

Reducing greenhouse gas emissions from forest civil engineering

The management of forests and woodlands requires an effective road network to provide access for the machinery required to plant and harvest trees and extract timber and wood products. Roads are also used by visitors for access and activities such as cycling and mountain biking. Forest roads and bridges must be constructed so that they are fit for purpose and robust enough to cope with intensive forest operations. However, building and maintaining road networks uses energy and releases carbon dioxide and other greenhouse gases – from the disturbance of soil for new roads and the quarrying of materials to the emissions from construction vehicles. It is important that these emissions are reduced wherever possible by following good practice in construction and by minimising soil disturbance, especially on sites with peaty soils. This Technical Note describes how the greenhouse gas release from forest civil engineering operations can be controlled and reduced, while still ensuring the development and maintenance of a robust forest road network. It is aimed at forest civil engineers, planners, managers and owners.

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Technical Note



Introduction

Well-built and well-maintained forest road networks are essential for forest and woodland management. The design and construction of each type of road must be to an appropriate standard of engineering to fulfil its use and ensure the safety of road users. Forestry Commission forest roads are classed according to their use: Class A arterial roads are designed for regular use by large vehicles (up to 44 tonnes); Class B are less frequently used spur roads; Class C are other-purpose roads.

In the UK, forest roads are usually 'water-bound macadam' built using two layers of aggregate over an existing sub-grade, i.e. the original surface that is exposed by excavation (Figure 1). Forest roads are built either as 'formation' or 'overlay' roads:

- **Formation roads** are constructed on sub-grades that are as firm as possible, with the original surface material removed – usually to depths of no more than about 1–2 m.
- **Overlay roads** ('on-top' construction) avoid the need for excavating down to a firm sub-grade where the existing sub-grade is excessively deep or weak, but there is a risk that they will be unstable and may settle or subside. Overlay roads are built using tree material and/or geo-membranes on top of softer material – often peat – and for this reason they are commonly known as 'floating roads'. The shortest route should be taken when this technique is used.

All roads must be constructed to specified gradients (e.g. 1 in 10) and specified surface profiles to minimise rutting and degradation. The top layer should be compacted and graded and a durable, hard stone with an aggregate impact value (AIV) (BS 812) of between 20 and 30 should be used.

Road planning and design

For all forest roads, the longer the length of road, the higher the cost and the greater the need for soil excavation and quarried road stone. Good planning and design to minimise road length will reduce overall costs and the emissions of greenhouse gases. Consider reducing, reusing and recycling road materials (Box 1).

