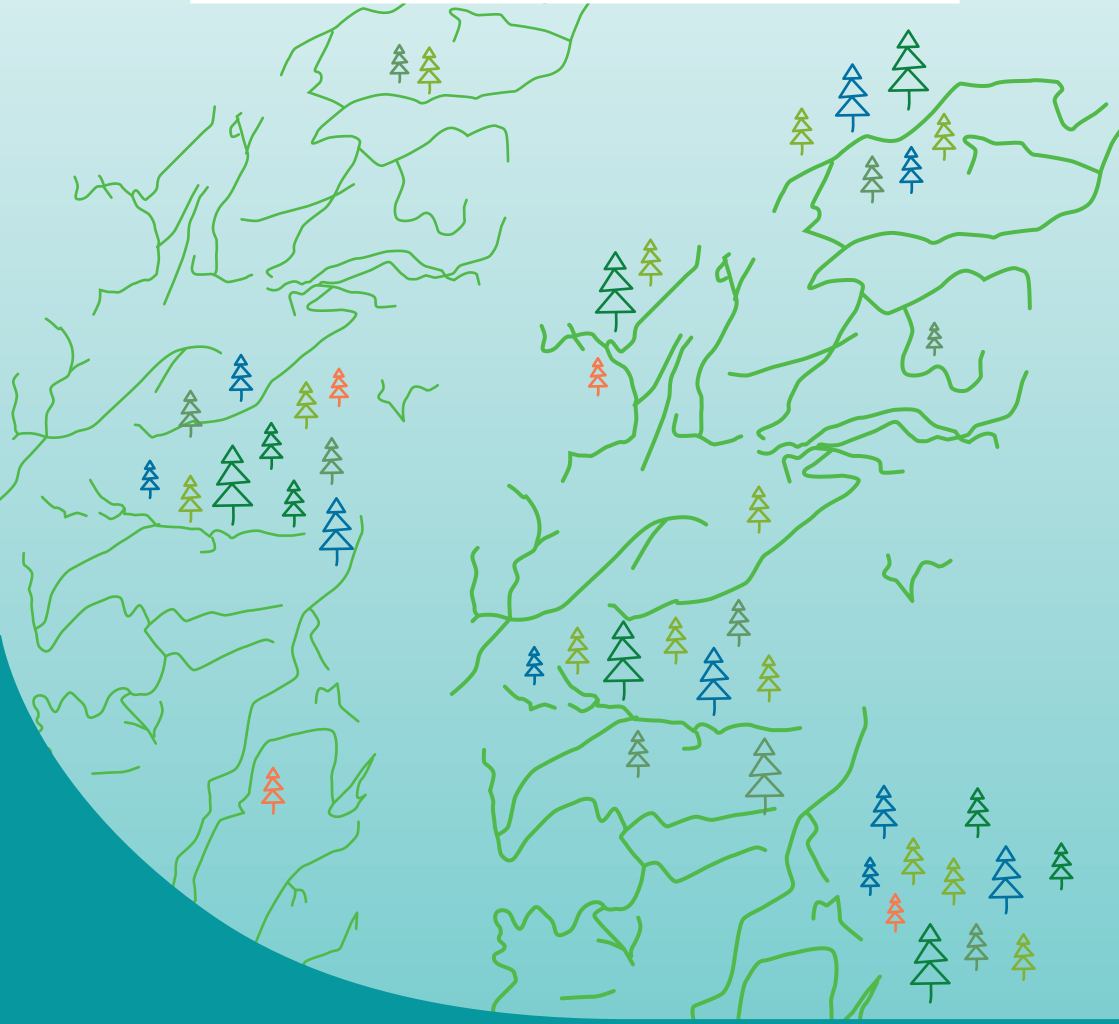
Food and Agriculture
Organization of the
United Nations

Guide for planning, construction and maintenance of forest roads



Guide for planning, construction and maintenance of forest roads

by

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Acronyms

GIS – Geographic Information System
MCA – Multi-Criterial-Analysis
LIDAR – Light Detection and Ranging

01

Forest road network planning

For a long time, forest roads and road networks were built mainly to support forest management and harvesting. In recent years there have been many publications on computerized planning of forest management and one thing that the various approaches have in common is that they examine many alternatives and consider the costs for construction, maintenance and transport (*Bettinger 2004; Stückelberger 2006*). Some of the solutions use a point approach, which is about connecting destination points, while some use an area approach by maximizing the service area to cope with forest management needs in the future.

All solid solutions need to be based on reliable data on terrain conditions and modern forest road network planning has to consider many issues. The major aspects are listed below.

- Economic values
  - harvesting costs
  - road construction costs
  - maintenance costs
  - mobilization of resources

- Environmental values
  - water quality
  - natural beauty
  - effects on biodiversity
  - ecological impacts
  - land requirement

- Social values
  - recreation
  - safety aspects (intervention time for first aid)
  - rural development
  - employment

Some aspects have both an economic and environmental aspect. To analyse the quality of a planned forest road while respecting the different major aspects, various Multi-Criterial-Analysis (MCA) tools are recommended.

For forest road networks in mountainous areas, the width of the road corridor (including the cut and fill slope) increases with slope inclination. Figure 1 and Figure 2 show the details of a typical cross section. In a Bulldozer profile with an inclination of 100 percent for the cut slope and 75 percent for the fill slope, an excavator is able to shape a cut slope of up to 200 percent and a fill slope of up to 150 percent under favourable soil/subsoil conditions (stable rock, enough blocks to build a stonewall). For comparison, Figure 3 shows a road with a width of 4 m, which is assumed to have two thirds of the road on the bench and just one third on the fill.

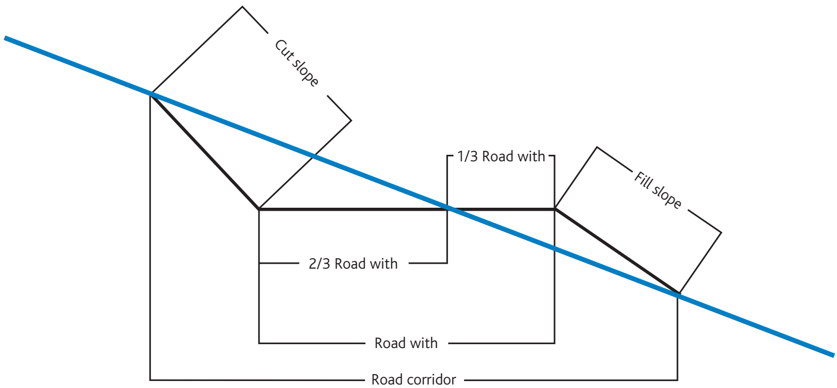


Figure 1: Typical Cross section for construction with bulldozer/angle dozer [PERTLIK]

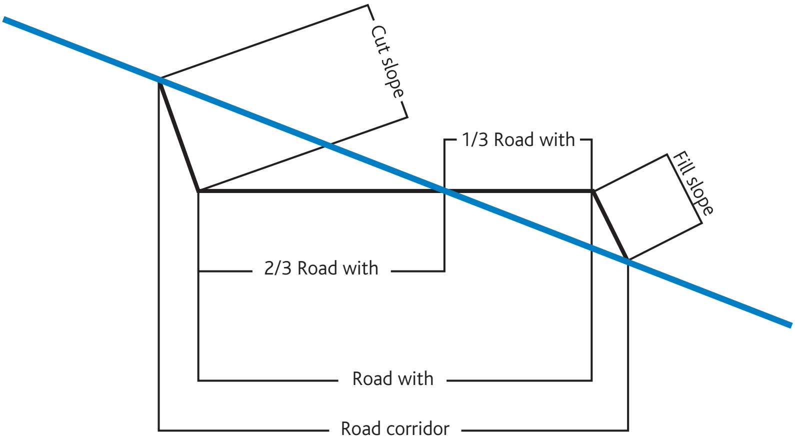
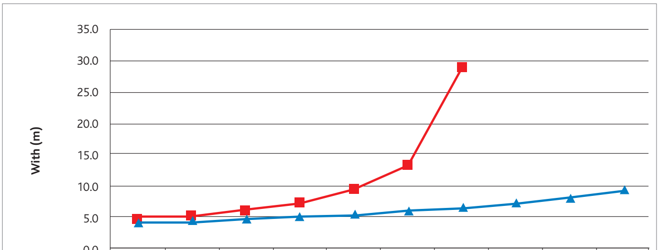


Figure 2: Typical Cross section for construction with bulldozer/angle dozer [PERTLIK]

Minimizing the area used for building roads is necessary to keep the environmental impact as low as possible and to maintain forest productivity.

