Environmental Guidelines for Small-Scale Activities in Africa (EGSSAA)

Chapter 14: Rural Roads

Contents

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Brief Description of the Sector

USAID support for rural roads is generally confined to the development or rehabilitation of non-asphalt roads, with one- or two-lane unpaved surfaces. These may be constructed to provide farmers with access to markets or to increase community access to services, such as health care or schools. In some cases USAID may also provide support to improve roads leading to protected areas, or within them, in order to encourage tourism.

Road improvements can bring substantial economic and social benefits to both rural communities and national economies. But they may also lead to significant and long-lasting environmental damage. That is why USAID's environmental procedures typically require an Environmental Assessment before any major new road construction. This section briefly summarizes a few of the major impacts and outlines key mitigation measures, in order to familiarize project developers and mangers with these issues.

Practitioners are also referred to *Low-Volume Roads Engineering Best Management Practices Field Guide* (Keller and Sherar 2003 [forthcoming]), developed for the USDA Forest Service's International Programs and USAID. Many other excellent references are listed in the Resources and References section of this briefing; these offer technical guidance on best practices for road improvements. Almost all of these are drawn from Keller and Sherar's bibliography.

Rural Roads

In this chapter, you will learn about:

- Common types of environmental damage from road projects
- Proper planning of road projects to avoid environmental degradation
- Putting operation and maintenance programs into effect to prevent and mitigate environmental impacts
- Best means of decommissioning roads to prevent erosion and loss of resources

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Potential Environmental Impacts

Some impacts of road projects are:

- Soil erosion
- Degradation of water quality
- Adverse effects on quantities of water
- Altered hydrology and flooding
- Deforestation
- Damage to valuable ecosystems and habitats
- Damage to scenic quality and tourism
- Adverse impacts on human health and safety
- Changes to local culture and society

Potential Environmental Impacts of Development Programs in the Sector and Their Causes

Many of the most common adverse environmental impacts associated with road improvements are summarized in Annex A, "Sample Road Improvements Environmental Impact Matrix." Of these, some of the most significant may include:

Soil erosion. Soil erosion is often caused by failing to keep water off road surfaces. Roads that cross hilly or steep terrain without following contours or minimizing grades are especially susceptible to erosion, as are roads that collect water and do not have enough side drainage to handle heavy precipitation or abnormal flooding.

Roads may also contribute to soil erosion through the development of multiple tracks, as travelers try to avoid standing water and ruts. Multiple track development occurs wherever inadequate attention is paid to keeping standing water off the road surface. These effects may be particularly pronounced where roads pass through "black cotton" heavy clay soils (vertisols) or across wetlands. Abandoned roads, if not properly decommissioned, can also become gulleys, with severe erosion impacts. Other barren areas associated with roads can contribute to soil erosion, including building material sources, work areas, temporary routes, excessively wide shoulders, and turnout or parking areas.

Degradation of water quality. Water quality may be damaged by soil erosion and the siltation of nearby rivers, streams, lakes and wetlands. The chief indirect cause of siltation is agricultural development. Such development tends to increase significantly with the expansion of new roads into previously inaccessible areas, but can also occur with the rehabilitation or upgrading of existing roads. Siltation also occurs as a secondary effect of soil erosion resulting from road improvements.

Adverse impacts on water quality may also be associated with poor management of fuel and lubricants at road camps, vehicle maintenance depots and fueling areas.

Borrow pits associated with road construction and maintenance fill with water during rains, creating safety hazards and pools that attract mosquitoes and other disease vectors

Adverse effects on water quantity. Large quantities of water are needed to help prepare and compact the road surface during road construction and maintenance. Although this demand for water is temporary, it may significantly affect local water supplies. In arid and semi-arid areas, drawing water for road improvements may harm aquatic species and farm production, especially if the water is taken during dry seasons.

Roads and quarries or “borrow pits” may also create artificial ponds and lakes (impoundments) that breed mosquitoes or harbor water-borne diseases. Road builders may create such ponds inadvertently, by damming gullies or other small catchment areas or streams, or intentionally, by constructing retention basins and settling ponds to minimize erosion and sedimentation.

Altered hydrology. Roads crossing areas with high water tables or wetlands may act like dams to block surface and sub-surface water flows. This is especially true where large quantities of initial material must be added to raise the road above the land surface, and where new material must be added annually to keep the road elevated. Under these circumstances, land on one side of the road can become much wetter than it was before the improvement, while land on the opposite side may be drier. This may adversely affect crop production, the composition of species in the local ecosystem, and road stability.

Alternatively, poorly installed culverts in wet or meadow areas may concentrate water and then form gullies upslope and/or downslope of the road. These gullies can subsequently drain the area and contribute to drying up the wetland.

Deforestation. Opening up new roads for expanded agricultural development puts adjacent forests at risk, especially where no effective forest management systems are in place. Typically, the most significant impact on forests results from the clearing of land for farms. However, once a road is in place, it also provides access to people wanting to supply urban or peri-urban charcoal and fuelwood markets.

Damage to valuable ecosystems and habitats. International concern over the protection of biodiversity continues to grow. Inadequate attention to biodiversity issues in road improvement projects can lead to the loss of species locally and to significant adverse effects on threatened or endangered species. New roads, or the rehabilitation of existing roads, may disrupt the integrity of plant and animal populations and permanently alter sensitive ecosystems.

The construction of new roads may also lead to the introduction of exotic or non-indigenous flora and fauna that may severely destabilize local plant and animal communities. Road access can also contribute to poaching and the trapping of exotic species. High-speed roads can significantly raise animal mortality (road kill).

Declines in scenic quality. Construction of new roads or the realignment of existing roads may adversely affect viewsheds (scenic vistas). Under some circumstances, such damage can lower tourism revenues. The cumulative effects of poorly located and poorly managed quarries and borrow pits supplying building materials for road projects may also cause significant loss in scenic values.

Adverse impacts on human health and safety. Potential concerns include:

Dust and noise. Depending on local conditions and the vicinity of houses and communities, dust and noise may damage human health during construction and, especially, once the road is in use. The health of road construction and maintenance staff may also be adversely affected by noise and dust produced from construction, road rehabilitation and maintenance.

Spread of communicable diseases. Road improvements increase communication among rural and urban populations. This in turn increases the potential for exposure to sexually transmitted diseases (including HIV/AIDS) and other communicable diseases such as tuberculosis. Road construction crews are often the first sources of such infections in an area.

Spread of water-borne diseases. Where poor road design and maintenance result in poor drainage and areas of standing water, the risk of water-borne disease such as cholera or malaria increases. The same is true for standing water found in open quarries and borrow pits.

Traffic hazards. Road improvements, especially those that allow increased vehicular speed, can lead to significant increases in accident rates for both human and animal populations.

Road works hazards. The operation of road works machinery often endangers both operators and laborers during construction and road maintenance. Poorly planned borrow pits and quarries for road works can also pose threats, ranging from falls from quarry faces to drowning in quarry pits that have become standing water reservoirs.

Change local culture and society. The development of new roads, or rehabilitation of existing ones, often improves personal livelihoods. Access to educational opportunities and to social services, including health care, is often a key rationale for road improvements. However, socio-cultural values may also be altered and the stability of communities adversely affected by exposure to rapid social change or tourism.

Road construction and maintenance may also provide income for local laborers and farmers. However, under some circumstances it could compete with farms for labor during harvest and planting seasons.

