REVIEW OF SOIL ASSESSMENTS OF STATE FORESTS IN THE KALANG CATCHMENT, NORTHEAST REGION, NSW

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December 2017

INTRODUCTION

This report has been requested by Mr Ashley Love (Bellingen Environment Centre), who represents residents concerned about proposed logging activities on steep land by the Forestry Corporation (Forestry Corporation of NSW, 2017) in the Oakes, Roses Creek and Scotchman State Forests in the headwaters of the Kalang River catchment on the NSW mid north coast. The concerns relate to the impacts of proposed forestry operations on soil erosion and its effects on pollution and sedimentation in downstream waterways

FC proposes to log Compartments 125, 126, 127, 128, 138, 139, 140, 141, 142, 143 and 144 of Oakes, Roses Creek and Scotchman State Forests in 2019. These will be known as “the Compartments” in this report.

There is a Harvesting and Roading Plan for Oaks State Forest Compartments 391 and 392 (FC 2012) and a Draft Harvest Plan for Operations in Scotchman and Roses Creek SFs Compartments 125, 126, 127 and 128 (FC 2017). Otherwise, detailed harvest plans have not yet been provided. Forestry operations in these State Forests are currently regulated by the Integrated Forestry Operations Approval for the Lower North East Region (IFOA). This is a preliminary report pending this information.

The residents are primarily concerned that the soil assessment methods used to prepare the draft Harvest Plans are inadequate. These are termed “Methods for assessing the soil erosion and water pollution hazard associated with scheduled and non-scheduled forestry activities” (Soil and Water Methodology). The current version of the Soil and Water Methodology can be found at Schedule 3 of the Lower North East Region Environmental Protection Licence (EPL), which is Attachment A to the IFOA.

This report will address—

- The erodibility of soils and regolith within the Compartments;
- The special case to be made for the Nambucca Beds with regard to their erodibility and erosion hazards;
- The thresholds of settings of the Inherent Hazard Levels, and the restrictions on logging for each level, in preventing erosion and water pollution;
- Catchment management issues.

PHYSICAL ASPECTS

Terrain is predominately rolling to very steep dissected mountain slopes, dominated by ridge and ravine terrain of narrow ridges and deeply incised valleys with interlocking spurs (Eddie 2000). Slope gradients range from 25% to 60 - 70%, local relief is 150 - 600m, and elevation ranges from 80m on the Kalang River to 820m on Horseshoe Road at Boot Hill on the dividing ridge above Oakes SF. Ridge crests are narrow (50 - 150m), and sideslopes are long (800 – 2,400m). The long side-slopes often comprise the colluvial footslopes to steeper upper slopes and ridges. Rock outcrop is uncommon, but there may be areas of talus slopes. More detailed information on physiography is provided in McGarity (1988). This terrain is extensive throughout the escarpment country in the upper Bellingen, Kalang and Nambucca catchments.

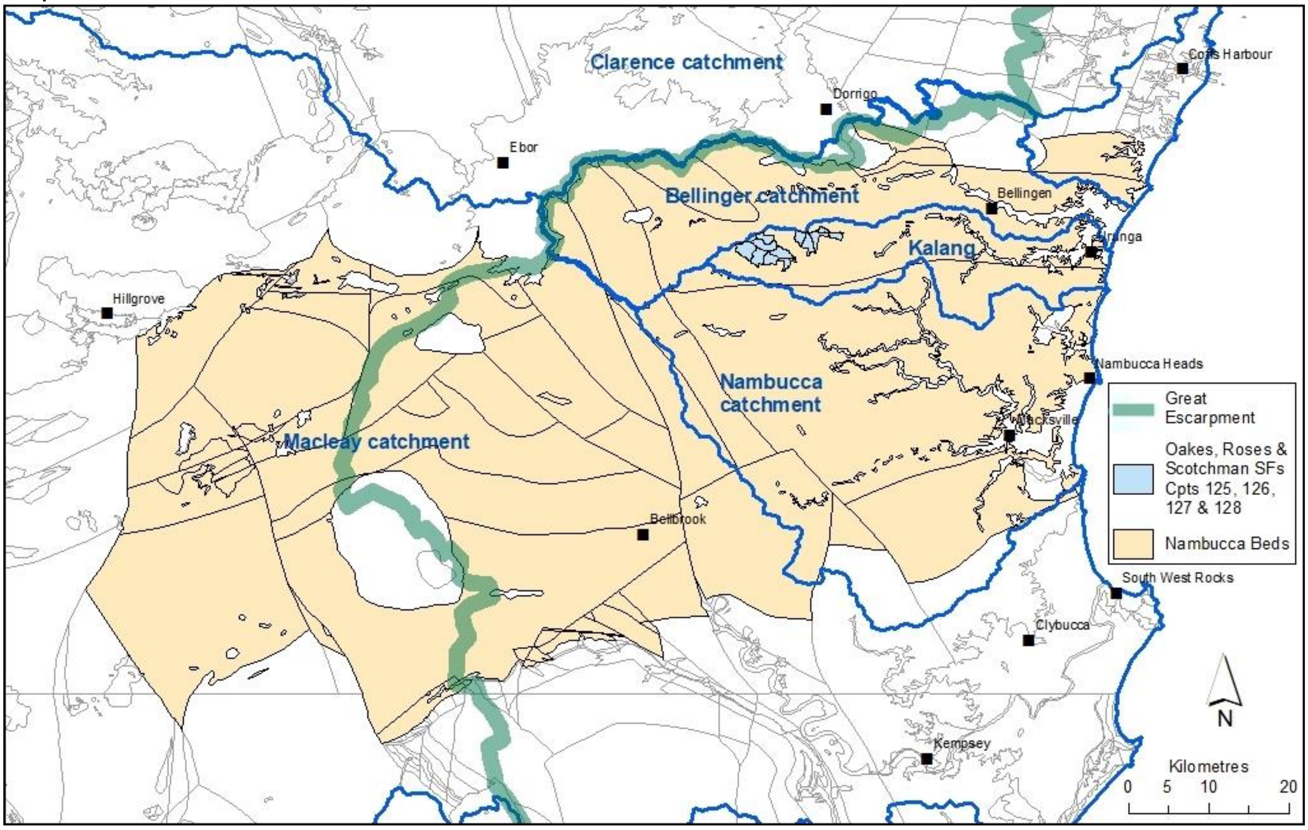
Figure 1. Steep ridge and ravine terrain in the upper Nambucca escarpment, typical of that found in State Forests in the upper Kalang catchment. Photo: M. Eddie.

