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Protecting the Environment during Mechanised Harvesting Operations

TECHNICAL NOTE

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SUMMARY

Best practice can minimise the risk of environmental damage during harvesting operations on soft ground. This may increase operational costs but can be justified by the need to protect soils and prevent erosion and subsequent siltation within watercourses. The selection of preventive rather than 'first aid' methods should be encouraged.

INTRODUCTION

This Technical Note provides guidance on matching harvesting systems to site conditions to reduce the risk of soil damage and water pollution. It updates some previously identified issues and describes some new techniques. Information is provided on site planning, selection of machines, brash mat construction and maintenance, forest road approaches/drainage and roadside stacking.

The Forestry Commission work study report *Soft ground harvesting: review of methods to minimise site damage* (Spencer, 1991) describes methods for minimising harvesting damage on soft ground. Some of the techniques described in the report, e.g. fascines (bundles of secured pipes) have not been widely adopted. Using stemwood to create corduroy routes in soft areas is still a viable option. Forest Research has continued to research and develop methods of reducing the risk of ground damage and water contamination (Figure 1). This Note describes the best techniques to protect the environment while maintaining good machine performance.

Within a well-planned harvesting operation, a range of operational techniques are available to avoid or minimise the risk of soil erosion and siltation. Some of these involve civil engineering works and may need to be planned at an early stage.

Forest Research staff investigated a number of harvesting operations and observed techniques relevant to:

- brash mat construction and maintenance;
- drain and watercourse crossings;
- forest to road approaches;
- roadside stacking;
- roadside drainage.

Figure 1

Watercourse crossing.

Although site managers may have a limited choice of machinery, it is important that the impact of particular machines on the site is considered so that additional protective measures are adequately planned for. In some cases, due to the risk of damage a different system or machine may be required to that originally proposed. Therefore, good site planning is very important before selecting the appropriate machine(s).

SITE PLANNING

Good site planning is essential and the following points need to be considered when assessing the potential impact of harvesting operations on the environment:

- site conditions – soil, slope, drainage, access;
- crop characteristics – species, size;
- constraints/sensitivities;
- timing of operations;
- machine choice.

MACHINE SELECTION

There may not always be a wide choice of harvesting and extraction machinery available but an understanding of the effect of machine type on site impact will help to determine the risk of site damage and the need for additional protective measures.

Excavator-based harvesters

Tracked excavators frequently used in clearfell operations exert a low ground pressure. For example, a JS 200 LC harvester with 700 mm tracks and a 4.46 m carriage has an average ground pressure of 0.33 kg cm^{-2}. Longer tracks improve stability and flotation. Operating on brash mats prevents excessive wear and damage to running gear.

Slope is the principal limitation when using excavator-based harvesters on clearfell sites. As slope increases, the ability of the machine to slew trees up-slope for processing diminishes to the point where productivity falls off. Therefore, the width of the drift harvested up-slope is reduced to make slewing easier. These narrower drifts of *c.* 4 rows provide less effective brash mats, although such mats on sloping ground will usually be sufficient for extraction purposes. Safety and the risk of erosion in track and wheel ruts must be considered.

Conversely, on more level ground, which can be softer, drift width can be increased to 8 or 10 rows (depending on row spacing) to the full reach of the machine. Output increases of up to 17% have been recorded for 10 row working compared to 4 row working. Further details can be found in *Harvester output: the effect of drift width* (Spencer, 1998a). On very soft sites, or in situations where large volumes of timber will be carried over key routes, full reach brash mats are required to protect the soil.

Purpose-built tracked tilting base harvesters

As described, using the standard excavator based harvester on steeper slopes reduces the felling drift width and the volume of the brash mat. The introduction of tilting base harvesters enables felling drift width to be maintained on slopes, resulting in good brash mat construction.

The ground pressure of such machines ranges from 0.45 kg cm^{-2} to 0.52 kg cm^{-2} depending on the track plate width.

