Land and Soil Hazards on the Nambucca Beds, Northeast NSW

Michael Eddie

March 2018

Senior Soil Scientist (retired), formerly of the Science Division, NSW Office of Environment and Heritage.

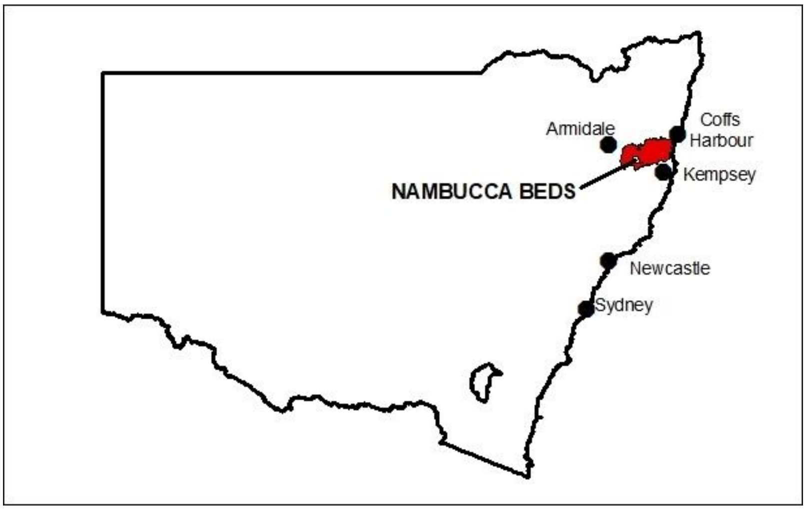
Author, Eddie M.W. (2000). *Soil Landscapes of the Macksville & Nambucca 1:100 000 Sheets*, DLWC, Sydney.

Member, Australian Soil Science Society.

INTRODUCTION

This report was commissioned by Mr Ashley Love of the Bellingen Environment Centre, on behalf of the North Coast Environment Council (NCEC), due to concerns about proposed logging activities on steep land by the NSW Forestry Corporation in river catchments on the Nambucca Beds on the NSW mid north coast. The concerns primarily relate to the impacts of proposed forestry operations in the steep headwaters on soil erosion and its effects on pollution and sedimentation in downstream waterways.

Figure 1. Location.



Two reports were recently commissioned regarding logging risks in the upper Nambucca and Kalang catchments—

1. A report was commissioned through the Environmental Defender's Office on behalf of Ms Joy van Son, landowner, in relation to her concerns about the adequacy of the methods proposed to be used by the Forestry Corporation of NSW (FC) to assess the impacts on soils and downstream waterways of proposed forestry operations in Mistake State Forest in the upper Nambucca catchment (Eddie, 2017a).
2. A report was requested by Mr Ashley Love (Bellingen Environment Centre), who represented 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 (Eddie, 2017b).

Logging and associated erosion and mass movement on steep land in Oakes SF was investigated by Atkinson *et al* (1992).

Residents downstream of these State Forests are concerned that the soil assessment methods used to prepare the draft Harvest Plans are inadequate and that Forests NSW might not sufficiently adhere to them. 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.

The most severe impacts occur on the underlying Nambucca Beds geology, which have been identified as having especially severe erosion and mass movement hazards. The Nambucca Beds cover all of the Kalang River catchment, most of the Bellingen and Nambucca catchments and much of the middle Macleay in the Macleay Gorges (Map 2).

State Forests on the Nambucca Beds are the Buckra Bendinni, Gladstone, Irishman, Lower Creek, Mistake, Nulla-Five Day, Oakes, Pee Dee, Roses Creek, Scotchman, Styx River, and Thumb Creek State Forests. Forestry operations in these State Forests are currently regulated by the Integrated Forestry Operations Approval for the Lower North East Region (IFOA).

This report will—

- Focus on the steep mountainous terrain on the Nambucca Beds;
- Address the critical nature of soils and regolith on the Nambucca Beds and the special case to be made for the Nambucca Beds with regard to erodibility of their soils and regolith;
- Address the thresholds of settings of the Inherent Hazard Levels, and the restrictions on logging for each level, in preventing erosion and water pollution;
- Address catchment management issues.

Relevant maps are presented in Appendix 1.

PHYSICAL ASPECTS

Physiography

The area covered by the Nambucca Beds falls within the **NSW North Coast** and **New England Tablelands** Biogeographic Regions (Thackway and Cresswell, 1995). See Map 1.

The IBRA **New England Tablelands** Biogeographic Region is described as “Elevated plateau of hills and plains on Palaeozoic sediments, granites and basalts; dominated by stringy bark/peppermint/box species, including *Eucalyptus caliginosa*, *E. nova-anglica*, *E. melliodora* and *E. blakleyi*”. The relevant Subregions of the New England Tablelands include the Armidale Plateau, Walcha Plateau, Carrai Plateau and Round Mountain Subregions. The Armidale and Walcha Plateaus can be treated as a single unit (Tablelands).

Figure 2. Steep ridge and ravine terrain of the upper Nambucca catchment in the Coffs Escarpment.

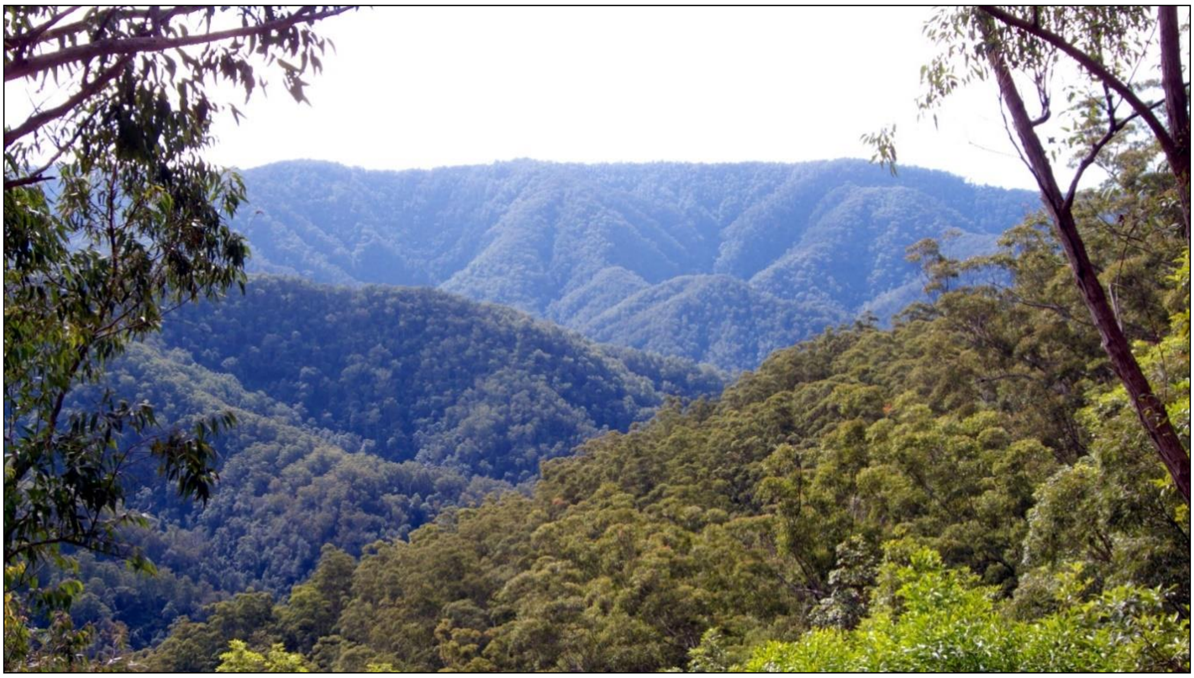


Figure 3. Precipitous terrain at Wollomombi Falls at the head of the Macleay Gorges below the Armidale Plateau.