Sector Program Design—Some Specific Guidance

If your organization plans to undertake rural road improvement activities, engineering, ecological and social science expertise should be engaged, at a minimum, and the references listed at the end of this section should be reviewed in depth.

Many of the impacts summarized above can be avoided or minimized through careful attention in the initial planning and design stage. Specifications can be incorporated into construction contracts or road works procedures for governments or communities, and appropriate training in mitigation can be provided during construction, operation and maintenance.

One important aspect of road building is anticipating future development consequences. Here a road was built in a forested area, leading to in-migration and indiscriminant cutting for charcoal production

Planning and design

For this sector it is particularly important to evaluate the **need** for the road by assessing the **purposes** it will serve. For example, if the primary purpose is to transport produce from farm to market, approximate tonnages and seasonal transport patterns need to be identified. Then the costs and benefits of **potential alternatives** should be weighed. In some cases, transport by water, rail, bicycle or footpath may prove more practicable and desirable from an economic and environmental standpoint. Similarly, if the primary purpose is tourism, then road construction or rehabilitation should be weighed within the context of overall plans for the transportation network. In some cases tourist roads can be re-routed to improve effects on viewsheds (for example, by following contours, avoiding straight, highly visible stretches, creating more pleasing meandering tracks through woodlands, etc.). In other cases, building walking trails instead of roads can improve visitors' experiences and also provide greater protection to sensitive resources and ecosystems in protected areas.

Planning and design suggestions include:

- Estimate future demand in order to decide on the type and size of road to be provided. It is important to decide how many vehicles can be expected to move on the road and the approximate tonnage they will carry seasonally. This information is needed both to design the road to last and to balance environmental sustainability with human needs.

- Assess the long-term impact of the road against the "no-action" alternative, since road improvements can have many direct and indirect effects on the environment. Over a 20- or 30-year period, these impacts, such as increased agricultural expansion or deforestation, may prove cumulative and highly significant. Ancillary developments can be expected, including gas stations, restaurants, hotels, markets, shops, retail stores and bars. In the case of road improvements associated with protected areas, a long-term benefit can be an increase in revenues for the protected area management systems from consumptive uses (e.g., getting food and shelter) and non-consumptive ones (e.g., sightseeing). However, these must be balanced against the potential damage to sensitive ecosystems and biodiversity.

- In siting roads, ensure that professional hydrologic and engineering studies are done first, to avoid potentially adverse impacts on soils; to minimize possible effects on surface or sub-surface water resources; to ensure correct design of drainage structures and systems; and to reduce the potential for damage from unusually heavy rains and floods, including the rare but catastrophic kind known as "100-year floods." Avoid problematic areas such as springs, wetlands, landslides, steep canyons, flood plains and large rock outcrops. Be sure to involve hydraulic and geotechnical specialists in planning expensive and high-risk structures such as bridges, retaining walls and slide stabilization structures.

- Require that road designs follow contours and minimize harm to viewsheds where feasible.

Planning and Design Elements

It is particularly important to assess the need for, and purposes of, a new road. Some ways of accomplishing this are to:

- Estimate future demand for transport and road use
- Assess the long term impact of limiting building or reconstruction of a road
- Use professional hydrologists, engineers and social scientists in planning and assessing a project
- Follow land contours in road building
- Provide specifications for designing and maintaining drains
- Properly assess the need for construction and road-building materials from quarries, forests and "borrow pits"
- Train equipment operators and maintenance personnel
- Develop and erosion control plan for every project

A rural road in Zambia. Upgrading the road will require elevating the roadbed across a wetland area, adversely affecting local water flow. Could USAID funds still be used for this project?

Special areas for consideration

Maintenance and operation are the areas where most adverse of road projects impacts occur. Be sure to train all equipment operators in the environmentally sound operation of their machinery. Maintenance personnel should be trained to maintain the roadway in a manner that prevents erosion and damage to water and natural resources.

Decommissioning is also an important aspect of a road project. Old roads should be blocked, to prevent their continued use, or "ripped" to encourage revegetation.

- Provide specifications for road design and maintenance that keep water off road surfaces, such as use of camber and turnout drains.
- Ensure that specifications cover the quantity of road construction material needed and its potential sources, based on the quantity and quality of material at various sites. Prepare quarry and borrow pit management plans that identify locations, specify amounts to be removed from each site, and provide specific instructions for reclamation at each site. Quarries and pits are often left unclosed because the planners never decided how much of each resource should be used and thus never prepared a plan for phased closure. Develop these plans in consultation with affected stakeholders. (**Note:** The maintenance of a rural unpaved road for 20 years or more can require extensive use of road material, and unplanned use of quarries and borrow pits can cause very significant harm over time.)
- Provide for training of equipment operators and road works crews in environmentally sound road construction and maintenance.
- Develop a Project Erosion Control Plan for every construction or reconstruction project.

Operation and Maintenance

The main goal of environmentally sound road maintenance is to keep the road in working condition and minimize environmental damage. Good road maintenance practices that keep the road usable and durable, such as clearing drainage structures and restoring camber, will minimize much of the environmental damage the road might cause. Other practices, such as proper management of petrol and oil from equipment, are also necessary for optimal environmental protection.

The day-to-day work of road maintenance involves adjusting road surface and drainage structures to control the flow of water over and alongside the road, clearing vegetation, maintaining vehicles, and managing road use and user behavior.

Accomplishing these tasks effectively requires a good management plan and well-trained and equipped road works personnel. *When adequately funded,* these elements together can ensure that roads remain in good condition and minimize environmental damage.

Poor or inadequate maintenance—a primary cause of environmental damage from unpaved roads

Environmental damage from unpaved rural road construction frequently stems from insufficient or poor quality maintenance. These in turn derive from poorly or incompletely trained maintenance personnel, broken or incorrect equipment, and lack of regular maintenance schedules. To succeed, a maintenance program for rural unpaved road must therefore:

- *Provide timely, comprehensive, regular training to equipment operators.* For example, well-trained grader operators are key to the proper shaping of road surfaces that will direct water away from vehicle tracks and keep it from accumulating on road surfaces. Equipment

operators rarely receive adequate training and frequently fail to perform even basic standard procedures, such as keeping logbooks on equipment use. Operators should be given good training and frequent refresher courses on correct and environmentally sound use of their equipment.

- *Purchase appropriate, maintainable equipment, apply preventive maintenance, and keep mechanics trained and equipped; consider using manual labor as an alternative.* In the average road maintenance operation in Africa, most of the heavy road equipment is broken. If the equipment is not available when needed, roads may incur heavy, costly damage. To keep equipment in working order:

    1. Only purchase equipment in good working condition and suited to the types of tasks it will be used for. It should be of the correct size, purpose and durability and of a brand and model for which replacement parts are readily available.

    2. Carry out regular preventive maintenance by keeping records on use, stocking a full array of tools, hoists, spare parts, etc., and hiring mechanics who can read and understand foreign technical equipment manuals. Alternatively, if possible, contract with a private firm to perform preventive maintenance.

    3. Provide sufficient funding for operation and repair. Try to account for expected recurring costs and assign funds to cover them in the annual budget.

    4. An alternative approach is to use local manual labor and hand tools for road maintenance instead of heavy equipment. In some cases this may be both practical and economical, and it avoids the problems associated with heavy equipment. Hand labor–based methods also create employment opportunities, often enhance workers' skills, and can improve economic conditions in their home towns and nearby communities. Building local capacity in this way may make sustained maintenance of the road truly achievable.

