Planning for karst management in multiple-use forest: The Junee–Florentine karst study

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Abstract

The Junee–Florentine karst area has been the focus of a major management-oriented study by Forestry Tasmania. The study involved the systematic mapping and inventory of karst landforms and drainage relationships across an area of about 24 000 ha. The information collected provided the basis for zoning the karst into areas of differing sensitivity with respect to the potential impacts of forest operations and other land uses on karst values: about 68% of the area was zoned Low Sensitivity, about 11% was zoned Medium Sensitivity and about 21% was zoned High Sensitivity. In State forest and private lands subject to forestry, Low Sensitivity implies that no special management prescriptions are likely to be needed beyond the normal requirements of the Forest Practices Code. Medium Sensitivity implies that forest operations may need to be modified to adequately protect karst values, while High Sensitivity implies that forest operations are incompatible with highly significant and sensitive karst features. The study provides an example of a strategic approach to planning for landform protection in a production forestry context.

Introduction

It is a legislated requirement of the *Public Land (Administration and Forests) Act 1991* for Forestry Tasmania to take landform protection into account in planning for the sustainable use of forest resources. This is implemented through provisions for landform protection set out in the Forest Practices Code (Forestry Commission 1993). The Code gives detailed guidelines for forest operations in karst areas, an emphasis that is consistent with evidence that some elements of karst geodiversity are relatively vulnerable to a range of land-use impacts. The emphasis on karst also reflects the fact that some significant elements of Tasmania's karst estate are located in State forest and other lands subject to forest operations. Protective management principles for landforms, including karst, are further elaborated in Forestry Tasmania's *Geomorphology Manual* (Kiernan 1990). However, karst is only one of a number of potentially sensitive aspects of geodiversity likely to be encountered during forest operations.

In addition to its conservation values, karst is an issue for forest operations in relation to a range of geomorphic hazards. For example, in karst areas, accelerated sinkhole formation and subsidence may threaten roads and other engineering works, erosion of skeletal limestone soils may be problematic for maintaining forest productivity, water resources may be threatened by pollution of karst aquifers, and drought stress exacerbated by subterranean drainage pathways may affect tree growth.

In order to successfully manage multiple-use forest areas containing sensitive geomorphic features such as karst, detailed mapping and inventories of the landforms and drainage relationships are essential. Considerable effort has therefore been devoted to developing a

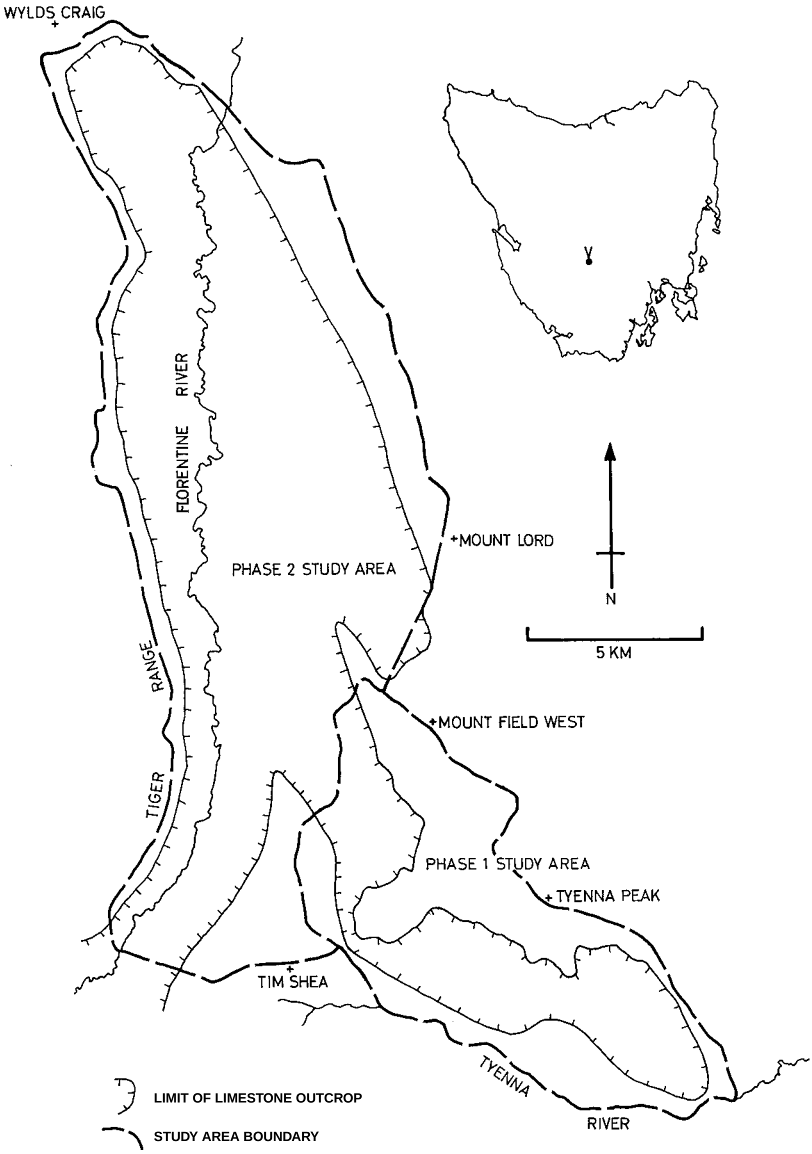

Figure 1. The Junee–Florentine karst area showing the location of the Phase 1 (Junee River) and Phase 2 (Florentine Valley) study areas. Note that the margins of the limestone outcrop do not necessarily define the limits of karstification, which may occur in limestone underlying other rock types. This occurs at a number of sites in the Junee–Florentine area.

