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Soil erodibility and erosion hazard: Extending these cornerstone soil conservation concepts to headwater streams in the forestry estate in Tasmania

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Abstract

Soil erodibility is defined as 'the inherent susceptibility of soil particles or aggregates to become detached or transported by erosive agents such as rainfall, runoff, throughflow, wind or frost'. In Tasmania soil erodibility is routinely assessed using a combination of standard laboratory methods and observations of profile characteristics. Five soil erodibility classes are defined: low, moderate, moderate-high, high and very high.

A plot of soil erodibility against slope produces an erosion hazard matrix. Erosion hazard increases with increasing soil erodibility or slope. Informal matrices have been used in the Tasmanian Forest Practices Code to define the harvest machinery and cultivations techniques appropriate for different soil erodibility/slope combinations. We are formalising these matrices to define five erosion hazard classes, ranging from Class A (low erosion hazard) to Class E (very high erosion hazard), and extending the erosion hazard concept to riparian zones.

At present forest streams in Tasmania receive riparian protection related to the size of the upstream catchment. Streams are classified into Class 1 (largest), Class 2, Class 3 and Class 4 (headwaters). Class 4 streams, which have a catchment area of 50 ha or less, are least protected. In the Tasmanian Forest Practices Code the standard prescription for Class 4 streams is to allow harvest of timber trees but to apply a 10 m machinery exclusion zone. Protection can be upgraded for biological conservation reasons or by the recommendation of a Forest Practices Officer or a specialist advisor.

Observations in >400 headwater 4 streams in forestry coupes (harvest areas) indicates that, within a stream or its 0–10 m riparian zone, the incidence of seven 'erosion features' (channel >4 m wide; recent boulder movement; near-vertical stream banks >1 m high; significant sediment accumulation; tunnel gully, gully and rill erosion; sheet erosion; landslides or slumps) is correlated with riparian erosion hazard class. For 66% of streams in coupes in which advice was sought for environmental protection reasons, measures to provide greater protection than the standard 0–10 m machinery exclusion zone were recommended. These measures ranged from wider machinery-exclusion zones where riparian zones are steep, to 20 m no-harvest streamside reserves where erosion risks are considered to be high. This paper formalises the decision-making process for applying such protection measures to 'at-risk' headwater streams.

Prescribing headwater stream riparian buffer types and widths using the erosion hazard and erosion features concepts is considered to be superior to using riparian slope alone (as commonly done in overseas codes of practice) because the defined erosion hazard classes and erosion features identify the most vulnerable streams and riparian zones in the

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proposed forest harvest area, allow environmental risks to be objectively assessed, and tailor protection measures to the specific risks identified. The proposed system is generic and likely to be applicable to headwater streams in other temperate regions.

Keywords: Headwater streams; Riparian; Soil erodibility; Erosion hazard; Erosion risk; Tasmania; Forest soils

1. Introduction

1.1. Characteristics of headwater streams

For the operational convenience of having a simple definition, headwater streams in the forestry estate in Tasmania are called Class 4 streams and are defined in the Tasmanian Forest Practices Code (Forest Practices Board, 2000) as streams with a catchment area of 50 ha or less. Class 4 streams in Tasmania and headwater streams in general are systems with complex hydrologic, geomorphic and biological interactions that are not well described and are poorly understood (Davies et al., 1999; Gomi et al., 2002). Extrapolation from studies on large streams is difficult because headwater streams have unique characteristics. These include more variable flow than larger streams; more variable sediment sizes over short distances and between streams; changes from erosion to aggradation over short distances; a significant role of woody debris in defining channel character; and an important influence of riparian processes on stream character because of a high edge to water-area ratio (Bunce, 2000).

The length of headwater streams in a major forestry catchment in Tasmania (the South Esk River catchment) has been estimated to be over 75% of the total watercourse length (Forestry Tasmania, unpublished data) and other studies have shown that about 90% of catchment stream flow may come from first and second order (headwater) streams (Burt, 1997, in Deschamps et al., 1999). The number of small streams and their potential to have a cumulative downstream effect make them important for achieving land management objectives. As a result of Burt's findings, Deschamps et al. (1999) suggested that the control of water quality in headwaters should be a priority to improve downstream river water quality, a concern that was echoed in a review of soil and water provisions of the Tasmanian Forest Practices Code (Davies et al., 1999). The latter authors recognised the great diversity of Class 4 streams and their varied morphological setting (soils, geology and slopes) and erosion risk in Tasmania, and recommended increased research on the protection of Class 4 streams. This paper is one of several studies resulting from the recommendations of the above-mentioned soil and water review (Davies et al., 1999).

