Acknowledgments

The authors wish to thank many people for support and advice on many diverse topics during the course of this project, including:

Damon Telfer, Emma Watt, Fiona Wells, Geoff Peters, Guy Lampert, Helen Locher, Helen Morgan, Jason Bradbury, John Ashworth, John Corbett, John Gooderham, Kath Sund, Lee Drummond, Leon Barmuta, Matt Brook, Mike Askey-Doran, Mike Pemberton, Mike Temple-Smith, Penny Wells, Peter Cale, Sharon Cunial, Simon Pigot, and Wengui Su.

In particular, we would like to thank Chris Sharples for extensive advice on the influence of geology on geomorphology in Tasmania, and many discussions on this and other useful topics.

For the use of river characterisation data, we wish to thank:
Guy Lampert, Damon Telfer, Peter Stronach, Daniel Sprod, and Andy Baird.

We thank Chris Sharples, Rolan Eberhard and Jason Bradbury for the use of photographs.

This project was funded by the Natural Heritage Trust.

ISSN No. 1441 0680
# Table of Contents

## Volume 1

- Acknowledgments .......................................................................................................... i
- Table of Contents .......................................................................................................... ii
- Table of Figures ............................................................................................................. iv
- Table of Tables .............................................................................................................. vii

## Summary
............................................................................................................................... ix

## Chapter 1. Introduction .......................................................................................................1
- Why do we need more information on rivers? ...............................................................1
- Why focus on geomorphology?......................................................................................3

## Chapter 2. River characterisation, classification and regionalisation.................................9
- Introduction ....................................................................................................................9
- Why is stream classification difficult? ...........................................................................9
- Existing approaches to describing river character from field, aerial photos and map based data .............................................................................................................14
- Existing approaches to predicting river form and character.........................................17
- Approaches to landform and landscape classification in Tasmania .............................18
- The approaches used in this study ................................................................................19

## Chapter 3. Methods ..........................................................................................................23
- The Environmental Domain Analysis ..........................................................................23
- Landscape scale analysis of domains ...........................................................................26
- River characterisation...................................................................................................26
- State wide analysis of river characterisations...............................................................27

## Chapter 4. What are the geomorphic controls on Tasmania’s rivers?..............................29
- Lithostructural elements ...............................................................................................29
- Climate .........................................................................................................................48
- Geomorphic process history regions ............................................................................51
- Topography ..................................................................................................................61
- Other influences on stream geomorphology.................................................................62

## Chapter 5. The river environmental domains - results and technical discussion..............67
- An overview of the relationship between domains and system controls.......................69
- Identifying larger scale patterns – mosaics and subregions in the Upper Macquarie Catchment.............................................................................................................77
- Conclusions and improvements that could be made to the Environmental Domain Analysis .............................................................................................................78

## Chapter 6. Putting the picture together: linking river landscapes and river character......81
- Things to consider when linking river landscapes to river character ............................81
- Overview of the case study area ...................................................................................84
- Apsley Uplands ............................................................................................................85
- Apsley Lowlands ..........................................................................................................86
- Crest of the Eastern Tiers .............................................................................................89
- East Draining Uplands .................................................................................................90
- East Draining Foothills ...............................................................................................93
- East Draining Lowlands ...............................................................................................93
- West Draining Uplands ...............................................................................................95
West Draining Basalt Basin .......................................................... 96
The Pink Mosaics ................................................................. 96
Eastern Tiers Western Foothills .................................................. 98
Midlands boundary and Macquarie Tier .................................... 99
Midlands ................................................................. 99
An overview of the domain mosaics and the system controls on river development and behaviour in the case study area. ................................................................. 102
The relationship between river landscapes and river form and behaviour in the case study area. ................................................................. 103
Conclusions ................................................................. 104

Chapter 7. Field based characterisation and classification of rivers .......... 105
Introduction ................................................................. 105
River characterisations completed for this project .................... 105
A comparison of existing characterisations around the state .......... 105
The Taswide classification .......................................................... 107
Limitations of existing river characterisations .......................... 110

Chapter 8. Conclusions and recommendations .......................... 113
Recommendations ............................................................. 115

References cited ................................................................. 117

Volume 2. Appendices

Appendix 1. Conversion from 1:250,000 geology map codes to lithostructural elements ................................................................. A1-1

Appendix 2. Development of the peat process region from Kirkpatrick and Dickinson (1984) vegetation codes .............................................. A2-1

Appendix 3. Regionalisation Results 1. The relationship between the stream domains and the system controls on river development and behaviour .......... A3-1

Appendix 4. Regionalisation Results 2. The domains found in the case study area sub-regional domain mosaics ................................................................. A4-1

Appendix 5. Regionalisation Results 3. The domain based variability in system controls in the domain mosaics of the upper Macquarie and Apsley case study area. A5-1

Appendix 6. Regionalisation Results 4. The Upper Macquarie and Apsley domain mosaics and the system controls on river development and behaviour .......... A6-1

Appendix 7. The conservation and management of rivers and streams of King Island................................................................. A7-1

Appendix 8. Rivers of the Birchs Inlet Region ............................................. A8-1

Appendix 9. The Upper Macquarie River catchment ..................................... A9-1

Appendix 10. The state wide river characterisation database ................. A10-1
Table of Figures

Figure 1. The Welcome River swamp forest is valuable because it supports a rare forest type, but also because it is one of very few examples of this river type in Tasmania or south eastern Australia. ................................................................. 4

Figure 2. Aerial photograph of the Meander River at Meander, showing a terrace confined reach immediately downstream of the gorge reach, the township of Meander, and the wandering gravel bed reach, which naturally has multiple channels. The river flows towards the top of the page. .............................................................................................................................................. 7

Figure 3. Three very different examples of meandering lowland streams. Top left: The Sorell River in south west Tasmania is relatively steep and has a single channel with a relatively coarse gravel bed. The river banks are stable partly because they are capped with an erosion resistant peat layer. Bottom left: The Serpentine River, now drowned under the artificial Lake Pedder, was a very low gradient anastomosing (multi channelled) meandering system. C. The Meander River downstream of Deloraine is very low gradient and runs through clay rich floodplains. ...................................................................................................................................... 11

Figure 4. Dunnings Rivulet, a tributary of the Meander River in northern Tasmania. In a very large flood in 1996, erosion massively enlarged the channel. It appears that this was a natural event. Note the person in the centre of the photograph for scale. .................................................. 12

Figure 5. These two sections of the St Patricks River at Wombat Plain in north east Tasmania have very different channel form and probably different behaviour in terms of flood frequency and style of channel movement. Left: a deep and stable meandering channel. Right: a wide, shallow sand bed channel that sometimes splits into several channels. The river at this point has an entirely granitoid catchment, which produces large quantities of sand. It appears likely that the lower channel is a response to a disturbance that released a large quantity of sand into the channel. This was most likely forestry activities, but the stream form could also be a response to a natural disturbance such as a very large magnitude flood or fire and flood combination. .............................................................................................................. 12

Figure 6. An example of a classification of river planform, from Kellerhals et al 1976. 74 ................. 14

Figure 7. The ‘Partly confined gravel bed’ river style was identified on the upstream and downstream extremes of the main floodplain on the middle St Patricks River. 93 ............................... 16

Figure 8. The valley of Eel Creek, a small stream on King Island in the process of losing an argument with a sand dune. The volume of sand being blown into the creek is far too large for the stream to transport, and the eventual result will probably be a dune barred lagoon or wetland. ........................................................................................................................................ 32

Figure 9. Left: A typical unvegetated dolerite scree on the upper slopes of Great Western Tiers in the valley of the Meander River. Right: This road cutting though vegetated dolerite scree has exposed an underground channel in the St Pauls River catchment. .................................................. 33

Figure 10. Left: A lake dammed by moraine in the James River catchment on the Central Plateau. Right: A stream cascades over a moraine in the upper Meander River catchment. .......................... 34

Figure 11. An outwash plain on the Collingwood River. Although this looks like a floodplain, the river is not able to easily modify the glacial outwash and instead of meandering across the plain flows along the flank of the bedrock hillside. ................................................................. 34

Figure 12. Floodplain deposits forming a distinct flat floor in the Serpentine River valley near Bronte. ........................................................................................................................................ 35

Figure 13. Left: Ferricrete in Tertiary sediments exposed in a road cutting north of Swansea. Right: A close up of some of the ferricrete. ................................................................................................................. 36

Figure 14. Dip falls, on the Dip River in the north west of Tasmania. Note the columns in the basalt. Photo by Chris Sharples. ............................................................................................................. 37

Figure 15. The upper Swan River running over a dolerite step. .................................................................. 38

Figure 16. A distinct step in the landscape above Collinsvale formed on Parmeeneer sediments. The mountain tops are resistant dolerite, below which extensive slope deposits cover the Parmeeneer rocks. ......................................................................................................................... 39

Figure 17. A digital image of the landscape south east of Tower Hill. The long thin spurs and valleys are formed on Mathinna rocks, and are typical of this lithostructure. ........................................ 40

Figure 18. Left. Volcaniclastic sedimentary rocks in the middle Spero River. Right. The valley of the Wanderer River flowing through a gently rolling erosion surface formed in volcano-sedimentary rocks on the west coast of Tasmania (photo by Jason Bradbury). .......................... 41

Figure 19. An outcrop of ultramafic rock in the Heazelwood Catchment. Photo by Chris Sharples. 42
Figure 20. The Rocky Cape group at Rocky Cape. Photo by Chris Sharples................................. 43
Figure 21. The view towards Frenchmans Cap from Donaghys Hill near the Lyell Highway. This landscape consists almost entirely of folded quartzite and schist associations........................................ 44
Figure 22. Left: The Weld River emerges from the Weld River Arch. Right: A stream sink in a blind valley at Mole Creek................................................................. 46
Figure 23. This distinctive sand in the bed of the Ringarooma River reflects the large area of granite in the catchment. Much of the sand in this river has been mobilised by tin mining........ 47
Figure 24. Terraces on the lower Styx River at Bushy Park. The pasture in the foreground is an abandoned floodplain, several metres higher than the modern floodplain that is used to grow hops................................................................. 52
Figure 25. Recessional moraines across the floor of the Broad River Valley downstream of Lake Webster. The river runs from left to right, and is forced to detour around the moraines........ 53
Figure 26. A myriad of small and very small lakes just north of Lake Pillans on the Central Plateau. These lakes are the result of ice scour of bedrock or the damming of drainage lines by moraine................................................................. 54
Figure 27. A block stream of periglacial origin confining the North West Bay River on Mount Wellington. The river has managed to carve a shallow, gorge like valley through the block stream................................................................. 55
Figure 28. A deflation hollow (dark area) and lunette on the south east side. This wetland is fed by a distributary of the Wye River. The deflation hollow is around 1.25 km long ..................... 57
Figure 29. Small streams that are controlled by longitudinal dunes are obvious on this 1:100,000 scale map. Dune crests are marked. Map from Dixon 1997.105................................................................. 58
Figure 30. Erosion resistant peat in the upper part of the bank of the Spero River, south of Macquarie Harbour................................................................. 59
Figure 31. The Salisbury River in southern Tasmania, flows over a dolerite plateau underlain by limestone. At Vanishing Falls, the river flows over the edge of the dolerite sill and drains straight into a cave system in the limestone. The channel downstream of the plunge pool flows only during floods. Photo by Rolan Eberhard................................................................. 60
Figure 32. This swamp forest on the Welcome River is so effective at slowing water and controlling erosion of the sandy soil that it forces the river to flow in multiple small channels. Without the vegetation, there would probably be a single deep channel here................................................................. 64
Figure 33. A slope map of the Mathinna Plains, with dark shades indicating steep slope, and pale shades close to flat. The northern part of Ben Lomond can be seen in the lower left corner. The peaks of Ben Nevis, Mt Saddleback, Mt Victoria and Mt Albert rise from the Mathinna Surface. The headwaters of the South Esk River in the south east, and the North Esk River to the north have deeply dissected this surface. The area shown is roughly 46 km from east to west................................................................. 65
Figure 34. A view of the Mathinna Plains erosion surface from Mount Maurice (the top left corner of Figure 33)................................................................................................................................. 65
Figure 35. These huge flights of terraces on the Sorrel River, south of Birchs Inlet are a result of the complex relationship between uplift, river incision and river capture................................................................. 66
Figure 36. The environmental domain analysis for the whole of Tasmania. Colours represent different domains. Note that it is not possible to produce 489 easily distinguishable colours. Bright colours covering large areas of the state each represent a single domain, but pale colours covering small areas may represent more than one domain................................................................. 68
Figure 37. The occurrence of granitoid lithostructure (hatching) in the north part of the state, and the suite of domains that occupy those areas (shading). Note that the two areas match almost exactly, indicating that the granitoid lithostructural element had a strong influence on the formation of the domains................................................................. 70
Figure 38. These graphs show the relationship between two of the lithostructural elements and the domain analysis. Granite has a strong influence on domain formation, and as a result domains tend to either be almost entirely granite, or almost entirely not granite. In contrast, dolerite had a less overriding influence on the domains, and there are many domains that are partly doleritic and partly some other lithostructure................................................................. 71
Figure 39. Examples of typical lithostructure composition of domains that include dolerite. Some domains are entirely dolerite, some are a combination of lithostructures that commonly occur together such as dolerite and the Parmeener Supergroup, while others contain a wide variety of lithostructure. Finally, dolerite sometimes occurs in very small percentages in domains dominated by slope deposits or soft sediments. This selection is intended to indicate the range of lithostructure composition, and is not necessarily a representative sample................................. 72
Figure 40. Graphs showing the average and the range of values for cross sectional curvature and effective precipitation for the domains 1 – 30. Error bars are the 5th and 95th percentiles.  
Figure 41. The range of each system control in domain 404. Note the large range for effective precipitation, and the coefficient of variation of effective precipitation, compared to the ranges of other system controls.  
Figure 42. A comparison of cross sectional curvature calculated at two different scales. At the top is a 25 m digital elevation model, with cross sectional curvature calculated with a 15 cell or 375 m window. In the middle is the same area with cross sectional curvature calculated from the 200 m DEM using a 3 cell or 600 m window. Note the coarse grain of this image, and the fact that smaller features are not detected. The lowest image is the rivers and 10 m contours from the 1:25000 topography maps. The peak is Byatts Razorback, immediately east of Ben Lomond. The view is approximately 5 km from north to south.  
Figure 43. Statewide maps of the system controls effective precipitation and cross sectional curvature (measured over 600 m). The climatic data shows gradual patterns of change across the state, while to topography data is so finely dissected that it is almost too fine to appreciate at this scale.  
Figure 44. The headwaters of the Wye River and Lost Falls Creek in the Eastern Tiers. Note that the ridgelines and some small valleys all consist of one huge domain, number 93, but that a series of different small domains make up the major valleys. The overall pattern of domains is informative, but the presence of an individual patch of a single domain is less useful. Different shading represents different domains. Contour interval is 20 m.  
Figure 45. The mosaics identified in the case study area of the central east coast and the upper Macquarie catchments. The mosaic boundaries are drawn in black. Note that the domains are shaded to highlight different mosaics, and that the colours do not imply the degree of similarity between domains.  
Figure 46. Alluvial fans on small streams draining the flank of Twelve Trees Range near Strathgordon.  
Figure 47. The Apsley River on entering this subregion forms an alluvial fan. The river has incised this large channel through the fan.  
Figure 48. A broadwater pool on the lower Apsley River.  
Figure 49. The small meandering channel immediately downstream of the broadwater shown in Figure 48.  
Figure 50. The upper Wye River in Shaws Bogs.  
Figure 51. A meandering section of the Macquarie River at Longmarsh.  
Figure 52. A steep valley confined reach of the Macquarie River upstream of Longmarsh.  
Figure 53. The Apsley River in the Apsley Gorge.  
Figure 54. The alluvial fan reach of the Wye River, from the confined valley just visible on the left of the photo to the confluence with the tidal reach of the Swan River on the right. Note the secondary channel crossing the floodplain, and the narrowing of the main channel as you move downstream.  
Figure 55. The Macquarie River at Cassiford Marsh, in the low angle alluvial fan. Note the secondary channels on the floodplain, and the low hills constricting the river.  
Figure 56. The Macquarie River in the low slope valley confined reach.  
Figure 57. A comparison of field observations of river character and the domain mosaic areas in the upper Macquarie and Apsley catchments.
Table of Tables

Table 1. Sources of system control data used in the Environmental Domain Analysis...........23
Table 2. River characters observed in the Apsley Lowlands landscape mosaic.......................88
Table 3. River characters observed in the East Draining Uplands landscape mosaic..................92
Table 4. River characters observed in the East Draining Lowlands landscape mosaic...............95
Table 5. River characters observed in the West Draining Uplands landscape mosaic.................95
Table 6. River characters observed in the Midlands landscape mosaic...................................101
Table 7. Criteria used to help differentiate Taswide styles. Note that this list reflects only the river characters identified in the catchments studied so far, and does not represent a comprehensive list for the state. ........................................................................................................108
Summary

River managers have a difficult task in sorting out the variety of complex and interacting issues that are associated with rivers. Rivers represent an important focus for conservation of biological and geomorphological values. They supply useful resources, particularly water supply for agriculture and town uses. They also supply natural hazards in the form of flooding, erosion and large scale sediment deposition, all of which can damage assets and infrastructure. Managing rivers to maximise the benefits to conservation, optimise use of water and minimise the risks of hazardous river behaviour is difficult and often contradictory. Compromises need to be made to balance all these uses of river systems, and this requires knowledge of the costs and benefits of any activity to all aspects of the stream, in terms of the long term impact on the river environment, as well as the immediate social and economic effects.

River geomorphology is the study of the shape of rivers, those processes that produced that shape over geological time and those that are maintaining or changing that shape today. Studying river geomorphology can tell you about the geoconservation value of a river, about the habitat that is the basis of the stream ecosystem, about the effect river processes may have on river management and very importantly, the effect that river management may have on river processes. An understanding of river geomorphology is essential if we are to manage our rivers as efficiently as possible.

Until recently, there has been little information about river geomorphology available to help land managers in Tasmania make decisions about river management. This project was designed to aid those whose task it is to manage Tasmania’s rivers and streams, by reviewing techniques available to characterise river form and behaviour and suggesting appropriate methods for this state, and by developing a map of river regions throughout the state. These things will provide:

- a context for assessments of conservation value on a state wide scale, particularly relating to the geoconservation values of rivers and streams;
- a basis for identifying template streams that are in excellent condition and are good examples of their type, which can then be used to assess condition of other streams and aid in the design of stream rehabilitation works, and
- a basis for developing regionally specific advice on river management for both conservation and utilitarian goals.

In the last few years, there have been a variety of catchment based assessments of river character around the state. This project concludes that field assessments of river character are the best way to develop reliable descriptions of present river form, condition, and potential behaviour. However, so long as river managers try to extrapolate their experience from one catchment to another, and so long as decisions about conservation value and resource use are made on a scale greater than a single catchment, then a regional synthesis is also important. While valuable information can be gained from either type of study, the most useful information comes from the combination of the two. Either one, without the other, gives only a partial picture of the river.

This project has developed a method for defining geomorphic river regions on a state wide scale based on those aspects of the environment that influence river development and form. The data sets required to develop the region map have been developed, and the region map is partially complete. When complete, this map must be subject to ongoing testing against field characterisations.
Summary

This document includes the following.

- A brief review of relevant literature on stream classification and characterisation. It discusses the challenges of stream classification, and describes the reasoning behind the selection of the methods used in this project.
- A brief technical discussion of the methods used.
- A description of how the climate and landscape of Tasmania influences river development and character. This chapter should be very useful for those who want to understand more about landscapes and rivers.
- A technical discussion of the GIS techniques used in developing the river regionalisation, and the degree to which they were successful.
- A discussion of the interactions between landscapes and rivers, both in theory and in relation to the case study area.
- A discussion of issues arising from a review of field assessments of river character in the state.
- Conclusions and recommendations for further work.
- River characterisations for King Island, Birchs Inlet and the upper Macquarie River.
- A state wide comparison of existing river characterisations, and suggestions for improving the consistency of these descriptions in the future. Part of this information is presented as a table, and part is presented as an Access database in the attached CD. This CD also includes a map of existing river characterisations in ArcView format.

The main recommendations of this report are as follows.

