry forest isolated from each other. The following activities are a part of the compensatory measures undertaken for the Honduras Road Development Project: strictly protecting 419.9 ha of dry thorn forest in an area controlled by the Honduran Air Force, acquiring additional private lands for strict conservation to build a network of core areas, establishing conservation easements to protect areas remaining in private ownership, and expanding the boundaries of the Pico Bonito National Park.



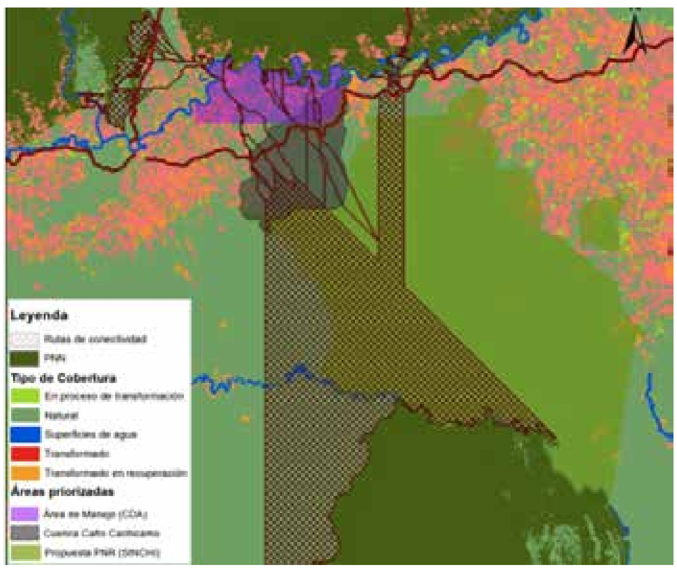
The Colombia Mocoa–San Francisco Road includes the creation and consolidation of a large biological conservation corridor with an area of 121,700 ha, including the expansion of the Forest Reserve from 34,600 ha to 65,289 ha and the creation of a Protected-Productive Forest Reserve (5,770 ha) in the reserve region to minimize habitat loss and establish and maintain an ecologically greater protected area. This compensation scheme was proposed prior to the adoption of the compensation law and therefore there it was not determined whether the measures provided equivalent or greater compensation than the impacts. However, this was the first time a compensation scheme was included as part of the design and set a precedent for projects to follow.



priority conservation areas and influence on conservation units. The compensation has to be carried out in the same watershed or affected biome, close to the project and based on a map of priority area of compensation. While financial compensation is a viable tool for offsetting impacts, it should not replace existing transfers from government budgets. It should serve as an additional funding source for protection of biodiversity.

Additionally, the impacts on natural habitats can be sheltered from the effects of fragmentation by improving the connectivity between forests or national parks or protected areas, allowing for the movement of animals. Habitat loss has to be halted and habitat restoration efforts are required, such as creating and/or protecting biological corridors. For example, the Puerto Rico to San Jose del Guaviare–La Macarena Road is located in a highly ecologically sensitive area, and the road would interfere and disturb the ecological connectivity between La Macarena and Chirbiquete National Parks, interrupting the connections between the Andes and Amazon ecosystems. Thus the project plans to protect an ecological corridor between the two parks (see Figure 28).

Figure 28. Restoring Connectivity



Source: From Puerto Rico to San Jose del Guaviare–La Macarena road project.

The project includes a number of measures to protect and enhance the connectivity of the wildlife. Local indigenous knowledge was critical in identifying the movement and behavior of local fauna aiding in the design and development of the connectivity analysis including placement of culverts, bridges and viaducts. Additionally, the project will include a green longitudinal corridor along the road and will develop a land use plan for the region. These measures are being planned through an inter-institutional collaboration between the Ministry of Transport, the road agency, the Ministry of Environment, the licensing authority and the provincial government. This is the first time in Colombia such upstream planning is being undertaken to avoid and minimize impacts to flora and fauna.

While this represents a landmark effort to minimize negative environmental impacts that could be caused by this road, nevertheless it must be recognized that the road traverses an ecological important and sensitive area. As such, avoidance must always be the principal objective of mitigation in areas of such biological significance.

In a number of road projects, location-specific mitigation and offset measures have been implemented to protect the biodiversity and ecosystems (see Table 16 for examples).

Table 16. Examples of Road Projects Protecting Biodiversity in Sensitive Areas

Measure	Project	Description
Surveys in roads in karstic areas	The Hubei Yiba Highway project, China	Biodiversity surveys in caves along the ROW. Inventory of fauna, bats, and insects.
Biodiversity surveys in forest and grasslands	Hubei Yiba Highway, China; Anhui Second Highway, China	More than 300 flora and fauna transects were carried out in this highway. Vegetation mapping of 500-meter corridor was prepared.
Fauna and flora rescue from ROW	Mocoa–San Francisco Bypass, Colombia	Lichens, orchids, and bird nests as well as small mammals were rescued from ROW before initiation of construction. Specimens were sent to nurseries, protected areas, or gene banks.
Screening tool for critical natural habitats	India PMGSY Rural Roads	Critical natural habitat maps prepared for each participating state. "No-go" areas defined and used as criteria for rejecting project proposals. Special measures for projects in or near protected areas.
Biodiversity corridor	Puerto Rico to San Jose del Guaviare–La Macarena Road	Project will support the establishment of a biodiversity corridor between two major national parks based on landscape management approaches.
Expansion of protected area	Mocoa–San Francisco Bypass, Colombia	The project will support the expansion of a forest reserve (doubling its size) to compensate for crossing the protected area.
Reforestation of degraded areas	Anhui Second Highway, China	Disposal sites along the highway were reforested and are part of the landscape program.
Reforestation of ROW	Hubei Yiba Highway, China; Anhui Second Highway, China	Reforestation of ROW as part of landscape program.
Restoration of quarries, borrow pits, and disposal sites as natural habitats	Access road to dam in Nam Theun 2 hydroelectric project	Borrow pit was restored as wetland area.
Creation of new protected area	Honduras Road Rehabilitation & Improvement II; Mocoa–San Francisco Bypass, Colombia	Protection of 2,200 hectares of fragmented dry forest habitat as a condition of loan. Ease payments to property owners.
ROW as biodiversity corridor	Argentina Santa Fe Road Improvement	Reforestation of ROW between two wetlands to create a biological corridor connecting the two wetlands. Reforestation of this segment is part of a landscape program for the entire highway.