The **Armidale – Walcha Plateaus** occur on mostly undulating with some steeper areas associated with scattered small hills and some strongly dissected terrain adjoining the Macleay Gorges. Some flat to very gently undulating plains also occur (King, 2004). Elevation is from approximately 800m rising to 1500m.

The IBRA **NSW North Coast** Biogeographic Region is described as "Humid; hills, coastal plains and sand dunes; *Eucalyptus - Lophostemon confertus* tall open forests, *Eucalyptus* open forests and woodlands, rainforest, *Melaleuca quinquenervia* wetlands, and heaths". This is a complex Region; the relevant Subregions of the NSW North Coast include the Coffs Escarpment, Macleay Gorges, Macleay - Upper Manning and Nambucca – Macleay Subregions.

The **Coffs Escarpment** subregion occurs below the Ebor – Dorrigo Plateau west to the Armidale Plateau. Drainage is south to the mid-Macleay River and east to the Bellinger – Nambucca catchment. The 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 150m rising to 1,000m, and elevation range from 1,500m at Point Lookout down to 100m near the coast. Ridge crests are narrow (50 - 150m), and sideslopes are long to very long (800m to up to 3,000m). 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).

The **Macleay Gorges** are narrow escarpments of the Macleay River and its tributaries and are actively retreating into the New England Tablelands. Terrain is comprised of deeply incised valleys with talus slopes, bedrock confined streams, cliffs and steep to precipitous sideslopes and footslopes. The gorges begin as small gullies on the Tablelands, then widen downstream to 11 km wide below the Carrai Plateau. Rivers which enter the gorge do so by way of waterfalls and other steep entry points (King, 2004). Much of the Macleay Gorges are reserved in the Oxley Wild Rivers National Park and the Macleay Gorge Wilderness area, and World heritage listed as part of the Central Eastern Rainforest Reserves (Australia).

Because of their mountainous terrain, this report will focus on the **Coffs Escarpment** and **Macleay Gorges** subregions. The complexity of this terrain exerts a major influence on climate and therefore on vegetation communities.

Geology

The Nambucca Block or Nambucca Slate Belt is a major structural unit in the eastern part of the New England Fold Belt (Brownlow et al., 1988), faulted against the Coffs Harbour Block to the north and the Hastings Block to the south. It comprises moderately to intensely folded and Late Carboniferous to Early Permian metasediments, and generally interpreted as products of accretionary prism accumulation east of a northerly-trending volcanic arc and fore-arc marine basin. 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. The Nambucca Beds (Pn) are a major component (Gilligan *et al*., 1992; Leitch, 1978; Lennox & Roberts, 1988).

The Nambucca Beds are Permian metasediments, at least 3 - 4km thick. The lower Nambucca Beds (Parrabel Beds, Pnpx) are dominated by diamictites. The upper Nambucca Beds (Bellingen slate, Pnbf; Five Day phyllites, Pnfm; Pee Dee Beds, Pnpf) are dominated by fine-grained sediments with conspicuous soft micaceous sandstones and siltstones. Rocks are moderately to intensely cleaved, fractured and deformed, with schistose foliation especially in shear zones. Higher-grade metamorphism occurred in the “Bowra culmination” in the central region, a reflection of greater uplift of the slate belt compared with the periphery. The total area of the Nambucca Beds is 5,137 km^2.

Injected quartz veins are distinctive and very common. Slip planes (which may be indicated by the presence of springs) may form when substrate dip angles are parallel to the ground surface, and when quartz veins occur in deeply weathered substrate. There are some Tertiary basalt caps (Tb) on some high ridges. More detailed information is provided in McGarity (1988).

Other geological units within the area covered by the Nambucca Beds, which are not under consideration in this report, are Triassic granitic batholith intrusions (Round Mountain, Carrai, etc), Tertiary volcanics (Ebor basalts), and Quaternary sediments (coastal and riverine).

Regolith on the Nambucca Beds is weathered rock of weak strength, with up to 4 m depth of strongly weathered silty clays (often deep red, with mottling at depth) on colluvium and footslopes in areas of weathered substrate, to very shallow on ridges and upper slopes. Soils developed on the deep regolith are red, strongly structured, and with weak texture contrast. Soils are acidic clays and slaking when wet but generally moderately fertile. Mica flakes impart silty textures to the soil materials. Quartz gravels are common as surface lag deposits (Eddie, 2000).

Figure 4. Detail of the Five Day Phyllites (Pnfm) substrate.

Soil landscapes

The soil landscapes in the area have been mapped at regional scale (1:100,000) by Eddie (2000) and King (2004), and at reconnaissance scale (1:250,000) by the NSW Comprehensive Regional Assessments (1999). Soil landscapes are indicative at the scale of mapping and enlarging the map cannot be expected to reveal further information, and it will produce distortions whereby map boundaries will no longer correspond to boundaries on-the-ground.

The mountainous area has been mapped as the Snowy Range (sn), Macleay Gorges (mg) and Mistake (mk) soil landscapes (Table 1). Mountainous terrain is defined as land with local relief of greater than 300 metres; this comprises 46% of the area of the Nambucca Beds.

Soil landscapes with slopes greater than 20º are Snowy Range (sn) and Macleay Gorge (mg). These are 50% of the total area of the above SFs, and 46% of the total area of the Nambucca Beds. Slopes above 20º are increasingly prone to mass movement and erosion hazards.

The Styx River SF is partly on the Armidale Tablelands and has the lowest proportion of mountainous terrain (Table 2).

Table 1. Soil landscapes of the mountainous terrain.

Soil landscape	IBRA Subregion	Slope class	Terrain	Area (km^2)	Percent on Nambucca Beds
Snowy Range (sn)	Coffs Escarpment	>30º	Ridge and ravine terrain. Very steep to precipitous rectilinear slopes.	1,498	29%
Mistake (mk)	Coffs Escarpment	15-30º	Rolling to steep slopes; long side-slopes and footslopes below Snowy Range (sn).	1,035	20%
Macleay Gorge (mg)	Macleay Gorges	>30º	Ridge and ravine terrain. Very steep to precipitous rectilinear slopes in deeply incised gorges.	885	17%
			Totals	3,588	70%

Soils

Soils in the Coffs Escarpment are described by Eddie (2000) as well drained, stony, shallow to moderately deep, Red Dermosols (Brown Earths) widespread on side-slopes on weathered substrate, with deep well drained Red Ferrosols and Red Dermosols (Krasnozems) on colluvium, and shallow Paralithic Leptic Rudosols and Paralithic Tenosols (Lithosols) mainly on upper slopes.