1. The recent effort that has been put into using river geomorphology as a source of information for river management, both for nature conservation and utilitarian goals should continue.
2. The regionalisation of river geomorphology should be completed as soon as possible.
3. To understand and predict river behaviour across the state requires good quality base data. Efforts should be made to map (based on field surveys or GIS modelling) the following variables. These will be valuable not just for developing a river region map, but also as a source of information for land managers in general. These include:
   - modern river sediments (ie floodplains)
   - coarse slope deposits (eg dolerite screes)
   - geological process regions (eg uplifted erosion surfaces and active faults).
4. The Environmental Domain Analysis that is the basis for the river region map should be improved in the ways described in the conclusion.
5. Greater effort should be put into making field based characterisations of river geomorphology consistent across the state. This should in part be achieved by couching assessments of river character within the river regions, when complete.
6. The Taswide river character should be discussed in the Tasmanian river geomorphology community, improved and adopted as a flexible basis for consistently naming river characters throughout the state.
7. When complete, the river regions will still require considerable testing against field data. This process, and the regular updating of the regions to reflect our growing knowledge of Tasmania’s river systems is of great importance and should continue.
Chapter 1. Introduction

Until recently, there has been little information about river geomorphology available to help land managers in Tasmania make decisions about river management. This project was designed to aid those whose task it is to manage Tasmania’s rivers and streams, by reviewing techniques available to characterise river form and behaviour, and by producing a map of river regions throughout the state. These things will provide:

- a context for assessments of conservation value, particularly relating to the geoconservation values of rivers and streams;
- a basis for identifying template streams that are in excellent condition and are good examples of their type, which can then be used to assess condition of other streams and aid in the design of stream rehabilitation works, and
- a basis for developing regionally specific advice on river management for both conservation and utilitarian goals.

The region map presented here is only partly complete, however the basis for extending the regions across the whole state exists, and the work is presently under way.

Why do we need more information on rivers?

River managers have an unenviable task in sorting out the variety of complex and interacting issues that are associated with rivers. Limited resources must be allocated between frequently conflicting goals. Those resources are the geomorphic and biotic components of the rivers and the water within them, as well as the money and materials for stream and riparian management. Conserving rivers, riparian zones and their inhabitants, utilising water resources for power generation and water supply, and managing the hazardous behaviour of rivers (such as flooding and erosion) are often in direct conflict. Compromises need to be made to optimise all these uses of river systems. This requires knowledge of the costs and benefits to all aspects of the stream, in terms of the long term impact on the river environment, as well as the immediate social and economic effects.

The existing impacts of past compromises, informed or uninformed, are already widespread. Since European settlement, many changes to the geomorphology of Australia’s streams have occurred. These changes include alterations to channel slope, headward extent (the distance stream channels extend up hill slopes), meander migration rates, bedforms, cross section width and depth, and in some cases position on the valley floor. Tasmania has not avoided these impacts, though they are generally less well documented than on the mainland. As well as this, direct and intentional impacts to our river systems include dams for electricity generation and water supply (1214 km² inundated throughout the state in 1996²), and the draining of at least 7000 ha of wetlands.² Changes to flow regimes resulting from dams and drainage works affect many kilometres of river.

This discussion is active in Tasmania at the moment. The Water Development Plan identifies the need for ‘a strategic approach to water development which integrates the needs of all users, the environment and our social and economic goals’.³ These goals include ‘making sure our natural streams, waterways and wetlands are properly looked after’ and that ‘water resources are being used wisely to increase production and create more jobs in farming and other water dependent industries’.³ Many of the large rivers in the state have already been dammed for electricity production. There is now a push to develop the remaining water resources to supply water for agriculture. There are a great many proposals for small farm dams. Large dams are also being proposed by government and industry, with proposals for nine large irrigation schemes listed in the present Water Development Plan. Many of these dams will use the natural stream channels to carry irrigation water. Each of these
developments will have implications for the conservation values of the river at the development site and downstream, and for the stability of the river downstream. In many cases, minimising these impacts will require in-stream and riparian management strategies including environmental flows, and potentially for riparian rehabilitation works and in-stream works.

In contrast to the development push, there is growing interest in improving the environmental condition of waterways, and protecting rivers that are still in good condition. Around Australia, tens of millions of dollars are spent on river management each year, ranging from NHT funded community Rivercare activities to government funded research. In Tasmania, the Water Development Plan includes the Conservation of Freshwater Ecosystem Values project, which has task of identifying important values associated with river, wetlands and related features, and developing and implementing a strategy to protect them.

**How does this project help?**

To resolve the conflict between nature conservation and utilitarian needs, we need to prioritise conservation efforts, and to improve our ability to design utilitarian stream management works to maximise their effectiveness and minimise their impact.

Since the early 1990’s and the advent of the National Reserve System, there has been an emphasis on designing reserves that cover a Comprehensive, Adequate and Representative (CAR) cross section of the environment. Comprehensive means that the full range of types present in the environment should be present in the reserve system. Adequate means that the reserve system is sufficient to maintain the environmental processes that maintain the environment. Representative means that each type in a reserve represents the diversity present in its class. This is the basic design adopted by the Conservation of Freshwater Ecosystem Values project. In order to achieve this for rivers, we need to know the full range of river types, where they occur, what environmental processes maintain each river type and the diversity of rivers within each type.

This project helps gather the information required to design a CAR reserve system in several ways. The regionalisation will help by defining areas where the same geomorphic river types are found. The river characterisation methods discussed and applied in Chapters 2 & 7 describe geomorphic river types and suggest what processes are necessary to maintain the health of those types. The combination of the regionalisation and the field assessments will also provide some information on the diversity of rivers within each type.

Condition is also an important concept when identifying conservation priorities. Condition, or naturalness, is typically defined as similarity to the pre-European condition. Higher priority is given to places that are in very good condition and are good representatives of their type, particularly if it is a rare to find an example of that type in good condition. This philosophy underlies major conservation efforts in Australia today, such as the Regional Forest Agreement, and the Conservation of Freshwater Ecosystem Values project referred to above. This regionalisation will aid assessments of geomorphic river condition by defining regions within which rivers should look basically similar. Within a region, a ‘template’ of the characteristics of a river in good condition can be developed. This will help make condition assessments.

This project also has much to offer any kind of stream management that involves controlling the form or behaviour of the river, whether the goal is to protect or improve the conservation value of the river, or a utilitarian goal such as reducing erosion rates or delivering water more effectively. It is often a combination of these, and whatever the goal, the tools are much the same. Flow manipulation can provide either environmental flows to re-create habitat and important triggers for in-stream and riparian flora and fauna, or flushing flows and channel
forming flows to maintain channel form. In-stream works can reconstruct habitats such as large woody debris or riffles, or stabilise the river bed and banks to prevent erosion. Riparian fencing and revegetation can improve the stream environment and increase bank stability. All of these tools are used with the intention of changing the local river behaviour, and often risk doing so in an unexpected way as a side effect.

It is important to understand the geomorphic processes that drive stream behaviour in order to judge whether it is necessary to intervene at all, and to design an intervention that will achieve the desired aim without causing undesired side effects. The stream characterisations discussed in Chapter 7 will help predict river behaviour, and the regionalisation will help extrapolate from well studied rivers to less well studied sites.

**Doesn’t this information already exist?**

Two existing regionalisations cover Tasmania, the Interim Biogeographic Regionalisation of Australia (IBRA) version 5, and the georegionalisation of Houshold et al. IBRA is essentially a biological regionalisation, based on the distribution of species and species assemblages across the state. With the exception of frogs, the species used were all terrestrial. Because of this, it is unlikely that IBRA will predict the distribution of aquatic ecosystems. It is even more unlikely that it will predict stream geomorphology. This is understandable, seeing that was not its purpose.

The geo-regionalisation produced by Houshold et al. has more potential to predict river character. However this regionalisation is not focussed on rivers, but on all aspects of geomorphology. Also, it was developed by overlaying data layers, a relatively primitive GIS technique that has some problems. It has been used to describe the state’s coastline, and the rivers of the Mt William National Park. The regionalisation described in this document follows the original concept of Houshold et al., but is focussed on river systems rather than on all geomorphic processes, and uses far more advanced GIS technology.

When this project started, there had been almost no work done on systematic characterisations or classification of river geomorphology in the state, despite their variety of character and the fact that many occur in scenic surroundings that make them ideal targets for study. This situation has changed somewhat in the last three years. Several fluvial geomorphologists have been employed by DPIWE, although none in ongoing positions. Geomorphic assessments have been included in some environmental flow and environmental impact studies, and have become a requirement for Rivercare plans. This report adds to this body of work.

**Why focus on geomorphology?**

Geomorphology is the study of the shape of the land, the processes that have made it that shape over geological time, and the processes that are maintaining or changing that shape today. In rivers, geomorphology describes and explains processes of erosion and deposition and their relationships with different substrates and flow patterns. The work presented in this report is focussed entirely on stream geomorphology, rather than regionalising stream biology or hydrology. There are several reasons for this focus, including:

- a lack of information on which to base conservation priorities for looking after the river component of Tasmania’s geoheritage,
- the manner in which geomorphology acts as an underlying control on the biological components of the stream ecosystem, and
- the importance of understanding geomorphic processes in rivers when you are planning river management for any purpose.
Chapter 1. Introduction

What do we mean by geoconservation?

Geo features and processes, including geology, geomorphology and soils, are important targets for conservation. The range of geo features and processes are known as geodiversity, and efforts to conserve them are know as geoconservation. Like plants and animals, geo features have intrinsic value, as well as the ecological value described above. Intrinsic value refers to the right of all things to exist, independent of their usefulness to humanity, and applies to geo features just as it applies to plants and animals. Ecological value refers to the role of geo features and processes in providing the living components of the environment with habitat and, in the case of plants, food. Anthropogenic values refer to that usefulness to humans, the value of a rock, landform or soil because of its aesthetic value, its scientific and education value, recreation and cultural values. For example, part of the value of the swamp forest reaches of the Welcome River in north west Tasmania comes from the distinctive and rare forest it supports. The Welcome River swamp is also intrinsically valuable because it is one of very few remaining examples of such a river type.

Figure 1. The Welcome River swamp forest is valuable because it supports a rare forest type, but also because it is one of very few examples of this river type in Tasmania or south eastern Australia.

In this state, geoconservation is now recognised in many planning regulations, particularly in the reserve classification which recognises geodiversity as a reason for conserving all types of reserve gazetted under the Parks and Reserves Management Act 2002. The Nature Conservation Strategy considers that protecting the non-living elements of the environment is fundamental to nature conservation. The state’s Forest Practices Code recognises the importance of geoconservation, and includes guidelines for planning and site management that aim to protect significant landforms. The legislative and management framework for geoconservation in Tasmania is reviewed in Dixon et al.

The state maintains a geoconservation database, which lists information about features that have been identified as having significant geoconservation value. This database includes sites nominated for their outstanding value, and sites nominated because they are representative of a type of feature. However, the identification of features that are significant
because of their representative nature lags behind, partly because of the lack of a suitable classification or regionalisation. There is a marked inequality in the amount of information available for identifying and protecting different forms of geodiversity. Considerable documentation exists describing karst landscapes in Tasmania, and how to manage them (eg24-28) and to a lesser extent glacial landscapes,27 and coastal landscapes.13 However, despite (or possibly because of) the fact that landforms developed by running water cover a far larger proportion of the state, very little documentation exists describing the range of stream features, their geoconservation value and management requirements. One exception is Wells’ recent work on headwater streams.28 This stream regionalisation goes some way toward filling this gap for streams with larger catchments.

What about stream ecosystems?
By concentrating entirely on geomorphology, we have neglected the inhabitants of that geomorphology, despite the fact that they are a more common focus for conservation and management. This intentional omission was because the authors felt that characterising and regionalising stream ecology is a major task in its own right, requiring different information and expertise than this geomorphic study. However, that does not mean that this project has nothing to contribute to the study of stream ecosystems, even though we included no data on the distribution of any plant or animal. Stream geomorphology is one of the main components of the habitat available for instream and riparian plants and animals, and does influence the distribution of species and communities (eg29-35). As such, the regionalisation and the stream characterisation methods discussed in this report may help understand or predict what types of plants and animals are found at a site. This has yet to be tested in Tasmania, as there has yet been no opportunity to compare biological distributions against this regionalisation. However, the same basic approach has been successful in other areas of the world (eg29,36,37).

We do recognise that this regionalisation, in isolation will not tell you about the distribution of aquatic and riparian plant and animal species. Rather, it is a potentially useful input into a different study with the specific goal of identifying bio-physical regions, that will have to take many other factors into account.38 Geomorphology is not the only component of stream and riparian habitat. The quantity and timing of water flowing through the river is also important, as is water quality.34,39 Biological components of the ecosystem form habitats for other organisms (for example, Victorian macroinvertebrate assemblages appear to respond to vegetation structure40). Also, habitat is obviously not the only influence on stream ecology. Interactions with other organisms are also important, as is the historical opportunity for a species to become established in the area. In riparian areas, terrestrial disturbances such as fires will have a major influence on the communities present. Given all these influences on stream ecology, it is obvious that geomorphic characterisations and regionalisation presented here ought not be used as a proxy for similar biological work, but that they are potentially an important component of that work should it occur.

Utilitarian stream management
A knowledge of stream geomorphology is an important utilitarian management tool in our river systems. Most active stream management, particularly in more degraded systems, either has the intention of changing the river form or behaviour, or will do so as a side effect of the intervention. Many activities fit both these categories, and the results are often mixed. For example, Erskine evaluated work to treat channel instability between 1954 and 1991 on the Williams River in New South Wales.41 He found that works had actually initiated bed erosion be removing natural gravel armour layers and boulder and log steps. They had damaged the natural structure and habitat diversity in the channel by removing pools either by sedimentation or erosion, removing large woody debris, and extensive bulldozing of the channel to remove bars and create an artificial single thread channel. The works had also planted large numbers of exotic trees in the riparian zone. Outhet et al. described a case also
in New South Wales, where willow removal on 4 km of stream resulted in 3 m of bed degradation that extended for 14 km, the destabilisation of banks, loss of native vegetation and the closure of a bridge. Rutherfurd et al. described the scour effects of instream structures, which may be part of the original design, or may be the cause of structure failure.

Given that fluvial geomorphology is the study of stream form and behaviour, it obviously has much to offer those planning work in or around their streams, whether that work is related to habitat improvement, environmental flows or general river stabilisation. An understanding of geomorphic processes can help plan such activities so that the chance of success is maximised and the risk of unintended side effects is minimised. It can also help identify the most efficient way to get the desired response from the river.

The stream characterisations described in Chapter 7 provide a great deal of useful information for people planning stream works. The regionalisation should help refine such characterisations, and will predict the range of river forms that can potentially occur beyond the presently documented systems. In the absence of further fieldwork, it will allow a rough assessment to be made of these attributes, which can then be tested in the field. This will provide a clearer context for making stream management decisions.

The regionalisation also allows the development of general rules about the types of river behaviour in any one region, which will aid the understanding of site scale issues. The range of river behaviour that is likely to occur depends on broad scale controls on river development. In its simplest form, this means we can say that steeper rivers are more powerful that those with similar flow but gentler gradients. Similarly, alluvial rivers, that are surrounded by a floodplain formed of material transported and deposited by river are able to make large scale changes in channel dimensions and planform, while rivers that are controlled by bedrock are not.

It is possible to go beyond such obvious statements, and use the regionalisation to discuss river behaviour in more individual situations. For example, when a powerful river, transporting a large quantity of cobbles and boulders suffers a decrease in power, the result is often a wandering gravel bed river form. An alluvial river immediately downstream of a very steep bedrock controlled reach with a large sediment supply is one situation where this occurs. Wandering gravel bed reaches have multiple channels as a mechanism for dispersing the load of rocks that must be deposited in this reach, and dispersing the large quantities of flood water that come rushing out of the upstream gorge. The presence of these multiple channels is not a sign that this river is unstable. Rather, it is the natural condition, and efforts to restrict the river to one channel can backfire and cause more erosion. The Meander River downstream of Meander is an example of this type of river (Figure 2). Similar forms are found along the length of the Great Western Tiers, where streams such as the Lake, Liffey, Western Creek, Lobster Rivulet and Mersey tributaries emerge from steep, bedrock controlled reaches of the escarpment onto flat alluvial plains. Their similarities should allow regionalisation into a common type.

A regionalisation based on landscape scale controls on the development of rivers will be able to identify areas where sections of river like those described above may occur. Although it wont be able to accurately prescribe management plans for those sites, it will be able to flag them as sections worthy of closer attention, or areas that may pose difficult management problems. River segments of a similar character, in the same region, will be likely to present similar management issues, and will potentially require similar solutions.
Figure 2. Aerial photograph of the Meander River at Meander, showing a terrace confined reach immediately downstream of the gorge reach, the township of Meander, and the wandering gravel bed reach, which naturally has multiple channels. The river flows towards the top of the page.
How to use this document
This document includes information at a variety of levels. Some chapters are very technical discussions of the methods used and results achieved in this project. Others contain information that will be very useful to anyone who wants a better understanding of why their river looks and behaves the way it does. In particular, Chapter 4 and section 1 of Chapter 6 may be of interest.

Chapter 2 is a brief review of relevant literature on stream classification and characterisation. It discusses the challenges of stream classification, and describes the reasoning behind the selection of the methods used in this project.

Chapter 3 is a brief technical discussion of the methods used.

Chapter 4 describes how the climate and landscape of Tasmania influences river development and character. It also describes the data used as inputs to the regionalisation process. This chapter should be very useful for those who want to understand more about landscapes and rivers.

Chapter 5 is a technical discussion of the GIS techniques used in developing the river regionalisation, and the degree to which they were successful.

Chapter 6 discusses the cumulative effect of landscapes on rivers, both in theory (section 1) and in relation to one case study area (section 2).

Chapter 7 is a discussion of issues arising from field assessments.

Chapter 8 contains conclusions and recommendations for further work.

Appendices 1-6 contain information about data development and present some of the results of the Environmental Domain Analysis.

Appendices 7-9 contain river characterisations for King Island, Birchs Inlet and the upper Macquarie River.

Appendix 10 contains the results of the state wide comparison of river characterisations. Part of this information is presented as a table, and part is presented as an Access database in the attached CD. This CD also includes a map of existing river characterisations in ArcView format.
Chapter 2. River characterisation, classification and regionalisation

Introduction

This is not the first time an attempt has been made to devise a scheme that identifies similar kinds of rivers. Many have been developed around the world. The 1994 review by Gurnell et al. found over 140 papers in the scientific literature that either proposed a river typology, or reviewed the classifications of others, since 1890. If reports to management agencies were included the count would probably be much higher. This chapter discusses why there have been so many attempts at developing a river classification, what form some of those classifications take, and exactly what it is we have attempted to achieve in this project. It is not intended as a comprehensive review of river classification, as such a task is very large and would unnecessarily replicate the work of many others eg.51-55

There are two components to this project. One is the description of the character of individual rivers from field and paper evidence at the scale of individual catchment (classification or characterisation). The other is a search for regional patterns in river character. Knowing these can improve our understanding of rivers at a local scale, and can help extrapolate descriptions of well known rivers to describe the potential character of rivers that have not been visited in the field (regionalisation).

Why is stream classification difficult?

River classification, like any effort to classify the natural environment, is a difficult thing. Rivers do not fall neatly into boxes, for a variety of reasons. Not all aspects of rivers change in the same places, so the boundaries you draw between river types depends on the purpose underlying your classification. There is a continuum of river form, both within individual classes of river and between types as you move downstream. Confusion about the difference between river type and river condition can hopelessly muddle a classification. River form is not always a good predictor of river behaviour, and our understanding of the controls on river behaviour is often superficial and incomplete. All this makes it very difficult to decide where to draw the line between river types, both conceptually and on the ground. Because there are no absolute natural groups, river classifications, like all classifications of the natural environment, are artificial groupings that owe as much to the purpose and preconceptions of the classifier as to the natural features being classified.56 The implications of these points are now discussed in a little more detail.

Not all aspects of the river change in the same places.

Not all components of the river system will change at once. A change in the species of riparian vegetation will not necessarily be accompanied by a change in geomorphology, and there may by a change in instream fauna when neither the geomorphology nor vegetation has altered significantly. As a result, a single classification cannot reflect all aspects of the stream environment. Because of this, the purpose of a classification has an enormous influence on the categories described. Amongst other fundamentals of classification, Mosley lists that the “classification should be designed for a specific purpose”, and that the “differentiating characteristics must be important or relevant to the purpose of classification”. Most existing river classifications are based either on biology, geomorphology or hydrology. The use to which the classification will be put varies from improving scientific understanding, improving management of a resource such as a fishery or water supply, or providing information that can
be used for conservation either by prioritising river types for conservation effort, or monitoring the ‘health’ of the waterways.

It is worth noting that internationally, a significant proportion of the effort that has been made to describe river types has had biological rather than geomorphic goals, even when the classification is based on physical characteristics of the stream (eg.\(^\text{36,57-61}\) and see\(^\text{51}\)). Such classifications will have limited ability to predict geomorphic form or behaviour, because that is not what they were intended to do. Thomson \textit{et al.}’s 2001 work\(^\text{62}\) is one of relatively few attempts to cover the geomorphic and habitat implications of stream features in a single classification scheme.