Measure	Project	Description
Viaducts as fauna crossings	Hubei Yiba Highway Project, China	Yiba Highway is inside the Three Gorges Geological Park. High sensitivity of natural habitats. Tunnel-viaduct scheme implemented.
Enhanced box culverts for fauna crossings/ fish connectivity	U.S. Forest Service, forest roads	Correct placement of drains/culverts allows connectivity of aquatic ecosystem.
Multiple culverts in wetland areas	Belize Road Sector Project	Multiple culverts allow hydraulic connectivity for two sides of the road. Long embankment that would have acted as dam was avoided. Increased maintenance is needed for this segment.
Environmental specifications for contractors	Hubei Yiba Highway Project, China; Da Nang–Quang Ngai Expressway, Vietnam; Argentina Santa Fe Road Improvement	Environmental specifications for contractors include code of conduct establishing penalties for poaching/illegal logging, specific restrictions/measures for flora and fauna, environmental/ecological sensitivity training.
Special measures in protected/sensitive areas	Hubei Yiba Highway	Project special measures for protecting karstic caves near the ROW during construction. Workers' restrictions. Demarcation and enclosure of caves. Monitoring during construction.

Source: JICA 2013.

Chapter 6
Innovative Technologies for Roads

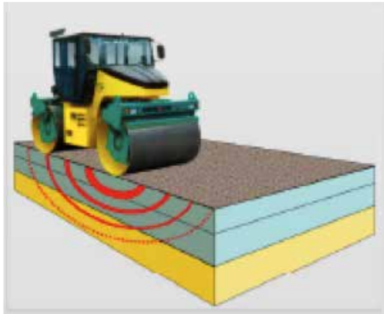
Complementing the good practices described in the preceding chapters, using smart and innovative technologies can minimize environmental impacts arising from construction equipment and road products. The benefits of the new technologies and products include lower emissions and pollution, use of less energy, and minimization of the amount of waste generated. Products such as tire-derived aggregate and rubberized asphalt concrete made from scrap tires minimize the use of natural resources and wastes going into landfills. Others, such as Grade Control Systems, improve productivity and the safety of workers.

This chapter presents some of the latest innovative technologies and products available. Also online tools for impact prediction that can inform planning decisions and environmental screening are described in the chapter. Though these products and technologies improve and change over time as new products are developed, the aim of the chapter is to make practitioners aware of a sample of the latest technologies currently available. While the list is by no means comprehensive, the latest advances in road construction technology and tools can contribute to better roads and improve their overall sustainability.[5]

The mention of specific products and technologies in this chapter is not meant as a commercial endorsement, assessment, opinion, promotion or recommendation by LACC or TNC about such products or their description. The aim is to motivate sponsors and contractors to include, in addition to financial and technical considerations, environmental and conservation considerations in their independent analysis and decision about the different products available in the marketplace.

Road Construction Equipment

New Mixing and Compaction Technologies



Intelligent compaction with vibration modification

New technologies have allowed asphalt temperatures to be reduced. New compaction technologies and equipment enable the operator of a roller to choose the optimal vibration mode on the road construction site. Very fast compaction is achieved, and the level of compaction is measured constantly. Excessive or over compaction is prevented. The compaction machines can be controlled using GPS technology. Real-time displays of machines' current positions, compaction work done, and positions where additional compaction is necessary allow drivers and construction coordinators to plan the use of their machines. It is now possible to stay within a narrower time slot for compaction. The combination of intelligent compaction modes, positioning technology, and on-machine displays allows the new low-temperature asphalts to be applied on road construction sites.

5 Information for this chapter is taken from the International Road Federation's publication on green roads and information presented by ACCIONA Infrastructure company, Dow, and Caterpillar. A generic description of the technologies is given. Thus, some of the benefits do not apply to all models/products available in the market. It is recommended that specific data be obtained for each technology/product.

The compaction machines can be controlled using GPS technology. Real-time displays of machines' current positions, compaction work done, and positions where additional compaction is necessary allow drivers and construction coordinators to plan the use of their machines. The combination of intelligent compaction modes, positioning technology, and on-machine displays allows the new low-temperature asphalts to be applied on road construction sites.

Wheel Loader

The wheel loader is a heavy equipment machine used in construction to move aside or load materials such as asphalt, demolition debris, dirt, gravel, raw minerals, rock and sand into or onto another type of machinery (such as a dump truck, conveyor belt, feed-hopper, or railroad car). An advanced powertrain combines the benefits of different types of transmissions (such as planetary, counter shaft, or hydrostatic), simplifying the operator's interface and operating technique. Using a hydraulic pump and motor (variator unit) allows for a smooth and continuous gear ratio change between engine speed and machine speed. The variator provides this ratio flexibility while greatly reducing the heat load generated by the drive train when the machine is digging, pushing, and climbing under heavy loads.

Improved fuel efficiency means less fuel is consumed, which results in lower emissions and also minimizes the consumption of natural resources. Operator efficiency is improved through enhanced visibility and reduced noise/vibration levels. There are numerous features in the loaders that enable friendly environmental operations, such as auto idle shutdown; ecology drains for engine, transmission, and hydraulics; and oil sampling valves.