- *Develop and follow a good management plan.* A good management plan, and the annual work plans derived from it, should encompass a number of elements, including timetables for maintaining sections of the road network; a schedule for introductory and refresher training for equipment operators and mechanics, as well as a list of topics to be covered in the training; and, possibly, a schedule and instructions for routine maintenance of equipment.

Other sources of environmental damage

The overall management plan must also address other sources of environmental damage associated with building and maintaining rural roads, including spilling and dumping of solid waste, hazardous fluids and solvents; off-road driving and use of roads in the rainy season; the spread of invasive non-native plants; adverse impacts from extracting murram and other road repair materials; and the spread of HIV and other diseases.

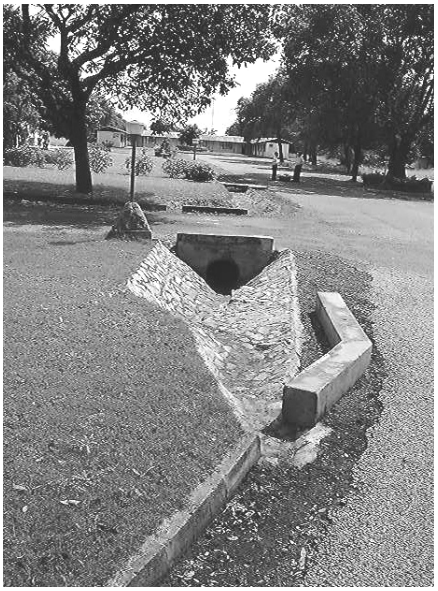
- *Maintaining vehicles.* Dumping and spillage of hazardous fluids generated during vehicle maintenance, such as used oil, petrol and solvents, is a common problem. It can be avoided by training staff in

sound practices and installing correctly designed maintenance structures such as concrete pads for vehicle servicing. Equipment operators and mechanics should receive training in the safe storage, use and disposal of fuel, lubricants, solvents and other chemicals.

  - *Off-road driving and out-of-season road use.* Much off-road driving near existing roads results from drivers' attempts to avoid deep ruts and flooding in the official roadway. Regular, correct maintenance of the road surface and drainage system will minimize the problem by preventing the flooding and the growth of ruts. Wet-season traffic on roads designed only for dry-season use can severely damage the road surface and promote erosion. Closure and enforcement are the recommend management measure, but they often provoke off-road driving. The best solution, if there is a significant demand during the rainy season, is to upgrade the road for wet use.

- *Invasive plants.* Attention also needs to be paid to ensuring that crews are trained in the early removal of exotic plant species and preservation of native plants, especially when roads pass near or within protected areas.

- *Quarries and borrow pits.* Extraction of road materials from quarries and borrow pits must be **closely supervised,** and procedures for reclamation, which should have been prepared during the planning and design stage, must be carefully followed.



A well-designed decommissioning plan helped a Zambian landowner and a road construction company convert a construction camp into a hotel complex.

- *HIV/AIDS and other diseases.* Road crew members from other geographic areas can spread various health problems, especially HIV/AIDS and other sexually transmitted infections (STIs), to local populations. To protect both employees and local residents, road maintenance projects should implement HIV-prevention programs that focus on changing risky behaviors and the parts of organizational culture that encourage them, by encouraging condom use, by teaching how HIV is spread and how to reduce STIs, by promoting tolerance of HIV-infected individuals, and by encouraging voluntary testing. Three common and relatively inexpensive first steps are to provide regular HIV/STD awareness training, condom use education, and easily accessible free condoms. Sources of more detailed guidance can be found in this guide's *References and Useful Resources* section.

Decommissioning

Re-alignment of an existing road is not uncommon in rural road improvement programs. When this occurs, old roads may need to blocked off with stones, mounds of earth, or other devices to prevent continuing use. In some cases the old surface must be scraped for drainage or "ripped" to encourage revegetation.

Table 1: Environmental Mitigation and Monitoring Issues for Rural Roads Projects

Activity	**Impact** *The activity may. . .*	**Mitigation** Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Planning and Design in General (New and Existing Roads)		
Identification and weighing of alternatives		• Identify known and potential areas of ecological, archeological, paleontological, historic, religious or cultural significance and ecologically sensitive areas such as tropical forests, wetlands, and other areas of high biodiversity or threatened species along possible routes (P&D)
Establishing design standards	Damage valuable ecosystems and habitats Damage valuable historic, religious, cultural, and paleontological resources Change local culture and society Cause soil erosion Degrade water quality and/or alter hydrology Mar scenic views Lead to injury, disease, or death of workers, and local residents	• Choose or develop design standards for each facet of construction and related activities, e.g., road bed, road surface drainage, culvert installation, erosion control, revegetation, stream crossing, sensitive areas, steep slopes, material extraction, transport and storage, construction camps, decommissioning, etc. (P&D) • Provide plans to identify and protect sensitive habitats (P&D) • Take patterns of local weather and natural phenomena into account, e.g., fog, flooding, earthquakes, heavy rain, mudslides, drought, etc. (P&D) • Develop an Erosion Control Plan for all projects (P&D)

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Planning route	Damage valuable ecosystems and habitats Damage valuable historic, religious, cultural, and paleontological resources Change local culture and society Cause soil erosion Degrade water quality Alter hydrology Contribute to deforestation Mar scenic views	• Have a multidisciplinary team involved in planning new routes. Ideally the team will include an ecologist, geotechnical and road engineer, soil scientist, hydrologist and other relevant professionals, such as an archeologist or tourism specialist (P&D) • Avoid routing road through sites of known paleontological, archeological, historic, religious or cultural significance (P&D) • Avoid routing across agriculturally productive soils (P&D) • Take problem areas involving soil and slope stability into account. Note seasonal and long-term (50- and 100-year) flooding patterns (P&D) • Whenever possible, site roads to follow hill contours (P&D, C) • Avoid creating road grades of greater than 10% as well as long straight downhill stretches (P&D) (C) • Identify sites for temporary/permanent storage of excavated material and construction materials. If excavated material will not be reused, decide how it will be disposed of or shaped (P&D) (C) • Keep the route a safe distance from river and stream banks (P&D) • Avoid environmentally sensitive areas, such as wetlands, and places near protected areas or relatively undegraded forests. Explore possible “compromise” alternatives such as building a narrow, improved trail across protected area lands to provide access on foot, bicycle or motorcycle, with construction of main access roads around these areas (P&D) (C) • Avoid constructing roads through forest areas, especially tropical forest, if possible. If clearing is unavoidable, protect or restore forests elsewhere within the drainage basin as close as possible to those that were lost (P&D) • Minimize impacts on viewsheds (scenic landscapes) by avoiding planning roads that cut long straight paths across valleys and plains. Instead, hide roads beneath forest cover to minimize aesthetic damage, and provide meanders where feasible (P&D) • Avoid siting roads where they may disturb animal behavior such as feedin, mating, and migration patterns (P&D) • If sensitive areas cannot be avoided, involve ecologists and engineers in designing road, construction camp, quarries and other areas. (P&D) (C)