River classifications have been developed or used in Tasmania for several of these purposes. AusRivas, is used to monitor the health of macroinvertebrate communities in rivers across Australia\(^\text{63}\). This is based on a biological classification of sites on rivers, that allows a condition assessment to be made in order to monitor river health. In 1987, Hughes developed a hydrological classification to aid her work looking at the distribution of aquatic plants throughout the state.\(^\text{64}\) A broadly similar view of hydrology has been produced by Hine and Graham,\(^\text{65}\) in order to predict hydrological response for flood management and water supply. Finally, River styles, a characterisation of stream geomorphology, developed by Gary Brierley and associates of Macquarie University in New South Wales,\(^\text{66,67}\) has been widely applied in Tasmania in the last 3 years. As this report is devoted to the construction of a classification of stream geomorphology, and to the extent possible predict geomorphic behaviour, the discussion from this point will be restricted to classification schemes that at least partly focus on geomorphology.

**There is a great variety of river form within an individual class as well as between classes.**

Many authors have made the observation that rivers do not naturally fall into discrete groups (eg.\(^\text{52,54,56}\)). Although there are easily recognised river types, such as a lowland meandering stream, there is great variability within these categories. For example, Figure 3 shows three meandering rivers in Tasmania. Differences in stream power, and the sediments through which these rivers run means they form quite different landforms, and would behave quite differently in response to disturbance. For example, the fire that could potentially destabilise the Sorell River would have little effect on the geomorphology of the Meander River. This relates to the idea of equifinality. This is the theory that the same geomorphic form can come about as the result of very different geomorphic processes. As a result, river form is not always an easy guide to the processes that created that form, or to how the river will respond to disturbance.\(^\text{68}\)

**The important controls on river form and behaviour change depending on where you are.**

The variables used to differentiate types in a classification should be directly related to the purpose of the classification.\(^\text{54}\) However, river character depends on the complex interactions of many aspects of the environment over time, and so in different areas different levels of different variables need to be incorporated into the classification.\(^\text{61}\) For example, in a steep catchment on the erodible sediments formed from a coarse grained granite in the north east of Tasmania, the amount of rain needed to create a flood that changes the river form may be much less than in a low gradient catchment in western Tasmania where peat and dense vegetation stabilise the river banks.
Figure 3. Three very different examples of meandering lowland streams. Top left: The Sorell River in south west Tasmania is relatively steep and has a single channel with a relatively coarse gravel bed. The river banks are stable partly because they are capped with an erosion resistant peat layer. Bottom left: The Serpentine River, now drowned under the artificial Lake Pedder, was a very low gradient anastomosing (multi channelled) meandering system. C. The Meander River downstream of Deloraine is very low gradient and runs through clay rich floodplains.

Rivers change over time – the difficulty of differentiating between river type and river condition

The difficulty of identifying similar forms of river is increased by the fact that river form changes over time in response to floods and other natural or human induced disturbance. Some changes are almost small and continuous, occurring in response to frequent small floods. The downstream migration of a gravel bar is an example of this. These changes are unlikely to alter the channel form. Other changes are more episodic, and often occur on much larger scales and can dramatically alter channel form. Examples may be the incision of a channel into the surrounding sediments (eg Figure 4), or an avulsion, where the river abandons its old channel and jumps into a new course, or even large scale deposition of sediment (eg Figure 5). Such changes can be sparked by any one or a combination of large floods, human disturbance, or to the crossing of an intrinsic threshold. On the largest time and spatial scale, the whole landscape changes as the climate changes, mountains are eroded, alluvial plains deposited, and sea levels rise and fall. Rivers may take from tens to thousands of years to respond to these landscape scale changes, once they have occurred.

Small changes of channel features, and wholesale change of channel form can both confound stream classifications. A classification of stream type, as separate from an assessment of stream condition, ought to put the same stream into the same category in two consecutive years, even if some disturbance has occurred in between. Similarly, a statewide map of river character would ideally reflect consistent patterns in river character, rather than the intensity of human disturbance. This is especially important if the river classification is to be used to set conservation priorities. If rivers in degraded condition are mistaken for a distinct type of river, then these sites that are likely to be the least valuable from a conservation viewpoint will be treated as having equal worth as rivers in essentially natural condition.
Figure 4. Dunnings Rivulet, a tributary of the Meander River in northern Tasmania. In a very large flood in 1996, erosion massively enlarged the channel. It appears that this was a natural event. Note the person in the centre of the photograph for scale.

Figure 5. These two sections of the St Patricks River at Wombat Plain in north east Tasmania have very different channel form and probably different behaviour in terms of flood frequency and style of channel movement. Left: a deep and stable meandering channel. Right: a wide, shallow sand bed channel that sometimes splits into several channels. The river at this point has an entirely granitoid catchment, which produces large quantities of sand. It appears likely that the lower channel is a response to a disturbance that released a large quantity of sand into the channel. This was most likely forestry activities, but the stream form could also be a response to a natural disturbance such as a very large magnitude flood or fire and flood combination.

Predicting river behaviour is not easy!
As we have just discussed, ideally a stream classification will tell you not only about the present form of the river, but also its potential to change that form. In other words, it should not only tell you about the present form of the river, but also the potential behaviour of the river. However, this ideal is not likely to be easy to achieve. It requires an understanding of the processes that have created the stream form, some of which may no longer be operating. It also requires an understanding of the present day geomorphic processes that maintain that form, and the thresholds where the influence of those processes begins and ends. Finally, it requires knowledge of the likely disturbance regime in the future. For example, the response
of a river to an individual flood depends not only on the size of that flood, but also on the sequence of preceding floods. The art of geomorphic classification rests both on identifying consistency in reach geomorphology, and as importantly, in the history of the environmental controls on that morphology. The lags between changes in environment and the character of the reach must also be taken into account.

Some geomorphologists doubt that our knowledge of stream processes is sufficient to really understand the relationship between disturbance and stream response. “Our current understanding of fluvial systems does not allow for the prediction of the type or magnitude of geomorphic response to a given perturbation”, wrote Miller and Ritter in 1996. In fact, even with a relatively well studied stream and the benefit of hindsight and real data, there is often disagreement about the relationship between disturbance and river channel change. For example, discussion continued for many years over whether the massive damage to the Hunter River in NSW in the floods of the 1950’s was triggered by climate variation or catchment disturbance. The risk of basing a stream classification on our present understanding of stream processes is that where our knowledge is faulty, the classification will also be faulty, and as our understanding changes, the classification will quickly become outmoded. It is therefore important to develop a classification that can be updated as new information becomes available.

However Rosgen points out that there are distinct patterns in the behaviour of different types of rivers in response to different types of disturbance, that have been observed in the historical record. An example might be gully incision into previously unchannelled valley floors, which was widespread after European settlement and has been related to large floods following disturbance of the vegetation on the valley floor. Rather than a prediction of the exact response to an individual event, these patterns can be used to indicate what type of disturbance is likely to cause a change in the river form, and what type of response that is likely to occur. This is a very valuable tool for developing river management that minimises the chance of such detrimental behaviour occurring, and does appear to be a realistic goal for a stream classification system. Even Miller and Ritter agree that “…the best we can currently hope for is to predict the variety of possible responses…” It is also worth pointing out that it is by attempting to form and apply such classifications that the flaws in our present knowledge are found, and this is a valuable way of focussing the attention of researchers.

**Conclusion**

The ideal classification has a clearly defined goal and is carefully targeted to meet that goal. It will differentiate the continuum of stream character to a suitable level for that purpose. It will take into account that different aspects of the environment are important controls on different rivers, and that all rivers can change over time. It will not be distracted from river character by the condition of the river, but will still tell you about the present day river form and behaviour. While some aspects are relatively easy to achieve, the complete ideal classification is obviously a challenge. The spatially nested hierarchical classification designed by Frissell et al. does manage to combine many of these features. Classifying the stream at multiple scales, from the whole catchment down to micro habitats at a centimetre scale, has a variety of benefits. Classification of large areas can be used to narrow down variables used at smaller scales. It allows for different scales of change at different spatial scales, and it also allows the user of the classification to decide which scale of classification is most useful to their purpose.

We will now describe some of the existing approaches to stream classification. These are mostly based at Frissell et al’s segment and reach scales, although some are hierarchical and cover a variety of scales. They follow two general approaches, those that use characteristics of a given section of river as a basis for the classification, and those that attempt to predict river form and behaviour from the surrounding landscape.
**Existing approaches to describing river character from field, aerial photos and map based data**

Around the world there have been a variety of attempts to describe river form and behaviour in some kind of systematic way, based on field observations, remote sensing, historical records and maps. These are sometimes closer to characterisation than classification – that is they are a consistent method of description, rather than a clear structure for assigning rivers to rigidly defined classes.

There has been a great deal of work looking at describing points on the continuum of channel types (e.g.\(^74,75\)), and in correlating these different patterns with variables such as bank material and sediment supply and flow (e.g.\(^76\)). Efforts to improve such classifications, and to extend the range of rivers described continue today (e.g.\(^77,78\)). Classifications such as these are empirical, that is they are based on observations of channel form.

**Figure 6. An example of a classification of river planform, from Kellerhals et al 1976.\(^74\)**

Another classification approach uses statistics to classify large data sets that describe many different river sites. This approach recognises the continuum of channel form. It relies on the large data sets to encompass this variation, and the statistical analysis to find groups of river sites that have many attributes in common. So far, these methods appear to have met with mixed success. Mosley,\(^54\) reported on an attempt to use cluster analysis to classify the geomorphology of the rivers of New Zealand. The analysis revealed 10 major groups, of which four appeared to be meaningful while the remaining clusters “included watercourses which to the geomorphologist or biologists appear quite different.”\(^79\) In the UK, a multivariate classification of rivers based on data collected for the River Habitat Survey was more successful. It defined 11 readily identifiable river types in England and Wales, but had little ability to predict river stability.\(^80,81\) It is not clear how useful this classification would be to river management.\(^82\)

In several countries, characterisations have been developed based on the principle of identifying individual geomorphic features associated with the channel or floodplain, and classifying the river into reaches where similar assemblages of these features occur. Examples of these features include depositional features such as point bars, erosional features such as pools or undercut banks, bedrock outcrops, and floodplain features such as abandoned channels flood chutes or terraces. This procedure can work very well, because the each feature is associated with a stream process that drives the river form, and also the behaviour. For example, a point bar and erosion on the opposite bank is indicative of active meandering.
processes. This approach has been developed to describe streams in Canada, South Africa and Australia.

**The river styles methodology**

The River Styles methodology developed in New South Wales by Brierley and others has been widely used in south eastern Australia, including Tasmania. Because of this, we will discuss it in some depth. The River Styles methodology is a nested hierarchical classification system, that looks at the landscape and rivers at four scales – catchment, landscape units, river styles and geomorphic units. Landscape units are defined in terms of landscape position and morphology. They form large easily recognised features such as a plateau, an escarpment or a lowland plain. River styles are reaches of river that have characteristic channel geometry, planform and assemblages of geomorphic units. Geomorphic units are features of the channel and floodplain that can be related to the processes that produced their form. Examples include point bars, pools, riffles, and terraces. Once river styles are defined, they can be used as a basis for assessing the controls on stream morphology, assessments of condition and likely future behaviour, and prioritisation of stream rehabilitation activities.

Although this classification is described as hierarchical, there is not a rigid relationship between the different scales of analysis. Geomorphic units not only occur within river styles, but also help to define the extent of the style. Also, the same river style can occur within different landscape units. For example, in the Mersey Catchment in northern Tasmania, the meandering gravel bed river style occurs in three of the four landscape units that are found in the catchment.

The river styles methodology is an excellent method for describing the variation in stream geomorphology within a catchment, emphasising the connections between stream reaches and the geomorphic processes that created and maintain stream form. It has been widely used in Tasmania over recent years to provide geomorphic descriptions for Rivercare plans, environmental flow assessments and research. The methodology has been followed with varying degrees of faithfulness and expertise around the state, but has influenced most geomorphic assessments of rivers in the last 4 years. Through this extensive use, several shortcomings have become apparent. These relate to the manner in which river styles are defined and described, and, with particular relevance to this project, the ease with which river styles can be compared between catchments.

Although the river styles methodology does involve the identification of landscape units, the identification of river styles is related to the smaller scale features of channel geometry and planform, and the assemblages of geomorphic units. The wider landscape and its history has little influence on the identification and characterisation of river styles. River styles are typically named for their planform and relationship to alluvium and valley walls (eg partly-confined valley with bedrock controlled discontinuous floodplains). In practice, these characteristics often dominate the identification of river styles, particularly by less experienced operators, or when short time available for field work places greater emphasis on map based interpretation of river styles. This means that it is easy to concentrate on the present day form of the river, and neglect the influence of the wider landscape and geomorphic history. This is unfortunate, because these can be important controls on river behaviour.

For example, a river styles analysis of the St Patricks River in north eastern Tasmania identified two reaches of the partly confined gravel bed river style. These occur at either end of the main floodplain, one upstream of Targa where the river enters the plain, the other near Nunamara, shortly before the river enters the downstream gorge. These two reaches are similar in terms of their planform and their relationship to the valley walls. In both reaches, the river flows first against one side of the valley, then crosses and flows on the other side of
the valley. However, because of the landscape context of these two reaches, there is the potential for quite different behaviour in response to disturbance. The upstream reach at Targa is immediately downstream of 8 km of steep, confined river. It will receive relatively high energy floodwaters, with a high natural sediment load, particularly in terms of the gravel and cobble that travel on the river bed. It will be prone to stripping of the floodplain beside the channel. In contrast, the reach at Nunamara is downstream of a large floodplain. Floodwaters are likely to be slower moving, and the sediment load is likely to be dominated by finer material such as sand silt and clay. This reach may be on the receiving end of large quantities of sediment should the floodplain reaches upstream become unstable.

Figure 7. The ‘Partly confined gravel bed’ river style was identified on the upstream and downstream extremes of the main floodplain on the middle St Patricks River. The second shortcoming relates to the difficulty of comparing river styles analyses between catchments. River styles analyses typically are catchment based, indeed the catchment forms the highest level in the hierarchical structure of the classification. Styles are usually clearly defined with reference to the rest of the catchment, and are used consistently within that catchment. However, relationships with river reaches outside the catchment are often less clear. River style names are more of a description than a classification, and as a result very similar sections of river in different catchments can easily be given different names. Brierley et al. present numerous examples of this. Conversely, very different reaches in different catchments are sometimes given the same name, and this has proved to be more of a problem in Tasmania, possibly because of the comparative diversity of river types found in the state. This is further exacerbated by the lack of emphasis on wider catchment influences and geomorphic history described above.

Headwater streams are a classic example of this. In some catchments (eg the Mersey) the headwaters river style is described as low order streams with relatively steep gradients, that are completely bedrock confined such that no floodplains develop. Sediment storage is limited to gravel and boulder bars. In basalt areas of the catchment, gradients are gentler. In contrast, in the Duck catchment in the north west, the headwater river style is described as low order streams with moderate gradients, that develop thin valley fills with swampy
conditions in lower gradient settings. Defined channel isn't always present, and flows can be subsurface particularly where catchment areas are very small. Clearly, these two stream types are different in terms of stream power, sediment storage, probably also in their potential response to disturbance.

Having said this, it is possible to compare river styles analyses between catchments, if sufficient care is taken to compare not just the river style names but also the detail of the descriptions. Such a regional analysis has been undertaken for the river styles analyses covering catchments of the north coast of New South Wales. This task is also attempted for Tasmanian rivers later in this report.

**Existing approaches to predicting river form and character**

Jensen *et al.*, referring to the work of Lotspeich pointed out that “it is not financially prudent to study every drainage basin individually”. While these authors were speaking about biophysical classification schemes, the comment is equally true when talking about stream geomorphology. For this reason, it is important to devise some method of predicting the geomorphic character of waterways prior to depth field assessments. One way of doing this is to classify or describe the landscape and use this to predict river character. A large portion of this project has been devoted to this goal. While this will by no means render field assessments unnecessary, it will help by predicting the likely issues for stream management, that can then be assessed more carefully in the field. It can also give a larger scale picture of the variation in stream character than can quickly be developed by field assessments, and this can be very important when identifying conservation priorities. Such work should be used as an initial guide only, to set hypotheses and prioritise further research, not be used as a substitute for that work.

Information that is commonly used to make such predictions is typically map based. Topography is the most commonly used, but geology, climate and landscape history are also used by some authors. These factors between them influence the amount of sediment and water delivered the river, as well as the slope and therefore the energy of the river. Some predictive classifications also use characteristics of rivers that can be easily extracted from maps, such as sinuosity or catchment area. A classification that is based purely on the river landscape rather than the characteristics of the rivers, such as Whiting and Bradley’s headwater stream classification, will not be able to predict the present day river form, but rather the range of possible river forms. This is because the present river form depends not only on the controls on the river, but also on the condition of the river. River form can and does change after natural and human induced disturbances such as floods or riparian clearing.

One of the simplest and oldest classifications of river landscapes is that of Davis, who identified three zones, the young, mature and old age zones. This scheme has reappeared in similar forms with the zones renamed headwater, middle order and lowland, or the sediment production zone, transfer zone and deposition zone which has been further developed by a variety of authors including Church. While these schemes are in many ways simplistic, all identify the association between landscape and the character or processes dominating the river. Steep landscapes have steep powerful rivers that are well supplied with sediment from surrounding slopes, transport all but the very coarse parts of that sediment and are heavily influenced by bedrock in the channel. In contrast, low relief areas are long term sediment sinks, where rivers are likely to meander and are dominated by fine sediments.

One of the main limitations of these classifications is the underlying assumption of how the landscape is put together, with high relief area in the headwaters of catchments, grading to broad flat plains near the coast. This is frequently not the case in Australia. The southern part of King Island is an excellent example of a place where the low energy meandering rivers
are found on the plateau that forms the bulk of the island, and the steep high energy reaches often have the largest catchments and occur just upstream of the coast. It is also worth noting that these schemes identify sediment sources and sinks over very long time scales. On management timeframes, the biggest sources of problem sediment are often the long term deposition sites of floodplains and valley fills. Even in lowland areas erosion of these deposits can release huge quantities of sediment into the stream.

In New Zealand, a useful classification of rivers was developed for engineering purposes by Nevins. This classification was based on the lithology of the catchment and position along the longitudinal profile of the river. The geology of New Zealand was grouped into four lithology categories for this classification, based on their erodibility and the type of detritus produced.

Rosgen’s river classification offers a far more detailed analysis of the relationship between landscape and river form and character, for those rivers that occur in western USA. This is a hierarchical classification, which uses landscape and channel features to describe river form and function at the first level of the classification. In particular, it focuses on valley morphology and the presence of hard bedrock or soft sediment in the valley floor, in combination stream slope, planform and number of channels to differentiate 9 broad types of stream form. The classification uses characteristics of the channel, riparian vegetation, sediment movement and hydrology to refine these groups by describing morphology, condition and validating the description. This work does describe easily recognisable river forms. It has been criticised for a lack of theory backing up the geomorphic significance of the boundaries between categories (eg why should the boundary between type 1 and 2 be and entrenchment ratio of x, rather than y or z. It is also criticised for only including those parameters that are important for differentiating stream types in western USA, a comment that is hardly fair given that this is the area where it was developed, but one that should be remembered by anyone contemplating applying this classification in Australia.

If a classification is to be used as a guide to stream behaviour, then the boundaries between different types in the classification need to be meaningful in terms of geomorphic processes, rather than defined for convenience. Whiting and Bradley’s classification system for headwater streams in the Pacific Northwest of the USA is a good example of such a process based classification. This classification divides streams according to thresholds in the processes that mobilise and transport sediment into the stream and through the stream. Using similar principles, Montgomery and Buffington have produced a similar process based classification of channel morphology in steep mountain rivers. Such process based classifications have in theory a greater potential to successfully predict stream response to disturbance, because they are based on the thresholds in the geomorphic processes that formed the streams. However, they are typically produced for well defined small areas and catchment sizes, where the influences on streams will be consistent, and the process thresholds identified uniformly relevant. A detailed process based classification of streams over larger areas, including a range of catchment sizes and landscape influences has not yet appeared, to the authors knowledge.

Approaches to landform and landscape classification in Tasmania

Although little work on river geomorphology has taken place in Tasmania, there have been considerable effort put onto landform and landscape classification for conservation and management purposes. Kiernan’s work on the conservation of karst, glacial and coastal landforms looks at landform diversity a four levels: system controls, landforms, landform contents and human use & aesthetics. System controls are those aspects of the landscape and climate that
influence the genesis of landforms. They are the topography, climate, geology, and geomorphic processes that interact shape the present day landscape.