Hydraulic and Hybrid Excavator

Hydraulic accumulator storage is efficient, simple, durable, and economical. It is designed for quick power cycles typical of excavators. Some hybrid systems incorporate hydraulic innovations to improve job site efficiency through low ownership and operating costs, excellent performance, high versatility, and—most important—a fuel reduction of up to 25%. The concept is basically to capture and retain energy to be reused and thus save fuel. The hydraulic hybrid system is a simple, reliable, and cost-effective solution that can help reduce a customer cost per ton significantly, using up to 25% less fuel than traditional excavators.

Smart Tractors

Everyday new features are added to tractors. As an example, a new track-type tractor (bulldozer) with electric drive that increases dozing efficiency by 25% (cubic meters/liter) and lowers operating costs by 10% is now on the market. This integrated powertrain reduces fuel consumption by 10–30% and uses fewer parts and fluids during its life. The most significant design feature is an AC electric drive train, which replaces the power shift transmission that is typically used in this size of track-type tractors. It features a beltless design. The control system utilizes either laser or GPS signals to help the operator move the material in an efficient manner and to achieve grade.

These tractors have lower CO_2 and gaseous emissions. The control system allows for an additional 30% improvement in the time to complete a job (due to moving the material efficiently).

Fleet Management Systems

Fleet management systems can help contractors optimize fleet performance and reduce fuel consumption and emissions. These enable customized reports and improve mapping and mixed fleet capabilities. Information can be transmitted via cell and satellite. Timely and accurate information about the location, use, and condition of equipment can be obtained.

Grade Control Systems

Current earth-moving and fine-grading processes are labor-intensive and dependent on workers and instruments. Technologies using GPS help operators work to the design plan by accurately cutting, filling, and reducing material costs. This technology control system is a good solution when the construction site involves contours rather than single or dual slope planes.

The system is a high-technology machine control and guidance system that allows dozer operators to grade with increased accuracy, without the need for survey stakes (see Box 16). Digital design data, in-cab operator guidance features, and automatic blade controls help the operator achieve grade faster. The benefits include:

- It reduces guesswork and costly reworking by moving dirt right the first time. It reduces survey costs by up to 90%.
- In-cab display brings the design to the cab and gives the operator more responsibility. It gives the operator real-time results.
- Grade control systems remove grade stakers and checkers from the worksite and away from the heavy equipment. Safety interlock ensures the blade is securely locked when system is inactive.

Box 16. Increasing Efficiency through the Use of Innovative Technologies

As part of the South Florida Water Management District's efforts to clean up a reservoir (Lake Okeechobee) that supplies the Everglades and 8.1 million Florida residents with freshwater, slope stabilization work in a canal was required. Years of use and damage inflicted in 2005 by Hurricane Wilma had badly eroded the 60-year-old canal's banks. The worksite was remote, partially submerged, and home to hundreds of alligators.

Previous efforts to stabilize the canal banks had attempted to re-establish the original shape of the waterway by backfilling the eroded slopes. But the approach proved controversial because it required putting dirt in the canal water, compounding the murkiness that officials sought to eliminate. Rather than try to restore the canal's original contours, it was decided to reshape the canal to conform to its eroded condition, making it wider and more useful during floods.

As the operators of the hydraulic excavators doing the actual regrading work needed to be able to clearly navigate underwater, innovative technologies such as machinery that used grade control systems were used. This allowed the excavator operators to maintain consistent to-spec grade even when they were working below the waterline and could not see what they were doing. Combining digital design data, in-cab operator guidance features, automatic bucket control, and GPS technology, this system allowed the job to be completed well ahead of schedule. In addition, Product Link helped save time, as any issue with the machinery was easily identified, allowing maintenance to be carried out quickly.

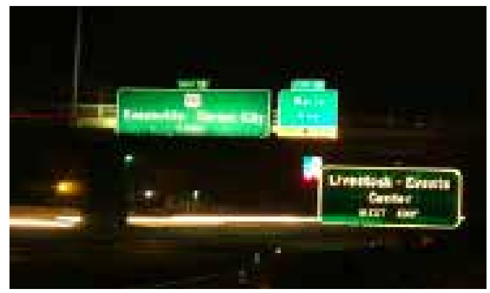
Source: Caterpillar undated.

Road Products and Construction Materials

Reflective Sheeting

This uses a microprismatic manufacturing process with higher molecular weight polymers. No solvents are required, unlike traditional reflective sheeting processes that are based on a multi-layer coating process made up of lower molecular weight polymers. The high molecular weight polymers provide a better UV and weather-resistant retro-reflective film construction. This results in traffic signs than offer a longer effective life cycle. In addition, this sheeting means illuminated signs can be replaced with no negative impact on driver behavior.

Road Marking Products



Some airless line markers and sprays are made from pine resins, vegetable oils, and ground oyster shells. These replace quarry lime, eliminating the need for extraction and much of the raw material transport. The water-based road marking technology has a high affinity with glass spheres to improve retro reflectivity and is weather-resistant. Benefits include reduction of VOC emissions, solid waste and water use, chemical oxygen demand, primary energy use, and human toxicity (Mantilla 2015).

Recycled Road Products and Techniques

There are silent, natural, low-temperature, recycled road products available now. These include noise-reducing surfacing, plant-based binders made of renewable plant products as a substitute for bitumen, flux agents containing plant-based raw materials, and asphalt mixes (environmentally friendly and energy-efficient) manufactured at lower temperatures than conventional mixes.

The noise-reducing surfacing can ensure a 9 dB(A) decrease of traffic noise compared with conventional mixes, dividing noise power by 8. Plant-based binders can serve as a carbon sink and allow for production of asphalt mixes at temperatures that are 40°C lower than conventional mixes. The flux agents do not emit VOCs.

Sustainable Construction Chemicals

Special cure membranes and sealers: These are applied to fresh concrete (usually within two hours) to retain water and to hydrate Portland cement in certain situations. Cure membranes disappear after 28 days of service. They also offer performance benefits such as UV resistance and water durability. Sealers are typically applied to fully cured concrete. They provide gloss, stain resistance, long-term UV and water durability, and hot-tire pick-up resistance.