Wheeled harvesters

Purpose-built wheeled machines are more versatile than excavator based harvesters, especially for thinnings and working on steeper ground. Slopes up to 45% have been harvested with a TJ 1270/762 wheeled harvester equipped with bandtracks and chains.

Ground pressures, without bandtracks, can range from 0.27 kg cm^{-2} for an eight-wheeled machine to 0.63 kg cm^{-2} for six-wheeled machines. The following variables can influence static ground pressure calculations:

- tyre and wheel configurations;
- machine characteristics;
- soil conditions.

It cannot be assumed that an eight-wheel machine will always exert a lesser ground pressure than some six-wheel configurations.

Further information on ground pressure calculations related to soil conditions can be found in *Review of tyres and traction aids* (Morgan, 2001).

Bandtracks fitted to the bogie wheels improve stability and flotation on soft ground.

Forwarders

Although modern forwarders are versatile and capable machines, a number of factors affect operational results in terms of both environmental impact and economics. Forwarder extraction is by far the most common method of extraction on all but the steepest sites (>50%) and has the potential to cause significant soil damage on soft ground. Therefore, care in machine selection is particularly important. The main factors to consider are:

- Eight-wheeled forwarders exert lower ground pressures and are therefore better suited to soft, wet conditions than most standard six-wheeled machines.

- Band tracks can be fitted on the rear bogies of wheeled machines and in particularly difficult conditions onto the front bogies of most eight-wheeled forwarders. Further information on traction aids can be found in *Review of tyres and traction aids* (Morgan, 2001).

- Static/footprint ground pressure, machine weight, soil/brash conditions and number of passes influence ground rutting and compaction.

- Larger, 16 tonne (t) to 18 t forwarders are more efficient than medium 10 t to 12 t machines for extraction over longer distances of over 400 m 'out wood', although they require stronger brash mats.

- Larger forwarders are heavier both laden and unladen than medium forwarders. For example, a Timberjack 1710D forwarder fully laden might weigh over 37 t compared to a gross weight of around 29 t for a Valmet 860.1.

- Where soil and brash mat bearing capacity is insufficient to sustain a large forwarder, a smaller machine must be used.

- Load sizes can be reduced on very wet sections. Local experience is invaluable.

- Flotation band tracks are available in a variety of specifications and have different characteristics. Some older designs that have the track plate links significantly below the crown of the tyre can scuff brash mat and road surfaces to a greater extent than modern designs with track plate links closer to the crown of the tyre.

Skidders

Winch or grapple skidding is no longer a significant extraction method on British conifer clearfell sites. Brash mats resulting from motor-manual felling are less robust than those constructed by harvesters and potentially offer less machine flotation and soil protection.

Clambunk skidding of whole poles or whole trees has been practised on some upland conifer sites in Britain. Whole tree extraction can be organised using key harvester brash mat routes at intervals such as 50 m across the site. These key routes reduce trafficking on the unprotected ground and may increase machine travel speed. Whole-tree extraction should be confined to firm mineral sites on which the additional nutrient loss will not have a significant impact. Clambunk skidding off brash mats on wet sites will result in significant ground damage and possibly water pollution and bogging. Further advice on whole-tree harvesting can be found in *Whole-tree harvesting: a guide to good practice* (Nisbet *et al.*, 1997) and *Whole-tree extraction: technical development studies* (Wall, 1996).

Skyline winch system

Skyline cableway and highlead winch systems are rarely used on soft, less steep ground because of low outputs and high costs. These systems have the potential to pose the least risk of ground damage. Winch technology is developing and excavator based cableway systems can reduce set-up times. Hydraulic and other fast haul back line speeds may improve competitiveness in the medium term. Nevertheless, cableway systems are unlikely to be the first choice on less steep ground except on the most sensitive sites.