This concept was developed further by Houshold et al. They produced a georegionalisation of Tasmania based on variation in these system controls across the state, and added the concept of using the history of geomorphic processes. Their hypothesis was that distinct landforms would be produced by different levels of the system controls, and the types of geomorphic processes that have acted on them over long time periods. The amount of detail included in this georegionalisation was limited by a lack of access to GIS technology. The regions were produced using simple overlay techniques. Each system control was represented by categorical variables. For example, topography, was represented by four slope classes: 0-6°, 6-20°, >20° and mountains. Climate was represented by precipitation three classes: <600mm, 600-1400mm, >1400mm. This approach is not ideal, partly because each class includes considerable internal variation, and also because it ignores the potential for interaction between the different system controls. For example, under the dense and long lived rainforest in the wetter areas of the state, steep slopes might be more stable than in the drier, more poorly vegetated areas.

The approaches used in this study

The goals of this project were to aid river management and conservation in Tasmania by providing:

- a context for assessments of conservation value, particularly relating to the geoconservation values of rivers and streams and the identification of the best remnants of those types;
- a basis for identifying template streams that are in excellent condition and are good examples of their type, which can then be used to assess condition of other streams and aid in the design of stream rehabilitation works, and
- a basis for developing regionally specific advice on river management for both conservation and utilitarian goals.

Each of these dot points has similar and related requirements. To develop regionally specific river management guidelines requires both an assessment of stream form and likely response to both natural and artificial disturbances (including stream management activities), and the identification of the region within which one finds similar rivers. Such river regions will also define groups of rivers that would, in good condition, have similar form. In other words, river regions show you the area in which to search for a section of river in excellent condition that can be used as a template for assessing the condition of other sites. Finally, such a regional map provides the context for assessing geoconservation value of rivers. Conservation value is closely related to condition and rarity. It is generally accepted that a site or section of river that is close to pristine condition has high conservation value, and that it is more important if there are few other similar sites in similarly good condition. What is needed to achieve these goals is a method for assessing stream character, and a regional map that shows areas where streams of similar character are found.

Field assessments of stream character broadly followed the River Styles methodology developed by Brierley et al. However, as described above, there are several shortcomings to this method. Firstly, the method tends to put too little emphasis on the wider context of river reaches in terms of both the wider landscape, and the landscape history. Instead, it concentrates on channel geometry, planform and assemblages of geomorphic units. Secondly, it is difficult to achieve a consistent naming of river styles between catchments, particularly where different geomorphologists are making the assessments. Therefore, the field assessment component of this project consisted of two parts:
1. field assessments of rivers around the state that had a greater focus on the temporal and landscape context than that typical of a river styles analysis, and
2. a comparison of the existing river styles analyses, to attempt to develop a consistent set of river styles names around the state.

Identifying a methodology for developing a river region map that would show areas of internally uniform river geomorphology was more difficult, because there was no existing method that focussed on geomorphic rather than biological character and that covered such a large and diverse area. Two possible approaches were to either extrapolate an empirical classification of river character by correlating river types with environmental variables, or to develop a predictive model based on our knowledge of geomorphic processes that control the development and behaviour of rivers. The empirical approach required a large quantity of data. This data could have been a large body of river styles type assessments of river character, or a quantity of site based morphology information that could be used in a multivariate classification of rivers similar to that of Mosely or Clark et al. Neither form of data was available at the start of the project, and is probably still not available in great quantity today. Also, given the limited success of multivariate classification of morphological data elsewhere this method was not considered ideal. Instead, we have developed a predictive model, not of river character itself, but of areas where rivers of similar character are likely to be found. This must be subject to ongoing testing by detailed field characterisation and iterative modification of the predictive model to increase its accuracy.

As described in sections above, predicting river character requires knowledge of what geomorphic processes create that character, and of the important environmental thresholds above and below which different processes operate. For example, Whiting and Bradley identified critical hill slope conditions where debris flows were likely to occur, and typical valley widths above which valley side debris flows were unlikely to reach the river channel. Such knowledge is not available for the myriad of processes that influence rivers across the range of Tasmanian environments. The intensity or likelihood of a process such as landslides does not just relate to one environmental variable, but to the interaction between rainfall intensity, bedrock structure and strength, slope steepness and soil characteristics. This is just one of the processes that can influence sediment supply to waterways.

Rather than focus on important environmental thresholds, we have followed Houshold et al. in mapping the distribution through time and space of critical controls on the fluvial system. We aim to classify the fluvial landscape by finding areas where the system controls (including environmental history) on river development and behaviour are essentially uniform, on the presumption that this will coincide with areas of similar river form and character. To achieve this, we have available to us computing technology that was not available in 1996 when Houshold et al. developed their georegionalisation of Tasmania. Rather than having to rely on paper overlays of the system control data, we have used a GIS technique called Environmental Domain Analysis. This method searches for natural breaks in the values of the system controls, and so finds areas where the environment has low variability, bounded by areas of high variability.

An Environmental Domain Analysis has several benefits over a simple overlay procedure. It avoids the need to translate continuous variables into rigid classes. It also has the ability to identify environments that are similar overall, even though they may differ in terms of some system controls. For example, two large floodplains, on similar sediments and with similar topography, may have essentially the same effect on a river, even though one may be underlain by karst (for example the lower Duck River) and the other by Tertiary lake deposits (for example the lower Meander River). An EDA does not only describe the landscape, but also expresses that landscape’s similarity to all other areas of the state.
Chapter 2. River characterisation, classification and regionalisation

Using the Environmental Domain Analysis, we have developed a spatially hierarchical regionalisation that provides information on the river landscape at three different scales. The river domains identified by this procedure typically occur as small patches, as would be expected for internally uniform areas. These identify individual features in the landscape such as a ridge or valley floor that are typically associated with a particular geology, climate and history of geomorphic processes. Sub regional landscapes occur on a larger scale. They are not internally uniform, but are made up of mosaics of domains, representing a pattern of repeating land features. Finally, at the largest scale are the regional landscapes, within which rivers flow through a similar sequence of subregions from their headwaters to their estuaries. Thus the regionalisation contains information about whole river systems and individual river reaches.

Testing of this regionalisation against field assessments of river character will be very important, for two reasons. Firstly, no information directly relating to river form or river behaviour was included in the development of the regions. The theoretical basis for the regions is that you can predict river character from the system controls we have chosen to represent the surrounding landscape. Secondly, by using an environmental domain analysis to find natural breaks in the system control data, we have avoided by problem of imposing rigid classes on that data. However, changes in river form do not always correspond to changes in the local landscape. In fact, almost all rivers at some point change their character where there is not change in the local environment. The Environmental Domain Analysis will not identify these boundaries. However, it is thought that this problem will occur relatively infrequently because of the diverse nature of Tasmania’s geomorphic system controls and the relatively steep environmental gradients common in this state.

For these reasons the regionalisation must be subject to ongoing testing. It is likely that many years work are required to provide an accurate picture of the diversity of Tasmania’s fluvial landscape. An initial test of the process has been undertaken in the Eastern Tiers, which confirms the general accuracy of the model. However, it also questions the validity of some of the major boundaries of the Environmental Domain Analysis, suggesting improvements to those boundaries. Further work necessary to undertake an ongoing program of stream characterisation and regionalisation is presented in Chapter 8.
Chapter 3. Methods

The Environmental Domain Analysis

Data collection and treatment prior to analysis

The sources of the system control data used as input in the EDA are described in Table 1. The system controls are described in more detail in Chapter 4.

For the purposes of the analysis, continuous variables were standardised to a range of 0-255. Categorical variables were input as binary layers. This involved treating lithostructure as 15 separate binary layers. The final result is a stack of 30 layers to input into the EDA.

Table 1. Sources of system control data used in the Environmental Domain Analysis

<table>
<thead>
<tr>
<th>System control</th>
<th>Type of data</th>
<th>Source of data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lithostructural elements</td>
<td>Categorical</td>
<td>Based on lithostructural elements map was first produced by Duhig et al.&quot;10 at a 1:500,000 scale. Updated using the latest 1:250 000 geology cover of the state, and reviewed with the assistance of Chris Sharples. The category of unconsolidated surficial deposits was split into five types according to the age and the geomorphic processes that deposited the sediment. A table showing the conversion from the 1:250,000 geology map to the lithostructural elements map can be found in Appendix 1.</td>
</tr>
<tr>
<td>Peat process history region</td>
<td>Categorical</td>
<td>Developed for this project, using Kirkpatrick and Dickinson&quot;11 as a base map. Appendix 2 for a table showing the conversion from Kirkpatrick and Dickinson to the peat process region.</td>
</tr>
<tr>
<td>Aeolian process history region</td>
<td>Categorical</td>
<td>Used last glacial aeolian region of Houshold et al.&quot;11 Extended mapping to Bass Strait Islands Extended mapping to Bass Strait Islands, based on data in Land Systems analysis&quot;12,13 and the work of Jennings.&quot;14</td>
</tr>
<tr>
<td>Maximum glaciation process history region</td>
<td>Categorical</td>
<td>Used mapping of Houshold et al.&quot;11</td>
</tr>
<tr>
<td>Last glacial maximum process history region</td>
<td>Categorical</td>
<td>Used mapping of Houshold et al.&quot;11</td>
</tr>
<tr>
<td>Periglacial process region (present day)</td>
<td>Categorical</td>
<td>Used mapping of Houshold et al.&quot;11</td>
</tr>
<tr>
<td>Karst process region (present and historical)</td>
<td>Categorical</td>
<td>Used mapping of Houshold et al.&quot;11 Extended mapping to Bass Strait Islands, based on data in Land Systems analysis&quot;12,13 and Jennings 1959.&quot;14</td>
</tr>
<tr>
<td>Climate data</td>
<td>Continuous</td>
<td>The climatic inputs to this project were calculated by the Bureau of Meteorology. Calculations were based on all the years of record, at all weather stations that have at least 15 years of data. Grids (raster images) were generated from these stations using a 3D ANU spline. The resolution of the data supplied from the bureau was 2.5 kilometres apart from</td>
</tr>
</tbody>
</table>
Chapter 3. Methods

<table>
<thead>
<tr>
<th>Method Description</th>
<th>Type</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>for the maps based on evapotranspiration, where the resolution was 10 km. The data used had been through the Bureau of Meteorology quality control process.</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>• Average annual effective precipitation</td>
<td>Continuous</td>
<td>Calculated by subtracting the average annual areal actual evapotranspiration grid from the average annual precipitation grid. Evapotranspiration data was from the latest model produced by the Bureau of Meteorology and the CRC for Catchment Hydrology. The precipitation grid was resampled so that both grids were at a 10 km scale.</td>
</tr>
<tr>
<td>• C\text{v} effective precipitation</td>
<td>Continuous</td>
<td>Calculated by dividing the standard deviation of annual effective precipitation by the mean effective precipitation</td>
</tr>
<tr>
<td>• Average annual max daily rainfall</td>
<td>Continuous</td>
<td>Calculated by taking an average of the highest daily rainfall total in each year of record. The state wide grid was interpolated from these calculated values. Any accumulated values were excluded from the analysis, and where this meant that a weather station was missing too many values, it was dropped from the analysis.</td>
</tr>
<tr>
<td>• C\text{v} average annual max daily rainfall</td>
<td>Continuous</td>
<td>Calculated by dividing the standard deviation of annual highest daily rainfall by the mean highest daily rainfall</td>
</tr>
<tr>
<td>Topography</td>
<td></td>
<td>Topographic variables were derived from the 200 m Digital Elevation Model for Tasmania. This was developed by the GIS section from spot heights on the 1:100,000 topographic map series.</td>
</tr>
<tr>
<td>• Slope</td>
<td>Continuous</td>
<td>Calculated from 200m DEM, using the algorithm presented in Wood over a 3 by 3 cell window (ie. 600 m square)</td>
</tr>
<tr>
<td>• Relief</td>
<td>Continuous</td>
<td>Calculated from 200m DEM, using a 11 by 11 cell window (ie. 2,200 m square) and subtracting the lowest elevation from the highest elevation in that area.</td>
</tr>
<tr>
<td>• Cross sectional curvature</td>
<td>Continuous</td>
<td>Calculated from 200m DEM, following the algorithm presented in Wood. Because valley confinement is relative to the size of the stream that flows in the valley, cross section curvature was calculated at two scales, a 3 by 3 cell window (ie. 600 m square), and a 15 by 15 cell window (ie. 3,000 m square)</td>
</tr>
<tr>
<td>• Profile curvature</td>
<td>Continuous</td>
<td>Calculated from 200m DEM, following the algorithm presented in Wood, using a 3 by 3 cell window (ie. 600 m square).</td>
</tr>
</tbody>
</table>

The Environmental Domain Analysis

The Environmental Domain Analysis involves three steps: data sampling and rule analysis, Principle Component Analysis and domain definition and mapping. A summary of the method is presented here.

Sampling and rule development

The lithostructural elements map was used to define the region of interest for this analysis, because it was the data layer with the greatest spatial limits. This map covers all areas of the state for which geological mapping at 1:250,000 scale exists. It excludes large waterbodies, including some but not all impoundments. For example, geological data is available for the area covered by Lake Gordon, but not for the area inundated by Lake Pedder.

The land area of the state is represented by a total of 1,672,661 200m grid cells, each of which has an estimated value for each of the 30 input variables. Each cell can be described in terms
Chapter 3. Methods

of its value for each of these inputs. This data set poses two problems. Firstly, some combinations of input data are spatially very common while many others are relatively rare, which raises the possibility that the common features will overwhelm the rare in further analysis. Secondly, the sheer volume of data is orders of magnitude beyond the capacity of the statistical packages required for further analysis. Analysing a sample of the data, rather than the whole data set solved both these problems. This was achieved by developing a set of rules that samples all combinations of system controls values within the region of interest. This rule set, rather than the original cells, then becomes the basis for further analysis. Developing the rule set involved the following steps.

1. randomly select a patch of neighbouring cells
2. formulate a rule that described how these pixels relate to all the system controls. For example, slope = 55-67, cross sectional curvature (3x3) = 200-233, cross sectional curvature (15x15) = 187-215 etc (remember that each system control has been standardised to a range of 0-255).
3. Sample a new patch of cells. If its cells satisfy an existing rule, move on to the next sample. If they do not fit an existing rule, a new rule added to the rule set.
4. Continue sampling patches of pixels until all combinations of system controls that exist in the region of interest are represented by at least one rule.

Rules can be made more or less specific by varying patch size or “stretch”. The more specific the rules are, the more rules are required to describe the state. Patch size refers to the spatial extent of the neighbourhood of each sample location. Stretch refers to the degree to which the continuous system control value-ranges are relaxed. For example, if the slope value at a sample point is 200, a stretch of 10 would write a rule that specifies slope between 190 and 210. Clearly, larger patch sizes and larger stretches result in a smaller number of more general rules needed to describe the whole state. For this analysis, patch size was set at 1 cell, and stretch was, set at 25 (10%). Stretch and patch size were adjusted to produce the most specific rules that resulted in a non-trivial PCA. Categorical variables were not stretched.

Principal component analysis
Once the rule set was completed, a Principal Component Analysis (PCA) was undertaken to extract the major independent axes of variation in the data.

To view the results of the PCA in terms of spatial patterns, the PCA’s transformation matrix was used to calculate the principle component scores for each cell by simply adding the product of the value of each variable for that cell and the PC score for that variable, and dividing by the total number of variables. Once each cell has a score for each principle component, the components can be visualised 3 at a time using remote sensing image analysis (see Peters and Thackway\textsuperscript{10} for an explanation).

Domain mapping
The final step involves forming domains by partitioning the continuous principal component space. The goal here was to divide the principle component space into equally sized portions, to ensure that each domain represented a similar amount of variation. All non-noisy principle components (eigenvalue greater than 0.05) were used.

On the basis of its PCA scores each cell was allocated to its domain and spatially contiguous cells of the same domain type were used to delineate “patches”. Small patches (<= 3 cells) were assigned to whichever spatially neighbouring patch was least dissimilar, based on Euclidean distance in the PCA space.

Relating domains to system controls
To describe the relationship between the unstandardised system controls and the domains, the domain map was intersected with the system control data. The following statistics were
derived from the result: mean, medium, standard deviation, 0, 5\textsuperscript{th}, 95\textsuperscript{th} and 100\textsuperscript{th} percentiles for the continuous system controls, and percent of domain area covered by each categorical system control.

A ‘driller’ program has been developed that will identify for any pixel: the values of the system controls at that point, the distribution of other pixels in that domain, and the level of similarity between that domain and all other domains in the state.

**Landscape scale analysis of domains**

**Sub-regions**

Possibly the most useful information about river landscapes comes from a landscape scale analysis of domains, which identifies areas that are not uniform, but include the same repeating features. We have termed these subregional mosaics. For example, the Midlands includes flat modern floodplains, raised terraces of Tertiary sediments, and low hills of dolerite, basalt or Parmeener Supergroup lithostructure. Each feature is represented by different domains, and the mosaic of these domains identifies the area where this landscape is found.

The method for identifying mosaics involved searching for ‘diagnostic’ domains or combinations of domains. These are domains which only occur in a particular mosaic. Once these are identified, a line drawn around their distribution identifies the extent of the mosaic. For many of these mosaic areas diagnostic sets of domains were relatively easily identified by examining the proportion of each domain found in a mosaic, as compared to its distribution across the whole study area.

**Regions**

Regions consist of groups of catchments where most rivers flow through a similar sequence of sub regions from the headwaters to the coast. This will give the most realistic representation of the local and regional influence of system controls on river character. This process is not yet complete.

**River characterisation**

Methods used to characterise streams in the field broadly followed the approach of Brierley et al.\textsuperscript{66} Office based work included assessments of topographic and geology maps at the largest available scale, aerial photographs including the most recent and earliest available, and production of long profiles. Field assessments followed, covering as much of the length of the river as possible. Field assessments involved the interpretation of inchannel, floodplain and landscape features (mostly analogous to Brierley’s geomorphic units) in terms of their spatial and temporal context. Particular emphasis was placed on understanding the relationship between river form and the landscape scale controls used to develop the regionalisation. The rivers were divided into segments where similar features and relationship to the landscape and environmental history were found based on this field work. The resulting description of segment character was mapped using GIS. These assessments of character amount to a combination of description of river form and hypothesis of the history and processes that lead to that form. Time and money limitations prohibited further investigation of these hypotheses by more detailed mapping of features or dating of river deposits.
State wide analysis of river characterisations.

The state wide analysis of river characterisations involved reviewing all available studies that included a mapped and written assessment of stream geomorphology. These included environmental flow reports, the field studies for this project and Rivercare Plans. River characters were grouped according to slope, and form and materials of river channel, floodplains and valley. The classification of river characters was nested, allowing different levels of classification according to how much information had been included in the source publication. All river segments included in this state wide analysis were included in Appendix 10 as an Access Database and ArcView shapefile.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

This section describes the system controls on Tasmania’s rivers, and also how they have been mapped in order to produce the environmental domain analysis that is the basis of the river regions. System controls are those aspects of the present or past environments that control or have controlled the development and behaviour of river systems. They have the following characteristics.

1. System controls are independent of the river at management timescales. They should reflect those aspects of the landscape that influence the river, rather than features produced by the river itself.

2. System controls should be mapped in a way that reflects the pre-European environment. This river regionalisation is designed to reflect natural river form and character, not patterns of European landuse. Assessing river condition is a different task.

3. Because of the technical requirements of the regionalisation process, it was necessary to present the system controls as continuous data on a 200 m grid across the whole state, rather than as point data. Where the controls have been measured in points, as is the case with climate, interpolation was required to extend these points to the rest of the state.

For this study, the lithostructure (the character and structure of geology), topography, climate and the history of geomorphic processes were considered to be the main controls on the geomorphic development and character of rivers in Tasmania. Other possible controls that were not used include vegetation and geological processes. All of these are discussed below.

The purpose of this section is twofold. It is meant to discuss and justify the variables used to develop and describe the river regions, and also acknowledge influences on rivers that were not used as system controls. But, more importantly, it is also a brief description of the large scale and long term influences on river development and behaviour in Tasmania. It will hopefully be an informative and interesting read for anyone who works in river landscapes in this state.

We must emphasise that the descriptions of the system controls in this section are brief and simple. Entire texts can and have been written on any one of these. This section attempts to describe the range of controls on rivers throughout Tasmania, in a way that is understandable to people without a degree in geology or geomorphology, and in a reasonable number of pages and while maintaining a reasonable level of interest. The information presented is an overview of the far more detailed knowledge of past and present Tasmanian environments.

Lithostructural elements

Geology is often one of the most obvious controls on the character and behaviour of rivers and the wider landscape. It is useful to consider two separate aspects of geology, the large scale structures present in the rocks, and the lithology, or character of the rocks themselves.