Grouts and repair mortars: These are adhesives that are used to adhere concrete segments and to repair old or new concrete structures. Some solutions provide greater elasticity and reduced fragility compared with conventional alternatives, delivering better compressive, flexural, and tensile strength.

Super plasticizers backbones: These are high-range water reducers. Chemical admixtures used to improve flow characteristics, allowing the reduction of the water-to-cement ratio, not affecting the workability of the mixture. The strength of concrete increases when the water-to-cement ratio decreases.

Sustainable Construction Materials

For dust control: An additive has been developed that agglomerates particles, making them heavier and lowering dispersion in the air, generating less dust. This leads to better air quality on site, less material wasting (0.5–1% cement saving), and a cleaner job site.

New Cellulose Ether: Some innovations includes a cellulose ether with super-high performance optimizing mortars properties, enhancing mechanical properties, and optimizing cement usage.

Renders: Using special cellulose ethers, new rendering application methods lead to better construction quality, less material waste, less logistical cost, and lower CO_2 emissions than traditional manual mortar.

Polymeric mortars: This is a new mortar application method allowed by the usage of acrylic emulsions. Cement is not required. It leads to better construction quality, lower logistical costs, and lower CO_2 emissions than traditional manual mortar.

Waterproofing: Waterproofing is an important phase of the construction process because it guarantees no water infiltration and therefore a long life to the construction, preventing pathologies and renovation costs. A sustainable emulsion for the bi-component cementitious waterproofing membranes has been developed. It maintains all mechanical properties and cement compatibility, is free of formaldehyde and ammonia, and has lower VOC emissions.

Cool roof: Elastomeric roof coating reflects the sun's heat and prevents it from being absorbed by roofs. It leads to lower energy usage, avoids the heat island effect, has water-resistant properties that avoid mold formation, and requires less maintenance. This coating can be applied on roads to keep them cooler in warm climates.

Cool roof sealer: There are water-based, ready-to-use sealers for enhancing protection and durability of different substrates (concrete, fiber-cement, ceramic). As the sealer is water-based, it has low VOC emissions. It has hydrophobic characteristics, is UV-resistant, is resistant to weather and mold formation, and enhances the durability of surfaces.

Polyurea: Polyurea protective coatings are effective solutions for primary and secondary containment, chemical-resistant liner, corrosion resistance/protection, waterproofing, abrasion resistance, non-skid floor coatings, spray-on bed liner, structural enhancement, and decoration. In roads and bridges construction, polyurea proves useful in waterproofing and corrosion prevention (see Box 17). Polyurea coatings contain zero VOCs or solvents and are non-toxic. They are able to withstand substrate expansion and contraction caused by harsh annual weather cycles, reduce maintenance costs and downtime, and can be applied in a wide range of temperatures.

Box 17. Extending Life of Concrete with Polyurea

While renovating an old tunnel to restore damaged concrete and fix water problems, it was observed that previous coatings had begun cracking and peeling after only a short time. During renovations, the entire tunnel was sandblasted to remove the old coatings, cleaned with a high-pressure wash, and primed. Polyurea was then applied at 50 mils. This new protective coating has been preserving the concrete and can be easily cleaned using a high-pressure wash, reducing maintenance costs. Even after 12 years no additional repairs have been necessary.

Crumb Rubber Modified Asphalt

Finely ground scrap tires (crumb rubber) are added to asphalt to yield a crack sealant. This helps makes a quieter pavement (see Box 18). Smooth surfaces are quieter than rough surfaces; porous are quieter than non-porous; elastic are quieter than non-elastic. Crumb rubber modified asphalt binders have been shown in numerous studies to withstand greater temperatures without deforming.

Box 18. Sustainability in Concrete Road Construction

From 2007–2008, a part of the motorway E34 near Antwerp, Belgium, was rehabilitated with a double-layered continuously reinforced concrete pavement. During the renovation, it was decided to apply two-lift concrete with recycled aggregates in the lower course. The technique of double-layered concrete or two-lift paving consists of dividing the concrete pavement into a bottom lift of approximately 80% of the total design thickness and a top lift of approximately 20% of the total thickness. The thinner upper course makes it economically justifiable to use fine, hard, but also more expensive, stones.

Environmental Benefits: In terms of rolling noise, a reduction of more than 3 dBA was achieved with the two-lift paving technique, compared with the traditional single-layer exposed aggregate concrete with a maximum aggregate size of 20 mm.

Products for Asphalt Cement

One of the major problems in paved roads is the filtration of water through the pavement. When water seeps into pavement and migrates between the asphalt-aggregate interface (through various mechanisms leading to cracking of the pavement.

Ethyleneamines are used to produce different anti-strip additives as amidoamines (which work as emulsifiers that improve asphalt-aggregate adhesion by reducing the surface tension), imidazolines (improves adhesion to aggregate, particularly under wet conditions; provides higher temperature stability), and fatty amines (very effective as adhesion agents for bitumen; relatively unstable at high temperatures). These products orientate themselves such that the hydrocarbon organic chain is retained in the bitumen while the amine group remains at the surface or bitumen-aggregate interface. The net effect is that the long hydrocarbon chain acts as a bridge between the bitumen and aggregate, thus ensuring a strong bond. Amines reduce the amount of fuel used to apply the asphalt (cold mix), reduce CO_2 emission due to the better asphalt quality, and increase the life of asphalt.

