A Compendium of Ecological Information on Australia’s Northern Tropical Rivers

REPORT 1

Geomorphic classification

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1. Executive Summary

The preliminary typology of Australian tropical rivers proposed by Erskine et al. (2005) has been revised to provide a continental-scale geomorphic classification of all the rivers in northern Australia represented on the 1:2,500,000 drainage dataset, and a catchment-scale classification to the complete channel network (named and major rivers) shown on the 1:250,000 topographic maps for three large drainage basins in northern Australia (Daly River, NT; Fitzroy River, WA; Flinders River, Qld). This work is part of the Tropical Rivers Inventory and Assessment Project funded by Land and Water Australia and the Natural Heritage Trust. The continental-scale typology used continental-scale soil and landform information to categorise rivers into the following seven broad geomorphic river types across northern Australia (1) bedrock channel; (2) bedrock confined; (3) level alluvial plain; (4) undulating alluvial plain; (5) rolling alluvial plain; (6) lake/swamp; (7) estuarine. The catchment scale classification is significant as this is the first time that the whole channel network of all three catchments has been classified into homogeneous river reaches based on geomorphic criteria. Previous river classification exercises on these rivers have only investigated a minor component of the total channel network. The nine river types of Erskine et al. (2005) were revised by additions, amalgamations and deletions to 12 to accommodate the full range of river types present. The 12 river types mapped as homogeneous river reaches were: (1) bedrock rivers; (2) confined and constrained rivers; (3) low sinuosity rivers; (4) meandering rivers; (5) wandering rivers; (6) anabranching rivers; (7) chain of ponds; (8) gullies; (9) floodouts; (10) lakes, swamps or billabongs; (11) non-channelised valley floors; and (12) estuarine rivers. The floodplains associated with each river type are also different and are included in the classification. At scales larger than 1:250,000, subdivision of each river type is recommended. In the Daly River catchment, confined and constrained rivers dominate, with bedrock, meandering and anabranching rivers subdominant. In the Fitzroy River catchment, confined and constrained rivers and anabranching rivers dominate, with bedrock, meandering and low sinuosity rivers subdominant. In the Flinders River catchment, anabranching rivers predominate, with confined and constrained rivers also present. Wandering rivers, floodouts and non-channelised valley floors were rare for the 1:250,000 channel network. Predicted climate change for the Australian tropics includes higher temperatures, a more intense monsoon, general increase in rainfall intensities, possible marked increase in heavy rains, more floods and dry spells, increased potential evaporation and enhanced topographic effects on rainfall. Irrigated agriculture is also changing focus from temperate to tropical Australia where there are currently many proposed developments. To predict river response to climate change and agricultural development it is essential to benchmark the location and condition of existing river types in the Australian tropics and understand their structure and function. The proposed river classification scheme enables the identification of the major river types present and the prioritisation of research on the structure and function of the dominant river types. It is unlikely that the dominant river types in tropical Australia are sensitive to climate change because of either extensive floodplains (anabranching and meandering rivers) to dissipate flood power or resistant channel boundaries (confined and constrained rivers and bedrock rivers). Nevertheless, riparian vegetation is an important control on channel stability and climate-induced changes in riparian vegetation will have significant implications for the characteristics of the identified river types.

2. Background

A number of attempts have been made at developing a geomorphic classification scheme which could be applied at the continental scale eg Rosgen (1994) and Brierly and Fryirs (2005). However, at present there is no consensus on what would constitute a universally accepted geomorphic river classification scheme at the continental scale that could be easily repeated by different operators (Naiman, 1992; Kondolf, 1995, Parsons *et al* 2004).