Major soil types of the Macleay Gorge (King 2004) are Rudosols (Lithosols) and other shallow soils such as Red Kurosols (Red Podzolic Soils), Yellow Kurosols (Yellow Podzolic Soils), Yellow Chromosols (Yellow Podzolic Soils) and Yellow and Red Kandosols (Yellow and Red Earths).

These 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). Beavis (2009) provided a comparison of previous and current soil assessments.

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.

Table 2. Proportional areas of mountainous terrain within each State Forest on the Nambucca Beds.

State Forest (SF)	Area (km^2)	Soil landscape	Area (km^2)	Percent of SF	Slopes > 20°		Percent of SF in mountainous terrain
					Area (km^2)	Percent	
Buckra Bendinni	17.6	Mistake (mk)	12.9	74%	4.7	26%	100%
		Snowy Range (sn)	4.7	26%			
Gladstone	68.2	Mistake (mk)	8.0	12%	26.7	39%	51%
		Snowy Range (sn)	26.7	39%			
Irishman	27.3	Mistake (mk)	13.1	48%	13.2	48%	96%
		Snowy Range (sn)	13.2	48%			
Lower Creek	12.7	Snowy Range (sn)	12.7	100%	12.7	100%	100%
Mistake	51.2	Mistake (mk)	24.5	48%	26.0	51%	99%
		Snowy Range (sn)	26.0	51%			
Nulla-five Day	32.4	Mistake (mk)	4.7	15%	27.4	85%	99%
		Snowy Range (sn)	27.4	85%			
Oakes	76.2	Mistake (mk)	21.2	28%	53.8	71%	98%
		Snowy Range (sn)	53.8	71%			
Pee Dee	0.6	Mistake (mk)	0.6	100%	0.0	0%	100%
Roses Creek	30.7	Mistake (mk)	12.0	39%	16.9	55%	94%
		Snowy Range (sn)	16.9	55%			
Scotchman	31.4	Mistake (mk)	3.0	10%	9.6	31%	40%
		Snowy Range (sn)	9.6	31%			
Styx River	163.8	Macleay Gorge (mg)	32.3	20%	70.8	43%	46%
		Mistake (mk)	5.1	3%			
		Snowy Range (sn)	38.5	23%			
Thumb Creek	40.8	Mistake (mk)	27.9	68%	12.8	31%	100%
		Snowy Range (sn)	12.8	31%			

Native vegetation

In the Coffs Escarpment, tall open forests (wet sclerophyll forest) of the *Eucalyptus pilularis - E. microcorys* suballiance (Hager and Benson, 1994) are common, with a *Corymbia intermedia - E. acmenoides* suballiance on exposed sites, and *Argyrodendron actinophyllum* subtropical rainforests (Floyd 1990) on sheltered slopes. The *Eucalyptus campanulata* alliance occurs above about 700m elevation, merging to subtropical rainforest of the *Sloanea woollsii - Dysoxylon fraserianum -*

Argyrodenron actinophyllum - Caldcluvia paniculosa suballiance. The *Eucalyptus grandis* suballiance occurs on sheltered lower slopes (Eddie, 2000).

In the Macleay Gorges, open woodland to open forest communities of the *Eucalyptus tereticornis - E. laevopinea - E. melliodora - Angophora floribunda* suballiance are dominant. Areas of dry rainforest are to be found on sheltered hillslopes and gullies and more commonly in incised drainage depressions and valley lines, on gradients of moisture, exposure and soil depth. Species composition is variable according to location. They are dominated by the *Backhousia sciadophora – Dendrocnide – Drypetes* and *Alectyron forsythii - Notelaea microcarpa - Olea paniculata* suballiances (Floyd 1990). Some more exposed slopes and rocky sites and on talus slopes have small stands of shrublands and vine thicket with *Pomaderris lanigera*, *Olearia elliptica*, *Cassinia quinquefaria*, *Prosanthera lasianthos*, *Bursaria spinosa* and *Acacia diphylla* (King, 2004).

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. There are very intense orographic effects. Microclimatic effects due to relative exposure produce cooler and wetter conditions on southerly and easterly aspects, especially in the deep valleys of the ranges, and there is a strong rainshadow effect in the Macleay Gorges. Drainage lines are closely spaced (80 - 300m), low order tributary, trellised, convergent and eroding. McGarity (1988) provided further information on climate.

Rainfall

Average annual rainfall ranges from 900mm per annum in the upper Macleay Gorges and 900 – 1,300mm on the Tablelands, while the Coffs Escarpment receives 1,000mm on the lower slopes and alluvial flats and up to 2,000mm at the top below the Dorrigo Plateau (B.o.M., 1997). See Map 3.

Rainfall Erosivity

Rainfall erosivity is a critical issue to land management in the mountainous terrain. 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 1,500 in the Macleay Gorges to 7,000 in the Coffs Escarpment (Map 4). 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 study area is very high (R 5000), which results in very high rates of runoff.

Erosion

Moderate to severe sheet and rill erosion with minor gully erosion has been observed on steep slopes associated with road works and forestry operations (Milford, 1995; Eddie, 2000). Soils are especially erodible due to the weathered mica flakes which impart silty textures to the soil materials, and induces slaking when wet.

Figure 5. Sheet erosion and roadside slumping.

Mass Movement

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).

Streambank erosion and sedimentation

The offsite consequences of erosion and mass movement are potentially severe, as sedimentation and pollution of downstream waterways. 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.

An estimated 46% of land within the Nambucca Beds (based on soil landscape mapping) is of slopes gradients greater than 20º. Erosion hazards increase closer to the Great Escarpment where rainfall erosivity is greater.

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.

EROSION HAZARD ASSESSMENTS

There are four methods in use for assessing soil erodibility—

1. **Soil Dispersibility**.

   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.

   Table 3. Emerson Aggregate Test classes (Hazelton and Murphy, 2013).

Class	Result	
1	Slakes	Complete dispersion
2	Slakes	Some dispersion
3	Slakes	Some dispersion after remoulding
4	Slakes	No dispersion (carbonate or gypsum present)
5	Slakes	Dispersion in shaken suspension
6	Slakes	Flocculates in shaken suspension
7	No slaking	Swells in water
8	No slaking	Does not swell

   Table 4. EAT Classes 2 and 3 can be divided into subclasses —

Subclass	Dispersion
(1)	Slight milkiness immediately adjacent to the aggregate
(2)	Obvious milkiness, <50% of the aggregate affected
(3)	Obvious milkiness, >50% of the aggregate affected
(4)	Total dispersion, leaving only sand grains.

   The subclass is put in brackets. For example, a Class 3 aggregate that disperses completely on working leaving only sand grains is noted as Class 3(4). Class 2(4) is equal to Class 1.

   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. Ratings for Dispersion Percentage is shown in Table 3.

   Table 5. Ratings for Dispersion Percentage (Hazelton and Murphy, 2013).