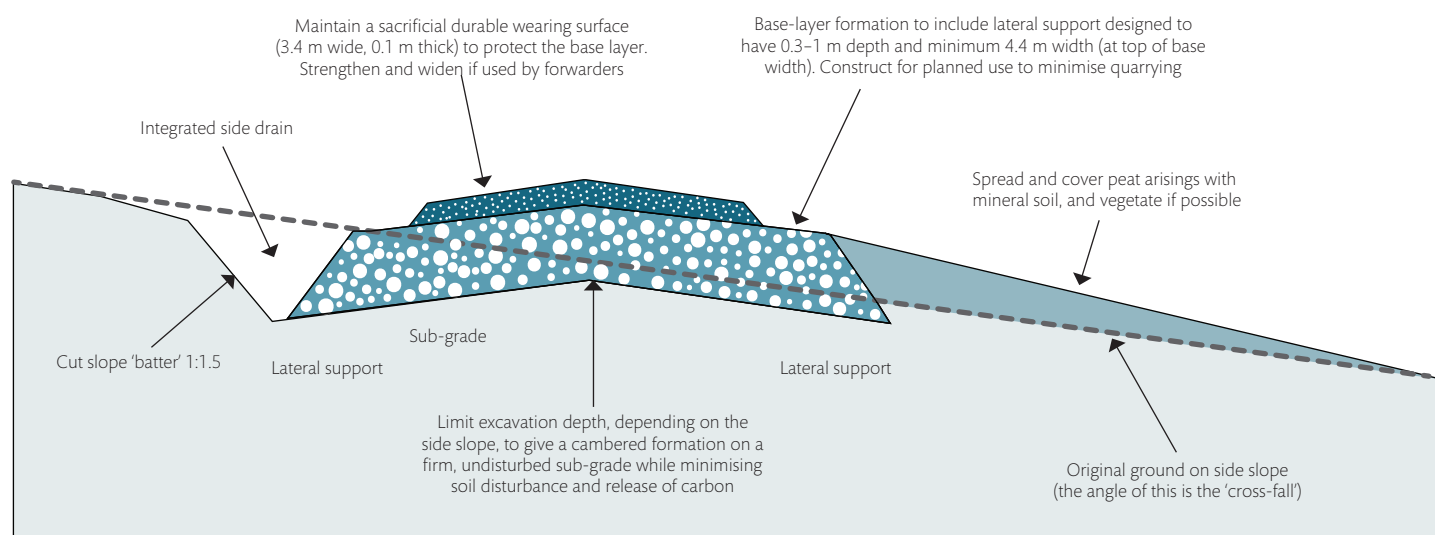
Road density

Forest road density will be influenced by the location, size and timing of harvesting operations and by the choice of harvesting system. When designing the road network, the aim should be to avoid excessive road length wherever possible, for example by reducing the number of loops. However, longer roads will sometimes be unavoidable due to site topography or the need to avoid sensitive features such as areas with a high conservation value or soils with a high organic carbon content.

Planning the route

The careful planning of a route, taking into account all possible options, is important in minimising road building and maintenance costs and reducing greenhouse gas emissions (Figure 2). For example, it may be possible to balance building a longer length of road against building a bridge. In financial terms one bridge is perhaps equivalent to 1 km of road, but the greenhouse gas costs of a bridge may be considerably less. A typical steel and timber bridge with a 10 m span may be expected to release less than 100 tonnes of carbon (CO₂ equivalent), while constructing 1 km of forest road would be expected to lead to the release of between 145 and 3677 tonnes CO₂ equivalent (Box 2), depending on the type of soil that is disturbed during the construction process.

Figure 1 A cross-section of a typical forest road illustrating good practice for construction and maintenance.



Box 1 Reduce, Reuse and Recycle



Consider opportunities for reducing greenhouse gas emissions from forest civil engineering by using the 'Reduce, Reuse and Recycle' approach

Reduce

- Reduce the need for materials and construction by designing and constructing roads using the minimum structure necessary to ensure they are robust enough for their intended use and so that they require the minimum of maintenance.
- Reduce greenhouse gas emissions from soils by routing roads to avoid disturbing soils with a high organic content (e.g. peat).
- Reduce road wear and maintenance by using tyre pressure control systems on large commercial vehicles.

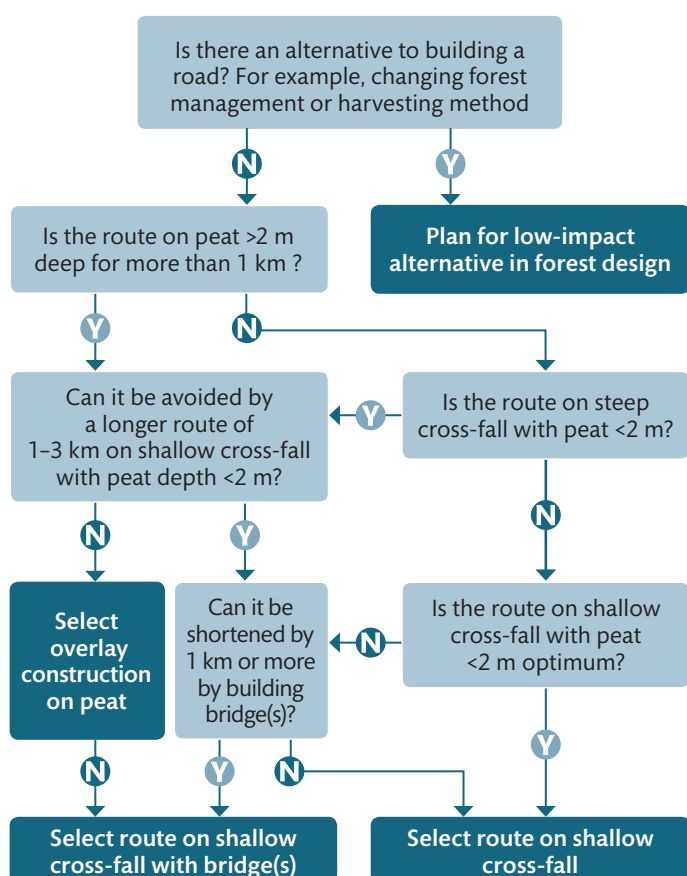
Reuse

- Reuse road material if possible. For example, stone may be reused from stacking/loading areas if it is in a concentrated bulk and not contaminated with organic material.

Recycle

- Recycle other materials from outside the forest if appropriate. For example, recycled bitumen-macadam ('bitmac') road planings have been used in forest road building. However, avoid using materials that have to be transported over long distances to help minimise carbon emissions.

Figure 2 Planning 'decision-tree' to reduce greenhouse gas emissions. Note that a steep cross-fall (Figure 1) is defined here as $>20^\circ$. See also Figure 3 for an illustration of these points.