Figure 3 clearly shows the advantage of smaller areas being used for excavator construction. Construction with dozers is limited on terrain inclinations steeper than the possible fill slope (~70 percent depending on the soil) inclination. In such cases the road has to be built on full bench and the material has to be removed and landfilled.



	10	20	30	40	50	60	70	80	90	100
Bulldozer	4.5	5.2	6.0	7.3	9.3	13.3	28.9			
Excavator	4.2	4.5	4.8	5.2	5.6	6.0	6.6	7.3	8.2	9.3

Figure 3: Width (m) of road corridor using bulldozer /excavator versus slope percent [PERTLIK]

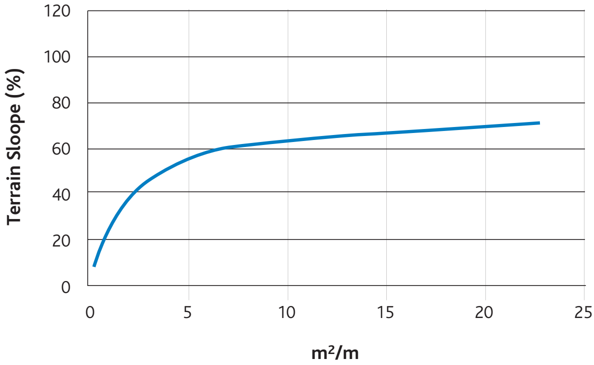
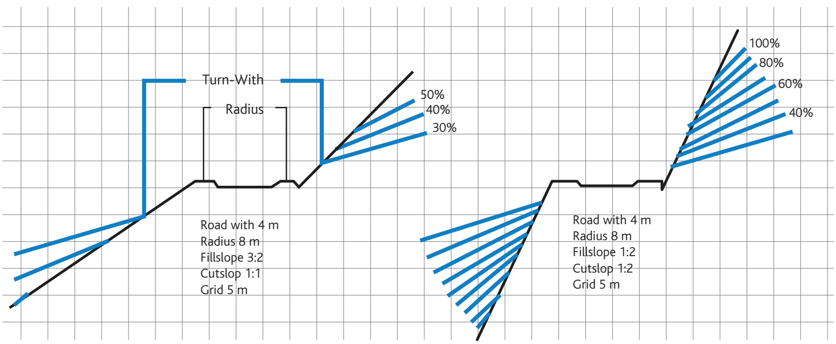


Figure 4: Area [m²/m] saved by the use of an excavator instead of bulldozer vs. terrain slope [PERTLIK]

The comparison of the 4 m wide road built using a bulldozer vs. an excavator is shown in Figure 4. This can achieve a saving of up to 20 m² per m of road built.

Compared to flat areas, the space needed for turns dramatically increases with the hill slope inclination. Figure 5 gives the diameter for a turn built with a bulldozer (earth template) or with an excavator (rock template). The general layout of a forest road network in mountainous areas has to focus on the optimal localization of turns, taking into account the subgrade stability, the slope inclination and the effect on the accessibility of the forest area for forest operations.



<table>
<tr><th>Hillslope</th><th>With of Turn Rock-Template [m]</th><th>With of Turn Earth-Template [m]</th></tr>
<tr><td>30%</td><td>24.7</td><td>34.1</td></tr>
<tr><td>40%</td><td>26.3</td><td>43.8</td></tr>
<tr><td>50%</td><td>29.0</td><td>63.0</td></tr>
<tr><td>60%</td><td>31.2</td><td rowspan="5">too steep for this template</td></tr>
<tr><td>70%</td><td>33.7</td></tr>
<tr><td>80%</td><td>36.6</td></tr>
<tr><td>90%</td><td>40.1</td></tr>
<tr><td>100%</td><td>44.3</td></tr>
</table>

Figure 5: Diameter for a turn including cut and fill, in comparison with the hill slope inclination [PERTLIK]

1.1 Access key figures

A quantitative and qualitative description of a road network can be done in many ways. For point-to-point issues the distance is the only relevant variable. However, forest roads have to serve two functions. The first is the point-to-point issue for all kind of transportation of forest products. The second function is the spatial opening of the areas on both sides of the road for all operations related to forest management; e.g. harvesting, silviculture, forest protection and firefighting.

Road spacing gives the first indication of whether the road network fits the management systems in use. In flat areas with a wide ratio between road length and number of junctions the road spacing gives a good indication of the quality of a road network. For areas where the slope inclination is higher than the maximum accepted road inclination, the development of a road network needs more junctions and turns to provide access to all relevant areas. According to topography and ground conditions, road networks show varying road spacing and, thus, the road spacing can only provide average, less accurate information about the accessible areas.

Figure 6 and Figure 7 show the efficiency of typical design elements for forest road networks. The squares are 2 by 2 km representing 400 ha.

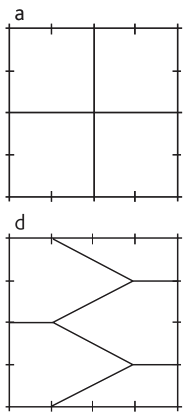


Figure 6: Road length and Road density for different road network patterns a-f [PERTLIK]

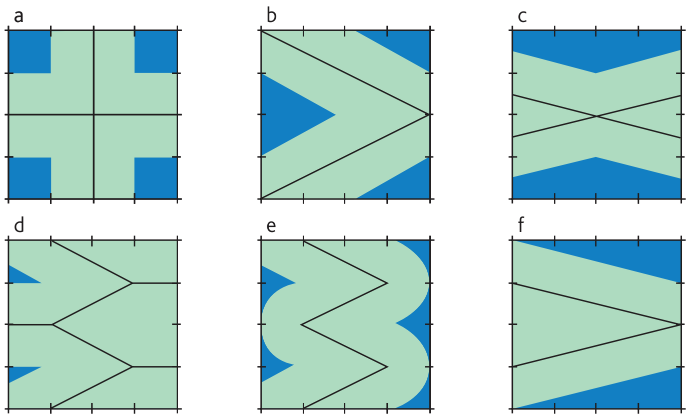


Figure 7: Road space and Access area (500 m range in green) in percent for different road network patterns a-f [PERTLIK]

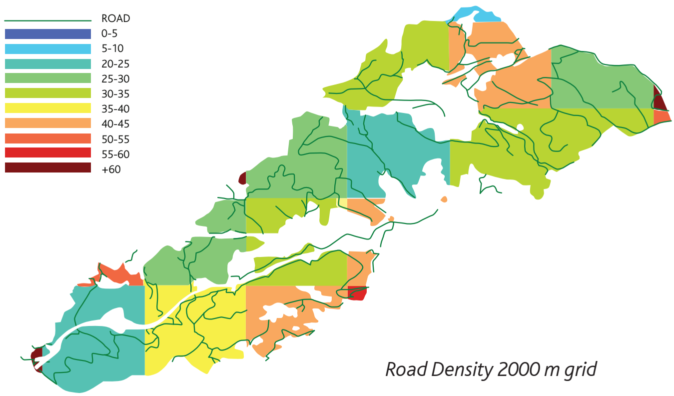
Road density is commonly used to describe the quality of a road network. It is easy to calculate (road length/forest area), although it is only a useful indication about the access situation of large areas at regional or national level. At enterprise level it is much better to evaluate the access situation with other figures. Road density does not give any information on how accessibility is distributed over the forest area. A road close to the boundaries of the forest area, which only has an opening effect on one side of the road is considered in the same way as a road in the middle of the forest that has access on both sides. A close series of hairpins will increase the road density but not improve the access situation in the same dimension. *Table 1* shows how the layout influences the accessible area. Patterns *b* and *e* have the same length, spacing and density but pattern *e* has a distinctly larger accessible area. The same is true for patterns *c* and *f*. Turns and junctions in steep areas will look like pattern *f* while flat sections will resemble pattern *b*. These general patterns just demonstrate that the often used road density should not be used as the only decision criterion.

		a	b	c	d	e	f
Road Length	m	4 000	4 472	4 123	5 972	4 472	4 123
Road Density	m/ha	10.00	11.18	10.31	14.93	11.18	10.31
Road Spacing	m	1 000	894	970	670	894	970
Access Percentage	%	75%	81%	64%	98%	90%	77%

Table 1: Key figures for the road network pattern a-f in Figure 6 and 7 [PERTLIK]

At enterprise level it is important to show the distribution of areas with dense road networks and those with low densities. A different approach – suitable for bigger areas – is to calculate the density on a grid base, which is dependent from the area analysed. For forest units of ~5 000 ha a grid size of 500 to 1 000 m is recommended, for bigger forest areas at regional or national level larger grids could be used – fragmentation of the forested area may limit that increase. *Figure 8* shows areas where improvement of the road network is intended.