1.2. Effects of logging on streams

Some headwater streams display the typical stream morphology of channels, pools and bars and stream banks that are the familiar terminology of stream description and classification systems (e.g. Petts and Calow, 1996; Rosgen, 1996); in others the limits of the stream channel and other morphological components may be unclear—the stream may flow over soil; living trees, shrubs and ferns may be growing in the stream channel; and both large and small roots and woody debris may be significant structural components of the stream. In such a complex environment the removal of one structural component (the vegetation) can have significant effects, especially in vulnerable landscapes (Haigh et al., 2004). While the effects of intermittent harvest cycles on headwater streams in Tasmania might reasonably be expected to be much less than in the deforestation case studies described by Haigh et al. (2004), the sustainability of present forest practices in Tasmanian headwaters nevertheless requires attention, as the Tasmanian Forest Practices Code (Forest Practices Board, 2000) is based on the sustainability principle and requires (Code p. 55) that forestry operations minimise disturbance to watercourse channels and riparian (streamside) zones and requires downstream impacts to be considered.

When researching the effects of forestry operations on stream morphology it is important to distinguish between the *direct* morphological effects on streams and riparian zones, resulting from machine and harvesting disturbance of soil and water, and *indirect* effects resulting from increased stream flows after harvest. Mitigation of the effects of these two types of disturbance requires different management approaches.

Direct effects include soil compaction and weakening (Slaymaker and McPherson, 1977), soil erosion due to wind throw (Winfield, 1999), sediment plumes entering riparian zones and streams from harvested areas (Dignan, 1999), soil disturbance and sediment inputs associated with roads and stream crossings (Davies and Nelson, 1993; Croke et al., 1999), short-term increases in silt and organic matter contents of sediment after steepland harvesting (Davies and Nelson, 1993), effects of site preparation and drainage (Cassells, 1982), increases in riffle sediment (Davies and Nelson, 1994) and changes in the amount of large woody debris in streams after logging (Bryant, 1985; Bunce et al., 2001). Although harvest may increase the amount of woody debris in streams, in the long term harvesting of old trees and their replacement by a juvenile population reduces the amount of woody debris reaching streams (Webster et al., 1992).

Indirect effects are a consequence of streamflows increasing and peaking in the first 3 years after harvest—in southeast Australian native forests flows generally return to pre-harvest levels after about 5–6 years and then remain below pre-harvest levels for decades or more (Vertessy, 1999; Vertessy et al., 2001). (Plantation forests have a similar but shortened cycle.) Indirect effects include water table change, change to the nature of overland flow, decreased stream bank stability, change to stream channel profiles, and decreased stream sediment retention (Borg et al., 1988; Ralph et al., 1994; Vanderwel, 1994; Webster et al., 1992). Peak and storm flows can be greater after intense bush fires and after logging than in undisturbed catchments (Mackay and Cornish, 1982). Increased stream incision, a higher proportion of channel and bar morphology at the expense of pools, sediment coarsening, organic matter decline and lower carbon/nitrogen (C/N) ratio of sediment in headwater streams have been noted in logged Tasmanian catchments 15 years after harvest (Bunce, 2000; Bunce et al., 2001).

In retrospective studies direct effects of disturbance may be difficult to distinguish from indirect effects (Bunce et al., 2001). Croke et al. (1999, p. 32) questioned whether increases in sediment yield reported in streams were the result of hillslope erosion and implied that indirect erosion processes affecting channel stability may be more important than credited to date.

Direct effects such as stream disturbance can be relatively easily avoided by limiting machine access to streams and riparian areas and controlling felling directions of trees in riparian zones. Mitigation of indirect effects such as increased streamflows after harvest may require harvest next to streams to be limited in order to allow trees to supply steady amounts of woody debris and litter to streams by natural processes, thereby slowing stream flow and prevent downcutting and bank erosion.

1.3. Importance of the riparian zone as a buffer

Streamside reserves, machinery exclusion zones and filter strips are all methods for maintaining the stability of streams and protecting their associated ecosystems. In recent Australian studies reviewed by Askey-Doran et al. (1996) it was determined that natural vegetation or grassy strips could trap approximately 90% of incoming sediment from hillslopes. Under experimental conditions a 6 m wide forested riparian zone can remove 99.5% of incoming sediment (Bren et al., 1997). However the effectiveness of the streamside reserve depends both on the amount of incoming sediment and the nature of the buffer itself. Slopes, soil erodibility, and geology affect sediment supply from outside the riparian zone (Laffan et al., 1996; Fogarty and Ryan, 1999) and the type of ground vegetation cover within the riparian zone controls sediment trapping ability (Croke et al., 1999). Davies and Nelson (1994) found that the success of streamside reserves in reducing stream impacts was related to the width of the reserves: they recommended that streamside reserves should be 30 m wide if impacts of logging on physical stream characteristics are to be minimised. However, if such reserves were to be applied to headwater streams, not only would the harvestable area of coupes[1] be reduced, but broad-scale burning of eucalypt harvest slash, necessary for eucalypt regeneration (Mount, 1979), would become difficult or impossible in some situations, because of the presence within coupes of reserve areas requiring protection.

[1] A coupe is an area of forest designated for harvest, generally ranging from 50 to 100 ha in size.