Dispersion Percentage	Dispersal Index Ratio (Ritchie)	Dispersibility
<6	>16	Negligible
6 – 30	3 – 16	Slight
30 – 50	2.0 – 3.0	Moderate
50 – 65	1.5 – 2.0	High
>65	<1.65	Very high

c. The **Soil Dispersibility Testing Method** prescribed in Section 3 of the EPL guidelines is a very much reduced version of the EAT. After observing the behaviour of soil aggregates in water, score—

0 for no dispersion within 2 hours;
1 for slight dispersion within 2 hours;
2 for slight dispersion within 10 minutes and complete dispersion within 2 hours;
3 for strong dispersion within 10 minutes or complete dispersion within 2 hours;
4 for complete dispersion within 10 minutes.

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 6. 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).

See Table 7 below.

DISCUSSION

Assessment of dispersion

K factors for soils in the Snowy Range (sn) and Mistake (mk) 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 have dispersible subsoils. However, Beavis (2009) noted that 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 any 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.

The Emerson Aggregate Test (EAT) is the minimum standard for assessment of dispersion and should be backed by Dispersion Percentage / Rithie Method.

Soil Regolith Stability Class assessment

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 the Nambucca Beds.** Several lines of evidence indicate high sediment delivery potential because of the high erodibility of the Nambucca Beds—

1. In the Snowy Range (sn) and Mistake (mk) soil landscapes (Milford, 1995; Eddie, 2000), the **subsoils typically slake when wet** due to the weathered mica content. 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 adjacent the Coffs Harbour and Dyamberin blocks, undermining the overlying Tertiary Volcanics of the Dorrigo Plateau (Ollier, 1982). See Figure 6. This observation is supported by Milford (1995). Further, the Carrai Plateau and Round Mountain granitic batholiths have persisted against erosion by escarpment retreat or by riparian erosion by the Macleay River because of their resistant nature relative to the Nambucca Beds.
4. **Soil Regolith Stability Class R3 should therefore be applied throughout the Nambucca Beds**, 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

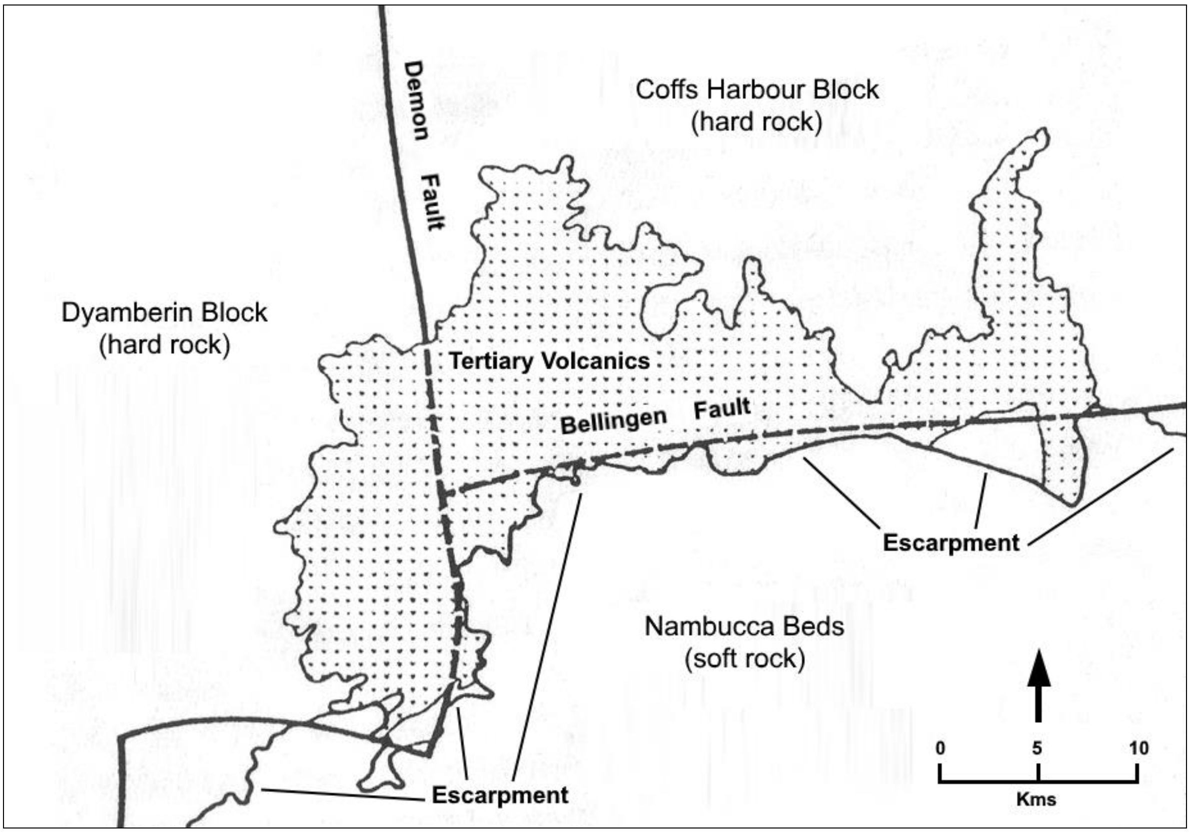
assessed as Class R1 are too rare to consider; in any case their subsoils do slake. Class R3 soil, where exposed, may display common rilling, minor gully development in drainage lines and moderate incision along road gutters (Murphy *et al*, 1998). This has been commonly observed in the field by McGarity (1993a, 1993c), Milford (1995) and Eddie (2000). 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).

Mass movement assessment

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

Geotechnical investigation of mass movement is recommended prior to any proposed disturbance, and to be undertaken by a suitably qualified geophysical surveyor. Mass movement hazards are site-specific and must be geo-located in some way. 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, it should be assumed that all land on slopes greater than 20º is subject to mass movement.

Figure 6. The relationships between hard (resistant to erosion) basement rock, preserved volcanic rocks, and the Great Escarpment. From Ollier (1982).



Subsoil erodibility assessment

It follows that from the soil variability and unpredictability, there is expected to be variability in dispersibility. The worst case should be assumed in a conservative approach required in Schedule 3 of the EPL; McGarity (1993a) found this in his investigation in Mistake SF. Data should not be averaged for assessment of risks. Subsoil samples should therefore be collected on representative terrain facets for—

1. The Dispersion Percentage test, which should be undertaken and tested in a NATA registered laboratory. The dispersion percentage test is the most useful, quick way of determining the degree of dispersion susceptibility (Craze and Hamilton, 2000). The results can be presented as percentage or as Dispersal Index Ratio (Ritchie Method) as in Table 3 above.
2. The Emerson Aggregate Test. The Soil Dispersibility Testing Method as prescribed in Section 3 of the EPL guidelines is inadequate. Aggregate erodibility should be determined by using the Emerson Aggregate Test as a minimum standard.
3. Soil Regolith Stability Class. Soils mapping at the compartment scale (1:25,000 to 1:10,000) should be undertaken to determine the range and variability of regolith stability; this may not necessary when in the assessor’s professional judgement the Soil Regolith Stability Class is applied uniformly (in this case at R3).

Information on the EAT and DP tests can be obtained in Charman and Murphy (2000).

The special case to be made for the Nambucca Beds

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 due to the mica content. This is consistent with Regolith Stability Class assessment of R3 (Murphy *et al*, 1998). Eddie (2017a, 2017b) noted that it is not known whether subsoil erodibility assessments had been undertaken within the compartments under consideration in the Mistake SF and State forests in the Kalang catchment.