Lithology is an important control on rivers and landscapes. The hardness of underlying rock determines how fast a river can erode its landscape. For example, quartzite and phyllite are both common rocks in western Tasmania. The former is very hard, and tends to form high ground, the latter is much softer and tends to form valleys. The way in which different rocks weather and break down influences the detailed shape of the landscape through which the river flows, and the character and quantity of the sediment that the river carries. For example, a river in a granitic landscape will always carry more sand and small gravel than one in a basalt landscape. Rivers in limestone often flow underground through cave systems.
Geological structures include faults, folds, joints and bedding planes. These large scale structures of rocks influence the shape of the landscape, the direction that rivers flow, and the obstacles they must flow past before reaching the sea. Davies described fault and fold structural provinces in Tasmania. Faults are where bedrock has been fractured to considerable depth and the rock has moved along that fracture so that one side is displaced relative to the other. Commonly, one side of the fault is lifted, and the other drops, forming high and low ground respectively, with obvious implications for the direction and character of rivers. Where the bedrock is generally flat lying, as is the case in much of eastern Tasmania, faulting creates a landscape of flat topped mountains and plateaus. The Tamar valley, Western Tiers and Ben Lomond are examples of features initially created by faulting on a very large scale. This kind of geological structure dominates much of eastern Tasmania. In western Tasmania, the landscape is dominated by fold structures. In this case, the rocks have been folded and tilted, and the landscape is one of long mountainous ridges and wide valleys. The different lithology of layers within the rock means that some, like phyllite are soft and erode away to form valleys, leaving hard rocks like quartzite to form ridges. These ridges reflect the direction or ‘strike’ of the underlying folded rock. Large scale strike valleys control the direction of rivers. The Davey, Olga and Franklin Rivers all flow for a part of their length down the same huge strike valley.

Structure and lithology do not always control the form of rivers and landscapes. Raised erosion surfaces are an example of this. They are discussed in ‘Geological processes’, in the ‘Other influences on stream geomorphology’ section of this chapter. Superimposed drainage patterns are another example. This refers to the situation where the direction in which a river flows is inherited from a previous landscape, rather than primarily influenced by the structure of the underlying rocks. The Gordon River is an example of this. The Gordon flows from east to west, against the grain of the underlying folded Precambrian rocks that run roughly north south. Where it cuts through ridges of harder rock such as quartzite, it forms spectacular gorges such as The Splits. One theory to explain why the Gordon flows this way is that it is a superimposed stream. That is, the direction of the Gordon River was determined when the landscape of western Tasmania was very different from today. It may have been covered with dolerite and Parmeener rocks, like the east of the state today, or it may have been a flat erosional plain that was uplifted. As the landscape was gradually eroded to reveal the structures of the underlying quartzite, the river was stuck in its pre-existing valley. It would have maintained its course through the Precambrian rocks by nickpoint retreat. On a smaller scale, this process can be seen in the rivers south of Macquarie Harbour.

It is important to recognise that geology never acts alone to determine the character of rivers and the shape of the landscape. Rather, it is the interaction between particular rock types and other system controls including geomorphic processes that produce the distinct features seen in any landscape. For example, many of the scree slopes that are so characteristic of Tasmania’s high mountains are derived from dolerite. Dolerite has properties that encourage the formation of these features, namely it is a hard rock that typically has a columnar internal structure that allows the rock to be relatively easily broken up into boulders. However, without the periglacial processes of ice wedging apart the dolerite columns, and frost heave moving the boulders down slope, these scree would not occur. In some cases, the history of geomorphic processes prevents geology from influencing the form of the landscape at all. In these cases, you see a flat plain that is underlain by a variety of geological structures and lithology. This is discussed in more detail in the section ‘Other influences on stream geomorphology’.

For this regionalisation, we have adapted the geology maps produced by Mineral Resources Tasmania. The statewide 1:250,000 scale geology map includes almost 1000 different types of geology. This includes lots of information that is not necessary for this state scale river regionalisation. This complicated map was grouped into 16 lithostructural elements, each of which has similar structure and lithology, and therefore a similar effect on how the landscape
has developed. The step from 1000 categories to 16 required making two generalisations. The lithostructural elements are the overarching rock types, such as basalt, whereas most geology maps break these down into different types of basalt (eg. nodular basalt, porphyritic basalt, alkaline basalt and so on). Also, the lithostructural elements are not necessarily divided according to the age of the rocks, as is the case with standard geological mapping. So, the basalt lithostructural element includes basalts from the Triassic and the Tertiary, which are split in standard geology mapping. Similar approaches have been used in other river classifications, such as that of Nevins’ classification of the rivers of New Zealand.\textsuperscript{118}

The lithostructural elements map was first produced by Duhig \textit{et al.}\textsuperscript{110} at a 1:500,000 scale. It has since been used by Houshold \textit{et al.}\textsuperscript{11} as an input to their georegionalisation of Tasmania, and by Sharples\textsuperscript{119} to produce a comprehensive classification of Tasmania’s coastal geomorphology. This map was updated using the latest 1:250 000 geology cover of the state, and reviewed with the assistance of Chris Sharples. Because of the importance of soft sediments in determining the character of rivers, the category of unconsolidated surficial deposits was split into five types, according to the age and the geomorphic processes that deposited the sediment. A table showing the conversion from the 1:250,000 geology map to the lithostructural elements map can be found in Appendix 1.

The following section contains a simple description of the different lithostructural elements, and their effects on landscapes and rivers. Information came from Burrett and Martin\textsuperscript{120} and Fish and Yaxley,\textsuperscript{121} and also from people familiar with the interaction between Tasmania’s geology and river systems. Readers seeking more detailed information could try references such as the recent edition of Behind the Scenery\textsuperscript{122}, Kiernan’s works on geoconservation of various landforms\textsuperscript{24,27,108}, or Sharples’ series of reports on the landforms and geology of various Forestry Districts.\textsuperscript{123-128}

\textbf{Coastal sand and gravel}

Coastal sand and gravel form beaches, sand dunes and sand sheets associated with coastlines. These can have a dramatic effect on the lower sections of rivers. Dunes can dam small streams, so that they end in lagoons, or divert them so that the channel must take a long and tortuous path to the sea (eg\textsuperscript{129}). Figure 8 shows a sand dune in the process of cutting off a small creek on King Island. Sand spits can even divert the mouths of large rivers, and can at times prevent them from reaching the sea at all. Where dunes are made of shell, rather than sand, they are particularly efficient at stealing water from the surface channels, and allowing it to drain underground to the sea.

The coastal sand and gravels mapped here are of Quaternary age (1.8 million years to present). This includes not just the modern dunes and beaches that are developing today, but also the features left from previous interglacials (see the process history section of this chapter for a description of glacial and interglacial climates). Sea levels during the last interglacial were roughly 4 - 6 metres higher than present.\textsuperscript{130} Tasmania has also been slowly lifted out of the sea, so last interglacial shorelines have been found up to 30 m above the present sea level in some places.\textsuperscript{131} The net result of all this is that coastal sand and gravel can be found up to 10’s of kilometres inland in some areas.

\textbf{Coarse slope deposits}

This lithostructural element is made up of various forms of slope deposits (sometimes called colluvium) that includes large rocks and boulders. It includes talus and scree, which refer to accumulations of rock fragments that are found at the base of a cliff, and features such as blockstreams that formed through the action of ice. These features can been seen on the slopes of all the high dolerite mountains in Tasmania. The size of the fragments can vary from gravel to huge boulders, but is usually fairly consistent within any one scree, generally depending on parent material. The terms scree and talus are sometimes used to indicate
whether or not there is soil present between the boulders, but they are used inconsistently, and for the purposes of this project can be considered to be interchangeable.

Figure 8. The valley of Eel Creek, a small stream on King Island in the process of losing an argument with a sand dune. The volume of sand being blown into the creek is far too large for the stream to transport, and the eventual result will probably be a dune barred lagoon or wetland.

Screes are not just found at the base of cliffs. They are also found around any outcrop of bedrock that has been subject to periglacial processes, where ice wedges have split the rock and slowly heaved the fragments down slope. Ice heave can move a block stream a considerable distance from the source of rock, even on almost flat slopes.\textsuperscript{132} Often the slope deposits are made up of many lobes of rocks, creating a slightly stepped profile. The flatter tops of the lobes are more likely to become vegetated than the steep downhill faces.

The size of the rock fragments making up a scree depends partly on the characteristics of the source bed rock. Dolerite is particularly efficient at forming screes of large to very large boulders, because the internal column structure of the rock means that it is easily broken up by ice wedging. Permian rocks are more likely to produce a fine scree, because of the way the rock breaks down. Large screes are also produced by basalt, granitiods, and some well bedded metamorphosed sediments such as quartzite and sandstone.

Slope deposits can have a significant and variable effect on streams. On steep slopes, small streams frequently drain through these deposits, rather than on the surface (eg\textsuperscript{133}). Small streams are rare on scree slopes, and even larger rivers may disappear for a length under a deep field of dolerite boulders. Even very large rivers can run underground through slope deposits. The Blythe River, with a catchment of 173 km\textsuperscript{2} disappears for several kilometres into a mass of huge granite boulders. In other circumstances, lobes of slope deposit may actually dam or divert streams to form marshes or even small lakes.\textsuperscript{134} Finally, these deposits provided much of the sediment that streams transported during glacial conditions.

The area of scree and talus mapped on the 1:250,000 geology maps under represents the actual distribution. This is because where possible, geologists tend to map the underlying bedrock, rather than the Quaternary deposits on top. A useful future project would be to use existing GIS capabilities to develop and field test a model of the distribution of major scree
areas. This could follow the method of Sharples who has done precisely this in the East Florentine Valley.

**Figure 9.** Left: A typical unvegetated dolerite scree on the upper slopes of Great Western Tiers in the valley of the Meander River. Right: This road cutting through a vegetated dolerite scree has exposed an underground channel in the St Pauls River catchment.

**Glacial deposits**

Glaciers covered large areas of Tasmania at various times during the Quaternary, as ice caps and as valley glaciers. Glaciers are able to move large quantities of whatever rock and soil stands in their path, often grinding the rocks into sand and mud. This lithostructural element refers to that debris that has been transported by ice. The area that was eroded by glaciers also affects present day rivers, but this is mapped by the glacial process region. Ice transported debris can be split into two classes: material that remains where it was deposited by ice, and material that was then transported by melt water. The basic difference is that glaciers do not sort the material they transport, so boulders end up mixed with clay, whereas material deposited by water is sorted into areas of different particle sizes.

Material that has been deposited by ice is known as till, and it forms a distinct group of landforms called moraines. Till is usually a combination of fine clay and silt through to cobbles and boulders. It has often been compacted by the weight of the ice. Unless the river is very big, and the till contains only small boulders, it is a very difficult material for rivers to erode. In some ways, till can control the river in the same way that bedrock does. Rivers are instead forced to go over or around these obstacles.

Till gets formed into moraines of different shapes. Ground moraine, hummocky moraine and drumlins are deposited underneath glaciers. They can be mounds that are large enough to force a river to wind a way between the hummocks. Often several hummocks together effectively dam a stream to form a small lake. Lateral moraines are long mounds that formed at the sides of the glacier. They are usually plastered on the valley wall. They can interfere with the course of tributary streams that are trying to reach the valley floor. Many marshes and deranged drainages in the Central Highlands are due to lateral moraines. Terminal and recessional moraines are deposited at the snout of the glacier, either at its maximum extent (terminal) or where the ice paused as it retreated (recessional). These moraines are like low ridges that cross the valley floor. They can dam rivers, and form quite large lakes.
Material that has been moved and deposited by meltwater is known as outwash (sometimes fluvioglacial outwash). It is different to till because it was deposited by running water rather than ice, and that means that running water has a fair chance of eroding it again. Unlike till, it doesn’t act like bedrock. However, under glacial climates, many rivers had much larger floods than they do under the present climate. This means that the glacial age rivers were able to transport rocks that are too big for modern rivers to move. So, whether or not modern rivers will be able to erode outwash gravels depends on the size of the river and the characteristics of the outwash plain that it runs through.

The glacial lithostructural element doesn’t differentiate between moraines and outwash. This is unfortunate, because the two types of deposit have such different effects on rivers. To an extent, this problem can be circumvented by viewing this element in combination with the glacial process regions, which show the maximum extent of moraines. Within the process regions, there will be a mosaic of moraines and outwash deposits, while outside this area there will only be outwash.
Undifferentiated Tertiary and Quaternary Sediments

These gravels, sands and clays of Tertiary or Quaternary age are deposits that have not been attributed to any of the other categories. Most are from the Quaternary (1.8 million years to present), and include some slope deposits, river deposits, swamp, lake and shoreline deposits, and inland windblown sediments. Some are possibly from the Tertiary (65 to 1.8 million years old), but these contain no obvious evidence of their age, and so ought not contain the rock like laterites that are found in more easily identifiable Tertiary deposits. Compared to bedrock, these sediments should all be fairly erodible by today’s rivers. However, they do form a variety of features that interact with rivers in different ways. To an extent, topography can be used to differentiate these deposits.

River deposits include modern floodplains (Figure 12), terraces and alluvial fans. Modern floodplains are gently sloping surfaces close to rivers. They reflect the sediment transported by the river under the present climate, and so can be modified by the river. In contrast, terraces are old abandoned floodplains that are higher than the present river. They were often built under a climate that increased sediment supply to the river, and potentially increased stream power. Terraces are usually more erosion resistant than floodplains, partly because they often contain larger stones, and partly because their greater age means that they are more consolidated. Alluvial fans are quite steeply sloping river deposits that form where a river leaves a steep confined valley and moved onto a wide flat plain. Like terraces, these mostly reflect different climates, and are relatively erosion resistant. The other Tertiary and Quaternary sediment types may also be found in close proximity to the rivers, and will have varying effects from being highly erodible to highly erosion resistant, depending on their local character.

This class of sediments is under-represented on geology maps, and therefore also on the lithostructural elements map that was used in this project. This is because geological mapping is generally focussed on bedrock rather than soft sediments, and so where possible it is the rocks that get mapped, rather than the sediments. Similarly, it appears that at the state wide scale, geologists are not interested in separating the different types of Quaternary deposit. This is particularly true of the older geological mapping, more recent maps tend represent Quaternary deposits in greater detail. However, a program of Quaternary mapping would be invaluable for predicting river behaviour, and for river management. In particular, separating modern floodplains from the other deposits in this category would be valuable. Failing this, existing GIS capabilities could be used to develop and test a model of where floodplains are found. This would greatly improve the ability to predict lowland river types.

Figure 12. Floodplain deposits forming a distinct flat floor in the Serpentine River valley near Bronte.
Tertiary sediments

Tertiary sediments are highly variable in quantity and character around the state. The Tertiary refers to the period of time between 65 and 1.8 million years ago. The thickest sediments of this age found in deep basins formed by faulting in the early Tertiary, and are also associated with basalt flows. Considerable quantities of sediment were deposited during the Tertiary. Their character varies depending on the environment where deposition occurred. The southern part of the Macquarie Graben, south of Macquarie Harbour, is partly filled with large cobbles deposited by high energy gravel bed rivers. The Launceston Tertiary Basin, which runs from Launceston to Ross, is largely filled with lake deposits, although some gravels occur there too.

In general, Tertiary sediments are too young to have turned to hard rock. They can remain almost as erodible as when they were originally deposited, or they can be compacted and slightly more erosion resistant. In places there are rock like layers in the sediments, called hard pans. These occur where certain components of the soil, usually iron, silica or calcium, were mobilised and concentrated into a distinct horizon. There they act like cement, gluing together the rest of the soil into either a rock sheet, or gravel like nodules. The nodules may end up fused together to make a hard lumpy rock. Iron rich hardpans are known as ferricrete, silica rich pans as silcrete, and calcium rich pans as calcrete. Ferricrete and silcrete are most commonly seen near basalt which has protected them from erosion, but also occur elsewhere.\textsuperscript{136,137} Calcretes form in arid to semi-arid conditions, and near some springs. All of these hardpans can be very important local controls on rivers, because they are rock hard in an otherwise erodible environment.

Tertiary sediments are sometimes a focus for mining activity. Some minerals get concentrated in river sediment, so the preserved Tertiary river beds and floodplains are a valuable resource. In the Ringarooma area, Tertiary sediments beneath basalt flows were mined for their tin content, with major implications for the condition of the river (for example, see Knighton’s work on tin mining in the Ringarooma.\textsuperscript{138})

The effect of Tertiary sediments on today’s rivers depends largely on the character of the sediment. Tertiary sediments can be sands and fine gravel that are very easily eroded, cohesive clays that resist erosion, or coarse gravels that can only be moved by high energy rivers. Sometimes, a river will expose highly erodible sediments, and an oversized channel will develop. This is possibly the cause of the huge broadwater pools found on some eastern Tasmanian rivers. In contrast, where rock like hardpans occur, the river will have some of the characteristics of a bedrock controlled river, even though it appears to be surrounded by erodible sediment. The lower Lake River is in part controlled by a hardpan. In very deep sediment deposits, entire river systems may develop free from the influence of bedrock. It is necessary to assess the individual effect of any one deposit on the rivers that run through it.

Figure 13. Left: Ferricrete in Tertiary sediments exposed in a road cutting north of Swansea. Right: A close up of some of the ferricrete.
**Undeformed, largely unfaulted basalt**

Basalt is an igneous rock (a cooled down bit of the earths core). Most of the unfaulted basalts in Tasmania are of Tertiary age (between 59 and 8 million years old), but some date from the Jurassic and Triassic (around 233 million years old). There are older basalts, from the Cambrian and Precambrian (ie older than 510 million years), but they are included in the volcano-sedimentary lithostructural element because the have been faulted and deformed, and do not behave in the same way as the younger basalts.

Basalt flows as lava from volcanos. Lava is liquid, which means that it flows to the lowest point in the landscape – usually a river valley. Because of this, basalt is often underlain by significant depths of river or lake sediments. Basalt often occurs as multiple flows, which can eventually result in rock 100’s of metres deep. Sometimes, other volcanic material or river sediments are deposited between flows, resulting in a layer cake of interbedded basalt and sediments.

Basalt can have dramatic effects on river systems, by filling valleys with a layer of very hard rock. This can form lakes until the river either cuts a path through the basalt, or is diverted down a different path. The most dramatic example of this in Tasmania is the South Esk River near Evandale. There is good evidence that the South Esk once flowed north from Evandale, directly to Launceston. However, a basalt flow just north of Evandale diverted the river to its present course, west and then north through a dolerite valley at Cataract Gorge. There are many other examples of large rivers affected by basalt including the Ringarooma River, and the Mersey and Forth Rivers. Sometimes, the basalt is deep enough to flood out of the river valleys and cover the whole landscape. This has occurred in the north west of the state, in the Hampshire – Guildford region. Rivers have since eroded valleys into this basalt sheet, but these are not related to the pre-basalt topography. This young basalt has very few large scale structures that effect the development of streams, and the drainage networks that develop tend to have dendritically branching valleys.

Like dolerite, basalt can have a columnar internal structure related to the rock fracturing as it cools and shrinks. As well as being very pretty where these columns are exposed, these fractures mean that the rock is quite permeable. So, where basalt occurs up hill of another, less permeable rock, water that has soaked down through the basalt is unable to move through the underlying rock, and instead emerges at the contact as a row of springs.

Very picturesque waterfalls can form at the edges of basalt flows, where rivers can rapidly erode the softer sediments underlying the basalt, creating a scarp capped by rock that is eroded only slowly. These are common in the north west of the state.

![Figure 14. Dip falls, on the Dip River in the north west of Tasmania. Note the columns in the basalt. Photo by Chris Sharples.](image-url)
Basalt weathers to a clayey soil that is prone to mass movement. Where it is mechanically eroded, it will produce cobbles and gravel that can be transported by river.

**Dolerite**

This lithostructural element includes the huge area of Jurassic dolerite that dominates the geology of south eastern Tasmania. It also includes the few large Cretaceous syenite masses that occur in the state that are considered to have lithostructural characteristics comparable to dolerite for the purposes of this project.

Dolerite is an intrusive rock. Like lava that didn’t manage to reach the surface, molten dolerite was injected between layers of other rock in the earth’s crust, and is exposed when the rock on top is eroded. Most dolerite was intruded during the Jurassic, and is around 175 million years old. Because dolerite was commonly intruded between layers of flat lying Parmeener Supergroup rocks, it commonly occurs as flat sheets or gentle domes. It can occur at any level in Parmeener rocks, and frequently occurs at multiple levels, forming a complicated layer cake of sedimentary and intrusive rocks. Dolerite typically has columnar jointing, which is related to the way the molten rock shrank as it cools. This forms the classic Organ Pipes type cliff. Dolerite typically has large scale faults and joints that can exert a strong control on drainage patterns.

Dolerite is harder than the Parmeener Supergroup rocks it is commonly associated with. As a result, it often remains where the softer sedimentary rocks have eroded away. That is why the tops of mountains in south eastern and central Tasmania are so often flat dolerite. This resistance to erosion also means that where a river does cut into a large body of dolerite, it often forms gorges or quite narrow valleys. River reaches that have a wider valley and a large floodplain often occur where the valley has intersected a section of one of the softer sedimentary rocks that underlie the dolerite.