Climate and Hydrology. Rainfall is summer-dominated, with a marked spring dry season and summer-autumn wet period. This pattern is fairly reliable in its relative monthly distribution whether in drought or wet years. About 60% of average annual rainfall occurs in the five-month period between December and April. Drier conditions are experienced between July and November with only about 30% of annual rainfall occurring during that five-month period. Thunder storms break the spring droughts usually in November and continue through the summer, building up convectively on hot summer days or accompanying the passage of cold fronts through the area. Microclimatic effects due to relative exposure produce cooler and wetter conditions on southerly and easterly aspects, especially in the deep valleys of the ranges. There are very intense orographic effects.

Average annual rainfall in the area ranges from 1,550mm on the lower slopes and alluvial flats to 1,720mm on the Horseshoe Road at Boot Hill, while nearby Thumb Creek receives 1,994mm p.a. (B.o.M., 1997). Drainage lines are closely spaced (80 - 300m), low order tributary, trellised, convergent and eroding. McGarity (1988) provided further information on climate.

Geology. The Compartments fall within the Nambucca Block or Nambucca slate belt, which is a major structural unit in the eastern part of the New England Fold Belt (Brownlow *et al*., 1988). It comprises moderately to intensely folded and Late Carboniferous - Early Permian metasediments. Intense orogenic deformation occurred during the Late Permian, characterised by regional dynamic and thermal metamorphism, most intensely in the core of the belt. The distribution of lithologies is complex, owing to large-scale displacement.

Map 1. The extent of the Nambucca Beds.



The Permian Nambucca Beds (Pn) are a major component, consisting of metasediments at least 3 - 4km thick. They occupy most of the Nambucca – Bellingen catchments, extending to the Great Escarpment, and a large proportion of the Macleay gorges. Rocks are moderately to intensely cleaved, fractured and deformed, with distinctive and very common injected quartz veins. The unit in the Compartments is the Bellingen Slate (Pnbf)– dark micaceous slate, lithofeldspathic sandstone, phyllite and minor conglomerate, moderately to intensely cleaved, fractured, deformed and metamorphosed, exhibiting schistose foliation especially in shear zones. In the southern portion of the Kalang catchment is the Five Day Phyllites (Pnfm)– micaceous phyllite, schist and rare metabasalt. There are some Tertiary basalt caps (Tb) on some high ridges. More detailed information is provided in McGarity (1988).

Figure 2. Detail of phyllite substrate in the Nambucca Beds. Photo: M. Eddie.

Regolith is very stony with a red or brown sandy or silty clay matrix with quartz gravels, consisting of shallow to deep moderately to strongly-weathered saprolite of weak strength, and old debris avalanche deposits and colluvial fills up to 4m deep. Soils developed on deep regolith are red, strongly structured, and with weak texture contrast (Eddie 2000).

Soils in the Compartments are described by Eddie (2000) as: well drained, stony, shallow to moderately deep (50 - 120cm), Red Dermosols (Brown Earths) widespread on side-slopes on weathered substrate, with deep (120 - 200cm) well drained Red Ferrosols and Red Dermosols (Krasnozems) on colluvium, and <70cm Paralithic Leptic Rudosols and Paralithic Tenosols (Lithosols) mainly on upper slopes. The soils are spatially heterogeneous according to variations in parent material lithology and mineralogy, weathering and mass movement history; this is in accordance with the views of McGarity (1993c).

Weathering of mica flakes imparts silty textures to soils and are slaking when wet. There is often a stone line between the A and B horizons, which indicates a colluvial history, and quartz gravels are common as surface lag deposits.