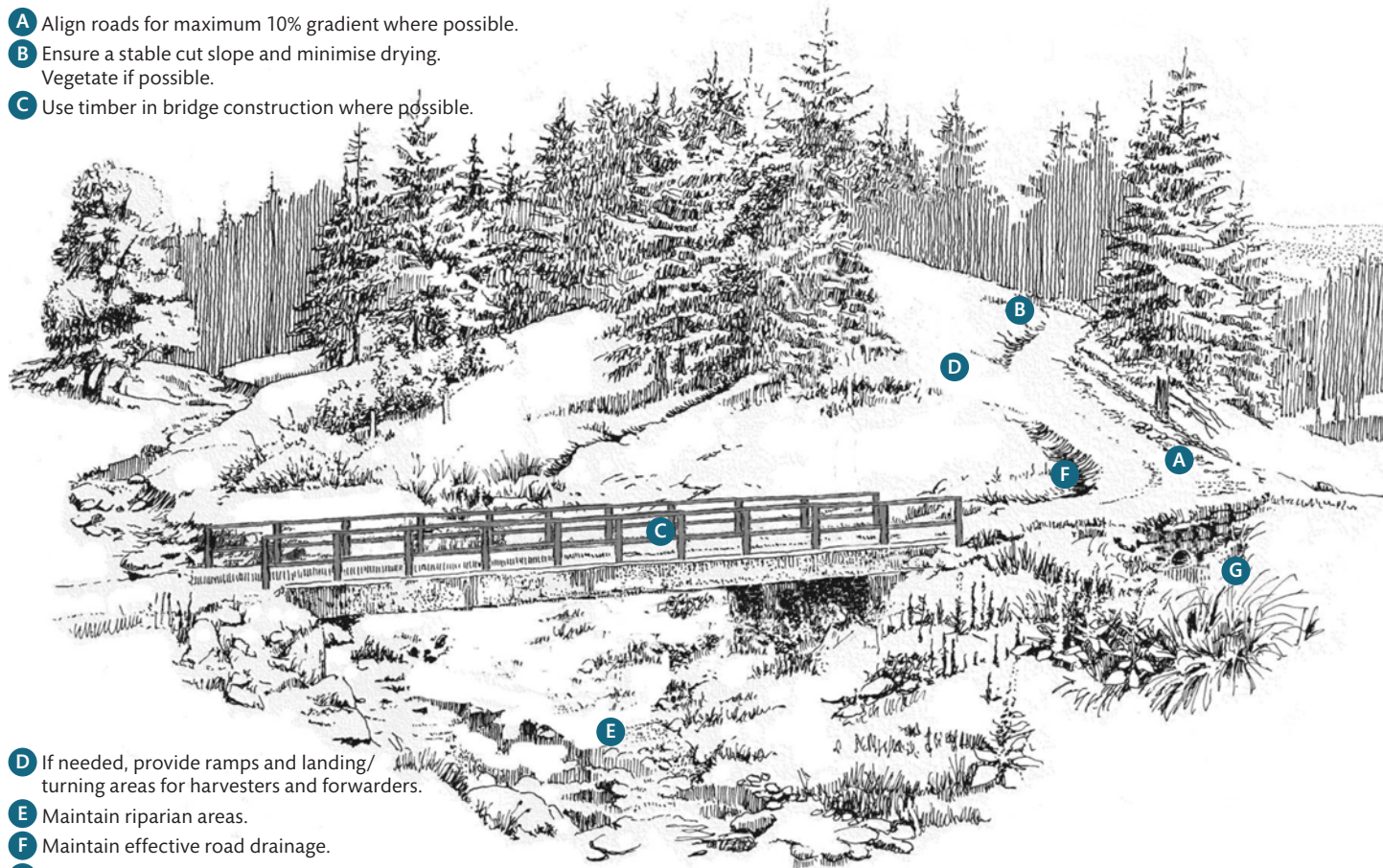
Where possible, there is a need to avoid peat soils over 2 m deep during road construction. Disturbing peat soil has the potential to release large amounts of carbon dioxide, which, along with long-term losses of peat from roadside drainage, dwarf the cumulative effect of all other processes in road building (see Box 3 case study). Balancing the greenhouse gas emissions from increased road length against the greenhouse gas benefits of avoiding peat is especially important if the road is not an overlay road and the cut depth would be greater than 1–2 m. In some cases there will be a clear benefit – for example, building twice the length of road to avoid disturbing areas with deep (>2 m) peat profiles.