Dolerite eventually weathers down to clay, but before this stage is reached it produces cobbles, gravel and sand sized particles. The cobbles are tough, and may be transported by river a long way from the dolerite source.

![Figure 15. The upper Swan River running over a dolerite step.](image-url)
Flat-lying dominantly arenite/lutite sequences (Parmeener Supergroup)

Simply translated, these are sandstone (arenite), and siltstone and mudstone (lutite) beds that have not been significantly bent, tilted or faulted. This lithostructural element is largely made up of a group of rocks known as the Parmeener Supergroup. These rocks are very common in south eastern Tasmania, but occur almost statewide. Small areas of dolerite and syenite that have intruded the Parmeener rocks are often included in this category, simply because they are too small to map individually.

The Parmeener Supergroup is made up of two main ages of sedimentary rock. Permian rocks (290-245 million years old) are mostly layers of marine siltstones and mudstones. Some beds of Permian mudstone contain enough marine fossils to be considered limestone. On top of these are the Triassic rocks (245-208 million years), which are typically layers of terrestrial sand, silt and mudstones. In areas of high relief, these rocks can make dramatic cliffs.

Parmeener rocks are generally fairly easy to weather and erode, compared to some of the other rocks in the Tasmanian landscape. But, different beds within the Parmeener vary in hardness. This means you often get a stepped landscape, because harder layers resist erosion, and protect the softer rock immediately underneath. When this happens in a stream bed, you get waterfalls or a series of bedrock steps. Russell Falls, in Mount Field National Park, are a dramatic example of this, and there are innumerable small waterfalls of a similar origin.

Parmeener rocks are quite variable in the manner in which they break down and are transported by river. Generally, the rocks are not very hard, and do not survive for long as cobbles and gravel in high energy rivers. The sandstones often break down quite easily into quartz sand, and so streams draining this geology frequently carry large quantities of sand.

This lithostructural element often occurs in close proximity to dolerite, which is more resistant to erosion. Where this is the case, the greater erodibility of the Parmeener rocks creates features such as steep sided flat topped mountains where a dolerite cap protects the soft underlying Parmeener rocks, and enclosed floodplains where a river cutting through dolerite hits a pocket of Parmeener rock and is able to widen its valley.

Figure 16. A distinct step in the landscape above Collinsvale formed on Parmeener sediments. The mountain tops are resistant dolerite, below which extensive slope deposits cover the Parmeener rocks.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

Folded dominantly arenite/lutite sequences (Mathinna and Eldon Groups)
This element translates as sequences of sandstone (arenite), siltstone and mudstone (lutite) that have been tightly folded, so they no longer sit flat in the landscape (this is a good way to tell the difference between this group and the generally flat-lying Parmeener Supergroup). These rocks have also been partly metamorphosed, so some layers are baked hard. The element mainly consists of the Mathinna Group in the north east, and the Eldon and Tiger Groups in the west. The ages of these rocks vary between the Ordovician (starting 510 million years ago) to the Devonian (ending 362.5 million years ago).

Folded rocks have the potential to produce a very distinctive landscape, where less resistant beds are eroded out to form valleys, and more resistant rocks remain, forming ridges. Excellent examples of this are found in other lithostructural elements, particularly the folded quartzite and schist associations in the southwest of the state. However, this lithostructural element is distinctive because it seldom forms strike ridges, particularly in the north east of the state. The component rocks vary quite a lot in character between the mudstones and sandstones, and in the degree of metamorphosis. However, the individual beds are often quite thin, and the whole sequence has been very well squashed together by folding and faulting. As a result, the structures of the rocks are generally too broken up to show up in the landscape like the benches and steps found on the Parmeener Supergroup, or distinctive strike ridges on the folded quartzite. Instead, it tends to produce long thin valleys and steep narrow ridges, particularly in the north east of the state. It forms very erodible stony soils. It produces a full range of sediment sizes, including plenty of flat cobbles and gravel that can be transported by streams.

Figure 17. A digital image of the landscape south east of Tower Hill. The long thin spurs and valleys are formed on Mathinna rocks, and are typical of this lithostructure.

Folded, structurally dismembered sedimentary and volcano-sedimentary sequences.
These rocks are mostly Late Precambrian – Cambrian sequences. They are sedimentary rocks that have been folded and faulted until their original depositional structures are no longer evident – a state that geologists somewhat dramatically refer to as being structurally dismembered. The sediments were originally deposited in troughs in the older Precambrian sediments described below. Volcanic rocks were laid down in these basins, and in the intervening seas shallow water sedimentary rocks were deposited, combining a mixture of material eroded from both surrounding Precambrian sediments and the volcanics themselves.
The result is a range of related volcanics and sediments which stretch in a broad arc from Elliot Bay around the western and northern boundary of the Precambrian quartzites to the Golden Valley area, and north to the coast. A second large area forms the valley walls of the Duck, Montagu and Welcome River karst plains. Another area stretches to the north of Lake Pedder with outliers in the Maydena area. Further small outliers are found on the south coast around New River Lagoon and near Port Davey.

These rocks are relatively easily weathered, leading to well rounded landforms and deep fertile soils, particularly on the volcanics. This group appears prone to forming erosion surfaces (flat plains above sea level, see ‘Geological processes’ later in this chapter) possibly because they are soft enough to form a flat plain, yet still hard enough to resist erosion for some time after uplift. Quartzite residual hills emerge from the plains. Erosion surfaces are particularly well preserved to the south of Macquarie Harbour. Further inland these rocks have been preserved beneath dolerite caprocks and attain considerable relief in the spurs of Mt Dundas and the western flanks of the West Coast Range.

These rocks do not produce significant thicknesses of periglacial slope deposits and, apart from where rare, particularly hard strata are found in patches south of Macquarie Harbour, exert little structural control over stream courses. Streams tend to cut valleys according to the shortest distance to base level. Hence they follow shallow courses radiating from erosional remnants on erosion surfaces, but form deep, v-shaped valleys downstream from major nickpoints, summits of mountain peaks, or downslope of where this unit abuts ranges composed of Precambrian – Ordovician quartzites as commonly occurs throughout its distribution. Streams tend to carry small cobble to pebble sized bedload with a wide variety of lithologies.

![Figure 18. Left. Volcaniclastic sedimentary rocks in the middle Spero River. Right. The valley of the Wanderer River flowing through a gently rolling erosion surface formed in volcano-sedimentary rocks on the west coast of Tasmania (photo by Jason Bradbury).](image)

**Mafic/ultramafic complexes**

These rocks are mostly of Cambrian age. This small lithostructural unit is composed of restricted areas of serpentinite and associated volcano-sediments. They are special in that, whilst they are structurally similar to other rocks in the Cambrian volcano-sediments, they contain a large proportion of magnesium and iron. They were deposited in a similar way to the sedimentary and volcano-sedimentary rocks described above. There are fifteen separate areas of this rock, with units centred south of Macquarie Harbour, in the Rosebery – Savage
River area, the Adamsfield area and in the west Tamar hills. The largest of these units covers an area of only 9 x 7 km to the west of Luina. This lithostructural unit has a dramatic effect on vegetation, because it forms distinctive soils with high levels of some minerals. Relatively little is known about the effect of these rocks on landscape.

The soils resulting from the weathering of mafic and ultramafic rocks produce distinctive vegetation communities, often quite different from surrounding communities. This is likely to have a noticeable effect on stream geomorphology, because of the influence of vegetation on sediment movement and river bank stability. For example in the Heazelwood River area the serpentinite soils are covered in a mixture of stunted heathland and open woodland of Smithton Peppermint. This area has an average annual rainfall of over 2 metres and surrounding more fertile units of the Cambrian volcano-sediments support closed rainforest communities.

The area is susceptible to sheet and gully erosion, particularly following fires. Headwater streams are deeply entrenched and supply medium to fine grained sediments to major rivers. Whether these areas are sufficiently large to exert a significant influence on the form of medium to major streams is as yet unknown.

**Figure 19.** An outcrop of ultramafic rock in the Heazelwood Catchment. Photo by Chris Sharples.

**Folded, dominantly lutite sequences.**
This lithostructural element includes the Lower to Middle Rocky Cape group and correlates. These are folded sedimentary rocks that are dominated by siltstones and mudstones (ie lutite). They are mainly found in the far northwest of the state, in a v-shaped pattern of low to medium hills surrounding the karst basins of the tributaries of the Duck and Welcome Rivers. A second, smaller set of outcrops is found in the area between the flanks of the Jubilee Range and the Middle Huon Valley. They are the same age as the Precambrian quartzites and schists described below, but are nowhere near as hard. This is because the folding, faulting and heating which created them was far less intense.

Because these rocks are easier to weather and erode than neighbouring quartzites, hills are far more rounded, strike ridges and associated gorges are not as pronounced, and soils are deeper. Erosion surfaces are well preserved in the northwest, with residual hills composed of quartzite outcrops (such as the Norfolk Range) remaining as emergents. These rocks and landforms developed on them bear some similarity to those of the folded dominantly
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

arenite/lutite sequences of the Mathinna and Eldon groups. They produce similar deep, well bedded slope deposits composed of angular pebble to cobble sized fragments. However, they lack the harder, more quartz rich beds of the Mathinna and Eldon Groups, resulting in a generally more rounded landscape. This unit also hosts a series of north-south trending basalt-dolerite dykes which may locally steepen topography and produce small gorges on medium sized streams.

Headwater streams take the form of either low gradient, plateau reaches on remnant surfaces, or steeper reaches cutting into plateaus or remnant ridges. Where they are incised into bedded slope deposits, local slope instability is common, and stream bank erosion may be pronounced. Medium sized streams tend to be strike controlled, carving NE/SW trending valleys into erosion surfaces. The larger rivers cut across the grain of the country, taking the shortest, steepest route to the sea on the west coast.

Because of the closely spaced joints and obvious bedding in these rocks, a strong periglacial history and lack of glaciation in the past, most of the material carried by streams is relatively small in size, although the diverse makeup of the different beds produces a wide range of attractively coloured cobbles and pebbles on point bars.

Figure 20. The Rocky Cape group at Rocky Cape. Photo by Chris Sharples

Folded, quartzite/schist associations and quartzose clastic sequences.

This group includes the Precambrian quartzites and quartzite/schist associations, Owen Group conglomerates, and the Upper Rocky Cape Group. These rocks form the crests of the magnificent mountain ranges of southwest Tasmania. They are metamorphosed sedimentary rocks that are dominated by quartz. Quartzites are metamorphosed sandstone, schists are rocks that easily spit into slabs or flakes, and quartzose clastic sequences are metamorphosed conglomerate.

Hard and relatively dense, these relatively strongly altered rocks resist weathering and erosion. Where they are steeply dipping, strike ridges are found where the hardest quartzite units have resisted erosion best. The broad arc of the Arthur and Frankland Ranges, and parallel ranges such as the Prince of Wales Range, the Spires and the Denison Range contain the sources of streams which flow in the broad parallel valleys, through softer schistose units of this lithostructural type. Alternatively, very large rivers flow through near-vertical walled gorges such as the Gordon Splits, which traverse them at right angles (see the introductory
Discussion to this section). The hardness of these rocks is displayed in the steepness of these east-west gorge sections, which have resisted slope processes for millions of years.

These rocks are also found running south from Rocky Cape along one of Tasmania’s major structural lineaments – the Arthur lineament – which separates them from relatively unmetamorphosed Precambrian sedimentary rocks of the far northwest. A second ‘branch’ of this structure arcs northeast around the Central Plateau through Mt Roland and the Gog Range, ending just west of Golden Valley. This high strike ridge, composed of Ordovician conglomerates similar to those of the West Coast Range, separates the karstic basins of Mole Creek and Meander from the Tertiary basin of the middle Meander Valley. Isolated exposures of this unit are found north of the Meander almost as far east as the Tamar estuary. This unit also abuts the relatively unaltered Precambrian sequences along the north-south axis of King Island.

These rocks appear to have been exposed through the removal of overlying Parmeener Supergroup and dolerite sequences through the action of glaciers and powerful west flowing rivers such as the Gordon and Franklin. The strong precipitation gradient across Tasmania, combined with the increasing elevation of the unconformity between the two rock types has accelerated stripping of the caprock in the west of the state.

These rocks have been subjected to glacial and periglacial weathering and erosion since the mid Tertiary. Glaciers have carved alpine cirques in the higher ranges, although over deepened valleys are rare. Today’s headwater streams occupy these glacial valleys where waterfalls into cirque headwalls and over hanging valleys are common. Periglacial action has produced extensive slope deposits and alluvial fans, although grainsize is much smaller than equivalent dolerite screes of eastern Tasmania, due to the much finer jointing pattern in the bedrock. Streams still flow underground through the uppermost of these periglacial systems, although not as spectacularly as in dolerite. Where the deposits converge into alluvial fans streams anastomose over the surface, although most fans in the southwest are relatively stable today.

These rocks form very thin, highly infertile mineral soils. This, combined with their resistance to weathering, has contributed to the formation of blanket bog peats on all but the steepest of slopes in lower elevations, derived primarily from decomposed heathland plants. These peat soils have a distinctive effect on stream type (see the section on the peat process history).

Figure 21. The view towards Frenchmans Cap from Donaghys Hill near the Lyell Highway. This landscape consists almost entirely of folded quartzite and schist associations.
Carbonate rocks

The carbonate rocks include limestone, dolomite and magnesite of various ages. The youngest are spring deposits and aeolian limestones dating from this and the previous interglacial periods. The oldest are Precambrian dolomites and magnesite, older than 570 million years. In between are Cainozoic freshwater limestones (65 million to 10,000 years), Tertiary marine limestones (65 – 1.8 million years old), Permian limestone (290 – 245 million years old), Palaeozoic limestones (510 – 362.5 million years old) and Cambrian dolomite (570 – 510 million years old).

Limestone, dolomite and magnesite are similar rocks that contain slightly different mixes of similar minerals. Limestone is largely calcium carbonate, dolomite is a mix of calcium and magnesium carbonates, and magnesite is almost pure magnesium carbonate. Carbonates are soluble, which means that they will dissolve in acidic water. Most soil waters are slightly acid, particularly those that have lots of organic material. Features such as caves that are produced by solution are called karst features. Limestone dissolves faster than dolomite, but dolomite and even magnesite will dissolve in the very acidic water that has drained through the peaty soils of western Tasmania.

The solubility of carbonate rocks means that the landscape shapes that they form are developed more by the removal of rock underground by chemical solution, rather than the mechanical erosion of rock and soil at the surface of the landscape, which dominates the development of landscape shape in other geologies. In Tasmania, karst landscapes typically form fairly flat plains and valley floors, sometimes in combination with very steep valley walls where the top of the ridge is protected by an insoluble rock type. Sink holes may be a common feature in the carbonate lithostructural element. These are places where the ground has subsided, leaving a closed depression in the ground surface. On these flat plains, the carbonate bedrock is often covered by soils and river deposits. This is why the karst process region is so much larger than the actual area of carbonate rock on the lithostructural element map.

Carbonate bedrock has an influence on streams beyond its affect on the surface landscape. This is its tendency to steal water into cave systems, and to deliver water back to the surface via springs. Which of these occurs depends on where you are in the landscape, and on how much it has been raining. Water can enter the cave system in a discrete place, through a stream sink. Sometimes a blind valley develops at this point, and the river pours into a cave at the foot of a cliff. In other cases, the river valley continues past the sink hole, and there may even be a dry channel that is used during large floods. Alternatively, water can just gradually be lost through the stream bed, resulting in smaller and smaller flows as you move downstream. Similarly, water may be returned to the surface stream through a large discrete spring, or may just seep back up through the stream bed. Sometimes, caves will cross surface drainage divides, so that a stream that starts life in one catchment will be diverted through a cave into a neighbouring catchment. For example, the Junee Cave system takes water from the Florentine valley to the Tyenna.

Karst aquifers themselves form a distinct type of stream system. Where there are well developed cave systems, you get a ‘river with a roof’. Where this happens, you get most of the normal river processes of sediment transport and deposition, all happening underground and without the influence of vegetation. However, there does not have to be a large cave for water to flow underground. Sometimes a river will filter through coarse debris where caves have collapsed, or through tiny pore holes in the rock, where no large cave has formed.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

Figure 22. Left: The Weld River emerges from the Weld River Arch. Right: A stream sink in a blind valley at Mole Creek.

Granitoids

This category includes all Tasmanian occurrences of granite type rocks. They range in age from Devonian (408.5 - 362.5 million years old), Cambrian (570 - 510 million years) to Precambrian (older than 570 million years). Like dolerite and basalt, these rocks are igneous (cooled down bits of the earth’s core) rather than sedimentary in origin. Most of the granite type rocks are made up of coarse grains of quartz and other minerals.

Granitoids do not have a fine internal structure like the beds found in rocks of sedimentary origin. However, they do usually have widely spaced joints or fractures. These joints tend to form the granite into large blocks. Joints are important at controlling how fast the rock weathers, because water gets in along the cracks. A body of granite with many fractures will weather faster than one with very few. On a large scale, joint patterns can affect the shape of the stream network. Granite with widely spaced joints will have lots of outcropping rock, and a strong joint control on the streams. This will give a very rectangular form to the stream network. Granite with many closely spaced joints will be much more evenly weathered, and the stream network will have a more dendritic form.

Granitoids have a way of weathering that is very distinctive. Unlike many rocks of sedimentary origin, granitoids do not tend to produce many rock fragments (adamellite is an exception to this). Instead, large boulders weather slowly and thoroughly from the outside. Many of the minerals present in the rock break down to make clay, but the quartz grains are tough and don’t change. The result is usually a clay and sand or gravel mass, depending on the size of the quartz grains in the granite. Weathered granite is usually very erodible. This produces very distinctive sand bed streams. The clay fraction often ends up deposited in very low energy river environments.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

Figure 23. This distinctive sand in the bed of the Ringarooma River reflects the large area of granite in the catchment. Much of the sand in this river has been mobilised by tin mining.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

Climate
Climate controls the development and behaviour of rivers through its influence on hydrology and vegetation. For this project, we have concentrated on finding variables that reflect the influence of climate on stream hydrology. Hydrology is the pattern and quantity of water flow in a river. This is important for the geomorphology, as well as for water supply to towns and irrigators, and the fish and other inhabitants of river. It is particularly important for the geomorphology of alluvial rivers, where the channel is surrounded by erodible sediments. Here, hydrology is one of the chief controls on channel size, in-channel features such as bars and pools, and channel planform and migration rate.75

The importance of the flow regime is particularly evident once it has changed. In Tasmania, regulated flows associated with hydro dams and interbasin transfers of water that have increased flows have been associated with bank erosion and channel enlargement on the Gordon River144 and Brumbys Creek.145 On the Mersey River, greatly reduced flows downstream of Parangana Dam have lead to channel contraction, where vegetation and sediment accumulate in the channel and are not removed by floods.146 On the Coal River, flow regulation for irrigation has associated with limited bed erosion immediately below the dam, and channel contraction further downstream.147 In contrast, on the lower Derwent River there has been relatively little response to flow regulation.148 Some work has already been done investigating hydrological regions in Tasmania.64,65,149,150

Having said how important hydrology is, it may seem strange that this section is headed ‘climate’, which is an indirect way of identifying patterns in river flow. There several reasons why climate is more appropriate than hydrology for use as a system control.

Hydrology depends not only on patterns of rainfall and evaporation, but on the size and shape of the catchment that gathers that water and delivers it to the stream, on the underlying geology, on the vegetation that intercepts the water and transpires some of it, and on the character of the stream channel itself. Even within the same river region, two streams with different catchment sizes will have distinctly different hydrology. Hydrology is not independent of the river character.

Hydrology is also not independent of river condition. Over a large portion of the state, there have been changes to river condition that impact on hydrology. This includes some extreme changes, such as Hydro schemes that divert almost all the flow from one river into another, as has happened with the Mersey and Forth Rivers. More subtle but far more widespread changes are brought about by catchment clearing and river improvements such as levee construction, channel straightening and desnagging, which change flood depth and duration. River regions should reflect the natural distribution of river types, not patterns of European landuse. There is very little available hydrological data that is not effected by changes to the landscape since European settlement.

Finally, the method used to define river regions requires data that covers the whole state. Hydrological data is inherently site based, with each data series reflecting the hydrology of a single river at a single point on its course. Because hydrology depends on characteristics of the river and catchment, as well as climate, it is difficult to extrapolate from those points to the wider catchment, and the state as a whole. For example, Hine and Graham65 found that several of his catchments that were represented by one gauge included several gauged subcatchments that had been incorporated in Hughes study,64 and had fallen into separate groups in her classification.