DISCUSSION

Soil landscapes are described by Milford (1995) and Eddie (2000). Soil landscapes are depicted at 1:100,000 scale and are indicative only at the compartment scale. The area is dominated by the Snowy Range (sn) and Mistake (mk) soil landscapes, with small alluvial flats of the Nambucca River (nr) soil landscape (Table 1).

Map 2. Soil Landscapes, Oakes, Roses Creek and Scotchman State Forests and Compartments.

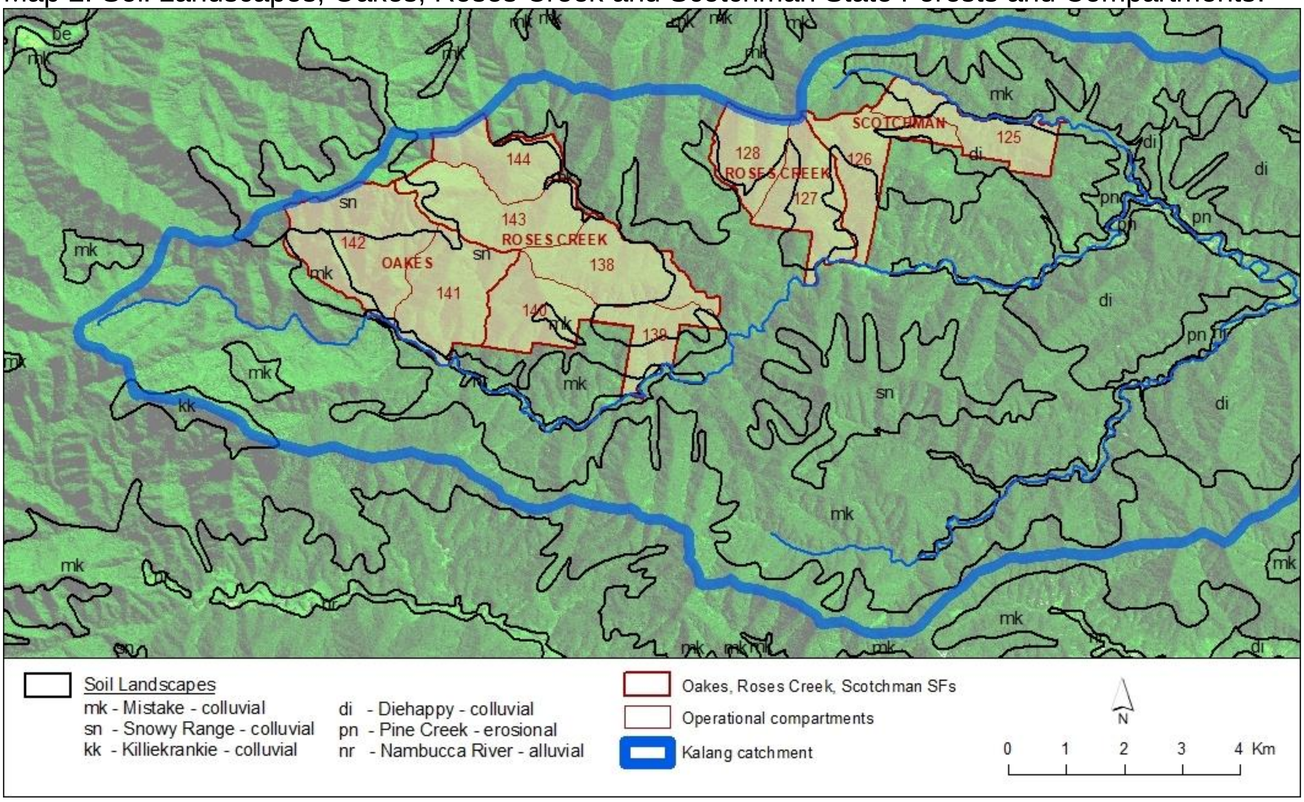


Table 1. Soil landscapes within the Compartments.

Soil Landscape	Description
Snowy Range (sn)	Very steep to precipitous mountains on Nambucca Beds, slopes rectilinear, >30º, local relief >300m
Mistake (mk)	Rolling to steep mountains on Nambucca Beds, slopes 15-30º, local relief >300m
Diehappy (di)	Steep hills on Nambucca Beds, slopes >20º, local relief 100-300m
Nambucca River (nr)	Alluvial flats derived from Nambucca Beds

Table 2. Proportional areas of soil landscapes within the Compartments.