database of sensitive and significant landforms on State forest in Tasmania. Reconnaissance inventories have been undertaken, or are in progress, for all forest Districts (Sharples 1993). These inventories are based primarily on published sources and address karst as only one aspect of forest geodiversity. A number of specific karst inventories have been undertaken, notably Kiernan's (1984) study of the Mole Creek karst. His *Atlas of Tasmanian Karst* (Kiernan 1995) has subsequently documented karst values on a statewide basis, incorporating the results of more detailed studies in several areas. In a somewhat different context, the Savage River Caving Club has co-operated with North Forest Products in investigating and reporting on karst values in the Mount

Cripps area (Gray and Heap 1996). Inventories of this type are an important starting point for integrating landform protection in forest management planning systems (Sharples 1995; Dixon *et al*. 1997).

The process of compiling detailed inventories of karst values in State forest was recently extended with the completion of a two-year project focussing on the Junee–Florentine area in central southern Tasmania (Eberhard 1994, 1996). This paper summarises the results of that project, particularly the methodological aspects relevant to the management of karst and other sensitive landforms in a production forestry context. Interpretation of the forestry implications of the study was facilitated through the development and application of a geomorphic sensitivity zoning system.

The Junee–Florentine karst

The Junee–Florentine karst is developed in an extensive belt of Ordovician limestones that underlie the major portion of the Florentine Valley. Limestone also extends into the neighbouring Tyenna River valley, approaching the township of Maydena to the south-east ('Junee area') (Figure 1). The total area of limestone and potentially karstic terrain is in the order of 18 500 ha. Most of the karst is located in State forest, formerly part of the Australian Newsprint Mills Florentine Valley Concession. Parts of the eastern margin of the karst and its catchment are located within the Mount Field National Park. Some additional areas of karst lie within the Junee Cave State Reserve, new reserves created under the Regional Forest Agreement and on private land. The karst poses a variety of difficulties for forest operations in this area (Luttrell 1997). In particular, the existence of karst conduit networks which are continuous across land-tenure boundaries drew attention to the need for a better understanding of the karst hydrology as a basis for land-management planning in this area.

The study was undertaken in two parts. Phase 1 tackled the Junee River catchment, an area of about 7500 ha largely defined by the catchment of Junee Cave near Maydena (Photo 1). Separate nearby limestone deposits at John Bull Creek and Risbys Basin were excluded, although both areas are forested and known to be cavernous. Phase 2 focussed on the Florentine Valley, an area of about 16 000 ha comprising much of the remainder of the Junee–Florentine karst. The total study area (about 24 000 ha) was somewhat greater than the area of karst within its boundaries due to the inclusion of some areas of non-carbonate bedrock within the karst catchment. In places, limestone overlain by non-karstic rocks hosts significant karst development. Karst in the upper Florentine Valley to the south of the Adamsfield Track, also State forest, was not investigated during the present study.

Aims and methods

The study involved an intensive field component with the following aims:

- Supplement existing data on the location of geological boundaries and features relevant to karstification;
- Map the distribution of known karst features, including surface features such as cave entrances and sinkholes, as well as subterranean passages;
- Investigate areas of high prospectivity for karst features, particularly areas most relevant for production forestry;
- Systematically document the recreational, scientific and conservation values of the karst; and
- Elucidate aspects of the local karst hydrology through water tracing, discharge monitoring and other means.

A considerable body of pre-existing data was available in the form of cave descriptions and surveys carried out by cavers. This was valuable but tended to focus on caves (as opposed to other aspects of karst geodiversity), and some areas of interest from a forestry point of view had been poorly prospected. Many of the caves have only been cursorily explored,

Photo 1. The Mount Field massif from the Maydena Range to the south. The township of Maydena is in the foreground. The karst extends northwards from Maydena along the middle and lower forested slopes of Tyenna Peak (1320 m) and other peaks to the north. Run-off from the upper mountain slopes, which are underlain by dolerite and non-carbonate marine sediments, sinks rapidly underground upon reaching the level of the limestone. This has contributed to the development of the extensive cave systems of the area. Much of the water reappears as a karst spring at Junee Cave near Maydena.

and it was recognised that the potential for new cave discoveries with important management implications was high.