These problems are all avoided by using climatic data as a surrogate for hydrology. Patterns of rainfall and evaporation are independent of river character and condition. Although
climate is now changing, these changes have so far been relatively small,\textsuperscript{151} and despite the decline in Tasmania’s rainfall in the 1970’s and 80’s, there is there is not yet any long term trend of rainfall change.\textsuperscript{152} Long term climate averages are therefore the best approximation available of pre-European conditions. The techniques for extrapolating those patterns across the rest of the state are well established, so the data can be produced in a form that is sympathetic to the regionalisation procedure. Climatic variables were designed to reflect the hydrological and geomorphological processes thought to be important drivers of river character.

The climatic inputs to this project were calculated by the Bureau of Meteorology. Calculations were based on all the years of record, at all weather stations that have at least 15 years of data. Grids (raster images) were generated from these stations using a 3D ANU spline. The resolution of the data supplied from the bureau was 2.5 kilometres apart from for the maps based on evapotranspiration, where the resolution was 10 km.

**Average annual effective precipitation**

Effective precipitation is the difference between the amount of water that arrives as rain or other precipitation, and the amount that is lost to evaporation and transpiration by plants. It indicates how wet an area is, and is used here as an indicator of annual stream discharge. It will also be generally indicative of the density of natural vegetation. Average annual effective precipitation was calculated by subtracting the average annual areal actual evapotranspiration grid from the average annual precipitation grid. Evapotranspiration data was from the latest model produced by the Bureau of Meteorology and the CRC for Catchment Hydrology.\textsuperscript{115} The precipitation grid was resampled so that both grids were at a 10 km scale.

**Coefficient of variation (C_v) of average monthly effective precipitation**

This statistic is really just a measure of seasonality – the difference between wet and dry seasons. It is calculated by comparing the average effective precipitation for each month of the year. In areas with pronounced seasonality, there will be distinctly wet months and distinctly dry months, and the C_v will be high. Where rainfall is not seasonal, each month will have a similar average effective precipitation and the C_v will be low. The coefficient of variation is calculated by dividing the standard deviation by the mean. This means that it is dimensionless – the variation is expressed as a proportion of the mean.

The variation in stream base flow has implications for what geomorphic processes get a chance to work on the stream bed and banks, how vegetation gets established on the banks, and for the channel dimensions and features within the channel. In highly seasonal areas, effective precipitation varies greatly between months, so will the base flow of the rivers. Channel capacity will be relatively large for the annual discharge, because the bulk of the water flows in only part of the year (note that channel capacity also depends on flood variability, which the next two climatic variables attempt to cover). Vegetation may have a chance to get established in the channel during the low flow period. Also, when the stream bed is dry, the geomorphic processes related to rivers will obviously stop, but this allows a different set of processes to work on the bed and banks. These subaerial (in air) processes include frost heave, desiccation cracking, rain splash, and animal damage. There is a brief discussion of these processes in Rutherfurd \textit{et al.}\textsuperscript{153}

Where effective precipitation remains fairly constant throughout the year, a large portion of the stream bed is likely to remain covered by water throughout the year. There will be little opportunity for sub-aerial processes to work on the bed and banks. The channel can be relatively small for its average discharge, because that discharge is distributed evenly throughout the year.
Average annual highest daily rainfall

This measure is used as an indicator of the size of the average annual flood. The annual flood was chosen because it is in the range of flows that are thought to transport the most sediment, over a long period of time. This harks back to the work of Wolman and Miller, who pointed out that although very big floods transport a lot of sediment, they happen very rarely, and flows that are very frequent are so small that they carry very little sediment. It is the moderate sized floods, that occur with moderate frequency, that do the most work over a long period, and so are responsible for maintaining the channel. These are sometimes called the channel forming flows. According to conventional theory, these flows typically just fill the channel, and usually occur every one or two years. This rule seems to work moderately well, but only when it is applied to alluvial rivers that are in equilibrium with their hydrology. In some cases, such as the swamp forests found in the north west of the state, vegetation is so effective at trapping and stabilising sediment that the channel capacity is very small and bankfull floods occur much more frequently than once every one or two years. Conversely, sometimes erosion will enlarge a channel, and bankfull flows will be very rare. However, in north east Tasmania, Knighton found that bankfull flows had a recurrence interval between 1.1 and 2 years.

It ought to be acknowledged that the highest daily rainfall statistic was chosen largely for the pragmatic reason that it is possible to calculate it from the available rainfall data. It is not without flaws. Firstly, channel forming flows are not that easy to pin down. In regions where flows are very consistent, bankfull flows do occur every one or two years. But, in regions where the climate is more variable, as is the case in Australia, bankfull flows are less frequent. Also, it is a vast simplification to say that only one flood size is responsible for maintaining channel dimensions. In reality, a range of flood sizes do this. Finally, using the maximum rainfall in one day as an indicator of flood size ignores the importance of the preceding conditions. Severe flooding is often caused by more than one day of rain. However, despite these failings, this measure still picks up the variation in rainfall patterns across the state, and so is still useful in the production of river regions at that scale.

Average annual highest daily rainfall was calculated by taking an average of the highest daily rainfall total in each year of record. The state wide grid was interpolated from these calculated values. Missing data and accumulated data (when several days of rain accumulates in the gauge before reading) can be a problem when making calculations of extreme events. Any accumulated values were excluded from the analysis, and where this meant that a weather station was missing too many values, it was dropped from the analysis. The data used had been through the Bureau of Meteorology quality control process.

Coefficient of variation of the average annual highest daily rainfall

This is a measure of the variability in annual flood size. In other words, a measure of the chance of a flood occurring that is many times the size of the annual flood. In low variability climates, the one in 10 year flood will not be too much bigger than the annual flood, but in highly variable climates, it will be much bigger. Australia as a whole has a highly variable climate. Generally, drier climates are more variable, and this pattern does hold for Tasmanian rivers. The size of rare floods is geomorphically important because they can cause catastrophic changes to the river channel and surrounding landscape (eg). Under variable climates, the annual flood is much smaller than the bank full flood, because the size of the channel is influenced by the frequency of relatively large floods.

Coefficient of variation of the average annual highest daily rainfall was calculated by dividing the standard deviation of annual highest daily rainfall by the mean highest daily rainfall.
Desirable but unachievable climatic variables

One aspect of climate that affects hydrology that we have not yet discussed is snow. Where lots of snow falls, this has the potential to influence the hydrology of downstream rivers. Flood peaks can be smoothed out, when a large dump of snow melts over a prolonged period. Alternatively, when a considerable depth of snow melts quickly, as may happen when the weather changes and relatively warm rain falls, floods can be considerably larger that would otherwise be the case. Unfortunately, it is very difficult to design a weather station to record the quantity of water falling as snow, and as a result this data has almost never been collected in Tasmania. As a result, snowfall has been left out of this analysis.

Geomorphic process history regions

Geomorphic processes are the mechanisms that shape the landscape out of the available geology and topography, with the available climate. In terrestrial systems, they include the work of running water, standing water, ice, vegetation and wind. Fluvial (running water) processes dominate the present day landscape. Different processes produce different features in the landscape – wind produces sand dunes and deflation hollows; ice, depending on its form, produces periglacial scree or glacial moraine (these terms are described below). It is important to map the areas where different processes have been operating, because the features that they produce interact with rivers to form reaches with distinct character and behaviour.

All geomorphic processes are affected by climate, and this has fluctuated widely between glacial and interglacials over the last 2 million years. During that time, most of the processes that we are interested in have changed in extent or intensity. These changes influenced the rivers, and the effects are the effects of these changes on rivers are still evident in the landscape today.157

During glacial periods, the climate was colder, drier and windier, with less vegetation.158 In response glaciers developed in Tasmania, and periglacial processes (related to repeated freezing and thawing of ice) were far more extensive and intense. Sea levels were up to 120 m lower than present, because of the quantity of water locked up in the large ice caps. Evidence for the windy and sparsely vegetated conditions can be found in the many aeolian features dating from this time. Overall, the climate was drier, but it was also more seasonal. This means that although the average discharge of rivers would have been lower, seasonal floods would have been bigger, leading to larger river channels that would have carried more sediment and been able to move larger particles (eg159,160). This would have been particularly important for those rivers receiving melt water from glaciers and snow. As a response to the harsh climate, vegetation was much sparser, with forests disappearing from much of south eastern Australia and being replaced by grassland or bare surfaces. This sparse vegetation means that erosion of soil and sediment would have been relatively easy, even away from the influence of glacial or periglacial ice.

As the climate warmed up in the interglacials, glacial ice melted and periglacial activity decreased in intensity and extent. Sea levels rose. The climate became wetter, vegetation cover increased, and forests were re-established. Peat developed where conditions were suitable. The wind was no longer strong enough to build inland sand dunes, particularly in the face of increasing vegetation that stabilised sand sources. The sediment supply to rivers reduced, and their stability increased as seasonal floods reduced in size, and vegetation stabilised the banks.161

Changes in these geomorphic processes led to changes in river character and behaviour. For example, when periglacial processes ceased the sediment load entering rivers from hillsides decreased. In general, rivers stopped depositing sediment in their floodplain reaches, and
instead some eroded those floodplains to form the terraces that are so common today. Much smaller active floodplains are now being deposited between these terraces. However, it is important to realise that the geomorphic processes associated with glacial climates have not stopped completely. Periglacial processes, for example, still occur at high altitude today, and are possibly still an important source of sediment for rivers such as the Meander. It is also important to recognise that many rivers are still responding to the changes in geomorphic processes, and will continue to slowly change their form over very long time scales.

Figure 24. Terraces on the lower Styx River at Bushy Park. The pasture in the foreground is an abandoned floodplain, several metres higher than the modern floodplain that is used to grow hops.

The process history maps used in this project were first developed for the georegionalisation of Houshold et al.\textsuperscript{11} This mapping was done using the available published data, and an expert panel of people familiar with the products of these geomorphic processes. For this project, these maps were digitised, and where necessary were extended to cover King and Flinders Islands. The peat map was developed for this project.

The area affected by most important and universal of Tasmania’s geomorphological processes has not been mapped. This is the area where fluvial (river) processes have been operating. These processes have had a huge influence on the Tasmanian landscape, and obviously have a direct influence on the rivers of today. However, as these processes have affected all of Tasmania, a map of the fluvial process region would simply be a map of the state, and would be of little help in an attempt to investigate the variation in river character within the state.

\textbf{Last Glaciation (15-22 thousand years ago)}

In Tasmania, the most recent glaciation probably began in earnest some 25 thousand years ago, and reached its peak intensity at roughly 19 thousand years. Glaciers persisted at high altitude until around 10 thousand years ago\textsuperscript{162}. Colhoun \textit{et al.}\textsuperscript{162} includes a basic description of the glaciated areas around the state. At the peak of the glaciation, there was an ice cap over the western part of the Central Plateau, and a small cap on the West Coast Range. Numerous valley glaciers were fed by these ice caps, and by other local sources of ice. Other cirques and valley glaciers were found on high peaks through the south west and east of the state.

The topography and the deposits left by glaciers are often beyond the ability of rivers to modify, particularly in the short time since the ice retreated. Ice erodes by abrasion and
plucking of bedrock. Fish and Yaxely\textsuperscript{121} give a good description of the landforms associated with glaciation in Tasmania, although their comments on the ages and extent of glaciation are now out of date. A more up to date description can be found in Kiernan (1990)\textsuperscript{163}

Valley glaciers leave wide valleys with flat floors. In places, the valley floor might be over deepened, and a lake forms in the depression. Cirque lakes are one example of this. Where a glacier cuts a very deep valley, smaller tributary valleys can be left high up the valley wall once the ice has gone, and so form waterfalls. These are called hanging valleys. Valhalla Creek falls over a hanging valley where it joins the Broad River.\textsuperscript{121} Eventually, the ice deposits the material it has eroded. This material is called till, and the deposits are called moraines. Till is are made up of sediment from clay to very large boulders, although this does depend partly on the bedrock geology.\textsuperscript{164} Because of the frequency of boulders, and because they are often very compacted by the force of the ice, moraines are very hard for today’s rivers to erode. Lateral moraines form along the sides of valley glaciers. They are usually found on the valley walls. Tributary streams trying to reach the valley floor can be diverted by lateral moraines, and forced to run parallel to the main valley until they breach the moraine. End moraines are deposited in front of the glacier, either at the farthest point that it reached (terminal moraine), or where it paused as it retreated (recessional moraines). End moraines can be 10’s to 100’s of metres high.\textsuperscript{162} These moraines can stretch right across a valley, damming the modern river and forming a lake. Often, the lake has filled with sediment, leaving a very low gradient swampy plain, followed by a steep section where the river cascades down the face of the moraine.

![Figure 25. Recessional moraines across the floor of the Broad River Valley downstream of Lake Webster. The river runs from left to right, and is forced to detour around the moraines.](image)

Ice caps leave somewhat different traces. These are very large areas of thick ice formed on a fairly flat topography, although there may be some mountain peaks protruding. The ice spreads out under its own weight. Rather than carving deep valleys, an ice cap scrapes the whole plateau back to bedrock, and creates a confusing undulating bedrock topography that reflects both the direction of ice movement, and the structure of the underlying bedrock.\textsuperscript{162} Once the ice has gone, this landscape is covered with small lakes and streams. In the depositional areas towards the edges of the ice cap, large areas of areas of hummocky moraine are deposited. This also forms many small lakes. Sometimes an ice cap will leave large terminal moraines, which can dam rivers to form quite large lakes.

The geomorphic influence of glacial ice is not restricted to the area that was ice covered. Glaciers, particularly the more active ones, produce large quantities of water and sediment
that modify landscapes downstream by producing outwash plains. These areas are not included in the glacial process region, but they are included in the glacial deposits lithostructural element.

Figure 26. A myriad of small and very small lakes just north of Lake Pillans on the Central Plateau. These lakes are the result of ice scour of bedrock or the damming of drainage lines by moraine.

Maximum Pleistocene glaciation (> 780 thousand years ago)

Through the Pleistocene (1.8 million years to 10,000 years ago) there have been multiple periods of glaciation. The erosion and deposition related to the latest glaciation is obviously freshest, however, earlier glaciations covered more extensive areas of the state and were responsible for creating many of the glacial landscape feature that are still seen today. The glaciation with the maximum extent of ice has been dated at older than 780 thousand years ago. The features produced have been modified over the millennia by other geomorphic processes, particularly periglacial processes. Old moraines have more rounded crests, outwash plains have been dissected, individual large grains in the moraines have been weathered, and there is soil development in the deposits.

Despite modification, these old glacial features can still operate as controls on river systems in a similar to the young glacial features. For this reason, the area affected by glacial ice during this maximum glaciation has been used to indicate where there is the potential for glacial features to influence river systems. The boundaries of this glaciation are often unclear in the landscape, because of the weathered nature of the deposits. Where the boundaries could not be based on field evidence, they were interpolated by an expert panel.

Periglacial processes

Periglacial processes are those that are driven by the freezing and thawing of ice, which can be a strong enough force to crack rock and move huge boulders. They occur in cold climate areas that are not actually covered by a glacier. This means that periglacial processes dominate the landscape on the slopes surrounding glaciers, and on the mountains that stick up above the glacial ice. They also occur in far milder climates, including many areas of
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

Tasmania today, but are limited to moving fine grained sediment rather than car sized boulders.

Many different features are developed at least partly by periglacial processes. Of these, the most important in terms of their influence on modern rivers are those deposits dominated by loosely packed boulders, including rock glaciers, block streams and fields, screees and solifluction deposits. Sometimes finer sediments form a soil between the boulders, and the deposit is vegetated. In other cases, the rocks are bare, either because the soil has never been present (for example the boulders at the bottom of the cliff), or because the soil has been eroded. Such deposits can be very deep, particularly on dolerite slopes where the jointing of the bedrock and the tendency for corestones to remain in weathered material, provide large quantities of rocks. The exact processes that formed these deposits vary, but it seems that ice plays a roll in all. Certainly, the features consisting of very large boulders are effectively inactive under the present climate, although they may be reworked on a small scale by landslides. The few dates available suggest that the large block streams were either formed or were added to during the last glaciation. These are often mapped as talus and scree on geology maps and on the lithostructural elements map used in this project.

The effect of boulder sized periglacial deposits on rivers can be striking. In some cases, the boulders act like bedrock valley walls and spurs, because the local streams are unable to move such large material. In other circumstances, these deposits act quite differently to their parent bedrock. Because the deposits are to some degree formed of loosely packed boulders, they are quite permeable, and there is a tendency for a large portion of stream flow to be subterranean. This is particularly marked on steep dolerite slopes, where small catchment streams are often entirely subterranean (eg), and an examination of the 1:25,000 scale topographic maps reveal that these slopes are usually devoid of small stream valleys.

![Figure 27. A block stream of periglacial origin confining the North West Bay River on Mount Wellington. The river has managed to carve a shallow, gorge like valley through the block stream.](image)

These coarse periglacial features are all relics of glacial climates. During the last glaciation, there is evidence that periglacial activity extended down to what is now sea level. For this reason, Household et al. considered that all of Tasmania was influenced by periglacial processes during the last glaciation, so no map was produced. However, there was still variation in the type and intensity of periglacial processes. Conditions of boulder moving intensity were restricted to higher altitudes. A map of the affected areas would be very valuable to this project, but these deposits have not been comprehensively mapped around the
state. The distribution of these features depends not just on altitude, but also geology, topography and climate. Solifluction deposits are found mainly above 500 m asl, but do extend as low as 350 m in places.\(^{160}\) There is the potential to model the distribution of these deposits, however this was beyond the scope of this project.

Periglacial processes do occur today at high altitude. However, under today’s climate, these processes move gravel and soil, rather than boulders. Frost heave is caused by the growth of needle ice just below the surface of unvegetated soil. As the ice melts, the crumbs of soil move slightly down slope. This process can eventually move enough soil and rock to form small lobes and terraces on gentle slopes.\(^{160}\) However, a more important effect is that frost heave prepares the soil surface for erosion by other processes, and has been found to be the cause of high rates of bank erosion in a canal on the Central Plateau.\(^{170}\) Areas affected by frost heave are moist bare soils that get sufficiently cold for the formation of needle ice. This can occur at quite low altitudes, particularly in areas affected by cold air drainage, but mostly occurs at higher altitudes, particularly on high plateaus.\(^{164}\) Terraces formed by frost heave have been observed as low as 850 m asl.\(^{160}\) However, the intensity increases with altitude, and an arbitrary limit of 1000 m was chosen to map the area potentially affected by the more intense active frost heave.

**Aeolian processes**

The erosion, transport and deposition of sediments by wind are aeolian processes. They occur in coastal and inland environments where there are strong winds and available sediment. Under today’s climate, the development of aeolian features is restricted to coastal areas, but under glacial conditions such features also formed inland.

Coastal dunes come in a variety of forms. Most beaches will have a fore dune which runs parallel to the beach. Often there is a series of old foredunes inland of the active foredune, forming a series of more or less parallel ridges. On very windy beaches (like most on the west coast) parabolic dune fields may form. These coastal aeolian features are related to the present climate. In many places, there are also relic coastal dunes that formed during the last interglacial. These are similar to modern dunes, but have a more gentle topography, and better developed soil profiles.

Coastal dunes can control the direction and long profile of rivers in their last reaches before the estuary. By blocking the path of rivers, coastal dunes can create extensive wetlands and even lakes (eq.\(^ {129}\)). These effects are particularly evident on small to medium sized streams.

Inland aeolian features found in Tasmania include deflation basins, lunettes, sand sheets, and longitudinal dunes. An account of how these features form, and their occurrence in Tasmania can be found in Dixon\(^ {105}\) but a very brief description follows here. Deflation basins are depressions that have been created by wind erosion of sand and clay. Lunettes are the crescent shaped dunes that are often found on the down wind side of deflation basins. They can have a large clay component. Sand sheets, as their name suggests, are layers of sand centimetres to metres deep. They may include low dunes, but are often fairly featureless. Longitudinal dunes are long fairly parallel ridges of sand that are aligned with the dominant wind direction. Sandsheets, deflation basins and associated lunettes are found in the Central Plateau, Midlands, the northeast and southeast of Tasmania.\(^ {105,171}\) Longitudinal dunes are restricted to the north, where they occur on the coastal plain.\(^ {105,123}\) They are considered inland dunes, because at the time of their formation, low sea levels had exposed Bass Strait as a low sandy plain.\(^ {123}\)

None of these features are now active in Tasmania, except where they have been heavily disturbed by present land use.\(^ {105}\) They are relics of a previous climate. Around the world, an
increase in the area of land subject to aeolian activity was associated with the arid windy and cold conditions of last glacial maximum.\textsuperscript{172}

The effect of inland aeolian features on rivers varies depending on the feature. Deflation basins and lunettes require seasonally wet condition to form. The water can be supplied by the distributary systems of rivers. This appears to be the case with the several deflation basins and accompanying lunettes on the Wye River alluvial fan (Figure 28). Occasionally a deflation basin can form on the main stream of a river. Lake Tiberias, in the headwaters of the Jordan River, is an example of this. Important wetlands have developed in the stabilised deflation hollows.