BRASH MAT CONSTRUCTION AND MAINTENANCE

Harvesters can produce strong brash key routes for forwarder extraction. Key routes can be formed by cutting wider drifts and usually require additional strengthening, using forwarders to carry in more brash as needed. Further information can be found in *Kielder harvesting brash mat trial: an assessment of soil protection* (Wall and Saunders, 1998). In the absence of good brash mats, the bearing capacity of soft soils can quickly be severely reduced, resulting in deep wheel ruts and silt laden run-off (Figure 2).

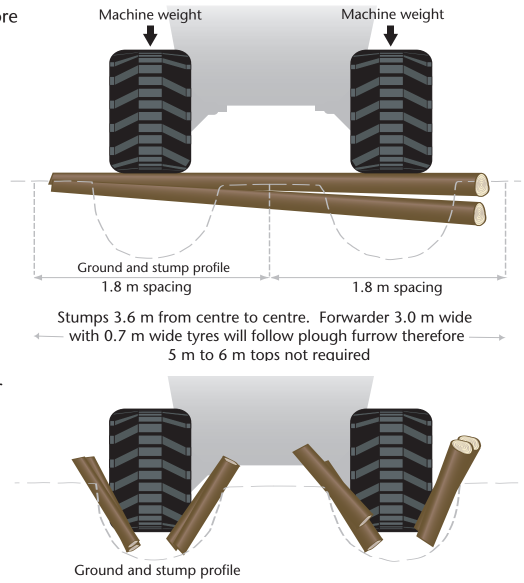
The bearing capacity and durability of brash mats is influenced by the depth, length, type (tree species) and age of brash, as well as by the presence and orientation of tops and dead trees. Recent work has indicated that cutting the lop and top into 2 m sections produces an improved route compared to leaving the lop and top in 4–5 m lengths. The longer tops were broken at weak points by machine travel. The tops break at points where there is no support, such as between the stumps and plough ridges, creating a 'W' effect (Figure 3) that permitted the ends of the timber to pierce the surface of the ground. These broken sections were pushed into the ground after each pass of the machine, reducing the strength and durability of the route.

Figure 2

Deep eroded wheel ruts in unprotected soil.

Figure 3

The 'W' effect. Diagram based on a Valemet 890 forwarder.



Brash depth depends on the width of drift cut by the harvester. The number of rows harvested affects output and cost. There was a significant increase in output when a TJ 1270/762 harvester felled six rows compared to four, with a smaller increase when felling eight to ten rows. Further output information can be found in *Clearfell harvesting systems for purpose built and tracked harvesters* (Spencer, 1998b). Brash mat density can be increased by using harvesters with long reach booms (10 m) that enable a wider drift to be cut, improving brash mat support for machinery.

Strengthened brash mats

A trial at Racks Moss in south Scotland: *Extraction route evaluation on deep peat* (Saunders, 2001) compared 'standard' brash mats and brash mats strengthened with unrolled straw bales (Figure 4) and brash bales. These techniques have a cost penalty and are more likely to be used on sensitive sites where conventional brash mat maintenance practices are not possible.

Straw bales

Forest Research has carried out development work on lodgepole pine extraction route construction at Rumster Forest, north Scotland and Racks Moss plantation, when extracting timber over deep peat. Rumster had a lodgepole pine stand with 2250 trees per ha compared to Racks Moss with dead and windblown trees at 1400 trees per ha. At Rumster extraction over 4.5 m deep peat was successful using a fully tracked 8 t forwarder.

Figure 4

Straw bales used to strengthen key route.

The results of the trial at Racks Moss showed that the extraction route constructed (using only lodgepole pine brash) from the less dense lodgepole pine crop was a complete failure. At Racks Moss the addition of agricultural straw using round bales dramatically improved harvesting machinery flotation and route durability. The bales of straw were rolled out along the brash mat following the wheel imprint of the harvester. This can be done manually or by using the crane on the forwarder. Six layers of straw were placed on the route for the lodgepole pine crop and four layers were used for the Sitka spruce crop. As the forwarder travelled over the site the straw was compacted and formed a supportive mat.