The karst hydrology of the area had been the subject of previous investigations, notably by Goede (1973, 1976), Hume (1991), Gleeson (1976) and Eberhard (1992). Much of this previous work was confined to the Junee River catchment, where the broad configuration of an extensive drainage network associated with the Junee Cave outflow had been established. However, at the commencement of the study, some important questions remained to be addressed in the Junee River catchment, and only very limited hydrological work had been carried out in the Florentine Valley.

A Karst Sensitivity Zoning Scheme

Classification of karst environments on the basis of their sensitivity to land-use impacts has been undertaken in various contexts. Kiernan (1995) classified Tasmanian karst areas into four categories on the basis of their known or probable degree of karstification, providing an indication of the extent to which karst is likely to be an issue in developing appropriate management responses. A 10-point sensitivity scale developed by Kiernan was used by Dixon and Duhig (1996) to rank the sensitivity of sites of geoconservation significance assessed during the Regional Forest Agreement process. The sensitivity scale provided the basis for identifying some of the broad management requirements across a spectrum of site sensitivities (Dixon *et al.* 1997). The above approaches provide an overall indication of site sensitivity relevant to land-management planning. However, more detailed information on the location and appropriate management of sensitive component features is required to effectively plan forest operations.

The Karst Sensitivity Zoning Scheme developed for the Junee–Florentine area

Table 1. Summary of the Karst Sensitivity Zoning Scheme as applied to State forest. MDC status refers to Forestry Tasmania's Management Decision Classification scheme (Forestry Commission 1991; Orr and Gerrand 1998). The study area is mainly State forest but extended into other tenures, notably reserved lands in the Phase 1 study area.

LOW SENSITIVITY ZONE

Criteria: areas of low or negligible sensitivity from a karst conservation perspective; for example, areas of very subdued karst relief where there is no evidence of caves or other significant karst landforms; karst mantled by deep Quaternary cover.

Appropriate land uses: as defined in the Forest Practices Code and other relevant regulations; no special provision necessary for the protection of karst values in the zone area; conservation requirements of adjacent Medium and High Sensitivity Zones may need to be considered in some instances.

Potential MDC status: Production / Plantation.

MEDIUM SENSITIVITY ZONE

Criteria: areas containing significant karst landforms where this implies a need for some constraints on land-use activities; for example, areas containing significant sinkhole development but which appear to lack highly significant or sensitive underground landforms; some cave catchments.

Appropriate land uses: implications for land use determined by the nature of karst values present; some constraints on production forestry probable, such as longer rotations and enlarged streamside protection zones and buffers around caves and sinkholes.

Potential MDC status: Production with Special Management.

HIGH SENSITIVITY ZONE

Criteria: areas of very high significance and sensitivity from a karst management perspective; for example, areas containing extensive cave systems and surface karst landform assemblages of high conservation significance.

Appropriate land uses: maintenance of the natural environment, including ongoing geomorphic processes, of paramount importance; extractive land uses inappropriate.

Potential MDC status: Protection.

recognised three levels of sensitivity using criteria based on levels of karstification, potential for systemic links within the karst environmental system, and assumptions about the probable impacts on karst values of forest operations and other land uses (Table 1). Sensitivity was defined in terms of the potential for land-use activities to degrade landform systems and assemblages, either through direct physical impacts or by impinging on ongoing natural processes required to maintain their integrity over time. The basic assumption of sensitivity zoning is that the intensity of karstification and the degree of integration of the karst system via subterranean pathways will be uneven across the karst catchment. This implies that appropriate management responses will also vary. A range of local factors influence spatial variations in the intensity of karstification on carbonate rock substrates. In the Junee–Florentine area, important factors include the structural and lithological characteristics of the bedrock and environmental factors related to the concentration of run-off along the margins of the karst, hydrologic gradients, and the thickness of regolith materials which mantle the karst.

The particular characteristics of karst environments and the implications these may have for developing sustainable land-use practices are discussed by Kiernan (1984, 1995) and Watson *et al.* (1997). Given the highly karstified nature of the terrain and the degree to which the karst conduit networks are inter-connected, sensitivity zoning in the Junee–Florentine gave particular emphasis to the following issues:

- Karst features and environments are susceptible to human disturbance and may be permanently and unnaturally altered by a wide range of activities. In particular, maintenance of natural soil–vegetation systems is fundamental to the protective management of karst systems[2].
- The maintenance of natural karst processes, as well as individual landforms and landform contents, is an integral part of the conservation of karst systems. Maintaining both the rate and magnitude of change within naturally occurring parameters is essential in terms of managing karst as a naturally evolving environmental system (Photo 2).
- The existence of hydrological and meteorological pathways connecting widely dispersed portions of integrated karst drainage networks and conduit systems infers a high potential for the transfer of localised impacts to the wider system.
- Karst catchment areas (including catchment areas underlain by non-karstic rock types) are integral parts of karst systems. Effective management of karst systems therefore requires appropriate management of the karst catchment.

Compatibility with Forestry Tasmania's Management Decision Classification system (Forestry Commission 1991; Orr and Gerrand 1998) was an important consideration in developing the Sensitivity Zoning Scheme and applying it to State forest. A zoning scheme similar to that described here has subsequently been applied in the karstified forests of south-eastern Alaska (Baichtal *et al.* 1996).