Figure 8: Road density distribution [PERTLIK]



To include the spatial effect of a road network, BACKMUND (1966) used a buffer strip (half of the average road spacing) around the road to calculate an access percentage. The width of the buffer could be adapted to the harvesting systems in use. It is also possible to use different uphill and downhill buffer widths. Nowadays, with GIS tools it is very easy to calculate these values quickly. Figure 9A shows the accessible area according to BACKMUND (1966). Figure 9B shows the accessibility in constant buffer distances and Figure 9C solves the access problem as a calculation of the distance to the nearest road, based on 50 by 50 m grid. All this calculations can be done easily with GIS tools.

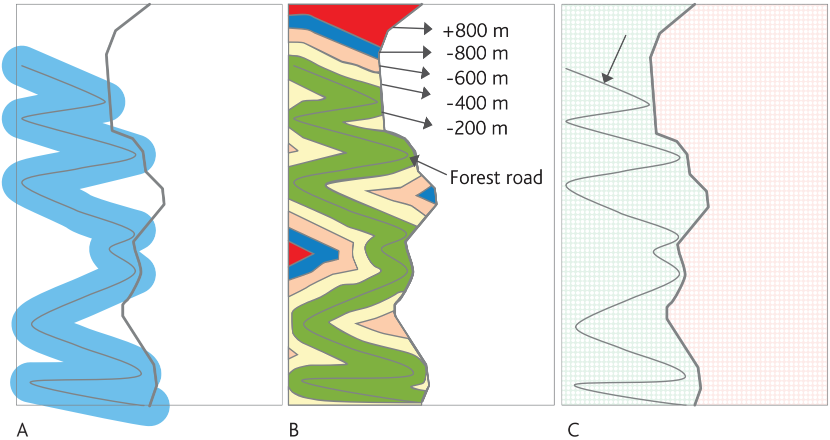


Figure 9:
A: buffer strip according to BACKMUND (1966)
B: constant buffer strips (each 200 m wide)
C: nearest distance to next road (based on a 50x50 m grid)

The first step is always to identify areas with "bad" accessibility. At enterprise level this may be done on a case by case basis but for larger areas it should be done in a structured way.

Operational cost, productivity and stand data should be combined to decide on the improvement of forest road networks. This data can be used to forecast the costs of forest operations (e.g. harvesting) over the life span of a road segment. A cost benefit analysis can be used to rank the economic effect of different alternatives. This reflects only the economic dimension of road construction. To include non-economic dimension into the decision as well it is necessary to use MCA methods. Figure 10 shows a flowchart for such a process. At regional and national level, where the decision makers have no detailed knowledge about the local situations and have to prioritize numerous well justified alternatives, an objective procedure gives solid support for decision making. The different Multi-Criteria-Analysis (MCA) make it possible to favour economic, ecologic or social criteria. It is important to define the criteria and the interactions (weight) between different criteria before the analysis and ranking procedure starts.

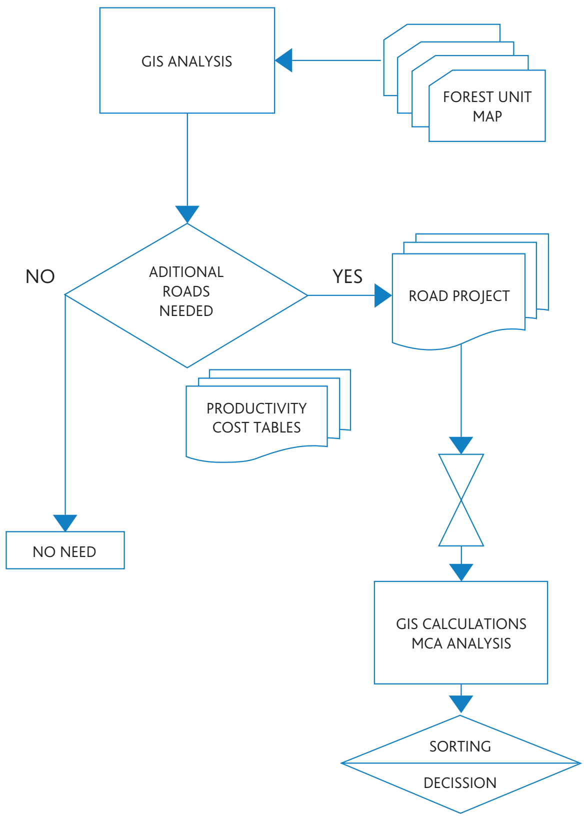


Figure 10: Flow chart of the prioritisation of road projects [PERTLIK]

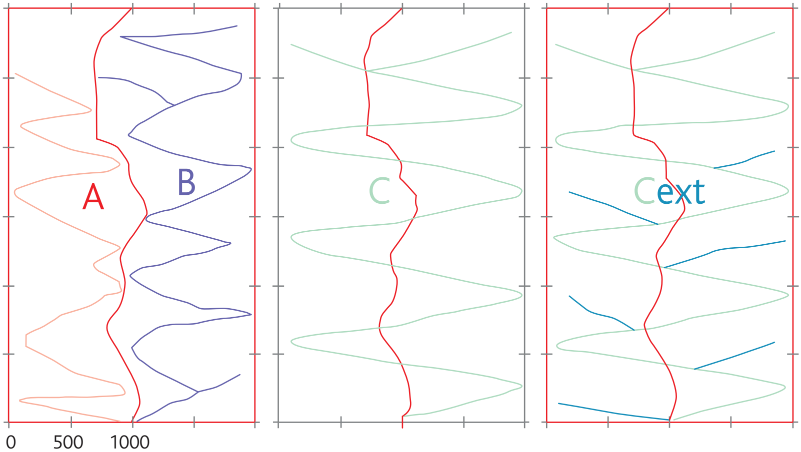


Figure 11: Possible Road Networks in mountainous terrain [PERTLIK]

Figure 11 shows a common situation in mountainous regions with unfavourable patterns for management, i.e. narrow strips following slope inclination and terrain features. A and B are road networks for access to each individual property (left and right of the property border). C and Cext are examples of cooperatively planned roads providing an integrated solution by making use of neighbouring properties and keeping the number of bends to a minimum. Such integrated solutions need clear agreements between the owners about costs (construction and maintenance).

1.2 Access concepts

The perfect road network – avoiding the overlap of openings – would be parallel roads without crossings (SEGEBADEN 1964). Forest road networks could often not be developed in a strict geometric pattern of parallel and/or rectangular roads due to topographical and geological conditions.

1.2.1 Flat terrain

For Areas where the maximum inclination of the terrain is lower than the maximum accepted road inclination, the road layout can be designed without considering the topography. If the ground conditions allow, a geometric regular road network is the best solution.

For oblong parcels (*Figure 13*) constant spacing of dead end roads provide full access on both the left and right of a main road. For broad forest areas a pattern of roads like a chess-board (*Figure 12*) will give good access to the forest.

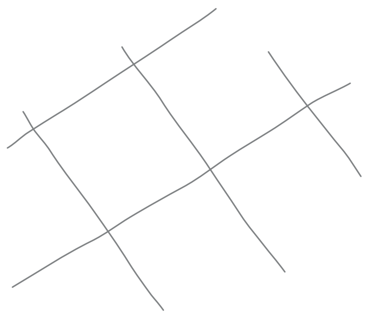


Figure 12: Quadrate layout

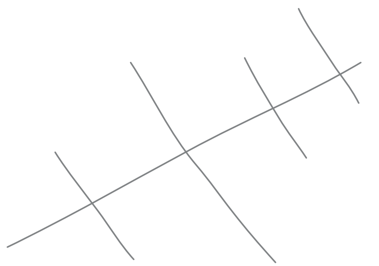


Figure 13: Linear layout

1.2.2 Mountainous terrain

For areas where the slope inclination is generally higher than the maximum acceptable road grade, the road network has to be developed in accordance with the topography. There are some basic principles to develop the network. The Examples are based on SEDLAK 1985.

1.2.3 Valley roads

To open forests areas roads follow the creek as long the creek inclination is within the limits of the grade of forest roads. Side valleys are connected with a back loop. The road should be built within a safe distance of the creek. The crossing of the creek as part of the back loop can be done as a ford, culvert or bridge, taking account of an unimpeded flow-through of water in case of floods. The location of the crossing should be above the point where the side creek flows into the main creek, to keep the road network functional during flooding.