In soil surveys for logging plans, subsoil samples should be collected on representative terrain facets. Soils should be classified according to the Australian Soil Classification (ASC) system (Isbell, 2002), and soil profile information should be provided to the NSW Office of Environment and Heritage SALIS database. Terrain and soils should be mapped at the compartment scale (1:25,000 to 1:10,000) to account for variability.

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

1. **All land on slopes greater than 20º should have a high erosion rating,**
2. **All land on slopes greater than 25º should have an extreme rating (McGarity, 1993a, 1993b),**
3. **Soil Regolith Stability Class R3 should be applied to regolith on the Nambucca Beds throughout their extent.**

The thresholds of settings of the Inherent Hazard Levels

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, and mass movement may also initiate sheet and gully erosion and stream sedimentation.

On the Nambucca Beds, in the absence of such information, to limit the potential for mass movement and erosion due to surface disturbance by forestry operations, **it should be assumed that all land on slopes greater than 20º is subject to mass movement.**

As a result of this, the Inherent Hazard Assessment Levels (Table 7) are redefined for forestry operations on the Nambucca Beds (and Soil Regolith Stability Class R3), by shifting the slope risk classes (Table 8).

The Inherent Hazard Assessment Levels are—

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.

Table 7. Inherent Hazard Assessment Levels for Native Forests, for slopes > 10º, and Soil Regolith Stability Class R3 (modified from EPA, 1997).

Forestry Operation	**Rainfall Erosivity (R-factors)**	**Slope Classes**			
		10<20º	**20<25º**	**25<30º**	**>30º**
Logging with greater than or equal to 50% canopy removal within the net harvestable area	0-2000	2	2	2	4
	2000-3000	2	2	2	4
	3000-4000	2	2	2	4
	4000-5000	2	2	4	4
	5000-6000	2	2	4	4
	6000+	2	4	4	4
Logging with less than 50% canopy removal within the net harvestable area	0-2000	2	2	2	4
	2000-3000	2	2	2	4
	3000-4000	2	2	2	4
	4000-5000	2	2	3	4
	5000-6000	2	2	3	4
	6000+	2	3	4	4
Native Forest Thinning Operation	0-2000	1	1	2	4
	2000-3000	1	1	2	4
	3000-4000	1	1	2	4
	5000-6000	1	2	2	4
	6000+	2	2	2	4

Table 8. Revised Inherent Hazard Assessment Levels for Soil Regolith Stability Class R3 (modified from EPA, 1997).

Forestry Operation	**Rainfall Erosivity (R-factors)**	**Slope Classes**			
		0<10º	**10<20º**	**20<25º**	**>25º**
Logging with greater than or equal to 50% canopy removal within the net harvestable area	0-2000	2	2	2	4
	2000-3000	2	2	2	4
	3000-4000	2	2	2	4
	4000-5000	2	2	4	4
	5000-6000	2	2	4	4
	6000+	2	4	4	4
Logging with less than 50% canopy removal within the net harvestable area	0-2000	2	2	2	4
	2000-3000	2	2	2	4
	3000-4000	2	2	2	4
	4000-5000	2	2	3	4
	5000-6000	2	2	3	4
	6000+	2	3	4	4
Native Forest Thinning Operation	0-2000	1	1	2	4
	2000-3000	1	1	2	4
	3000-4000	1	1	2	4
	5000-6000	1	2	2	4
	6000+	2	2	2	4

Therefore, because of the extreme rainfall erosivity and extreme erosion and mass movement risks on the Nambucca beds, to limit erosion and runoff and alleviate streambank erosion and sedimentation, **native forest logging is limited to slopes below 25º**.

Logging on slopes below 25º must take heed of the potential soil erosion and water pollution risks according to the Revised Inherent Hazard Assessment Levels.

Offsite effects of logging operations on steep terrain

Monitoring and reporting should be undertaken on water quality of streams entering and exiting any compartments considered for forestry operations, before, during and after forestry operations. This will provide information on any changes in water quality as a consequence of forestry operations.

Catchment hydrological modelling should be undertaken to model the surface and channel flows into, within and out of proposed logging compartments. This will provide insights to the erosion and sedimentation risks under various weather events.

Guidelines

McGarity (1988) noted that "the Standard Erosion Mitigation Conditions [at that time] are unsuitable guidelines for erosion control in the catchments examined in the Mistake State Forest". As an outcome of the RFA in 1999 the Environment Protection Licences (EPLs) were introduced and applied to all logging operations on public land in north-east NSW (Pugh, 2104).

Discrepancies between the Environment Protection Licence guidelines and the 2009 Harvest Plan for Compartments in the Mistake SF have been noted by Eddie (2017a).

CONCLUSION

The case is made for the special case to be made for the Nambucca Beds—

- There is strong evidence that the Soil Regolith Stability Class on the Nambucca Beds is high coherence with high sediment delivery (Class R3),
- The thresholds of settings of the Inherent Hazard Level matrix table are revised,
- Logging is limited to slopes below 25º.

On the Nambucca Beds, on slopes greater than 20º, in the absence of information to the contrary, it is assumed that—

- It is subject to mass movement;
- It has a high erosion rating;
- It has an extreme erosion rating;
- Native forest logging is prohibited.

In data collection—

- The Emerson Aggregate Test (EAT) is the minimum standard for assessment of dispersion and should be backed by Dispersion Percentage / Rithie Method.
- Data should not be averaged for assessment of risks.
- The worst case should be assumed in a conservative approach required in Schedule 3 of the EPL.

To ameliorate the offsite effects of logging on steep slopes on the Nambucca Beds—

- Monitoring and reporting should be undertaken on water quality of streams entering and exiting any compartments considered for forestry operations, before, during and after forestry operations.
- Catchment hydrological modelling should be undertaken to model the surface and channel flows into, within and out of proposed logging compartments.

Mountainous land on the Nambucca Beds on gradients greater than 20º should be reserved for catchment protection.

BIBLIOGRAPHY

Atkinson, G. (1992). *Urban and Rural Residential Capability Survey of the Nambucca Shire, Volumes 1 and 2*. Dept. of Conservation and Land Management. Report Prepared for Nambucca Shire Council.

Atkinson, G., Attwood, R.D., Kingman, J.J., and Saul, R.S. (1992). Soil Conservation Issues, Compartments 168 - 170, Oakes State Forest. Dept. of Conservation and Land Management.

Baker, P.W., Mounser, G.S. and Lowe, K.T. (1983). *Nambucca Shire Environmental Study*. A report prepared for Nambucca Shire Council. Baker Mounsell and Lowe, Port Macquarie.

Beavis, S.G. (2009). *A review of soil assessments of Compartments 340 and 341, Mistake State Forest, Upper North East Region, NSW*. Report to the Environmental Defenders Office.

Brownlow, J.W., Cameron, R.G., Chesnut, W.S., Leitch, E.C., Lindsay, J.F., Masman, K.A., Northcott, I.W., Teale, G.S. and Turvey, D. (1988). *Macksville 1:100 000 Geology Map.* NSW Geological Survey, Sydney.

Bureau of Meteorology (1988), *Climatic Averages of Australia*, Department of Administrative Services Meteorological Summary, Australian Government Publishing Service, Canberra.