Results and discussion

The study documented a total of more than 500 caves, the longest and deepest of which are listed in Table 2. Many of these caves had been recorded previously (Kiernan 1971; Goede *et al.* 1973; Matthews 1985; Drysdale 1992; Eberhard 1992), but significant new discoveries were made during the study. In particular, explorations in conjunction with local cavers revealed major new extensions to caves such as Niggly Cave and Threefortyone-Rift Cave. These explorations provided important insights into the nature and extent of cave development and subterranean drainage in the area, and highlight the incompletely explored nature of many of Tasmania's forested karst areas.

Forested slopes along the margins of the karst, notably the southern slopes of Wylds Craig, the eastern slopes of the Mount Field massif, and parts of the Tiger Range, were found to host rich assemblages of karst landforms. This reflects factors such as enhanced karstification due to abundant run-off from surrounding non-karstic rock types, the availability of ample limestone area and relief for the development of extensive caves and subterranean drainage networks, the existence of steep hydraulic gradients, the presence of high purity limestones such as the Benjamin Limestone and the Cashions Creek Limestone, and the exposure of the limestone bedrock to solutional processes over extended periods of time. At some of these sites, integrated conduit networks and subterranean drainage systems extending over vertical ranges of many hundreds of metres, and horizontally for many kilometres, have been demonstrated by direct cave exploration and water tracing (Table 3). Radiometric dating of secondary carbonates indicates a history of karstification that extends well back into the Pleistocene (Goede and Harmon 1983; Eberhard 1997).

[2] Disturbance to soil–vegetation systems, and the implications of this in terms of the physico-chemical characteristics of waters percolating underground, implies a potential for forest operations to impinge on speleothem processes in underlying cave systems. This issue is currently being investigated through cave dripwater monitoring programmes at Little Trimmer Cave (Mole Creek) and Frankcombes Cave (Florentine Valley).

Table 2. Major caves in the Junee–Florentine karst ranked according to depth and length. These include many of the deepest and longest caves in Tasmania. Niggly Cave is currently the deepest explored cave in Australia.

Deep caves	Depth (m)	Long caves	Length (m)
Niggly Cave	375	Growling Swallet	12 000
Ice Tube – Growling Swallet	360	Threefortyone-Rift Cave	7 000
Khazad-Dum	333	Niggly Cave	3 250
Cauldron Pot	305	Serendipity	2 940
Serendipity	278	Porcupine Pot	2 531
Rift Cave-Threefortyone	249	Khazad-Dum	1 774
Tassy Pot	238	The Chairman	1 216
Owl Pot	225	Burning Down The House	1 200
Niagara Pot	222	Cauldron Pot	1 071
Sesame	207	Tassy Pot	854
Flick Mints Hole	204	Sesame	800
Porcupine Pot	202	Owl Pot	786
The Chairman	197	Junee Cave	775
Peanut Brittle Pot	186	Frankcombes Cave	774
Udensala	181	Niagara Pot	611

Photo 2. While the Junee–Florentine karst is not generally noted for highly decorated caves, there are some important exceptions to this pattern. This photo depicts branching speleothems known as helictites in a cave in the Junee River catchment. The ongoing development of these unusual features is dependent on the natural characteristics of the cave atmosphere and water percolating underground through the soil and weaknesses in the bedrock. The photo also highlights an aspect of caves that can be rapidly degraded if cave visitors do not practice high standards of minimal impact caving techniques.

While many of the most impressive karst features are located along the margins of the karst, lower relief areas on the floor of the Florentine Valley were also found to contain areas of localised karst development on a significant scale. In particular, limestone hillocks and ridges rising above the otherwise subdued terrain of the valley floor proved to be highly karstified in many cases. At several sites, sizeable or otherwise significant caves have been discovered within relatively minor limestone outcrops (Photo 3). A more extensive example of subterranean drainage and conduit development in a low relief area is associated with the underground course of Lawrence Rivulet. This major stream rises in a glacial valley adjacent to Mount Field West and sinks underground upon encountering limestone in the Westfield Road area. Water tracing has confirmed that the Lawrence Rivulet sink is the principal source of a major karst spring some 3.4 km away near the Florentine River. Karst conduits which are presumed to connect the sink and spring may be largely water-filled as the intervening topography is low lying and the water-table is probably near the surface. Cave divers have explored submerged passages extending upstream from the spring for a distance of several hundred metres.