Based on their experience with tropical rivers in the Northern Territory, Erskine et al. (2005) proposed a preliminary typology of Australian tropical rivers for subsequent application to river reach mapping and classification. A geomorphological approach to river characterization and classification was adopted because it is the only one possible based on the limited existing information for Australian tropical rivers. River reaches are homogeneous lengths of stream channel within which hydrological, geological, and adjacent catchment surface conditions are sufficiently constant so that a uniform river morphology or a consistent pattern of alternating river morphologies is produced (Erskine, 2005a). Channel reaches consist of relatively homogeneous associations of landforms and habitat types, which distinguish them from adjoining reaches and are typically 10 km to greater than 100 km in length (Bisson and Montgomery, 1996). While the core length of a reach is easy to identify, it is more difficult to define precisely the transitional boundaries from one river type or reach to another (Erskine, 2005a).

The geomorphic classification for the Tropical Rivers Inventory and Assessment Project (TRIAP) was undertaken at two scales, a continental scale (nominally 1:2,500,000) and at a catchment scale (1:250,000). At the continental scale, all rivers represented on the 1:2,500,000 drainage datasets produced by Geoscience Australia have been classified using the continental geomorphic classification. A catchment scale classification was applied to the major and named drainage features extracted from the 1:250,000 Geodata drainage datasets for three catchments (Daly - NT, Flinders - QLD and Fitzroy – WA) which were selected as focus catchments (Figure 1).

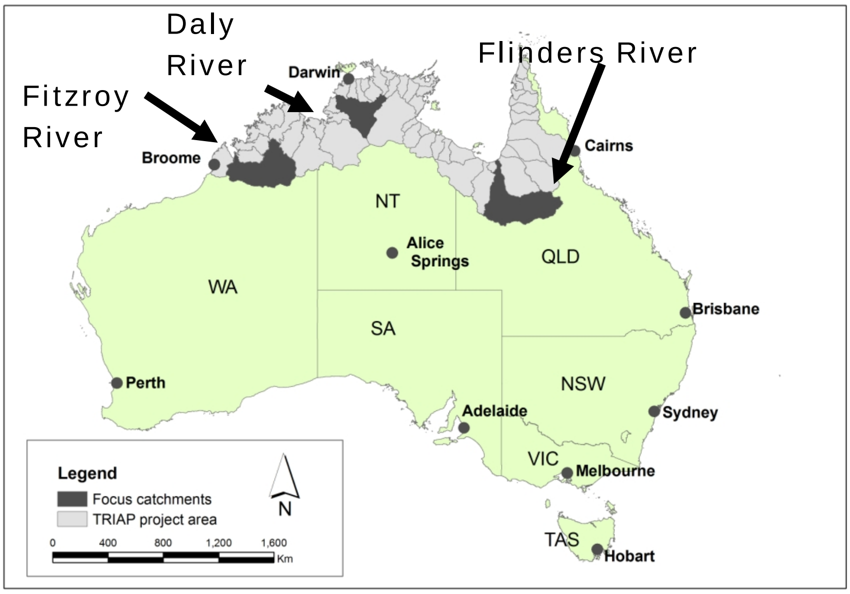

Figure 1: Location of the three focus catchments for the Tropical Rivers Inventory and Assessment project.

3. Geomorphic Classification - Continental Scale

Erskine *et al* (2005) originally proposed that nine broad tropical river types could be identified within northern Australia. Importantly, some of the proposed categories are unique, in that they describe river types that have not previously been categorized / classified in Australia or in similar environments overseas. The nine river types are:

1. Bedrock Channels
2. Bedrock-Confined Rivers
3. Avulsive Rivers
4. Meandering Rivers
5. Low sinuosity rivers (Straight Rivers)
6. Floodouts
7. Island- and Ridge-Anabranching Sand-Bed Rivers
8. Co-Existent Mud Braided and Anabranching Rivers
9. Extensive Wetlands and Billabongs

While the proposed river types could represent the progressive downstream change in geomorphology of a river from the headwaters to the mouth, it is important to understand that not all types will necessarily be observed on the same stream or river. Figure 2 illustrates the nine proposed river types; further detail is contained in Erskine *et al* (2005).