State Forest Compartment	Soil Landscape	Area (Ha)	Compartment area (Ha)	Cpt %	Land with slopes greater than 20º	
					Area (Ha)	Percent
Oakes - 141	Snowy Range (sn)	228	240	95	228	95%
	Nambucca River (nr)	12		5		
Oakes - 142	Snowy Range (sn)	253	322	79	253	79%
	Mistake (mk)	65		20		
	Nambucca River (nr)	3		1		
Roses Creek - 127	Snowy Range (sn)	117	195	60	117	60%
	Mistake (mk)	78		40		
Roses Creek - 128	Snowy Range (sn)	105	137	77	105	77%
	Mistake (mk)	32		23		
Roses Creek - 138	Snowy Range (sn)	193	228	85	193	85%
	Mistake (mk)	35		15		
Roses Creek - 139	Mistake (mk)	68	121	56	53	44%
	Snowy Range (sn)	53		44		
Roses Creek - 140	Snowy Range (sn)	154	168	92	154	92%
	Mistake (mk)	14		8		
Roses Creek - 143	Snowy Range (sn)	241	241	100	241	100%
Roses Creek - 144	Snowy Range (sn)	152	152	100	152	100%
Scotchman - 125	Diehappy (di)	116	162	72	132	82%
	Mistake (mk)	30		18		
	Snowy Range (sn)	16		10		
Scotchman - 126	Snowy Range (sn)	92	192	48	124	65%
	Mistake (mk)	68		35		
	Diehappy (di)	32		17		
		Total:	2,157		1,752	

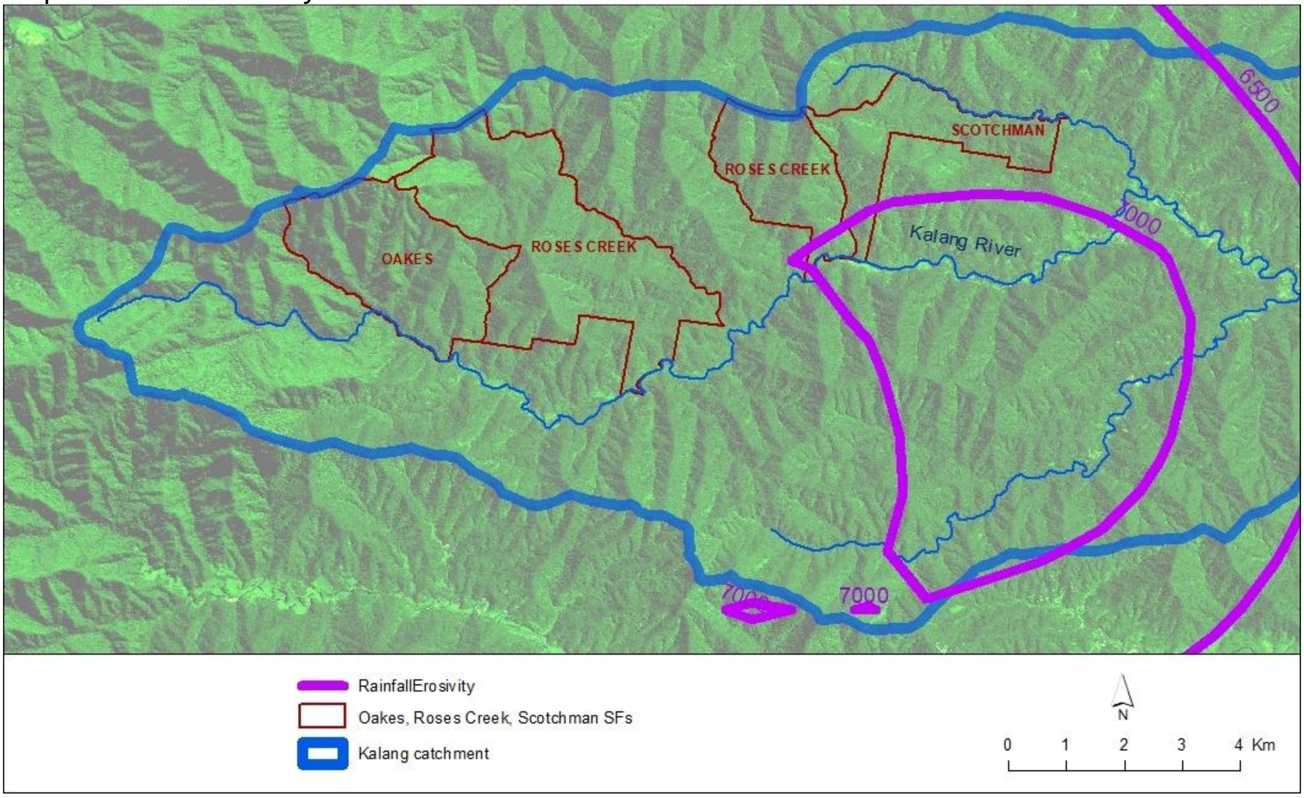
According to the above soil landscape mapping information, the Compartments are dominated by the Snowy Range (sn) or Diehappy (di) soil landscapes, with slopes greater than 20º.

Area >20° = 1,752 Ha
Total area = 2,157 Ha (from Table 2)

Proportion >20° = 100 x 1,752 / 2,157 = 81%.

Given the slope parameters of the soil landscapes, 81% of slopes in the Compartments are greater than 20º. Slopes above this gradient are increasingly prone to mass movement (Table 3). While soil landscape mapping is intended for regional rather than compartment scale, the above estimate of 81% of the Compartments in slopes greater than 20º can be assumed.

Map 3. Rainfall Erosivity.



Rainfall Erosivity and Erosion Hazards.