The water-tracing results provide important insights into the three-dimensional nature of karst drainage networks, which often conflict with the drainage patterns suggested by surface contours. For example, early water-tracing work by Goede (1976) and Gleeson (1976) established that water from Growling Swallet (a major inflow cave on the slopes of Wherretts Lookout in the Florentine Valley) flows southwards to Junee Cave, crossing a major topographic divide that separates the Tyenna Valley from the Florentine Valley. This confirmed earlier speculations along

Photo 3. Residual limestone hill on the floor of the Florentine Valley (Cashions Creek area). Considerable areas of limestone bedrock are exposed, demonstrating the limited soil cover of many limestone outcrops in the Florentine Valley. A sizeable cave has developed within the hill and contains the subfossil remains of extinct Pleistocene marsupials. This area was logged in the 1970s prior to the introduction of the Forest Practices Code.

these lines by Hills (1921) and possibly also Twelvetrees (1908). More recently, water tracing by Hume (1991) indicated a number of additional streamsink tributaries to Junee Cave, extending the confirmed limits of the Junee Cave catchment as far north as Burning Down the House Cave (Westfield Road area). Water tracing during the present study further refined the boundaries of the Junee Cave catchment. The most distant confirmed tributary is Rainbow Cave, an inflow cave located 13.2 km from Junee Cave in the Florentine Valley (Figure 2).

At least 14 discrete streamsinks have now been shown to contribute water to the Junee Cave outflow. A further 63 streamsinks probably also flow to Junee Cave, although these have not been formally tested by water-tracing. The water-tracing results and the outcomes of direct cave exploration suggest that Junee Cave forms part of a very extensive

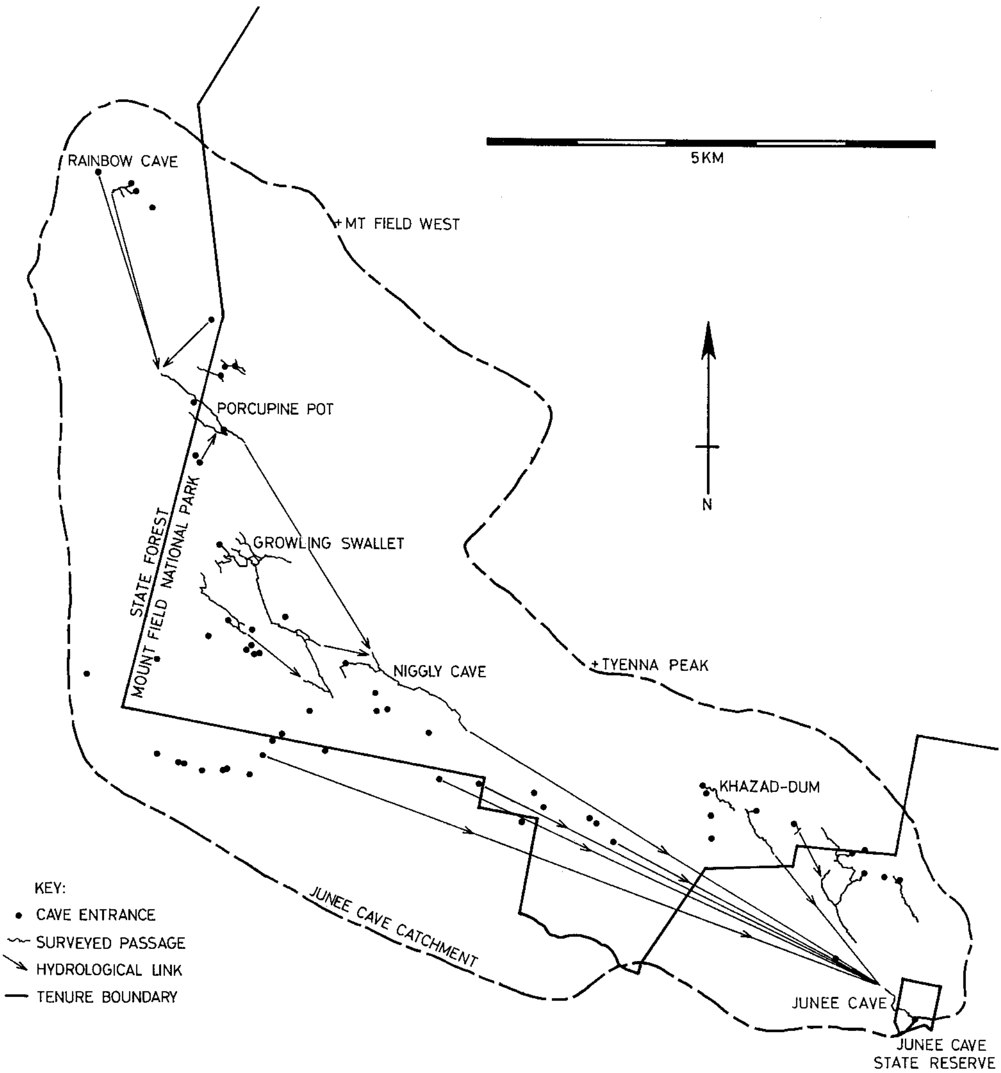

Figure 2. Cave relationships based on cave surveys, and subterranean drainage pathways inferred from water-tracing experiments, in the Junee River catchment. Preparation of this map benefited greatly from cave surveys prepared by members of the Tasmanian Caverneering Club and Southern Caving Society.