Charman, P.E.V. and Murphy, B.W. (ed) (2000). *Soils, Their Properties and Management*. Oxford University Press.

Craze, B. and Hamilton, G.J. (2000). Soil Physical Properties. In Charman and Murphy (eds), *Soils, Their Properties and Management*. Oxford University Press.

Eddie, M.W. (2000). *Soil Landscapes of the Macksville & Nambucca 1:100 000 Sheets*, Department of Land and Water Conservation, Sydney.

Eddie, M.W. (2017a). *Review of Soil Assessments of Compartments 340, 341 and 341 of Mistake State Forest, Northeast Region, NSW*. A Submission to the NSW Environmental Defenders Office. Unpublished report.

Eddie, M.W. (2017b). *Review of Soil Assessments of State Forests in the Kalang Catchment, Northeast Region, NSW*. Unpublished report.

Environment Protection Authority (1997). Environment Protection Licence, Lower North East Region, Forestry Commission of NSW. Section 55 Protection of the Environment Operations Act 1997. Schedule 3, *Methods for assessing the soil erosion and water pollution hazard associated with scheduled and non-scheduled forestry activities*.

Floyd, A.G. (1990). *Australian Rainforests in New South Wales, Volume 2.* Surrey Beatty & Sons, Chipping Norton, NSW.

Forestry Corporation of NSW (2017). Scotchman and Roses Creek State Forests Compartments 125, 126, 127 and 128 draft harvest haulage and roading plans. Operational Harvest Plan No. 58797. Forestry Corporation of NSW North East Region, Urunga.

Gilligan, L.B., Brownlow, J.W., Cameron, R.G. and Henley, H. (1992). *Dorrigo - Coffs Harbour 1:250,000 Metallogenic Map SH 51 - 13, SH 56 - 14*. Geol. Survey of NSW, Department of Mineral Resources, Sydney.

Hager, T and Benson, J.S. (1994). *Assessment of the conservation status of forest plant communities in North Eastern NSW.* Australian Heritage Commission, Canberra.

Hazelton, P.A. and Murphy, B.W. (2013). *Interpreting Soil Test Results: What Do All the Numbers Mean?* CSIRO Publishing, Collingwood, Vic.

Isbell, R.F. (2002). *The Australian Soil Classification.* Revised Edition. CSIRO Publishing, Collingwood, Vic.

King, D.P. 2004. *Soil Landscapes of the Armidale 1:100 000 Sheet.* Report, Department of Infrastructure, Planning and Natural Resources, Sydney.

Leitch, E.C. (1978). Structural succession in a Late Palaeozoic slate belt and its tectonic significance. *Tectonophysics* 47 311 - 323.

Lennox, P.G. and Roberts, J. (1988). The Hastings Block - a key to the tectonic development of the New England Orogen. In Kleeman, J.D. (ed.), *New England Orogen - Tectonics and Metalogenesis*. Pp 68 - 77. Dept. of Geology and Geophysics, University of New England, Armidale.

McGarity, J.W. (1988). Report on Some Aspects of the Environmental Impact of Logging in the Mistake State Forest, Nambucca NSW. Pedon Consultants Pty Ltd, Armidale NSW.

McGarity, J.W. (1993a). Report on Inspection of areas recently logged in the Mistake State Forest with reference to Compartments 368, 369, 341 and 342. Affidavit dated 8 July 1993. Pedon Consultants Pty Ltd, Armidale NSW.

McGarity, J.W. (1993b). Impact of Logging in Compartments 341 and 342 in Mistake State Forest. Affidavit dated 23 July 1993. Pedon Consultants Pty Ltd, Armidale NSW.

McGarity, J.W. (1993c). Reply to Veness. Affidavit dated 11 December 1993. Pedon Consultants Pty Ltd, Armidale NSW.

Milford, H. (1995). *Soil Landscapes of the Dorrigo 1:100,000 Sheet*. Soil Conservation Service of NSW, Sydney.

Murphy, C.L., Fogarty, P.J. and Ryan, P.J. 1998, Soil Regolith Stability Classification for State Forests in Eastern New South Wales, Technical Report No 41, Department of Land and Water Conservation, Sydney.

NSW Comprehensive Regional Assessments (1999). *Soil and Regolith Attributes for CRA/RFA Model Resolution, Upper North-east and Lower North-east CRA Regions*. Department of Land and Water Conservation, Sydney.

Ollier, C.D. (1982). Geomorphology and tectonics of the Dorrigo Plateau, N.S.W. Journal of the Geological Society of Australia 29: 431-435.

Pugh, D (2014). Submission to: Remake of the Coastal Integrated Forestry Operations Approvals, Discussion Paper. Prepared for the North East Forest Alliance.

Ritchie, J.C. (1963). Earthwork tunnelling and the application of soil testing procedures. Journal of Soil Conservation NSW 19, 111-129.

Rosewell, C.J. and Edwards, K. 1993, SOILOSS - A Program to Assist in the Selection of Management Practices to Reduce Soil Erosion, Technical Handbook No. 11, Soil Conservation Service of NSW, Sydney.

Rosewell, C.J. and Turner, J.B. (1992). Rainfall Erosivity in New South Wales, Technical Report No. 20, Dept. of Conservation and Land Management, Sydney.