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Constructing road surface	Increase sedimentation Cause discomfort to road users	• Stabilize the road surface with gravel/murram and other rocky surfacing material (P&D) (C) • Elevate road surface (measure from base of wheel tracks) above side channel water (see figure 3-1.2) (P&D) (C) • Clearly define the type of road surface shape and drainage method—insloped, outsloped, or cambered/crown roadway—to be used for each section of roadway (see figures 3-1.2 - 3-1.5 for examples of cambered roadway) (P&D) (C)
Drainage	Cause soil erosion Degrade water quality Alter hydrology Damage valuable ecosystems and habitats	• Install drainage structures during construction instead of after construction. Most erosion associated with roads occurs in the first year after construction. Delaying installation of the drainage features greatly increases the extent of erosion and damage during the first year (P&D) (C) • Clearly define the type of road surface shape and drainage method—insloped, outsloped, or crown roadway—to be used for each section of roadway. Use outside ditches to control surface water when necessary, but avoid general use, as they concentrate water flow and require the road to be at least a meter wider. Install frequent structures, such as berms or ditches , to divert water off the road before it directly reaches live stream channels (see figure 3-1.2 and 3-1.4) (P&D) (C) • Install frequent diversion structures, such as cross drains, drivable, rolling dips or water bars, to move water off the road frequently and minimize concentration of water (P&D) (C) • Install drainage crossings to pass water from the uphill to the downhill side. If using culvert pipes, at least roughly design them before or during construction. Use either the Rational Formula or back-calculation using Manning's Formula and high-water mark data to determine the anticipated flow. This will allow you to roughly determine the correct pipe sizes. Where flows are difficult to determine, use structures such as fords, rolling dips, and overflow dips that can accommodate any volume of flow and are not susceptible to plugging (P&D) (C) • Stabilize outlet ditches (inside and outside) with small stone riprap and/ or vegetative barriers placed on contour, to dissipate energy and to prevent the creation or enlargement of gullies (P&D) (C) • Extend runout drains far enough to allow water to dissipate evenly into the ground (P&D) (C) • Visually spot-check for drainage problems by looking for accumulation of water on road surfaces. Do this immediately after first heavy rains and again at the end of the rainy season. Institute appropriate corrective measures as necessary (C)

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Perennial and intermittent rivers and streams	Risk destruction of bridge by 50-or 100-year flood Cause damming and resultant meandering of stream which destroys neighboring sections of roadway, dwellings and/or native flora and fauna	• Construct drifts rather than bridges, where feasible and cost-effective. Since periodic replacement or reconstruction of damaged bridges and culverts can be costly, involve hydraulic engineers in bridge designs (P&D) (C) • When constructing a bridge, consider using a design, such as a Bailey Bridge, that can be erected and dismantled so if the waterway meanders, the structure can be moved to another site (P&D) (C) • Try "training" rivers and streams to follow desired channels by selectively removing debris. However, any channel changes should be minimized. Use a combination of hand labor and small machinery. Careful and selective bulldozing may be feasible in some cases. However, bulldozer tracks can easily expose soil to erosion and do more harm than good (P&D) (C)
Wetlands	Degrade wetland, damaging the valuable ecosystems and habitats Alter hydrology	• Avoid routing through these areas (see "Planning route" above for additional guidance) (P&D) • Minimize cuts and/or fills and compensate for impact by protecting other wetlands (P&D) (C) • Take special precautions to prevent release or dumping of debris, oil, fuel, sand cement and similar harmful materials (C) • Use elevated porous fills (rockfills) and/or multiple pipes to maintain natural flow patterns of groundwater and near-surface water (C)
Sloped areas and raised roads	Cause soil erosion Degrade water quality Alter hydrology Damage valuable ecosystems and habitats	• Stabilize slopes by planting vegetation. Work with agronomists to identify native species with the best erosion control properties, root strength, site adaptability, and other socially useful properties. Set up nurseries in project areas to supply necessary plants. Do not use non-native plants. Use soil-stabilizing chemicals or geotextiles (fabrics) where feasible and appropriate (P&D) (C) • Minimize use of vertical road cuts (even though they are easier to construct and require less space than flatter slopes). The majority of road cuts should have no more than a ¾:1 to 1:1 slope to promote plant growth. Vertical cuts are acceptable in rocky material and in well-cemented soils (P&D) (C) • Install drainage ditches or berms on up-hill slope to divert water away from road and into streams (see figure 3-1.4) (P&D) (C) • Install drainage turnouts at more frequent intervals and check dams to reduce ditch erosion (P&D) (C) • If possible, use higher-grade gravel, which is much less prone to erosion (P&D) (C) • If very steep sections cannot be avoided, provide soil stabilizers or surface with asphalt/concrete (P&D) (C)

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Construction contracts	Cause all types of damage mentioned	• Select or develop guidelines and procedures to be applied to each facet of road construction, and incorporate them into contracts with construction companies. These will apply, for example, to site clearing; bed and surface construction; drainage; fuel and materials usage; quarry site management; and procedures for operating construction camp and work site, including procedures addressing worker safety • Include incentives for adhering to guidelines and penalties for violating them
Maintenance agreements	Cause all types of damage mentioned	• Finalize maintenance agreements with local communities **before** beginning construction. All parties must clearly understand and be committed to the terms of the agreement, such as who will do what work, when, how frequently, for what compensation, and within what limits
Planning and Design—Existing Roads (Reconstruction/Repair/Realignment)		
All projects		• Use a "clean slate" approach, i.e., consider realigning all existing minimal/informal roads to follow contours and avoid sensitive areas (P&D)
Road surface is below grade of surrounding road	Cause soil erosion Degrade water quality Alter hydrology	• Raise road surface with stable fill material. Grade with inslope, outslope or cambered shape. Install sufficient cross-drains, ditches and settling ponds (Figure 3-1.1 and 3-1.2) (P&D) (C) (O&M)
Road is steeply sloped and eroding	Cause soil erosion Degrade water quality Alter hydrology	• Consider realigning the road section so that it conforms to preferred design parameters described above. Decommission original road sections after realignment (see "Decommissioning" below) (P&D) (C) (O&M)
Deteriorated road surface	Cause erosion Damage vehicles	• Determine cause of deterioration. If the cause is heavy use, either find a means of reducing traffic or upgrade road to a more durable surface (gravel, asphalt, or concrete) (figure 3-1.6) (P&D) (C) (O&M)
Drivers drive at excessively high speeds	Cause injury and death of people and animals	• Realign road sections to meander; curving roads deter speeding (P&D) • Add speed bumps in villages or populated areas (C)
Sections have multiple tracks/off-road driving	Cause soil erosion Degrade water quality Alter hydrology Damage valuable ecosystems and habitats	• Generally caused by either muddy/flooded roadway or highly deteriorated roadway. Maintain or upgrade road so road section no longer floods or becomes muddy (P&D) (O&M) • Raise the road bed or define the roadway with rocks. Realign the road to a better area. Avoid very flat terrain (P&D) (O&M)
Road section must be realigned		• Remove surface if necessary and loosen soil of previous track (to accelerate regeneration of vegetation). Block access with rocks, branches, roadblocks and signs. Narrow tracks will usually revegetate naturally with no noticeable scars or impact on the environment. Wider roads may require active planting and reseeding (C) (O&M)