Table 3. Summary of water-tracing results in the Junee–Florentine karst. BDTH = Burning Down The House. References: 1 = Goede (1971, 1973), 2 = Goede (1976), Gleeson (1976), 3 = Hume (1991), Hume and Goede (1993), 4 = Eberhard (1992), 5 = Eberhard (1994), 6 = Eberhard (1996), 7 = Mann (1970), Terauds (1971).

Hydrological connections from	to	Date	Travel time	Distance (km)	Tracing agent	Ref
JF259	Junee Cave	4/10/91	< 46 hrs	1.1	fluorescein	5
Rift Cave	Junee Cave	11/3/91	*c.* 60 hrs	2.0	fluorescein	3
Rift Cave	Junee Cave	9/6/93	36 hrs	2.0	rhodamine	5
Cauldron Pot	Junee Cave	1991?	*c.* 45 hrs	2.6	fluorescein	3
Khazad-Dum	Junee Cave	21/8/71	11 hrs	3.5	fluorescein	1
Khazad-Dum	Junee Cave	28/3/93	25.5 hrs	3.5	rhodamine	5
Satans Lair	Junee Cave	1976	?	3.9	fluorescein	2
Rescue Pot	Junee Cave	1976	?	5.5	fluorescein	2
Chrisps Creek	Junee Cave	19/3/91	40 hrs	5.9	fluorescein	3
Niggly Cave	Junee Cave	21/6/91	24 hrs	7.4	lycopodium	3
The Slip Swallet	Junee Cave	24/5/93	*c.* 52 hrs	7.8	rhodamine	5
Serendipity	Junee Cave	18/4/91	35 hrs	8.9	fluorescein	3
Growling Swallet	Junee Cave	26/8/76	24 hrs	9.4	fluorescein	2
Growling Swallet	Junee Cave	2/4/91	18 hrs	9.4	fluorescein	3
Growling Swallet	Junee Cave	18/4/91	22 hrs	9.4	lycopodium	3
Growling Swallet	Junee Cave	21/6/91	21 hrs	9.4	lycopodium	3
Gormenghast	Junee Cave	21/8/91	34 hrs	10.2	lycopodium	3
Porcupine Pot	Junee Cave	9/6/91	< 336 hrs	10.2	lycopodium	3
Porcupine Pot	Junee Cave	10/4/94	*c.* 67 hrs	10.2	rhodamine	5
Udensala	Junee Cave	17/4/91	75 hrs	11.1	lycopodium	3
Rainbow Cave	Junee Cave	13/11/91	< 8 days	13.2	rhodamine	4
Rainbow Cave	Junee Cave	4/7/93	90 hrs	13.2	rhodamine	5
Rift Cave	Threefortyone	9/6/93	< 9 days	0.6	rhodamine	5
Niagara Pot	Threefortyone	12/7/93	< 13 days	1.0	rhodamine	5
JF126	Threefortyone	24/9/93	< 23 days	0.3	fluorescein	5
Peanut Brittle Pot	Threefortyone-Rift	25/6/94	< 14 days	0.6	rhodamine	5
Washout Cave	Threefortyone-Rift	25/6/94	2 hrs	0.05	fluorescein	5
BDTH	Porcupine Pot	26/4/91	< 44 days	2.1	lycopodium	3
BDTH	Porcupine Pot	26/4/91	< 44 days	2.1	fluorescein	3
Sinking Stream	Porcupine Pot	27/5/91	< 13 days	1.8	lycopodium	3
Udensala	Porcupine Pot	17/4/91	< 53 days	0.9	lycopodium	3
Udensala	Porcupine Pot	17/4/94	< 11 days	0.9	rhodamine	5
Rainbow Cave	Porcupine Pot	4/7/93	< 15 days	2.4	rhodamine	5
Gormenghast	Porcupine Pot	12/7/93	< 7 days	0.4	fluorescein	5
Serendipity	Growling Swallet	14/10/92	< 8 days	1.0	fluorescein	5
Trapdoor Swallet	Growling Swallet	22/10/92	< 1 hr	0.04	fluorescein	5
Growling Swallet	Niggly Cave	25/8/93	< 10 hrs	2.4	rhodamine	5
Porcupine Pot	Niggly Cave	10/4/94	< 7 days	3.4	rhodamine	5
Khazad-Dum	Cauldron Pot	27/3/93	< 18 days	0.6	rhodamine	5
Three Falls Cave	Owl Pot	26/5/91	< 42 days	0.1	lycopodium	3
JF227	BDTH	13/11/91	3 hrs	0.4	fluorescein	4
Deep Throat	The Chairman	14/12/93	< 48 hrs	0.1	rhodamine	5
Lawrence Rivulet Sink	Lawrence Rivulet Rising	16/5/91	12.5 hrs	3.4	fluorescein	4
Lawrence Rivulet Sink	Lawrence Rivulet Rising	21/12/94	< 4 days	3.4	lycopodium	6
Frankcombes Cave	JF48	9/8/95	< 28 hrs	0.7	rhodamine	6
WS Streamsink 1	Welcome Stranger	21/5/91	< 19.5 hrs	*c.*1.0	fluorescein	4
WS Streamsink 2	Welcome Stranger	31/5/92	< 24 hrs	*c.*0.3	fluorescein	4
?WS Streamsink 2	Welcome Stranger	1971	33 mins	*c.*0.8	fluorescein	7
Eden Creek Sink	Westfield Spring	7/7/92	< 9 hrs	1.6	rhodamine	4