High intensity rainfall is generally associated with cyclonic depressions occurring off the NSW north coast during summer. Over a 30 minute period the intensity of rainfall can vary from 40 mm/hr for a one-year return period up to 145 mm/hr for a 100-year return period (State Forests, 1993). On average, rainfall intensities of 75 mm/hr for a 30 minute period can be expected to occur within a five-year period. Total rainfall of 200mm over a 24hr period is not uncommon. Under these conditions extensive runoff and flooding can occur, resulting in significant property damage.

Rainfall erosivity is a measure of the ability of rainfall to cause soil erosion. Average annual rainfall erosivity (USLE R-factor) has been calculated from rainfall statistics and mapped for NSW (Rosewell and Turner, 1992). There is a progressive increase in rainfall erosivity from about 4,200 along the coast to over 6,500 in the ranges. Rainfall erosivity, like rainfall, is heavily skewed towards the summer months. Rosewell and Turner (1992) demonstrated that a high percentage of erosive rainfall occurs in the four months from December to March. Rainfall erosivity in the Compartments is very high to extreme (R 6500 - 7000), which results in very high to extreme rates of runoff. See Map 3 above.

Mass Movement Hazards and Risks.

The Nambucca Beds are especially prone to mass movement. Slip planes may form with shear failure of steeply dipping decomposed phyllites and slates (Atkinson *et al.*, 1992), and with water entering deeply weathered regolith via quartz veins (Baker *et al.*, 1983). This is exacerbated where the shear plane is dipping in the direction of the slope (McGarity, 1988). Slip planes may be indicated by the presence of springs. Mass movement may be identified by hummocky terrain.

Mass movement hazards increase with slope gradient, from about 20º upwards, although some slopes on the Nambucca Beds have been observed to be susceptible to mass movement on gradients as low as 7º (Eddie, 2000). This is because the deep regolith which can be hydrostatically loaded with groundwater following rain; this tension is released as mass movement when disturbed.

Debris avalanches occur on slopes greater than the natural angle of repose of unconsolidated sediment (about (25º), creating talus slopes. Ground disturbance on steep slopes risks re-activating old landslips. Large-scale slips and debris avalanches are quite common on the very steep slopes in the ranges, particularly where road cuts occur; slumping of subsoils in road batters is common, as observed by McGarity (1988).

Mass movement risk is exacerbated by tree removal, which will increase the risk by reducing soil cohesiveness and increasing infiltration of water into potential slip planes. Maintaining forest cover on potential groundwater recharge sites upslope may reduce landslip risks. Mass movement hazards are site-specific and must be geo-located in some way. Geotechnical investigation is recommended prior to proposed disturbance.

Erosion Hazard Assessments

There are four methods in use for assessing soil erodibility—

1. **Soil Dispersibility**.

Soil dispersion is the structural breakdown of soil materials into individual suspended particles in water. Dispersible soils are often highly erodible, have low wet bearing strengths, and are frequently very hardsetting when dry. They are prone to severe structural degradation and require very careful management. Soil dispersion can be assessed in three ways—

a. The **Emerson Aggregate Test** (EAT) is an eight-class classification of soil aggregate coherence (slaking and dispersion) in distilled water. It can easily be tested in the field.

b. **Dispersion percentage** (DP) is a laboratory test that estimates the proportion of the clay fraction that has dispersed (Hazelton and Murphy, 2013). DP is sometimes presented as the Dispersal Index Ratio, also known as the Ritchie Method (Ritchie, 1963), which is the inverse of DP x 100.

c. The **Soil Dispersibility Testing Method** prescribed in Section 3 of the EPL guidelines is a very much reduced version of the EAT.

2. **Water erodibility (USLE K factor)**

The Unified Soil Loss Equation (USLE) includes a soil erodibility factor known as K (Wischmeier & Smith 1978), an index of the susceptibility of a soil sample to particle detachability through sheet and rill erosion. It is derived from particle size analysis which is done in the soil laboratory. The formula used to derive K factor is USLE modified for Australian conditions and based on that used in SOILOSS (Rosewell & Edwards 1988) with profile permeability modified to follow that used by Soil and Water Conservation Society (1993).

There are limitations in the use of the K Factor, as noted by Murphy *et al* (1998): “The USLE soil erodibility factor, K, has been shown by field experience in many situations to relate poorly to the behaviour of forest soils. The K factor relates specifically to the detachment of soil through sheet and rill erosion and not to other processes of erosion, most notably gully [and slump] erosion. The K factor also does not account for susceptibility of soil material to transport and delivery to receiving waters”.

3. **Soil Regolith Stability Class.**

The limitations of the K factor led to the development of the Soil Regolith Stability Class. This concept has two components, coherence and sediment delivery potential, to reflect the dual requirement to assess both soil erosion and water pollution hazard at the landscape level.

This approach permits a broad scale assessment which incorporates experience and knowledge of soil behaviour for the particular landscape unit from a range of similar sites. Subsequent site assessment at the harvest planning stage will verify the accuracy of the broader scale soil regolith stability classification for particular logging compartments and describe significant variability at a more localised scale (Murphy *et al*, 1998). It is assessed by field observation and requires professional judgement.

Table 4. Soil Regolith Stability Classes (Murphy *et al*, 1998).