1.4. Procedures to minimise the effects of forestry operations on headwater streams

The Forest Practices Code (Forest Practices Board, 2000, p. 52) requires that 'forest operations should not result in a significant deviation from natural rates of erosion and landslides'. At present harvest of large trees in the 0–10 m riparian zone adjacent to Class 4 streams is allowed (Forest Practices Code, Table 8) but with a few exceptions for low-impact vehicles, entry of machinery into the 0–10 m riparian zone is prohibited. Soils with very high erodibility (Laffan et al., 1996) and streams having special faunal value receive extra protection (Forest Practices Board, 2002a). Tasmanian Forest Practices Officers (certified forest planners) have discretion to upgrade a Class 4 stream to Class 3 status if they believe it requires extra protection. Class 3 status provides a stream with a 20 m streamside reserve. Such protection may be required, for example, to guard against excessive stream downcutting and bank erosion, to prevent erosion of the riparian zone, and to provide an adequate buffer zone against sediment entry into a stream from the surrounding coupe area, especially if that area is cultivated for plantations. However, the Forest Practices Code contains no formal system for assessing streams for extra protection.

In many overseas forest practice guidelines, watercourses are classified primarily on the basis of stream flow and/or geomorphic characteristics (see Appendix 1 in Wells (2002) for a summary and Lee et al. (2004) for an overview of stream protection protocols in North America), rather than by catchment area as in Tasmania. For example, in Georgia, USA, the buffer strip width required depends on riparian slope and stream type (Georgia Forestry Commission, 1999), with extra protection for trout streams. Similar principles are used in forestry codes in other states (Mississippi, Minnesota and South Carolina), in Britain and Canada (British Columbia) and New Zealand (Wells, 2002). In North America there has been a move away from a 'one size fits all' approach to stream and riparian protection (Lee et al., 2004); the trend is for 'tailor-made' buffers in which streamside reserves or buffers are designed taking into account modifying factors which may relate both to stream and riparian morphology and to fauna.

1.5. Aim of this paper

This aim of this paper is to assess the erosion hazard associated with Class 4 streams and their riparian zones in Tasmania, and to propose a new erosion risk assessment scheme, so that those streams requiring extra protection can be identified, and appropriate protection measures applied. The paper does not deal with issues of fauna and flora protection, which in the Tasmanian forest practices system are separately assessed.

2. Methods

In the forest practices system as practised in Tasmania the responsibility for forest coupe management is assigned to a certified Forest Practices Officer who consults with specialist advisors if he or she recognises special features requiring attention. Over the course of 6 years (1999–2004) the Forest Practices Board soil and water specialist has been notified about more than 200 coupes containing internal headwater streams having actual or potential erosion problems. In these coupes observations have been made on stream character, soil erodibility and geology. These observations form the basis of the present study.

To facilitate analysis, stream and riparian observations in notified coupes were retrospectively placed into seven morphological categories, four applying to streams and three applying to riparian zones (Table 1). The presence of these features, alone or in combination, is taken to indicate that a Class 4 stream and its riparian zone has experienced significant erosion in the past, and that in the future it is likely to be at greater risk of erosion than a stream without these features. Under the present Tasmanian forest practices system streams with

Table 1
Defined 'erosion features' which, if present in a stream or riparian zone, indicate that enhanced riparian protection is required

Location	Erosion feature
In stream	Channel >4 m wide
In stream	Recent boulder movement
In stream	Near-vertical stream banks >1 m high
In stream	Significant sediment accumulation
In riparian zone	Tunnel gully, gully and rill erosion
In riparian zone	Sheet erosion
In riparian zone	Landslides or slumps

such features would normally require assessment by a Forest Practices Officer or a specialist advisor and would be given greater protection than the standard 10 m machinery exclusion zone specified in the Forest Practices Code (Forest Practices Board, 2000). Enhanced protection measures were in fact recommended and implemented for most of the streams showing these features. So that field observations could be correlated with independent measures of inherent risk, soil erodibility and riparian slope next to the study streams were also recorded.

Soil erodibility was defined by Laffan et al. (1996) as 'the inherent susceptibility of a soil to the detachment and transportation of soil particles or aggregates by erosive agents such as rainfall, runoff, throughflow, wind or frost'. It is independent of other factors associated with erosion such as slope angle, rainfall intensity or crop management. Soil erodibility is assessed from a combination of laboratory measurements on soil horizons and field descriptions of soil profiles. Gentle wet-sieving of sampled soil horizons under controlled conditions provides a measure of the resistance of soil aggregates (peds) to dis-aggregation (Laffan et al., 1996). Ratings for 'water-stable aggregates' so obtained are modified by values for soil horizon stoniness, soil strength, horizon thickness and profile drainage to produce a five-class soil erodibility rating (low, medium, moderate to high, high and very high) (Laffan et al., 1996). There is a broad correlation of soil erodibility with soil classification (Grant et al., 1995a; Laffan et al., 2003): well-structured and well-drained soils (e.g. Dermosols (Isbell, 1996) or Hapludalfs (Soil Survey Staff, 2003a,b)) formed under relatively high rainfall (>1000 mm per annum) tend to have low or moderate soil erodibility whereas poorly-structured and/or imperfectly drained soils (e.g. Kurosols (Isbell, 1996) or Hapludults (Soil Survey Staff, 2003a,b)) formed under lower rainfall (<1000 mm per annum) tend to have moderate to high or higher erodibility. Soil erodibility on individual coupes is routinely assessed by Forest Practices Officers by correlating soils with published soil descriptions (Grant et al., 1995a; Forest Practices Board, 2002b), or by identifying the soils present from published soil maps (Grant et al., 1995b; Hill et al., 1995; Laffan et al., 1995), or by estimating soil erodibility in the field (Laffan, 2000).