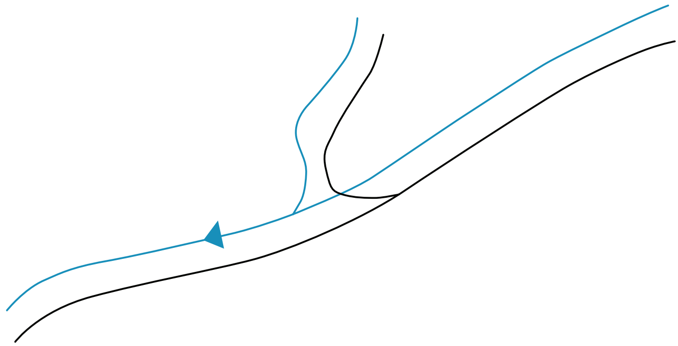


Figure 14: Valley road with junction into side valley

Creeks often have cataracts (*Figure 15*) where the inclination of the creek is far beyond the bandwidth of the road inclination. In such cases a serpentine on the slope or in a side valley is the solution to return close to the creek after the cataract. The longer alignment – and the elevation – of the road (compared to the creek) allows it to come back to the main valley and follow the alley up as long the creek inclination is within the bandwidth of the possible road inclination.

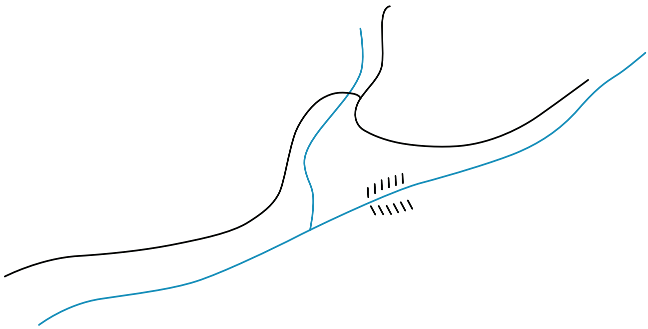


Figure 15: Valley road with serpentine and junction into side valley to bypass a cataract and return to the main valley

If the creek is steeper than the maximum road inclination the road network must leave the valley and be developed as slope roads. In Figure 16 it is developed on both sides of the creek. Still when the crossing is designed as a bridge or culvert, it must have a profile like a ford to avoid the outward flow of the creek over the road.

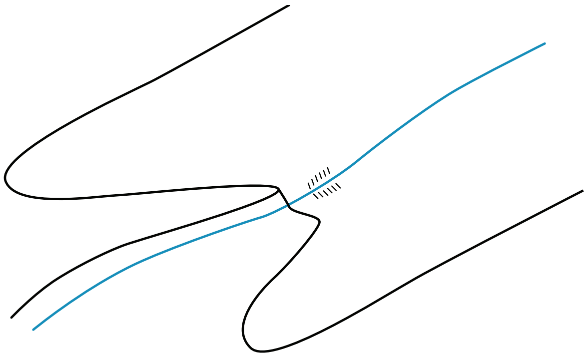


Figure 16: Slope roads where the creek inclination is to steep

1.2.4 Ridge roads

Areas along creeks often have swampy or otherwise unsuitable ground for road construction. Using geotextiles and other technical measures make it possible – but costly – to build roads in such an environment. Road alignment along ridges is therefore often the most favourable alternative.

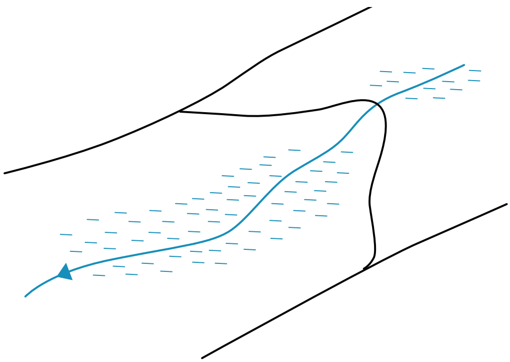


Figure 17: Forest road network in unstable ground conditions

1.2.5 Slope Roads

In all cases where the creek inclination is too steep, the road network has to be developed on the slopes. The road follows the creek as far as possible and then turns back in a loop (*Figure 18*) to the slope. It is important to minimize the number of turns and place them optimal (normally meaning stable and flat ground, see *Figure 6 and 7*).

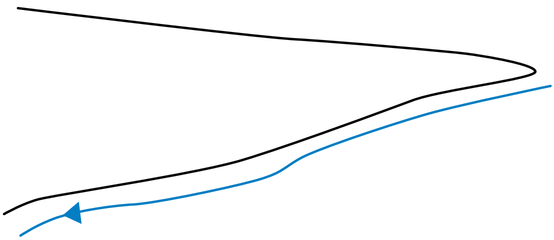


Figure 18: Slope road

Dead end roads and skid roads (*Figure 19*) are often connected at the turn to extend the accessible area.

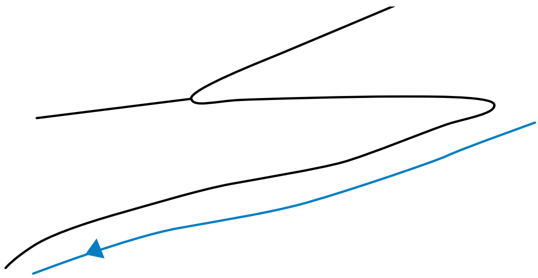


Figure 19: Slope road with junctions to develop the network

In mountainous regions land properties often show unfavourable patterns for management, i.e. narrow strips following the slope inclination, with the farmland in the valley bottom, followed by forest areas on the slope and on top of the slope pastures. Having the slopes divided by such property boundaries, a series of serpentines starting at the main valley provide access to the forest stands. This creates a lot of turns in a narrow spacing. Inefficient use of the landscape and a high risk of erosion/landslide generated by the close sequence of turns, which have a heavy impact on the slope stability, are the disadvantage of this type of forest road network. The main driver for such layouts is to have the road network on the owner's property. *Figure 20* shows this effect which could easily be avoided by integral solutions shown in *Figure 21*. In order to keep the number of bends to a minimum the owners of small properties should cooperate. The situation of unfavourable narrow property strips is also shown in *Figure 11*.

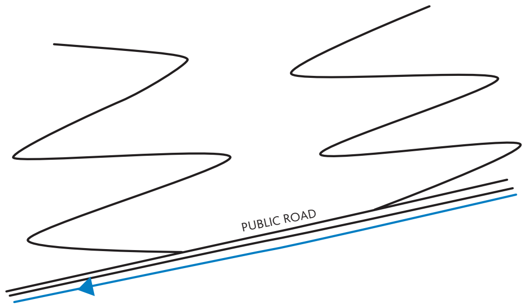


Figure 20: Bad example of the development of separated slope roads

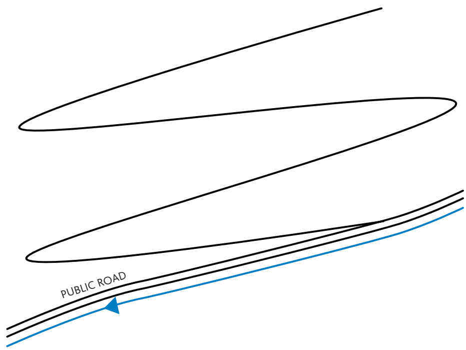


Figure 21: Good example of opening of a slope with long distances between the turns

1.3 Road elements

For slope inclination less than 50% linear road segments tend to be free of stability problems. The only exception is when a structurally unstable slope is crossed (experience shows that on convenient slopes the risk for slope failures is higher, in general, if a slope is steep by nature it is a sign of stability, if a slope is flat by nature its often a result of mass movements).

The most critical elements of forest road networks are the turns, creek crossings and to some extent culverts. They are more expensive to construct and the environmental impact is more severe. Turns and creek crossings have a heavy impact on the ground and slope hydrology. Therefore, selecting the placement of these elements is the first priority when developing a road network.

1.3.1 Turns

The comparison of common road templates for earth or rock subgrade (*Figure 5*) show the huge amount of space which is needed for turns. The selection of favourable spots for the turns is the most important part of general planning. In the first step, stable areas with shallow inclines should be identified. This areas which should be accessed in any case are called cardinal points. It does not matter if this is done based on accurate maps (LIDAR based ones give a more reliable topography than ones based on classic aerial photos) or on field surveys. In the future, remote sensing may become more useful in evaluating locations, but at the time of writing these are assessments that have to be made in the field by a forest engineer.