	Low sediment delivery	**High sediment delivery**
High coherence	**R1** High ferro-mangnesium soil regolith, eg basalt, dolerite; Fine-grained argillaceous soil regolith with high gravel content, eg siltstones, metasediments; Highly organic soil regolith, eg peats.	**R3** Fine-grained argillaceous (clay) soil regolith with low/no gravel contents; Fine-grained massive soil regolith.
Low coherence	**R2** Unconsolidated sands; Medium to coarse-grained felspathic-quartzose soil regolith, eg adamellite, quartz sandstone.	**R4** Unconsolidated deposits of silt and clay; Unconsolidated fine-grained weathered soil regolith (saprolite).

4. Inherent Hazard Assessment Levels for Native Forests.

This is presented in a matrix table and uses information from a number of sources—

a. Rainfall Erosivity (6500 in the Compartments)
b. Slope Class
c. Soil Regolith Stability Class (R3 in the Compartments)

Table 5. Inherent Hazard Assessment Levels for Native Forests for the Compartments, for Rainfall Erosivity 6000+, slopes > 10º, and Soil Regolith Stability Class R3 (modified from EPA, 1997a).

	Slope Class (degrees)			
Forestry Operation	**10<20º**	**20<25º**	**25<30º**	**>30º**
1. Logging with greater than or equal to 50% canopy removal within the net harvestable area (Dozer/Skidder extraction)	Level 2	Level 4	Level 4	Level 4
2. Logging with less than 50% canopy removal within the net harvestable area (Dozer/Skidder extraction)	Level 2	Level 3	Level 4	Level 4
3. Native Forest Thinning Operation	Level 2	Level 2	Level 2	Level 4

Key: Level 1: Low soil erosion and water pollution risk;
Level 2: High soil erosion and water pollution risk;
Level 3: Very high soil erosion and water pollution risk;
Level 4: Extreme soil erosion and water pollution risk— scheduled or non-scheduled forestry activities prohibited for the proposed method of timber harvesting and extraction.

Assessment of dispersion

K factors for soils in the Snowy Range (sn), Mistake (mk) and Diehappy (di) soil landscapes have been calculated and presented in Milford (1995) and Eddie (2000). K factors for topsoils are low (0.005 - 0.020), while K-factors for subsoils are high to very high (0.030 – 0.080). The high K factors for subsoils is probably due to their high mica content and silty textures. The subsoils typically slake when wet. McGarity (1993a, 1993c) also found a high proportion of soils in The Compartments have dispersible subsoils. However K values are only meant as a guide as a regional planning tool and do not preclude the need to do more intensive soil survey for detailed planning or operations.

Of twelve subsoil samples of these soil landscapes collected by Milford (1995) and Eddie (2000), Ritchie Method dispersion results range from 4.4 (slight, on metabasalt) to 1.9 (high, on phyllite).

EAT results indicate slaking with mostly high dispersibility—

- Ten samples, class 2(1): slakes, some dispersion, slight milkiness adjacent to the aggregate (high dispersibility);
- One sample, class 3(3): slakes, some dispersion after remoulding, obvious milkiness, >50% of the aggregate (high dispersibility);
- One sample (on metabasalt), class 6: slakes, flocculates in shaken suspension (low dispersibility).