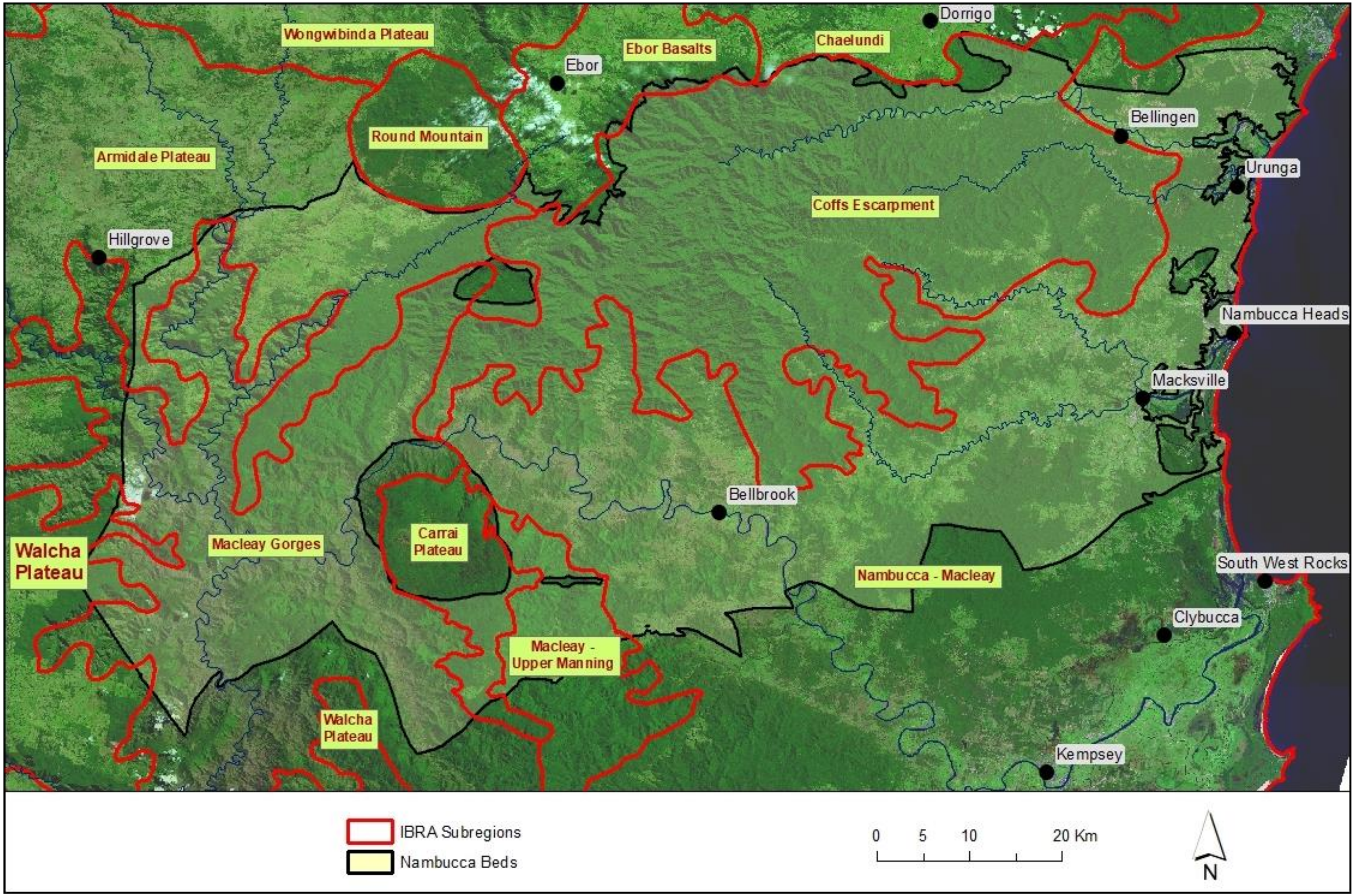
Soil and Land Information System (SALIS) User Manual v 5.1.3. http://www.environment.nsw.gov.au/topics/land-and-soil/soil-data/salis. Office of Environment and Heritage, Sydney.

Thackway, R. and Cresswell, I.D. (eds), 1995. *An Interim Biogeographic Regionalisation for Australia: a framework for setting priorities in the National Reserves System cooperative program.* Australian Nature Conservation Agency, Canberra.

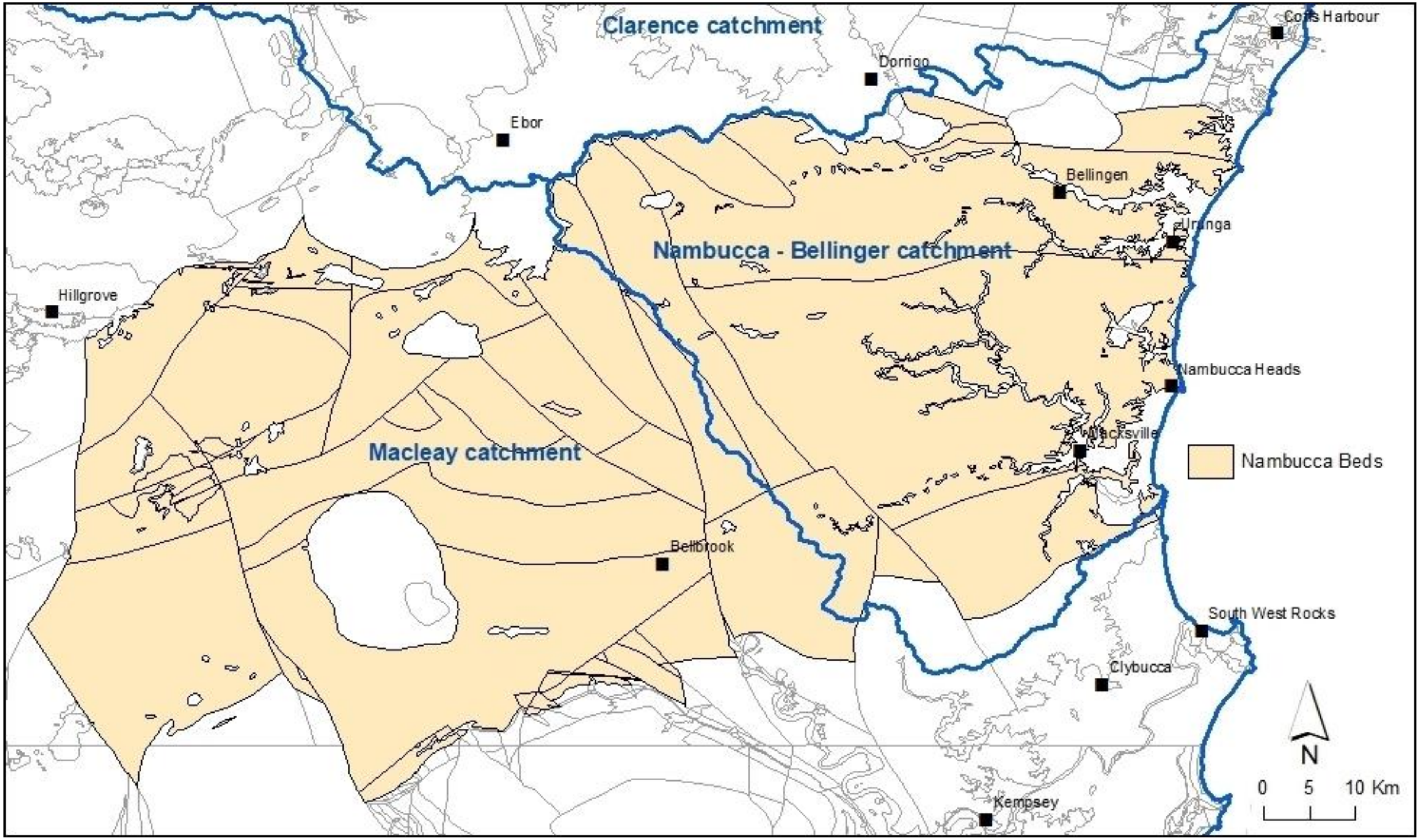
Wischmeier, W.H. and Smith, D.D. (1978). Predicting Rainfall Erosion Losses - A Guide to Conservation Planning, USDA Agricultural Handbook No. 537, US Government Printing Office, Washington, DC.

APPENDIX 1. MAPS.