Phasing construction

If a new road is considered necessary, a phased approach to construction (over at least three years) can be beneficial. This approach may require less material overall if a formation (the surface profile of the sub-grade, see Figure 1) can be prepared and then left to drain and strengthen, before continuing in the second year. The final year will allow the finished road to settle before it is used, reducing the need for subsequent maintenance. The scope for phased construction can be limited by terrain constraints such as river crossings or bogs, where it may be necessary to construct the road immediately after formation. In addition, some formations may need protection to avoid weathering and degradation, so this should also be taken into account when considering a phased approach.

Figure 3 Recommended good practice for road design and maintenance.

- A** Align roads for maximum 10% gradient where possible.
- B** Ensure a stable cut slope and minimise drying. Vegetate if possible.
- C** Use timber in bridge construction where possible.

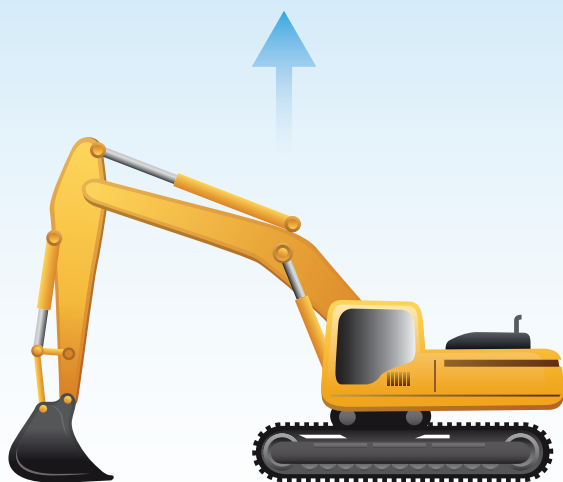


- D** If needed, provide ramps and landing/turning areas for harvesters and forwarders.
- E** Maintain riparian areas.
- F** Maintain effective road drainage.
- G** Maintain culverts.

Box 2 Understanding the greenhouse gas balance of forests and forest civil engineering

Emissions from road building

Road building and maintenance emissions are in the range of **0.02–0.45 t CO₂e per hectare per year** (depending on soil carbon content and excavation depth)



Sequestration by forests

Annual conifer forest carbon sequestration **15.8 t CO₂e per hectare per year** (based on yield class 14 Sitka spruce)



For comparison purposes greenhouse gas balance is expressed here as 'carbon dioxide equivalent' (CO₂e) per hectare per year. Emissions from road building are based on the case study in Box 3 over a 125-year (three rotation) management period. Between 145 and 3677 tonnes CO₂e are emitted per linear km, depending on soil type and level of disturbance. Therefore, assuming 62.5 hectares of forest is accessed by 1 km of road, emissions will be between 0.02 and 0.45 tonnes CO₂e per hectare per year. This is equivalent to between 0.1 and 2.8% of the carbon sequestered by the spruce forest over the same time period.

Timing of construction

The maximum loading on the formation and base layer of a road occurs during construction. The time of year for road building is particularly important as wet weather will lead to a weakened sub-grade formation. If it is possible to build and use a road in the driest periods, then the minimised construction specification could represent a 20% cost saving and a substantial greenhouse gas emission saving, compared with building in wetter conditions.

If the road is built for, and used by, vehicles with tyre pressure control (and/or multi-axles), then there could be a further reduction of around 20% in construction costs and related greenhouse gas emissions. However, roads built to the lowest standards in dry, summer weather may fail if used in winter, so it is always important to use enough road base material for the actual purpose.

Winter construction may add 20% to the construction costs expected in drier conditions, with a substantial increase in resultant greenhouse gas emissions. As a normal minimum standard, the base structure should have a depth of between 0.3 and 1 m, consisting of between 1.5 and 6 m³ stone* per linear metre of road, incorporating lateral support (Figure 1). The sacrificial surface layer over the base should be around 0.1 m thick, representing about 0.5 m³ stone per linear metre of road.

Minimising soil disturbance

Soil disturbance by excavation or spreading should be kept to a minimum, especially on sites with soils that have a high organic content (Box 3). Minimising soil disturbance starts with effective road design (Figures 1, 2 and 3) and this requires a good knowledge of sites and soils. More information on the carbon content of forest soils is provided in the 'Read Report' *Combating climate change – a role for UK forests*. TSO, Edinburgh.

The stability of a road is improved if it is founded wholly on an undisturbed sub-grade formation rather than on the side-cast arisings or fill. Therefore, the depth of dig has to be sufficient to create the full stable width of formation. On level peat sites, it may be acceptable to dig to formation if a firm sub-grade is at less than 1 m depth, excavating about 10 m³ per linear metre. On level sites, construction should be on top of stumps and trees and/or geo-membranes if the peat is deeper than 1 m. However, this overlay construction has the potential for instability by overturning and unplanned settlement, and should generally be avoided for both technical and sustainability reasons.