Amine and its Derivatives for Cement and Concrete Production

Triethanolamine, a tertiary ethanolamine, has the ability to chelate with certain metallic ions such as Fe3+ in highly alkaline media. Triisopropanolamine is a tertiary isopropanolamine primarily used as a grinding aid, and it is also used in concrete admixtures. The addition of small amounts of these materials improves the rate of the hydration reactions, which leads to faster setting and improved compressive strengths. Different grades of triethanolamine are available. These products effectively coat cement particles to prevent agglomeration and increase the early compressive strength. Addition of the amines can help increase levels of fly ash, slag, or crushed limestone while maintaining good compressive strength. It can reduce raw material costs and make use of waste materials.

Thermal Energy Asphalt Pavements

Asphalt pavements can heat up to 70 degrees Celsius during solar irradiation. Given the enormous area of asphalt pavement that is available, the thermal energy potential therefore appears infinite. This heat can be used in different ways. Several designs have been developed to extract heat from an asphalt pavement. Most apply a heat exchanger design by incorporating tubes in the asphalt pavement. This type of asphalt pavement in the Netherlands is known as "asphalt collector." Demand comes from buildings; supply, from the asphalt pavement. Through the use of an aquifer, the difference in timing between seasonal supply and demand is covered to a large extent.

Using an asphalt collector helps maintain the pavement. In summertime the maximum temperature of the asphalt pavement can be reduced so that chances of permanent deformation are mitigated. In winter it is possible to avoid slippery roads by increasing the minimum pavement temperature.

Terminal Blend Tire Rubber Asphalt (TBTRA)

A terminally blended asphalt manufacturing process is a more environmentally friendly option than the typical "wet" and "dry" tire rubber asphalt manufacturing processes. TBTRA is produced in a closed-system plant, preventing smoke and particulates from entering the atmosphere. TBTRA is smoother, quieter, and safer—particularly during rainstorms. It has proved to have a significantly lower concentration of roadway pollutants running into roadside ditches compared with contaminated storm water runoff of other asphalt pavements.

New Asphalt Technologies

Warm Mix Asphalt: This technology consists of adding additives such as polyvinyl resin, powder synthetic zeolite, or a liquid amine-based compound that reduces viscosity, so that asphalt aggregates can be coated at lower temperatures. This way, the mix is easier to manipulate and can be hauled for longer distances. Other benefits include better performance of pavements, time and costs saving at compaction, healthier conditions for workers, and lower emissions. Some studies have showed considerable reductions: 30% in energy consumption, 25% in particulate material released to the atmosphere, 30% in CO_2, 60% in N_2O, and 35% in SO_2 emissions (Ruiz, Acevedo, and Puello 2014). Half-Warm Mix Asphalt is a water-based technology (emulsified and foamed) with manufacturing temperatures below 100ºC. It does not produce any VOCs or greenhouse gas emissions.

Cold Mix Asphalt Technology: This technology uses a special type of asphalt that is composed of aggregate, an emulsion, and water. The emulsion reduces the viscosity of the asphalt, making it pliable even at cold temperatures. This technology requires substantially less energy, exposes road personnel to fewer hazards, and is generally far more cost-effective than hot mix paving.

Foamed Asphalt Technology: This technology involves injecting a small quantity of cold water (usually with a mass ratio of 1–5% to the asphalt binder), together with compressed air, into hot asphalt (140–170° C). The water becomes steam, and the asphalt is temporarily expanded into bubbles with a higher surface area per unit mass. Foamed asphalt can be added directly to cold granular materials at ambient temperature. The addition of synthetic zeolites to asphalt causes a foaming effect that can help lower the temperatures for manufacturing hot mix asphalt (Ruiz *et al.* 2014).

Rubberized Asphalt Concrete

Rubberized asphalt concrete (RAC) contains ground tire rubber, asphalt binder, and other aggregate materials. It is a longer lasting, more durable pavement that resists cracking, rutting, and shoving. It requires no special paving equipment and can be used at reduced thickness compared with conventional asphalt. It provides a skid-resistant surface and prolonged color contrast with striping and markings. RAC reduces noise pollution with lower tire noise.

Tire-Derived Aggregate

Tire-derived aggregate is made from shredded scrap tires and can be used in a wide range of construction projects. These uses include retaining wall backfill, lightweight embankment fill, landslide stabilization, vibration mitigation, and various landfill applications. It is less expensive than other lightweight fill materials and requires less excavation than soil fill when used for landslide repair.

Alternative Materials for Pavement Construction

Bio-products: These can replace petroleum-derived products, eliminate the use of hazardous substances, reduce greenhouse gas emissions, and lower energy consumption.

Polymeric Waste: These improve rutting resistance and modulus of the asphalt mixes, increasing road infrastructure durability.

Slag: This can be used in place of coarse aggregates in pavement construction, benefiting from the mechanical strength and skid resistance of slag particles. Slag enhances binder adhesion and promotes high frictional and abrasion properties.

Moveable Barriers

The Moveable Barrier System prevents tail-backs at motorway exits, allowing for rapid movement of the safety barrier that delimits motorway deviations and lanes. In the United States, the System is used for both construction sites and fixed plant, where the flow of commuter traffic is in different directions in the morning and evening. The system involves a machine that shifts the barrier sideways at a rate of 9 and 15 km/h. The barrier is made from shaped concrete elements. The top section is T shaped, making it possible for the machine to lift barrier elements by a few centimeters using a system of rollers that passes under the two side wings. Reconfiguring the roadway to expand the work zone without permanently closing lanes accelerates construction and relieves congestion.

Eco-Design of LED Traffic Lights and Variable Message Signs

A new traffic signal and a new generation of variable message signs (VMS) based on life-cycle assessment of these products has been developed. For example, the assessment considered raw material extraction, processing into semi-finished products, production of finished products, use phase (including energy consumption), and the end-of-life management. In terms of global warming potential, the overall reduction achieved by both new product generations compared with previous ones is around 60%. The redesign of the variable message sign will lead to a reduction of 25.5 tons of CO_2 emissions during the VMS 10-year life cycle.