Brash bales

The use of Sitka spruce brash bales was also evaluated during the extraction trials at Racks Moss. The bales were produced by the Timberjack 'Fibrepak' unit. This system compacts and rolls the brash into round bales approximately 3.7 m long by 0.50 m in diameter. The bales were placed across unplanted areas and provided adequate support for harvesting machines as they crossed these previously bare areas.

Techniques to improve brash mat durability

Planning

- Identify key routes early but be prepared to change.
- Choose drier key routes where possible, or locations where crowns or species will provide good brash.

Harvester

- Place dead trees and tree tops (cut into 2 m lengths) across the direction of machine travel, in addition to branches removed in processing.
- Cut the brash into 2 m lengths instead of the longer 4–5 m lop and top.
- Place tops along the furrow (when travelling with or across ploughing direction) to fill any pronounced hollows. Then place tops at right angles to travelling direction as with standard brash mat formation.
- Rotate the harvester head to turn the tops where necessary to maintain an even surface.
- Fill weak spots with extra brash or upturned stumps.
- Create 'spur racks', which may be extracted early to release brash for patching and strengthening the key route.

Forwarder

- Transport brash from extracted sections to strengthen remaining sections (Figure 5).
- Repair weak spots quickly, before the brash mat surface is significantly damaged and deep holes are created.

Where to use

Any harvesting site where machine travelling will lead to rutting or other significant damage to the soil.

Figure 5

Key route protection against the formation of wheel ruts.

Benefits

- Reduced risk of wheel rut formation, soil erosion and silt-laden run-off.
- Reduced soil compaction along extraction routes.
- Increased extraction machine travel speed.
- Avoidance of machine bogging and machine downtime.
- Improved operator ergonomics

Constraints

Brash mats can be a potential constraint to ground preparation, especially when they are strengthened. Research has shown (Morgan, 2004) that overall harvesting and ground preparation costs are not significantly affected when short tops are cut and ground preparation using spot brash raking is used to ensure good mound to soil contact. Some strengthened key routes may need to be excluded from ground preparation. Further information on soil protection can be found in *Forests and soil conservation guidelines* (Forestry Commission, 1998).

DRAIN AND WATERCOURSE CROSSINGS

Main drain and stream crossing points (using bridges or pipes) should be kept to a minimum. Crossing points need to be carefully selected and designed to prevent bank damage and the entry of silt into the watercourse. Machines must not work in streams, and crossings should be removed as soon as they are no longer required.

Further advice should be sought from the relevant water regulatory authority in relation to any work in watercourses, such as the installation of bridges or culverts, as a consent may be required. Ensure that works do not create a barrier to fish movement and migration within watercourses.

Pipes

- Pipes should be placed in drains and covered with brash and logs. Crossings should be checked regularly to ensure the free flow of water, and that pipes are not pushed into the ground.

- Up to a diameter of 375 mm, double walled high density polyethylene pipes are used. Where larger diameter pipes are required (400 mm to 1200 mm) double walled polypropylene pipes can be used.

Forwarder log bridge

Forwarders can build bridges using logs and brash for spans from 3–4 m (see Figure 6 and example specification in Figure 7 and Table 1). Deck logs (in line with stream flow) are roped to the main runner logs (at right angles to stream flow) which are placed on bearers parallel to the stream flow. The approach to the bridge can be built up with logs or stem wood placed at right angles to machine travel and covered with brash. A built up approach without brash can be seen on the right hand side of Figure 6. An example of a specification for a log bridge is given in Figure 7. Supervisors should refer to local civil engineers when installing a log bridge for the first time.

Where to use

- All watercourse crossings, even minor water channels. Pipes and logs are more suitable for drains and smaller watercourses and bridges should be used for larger watercourses.

Benefits

- Watercourse protection from bank collapse, erosion and siltation.

- Prevention of localised flooding and machine bogging.