Riparian slope was measured using a clinometer. Where there was a marked change of slope in the riparian zone (for example where the stream flows in a steep-sided incised gully in an otherwise undulating landscape) the steep slopes next to the stream were measured. Stream banks wetted by the stream were not included in riparian slope measurements. Where there was significant variation of slope (e.g. a steep riparian zone on one bank, an undulating zone on the other) the steeper slope was recorded, because it constituted the higher risk.

Soil erodibility and riparian slope measurements were combined to define 'erosion hazard', which is a broader concept than soil erodibility. Table 2 defines five erosion hazard classes based on a slope and soil erodibility matrix. It is derived from Table 10 of the Forest Practices Code (Forest Practices Board, 2000), which uses the same soil erodibility/slope matrix to define risks and limit erosion during cultivation. Coupe audits by the Forest Practices Board (2003) and independent observations by specialists have shown that application of the matrix is effective in minimising erosion in the broader area of coupes. Therefore

Table 2
Erosion hazard class as determined from a soil erodibility class/slope angle matrix

Maximum slope in riparian zone (°)[a]	Soil erodibility class				
	Low	Moderate	Moderate-high	High	Very high
<3	A	A	A	C	C
3–8	B	B	B	C	D
9–11	B	B	C	C	D
12–14	B	C	C	D	E
15–19	C	C	D	E	E
20–26	D	D	E	E	E
>26	E	E	E	E	E

A = lowest erosion hazard; E = highest erosion hazard.
[a] Stream banks themselves are not included. Slopes must cover a significant area e.g. at least 5–10% of the riparian zone (0–10 m).

the defined hazard classes in Table 2 are also likely to be operationally relevant in riparian zones.

Longitudinal stream gradient was not used as an erosion risk criterion, because it is difficult to measure accurately in forested terrain, especially in small streams in which trees and shrubs obscure the view, in streams which are not straight, and in streams in which step-pool morphology may introduce large measurement errors. Given these difficulties, subdivision of the predominant stream gradients (1–20°) in Tasmania to produce useful and meaningful erosion risk classes was considered to be impractical.

3. Results

3.1. Erosion noted

There is a strong relationship of incidence of erosion in unharvested coupes to erosion hazard class (Fig. 1). A near-vertical bank >1 m high is the most common erosion feature in all erosion hazard classes, followed by movement of fresh boulders and tunnel-gully erosion. Landslides are only important in erosion hazard classes D and E, as expected from the predominance of steeper riparian land in these classes (Table 2). The proportion of streams with erosion features increases from classes A and B to class E (Table 3). (The proportion of streams with no erosion features in classes A and B is understated in Table 3 because few coupes having low or moderate erodibility soils and falling into classes A and B are notified to the Forest Practices Board as requiring assessment for soil and water issues.) The incidence of

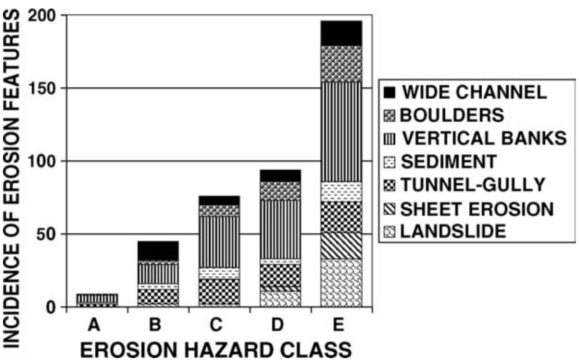


Fig. 1. Incidence of erosion hazard features in erosion hazard classes A–E.

Table 3
Proportion of streams with no erosion features and multiple erosion features, in each erosion hazard class

Erosion hazard class	Proportion of streams with no erosion features (%)	Proportion of streams with multiple erosion features (%)
A + B[a]	63[b]	13
C	55	20
D	55	20
E	26	38

[a] Data for streams in erosion hazard classes A and B have been combined because of the small sample size for erosion hazard class A.
[b] This figure is an underestimate as many coupes with low and moderate erodibility soils and having streams in erosion hazard classes A and B, without erosion features, were not notified as requiring inspection or assessment by a specialist.