Intelligent Electronic Road User Charging Systems

An integrated road user charging system based on GPS and Global System for Mobile Communications (GSM) technologies is one of the most advanced solutions for influencing route, controlling driving behavior and choice of vehicle. Studies show that reductions in travel times and traffic volumes achieved by tolling decreases congestion, fuel consumption, emissions, noise, and traffic accidents.

Ground Penetration Radar

Radio waves propagate through the ground, which allows “scanning” of the land, serving as a tool for undertaking pavement evaluation and design. It takes less time and cost than conventional techniques. It prevents overdesign or underdesign.

Eco-friendly Products for Soil Treatment

Polymeric products are an alternative ecofriendly solution to traditional soils stabilizers. They help in soil stabilization. The bearing capacity of soil can be stabilized by more than 70%.

Solar Heat-blocking Pavement

The surface layer has a solar reflective pigment that has been developed to reduce the surface temperature and extend pavement longevity.

Amphibian Rescue Fences

Amphibians periodically migrate, particularly during their breeding seasons. At such times, local populations can suffer 50–100% mortality rates from passing vehicles when they attempt to cross even lightly travelled roads. Amphibian rescue fences and channels provide safety for amphibians. Typically, the animals are held back before they reach the road and then channeled into tunnels connecting the different parts of their habitat. One particular guiding device consists of 400 cm long elements. The steel plates are hot-dipped galvanized and so have an average durability of more than 20 years. The elements' height of 40 cm and the overhanging edge of 7cm makes the system invincible for toads, frogs, and also small mammals. The large bottom area forms a vegetation-free running surface that channels the animals into safe crossing areas. The elements are fitted gap-free so animals do not get trapped or try to climb. An additional underground barrier makes it impossible to tunnel under the system. The system can be adjusted to the topography both vertically and horizontally. The elements can be connected in any angle.

Tools for Impact Evaluation

Impacts from infrastructure can be predicted using a number of tools and models as described in Chapter 5. Some of the commonly used tools are described in this section.

Terra-i

URL: http://www.terra-i.org/

Data can be downloaded for free but users have to register on the website to download it.

Terra-i detects land-cover changes resulting from human activities in near real-time, producing updates every 16 days. It currently runs for the whole of Latin America. The system is based on the premise that natural vegetation follows a predictable pattern of change in greenness from one date to the next, brought about by site-specific land and climatic conditions during the same period. The data produced are in RASTER ARC ASCII format at 250m spatial resolution, in decimal degrees and datum WGS84. It is derived from the USGS/NASA MODIS data. The data are processed to provide habitat change maps. The data represent yearly cumulative detections of land cover change since 2004 (CIAT undated).

Databasin

URL: http://databasin.org/

Free to use.

Data Basin assists in spatial analysis of environmental baseline. It aggregates and updates data on the World Database on Protected Areas, species of concern (from Alliance for Zero Extinction, Key Biodiversity Areas, Important Bird Area), terrestrial ecosystems, and much more—a large and continually growing body of datasets including both raw data (e.g., monitoring data on temperature and precipitation, road networks) and analytical results (e.g., projected changes in suitability for a species or ecosystem, interpretations, or recommendations). This online tool allows users to locate a project along with its area of influence in the interactive map making system. The datasets are member-uploaded spatial information, typically created using a geographic information system. They can be visualized and analyzed using mapping tools in Data Basin and downloaded for use in desktop GIS software. Datasets include shapefiles, ArcGRID files, ESRI File Geodatabases, and NetCDF files. Most datasets can be overlaid, styled, analyzed, and downloaded.

Integrated Biodiversity Assessment Tool for Business

URL: https://www.ibatforbusiness.org/login

Registration and fee are required.

IBAT is designed specifically to support businesses in biodiversity assessment. IBAT compiles critical biodiversity data in accordance with globally accepted standards. Businesses can obtain the information through the online mapping tool for screening potential investments, siting an operation in a given region, developing action plans to manage for biodiversity impacts, assessing risks associated with potential sourcing regions, and reporting on corporate biodiversity performance. At its core, IBAT is a central database for globally recognized biodiversity information, including key biodiversity areas and legally protected areas. Through an interactive mapping tool, decision-makers are able to obtain and use information to identify biodiversity risks and opportunities within a project boundary. Exportable maps make it easy for users to quickly share biodiversity assessment results, while downloadable data enable additional in-house analysis. Data are presented in spatial and tabular formats, together with simple mapping functionality.

ImazonGeo

URL: http://www.imazongeo.org.br/imazongeo.php

Free to use.

This is a tool developed in Brazil for monitoring the Amazon Basin. It is a deforestation monitoring system that makes it possible to know, in almost real time, where deforestation occurs. Imazon can assist in detecting environmental risk, such as identifying threats to protected areas and mapping deforested areas, timber harvest, forest typologies, and roads.

Global Forest Watch

URL: http://www.globalforestwatch.org

Free to use.

Global Forest Watch is an interactive, online forest monitoring and alert system. Information about the status of forest landscapes worldwide, including near real-time alerts showing suspected locations of recent tree cover loss, is available. Data on forest change, forest cover, land use, conservation priorities such as protected areas, biodiversity hotspots, birdlife endemic landscapes, and land and resource rights can be generated.

Tremarctos—COLOMBIA

URL: http://www.tremarctoscolombia.org/

Free to use.

This evaluates infrastructure impacts on biodiversity (screening) and provides recommendations regarding compensation that a project can undertake. Information is available on the distribution of species, sensitive ecosystems, protected areas, and areas of sociocultural importance. Risk analysis and analysis of impact to marine resources can also be performed.

Biodiversity and Ecosystem Services Trends and Conditions Assessment Tool (BestCat)

URL: http://bestcat.org.s3.amazonaws.com/index.html

Free to use.