On a cross-fall of 0–10° (Figure 1), the depth of cut on the higher

edge would be 2–3 m (16–24 m³ per linear metre of excavation), and on a cross-fall of 10–20°, the depth of cut on the higher edge would be around 2–4 m (18–36 m³ per linear metre). Consideration should be given to burying peat under mineral soils to minimise drying and the release of carbon dioxide. As a guide, a 16-tonne excavator can usually excavate soil at a rate of around 25 m³ per hour, including spreading and landscaping the spoil, trimming the cambered formation and digging an integrated side drain (using diesel oil at ~16 litres per hour).

The following issues should be considered to further reduce soil disturbance:

- On a side slope it is possible to minimise soil disturbance, especially peat, by minimising the depth of construction.
- Roadside 'batters' (Figure 1) should be stable and vegetated where possible to minimise soil erosion. This could mean an initial cut at gradients of 1 in 1.5 or less to avoid slips. If necessary, or desired, banks can be covered with living turf cut from ahead of the strip.
- Geotechnical and peat stability – risk assessment and management processes for road assets on difficult ground to avoid peat slide, slip and other instabilities are described in the Forestry Commission Scotland/Scottish Natural Heritage report *Floating roads on peat* – www.roadex.org.

Minimising the use of aggregates

In quarrying, the soil overburden strip should be no more than 4 m deep for high-quality rock. It is important to design the quarrying operation for safe and efficient use of explosives, considering the spacing and face height needed for maximum fragmentation, thus reducing the need for further processing (Figure 4). The same principles apply to road line blasting. Any subsequent rock processing, especially for road surfacing, should maximise particle size for optimum attrition life, while maintaining a tolerable ride for the end user (e.g. lorry or bike).

Material may be usable 'as dug' by the excavator, without the need for further processing. However, this material will usually be of lower strength, limiting its use to the fill and base layers. Over-construction can occur if the particles are oversized (i.e. more than half the layer thickness). In this case, some primary processing (crushing) may be advantageous. For small quantities, excavator-based crushers, which are relatively easy to move and set up, could also be considered.

There are clear benefits from processing the nearest available, hardest and most durable rock for the road base structure and

*Note that 1 m³ stone is approximately 2 tonnes.

Box 3 Comparing greenhouse gas emissions from different parts of the road building process: Eskdalemuir village bypass

Eskdalemuir and Craik forests in Dumfries and Galloway cover over 30 000 hectares and produce around 250 000 tonnes of timber per year. The Eskdalemuir village bypass road was built to allow timber haulage to bypass both Eskdalemuir village and the limited public road network on its way to Lockerbie and the M6 motorway.

The 4.5 km road was designed and built to a high standard to cope with the large volume of traffic encountered on this route – around 20 000 large-vehicle movements each year, equivalent to around 80 vehicles per working day.

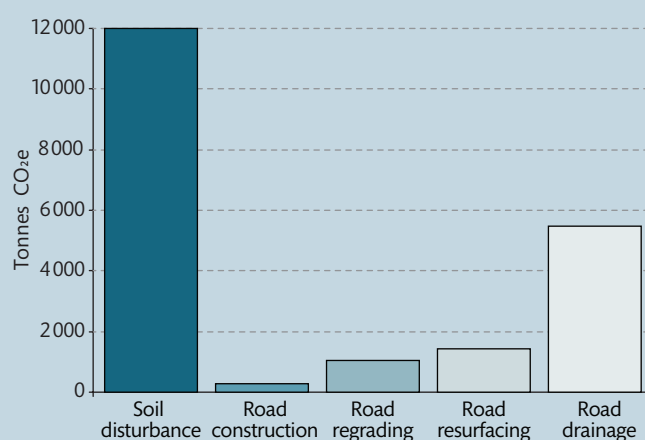
The building of the bypass provided an opportunity for the greenhouse gas emissions for different aspects of the road building and road maintenance process to be compared. Records have allowed emission values to be calculated for:

- Soil disturbance
- Road construction
- Road regrading
- Road resurfacing
- Road drainage

A wide range of soil and rock conditions were encountered during the construction of the road; soils ranged from mineral soils to deep peats, but were mostly peaty soils, with peat depths up to 3 m in places. Construction was designed to avoid excavating peat over 2 m deep.

The graph below demonstrates that, on sites such as at Eskdalemuir with soils with a high organic content, the impacts of soil disturbance and drainage greatly exceed the contribution of hard engineering works to greenhouse gas emissions, and the importance of avoiding, where possible, the excavation of peaty soils.