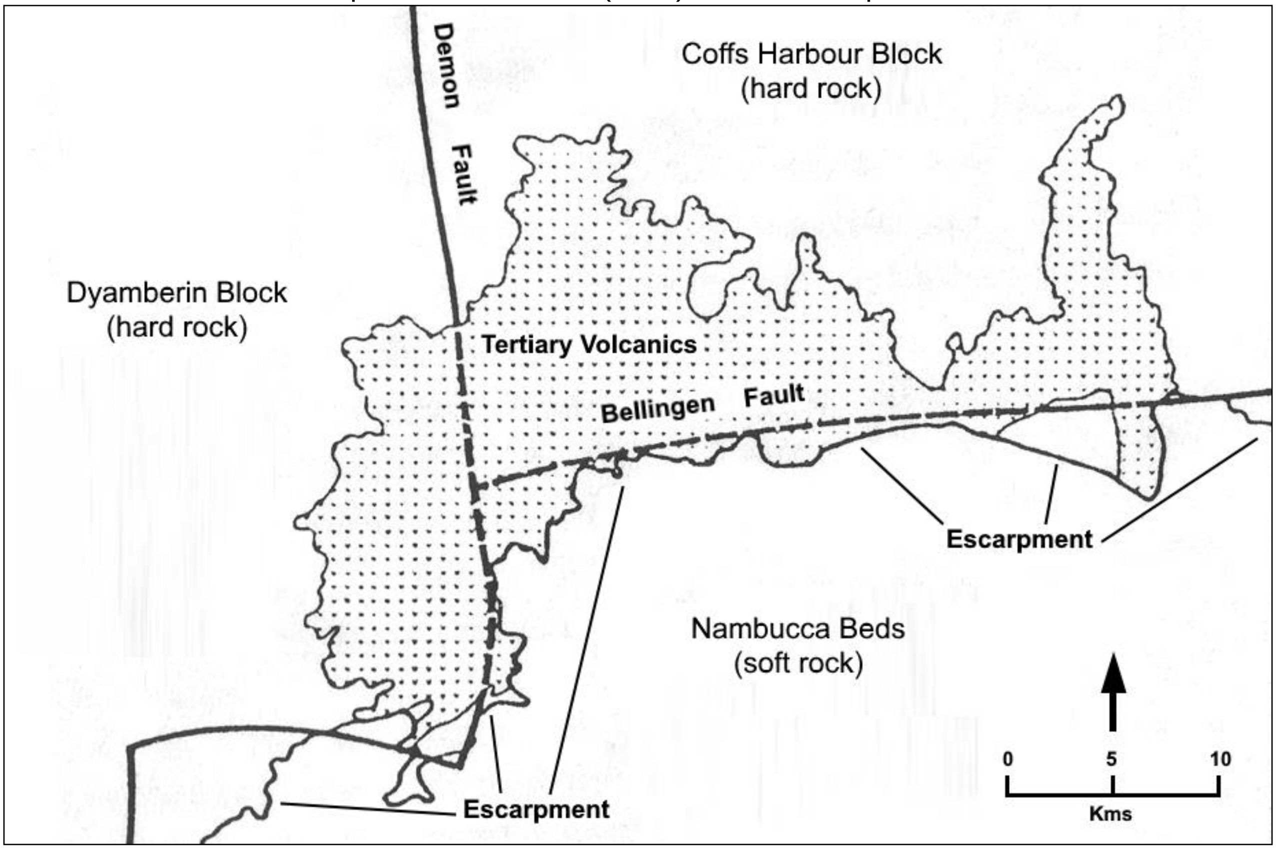
These figures are indicative only and do not necessarily represent soil profiles that may be present in the study area. However, it provides sufficient evidence for moderate to high dispersion in some subsoil samples. The key feature though is the variability of the dispersibility data, undoubtedly due to variability and unpredictability in the substrate lithology and mineralogy.

Soil Regolith Stability Class

Soil Regolith Stability Class was assessed as R1, high coherence with low sediment delivery, throughout compartments 340 and 341, consistent with the mapped regolith. Murphy *et al* (1998), p.45, 48, assigned R1 for all soils developed on the Nambucca Beds. I believe that the Soil Regolith Stability Class has been incorrectly assigned to R1 throughout. Several lines of evidence indicate high sediment delivery potential because of the high erodibility of the Nambucca Beds—

1. In the Snowy Range (sn), Mistake (mk) and Diehappy (di) soil landscapes (Milford, 1995; Eddie, 2000), the subsoils typically slake when wet. Slaking means that the soil particles detach readily when wet, as reflected in the moderate to high ratings for the K factors in those soil landscapes. McGarity (1993a) and Eddie (2000) found a range of dispersibility in subsoils from low to high.
2. The soils typically have a high stone content in the form of quartz gravels derived from the injected quartz veins within the substrate. Surface lag gravels are also common. The stoniness and lag gravels may have some armouring effect in resisting erosion (Murphy *et al,* 1998), but the lag gravels are present because they lag behind after the fine material has been removed by erosion. Indeed, gravel may increase erosion by reducing infiltration rates and by channelling surface flow on steep slopes (McGarity, 1993a).
3. The erodibility of the Nambucca Beds is demonstrated by the fact that they are much more subject to erosion than adjacent geological units. The Eastern Escarpment within the Nambucca Block has retreated, through differential erosion, to the more resistant basement rocks of the Coffs Harbour and Dyamberin blocks, undermining the overlying Tertiary Volcanics of the Dorrigo Plateau (Ollier, 1982). This observation is supported by Milford (1995). Basalt caps occur as remnants of the Dorrigo Basalts on some high ridges. See Maps 2 and 4.
4. Soil Regolith Stability Class R3 should therefore be applied throughout, because of the soils with high coherence due to the high clay content and high sediment delivery due to the slaking subsoils. The rare soils developed on metabasalt which would be assessed as Class R1 are too rare to consider; in any case their subsoils do slake. Class R3 soil, where exposed, may display common rilling, minor gully development in drainage lines and moderate incision along road gutters (Murphy *et al*, 1998). Erosion on this regolith will generate material that is susceptible to transport well beyond the source and potentially into receiving waters. The R3 soils include the Red and Brown Dermosols on deeply weathered regolith with slaking subsoils (Eddie, 2000) and the Yellow Podzolic and Red Podzolic soils identified and described by McGarity (1993a, 1993c).

Map 4. The relationships between hard (resistant to erosion) basement rock, preserved volcanic rocks, and the Great Escarpment. From Ollier (1982). See also Map 1 above.



Streambank erosion and sedimentation

McGarity (1988) observed that eroded material, especially from gullies and mass movement events, moves into drainage lines with the finer sediments being transported away, and the coarser gravels and boulders accumulating in the bed of the channel. Slumping of subsoils in road batters is a common source of sediment movement into streams. Stream sedimentation occurs when debris is transported at high energy and then deposited in channels of lower energy, while the suspended clays and silts are transported further and therefore contribute to turbidity in waterways. It is likely that this would contribute to changes in the flow characteristics of the streams.