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Construction		
Construction camp and crew	Damage local habitat, compact soil and create erosion via building and occupation of construction camp Contaminate surface water and spread disease via solid waste and feces generated by camp Spread communicable diseases including malaria, tuberculosis, and HIV/AIDS via construction crew members who come from outside the region Introduce alcohol or other socially destructive substances via construction crew Generate trash due to lack of solid waste management Adversely effect local fauna and flora (especially game and fuelwood) via poaching and collection by construction crews	• Explore off-site accommodation for crew. Avoid wet, muddy sites (P&D) (C) • Keep camp size to a minimum. Require that crew preserve as much vegetation as possible, e.g., by creating defined foot paths. Define areas of use (with rocks or fencing) (P&D) (C) • Provide potable water for crew (O&M) • Provide temporary sanitation on site, e.g., VIP latrine (assuming the water table is low enough and soil and geology is of appropriate composition) (also consult "Water Supply and Sanitation" in this volume). Where this is not possible, instruct road crews to employ soil mining (digging a pit for human waste and covering with soil immediately after use) (P&D) (C) • Use local or regional labor, if possible. Provide hygiene and public health training to road crews, including information about transmission of HIV/AIDS and other sexually transmitted diseases (P&D) (C) • Collect all solid waste (metal, glass, and burnable materials) from all work and living areas. Dispose of waste in local dump or landfill. If this is not possible, sell recyclables for reuse/recycling, place organic wastes in well-screened waste pits, covering with soil weekly, bury the remainder (excluding toxic materials). (Also consult "Management of solid waste from residential, commercial and industrial facilities" in this volume) • Set guidelines prohibiting the poaching and collection of plants/wood, with meaningful consequences for violation, such as termination of employment. Provide enough food and cooking fuel; both should be of good quality (C) • Restore site through revegetation and similar measures after camp is broken down (C) • Test grade drivers' ability to follow grade, slope, and contour design standards. Train if necessary (P&D) (C) • Test the ability of bulldozer drivers and other equipment operators to properly maintain drainage structures. Train if necessary (P&D) (C) • Test road crew's ability to keep roads clear of vegetation with least adverse environmental impacts. Train if necessary (P&D) (C) • Provide workers with appropriate safety equipment, e.g., earplugs or headgear to mute noise from very loud equipment; masks for workers exposed to large amounts of dust; safety glasses for workers doing jobs that may generate sharp projectiles

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Use of heavy equipment and hazardous materials	Cause erosion due to machinery tracks, damage to roads, stream banks, etc. Compact soil, changing surface and groundwater flows and adversely affecting future use for agriculture Contaminate ground or surface water when (1) machinery repairs result in spill or dumping of hydraulic oil, motor oil or other harmful mechanical fluids; and (2) hazardous construction materials are spilled or dumped Put workers at risk from exposure to hazardous materials	• Minimize use of heavy machinery (P&D) (C) • Set protocols for vehicle maintenance, such as requiring that repairs and fueling occur elsewhere or over an impervious surface such as plastic sheeting. Prevent dumping of hazardous materials. Capture leaks or spills with drop cloths or wood shavings. Burn waste oil **if** it is not reusable/readily recyclable, does not contain heavy metals and is flammable. Prohibit use of waste oil as cooking fuel (P&D) (C) • Investigate and use less toxic alternative products (P&D) (C) • Prevent fuel tank leaks by (a) monitoring and cross-checking fuel levels deliveries and use, (b) checking pipes and joints for leaks, (c) tightening generator fuel lines, and (d) preventing over-filling of main storage and vehicle tanks (C) (Also consult "Activities with Micro and Small Enterprises (MSEs)" in this volume)
Materials extraction: Quarrying, logging	Damage aquatic ecosystems through erosion and siltation Harm terrestrial ecosystems via harvesting of timber or other natural products Spread vector-borne diseases when stagnant water accumulates in active or abandoned quarries or borrow pits and breeds insect vectors Take land out of other useful production The quarry may become a safety hazard	• Identify the most environmentally sound source of materials that is within budget (P&D) (O&M) • Use material from local road cuts first, but only if it produces a fairly suitable, durable aggregate for either embankment fill or surface stabilization material. Local borrow material can be very cost-effective. Upon removal of material, the area should be restored and receive erosion control measures (P&D) (C) • Develop logging, quarrying and borrowing plans that take into account cumulative effects (P&D) • Take photos of site before initiating excavation, so that restoration can match original site characteristics as much as possible (C) (O&M) • Site quarries and gravel pits so that they are not visible to travelers on the roads (P&D) (C) (O&M) • Monitor adherence to plans and impacts of extraction practices. Modify as necessary (C) (O&M) • Decommission/restore area so it is suitable for sustainable use after extraction is completed (C) • Install drainage structures to direct water away from pit (C) (O&M) • Implement safety protocols to minimize risks from falling rock or debris, collapsing quarry walls, or accidental falls from cliffs (P&D) (C) (O&M) • Develop specific procedures for storing topsoil, as well as for phased closure, reshaping and restoration when extraction has been completed. Include plans for segregating gravel and quarry materials by quality and grade for possible future uses. Where appropriate, include reseeding or revegetation to reduce soil erosion, prevent gulleying and minimize visual impacts (P&D) (C) (O&M) • Discuss with local community the option of retaining quarry pits as water collection ponds for watering cattle, irrigating crops or similar uses. Highlight issues of disease transmission and the need to prohibit its use for drinking, bathing, and clothes washing (P&D) (C) (O&M)

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Storing materials	Deplete water resources Damage valuable ecosystems and habitats	• Pre-wet gravel when water is more available (i.e., not during dry season) and store gravel in a way that will keep it wet, e.g., covered with plastic sheeting (P&D) (C) • When siting storage areas, avoid using sensitive areas or sites that drain directly into a sensitive area (P&D) (C)
Site clearing and/or leveling	Damage or destroy sensitive terrestrial ecosystems Produce areas of bare soil which cause erosion, siltation, changes in natural water flow, and/or damage to aquatic ecosystems	• Minimize disturbance of native flora (vegetation) during construction. Minimize the amount of clearing. Clear small areas for active work one at a time (P&D) (C) • Avoid use of herbicides. Any use should follow health and safety procedures to protect people and the environment. At a minimum, herbicides should be used according to manufacturer's specifications (C) • Where possible, remove large plants and turf without destroying them, and preserve them for replanting in temporary nurseries (P&D) (C) • Move earth and remove vegetation only during dry periods. Store topsoil for respreading. If vegetation must be removed during wet periods, disturb ground only just before actual construction (P&D) (C) • Install temporary erosion control features when permanent ones will be delayed. Use erosion control measures such as hay bales, berms, straw or fabric barriers (C) • Revegetate with recovered plants and other appropriate local flora immediately after equipment is removed from a section of the site (C)
Excavation	Cause erosion, siltation, changes in natural water flow, and/or damage to aquatic ecosystems when excavated soil is piled inappropriately Expose inhabitants and crew to risk of falls and injuries in excavation pits Deprive down-gradient populations and ecosystems of water if upper regions of aquifer are blocked	• Cover pile with plastic sheeting; prevent run off with hay bales,or similar measures (P&D) (C) • Place fence around excavation (P&D) (C) • Investigate alternatives, such as shallower excavation and no excavation (P&D) • Have construction crews and supervisors be alert for buried historic, religious and cultural objects and provide them with procedures to follow if such objects are discovered. Provide incentives for recovery of objects and disincentives for their destruction or theft.(P&D) (C) • Ensure that excavation is accompanied by well-engineered drainage (P&D) (C)
Filling	Block water courses when fill is inappropriately placed Destroy valuable ecosystems when fill is inappropriately placed Cause later land subsidence or landslides when fill is inappropriately placed, causing injuries and damages.	• Do not fill the flow line of a watershed. Even in arid areas, occasional rains may create strong water flows in channels. A culvert may not supply adequate capacity for rare high-volume events(P&D) • Design so that filling will not be necessary. Transplant as much vegetation and turf as possible (P&D) (C) • Use good engineering practices. For example, do not use soil alone; first lay a bed of rock and gravel (P&D) (C) • Balance the cuts and fills (to minimize earthwork movement) whenever possible.

Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Cutting and filling	Cause soil erosion Degrade water quality Alter hydrology Damage valuable ecosystems and habitats	• Test grade driver's ability to follow design standards for grades, slopes, and contours. Train if necessary (P&D) (C)
Compacting to improve road materials performance	Deplete freshwater resources	• Water the road immediately before compacting it to strengthen the road surface. (Otherwise, traffic will soon beat back the road surface to pre-bladed condition) (P&D) (C) • When possible, delay compaction activities until the beginning of the wet season or when water becomes more available (P&D) (C)
Blasting	Cause soil erosion Degrade water quality Alter hydrology Damage valuable ecosystems and habitats	• Minimize blasting (P&D) (C) • Take safety precautions to protect workers and others from being injured by flying or falling rock and avalanches (P&D) (C)
Design verification Quality control		• Conduct independent inspections of work periodically to see that it conforms to original plan and design specifications. Provide incentives and disincentives to ensure conformance (C) • Drive roads after moderate rains to identify areas that collect or gully water. Mark and redesign/rehabilitate as necessary (C)
Operation and Maintenance		
Road maintenance to remove ruts, potholes, washboarding, standing water and materials blocking road	Create gulleys and standing pools Create mud holes, potholes Breed disease vectors in settling basins and retention ponds	• Monitor and maintain drainage structures and ditches, including culverts. Clean out culverts and side channels/runout (leadoff ditches) when they begin to fill with sediment and lose their effectiveness (O&M) • Fill mud holes and potholes with good quality gravel; remove downed trees and limbs obscuring roadways (O&M) • Use water from settling basins and retention ponds for road maintenance (O&M)
Construction camp and crew	(See "Construction camp and crew" above)	• (See "Construction camp and crew" above)
Use and maintenance of equipment	(See "Use of heavy equipment and hazardous materials" above)	• (See "Use of heavy equipment and hazardous materials" above) • Install concrete pads, drains and oil/water separators in areas where vehicle and equipment maintenance and fueling will occur regularly

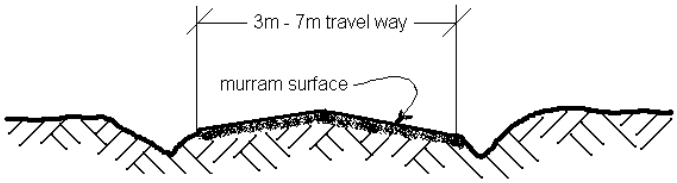
Activity	Impact *The activity may. . .*	Mitigation Note: Mitigations apply to specified project phase: *Planning and Design (P&D), Construction (C), or Operation and Maintenance (O&M)*
Decommissioning		
Decommissioning	Cause soil erosion Degrade water quality Damage valuable ecosystems and habitats	• Break up old road surface and soil. Remove and dispose of surfacing material (e.g., asphalt) if necessary, and loosen soil of previous track (to accelerate regeneration of vegetation) • Reshape eroded or culled surfaces with outsloping, or add cross-drains or water bars so that water will no longer follow the course of the roadway (See fig. 3-1.1) • Revegetate as needed. Narrow tracks will usually revegetate naturally with no noticeable scars or impact on the environment. Wider roads may require active planting and reseeding (O&M) • Block access with rocks, branches, roadblocks, waterbars and signs.

Figures 3-1.1 and 3-1.2

Typical Existing Road Section

Wear and grading or erosion has lowered road surface below surrounding landscape; road now collects rain runoff and is wetter than surroundings

Typical Proposed Road Cross Section

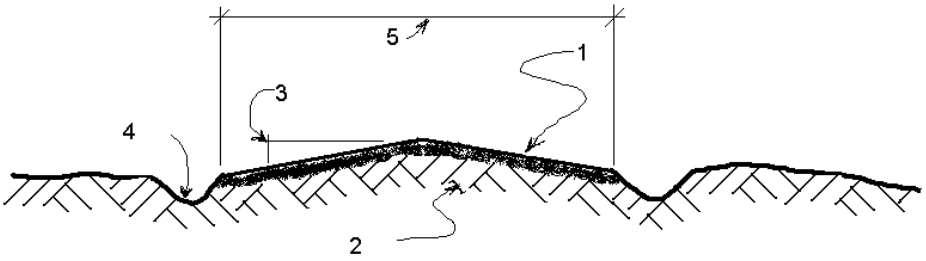


Side Drain Ditch - depth of ditch will vary along the length of the run between turnout or outlet

Note: Max Camber Slope:
1 in 40 to 1 in 33
(2.5%) (3%)

Figures 3-1.3 and 3-1.4

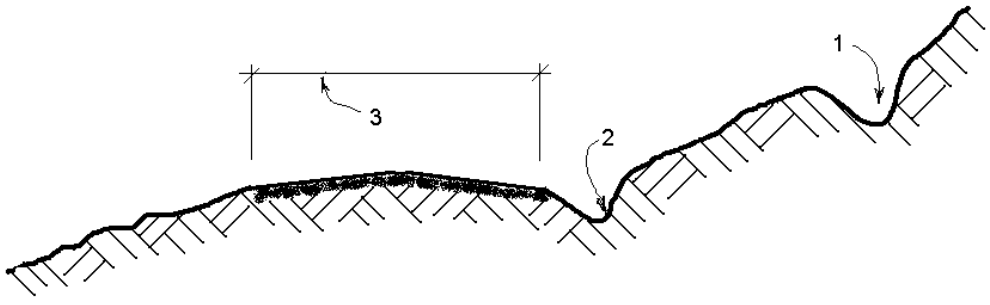
Cross Section of a Gravel Road



KEY
1 - Layer of murram; thickness of murram layer depends on soil type at site
2 - Subgrade
3 - Cross-slope 1 in 33 to 1 in 40
(3%) (2.5%)
4 - Side drain ditches
5 - Traveled way; width depends on the class of road

Drainage in Hilly Roads Cross Section

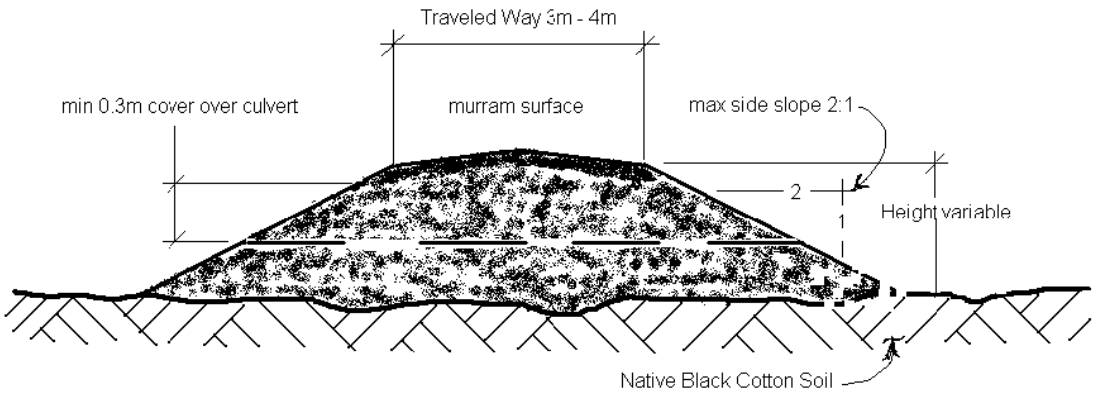
Key
1 - Water catchment ditches/drains
2 - Side ditch drain
3 - Traveled way