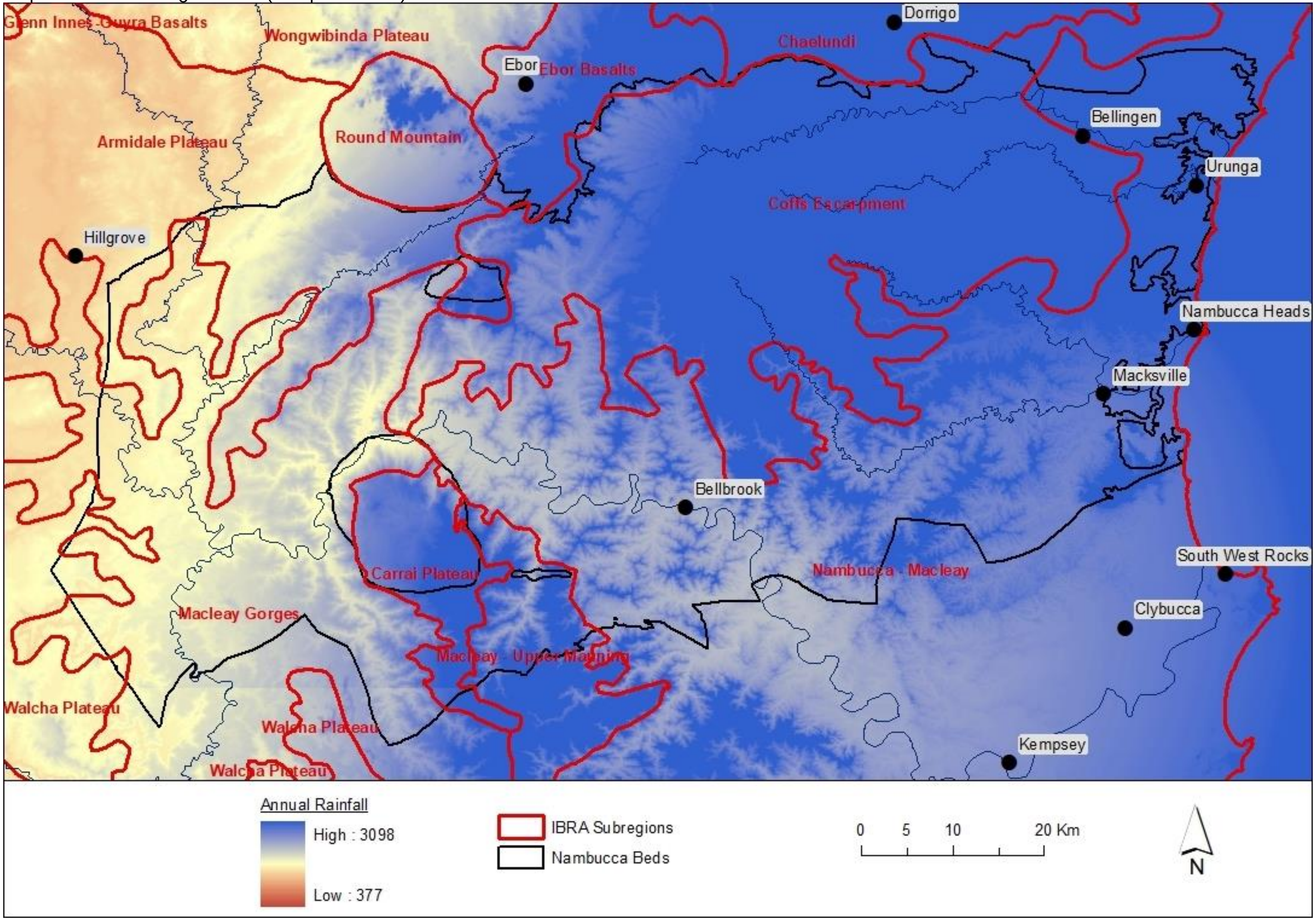
Map 1. The IBRA Subregions.



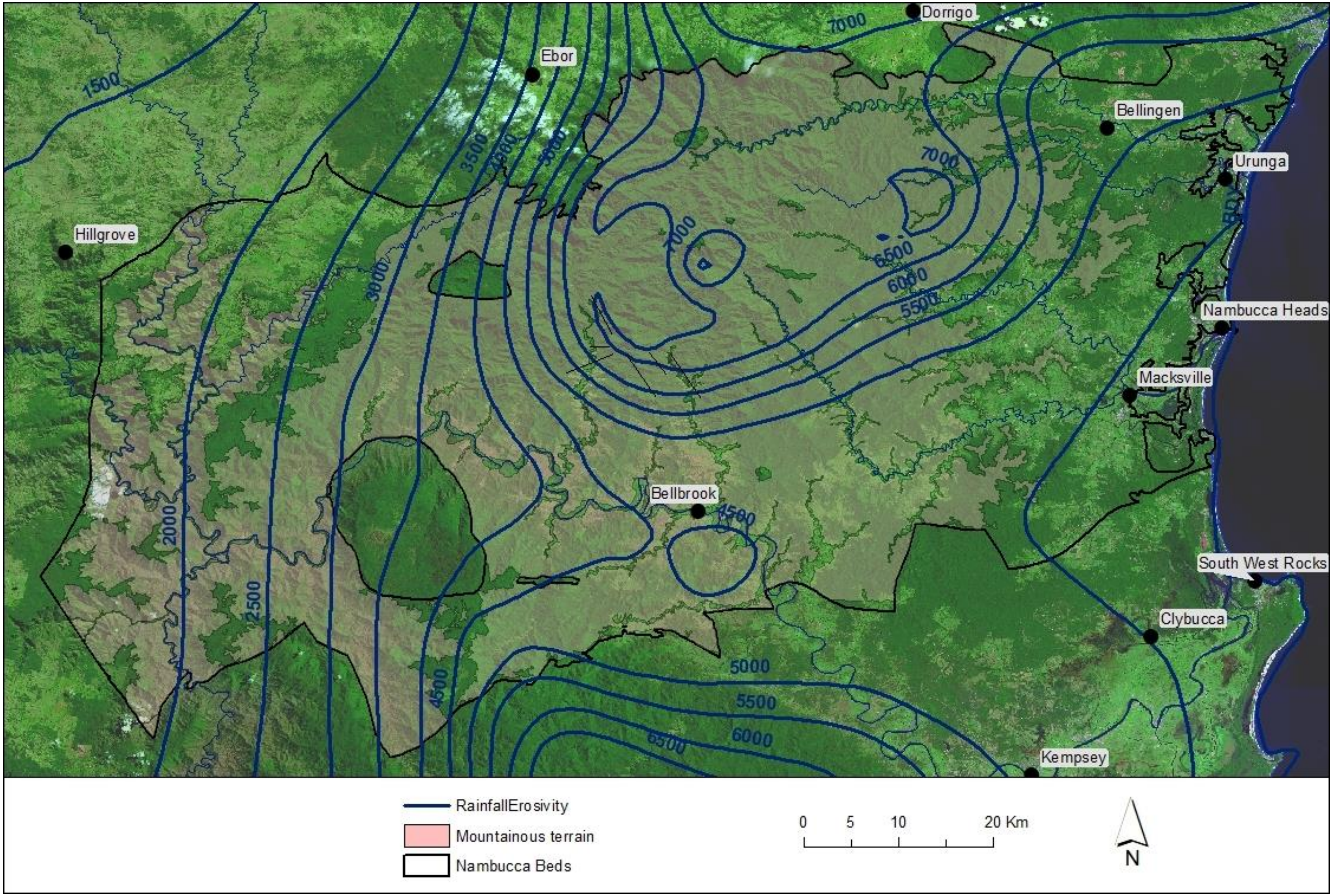
Map 2. The extent of the Nambucca Beds.



Map 3. Annual average rainfall (mm per annum).



Map 4. Rainfall Erosivity.



Map 5. State Forests on indicative mountainous terrain on the Nambucca Beds.