1.3.2 Creek crossings

When designing crossing of creeks, as fords, culvert or bridges, the functionality during floods has to be considered. The volume of water passing such cross sections is the product of cross section area and flow rate. Stable bank slopes and steep parts of a creek with rapid flow are favourable crossing locations. Areas where the creek flows slowly and creek bed location may change over the years, should be avoided. The capacity of such favourable crossing locations is higher due to higher flow velocity. Erosion of the creek bottom may jeopardise the foundations of the infrastructure and have to be avoided by consolidation measures. Bio-engineering measures offer a number of options (FANNIN 2007). To increase the capacity of a cross section it may be useful to straighten the creek bed under the bridge, but downstream, the flow speed has to be reduced to a safe level again. Natural structures like solid rock can substantially reduce the costs of bridges.

02

Forest road construction

The ability of excavators to separate and store organic material for subsequent use to cover the bare soil of cut and fill slopes for initiating a quick re-vegetation of the slopes, is one of the benefits of the excavator over the bulldozer/angle-dozer. This helps to reduce erosion on the newly built slopes and contributes to stable slopes. In contrast, a bulldozer cannot easily remove the organic topsoil (including roots and stumps) and, therefore, organic material will be mixed into the fill slope. The organic material will decompose over time and this may eventually lead the fill slope to slip down and destabilize.

If the ground is rocky, excavators can place rock pieces up to 0.5 m^3 as a base for the fill slope and build very stable and steep stonewalls on the fill side. A huge problem in steeper terrain is the uncontrolled rolling down of rocks. Larger pieces of rock develop a high dynamic energy on their way down and put humans and objects at risk.

The use of excavators becomes even more advantageous with greater slope inclination (*see Figure 3*).

2.1 Earth subgrade

For earth material without rocks, the use of bulldozers/angle dozers is still the most economical way of constructing roads. However, the separation of organic material (stumps, branches, topsoil) is all but impossible for bulldozers/angle dozers. Removing all dead organic material – especially stumps – from the fill slope is difficult to realize with bulldozers, although loaders in combination with bulldozers can be used to tackle such slopes. Dead organic material will for some years reinforce the fill slope. After that it will start destabilising fill slopes, engineering is required to preserve stability of hill slopes over time. Soil moisture strongly influences the mechanical properties of the earth and thus the drainage system is more important than on rocky subgrade. For optimal construction:

- keep the road body dry
- keep the road body – the fill – free of dead organic material
- consolidate the slopes with vegetation cover as soon as possible

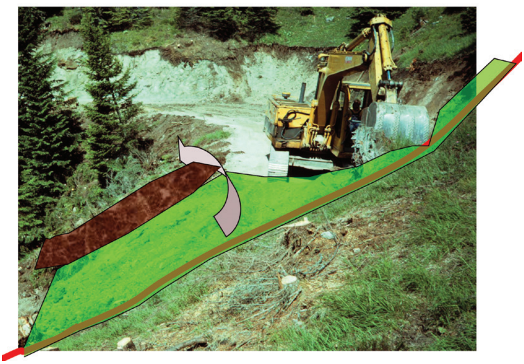
2.2 Rocky subgrade

The excavator should be used when bedrock has to be moved during construction. Excavators have the ability to separate materials, move them – while avoiding rock falls – and compact filled materials. Excavators can also be used to haul logs from the cleared strip. In many cases excavators (around 25 tonnes) can manipulate and crack the bedrock. Only compact hard rock needs to be blasted, hammered or mould where blasting is the highest impact on the environment with high risk for water supply infrastructure. *Figure 22* gives the sequence of construction steps.

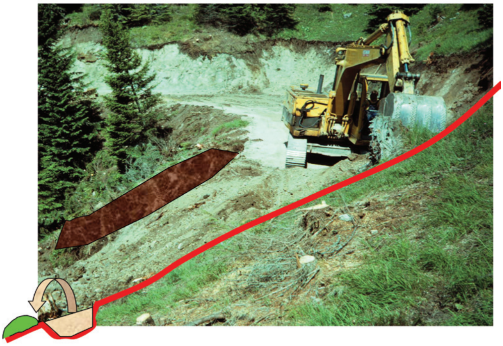
Construction steps

Description

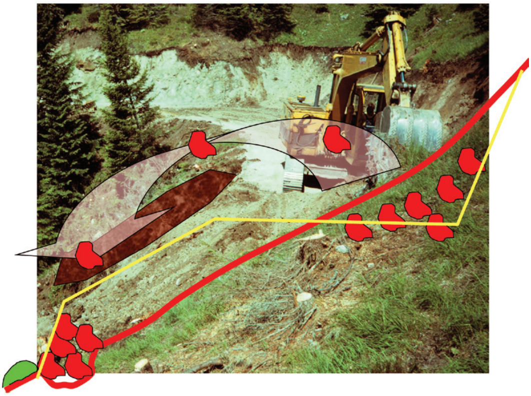
a) In many cases the rock can be handled by the excavator without blasting. If necessary the front end of the newly built road is blasted (just to break down the rock structure). Just the right amount of explosives are needed so that only the structure of the rock is destroyed. Unlike standard blasting methods, the spaces between loads are not filled with sand/gravel to reduce the peak of the blast power. It is recommended to have enough big rocks to establish a solid rock wall on the fill slope.



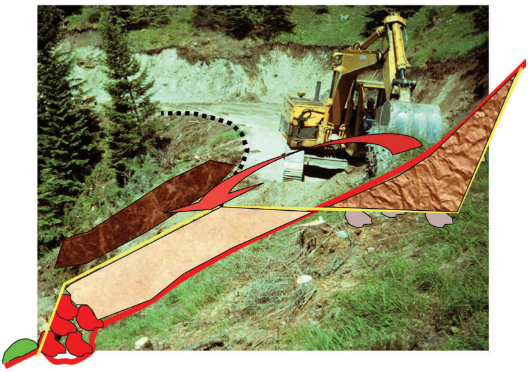
b) The excavator strips off the organic cover and top soil with autochthon seeds and nutrients. The top soil is deposed on the fill slope behind the excavator.



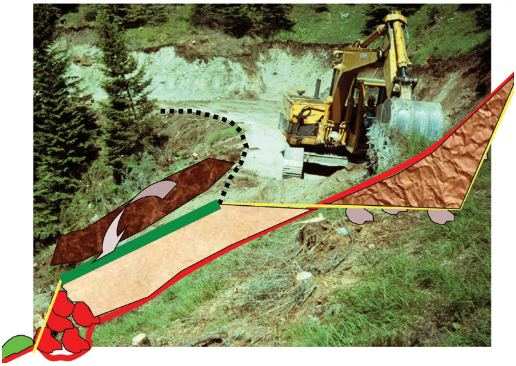
c) At the base of the fill slope a bench is excavated to serve as a bearing for the rocks to establish a rock wall of stones from the cut.



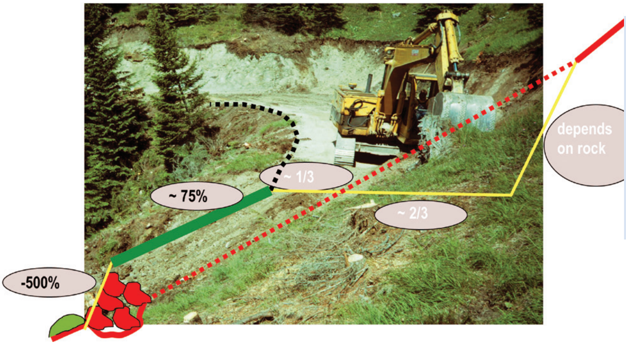
d) The excavator sorts first the rocks (first the big ones) and uses them to make a rock wall. This construction works also as a kind of drainage for the fill slope. According to the available amount of rock this rock wall can go up to the level of the road.



e) After taking off the coarse rock material the remaining aggregate is used to fill up the downhill slope. Any falling rock pieces should be avoided. The excavator shovel is used to place them safely. For turns the range of the hydraulic boom is often insufficient. Therefore, a temporary access track has to be built and the turn must be constructed in several steps.



f) Having filled the fill slope with soil material the deposed organic material is distributed over the newly built fill slope. For the cut slope it is recommended to start regeneration with bioengineering measures (due to the steepness it is often necessary to use a mix of seed, fertilizer and a kind of glue)



g) Typical excavator cross section. 2/3 of the road on the bench 1/3 of the road on the fill cut slop depends on material fill slope (soil) ~75 percent rock wall up to 500 percent

Figure 22: Construction steps with excavator

2.3 Pavement

Forest Roads are often built as earth roads without any pavement. That may be functional under perfect conditions (dry, ground with high carrying capacity) and for urgent interventions (calamities in general), but never match the requirements of a forest road. If such temporary roads are upgraded they will not contribute to a functional forest road net.