Comparison of five road engineering activities on the lifetime (125 years) CO₂e losses, for the Eskdalemuir village bypass. Estimates were generated from a 'bill of quantities', with one construction phase, 250 regrading activities (minimum of twice per year) and a complete resurfacing once every 7.5 years.



The entrance to Eskdalemuir village bypass - built to allow timber haulage to bypass Eskdalemuir village and the public road network.



Figure 4 Quarrying operations should be designed for safety and effectiveness.



for the surfacing sacrificial layers. However, the benefits of the durability and suitability of available rock must be balanced against transport distances. Transport distances that are considered to be efficient are less than 10 km for lower-quality material for the base layer (e.g. sedimentary sandstones and shale) and less than 50 km for stronger materials for surface layers that may include imported commercial materials (e.g. hard sedimentary rock and igneous rock such as basalt).

The use of dumper trucks instead of tippers to transport stone can lead to the over-construction of roads by up to 20% if not properly controlled. Dumper trucks are sometimes preferred because of their tolerance of rough terrain (e.g. when constructing roads for windfarms) – however, their use can lead to coarse construction and, because they tend to be wider than tippers, the completed road may be wider than is needed for subsequent vehicles. Site tippers are preferred as they are more similar to the vehicles for which the road is designed.

Bridge construction

Timber should be used wherever possible in forest road bridge construction to reduce greenhouse gas emissions (Figure 5). Although there are considerable carbon benefits in using timber when compared with concrete or steel (Figure 6), the benefits of using timber as a construction material should be balanced

against its longevity. For example, although having greenhouse gas emissions associated with its production, concrete can have a much longer design life and therefore potentially lower average emissions associated with repair and reconstruction. Comparisons of the relative greenhouse gas costs of building with timber, concrete or steel can be made using available data such as those published in the 'Read Report' *Combating climate change – a role for UK forests*. TSO, Edinburgh.

The final choice of construction materials for forest bridges is dependent on the engineering properties of the materials and the specific requirements of the bridge (Figure 7). The most important consideration is always the span. Forest road bridges often need to have longer spans than are technically necessary to protect flood areas and riparian corridors (e.g. for wildlife). However, longer bridges have the advantage of reduced concrete abutments.

In British forestry, short span bridges (up to 6 m) can be built using stress-laminated timber decks. Longer span timber bridges are being built in other countries, but appropriate techniques have not yet been developed for use in Britain. For spans over 6 m, road bridges in Britain use either steel or concrete beams to support highway loads and this can increase the amount of greenhouse gas emissions.

Another important consideration in bridge design is the plan shape. Skew bridges, where the road crosses at an angle to the river, require in-situ concrete slabs to cope with the twisting forces within the deck. Timber and steel are less suitable for this type of bridge, even for those with short spans.

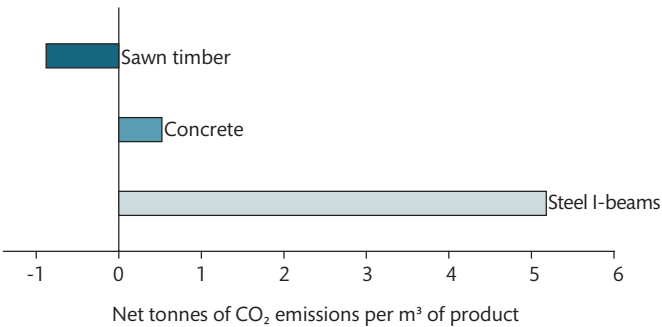
For bridge abutments, in-situ mass concrete walls are the most common. Reinforced earth may also be used; however, this is dependent on suitable material for compacting being available close to the bridge site. Further studies are under way to examine if the overall amount of carbon produced by reinforced earth abutments is more or less than similarly sized concrete abutments. It is possible to use gabion baskets (crushed rock in steel wire baskets) to act as abutments, but they will not have the same longevity as concrete. Abutments may also be constructed using interlocking timber beams, but again these will not have the same durability as concrete.

For steel and concrete bridge construction, timber can still be used as a component in the bridge design. Examples include handrails on both steel and concrete bridges and deck-boards that act as a running surface on steel bridges. Although timber components do not have the same durability as concrete or steel, and are more likely to need replacement during the life of the bridge, their use is still beneficial as an alternative to more carbon-intensive materials.

Figure 5 Timber is a net 'sink' of carbon dioxide (i.e. considerably more carbon is stored in it than is released in its production) while materials such as concrete and steel are net sources of carbon dioxide.



Figure 6 A comparison of net carbon dioxide emissions of timber, concrete and steel beams used for construction (diagram adapted from 'Trees in the greenhouse - why climate change is transforming the forest products business'. World Resources Institute).