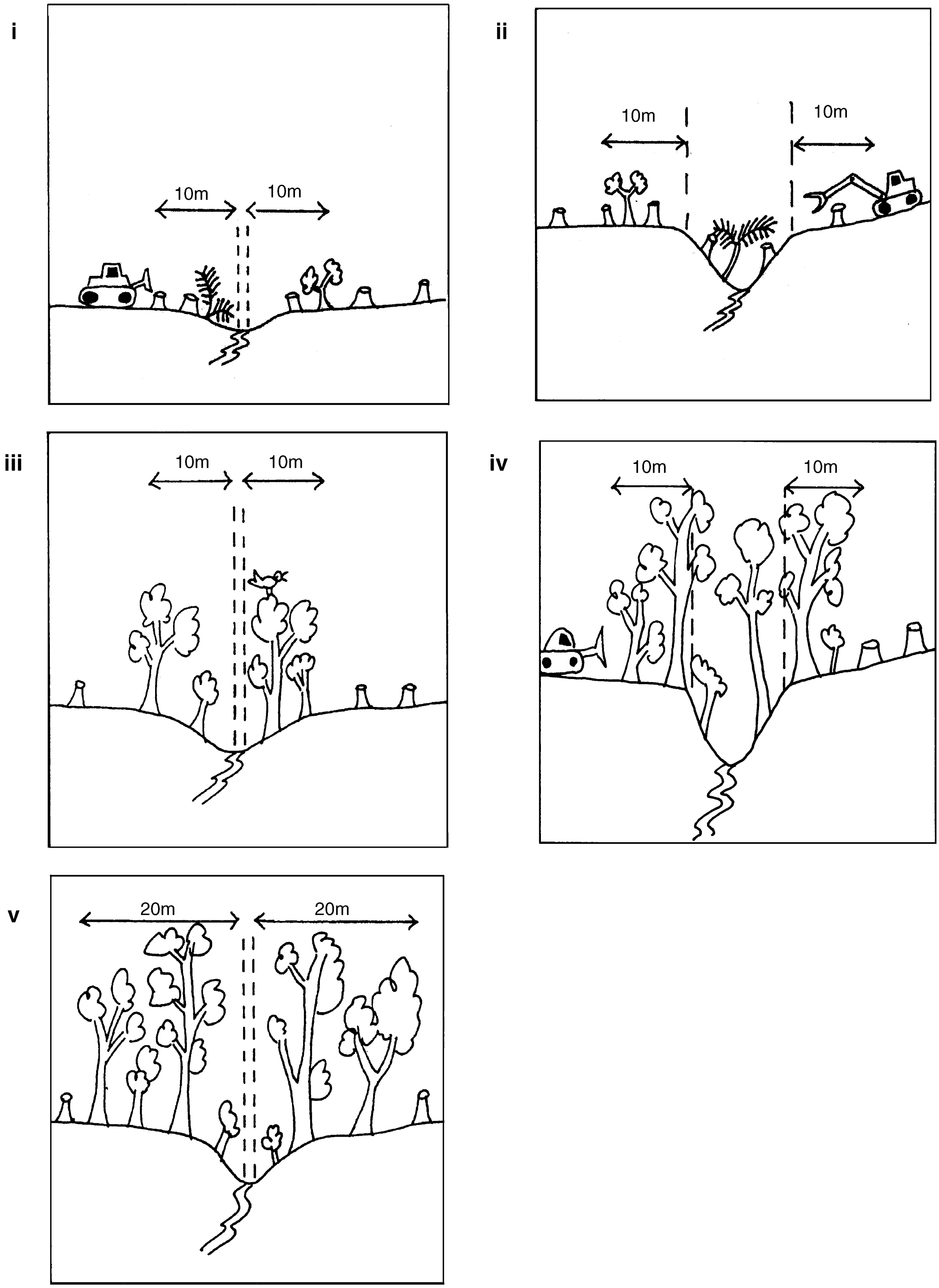
multiple (two or more) erosion features along a single stream increases markedly from streams in classes A and B to streams in class E (Table 3).

3.2. Prescriptions applied

The range of stream protection options that are operationally practical to apply fall into five categories (Fig. 2). The actual prescriptions applied, in relation to erosion hazard class, are shown in Fig. 3.

The Class 4 machinery exclusion zone prescription was applied only to those streams showing no erosion features. Some streams showing no erosion were given upgraded protection because they were judged to have significant risk based on features in the coupe as a whole (e.g. highly erodible soils formed in aeolian parent material, or evidence of erosion in other streams nearby), or because they were marginal cases (e.g. they were close to the slope limit for an erosion hazard class).