Figures 3-1.5 and 3-1.6

Raised Road Embankment

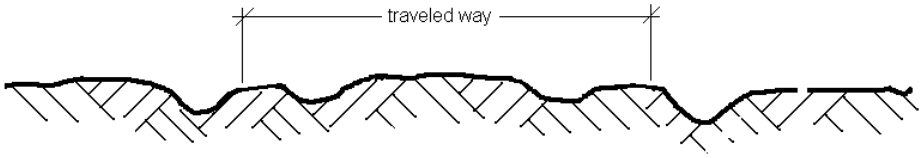
Typical proposed Black Cotton fill cross section



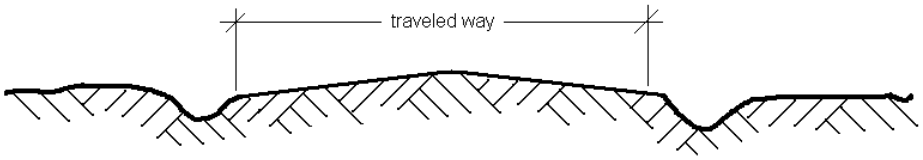
Note: Reapply surface vegetation and surface soil to new fill slopes to aid in revegetation

Longitudinal Ruts Correction

Typical road cross section with longitudinal ruts caused by vehicle tyres



Typical road cross section after filling up the longitudinal ruts by reshaping the road



References and Useful Resources

Almost all references here are taken from:

Keller, G., and James Sherar (2003). *Low-Volume Roads Engineering: Best Management Practices and Field Guide*. Washington, DC: USAID, USDA, and Virginia Polytechnic Institute and State University. http://ntl.bts.gov/lib/24000/24600/24650/Index_BMP_Field_Guide.htm

The guide also has an extended bibliography for readers in need of more depth or detail regarding specific issues and applications. In addition to the topics listed below, the extended bibliography offers references for hydrology for drainage crossing design; tools for hydraulic and road design including Manning's Formula, riprap, filters, and the use of geosynthetics; general considerations for drainage of low-volume roads; fords and low-water crossings; physical, vegetative and biotechnical methods of erosion control; and stabilization of gullies. The extended bibliography can be found at http://ntl.bts.gov/lib/24000/24600/24650/Chapters/Q_Selected_References.pdf.

Best Management Practices—General

- Environmental Protection Agency (2005). *National Management Measures to Control Nonpoint Source Pollution from Forestry*. EPA Contract No. 68-c7-0014, Work Assignment #2-20. Prepared for the U.S. Environmental Protection Agency's Office of Water by Tetra Tech, Fairfax, Virginia. http://www.epa.gov/nps/forestrymgmt/

  A comprehensive guide to measures for reducing water pollution from roads and logging activities.

- Vermont Department of Forests, Parks and Recreation (1987). *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont.* http://www.gwriters.com/saf/documents/AcceptableManagementPractices31.pdf

- Wisconsin Department of Natural Resources (1995). *Wisconsin's Forestry Best Management Practices for Water Quality: Field Manual for Loggers, Landowners and Land Managers. Publication No. FR093.* http://www.dnr.state.wi.us/forestry/usesof/bmp/bmpfieldmanual.htm

- World Bank, Transport Division of the Environmentally Sustainable Development Vice-Presidency and Transportation, Water & Urban Development Department. Washington, D.C. http://www.worldbank.org/transport/r&h_over.htm

  Links to tools and literature covering many dimensions of road construction, including planning, financing, institutional management, safety, construction and maintenance, environment, and tolls, among others.

- World Bank (1997). Roads and the Environment: A Handbook. World Bank Technical Report TWU 13, and update WB Technical Paper No. 376. World Bank, Washington, D.C. (Part II details specific environmental, social, and other impacts). Online: http://siteresources.worldbank.org/INTTRANSPORT/Resources/336291-1107880869673/covertoc.pdf

Planning Issues and Special Applications

- Dykstra, D. and R. Heinrich (1996). *FAO Model Code of Forest Harvesting Practice. Food and Agriculture Organization of the United Nations, Rome.* http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/V6530E/V6530E00.htm

- Keller, G., G. Bauer and M. Aldana (1995). *Minimum Impact Rural Roads (Caminos Rurales Con Impactos Minimos).* Training manual written in Spanish for the USDA Forest Service International Programs, USAID, and Programa de Caminos Rurales, Guatemala City, Guatemala. (Manual is currently being rewritten in English.)
- Oregon Department of Forestry (2000). *Forest Roads Manual.* Forest Engineering Coordinator, State Forests Program, Oregon Dept. of Forestry, Salem, OR (503-945-7371). http://www.oregon.gov/ODF/STATE_FORESTS/Roads_Manual.shtml

  This manual provides basic information about logging road design, construction and maintenance.
- Tanzania National Parks, et al. (2001) *TANAPA Programmatic Environmental Assessment for Road Improvements in Tanzania National Parks.* Four volumes, including Environmental Management Guidelines for Road Improvements. September. Available at http://www.encapafrica.org/docs/tanapa-pdf.zip [10MB download]

Basic Engineering Considerations for Low-Volume Roads

- Australian Road Research Board Limited (1993). *Unsealed Roads Manual: Guidelines to Good Practice.* Vermont, South Victoria, Australia. Available to order at http://www.arrb.com.au/index.php?option=content&task=view&id=328&Itemid=294

  A useful manual for gravel road design and maintenance, particularly in semi-arid regions.
- Casaday, E. and B. Merrill (2001). *Field Techniques for Forest and Range Road Removal.* Eureka, California. California State Parks, North Coast Redwoods District. 63p. http://www.parks.ca.gov/?page_id=23071

  A useful field guide to road closure and obliteration, with great photos and figures.

Culvert Use, Installation, and Sizing

- Normann, J.M., R.J. Houghtalen and W.J. Johnston (1985) (Reprinted 1998). Hydraulic Design of Highway Culverts. Hydraulic Design Series No. 5. Tech. Rep. No. FHWA-IP-86-15 HDS 5. September. McLean, VA: Department of Transportation, Federal Highway Administration, Office of Implementation. 265 p. http://www.fhwa.dot.gov/engineering/hydraulics/pubs/hds5si.pdf

  Includes a comprehensive design for both conventional culverts and culverts with inlet improvements.

Bridge Location and Design Factors

- American Association of State Highway and Transportation Officials (2002). Standard Specifications for Highway Bridges (17th Edition). ISBN Number: 1-56051-171-0 Available for purchase at: https://bookstore.transportation.org/item_details.aspx?ID=51

  Covers the design of wood, steel, and concrete bridges, as well as structural plate structures.

Slope Stabilization and Stability of Cuts and Fill

- Mohney, J. (1994). *Retaining Wall Design Guide.* 2d ed. Tech. Rep. No. EM-7170-14. Washington, DC: U.S. Department of Agriculture, Forest Service, Engineering Staff. Also, Pub. No. FHWA-FLP-94-006. September. Washington, D.C.: Department of Transportation, Federal Highway Administration, Federal Lands Highway Program. 537 p. http://www.ntis.gov/search/product.aspx?abbr=PB97194401

  Covers the analysis and design of a wide variety of retaining walls.