BestCat is a web-based mapping application that gives companies the ability to compare and contrast global assets based on value and condition of ecosystems and associated biodiversity. This application provides businesses with a preset data package that highlights biodiversity and ecosystem service risk and quickly identifies critical locations that require risk management. BestCat analysis provides a basis for developing cost-effective risk mitigation approaches by identifying areas that are associated with potential environmental liabilities. Currently, the application focuses primarily on biodiversity, with the goal of incorporating additional aspects of ecosystem services into the analysis.

MAFE (Mapeo de Fórmulas Equivalentes)

URL: http://bit.ly/MapeoEquivalentes

Free to use

In order to identify areas for compensation, the tool will identify fragments of affected ecosystem that are viable due to their size or landscape context and that have equal or better richness of species and threat level.

OPAL

URL: http://www.naturalcapitalproject.org/software/#opal

Free to use

OPAL helps identify mitigation options to restore the ecosystem services for people affected by a development project. OPAL combines available ecological and social data, along with spatially explicit models such as "Invest" of the Natural Capital Project to recommend compensation packages.

SIAC

URL: http://www.siac.gov.co/inicioVisor.html

Free to use

The SIAC "Geovisor" offers users the most relevant geographic, displayed at different scales and time frames, which facilitates territorial planning, the formulation and evaluation of policies, the decision making process and project management. Using the tool, the user can overlap the area of interest with the different layers of geographic information available. The user can also download the layers in shape or PDF format, which are categorized by environmental issues.

The IRF Greenhouse Gas Calculator—CHANGER

Available on CD-ROM from www.irfghg.org

This provides a methodology for the calculation and modeling of emission estimates in carbon equivalency for road construction and maintenance projects. The aim is to achieve energy savings and rationalize emissions data reporting. The calculator is compatible with Intergovernmental Panel on Climate Change guidelines, and the emission standards used are regularly cross-checked and validated. The calculations refer to the full life cycle of the road infrastructure and are repeated for different scenarios and different construction techniques. At present, it has two modules: pre-construction and pavement. The calculation model is based on a simple set of equations that enable accurate estimation of overall greenhouse gas emissions (outputs) generated by each identified and quantified source (inputs).

Appendix 1. Activities during Road Construction

Typical Road Construction Sequence	Construction Activity	Environmental Activity
Pre-construction	▶ Hiring of workforce according to national or local labor regulations	▶ Code of conduct ▶ Prohibitions ▶ Health plan ▶ Safety plan ▶ Community relations
Survey and staking	▶ Topographic survey ▶ Staking right-of-way ▶ Staking slopes and various design points ▶ Location of construction sites (offices, workers' camps, storage areas, asphalt plants, mixing plants, laboratories, etc.) ▶ Location of borrow pits, stockpile areas, disposal sites	▶ Safety plan ▶ Maintenance plan ▶ Chance-find procedures for historical and cultural sites
Clearing and grubbing **Removal of structures and obstructions**	▶ Right-of-way clearing by removing stumps, trees, shrubs, organic debris, rubbish ▶ Salvaging, removal, and disposal of debris, fences, structures, pavements, culverts, utilities, sidewalks, and other obstructions. ▶ Construction of offices, workers' camps, storage areas, asphalt plants, mixing plants, laboratories, etc. ▶ Construction of water supply system, electricity, sanitation and medical facilities, drainage, wastewater treatment plants, waste disposal	▶ Demarcation of vegetation that will not be removed ▶ Collection and storage of seeds, native vegetation, and topsoil for reuse during site restoration ▶ Preservation of topsoil and vegetation that will be used in the process of revegetation and landscaping in temporary nurseries ▶ Preservation of local fauna and flora ▶ Construction of infrastructure and facilities according with environmental specifications. ▶ Solid waste disposal ▶ Chance-find procedures for historical and cultural sites
Access roads	▶ Construction of access roads for the transportation of equipment, machinery, and materials to the project site	▶ Construction, improvement, or rehabilitation of existing roads following environmental specifications (erosion, sedimentation, noise, dust, slope stabilization, drainage, water runoff) ▶ Traffic management ▶ Safety plan ▶ Chance-find procedures for historical and cultural sites
Excavation, embankment, cuts, fill slopes	▶ Furnishing, hauling, stockpiling, placing, disposing, sloping, compacting, and finishing earthen and rocky material	▶ Location of borrow pits, stockpile areas, disposal sites ▶ Storage of construction material in approved sites ▶ Disposal of debris in authorized disposal sites ▶ Noise and dust control, air quality ▶ Sediment control, slope stabilization, water runoff, etc. ▶ Emergency procedures ▶ Safety plan ▶ Chance-find procedures for historical and cultural sites
Blasting	▶ Use of explosives for rock excavations, construction of tunnels, removal of major structures	▶ Use of appropriate blasting techniques according to the national regulations ▶ Procedures for transportation, storage, packaging, connection, blasting, and the disposal of blasting materials in accordance with the national safety and blasting regulations