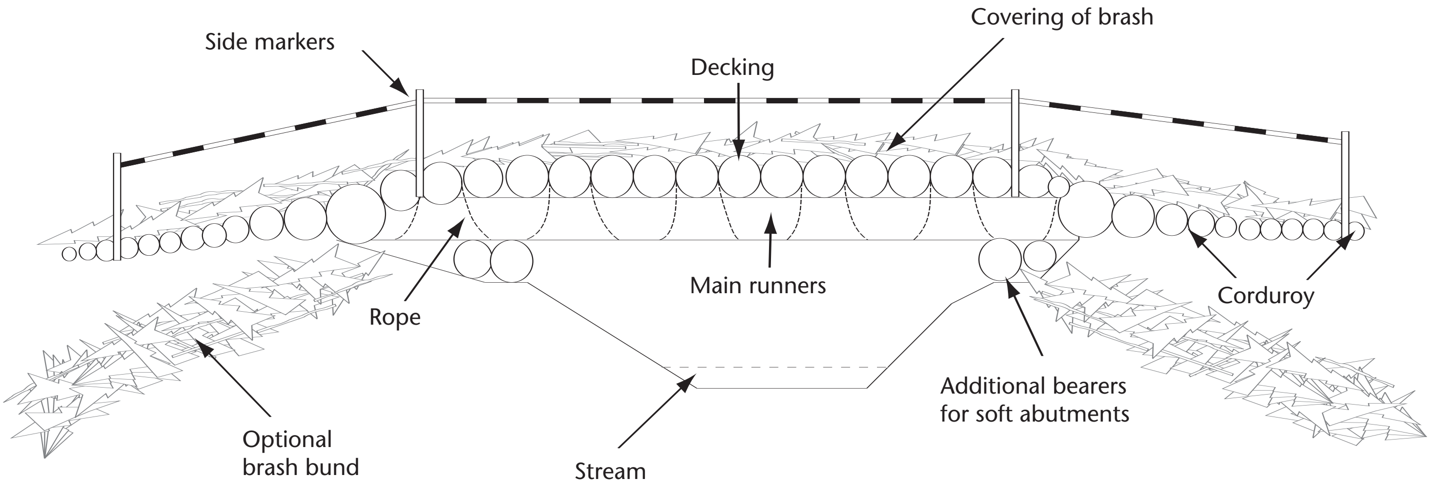
Figure 6

A narrow crossing point reduces the span length and keeps the structure clear of water during flood conditions.

Table 1 Log bridge specification.

Component	Specification
Main runners	8.8 m long x 35 cm minimum mid-diameter, 12 pieces side by side
Decking	4.4 m to 4.8 m x 20 cm minimum mid-diameter, even taper
Side markers	Plastic tape
Approaches	2 machine lengths, straight approach and exit
Height above stream	1.5 m (in this case the minimum height to allow full stream flow in flood without scouring abutments)
Maximum permitted load	11 t per bogie

Figure 7 Example specification for a temporary log bridge.



FOREST ROAD APPROACHES

The risk of ground damage and water pollution is often greatest where extraction machines approach and join the stacking area or forest road. These heavily used access points can collect or generate silt-laden water which can be pushed into roadside drains or off site into streams by the passage of machinery (Figure 8).

Site planning should identify the location and type of civil engineering works required for roadside facilities, including the strengthening of access points.

Figure 8

Silt run off from an extraction route.

Roadside ramps

Roadside ramps can be constructed at steeper access points connecting the woodland edge to the forest road. Pipes should be placed in drains and covered with brash and logs. Care is required to avoid drains becoming blocked. Ramps are constructed by excavator or bulldozer and can be covered with brash to trap soil particles. Ramps can be constructed from imported stone, or on site ‘as dug’ material where it can provide adequate support for machine travel.