Comparison of Figs. 1 and 3 shows that the stringency of the new recommendations is broadly related to the amount of observed erosion risk noted in streams: while the minimal protection of a 10 m machinery exclusion zone or an extended 10 m machinery exclusion zone still applies to most streams in erosion hazard classes A and B, this minimal protection applies to fewer than 50% of streams in erosion hazard classes C and D and to only 8% of streams in erosion hazard Class E. Although Figs. 1 and 3 and Table 3 do not constitute a scientific ‘proof’ that the four enhanced prescriptions are adequate to protect headwater streams, they do provide a reason-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able prediction of prescriptions that are likely to work, as many of the coupes in which the prescriptions have been applied have since been harvested and adverse effects have not been noted in environmental audits (e.g. Forest Practices Board, 2003). Furthermore, as 30 m streamside reserves have been found to minimise forest harvest effects in streams (Davies and Nelson, 1993, 1994) and 6–9 m of vegetated buffer has been shown to trap to 87–98% of incoming sediment from upslope (Bren et al., 1997; Mickelson et al., 2003) it is reasonable to suppose that vegetated reserves of up to 20 m on Class 4 streams will be progressively more effective in preventing riparian erosion and limiting sediment entry into streams. In addition, growth of large trees next to streams will help to stabilise channels by providing a steady supply of litter and woody debris (Toews and Moore, 1982) and live roots in and adjacent to headwater channels will help prevent channel downcutting and bank collapse (Zimmerman et al., 1967).

Where an erosion risk has been identified in streams and/or riparian zones, we are therefore justified in writing generalised rules and guidelines to implement progressively more protective prescriptions (Figs. 2 and 3), based on the observations of Fig. 1 and actual prescriptions applied. These proposed rules and guidelines are shown as flow diagrams in Fig. 4 (see also McIntosh (2004)). No weighting is given to particular erosion features, nor do the rules and guidelines give more weighting to multiple erosion features in streams than to single erosion features. However, the recommendations can be regarded as minimum recommendations, and some decisions allow for discretion to be exercised. It is to be expected that streams with more severe erosion features (e.g. riparian landslides or multiple features) will be given greater protection than streams with less severe erosion features (e.g. a short reach with active boulder movement).

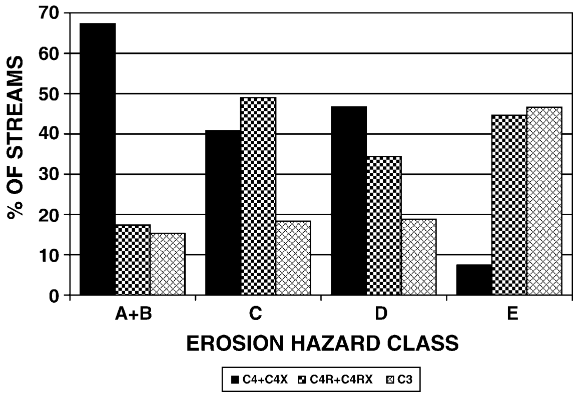

Fig. 3. Actual prescriptions applied to streams. C4 = standard 10 m machinery exclusion zone, with harvest allowed; C4X = 10 m machinery exclusion zone measured from where the steep (>19°) riparian zone begins; C4R = 10 m streamside reserve (no machinery, no harvest); C4RX = 10 m streamside reserve measured from where the steep (>19°) riparian zone begins; C3 = 20 m streamside reserve (no machinery, no harvest). For full explanation of terms see text.

These flow diagrams and the associated stream evaluation procedures are now being assessed for operational ease of application and effectiveness. In particular, a large-scale experiment involving morphological monitoring of 70 streams has been set up to assess the influence of harvest and non-harvest of pines on Class 4 stream morphology in paired catchments within greywacke steeplands of northeast Tasmania. Further monitoring of harvest effects in native eucalypt forest is also planned. The implementation system (Fig. 4) at present being tested will be modified in the light of these experiments.

Fig. 2. Options for protecting Class 4 (headwater) streams and riparian zones. (i) Standard 10 m machinery exclusion zone (C4). At present this is the standard Class 4 stream prescription in the Forest Practices Code (Forest Practices Board, 2000). Trees may be harvested up to the stream, but no harvesting machines may enter the 10 m zone, and undergrowth must be left intact. There are some exceptions for low-impact machinery such as feller-bunchers in plantations and for spot cultivation. (ii) Extended 10 m machinery exclusion zone (C4X). This prescription applies where streams flow in steep-sided (>19° slope) gullies. Instead of being measured from the stream bank, the outer limit of the machinery-exclusion zone is measured from the top of the steep riparian slope, to give a machinery exclusion zone having a total width of between 11 and 20 m. (iii) Class 4 streamside reserve (C4R). No harvest or machinery is allowed within the 0–10 m riparian zone (streamside reserve) adjacent to the stream. It is expected that the streamside reserve will be protected from burning. (iv) Extended Class 4 streamside reserve (C4RX). This prescription applies where streams flow in steep-sided (>19° slope) gullies. Instead of being measured from the stream bank, the outer limit of the streamside reserve is measured from the top of the steep riparian slope, to give a streamside reserve having a total width of between 11 and 20 m. It is expected that the streamside reserve will be protected from burning. (v) Class 3 streamside reserve (C3R). The Class 4 stream is upgraded to Class 3 status and receives a 20 m streamside reserve. It is expected that the streamside reserve will be protected from burning. Note: MEZ = machinery exclusion zone; SSR = streamside reserve.