Roadway Materials

- ARRB Transport Research Ltd. (1996). Road Dust Control Techniques: Evaluation of Chemical Dust Suppressants' Performance. Spec. Rep. 54. Victoria, Australia. Available to order from http://www.arrb.com.au/

  Covers the products available, how they work, selecting the product, and the product's environmental impacts.

HIV/AIDS Prevention

- HEARD - Health Economics and HIV/AIDS Research Division, University of Natal, Durban, RSA. http://www.heard.org.za/

  Provides toolkits, presentations, publications, links, statistics and more.

- Rau, B. 2002. Workplace HIV/AIDS Programs: An Action Guide for Managers. Family Health International. 85 p. http://www.fhi.org/en/HIVAIDS/pub/guide/Workplace_HIV_program_guide.htm

Annex A: Sample Road Improvements Environmental Impact Matrix

Legend

Adverse Impact Level		Beneficial Impact Level
λ	Low	μ
λ	Medium	μ
λ	High	μ

Impact Category ⇒	Physical Resources													Ecological Systems									Landscape					Socio-Economic												
Activities ⇓	Soil Erosion	Debris Deposition	Siltation	Soil Compaction	Surface Runoff	Hydrology	Topography	Drainage	Wetlands	Surface Water Quantity	Surface Water Quality	Ground Water Quantity	Ground Water Quality	Habitat Change	Species Diversity	Alien Species	Vegetation	Poaching	Wildlife Movement	Animal Harassment	Ecological Function	Exceptional Resources	Tropical Forest	Scenic Quality	Wilderness Quality	Viewshed	Carrying Capacity	Visitor Experience	Human Settlement	Compatibility w/ Policies	Cost to Agency	Benefit to Agency	Costs to Communities	Benefits to Communities	Health	Disease Vectors	Noise Levels	Dust Levels	Risks/Hazards	Employment	Local Economy	Tourist Industry
Construction																																									
Vegetation clearing	λ	λ	λ	λ	λ				λ	λ	λ	λ		λ	λ		λ		λ		λ	λ	λ	λ	λ		λ						μ			λ	λ	μ	μ	
Construction camp	λ		λ	λ	λ				λ	λ	λ		λ	λ	λ	λ	λ	μ	λ	λ	λ	λ	λ	λ	λ		λ	λ		λ	μ			λ		λ	λ	μ	μ	
Quarry management	λ		λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ		λ	λ	λ	λ	λ	λ	λ	λ			λ	λ	μ	λ	λ	λ	λ	λ	λ	μ	μ	

Impact Category ⇒	Physical Resources													Ecological Systems										Landscape					Socio-Economic												
Activities ⇓	Soil Erosion	Debris Deposition	Siltation	Soil Compaction	Surface Runoff	Hydrology	Topography	Drainage	Wetlands	Surface Water Quantity	Surface Water Quality	Ground Water Quantity	Ground Water Quality	Habitat Change	Species Diversity	Alien Species	Vegetation	Poaching	Wildlife Movement	Animal Harassment	Ecological Function	Exceptional Resources	Tropical Forest	Scenic Quality	Wilderness Quality	Viewshed	Carrying Capacity	Visitor Experience	Human Settlement	Compatibility w/ Policies	Cost to Agency	Benefit to Agency	Costs to Communities	Benefits to Communities	Health	Disease Vectors	Noise Levels	Dust Levels	Risks/Hazards	Employment	Local Economy	Tourist Industry
Trucking gravel	λ			λ	λ	λ					λ				λ	λ			λ	λ			λ	λ	λ	λ	λ				λ									
Cutting & filling	λ		λ	λ	λ	λ	λ	λ	λ	λ	λ	λ		λ	λ		λ		λ	λ	λ	λ	λ	λ	λ		λ									λ	λ	λ		
Blasting	λ	λ	λ	λ	λ	λ	λ	λ		λ	λ	λ			λ		λ		λ	λ	λ	λ	λ	λ	λ		λ						λ		λ	λ	λ			
Construction material use	λ		λ						λ		λ				λ	λ							λ	λ			λ					λ				λ	λ		λ	
Management of spoil	λ		λ	λ	λ			λ	λ		λ			λ	λ						λ		λ	λ	λ		λ									λ				
Storage of diesel/oils									λ		λ		λ	λ	λ		λ				λ	λ	λ						λ	λ		λ		λ			λ			
Waste management									λ		λ		λ	λ	λ		λ				λ	λ	λ	λ	λ	λ		λ	λ	λ	λ	λ		λ	λ		λ				
Water use	η		η		λ				λ	λ	λ	λ	λ	λ	λ		λ		λ	λ	λ		λ						λ	λ		λ						η		λ
Operation																																									
Vehicle Traffic Movement	λ		λ	λ	λ			λ	λ	λ	λ			λ	λ	λ	λ	η	λ	λ	λ	λ	λ	λ	λ	λ	λ		λ	λ	η	λ	η	λ		λ	λ			λ
Road maintenance	λ		λ	λ	λ	λ		λ	λ	λ	λ			λ	λ	λ	λ	η	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	λ	η		η	λ		λ	λ	λ	η	η	η
Maintenance of machinery									λ		λ				λ						λ			λ		λ		η			λ	η						λ	η	η	η	λ

Impact Category ⇒	Physical Resources													Ecological Systems										Landscape					Socio-Economic													
Activities ⇓	Soil Erosion	Debris Deposition	Siltation	Soil Compaction	Surface Runoff	Hydrology	Topography	Drainage	Wetlands	Surface Water Quantity	Surface Water Quality	Ground Water Quantity	Ground Water Quality	Habitat Change	Species Diversity	Alien Species	Vegetation	Poaching	Wildlife Movement	Animal Harassment	Ecological Function	Exceptional Resources	Tropical Forest	Scenic Quality	Wilderness Quality	Viewshed	Carrying Capacity	Visitor Experience	Human Settlement	Compatibility w/ Policies	Cost to Agency	Benefit to Agency	Costs to Communities	Benefits to Communities	Health	Disease Vectors	Noise Levels	Dust Levels	Risks/Hazards	Employment	Local Economy	Tourist Industry
Tourist activities	✓		✓	✓	✓			✓	✓		✓			✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✗	✓	✗	✓	✓		✓	✗	✗	✗
Waste management									✓		✓		✓	✓	✓	✓	✓			✓	✓			✓	✓	✓		✓		✓	✓	✗		✓	✓	✓		✓	✗		✓
Off-road driving	✓		✓	✓	✓	✓		✓	✓		✓			✓	✓		✓	✗	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓	✗					✓	✓			✓
De-commissioning																																									
Ripping old road	✓		✓		✗			✗	✓	✗	✓	✗			✓						✓		✗	✗	✓	✓				✓	✗										
Shaping	✗		✗	✓	✗		✗	✗	✗	✗	✓			✗	✓		✗				✓		✗	✗	✗	✗		✗			✓	✗					✗		✓	✗	✗	
Revegetation	✗		✗		✗	✗		✗	✗	✗	✗	✗		✗	✓		✗				✓		✗	✗	✗	✗		✗			✓	✗					✗		✗	✗	✗	