McGarity (1993a) stated that erosion of stream banks increases the sediment load “although the importance of this factor is unknown”. The accumulation of woody debris in drainage lines also alters stream flow at times of high runoff and further destabilised stream banks.

CONCLUSION

The erodibility of soils and regolith within the Compartments.

There is no information to hand on soils information within the Compartments. However, as discussed above, soils developed on the Nambucca Beds are highly erodible, because of the soils with high coherence due to the high clay content and high sediment delivery due to the slaking subsoils (Class R3). It is not known whether subsoil erodibility assessments have been undertaken within the Compartments. Subsoil samples should ideally be collected on representative terrain facets.

In the absence of information on soil erodibility, it should be assumed that—

1. All land on slopes greater than 20º should have a high erosion rating, and
2. All land on slopes greater than 25º should have an extreme rating (McGarity, 1993a, 1993b).

The special case to be made for the Nambucca Beds with regard to their erodibility and erosion hazards.

As discussed above, soils developed on the Nambucca Beds are highly erodible. Regolith in the Nambucca Beds generally has high coherence due to the high clay content and high sediment delivery due to the slaking subsoils.

Therefore, notwithstanding the mapping of Murphy et al (1998), Soil Regolith Stability Class R3 should be applied to regolith on the Nambucca Beds throughout their extent because of their very high erodibility.

The thresholds of settings of the Inherent Hazard Levels, and the restrictions on logging for each level, in preventing erosion and water pollution.

The area is susceptible to significant soil erosion and mass movement hazards. This is because of the steep dissected terrain, extreme rainfall erosivity, locally deep regolith which can be hydrostatically loaded with groundwater following rain, the presence of quartz veins which can charge slip planes, and high erodibility of the regolith. These carry significant risks for forestry operations.

Charman & Murphy (2000) recommend against disturbance on slopes greater than 20º due to mass movement risks. Sheet and gully erosion risks are also raised with operations on slopes greater than 20º. Disturbance on slopes above this gradient risks re-activating old landslips. Mass movement may also initiate sheet and gully erosion and stream sedimentation.

Mass movement hazards are site-specific and geotechnical investigation is recommended (Eddie, 2000). This should be undertaken by a suitably qualified geophysical surveyor. Mapping exercises should determine mass movement risk, including where the metamorphic cleavage planes dip angles are approximately parallel to the slope.

In the absence of such information, in the Compartments (and on the Nambucca Beds generally) to limit the potential for mass movement and erosion due to surface disturbance by forestry operations, <u>it should be assumed that all land on slopes greater than 20º is subject to mass movement</u>.

The Inherent Hazard Assessment Levels should be redefined for the Compartments (assuming Rainfall Erosivity 6000+ and Soil Regolith Stability Class R3), by shifting the slope risk classes.

Table 6. Redefined Inherent Hazard Assessment Levels for the Compartments.

	Slope Class (degrees)			
Forestry Operation	<10º	10<20º	20-25º	>25º
1. Logging with greater than or equal to 50% canopy removal within the net harvestable area (Dozer/Skidder extraction)	Level 2	Level 4	Level 4	Level 4
2. Logging with less than 50% canopy removal within the net harvestable area (Dozer/Skidder extraction)	Level 2	Level 3	Level 4	Level 4
3. Native Forest Thinning Operation	Level 2	Level 2	Level 2	Level 4

Level 1: Low soil erosion and water pollution risk;
Level 2: High soil erosion and water pollution risk;
Level 3: Very high soil erosion and water pollution risk;
Level 4: Extreme soil erosion and water pollution risk— scheduled or non-scheduled forestry activities prohibited for the proposed method of timber harvesting and extraction.

Therefore, because of the extreme rainfall erosivity and extreme erosion and mass movement risks in the Compartments, to limit erosion and runoff and alleviate streambank erosion and sedimentation,

1. Logging with <u>greater than or equal to 50% canopy removal</u> within the net harvestable area is limited to <u>slopes below 10º</u>;
2. Logging with <u>less than 50% canopy removal</u> within the net harvestable area is limited to <u>slopes below 20º</u>, with potentially very high soil erosion and water pollution risks.

Catchment management.

Recommendations for catchment management include—

1. Monitoring and report on water quality of streams entering and exiting the Compartments, before, during and after forestry operations. This will provide information on any changes in water quality as a consequence of forestry operations.
2. Undertake a catchment hydrological modelling exercise to model the surface and channel flows into, within and out of the proposed Compartments. This will provide insights to the erosion and sedimentation risks under various weather events.
3. Extend catchment hydrological modelling to the headwaters of the Bellingen, Kalang and Nambucca catchments.
4. An estimated 81% of land within the Compartments (based on soil landscape mapping) is of slopes gradients greater than 20º. This is probably typical of land in the headwaters of the Bellingen, Kalang and Nambucca catchments on the Nambucca Beds, and would increase closer to the Great Escarpment. Therefore, it would be wise to consider reserving these areas into Flora Reserves or Nature Reserves. This land should, at the very least, be reserved for catchment protection.

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