Log steps

These provide an artificial rise (Figure 9) to deflect water away from the roadside drains and help to dislodge soil from machine tracks and wheels. To form the step, logs are wedged against high cut stumps at right angles to machine travel and then covered with brash. They are usually left *in situ* even when the harvesting operation has been completed. Removal is carried out when ground preparation work is under way.

The route of deflected water should be assessed. Brash bunds can be used to manage water and trap eroded sediment. To create a bund, brash is heaped to form a low wall, which slows the water flow, enabling sediment to be trapped within the brash.

Where to use

On slopes:

- Where water can accumulate on extraction routes.
- Where extraction routes meet forest roads.

Benefits

- Prevention of pollution of roadside drains and watercourses.
- Protection of extraction routes from erosion.

Figure 9

Log step covered with brash situated at the top of an access ramp to divert water away from the roadside drain.

Log trench

Log trenches are constructed in the key extraction routes on sloping ground to reduce the flow of water and silt down the extraction route. This method is an alternative to log steps. Log steps used on sloping ground can increase the angle of slope that machines have to negotiate and may place the machine in an unsafe position especially when loaded. The harvester fells and processes the trees either to pole length or cross-cuts them into 8 m sections, depending on tree size. The timber and brash are then removed from the route. At predetermined points on the extraction route, an excavator digs a trench across the route with a slight downhill angle. The pole length trees or logs are placed into the trench and lop and top is placed over the logs. At the end of each open log trench, a silt trap and straw bale filter system is constructed to trap soil particles and allow the water to percolate away from the area. The volume of water on the extraction route is reduced by using the trenches to intercept water flow. This method can be particularly useful when approaching a watercourse or a forest road at the bottom of a slope.

Where to use

On slopes:

- Where water can accumulate on extraction routes.
- Where extraction routes meet forest road.

Roadside drainage

Road drains should be designed or modified to stop at least 5 m before a natural watercourse This may involve an extra culvert to divert water from the uphill side of a road to a buffer area on the lower side. The most effective buffer zones will have vegetation such as grasses and mosses to trap sediment. In sensitive areas, a silt trap can be used with buffer zones. Roadside drains should only be used to collect water run off from forest roads.

Where to use

- Where roadside drainage and natural watercourses are managed.

Benefits

- Water runoff from trafficked forest roads can contain sediment. The use of vegetated buffer zones will help to reduce sediment runoff into streams.

SILT TRAPS

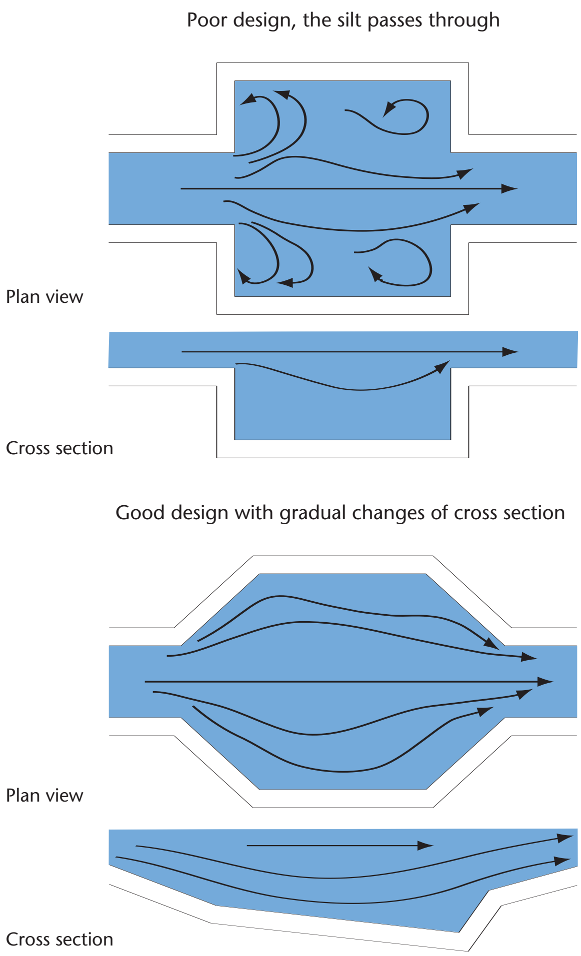
Investigations have shown that forest silt traps can effectively trap coarse silt and all types of sand particles. The complete trapping of clay and fine and medium silt particles will not be possible in many forest applications. Despite this limitation the term 'silt trap' is used in this Technical Note to describe a sediment trapping device.