On any subgrade a forest road needs a pavement (RYAN et al. 2004). The pavement has to protect the body of the road, if necessary strengthen the formation, and provide a smooth surface for vehicles. The pavement can be hard, using asphalt/tarmac or a soft using gravel. For forest roads gravel is the most common form of pavement. Sometimes the material can be gathered from local quarries opened along the road. In any case the material should be filled up when the formation is dry and should be compacted by rollers. For forest roads a gravel layer of 30 cm with a grading curve from 0 to 60 mm will work in most cases. There is a wealth of literature available (e.g. AASHTO 1993) for accurate design according to specific situations.

2.4 Water management

The top priority is to keep the road body dry. The side ditch has to collect all runoff and lead it to the down slope. This can be done with cross ditches or culverts. FANNIN 2007 gives indications about the general spacing between the culverts. Instead of a regular spacing it is better to place the culverts where the topography offers "channels" to drain. The culverts – mainly the exit – have to be protected against back erosion and erosion of the fill slope.

Where the subgrade has a high moisture content, drainage using big blocks can help to keep the road body dry. Mixing the muddy material with the drainage package can be avoided by using geotextiles.

03

Maintenance

3.1 Introduction

Regular maintenance and proper use of forest roads are both very important for forest management and multi-purpose use of forests. Besides, in many cases forest roads are planned and constructed for other purposes such as the development of villages, rural areas, truism and recreation.

Maintenance activities are intended to protect the initial capital investment in the road construction and, where necessary, provide for local improvements to increase the efficiency of use (FANNIN, LORBACH 2007). It is also necessary for the continued safety of users and to reduce vehicle operating costs.

Picture 1: Regular maintenance and proper use of forest roads are very important for normal forest management (Photo: Juri Beguš)

3.2 Goals of maintaining forest roads

Marinating of forest roads has several goals:

- to keep forest roads in good condition as long as possible;
- to protect users against accidents and hazards;
- to reduce damages on vehicles.

If forest roads are not maintained regularly and properly they lose their functionality and in the worst case they can collapse. If this happens, the costs of maintenance and repair increase, with the costs of wood transport and forestry operations also increasing (BEGUŠ, 2013).

3.3 Types of maintenance

In general we can talk about two main maintenance regimes; namely, preventive and on-demand maintenance.

- Under the preventive maintenance regime, forest roads are constantly maintained from day one to help prevent any major defects and pavement damage (LARCOMBE, 1999). This approach is called preventive maintenance, which prolongs the life of the road.
- On-demand or irregular maintenance corrects any defects as they arise. The costs of this approach are lower but the road may require rehabilitation sooner.

The maintenance regime to be adopted will be determined by the importance of the road – major roads will require preventive maintenance, whereas lower grade roads can be maintained on demand.

Several aspects of forest road maintaining are known (DOBRE, 1994):

- aspect of time
    - annually (every year)
    - periodically (from 5-10 years, resurfacing, reconstruction)
- aspect of economy
    - regular maintaining (yearly funds)
    - investing (investing funds)
- technical aspect
    - repairing of small damages on carriageway
    - reconstruction (resurfacing of the upper road layer)

The connection among different aspects
annually = regular = repairing
periodically = investing = reconstruction

- maintaining by working method
    - manually
    - mechanically
    - combination of both

3.4 Distinction between repair, maintenance and upgrade

Road upgrade is concerned with the reinstatement of road facilities to their former condition, sometimes this takes the form of maintenance and sometimes it consists in the reconstruction of forest roads. Repairs and maintenance of forest roads are separate operations (RYAN et al., 2004).

Road repair is associated with harvesting, as harvesting and timber haulage operations are the principal cause of road damage. For this reason most repairs are carried out during and immediately after harvesting. Costs for repairing must be incorporated in forestry operation costs.

Maintenance is concerned with keeping roads in a usable condition. It should be carried out on an ongoing basis and is financed from structural sources.

04

Legal background and financing

Depending the conditions and legislation in different countries, maintenance of forest roads can be

- regulated by the law
- the responsibility of forest owners
- both

This depends of the property structure, current practice, financial responsibility for maintenance, the non-forestry roles of forest roads and the dependency of rural areas form forest roads.

05

Principles of maintenance of forest roads

Maintenance of forest roads may be done in accordance with the principles of needs of forest management, natural protection, technical requirements and needs of other (non – forestry) users in a way that does not:

- endanger water sources and watercourses;
- cause erosion;
- damage forest ecosystems;
- threaten the habitats of rare and protected plant and animal species;
- prevent the normal flow of water from the torrents;
- destabilize the soil and increases the risk of landslides;
- threaten forests functions.

According to professional standards maintenance of forest roads should include:

- water/drainage management;
- repair of pavement and subgrade of forest roads;
    - manually, mechanized or combined;
- repair of retaining walls;
- cleaning the clay sediment and other material;
    - mostly in conjunction of forest roads and skid trails, mainly because skid trails are not properly designed or maintained (cross-channel) or during and after performing forestry operations;
- winter maintenance (cleaning snow and gritting);
- remediation of landslides etc.

Picture 2: When forestry operations finish, debris has to be cleaned (Photo: Juri Beguš)

06

The reasons for degradation of forest roads

Degradation of forest roads is caused by:

- improper planning and construction of forest roads;
- improper use (static and dynamic impacts of vehicle/traffic, forestry operations, higher traffic);
- environmental causes;
- improper maintenance.

6.1 Improper planning and construction

Even when planning opening forest areas, at the projection phase and at the construction phase it is necessary to consider the maintenance of forest roads. Improper planning and construction leads to higher maintenance costs (more frequent and laborious maintenance).

Picture 3: A ford made from concrete or stone should be foreseen at the planning phase of a creek crossing like the one shown above (Photo: Juri Beguš)

6.2 Improper use of forest roads

Improper use of forest roads is reflected as structural damage to the upper and lower road layer, which is mainly caused by:

- overloaded trucks;
- use of forest road with low bearing capacity (after heavy rain or snow melting);
- transport of caterpillar, tracked-wheeled tractors and other forestry machinery;
- logging operations;
- driving over the speed-limit;
- etc.

Picture 4: Overloaded trucks can cause serious damage (Photo: Juri Beguš)

In general, the impacts of traffic or vehicles are seen as static and dynamic impacts. Static impacts on carriageway occur when vehicle mass is higher than the bearing capacity of carriageway. The bearing capacity decreases due to thinning of the upper layer or due to the impact of water in the upper or lower layer of the road (softening), which occurs after long rainfall, thawing, and the impact of ground water etc. The most common consequences of dynamic impacts are ruts.

Picture 5: The lower bearing capacity of the road caused the ruts. Solutions in such cases are road closure at the time of lower bearing capacity, using proper material for reconstruction, using geotextile on the sequences of lower bearing capacity (Photo: Juri Beguš).

Dynamic impacts of vehicles on forest roads are caused by vehicles driving quickly. Damage occurs mainly on carriageways in a number of different forms:

- *pot-holes:* impacts of vehicles on carriageway with lower longitudinal grade;
- *rolling carriageway:* impacts of tyres on carriageway with lower longitudinal grade;
- *ruts:* impacts of lower bearing capacity of the road and impacts of traffic when tyres eject material of carriageway on the side.

Picture 6: Rolling carriageway can cause damage to vehicles (Photo: Juri Beguš)

6.3 Environmental causes

6.3.1 Water

Water management is one of the key elements of road construction and maintenance. Water comes in many ways and shapes e.g. rainfall water, running water, snow and ice. Adverse effects of water include:

- rain water (erosion of carriageway);
- liquid water (erosion of carriageway, banks, ...);
- freezing (decrease bearing capacity and deformation of carriageway);
- underground water;
- snow and ice.

The consequences of the water impact on forest roads are:

- rinsing away fine particles that are important for binding of the upper layer of the road;

- erosion of carriageway;
- deepening potholes;
- softening the carriageway;
- deposition of material;
- landslides;
- damage to embankments.

Snow and ice are problematic at melting temperature. The melting process results in surfaces having low bearing capacity, erosion and slush, which have a similar impact as rainwater and cause following types of damage: ground subsiding, site sliding, potholes etc. Freezing can cause falling stones, rocks and soil on the road, so called frostheaving.

Water can also cause landslides and damage to the cut slope or fill slope of the road.

6.3.2 Other environmental impacts

Vegetation (overgrown forest roads) might be an obstacle to proper drainage. Roots in the upper road layer loosen the road structure and allow water to soften the road structure and carriageway. Insufficient cleaning of culverts may result in vegetation and roots, contributing to incomplete drainage. Irregularly cleared vegetation along the road side – especially on the fill slope side – cause problems in preforming maintenance (grading).