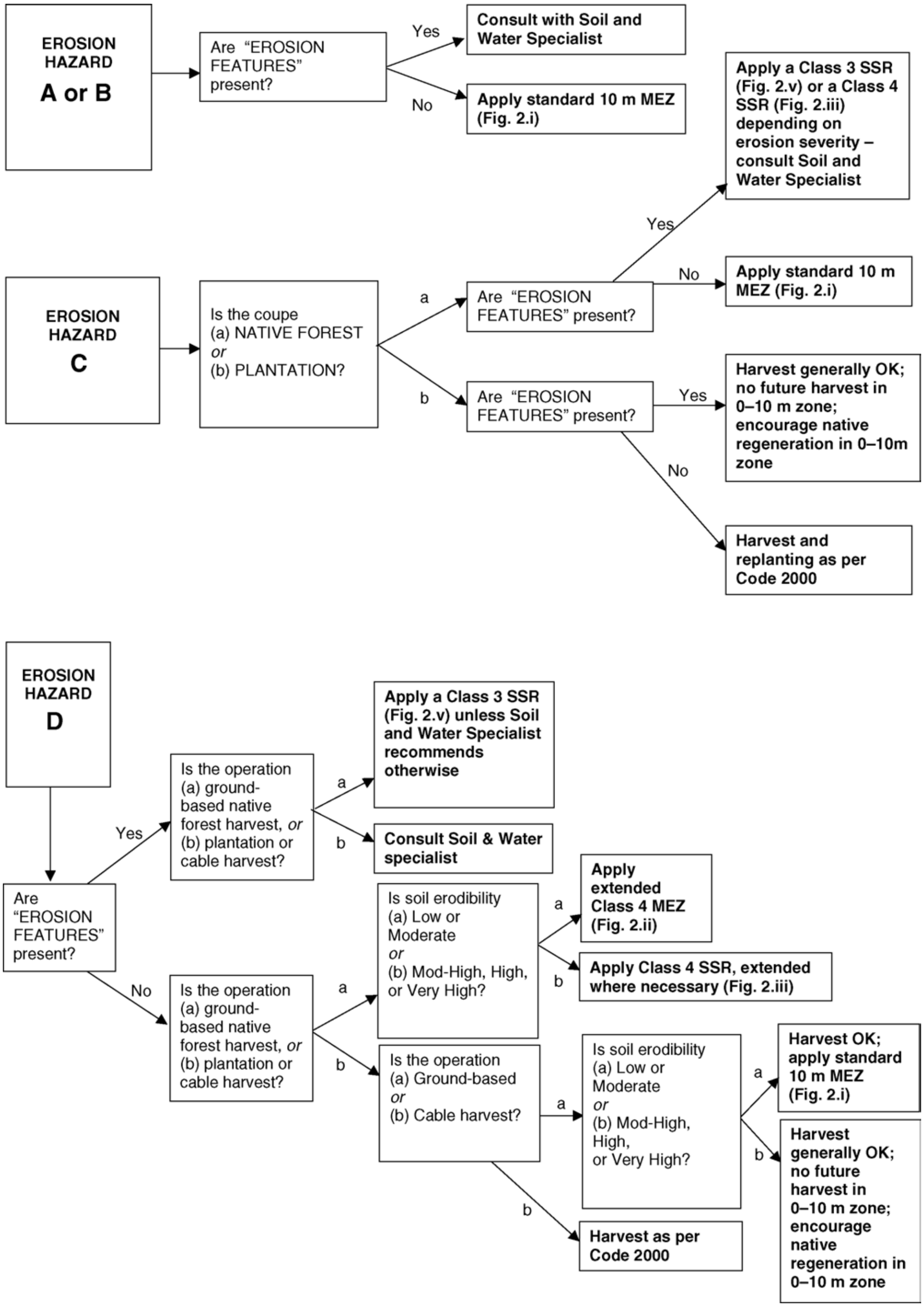

Fig. 4. Flow diagrams for keying out prescriptions for Class 4 streams.