Silt trap construction

The approach to a silt trap should have a shallow gradient to give an inlet speed of 1.0 to 1.8 km h^{-1}. Water should not be allowed to flow at high speed from extraction tracks or other sources. Surge velocities from extraction machinery can be reduced by restricting machine speeds near silt traps. To enable sediment to sink out of suspension within the trap, a slow water flow through the trap is essential. Silt trap design (Figure 10) must avoid turbulence because this mixes the sediment and maintains it in suspension. Traps are usually dug as a rectangle with 90° corners and a steep profile at the inlet and outlet.

Figure 10

Silt trap profiles.



These features often cause problems by creating turbulence, which can be reduced by digging a sloping bottom profile with a more gradual profile for the inlet and outlet avoiding angular internal geometry (Figure 10). For best results use a long trap (5–10 m) to promote slow water flow. Further information on silt trap design can be found in *Micro hydro power* (Frankel, 1991).

Silt traps should be used with drains, log steps and log trenches to intercept water that may become contaminated with sediment. They should be fenced off, identified with warning notices and emptied when necessary.

Where to use

- Where there is a high risk of sediment-laden run off or the site drains to a highly sensitive watercourse.

Benefits

- Reduction in the risk of water pollution by sediment.

ROADSIDE STACKING

Roadside stacking areas can also be a source of water pollution due to heavy trafficking by harvesting machinery and timber lorries. The road surface and foundations are readily damaged by machine traction aids, especially during turning operations and frequently require repair. Roadside drains at these locations should not be connected to natural watercourses but discharge to a buffer area of undisturbed ground.

Avoiding road damage

Where possible avoid extraction machines travelling on the forest road. The key route should run parallel to the roadside stacking area (Figure 11), and the brash mat strengthened using a 'corduroy' of dead trees or pulp wood (covered by brash) where required. Stacking area design must take account of:

- civil engineering constraints;
- site constraints (power lines, monuments, conservation issues, drainage etc);
- extraction routes and wood access;
- timber lorry access and turning;
- extraction and timber lorry haulage rates.

Figure 11

Stacking area avoiding road access: the key route runs parallel to the forest road.

Siting of stacking areas

- Where possible site stacking areas on drier ground close to the harvesting site.

Brash bunds

Surface flow from stacking areas should be collected by stacking area drains and directed into buffer areas, before it enters natural watercourses. The precautionary use of brash bunds and/or straw bales down-slope of stacking areas can also help to prevent silt-laden runoff reaching local watercourses in difficult conditions.

Where to use

- Stacking areas.

Benefits

- Prevention of water pollution.

CONCLUSIONS

Matching harvesting systems and operational techniques to different site conditions can greatly reduce the risk of soil damage and therefore water pollution. It is difficult to quantify the 'extra cost' of adopting best practice but this can be justified by the need to protect forest soils and avoid environmental pollution.

Other benefits include:

- better utilisation of mechanical harvesting techniques;
- reduced machine bogging and associated losses in production;
- reduced machine stress and failure;
- improved working conditions for operators.

Best practice should focus on prevention rather than cure. Forests with a tradition of using soft ground techniques do not rely on 'first aid' measures such as silt traps and brash bunds for general site management.

RECOMMENDATIONS

It is recommended that best practice mechanised harvesting systems and methods should be used where practicable to produce robust brash mats and extraction routes to protect the soil and minimise the risk of water pollution.

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