![Figure 28. A deflation hollow (dark area) and lunette on the south east side. This wetland is fed by a distributary of the Wye River. The deflation hollow is around 1.25 km long.](image)

Sand sheets are the most widespread of the inland aeolian features, and are frequently found very close to major Midlands rivers in their alluvial reaches, because river sediments are a common source for the sand.\textsuperscript{105} There is potential for sand sheets to effect the degree of confinement of the floodplain, and to influence channel migration rates. However, the effect is probably quite similar to that of a low alluvial terrace. A distinct form of river resulting from interaction with sand sheets has not been observed in Tasmania.

The longitudinal dunes in the northeast have more influence on waterways. Larger rivers cut their way through the dune field with little difficulty, but smaller streams are diverted by the parallel ridges. This has created a striking drainage pattern, that is easily visible on the 1:100,000 scape topographic maps.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

**Figure 29.** Small streams that are controlled by longitudinal dunes are obvious on this 1:100,000 scale map. Dune crests are marked. Map from Dixon 1997.

The aeolian process region map includes the areas where glacial age aeolian features are found, and also some large coastal dunefields on the Bass Strait Islands, that were formed during this and the previous interglacial. This mapping could be improved by splitting these aeolian features into the last interglacial, last glacial and Holocene ages, and by including a more comprehensive mapping of coastal aeolian features. To some extent, this information is included in the coastal lithostructural element.

**Peat**

Officially defined, peat is a soil where at least the top 30 cm is at least 20% organic matter. For this project peat is considered to be a soil that is dominated by organic matter. Peat forms where the plant remains accumulate, usually because rotting is slowed by some combination of waterlogging, low temperatures and low nutrients. Where conditions are sufficiently wet, such as in much of western Tasmania, peat is not restricted to topographic depressions, but blankets the landscape. Peat is far more common in Tasmania than in the rest of Australia. However, compared to the rest of the world, much of the peat in Tasmania is very shallow. Peat has several special properties that make it an important control on rivers. Although these have not yet been quantified in Australia, they can be described based on overseas studies and local observations.

The mechanical properties of peat in the stream bank will influence the form of the channel, and probably also the rate of channel migration. The resistance of bank material to erosion has a strong influence on the channel cross section (width and depth) and sinuosity. Channels with easily erodible sandy banks are wide and shallow, and channels with cohesive erosion resistant banks are relatively narrow and deep with steep banks. The peat found in the widespread buttongrass moorlands is a very cohesive substance and the dense root network that is often found in those moorlands adds to this effect. Peat found in sphagnum bogs or forest may be slightly different. General observation, and some published literature, suggests that peaty streams are relatively narrow and deep (eg), and are often highly sinuous. It seems likely that channel migration rates would be extremely slow in such material. These effects are likely to be particularly marked where the peat is sufficiently deep to form the channel bed, as well as banks. Except with very small streams, this is seldom the case in Tasmania. Where the river erodes inorganic sediments underlying the erosion resistant peat, the banks may retreat by mass failure of the peat horizon. The detached blocks of peat may be washed a considerable distance downstream. A further effect on stream morphology is tunnelling. Pipes are common in peat in the UK, and it is likely that they are also common in Tasmanian.
Figure 30. Erosion resistant peat in the upper part of the bank of the Spero River, south of Macquarie Harbour.

A peaty catchment can also affect stream form and behaviour. Peat can have a marked effect on stream hydrology although this does not appear to have been quantified in Australia (see the climate section above for a discussion on why hydrology is important). Peat is adept at holding on to water, and releasing it slowly. As a result, flood peaks in streams with peat catchments happen longer after the peak rainfall, are lower and last longer than flood peaks in similar catchments, with have similar rainfall but no peat (for example see Conway and Millar.\textsuperscript{176}) It is likely that damage to the peat surface, such as by fire, would temporarily reduce the hydrological influence.

In Tasmania, peat forming vegetation includes buttongrass moorland, sphagnum bogs, and some forests.\textsuperscript{177} Buttongrass moorland provides by far the most extensive area of peat. The map of the peat process region used in this analysis is based on the pre-European vegetation map of Kirkpatrick and Dickinson.\textsuperscript{111} It includes combinations of rainforest types and geology that are likely to produce significant depths of highly organic soils.\textsuperscript{178} Because of this broad definition of peat used in this project, and the scale of the source map, it is likely that this peat layer significantly overestimates the area of strictly defined peat soils in Tasmania. See Appendix 2 for a table showing the conversion from Kirkpatrick and Dickinson\textsuperscript{111} to the peat process region.

Karst processes

Karst refers to landforms resulting from the dissolution of rock by water. Many rock types can be partly dissolved, but this mostly happens very slowly and is accompanied by similar or greater rates of rock breakdown by mechanical or other chemical processes. Karst is the dominant process of landscape development on the most soluble of rocks, the carbonates. Given this straightforward link, it is not surprising that there is a basic similarity between this process region, and the carbonate element of the lithostructure map. However, the karst process region is much larger. This is because the lithostructure map shows where carbonate rocks occur at or near the surface of the landscape, while the karst region reflects all areas that have been effected by karst processes. Because carbonate rocks are so easy to dissolve, they often form low points in the landscape, and this means there is a tendency for the rock to be
covered by sediments delivered from rivers, surrounding hillsides, and any insoluble parts of the carbonate rock. So in many karst areas, the carbonate rocks are hidden from view.

Unlike the other process regions, karst development is not restricted to a particular time in the history of the landscape. Carbonate rocks will dissolve whenever they are exposed to slightly acid water. The karst regions of Tasmania would have been developing for as long as groundwater has had access to the rocks. However, the rate of development is likely to have varied as climate has changed. It is likely that the rate of solution was reduced during glacials. Under the cold dry climate, there would have been less runoff into the karst, and decreased plant activity would have lead to lower acid concentrations. Also, many pre-existing caves were filled with sediment derived from surrounding hillslopes, returning streamflow to the surface. However, in some locations, meltwater from glaciers appears to have increased rates of cave development.\(^{179}\)

The effect of carbonate bedrock on surface rivers is to steal water into cave systems, and to deliver water back to the surface via springs. Which of these occurs depends on where you are in the landscape, and on how much it has been raining. Water can enter the cave system in a discrete place, through a sink. Sometimes a blind valley develops at this point, and the river pours into a cave at the foot of a cliff. In other cases, the river valley continues past the sink hole, and there may even be a dry channel that is used during large floods. Alternatively, water can just gradually be lost through the stream bed, resulting in smaller and smaller flows as you move downstream. Similarly, water may be returned to the surface stream through a large discrete spring, or may just seep back up through the stream bed.

![Image](image-url)

**Figure 31.** The Salisbury River in southern Tasmania, flows over a dolerite plateau underlain by limestone. At Vanishing Falls, the river flows over the edge of the dolerite sill and drains straight into a cave system in the limestone. The channel downstream of the plunge pool flows only during floods. Photo by Rolan Eberhard.

Where there are well developed cave systems, you get a ‘river with a roof’. Where this happens, you get most of the normal river processes of sediment transport and deposition, all happening underground (although without the influence of vegetation!). There does not have to be a well defined river for water to disappear underground. Sometimes water will filter through coarse debris where caves have collapsed, or through tiny pore holes in the rock, where no large cave has formed.
The karst process region roughly corresponds to merged categories A and B karst and obscured karst in the Tasmanian Karst Atlas.\textsuperscript{24,25} This includes the intensely and substantially karstified areas of the state, and excludes partly and possibly karstified areas. An updated version of the Karst Atlas maps now exists, and in future work categories A and B karst and obscured karst from this version should be used as the karst process region.

**Topography**

The shape of the landscape has a huge influence on stream form and behaviour, as well as most other geomorphic processes. Landscape shape is a major control on the type and rate of processes that supply sediment to rivers, and on stream power, (which reflects the river’s ability to pick up and transport sediment). Over many millions of years, topography does change in response to geological and geomorphic process, but certainly at shorter timescales of tens to hundreds of thousands of years topography is fairly constant in Tasmania. It is a major influence on large scale patterns of areas of net erosion (eg steep rocky valleys) and deposition (eg floodplains). It can also be used to identify areas where geomorphic processes have dominated over lithostructure in shaping the landscape. In order to represent topography numerically, you have to consider individual components of landscape shape, and the role they play in determining the rate and magnitude of geomorphic processes.

Whiting and Bradley\textsuperscript{97} used this approach to develop a process based classification system for headwater streams in the Pacific Northwest of the USA. They used knowledge of the relationship between various geomorphic processes and topography, specifically the gradient of hill slopes, channel slopes, and valley width. Combining this information with channel and sediment characteristics, they defined stream types in terms of the role of geomorphic processes such as debris flows erosion and deposition zones on hill sides and in the valley floor.

For this project, we follow a similar approach to Whiting and Bradley. However, instead of focussing on the geomorphic processes that are relevant to headwater streams, we need to encompass the range of processes that influence streams of all sizes throughout Tasmania. Pragmatically, we were limited to data that could be calculated from a Digital Elevation Model (DEM) with 200 m cells. At this scale, measures of topography characterise the landscape, not the river system. For example, when referring to slope, we mean the slope over 600 m of hillside, (based on a minimum 3x3 pixel window in the DEM), not the slope that you might measure by surveying a particular point on a stream.

**Slope and Relief**

The slope of stream channels is one of the four things that influences stream power, the others being the dimensions of the channel, the roughness of the channel, and the amount of water. Stream power determines the calibre and the total amount of sediment that the stream can transport. Large scale patterns of erosion and deposition can be linked to changes in stream power as you move from steep to gently sloping reaches. Stream slope is one of the most universal variables used to describe river systems in the geomorphic literature.

Slope is also important outside of the stream channel. It influences the quantity and type of sediment produced on the valley sides. Geology and soil development being equal, gentle slopes will deliver only a small flow of relatively fine sediment, carried by slope wash and soil creep. On steep slopes, these processes will be able to move more and coarser material, and landslides and debris flows are more likely to occur.

Relief refers to the difference in elevation between the highest and lowest point in an area. Like slope, it is a measure of the energy available to move sediment around the landscape.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

However, while slope is a precise measure of local energy, relief is usually used as a much broader scale measure, indicative of the energy available in whole regions or catchments.

Slope was calculated using a 3 by 3 cell window (ie. 600 m square), using the algorithm presented in Wood. Relief was calculated using a 11 by 11 cell window (ie. 2,200 m square) and subtracting the lowest elevation from the highest elevation in that area.

**Valley confinement**

How closely the valley confines the river channel is also an important control on both stream power and sediment supply. A narrow valley confines flood waters and makes the flood deeper than it would otherwise be. For the same volume of water, a narrow deep channel will generally flow faster and so be more powerful than a wide shallow flow. The variation in valley confinement along a river is also important. Where a very narrow valley occurs just downstream of a large floodplain, it will act like a bottle neck and cause a backwater to develop on the floodplain.

Valley confinement is also an important control on sediment supply to the stream. Much sediment movement is actually on the relatively steep hill slopes that surround the valley floor. Wide areas of flat floodplain can act as an effective trap, which prevent that sediment from ever reaching the stream. In a confined valley setting, a stream is likely to pick up any sediment supplied from hillslopes, while in a wide valley that sediment will be stored on the floodplain margins.

Valley confinement has to be described relative to the size of the stream running through the valley. A valley width that confines a large river would not confine a small creek.

Valley confinement is represented in this regionalisation by measurements of cross section curvature. This was calculated following the algorithm presented in Wood. Because valley confinement is relative to the size of the stream that flows in the valley, cross section curvature was calculated at two scales, a 3 by 3 cell window (ie. 600 m square), and a 15 by 15 cell window (ie. 3,000 m square). The smaller window size identifies narrow valleys, that would confine all but the smallest streams. The larger window identifies larger valleys. Small streams would be unconfined in a valley identified by this window size, but big rivers would still show some effects of valley confinement.

**Breaks of slope**

Places where slope dramatically increases or decreases are important geomorphically. The former are areas of erosion. An extreme example is the very edge of the Great Western Tiers, where ice heave of individual rocks and the occasional landslide contribute to the slow retreat of the cliff. The latter are areas of deposition, and the toe of the Western Tiers is an example of this. The rocks that have been eroded from the very steep slopes above get deposited here. The landscape does not have to be this dramatic to create this pattern of deposition and erosion. Breaks of slope were measured using profile curvature, as described by Wood, using a 3 by 3 cell window (ie. 600 m square).

**Other influences on stream geomorphology**

The sections above described what we consider to be the main system controls on the development of stream systems. However, they are by no means the only influences. Vegetation, for example, is an important control on river form and behaviour. Geological processes such as uplift and earthquake subsidence have had recognisable effects in some areas of the state. Here we briefly address some other influences on streams, and discuss why they were not used as system controls in the development of this regionalisation.
Vegetation

Riparian vegetation is an obvious control on the form and behaviour of rivers. This influence is greatest on alluvial rivers, which are able to erode their bed and banks and so adjust their form, and least on bedrock controlled rivers that have a very limited capacity to adjust their form. Riparian vegetation influences the amount of energy the stream has to erode and transport sediment, and also the resistance of deposited sediment to erosion. On a catchment scale, vegetation influences the amount of rainfall that gets to the stream channel, and so influences stream hydrology.

The influence of riparian vegetation on the form and behaviour of stream channels has been the subject of a huge quantity of investigation, which has been reviewed by Hickin. Hickin identified a variety of mechanisms by which vegetation influences streams, the most important of which in the Tasmanian context are channel roughness, bank strength and woody debris. These effects depend partly on the size of the stream. Vegetation makes channels rougher, which increases resistance to flow. This means the water flows more slowly, reducing the energy available to erode and transport sediment. This can result in greater depths of slow moving water in the channel, for the same discharge (for example see). Vegetation increases the strength of stream banks, and in some cases stream beds, mainly by reinforcing the sediment with roots. This increase in bank strength can produce channels that are narrow relative to their depth (eg) although this is complicated by the production of large woody debris and vegetation growing on the stream bed rather than banks. Where vegetation grows in the channel bed, it can focus erosion on the banks, and create a relatively wide channel. Vegetation reinforcing riverbanks can also slow the rate of bank migration, sometimes to almost negligible rates (eg). Large woody debris, fallen from riparian vegetation, can stabilise banks or cause erosion, depending on its position in the stream. Generally, woody debris acts as a source of roughness that may cause local erosion but generally slows the flow, so decreasing stream power. It also stabilises stream beds.

Three categories of vegetation are strikingly efficient at influencing stream form. These are peat forming vegetation, very old riparian rainforest, and swamp forest. Dense riparian rainforest can be very effective at stabilising river banks, and because the forest is so long lived (huon pine can live for thousands of years), they enforce that stability over very long times. There is the potential for the forms of rivers lined by such vegetation to reflect the control of the vegetation, rather than the present character of the catchment. Swamp forests have a distinctive effect on rivers because they consist of plants that can grow in the channel as well as on the banks. They form dense stands, which are very effective at trapping and stabilising sediment in the channel and on the floodplain. As a result, the stream channel can be very small for the catchment area, and overbank floods will happen for a large portion of most years. Peat is addressed above in the process history section.

It is clear that vegetation has many important effects on stream geomorphology. However, it has not been included as a system control on rivers in this regionalisation. There are two reasons for this, one based on our theoretical understanding of system controls, and the other on the pragmatics of data availability. Firstly, system controls should be independent of the character and condition of the river, at least on management time scales. Although vegetation has a marked influence on the stream geomorphology, it is also plain that geomorphology has a distinct influence on the vegetation, by providing habitats and disturbance regimes. This lack of a clear independent role in controlling stream development and behaviour detracts from the value of vegetation as a system control. However, it was a pragmatic consideration that ruled out using vegetation in this project. Because the goals of the project are related to the conservation of natural streams, it is important that the data used to develop the regionalisation reflects the natural condition of the landscape, which we have taken to be the pre-European condition. However, data on pre-European vegetation is sketchy at best, and is not of a scale that is useful for mapping variation in riparian vegetation. Also, it is the
structure of the vegetation that determines its geomorphic effect, rather than the species. The stream is affected by the distribution and stiffness of the above ground parts of vegetation, and the distribution and strength of the roots. What information exists about natural vegetation is almost all in terms of the species present, rather than the structure of the vegetation community.

Figure 32. This swamp forest on the Welcome River is so effective at slowing water and controlling erosion of the sandy soil that it forces the river to flow in multiple small channels. Without the vegetation, there would probably be a single deep channel here.

Geological processes
Geological processes have been very important in shaping the landscape of Tasmania. Tectonics and volcanism were widespread during the early to mid Tertiary, and were a major control on the development on the present Tasmanian landscape. Volcanic activity during the Tertiary deposited large quantities of basalt in river valleys around the state. The effects of basalt on river systems have been discussed in the lithostructure section of this chapter. Uplift and down faulting have created much of the large scale patterns on mountains and valleys in eastern Tasmania. One distinctive effect is that flat plains (also called erosion surfaces), which may be underlain by a variety of lithostructural elements and are essentially a lowland feature, were raised to higher elevations. During uplift, some surfaces were disrupted by faulting, whilst others remained relatively intact. Being uplifted gives rivers the energy to erode valleys through the plain, but this is a very slow process. The result is an elevated flat landscape that reflects the history of erosion at base level (either sea level or some other control such as highly resistant strata impeding stream incision), rather than the present day potential for a steep landscape with forms reflecting the variety of lithostructure. Streams on that flat surface will have many similarities to streams on coastal plains. The Mathinna Plains are the remnants of such an erosion surface that has been largely removed by erosion from the headwaters of the South Esk River.
Chapter 4. What are the geomorphic controls on Tasmania’s rivers?

Figure 33. A slope map of the Mathinna Plains, with dark shades indicating steep slope, and pale shades close to flat. The northern part of Ben Lomond can be seen in the lower left corner. The peaks of Ben Nevis, Mt Saddleback, Mt Victoria and Mt Albert rise from the Mathinna Surface. The headwaters of the South Esk River in the south east, and the North Esk River to the north have deeply dissected this surface. The area shown is roughly 46 km from east to west.

Figure 34. A view of the Mathinna Plains erosion surface from Mount Maurice (the top left corner of Figure 33).

Not all flat surfaces elevated above sea level are raised erosion surfaces. Flat lying geology like dolerite or the Parmeener Supergroup rocks can also form a flat plain at any altitude. Where a plain is underlain by multiple lithostructural units, it suggests the flat surface is a true erosion surface. However, where a single geology type, particularly one that has a tendency to produce flat landscapes underlies a plain, it is very hard to tell what combination of lithostructure or process history are responsible.

Because of the widespread large scale uplift during the early and middle Tertiary, there are many examples of raised erosion surfaces in Tasmania. However, small tectonic movements
continue to occur. For example, the area south of Birchs Inlet has been lifted around 300 metres, probably very late in the Tertiary. In response, the rivers have incised, leaving a series of terraces cut into the uplifted landscape. The most recent uplift has occurred since the last interglacial, some 125,000 years ago. Parts of Tasmania have been uplifted between 10 and 30 m.\textsuperscript{131} Evidence for this comes from beach features and sea shells that are well above the present day sea level. This uplift has had a distinct effect on the coastal sections of many rivers, particularly those in the north of the state. Here, gently sloping coastal plains and the shallow nature of Bass Strait mean that this small uplift exposed a considerable area of land, and so considerably increased the length of already flat and low energy rivers. These rivers have responded to the uplift by eroding a valley through the old coastal plain. This incision has formed the terraces that can be seen on the last kilometres of many northern rivers, from the Welcome River to the Ringarooma.

Figure 35. These huge flights of terraces on the Sorrel River, south of Birchs Inlet are a result of the complex relationship between uplift, river incision and river capture.

Another result of relatively recent tectonics is the Lake Edgar Fault Scarp, south west of the original Lake Pedder. The scarp is 5 – 8 m high, and has dammed several tributaries of the Huon River to form Lake Edgar and numerous small ponds.\textsuperscript{121} This feature is relatively small. Although a small part of the fault scarp is still visible, Lake Edgar and most if not all of the smaller ponds have been drowned by the enlarged Lake Pedder.

These geological processes were not included in the river regionalisation. Should sufficient mapping of raised shorelines and other older raised surfaces become available, including the recently uplifted areas of the state as a geological process region may prove useful in explaining and predicting river behaviour. However, in the absence of this mapping, we are obliged to follow Houshold \textit{et al.},\textsuperscript{11} and rely on topographic variables to reveal the raised surfaces, and lithostructure to reveal areas affected by volcanism.