Upgrading existing forest roads

To minimise the level of construction needed to upgrade an existing road, it is possible to assess the additional depth of construction required. New tools for this are ground-penetrating radar and falling weight deflectometers that indicate the structural depth and sub-grade strength. Using these allows new stone to be concentrated where it is absolutely necessary, reducing the amount of material needed and the greenhouse gas emissions associated with stone quarrying and transport.

An important consideration during any reconstruction or upgrading of an existing road is whether the road is able to withstand intensive use by the heavy vehicles used for the reconstruction. If not, another option is to make the existing road adequate for timber haulage by, for example, using large commercial vehicles with tyre pressure control systems.

Roads constructed for windfarms are commonly built wider than those for usual forestry purposes. The depth may also be greater due to the level of construction that is necessary to allow the use of large, heavy dumper trucks. If such roads are subsequently modified for forestry, the verges should be brought in (without impeding surface water run-off) to reduce future road maintenance.

Figure 7 Footbridges should always be constructed from timber wherever this is possible.



Road maintenance

The life-cycle of a road can be improved by using the best available quality surfacing materials. Using durable and resilient materials will reduce wear and tear from attrition loss and extend replenishment periods. For Class A arterial roads, the replenishment period is usually between 5 and 15 years, depending on the material used. Replenishment periods for other road classes may be around 50 years, or once per rotation. However, there is a balance between stone quality, haul distance and frequency of replenishment. Poorer stone can have an extended life if control systems are used to adjust vehicle tyre pressure to suit the road conditions.

It is possible to reduce 'wash-away' and 'blow-away' of road material (Figure 8) by using harder aggregates that also have high attrition values – as long as these are well bound and are profiled in a well-shaped surface. Limiting vehicle speeds to the road design speed (commonly 25 km per hour) will also help.

Soil loss can be kept to a minimum by designing and maintaining good drains, with the minimum cut necessary. It is vital that culverts are well designed, selected, installed and maintained to reduce the risk of water damage to forest roads and other adverse effects on the environment. Good drainage is key to maintaining strength of formation and roads in general.

Selecting and maintaining culverts

Effective culverts that ensure adequate drainage away from the road will help to minimise the risk of damage to the road during and following high rainfall (Figure 9). Careful selection and maintenance of culverts is essential in ensuring the maximum life of a road and in keeping greenhouse gas emissions from maintenance to a minimum.

Any watercourse, however small, that is intercepted by a road should be culverted at that point. It is important to follow the UKFS Guidelines on *Forests and water* when considering the size and positioning of culverts. Where additional culverts are needed to discharge water from roadside drains, they should be large enough to avoid overloading, blocking or washout.

The carbon dioxide emissions for concrete and plastic pipes are about 50 kg per metre for a nominal internal diameter of 375 mm installed in a trench 1.5–2 m deep (based on Civil Engineering Standard Method of Measurement – CESMM4). Although concrete and plastic materials could have similar lifespans, plastic is lighter and easier to place in forest road construction (Figure 10).

Figure 8 Blow-away of dry road material.



Figure 9 Forest road washout due to winter rain.



Figure 10 A plastic culvert under a forest road.



Road use

There are a number of road use factors that influence the life-span of a forest road and the need for maintenance (Figure 11).

Timing of road use

The time of year that a forest road is used has a significant impact on its durability and need for maintenance. For example, intensive use in the winter can add 20% to maintenance costs. If a forest road is used during a freeze-thaw cycle, or too soon after a thaw, the road may collapse and require complete reconstruction.

To minimise maintenance and associated greenhouse gas emissions, it is important to minimise winter use, especially during freeze-thaw conditions and especially by heavy vehicles. It is also important to avoid using road salt to melt ice. The adverse effects of salt on road strength can be immediate and long-lasting, as water may continue to be drawn into, and weaken, the road long after the salt is applied.

Appropriate vehicle loading

Care should be taken to avoid vehicle and axle overloading. Where vehicles are overloaded, road damage increases in relation to increasing vehicle weight (Figure 12). Damage can be minimised by the use of tyre pressure control systems. For example, reduced pressures should be used by vehicles when driving on unsealed roads.

Efficient driving

Other considerations are driving style, speed and methods of loading, all of which have significant impacts on the durability

Figure 12 Percentage road damage against gross vehicle weight (from *Road haulage of round timber* – the Timber Transport Forum).



and ongoing maintenance of forest roads. Consideration should be given to allowing time for a road to recover following intense loading activity by large commercial vehicles.

Harvesters and forwarders

To protect forest soils, it is often necessary for harvesting machines and forwarders to use forest roads rather than travelling off road during forest operations. However, machines with band tracks are particularly damaging to forest roads and their use must be planned and managed. It is preferable to carry out pre-emptive widening and strengthening and this may add around 30% to costs. Without this, the possible damage may add about 50% to road costs. It will also be necessary to provide ramps and a landing/turning area beyond the road structure to maintain, as far as possible, the structural integrity of the road.