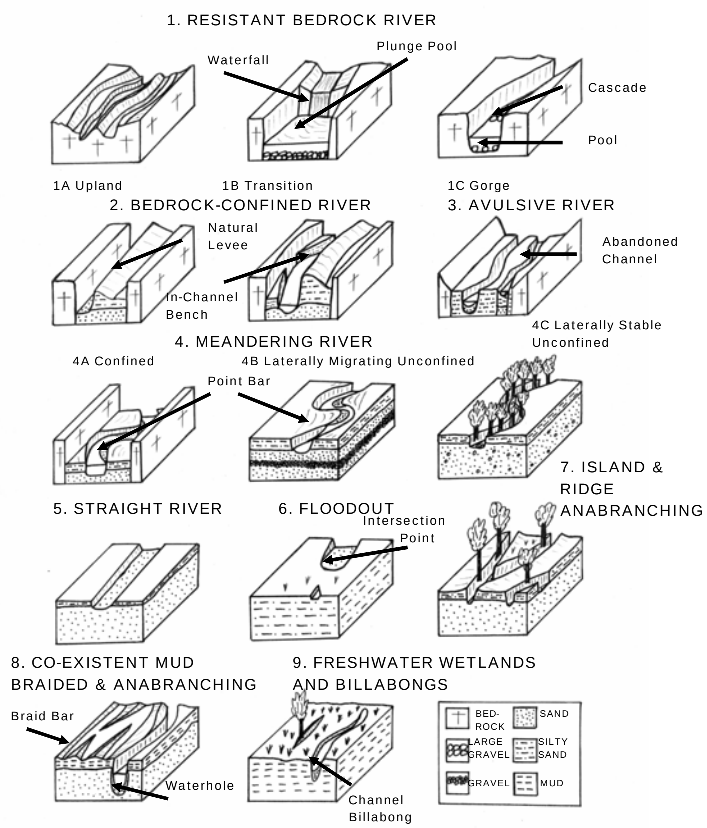

Figure 2: The nine main river types and their important variants found on Australian tropical rivers.

The nine classes were developed to provide a geomorphic classification for Australia's tropical rivers. However at the broad, continental scale it became apparent that it was not possible to identify or delineate each of the individual classes using existing, available data sets. This was particularly evident with regard to floodplain reaches that had multiple channels or those with a high sinuosity. A workshop was held in July 2005 (Darwin) where it was agreed that a broader scale classification was required at the continental scale, to complement the nine-class classification, which would be applied to individual focus catchments. Table 1 shows the broad scale classification and how it relates to the nine classes of Erskine *et al* (2005) originally intended for use at the focus-catchment level. Avulsive river types have been taken out of the classification as it was decided that it was a description of a process rather than a type of river. Initially, Tidal and Estuarine were also not considered by Erskine *et al* 2005 but have been added to Table 1 to allow for connectivity to the ocean. Further classification of tidal and estuarine classes will be completed elsewhere.

Table 1: Comparison of initial focus-catchment classification and initial broadscale geomorphic classification

Initial focus-catchment scale classification	Initial broad-scale classification
(1) Bedrock Channel	(1) Bedrock Channel
(2) Bedrock-confined	(2) Bedrock-confined
(3) Low sinuosity rivers (Straight Rivers)	
(4) Meandering rivers	
(5) Floodouts	
(6) Multiple channel rivers (Island- and Ridge-Anabranching & Co-Existant Mud Braided and Anabranching Rivers)	(3) Alluvial
(7) Wandering channel rivers (New category)	
(8) Non-channelised (Extensive Wetlands and Billabongs)	
(9) Swamp / waterbody dominated zone (Extensive Wetlands and Billabongs)	(4) Lake/Swamp
(10) Tidal	
	(5) Estuarine

Bedrock channels represent environments with highly resistant lithologies ie quartz sandstone, quartzite and granite, which have been eroded by very large floods. They may be represented as *upland bedrock* channels, which occur in channel scabland, or on plateau surfaces upstream of waterfalls. Channel scabland consists of extensive bedrock anabranching channels and scour pools eroded by catastrophic floods on bedrock uplands. Bedrock channels may also be represented as *deep bedrock channels*, which are incised into resistant bedrock, and are also formed after very large floods. Erosion by catastrophic floods produce a range of channel units which include deep pools (up to 30 metres deep), and boulder riffles, cascades and bars (Baker and Pickup 1987; Wohl 1992a, 1992b).