Typical Road Construction Sequence	Construction Activity	Environmental Activity
Excavation for selected major structures	▶ Construction of tunnels, channels, foundation of bridges, and other selected structures	▶ Use of explosives according to regulations ▶ Disposal of debris in authorized disposal sites ▶ Noise and dust control, air quality ▶ Sediment control, slope stabilization, water runoff, etc. ▶ Emergency procedures ▶ Safety plan ▶ Chance-find procedures for historical and cultural sites
Works in watercourses	▶ Construction of foundations of bridges, box culverts ▶ Works for bank protection ▶ Diversion of water bodies	▶ Waste management plan ▶ Measures to prevent toxic spills ▶ Preservation of aquatic flora and fauna ▶ Erosion and sedimentation control ▶ Revegetation of banks
Sub-grade and grade preparation and geotextiles	▶ Placing layers of base course, gravel surfacing, surface treatment, and other materials ▶ Disposal of excess earthen and rocky materials ▶ Compacting and shaping of slopes ▶ Completing slopes, ditches, culverts, riprap, and other underground structures ▶ Placing geotextile layers as a permeable separator or permanent erosion control measure	▶ Control of erosion and sedimentation ▶ Noise and dust control ▶ Air quality ▶ Runoff control ▶ Disposal of solid wastes ▶ Material handling, use and storage ▶ Site safety ▶ Emergency procedures
Compaction, watering, paving	▶ Compaction of fill material ▶ Spraying water to suppress dust ▶ Paving the right-of-way with surface durable materials such as asphalt and concrete	▶ Noise and dust control ▶ Air quality ▶ Runoff control ▶ Disposal of solid wastes ▶ Site safety ▶ Emergency procedures
Landscape design and restoration of disturbed areas	▶ Revegetation and restoration according to environmental specifications and decommissioning and restoration plan	▶ Use of approved vegetation ▶ Restoration of agricultural lands, watercourses, quarries, borrow pits, disposal sites ▶ Dismantling of workers' camps and working sites ▶ Disposal of construction debris and contaminated land in approved disposal sites ▶ Closing of septic tanks ▶ Revegetation of slopes, areas under bridges, etc.
Equipment for traffic control and road use	▶ Installation of traffic and warning signs, wooden poles, lighting, fences delimiting the right-of-way, line-marking, traffic lights, etc., according to specifications and contract documents	▶ Traffic management ▶ Safety plan ▶ Emergency procedures

Appendix 2. Additional Reading

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Appendix 3. Glossary[6]

Baseline: Description of existing conditions to provide a reference (e.g., pre-project condition of biodiversity) against which comparisons can be made (e.g., post-impact condition of biodiversity), allowing the change to be quantified.

Baseline Study: Work done to collect and interpret information on the condition/trends of the existing environment.

Best Environmental Practice: The application of the most appropriate combination of environmental control measures and strategies.

Biodiversity Offsets: Measurable conservation outcomes resulting from actions designed to compensate for significant residual adverse biodiversity impacts arising from project development after appropriate prevention and mitigation measures have been taken.

Climate Change: A change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer.

Conservation: Active management of the biosphere to ensure the survival of the maximum diversity of species and the maintenance of genetic variability within species. It includes the maintenance of biosphere function (e.g., nutrient cycling and ecosystem function).

Convention on International Trade in Endangered Species of Wild Fauna and Flora: An international agreement between governments that aims to ensure that international trade in specimens of wild animals and plants does not threaten their survival.

Critical Habitat: Any area of the planet with high biodiversity conservation significance based on the existence of habitat of significant importance to critically endangered or endangered species, restricted range or endemic species, globally significant concentrations of migratory and/or congregatory species, highly threatened and/or unique ecosystems, and key evolutionary processes.

Cumulative Impacts: The total impact arising from a project (under the control of the developer), other activities (that may be under the control of others, including other developers, local communities, government), and other background pressures and trends that may be unregulated. The project's impact is therefore one part of the total cumulative impact on the environment.

Deforestation: The natural or anthropogenic process that converts forest land to non-forest.

Ecology: A branch within biology that addresses the relationships between living organisms and their environment. Ecology can be addressed at a number of scales; it also includes the relationships of a particular organism to its environment.

Ecosystem Services: Benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other non-material benefits.

Endangered Species: Any species that is in danger of extinction throughout all or part of its range.

Environment: The totality of all the external conditions affecting the life, development, and survival of an organism.

Environmental Impact Assessment: An analytical process that systematically examines the possible environmental consequences of the implementation of projects, programs, and policies.

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[6] Definitions are taken from *Biodiversity A to Z* by the U.N. Environment Programme's World Conservation Monitoring Centre.

Forest: A land area of more than 0.5 ha with a tree canopy cover of more than 10%, which is not primarily under agricultural or other specific non-forest land use. In the case of young forests or regions where tree growth is climatically suppressed, the trees should be capable of reaching a height of 5m *in situ* and of meeting the canopy cover requirement.

Fragmentation: The "breaking apart" of continuous habitat into distinct pieces.

Habitat: The place or type of site where an organism or population naturally occurs.

Habitat Degradation: A decline in species-specific habitat quality that leads to reduced survival and/or reproductive success in a population (e.g., related to changes in food availability cover or climate).

Indicator: Information based on measured data used to represent a particular attribute, characteristic, or property of a system.

Landscape: An area of land that contains a mosaic of ecosystems, including human-dominated ecosystems.

Landscape Connectivity: The degree to which the landscape facilitates or impedes movement among resource patches.

Minimization: Measures taken to reduce the duration, intensity, and/or extent of impacts that cannot be completely avoided as far as is practically feasible.

Mitigation: Measures that aim to reduce impacts to the point where they have no adverse effects.

Mitigation Hierarchy: A tool that aims to help manage biodiversity risk and is commonly applied in Environmental Impact Assessments. It includes a hierarchy of steps: avoidance, minimization, rehabilitation, and offset.

Natural Capital: Natural assets in their role of providing natural resource inputs and environmental services for economic production. Natural capital includes land, minerals and fossil fuels, solar energy, water, living organisms, and the services provided by the interactions of all these elements in ecological systems.

Natural Habitat: Areas composed of viable assemblages of plant and/or animal species of largely native origin and/or where human activity has not essentially modified an area's primary ecological functions and species composition.

Natural Resources: Assets (raw materials) occurring in nature that can be used for economic production or consumption.

Net Gain to Biodiversity: Additional conservation outcomes that can be achieved for the biodiversity values for which the critical habitat was designated.

Protected Area: A geographically defined area that is designated or regulated and managed to achieve specific conservation objectives.

Sensitive Area: Terrestrial and aquatic areas containing natural features or ecological functions of such significance as to warrant their protection in the best long-term interest of the people and environment.

Species: Groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups.

Sustainability: A characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs.

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