Picture 7: Roadside with inadequate clearing of vegetation (Photo: Juri Beguš)

Storms (ice, snow, wind, rainfall) in different forms and combinations cause diverse damages on forest roads, reducing their general usefulness. The most frequent damage types include:

- road surface erosion;
- damages of drainage systems;
- roads blocked by falling or broken trees.

Picture 8: Heavy rain, improper use and insufficient/improper maintenance cause heavy erosion on the carriageway of a forest road (Photo: Juri Beguš)

6.4 Improper maintenance

Damage due to inadequate maintenance can be:

- the use of inadequate machinery (e.g. shaping of road profile is not done by grader);
- poor performance of maintaining operations mainly due to unskilled machine operator;
- the use of inappropriate material (gravel with much of soil);
- poor installation of various road structures (e.g. construction of pipe culvert directly on the ground).

Picture 9: It is better to shape the road profile with a grader rather than bull-dozer (Photo: Juri Beguš)

07

Elements of maintenance

The main elements to maintenance are (RYAN et al. 2004., POTOČNIK 2015)

- drainage of water
- surface/upper road layer
- foundation of the road/structure
- vegetation control

7.1 Water drainage

Drainage refers to the interception, collection and removal of water both from the road pavement itself and from the right-of-way on the upslope side of the road. As such, the term drainage refers primarily to methods of controlling any surface water and intercepted groundwater affecting a road (FANNIN, 2007). Maintenance of the drainage system is the most important aspect of road maintenance.

We distinguish between drainage of pavement and drainage bodies of forest roads. Drainage of the pavement is achieved with the side inclination of the carriageway and radial channels of different shapes. Drainage bodies of forest road are carried out with side ditches, culverts, Irish bridges, fords and bridges.

Elements of drainage used in forest roads include surface grading, ditches, culverts/bridges and fords. A drainage provisions should include (FANNIN, 2007):

- a transverse slope on the surface of the road pavement needs sufficient grade, which direct any surface water toward the ditch-line;
- a ditch of adequate capacity to accommodate flow;
- a culvert or bridge of adequate discharge capacity, which must be placed at a grade that maintains efficient flow;
- a ford that provides easy access for crossing.

Picture 10: A concrete ford enables creek crossing over the road (Photo: Juri Beguš)

Common mistakes in drainage include:

- a poor grade on the surface of the pavement, leading to surface water forming puddles;
- on steep ground in combination with existing ruts resulting in surface erosion;

Picture 11: Surface erosion on steep ground (Photo: Juri Beguš)

- a ditchline with an inadequate configuration may expose the road foundation to ingress the water;
- most failures of culverts arise from inadequate capacity and inadequate construction.

Picture 12: Culvert with an inadequate capacity (Photo: Juri Beguš)

7.2 Maintaining drainage systems

7.2.1 Grading of the road surface

With grading of pavement the profile of forest roads is shaped to improve surface runoff in a transverse direction. It can be directed to one side towards the ditching or it can have a "crowned" profile, which directs surface runoff to both sides of the road.

For the road surface use of gravel is recommended if possible and financially feasible. Gravel particles have sharp edges, which enable good contact among them. Gravel must contain a certain proportion of clay particles and it must be moist, rather than too dry or too wet, to enable good compaction.

The best way of grading is to use graders. After grading the surface should always be compacted with a roller. Avoid leaving a berm of loose material at the side of the carriageway, which may form a barrier to lateral drainage from surface water.

Picture 13: Avoid leaving a berm of loose material at the side of the carriageway (Photo: Juri Beguš)

Clear vegetation from the road to enable easy and efficient flow of the surface water. Special attention must be paid to trees on the side of the road, because if they become too big they can cause problems related to grading.

Picture 14: Vegetation on the left side of the picture makes normal grading impossible (Photo: Juri Beguš)

7.2.2 Configuration of ditches

A ditch must be of uniform shape without any obstructions that may impede or deflect flow of the water (wood residues, wood assortments, boulders, rocks...). Obstructions may lead to erosion of the road foundation or road surface. The purpose of ditches is not only to transport water, but also to intercept springs and depress the water table. We distinguish between side ditches and cross ditches.

Picture 15: Obstacles in the ditch (Photo: Juri Beguš)

Side ditches must have a longitudinal grade of 2 percent or more to ensure that the flow is free from undesirable ponding in the ditchline. A wide triangular shape should be used for the cross-sectional profile of the ditch as it leads to the compromise of flow capacity and ease of maintenance. A U-shape should not be used since it is prone to sloughing and this may undermine the edge of the cut slope or shoulder of the road.

The bottom of the ditch should be placed below the level of subgrade to prevent undesirable ingress of water to the base course. Cross-drain culverts must be placed at critical locations on the ditchline (at a low point in the road alignment, prior to a section of steep gradient). If a ditchline is located in very erodible soils it must be stabilized with stones or wood.

A very common type of ditch is drainage ditch, which is normally shaped in combination with a crowned profile of the road. They are built on permeable ground and in areas where large quantities of water are not expected.

Picture 16: Shaping of side ditch with grader blade (Photo: Juri Beguš)

Cross ditches are very useful for transporting surface water from the carriageway. They can be made in the road surface as a cross channel, or they can be built-in and made from iron, wood, concrete or other materials. They are effective only if they are cleared regularly, otherwise they create an obstacle on the road.

Picture 17: Cross ditch (Photo: Juri Beguš)

The maintenance of ditches (reshaping or cleaning) must be carried out during periods of dry weather conditions to minimize erosion and sedimentation. This work is best done by using a backhoe loader or excavator. Side ditches are re-shaped during grading the cross profile and this work is best done using a grader.

7.2.3 Culverts and bridges

In forestry a variety of culverts and bridges are used. The most common are concrete culverts composed of one meter long pipes, which cause some problems. Today plastic and metal culverts are becoming more and more common. Pipe culverts are composed of pipes, water inflow and water outflow.

Recommended diameters for culverts are:

- 400 mm for regions with modest rainfall;
- 600 mm for regions with heavy rainfall;
- diameters for plastic or metal tubes can be lower.

Place the culvert on top of bedding layer with a thickness equal of one quarter of the pipe diameter. This ensures solid foundation providing continuous and uniform support to the pipe.

Picture 18: Poorly constructed pipe culvert (Photo: Juri Beguš)

Culverts and bridges must be inspected regularly. This is particularly important after periods of heavy rain. If they are blocked or damaged, it can cause serious erosion of a road.

Bridges must be located and designed with the aim of limiting change to streamflow characteristics. There must be no other obstacles in the bridge profile. Water must flow through the bridge as fast as possible.

7.3 Surface/upper road layer

The most common damage types on the upper road layer are:

- potholes;
- erosion of carriageway due to water runoff;
- damaged carriageway due to traffic and overloading trucks.

7.3.1 Potholes

Potholes occur on forest roads with longitudinal inclination of 0-3 percent making them very common on flat sections of unbound roads. Potholes are caused by the increase in pore water pressure in pavement fines especially on impermeable formations resulting in the ejection of the fine material from the pavement (RYAN et al., 2004).

Picture 19: Pothole can cause damage to vehicles (Photo: Juri Beguš)

The presence of potholes causes a risk to the safety of the user and increases vehicle operating costs. In addition, potholes may weaken the road body in the long term.

Potholes can be fixed using the following measures: filled by gravel, re-grading and in some cases compaction. Small potholes can be repaired manually.

7.3.2 Erosion of carriageway due to water runoff

Erosion of the carriageway is mostly the consequence of damage to the forest road's drainage system (or the absence of a drainage system), and causes erosion channels in the upper layer of the carriageway, sometimes leading to more severe road damages.

Solutions include repairing drainage system, construction fill of gravel, grading and compaction.

Picture 20: Solutions for the problem in the picture are: removing vegetation, constructing a side ditch, filling the carriageway with gravel, grading the carriageway, and shaping the crown profile, compaction (Photo: Juri Beguš)

7.3.3 Damaged carriageway due to traffic and overloading trucks

Forest roads used mainly for forest management – which means mostly transportation of wood – can be damaged by overloaded trucks or too high speed of vehicles. Damage caused by overloaded trucks are closely connected with the bearing capacity of the road, which can decrease for various reasons, including:

- heavy rain;
- ice and snow melting;
- insufficient thickness of pavement;
- improper road construction (insufficient thickness of lower road layer);
- lack of maintenance;
- overloaded trucks (especially highly loaded single axles with single tires).

The solution is to regulate traffic. Restricted access helps to limit traffic to eligible traffic. Sometimes closing the road is an option, especially when the carriageway is too wet for driving or at the end of the winter. Another solution is to reinforce both, the lower (bearing layer) and the upper road layer by reconstructing the damaged road section.