Bedrock confined rivers are usually found downstream of gorges where the constraining medium is less effective in preventing valley widening, and the slope declines so that gravel and/or sandbed material is deposited. Pools are often sand floored, and riffles are composed of gravels (boulders) and/or bedrock. Riparian vegetation is important for stabilizing these rivers, and large wood starts to accumulate in the channel, although the high stream power means the loadings are low. The main channel units are a combination of still and fast-water habitats. Turbulent fast-water habitats can restrict fish passage due to vertical steps, turbulence and high velocity. Pools usually persist during the dry season, where streams are seasonal.

Alluvial rivers are usually found between the bedrock confined reaches and the Estuarine sections downstream. This class contains the five focus level classifications contained in Table 1. These rivers occur on level or gently undulating plains and can have either single or multiple channels of various curvatures or sinuosity's. These rivers would usually be characterised by sandy bed material and riparian vegetation along the banks. The channels would usually comprise of pools and riffles and when not in flood conditions the water would be slow moving which allows for easy fish passage. Many of these channels could dry out during dry season conditions leaving limited pool refuges for fish.

Lake / swamp . The dominant channel units are channel and floodplain billabongs, but there are also abandoned channels and seasonal backswamp wetlands that support a range of different plant communities. Swamps are perennial, although the area extent may vary seasonally. Factors which affect the distribution of swamps include the relative relief of the land, and the waterlogging characteristics of the soils. Lakes may be perennial or seasonal. Across northern Australia, perennial lakes are largely the result of human activity, such as the damming of rivers. Lake Argyle in the Kimberley, produced by the damming of the Ord River, is an example of this. Naturally-occurring lakes tend to be seasonal in nature.

Estuarine rivers are those sections that are influenced by tidal movement and thus have brackish or salty water. The estuarine sections of the rivers are being examined separately.

Unfortunately, many of the datasets which would be ideal for mapping the distribution of these characteristics across northern Australia either are not available, are incomplete, do not extend over the whole of northern Australia, or only exist at scales which are not useful. It was therefore necessary to try and identify these geomorphic classes using existing surrogate datasets which could delineate and identify the different geomorphic classes.

The initial break down into the proposed geomorphic classes at the continental scale was done in a GIS environment, using the 1:2,000,000 Digital Atlas of Australian Soils, which is itself based on the classification by Northcote *et al* (1960-1968). The descriptions of all 513 soil types that occurred within a 200-metre buffer of the centerline of the rivers represented in the 1:2,500,000 drainage dataset were downloaded as a text file and then imported into a spread sheet. These descriptions contained information of the surrounding landform and rock types, as well as depth and soil characteristics. The soil types were sorted alphabetically and subjectively assigned to one of the broad geomorphic classes listed in Table 1.

The attributes of the soil dataset were intersected with the linear feature representing the drainage line, and the soil attributes – including the geomorphic classification – assigned to the drainage feature. This enabled the drainage feature to be classified into the different geomorphic classes described earlier.

Any descriptions with the words plateau, dissected and other indications of bedrock or any references to rocky out crops etc were assigned as *Bedrock Channel* (class 1). Soil types described as hilly, or which referred to areas of undulating plains were assigned as *Bedrock Confined* (class 2). The *Alluvial* category (class 3) was composed of all descriptions with the word "plain/s" or that were described as "gently undulating" or "gently sloping". Classes 4

(*Lake / swamp*) and 5 (*Estuarine*) were reasonably self-evident when looking at the descriptions, with floodplains and swampy plains assigned category 4 and coastal dune systems assigned category 5. Compared to the other categories there were relatively few descriptions in categories 4 and 5.