karst drainage system and conduit network developed along the eastern margin of the Mount Field massif. A number of caves are continuous beneath the boundary between State forest and adjacent reserved areas, highlighting the potential for the transfer of impacts across tenure boundaries. The total catchment of the Junee River is now thought to be in the order of 5500 ha. About half of this catchment lies within the apparent catchment of the north-flowing Florentine River, although the Junee River itself flows southwards as a tributary to the Tyenna River. Flow velocities recorded during many of the water-tracing experiments were extremely rapid and provide an indication of the degree of conduit integration within the Junee River aquifer (Table 3).

Spatial data on the distribution of karst features and cave catchments were used to derive zones based on the Karst Sensitivity Zoning Scheme outlined above. The results of zoning are summarised in Table 4. For the study area as a whole, approximately 68% of the area was zoned Low Sensitivity, approximately 11% was zoned Medium Sensitivity and 21% was zoned High Sensitivity. If State forest alone is considered, about 90% of the area surveyed was considered potentially suitable for forest operations based on karst sensitivity criteria, albeit that Forest Practices Code requirements may need to be supplemented by additional measures in Medium Sensitivity Zones. Under current tenure arrangements, about 40% of lands in the Medium and High Sensitivity Zones are located in reserved tenures and are not available for timber harvesting.

Environmental parameters related to topographic setting are an important control on karstification processes, and strongly control the distribution of sensitivity zones across the Junee–Florentine area. High Sensitivity Zones within the Junee River catchment (Phase 1 study area) account for nearly 88% of areas zoned High Sensitivity across the study area as a whole (Figure 3). Conversely, some 87% of areas zoned Low Sensitivity are located in those portions of the Florentine Valley lying outside of the Junee River catchment (Phase 2 study area). Whereas the major portion of the Junee River catchment is located on the slopes of the Mount Field massif where limestone relief is high and steep hydraulic gradients prevail (Photo 4), much of the karst in the Florentine Valley is subdued terrain with only limited limestone relief and modest hydraulic gradients. In Kiernan’s (1995) karst area typology, the Junee River catchment represents a classic 'hill flank' topographic setting, while the more subdued relief of much of the Florentine Valley is more typical of a 'riverine and plains' karst. The relative proportion of sensitivity zones in each setting may have some predictive value in interpreting the land-use implications in other Tasmanian karst areas, although any extrapolation would need to be interpreted in the light of local factors which will affect karstification processes.

Table 4. Karst sensitivity zones in the Junee–Florentine study area. Results are in hectares and indicative only.

	Sensitivity zone		
	Low	Medium	High
Phase 1 study area	2 060	1 090	4 350
Phase 2 study area	14 270	1 570	620
Total	**16 330**	**2 660**	**4 970**

A range of geomorphic hazards associated with karst are an additional issue with important management implications for production forestry. Karst geomorphic hazards were not directly incorporated in the zoning scheme described here, which was primarily concerned with landform protection issues. Nevertheless, a high level of congruence between the location of karst geomorphic hazards and High Sensitivity Zones was noted. This reflects the fact that the most highly karstified areas are also subject to a range of factors that give rise to karst geomorphic hazards. For example, the presence of subterranean cavities such as caves will promote accelerated sinkhole formation if natural drainage characteristics are disturbed by activities such as road construction or forest removal.

Photo 4. Cave development in the Junee River catchment is characterised by steeply inclined or vertical conduits that descend to base-level conduits of more moderate gradient. This photo depicts a caver descending an unbroken vertical drop of 190 m in Niggly Cave, a confirmed tributary to Junee Cave. Clearly, specialised skills and equipment are required to explore these caves safely.

Conclusions

In highly sensitive geomorphic terrains such as karst, detailed and systematic field-based inventories are fundamental for planning forest operations consistent with landform protection requirements, as set out in the Forest Practices Code. The Junee–Florentine karst study provides an example of the application of the detailed inventory approach to a sizeable area of multiple-use forest known to contain well-developed karst land-forms and extensive subterranean drainage networks. The results of the study are likely to facilitate a more strategic approach to planning forest operations in this area.