Figure 11 Efficient road use minimises maintenance and associated greenhouse gas emissions.



Useful sources of information

Forestry Commission publications

- The UK Forestry Standard (UKFS)
- UKFS Guidelines on Forests and climate change
- UKFS Guidelines on Forests and landscape
- UKFS Guidelines on Forests and soil
- UKFS Guidelines on Forests and water

Guidance and good practice

- The identification of soils for forest management. Field Guide (FCFG001).
- Protecting the environment during mechanised harvesting operations. Technical Note (FCTN011).

Research

- Forests and carbon: valuation, discounting and risk management. Research Report (FCRP012).
- Understanding the carbon and greenhouse gas balance of forests in Britain. Research Report (FCRP018).
- Understanding the GHG implications of forestry on peat soils in Scotland. Forest Research, Farnham.

Other publications

- Civil Engineering Standard Method of Measurement (CESMM4) Carbon and Price Book 2012 (Institution of Civil Engineers).
- Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change (TSO, Edinburgh).
- Floating roads on peat. Scottish Natural Heritage/Forestry Commission Scotland (Roadex).
- Monitoring low volume roads (Roadex).
- Peatbogs and carbon – A critical synthesis (RSPB).
- Road haulage of round timber. Code of practice. 4th edition (Timber Transport Forum).
- The timber transport toolkit: hauling timber on the public highway (Timber Transport Forum).
- Understanding the carbon footprint of timber transport in the UK (North Energy).

British Standards

- BS 63 – Road aggregates
- BS 812 – Testing aggregates
- BS 1377 – Soils for civil engineering purposes
- BS 5911-6 – Concrete pipes and ancillary concrete products
- BS 5930 – Code of practice for site investigations
- BS 6031 – Code of practice for earthworks

- BS 6543 – Guide to the use of industrial by-products and waste materials in building and civil engineering
- BS 7755 – Soil quality
- BS 8006 – Code of practice for strengthened/reinforced soils and other fills
- BS ISO 11074:2005 – Soil quality – vocabulary
- BS EN 1992-2:2005 – Design of concrete structures – concrete bridges
- BS EN 1993-2:2006 – Design of steel structures – steel bridges
- BS EN 1995-2:2004 – Design of timber structures – bridges

Websites

- Forestry Commission (Civil Engineering) – www.forestry.gov.uk/civilengineering
- Department for Environment, Food and Rural Affairs (Defra) – www.defra.gov.uk
- Highways Agency – www.highways.gov.uk
- Roadex network – www.roadex.org
- Timber Transport Forum – www.timbertransportforum.org.uk
- CapIT online carbon and cost estimator – www.capit-online.com
- CEEQUAL The sustainability assessment, rating and awards scheme for civil engineering – www.ceequal.com

Summary of good practice in reducing greenhouse gas emissions from forest road and bridge building

- ✓ Minimise road build by good route planning and design.
- ✓ Optimise the route to avoid excessive loops, unless avoiding peat or dictated by harvesting needs or terrain constraints.
- ✓ Consider using a bridge to save 1–2 km of road for a similar cost but less greenhouse gas emission.
- ✓ Consider increasing road length by 1–3 km for every 1 km to avoid digging deep peat (>2 m)/steep side slopes (>20°).
- ✓ If building on peat (>2 m) is unavoidable and feasible – build 'on top' of tree stumps if present.
- ✓ Construct roads when dry, but design for use when wet.
- ✓ Use roads when dry but expect use when wet. Do not use during thaw and avoid using road salt.
- ✓ Use nearest, hardest rock and minimise rock processing, but avoid over-construction.
- ✓ Design quarry blasts for safety and effectiveness.
- ✓ Limit transport of weaker, softer rock for the road base to 10 km.
- ✓ Limit transport of stronger, harder rock for the road surface to 50 km.
- ✓ Minimise cut on side slopes.
- ✓ Spread and bury removed peat under mineral soils.
- ✓ Minimise depth of construction.
- ✓ Use site tippers, for given design load and sub-grade bearing capacity.
- ✓ Assess the need to upgrade existing roads using ground-penetrating radar and falling weight deflectometer.
- ✓ Reduce road wear by using heavy vehicles fitted with tyre pressure control systems.
- ✓ Avoid overloading lorries.
- ✓ Maintain good, hard-wearing surfacing by replenishing every 5–10 years on Class A arterial routes.
- ✓ Allow road recovery time when intensively used.
- ✓ Maintain good drainage of the formation, road structure and surface.

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