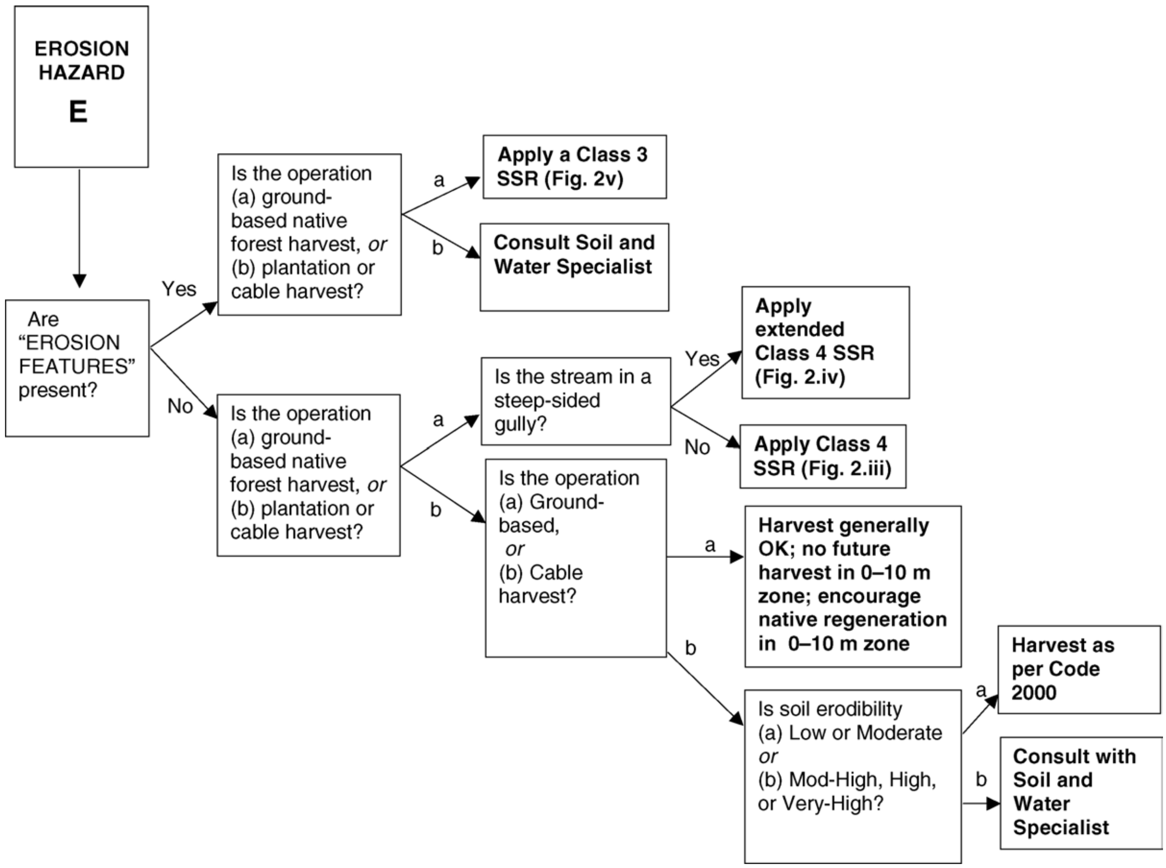

Fig. 4. (*Continued*).

4. Discussion and conclusions

In Tasmanian forestry coupes having headwater streams showing stream or riparian erosion features, the incidence of recorded erosion features broadly correlates with erosion hazard class as defined by a soil erodibility/slope matrix. The greater incidence of erosion in streams classified as having more severe erosion hazard indicates that the standard 10 m machinery exclusion zone at present applied to headwater streams (Forest Practices Board, 2000) is not an appropriate protection measure for all streams, and that enhanced protection is required where erosion features are noted in streams or riparian zones.

On the basis of erosion hazard class and prescriptions actually applied to streams, four enhanced protection measures are suggested, making a total of five graded prescriptions (ranging from the existing 10 m machinery exclusion zone to a 20 m streamside reserve) which are tailored to the range of headwater stream erosion risk actually encountered in Tasmanian commercial forestry operations. Flow diagrams have been designed to enable foresters to apply the new protection measures in a variety of situations, including native forests, forests on steeplands that will be cable-harvested, and plantations (Fig. 4).

The new guidelines (McIntosh, 2004) are being trialled both for operational ease of application and for effectiveness in limiting stream erosion. To date application of the guidelines has been straightforward and routine in selectively harvested coupes, in plantation coupes on land with slopes $<20^{\circ}$, and in native forest coupes designated for conversion to plantations, as these coupes are either not burnt, or burning is done after windrowing of harvest slash, which allows for small post-harvest fires which can be controlled easily. However, in native forest coupes where 'hot' broad-scale convection regeneration burns are required to create a satisfactory seedbed for eucalypt regeneration (Mount, 1979), the presence of streamside reserves within harvested coupes can create a problem for foresters: the unharvested streamside reserve areas are likely to be burnt during regeneration burns, which destroys the function of the reserves as soil and water protection zones. One solution to this management problem is to reduce the size of coupes so that streams with reserve status are on the perimeter of coupes rather than within them. Alternatively, areas with closely spaced streams requiring protection may need to be entirely omitted from the harvest area. A further problem arises on cable-harvest coupes in steep country, in which cabling configurations cannot always be designed to ensure that logs clear streamside vegetation, and damage to streamside reserve vegetation may, in some cases, be unavoidable. There is no simple solution to this management problem, so the new guidelines effectively require at-risk streams in cable coupes to be individually assessed, so that erosion mitigation measures can be worked out based on local conditions, the machinery types used and the skills of local operators.

A research experiment in the greywacke steeplands of northeast Tasmania will assess the impact of harvest and non-harvest of pine forests on stream morphology, and further modification of the guidelines may be necessary depending on the outcome of this study.

The headwater stream protection system proposed uses concepts and measurements which are not specific to regions, local soils, or geology, and application of the guidelines to streams and riparian zones in other temperate forests should be possible.

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