The Karst Sensitivity Zoning Scheme proved a useful tool for interpreting the broad implications of varying degrees of karstification for forest management planning. In particular, sensitivity zoning has provided a more rigorous and transparent basis for developing Management Decision

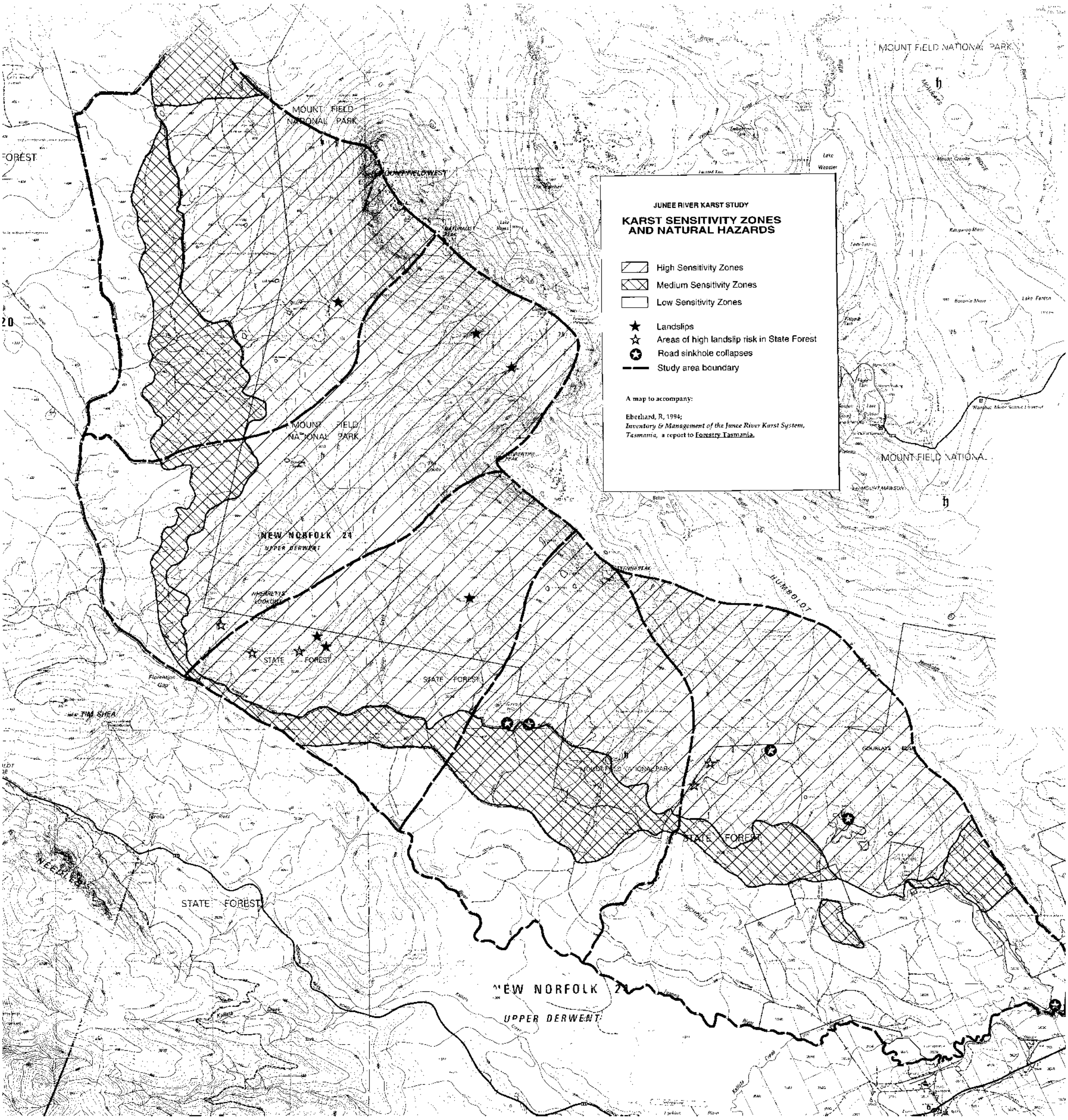

Figure 3. Distribution of karst sensitivity zones within the Junee River catchment (Phase 1 study area). In this hill flank topographic setting, extensive areas are zoned High Sensitivity. This contrasts with the situation in the Florentine Valley (Phase 2 study area) where karst development is much more localised. About 11% of the study area as a whole was zoned High Sensitivity.

Classification zones in this area. However, it must be emphasised that the sensitivity zoning process, including the identification of Low Sensitivity Zones, will not obviate the need for pre-logging coupe inspections by specialists and detailed coupe planning exercises in some cases. The sensitivity zones were delineated on the basis of the best available knowledge, taking into account systemic relationships of karst drainage networks across the area. As such, they provide a general indication of areas potentially most suitable for forest operations. Clearly, normal Forest Practices Code requirements will still apply.

Sensitivity zoning, as applied in the Junee–Florentine area, would appear to have a range of benefits relevant to questions of land management in sensitive geomorphic terrains. The potential utility of sensitivity zoning as a planning tool is probably not confined to forest operations in karst environments.

More generally, the study highlighted the fact that the influence of karst on drainage implies that topographic maps often fail to accurately portray catchment boundaries and hydrological relationships in karst areas. The Junee River catchment provides a spectacular illustration of the enigmatic nature of many karst drainage systems, with approximately half of the river catchment above Junee Cave located beyond an apparent drainage divide between the Florentine Valley and the headwaters of the Tyenna River. In such contexts, specialised techniques such as water tracing and direct cave exploration are essential tools for the karst investigator.

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