Picture 21: Curt-ruts on the road as a result of overloaded trucks driving on the road with improper drainage system and insufficient bearing capacity of pavement (Photo: Juri Beguš)

7.4 Foundation of the road/structure

Damage to the lower layer of forest roads is mainly caused by insufficient maintenance, erosion, or traffic. The only solution is a substantially sheeted upper road layer with material, re-grading, compaction, and then reconstruction of drainage system or complete reconstruction of the road.

Picture 22: The lack of an upper layer is the result of poor maintenance; this road needs reconstruction (Photo: Juri Beguš)

Landslides are common types of damage to forest roads. They cause instability of the road surface due to water softening the base soil and causing it to slide.

Possible actions are constructing stone stacks, retaining walls, and reinforced concrete crib revetments, stabilized by means of piles or timber crib revetments.

7.5 Vegetation

Roadside trees can impede proper road drainage. This may result in a loss of pavement strength due to saturation of the sub-soil. Where tree clearance is inadequate, consideration should be given to removing the trees along the road edge, aiming to allow the sunlight and wind reach the road surface, to let the surface dry out. Overhanging branches should also be removed for the same reasons (RYAN et al., 2004).

Picture 23: Overhanging branches should be removed to allow sunlight and wind to get at the road surface so it can dry out (Photo: Juri Beguš)

Grass cutting and cutting of woody growths before they become too substantial is necessary to ensure an unobstructed flow of water into drainage ditches.

08

The most common maintenance works

Annual maintenance commonly includes:

- inspecting the situation on forest roads: done mainly at the end of the winter, after storms or heavy rain;
- cleaning the drainage system;
- shaping the profile of carriageways in sequence where the crown profile is not in function of drainage;
- managing pot-holes;
- clearing the road of vegetation;
- maintaining road facilities (walls, bridges);
- weather maintenance (if necessary).

Some of this can be done manually (such as filling pot-holes and clearing vegetation), but work is generally done using machinery.

When carriageways cannot be maintained annually, or when the upper layer of the road is disappearing or is significantly damaged (many potholes, huge erosion etc.), the upper layer must be upgraded with new material/gravel. Such upgrading (periodical maintenance) has several phases:

- removal of logging residues, stones and other obstacles from the carriageway and drainage system;
- loosening of the upper layer with a ripper (ripper can be grader or tractor attachment);
- construction fill of gravel to a thickness of 6-10 cm after the compaction phase;
- spreading the material by truck or grader (the latter is preferable);
- shaping the profile of the carriageway and ditchline;
- compaction of the profile.

Upgrade of the road can be done on the road in one go or sequentially. If properly maintained after upgrading, upgraded carriageway can be in good shape from 5-10 years. This depends mainly of gradeline, traffic, ground condition and precipitation. During periodic maintenance all structures and the drainage system have to be inspected and if necessary repaired or replaced.

09

Mechanization for maintenance

Various types of machines are used to maintain forest roads. The following types of machinery is needed to maintain a gravel carriageway:

- machinery for clearing carriageway;
- machinery for maintaining carriageway;
- machinery for removing the vegetation.

9.1 Machinery for clearing carriageway

Use of machinery depends of the type of material which is needed to be cleared form carriageway. In winter time snow must be removed from carriageway. In spring time after the freezing period cleaning of the road from all kind of debris (e.g. slipped down materials from the cut slope), must take place. During the remaining period of the year, wood residues and dirt from forestry operations must be cleared.

For snow removal, snow blade, snow blowers for deep snow, bulldozers, and turbofrezes are commonly used. Sand spreaders can spread sand on frozen and icy roads to make them usable. These machines may be self-propelled or mounted on a truck or tractor.

To clean other material, graders, small bulldozers and backhoe loaders are used.

9.2 Mechanization for maintaining carriageways

For the maintenance and construction of drainage facilities the most appropriate machinery is

- backhoe loaders;
- excavators with a shovel or with a hammer head.

Picture 24: Nowadays excavators are one of the most appropriate pieces of equipment for maintenance of forest roads (Photo: Juri Beguš)

For loading and transport of materials the following machinery is used:

- loader
- truck

Picture 25: Trucks are used to transport and spread the material (Photo: Juri Beguš)

For the maintenance of carriageway diverse mechanization is used:

- rippers
- stone mills
- graders
- bulldozers
- rollers

Picture 26: Graders can help achieve an appropriate shape of forest road (Photo: Juri Beguš)

Picture 27: The final step of maintaining the carriageway is compaction. This extends the life span of forest roads (Photo: Juri Beguš)

9.3 Mechanization for removing the vegetation

The following machinery and equipment are commonly used to remove vegetation from carriageways:

- mulcher
- chain saw
- other hand tools (axe...)

10

Maintenance of skid trails

Maintenance of skid trails is of extreme importance not only to keep them functioning and to reduce erosion and other impacts on the environment (skid trails are one of the biggest source of the erosion in forests), but also to reduce their impacts on forest roads. The main task in maintaining skid trails is to reduce the impact of water on the skid trail itself, on the environment and consequently on the forest road. This is done with

- proper tracing and construction of skid trails;
- use of adequate mechanization;
- appropriate drainage (cross ditches);
- use of biotechnical measures to reduce erosion (sowing grass).

After skidding has been finished skid trails need to be properly protected. The following rules of thumb need to be observed:

- the carriageway of the skid trail has to be aligned, which can be done with a light bulldozer, excavator or skidder equipped with an appropriate blade;
- a certain number of cross ditches must be made; the number depends of the inclination of the skid trail, ground and precipitation,
  - cross ditches must direct surface water out of the skid trail,
  - they can be done with bulldozer, excavator or skidder.

Picture 28: Consequences after forestry operations in the conjunction of forest road and skid trail (Photo: Juri Beguš)

Improper maintenance of skid trails can have the following consequences:

- erosion on the skid trail which can lead to torrents;
- dirt and mud on forest road;
- erosion and drainage problems on forest road.

11

References

AASHTO 1993. AASHTO guide for design of pavement structures. American Association of State Highway and Transportation Officials, Washington, DC

ANDERSON A.E. and NELSON J. 2004. Projecting vector-based road networks with a shortest path algorithm. Can. J. For. Res. 34:1444-1457

BACKMUND F. 1966, Kennzahlen für den Grad der Erschließung von Forstbetrieben durch autofahrbare Wege. Forstwissenschaftliches Centralblatt, 85, 1966. – 12: S 342-354

BEGUŠ J. 2013. Održavanje i pravilna upotreba šumske infrastrukture (šumskih puteva i šumskih vlaka) (Maintenance and proper use of forestry infrastructure (forest roads and skid trails), manual for users of forestry infrastructure, Lux Development and Ministry of agriculture and rural development of Montenegro, Podgorica, Montenegro, 51 pages

BETTINGER P. and CHUNG W. 2004. The key literature of, and trends in, forest level planning in North America, 1950-2001. Int. For. Rev. 6:40-50

DOBRE A. 1994. Gozdne prometnice (Forestry infrastructure), Višješolski študij. Skeletno gradivo. Ljubljana, Univerza v Ljubljani, Biotehniška fakulteta, Oddelek za gozdarstvo: 71 pages

FANNIN J., LORBACH J. 2007. Guide to Forest Road Engineering in Mountainous Terrain, FAO, Rome, 88 pages

LARCOMBE, G. 1999. Forest Roading Manual, Liro Forestry Solutions, Rotorua, New Zeland

PERTLIK E. 2015. E-learning course "Erschliessung", University of Natural Resources and Life Sciences Vienna

POTOČNIK I. 2015. Maintenance of Forest Roads, Permanent Activity in Forest Engineering, lecture, University of Ljubljana

RYAN T., PHILLIPS H., RAMSAY J. and DEMPSEY J. 2004. Forest Road Manual. Guidelines for the design, construction and management of forest roads. CO-FORD, National Council for Forest Research and Development, Dublin.

SEDLAK O. 1985. General principles of planning forest road nets. In "Logging and transport in steep terrain" FAO FORSTRY PAPER 14 Rev. 1, Rome

SEGEBADEN G.v. 1964. Studies of Cross-Country Transport Distances and Road Net Extension. Studia Forestalia Suedica Nr. 18 Skogshögskolan Stockholm, 1964. - 69 S

STÜCKELBERGER J.A., HEINIMANN H.R. and BURLET E.C. 2006. Modelling spatial variability in the life cycle costs of low volume forest roads. Eur J Forest Res. 125.4 (2006): 377-390.

Zakon o šumama (Forest Act) 2010. Službeni glasnik Republike Srbije, broj 30/10 od 7. 5. 2010 i dalje

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