When the distribution of the alluvial class along the 1:2,500,000 drainage network was mapped, it became apparent, through initial feedback, that further differentiation within this class was required. The number of relevant datasets which have been compiled to a similar scale limited the number of datasets which could be used to differentiate this data. In the end, the dataset representing the dominant geomorphic landform characteristics of the region, compiled to a scale of 1:2,000,000 was used to differentiate and identify alluvial sub-classes.

Using the landform characteristics dataset, the alluvial class was divided into three categories, based on the following criteria:

- level alluvial plain (composed of those landforms classified as 'level plains;)
- undulating alluvial plain (those landforms classified as 'gently undulating', or 'undulating' plains)
- rolling alluvial plain (the remainder of the landforms that occurred within the previous 'alluvial floodplain' classification - includes rolling plains, rolling hills, undulating rises etc) - effectively to identify areas with greater relief.

Using these categories, which reflected relative relief and elevation in the landscape, had the effect of dividing the pre-existing alluvial category into lower, middle and upper sections.

As a result of this process, a final 7-class typology was generated for application at the broad (continental) scale. A comparison of the initial, and the final broad-scale classes is shown in Table 2. The 7-class typology was applied to all rivers within the tropical north represented on the 1:2,500,000 drainage dataset produced by Geoscience Australia (Figure 3). Figure 4 shows the application of the 7-classes to the Daly River NT. The river reaches have been classified using only the existing broad-scale data sets referred to earlier and there has not been any ground truthing to validate these classifications. The length of the different geomorphic classes within the project area of each state in the study area, and the total length of each class is shown in Table 3.

Table 3 shows the length of the mapped drainage for each of the continental geomorphic classes. Overall, ‘undulating alluvial plains’ are best represented of the classes across the entire study area. However, the distribution is extremely uneven, with more than two-thirds classified as occurring in Queensland, with comparatively few occurrences in Western Australia. Similarly, level alluvial plains are also found predominantly in Queensland. Bedrock channel and bedrock confined channels are next best represented, the greatest distribution in both cases being in the Northern Territory. Rolling alluvial plains are found primarily in WA. The classes with the shortest river lengths, ‘lake/swamp’ and ‘estuarine’ are found primarily in the Northern Territory. On a state-by-state basis, the undulating alluvial plain classification dominate rivers in Queensland, whilst bedrock confined / bedrock channel classifications dominate the Northern Territory. Western Australia has the lowest overall river length, with the bedrock confined class the dominant class present. Interestingly, Western Australia is the only state in which none of the rivers are classified as lake/ swamp, and has the lowest length of river classified as ‘estuarine’.

Again it should be stressed that this classification was developed from 1:2,000,000 Digital Atlas of Australian Soils and that the differences described above may be reflecting differences in soil type rather than differences in channel characteristics.

Table 2: Continental-scale geomorphic typology of rivers

Initial broad-scale classification	Final broad-scale classification
(1) Bedrock Channel	(1) Bedrock Channel
(2) Bedrock confined	(2) Bedrock-confined
(3) Alluvial	(3) Level alluvial plain (4) Undulating alluvial plain (5) Rolling alluvial plain
(4) Lake/Swamp	(6) Lake / Swamp
(5) Estuarine	(7) Estuarine

Table 3: Length of Continental Geomorphic Classes.

Geomorphic classification	Length of classified river WA (km)	Length of classified river NT (km)	Length of classified river QLD (km)	Total (km)
Bedrock Channel	4905.6	5109.5	2071.7	12086.8
Bedrock-confined	2244.3	5879	3363.8	11487.1
Estuarine	119.1	1679.9	951.2	2750.2
Lake / swamp	-	1673.4	395.4	2068.8
Level alluvial plain	2513.5	1381.6	9771.2	13666.3
Rolling alluvial plain	1945	1336.6	1394.1	4675.7
Undulating alluvial plain	518.2	5195.3	10062.7	15776.2
Total per State	**12245.7**	**22255.3**	**28010.1**	**62511.1**

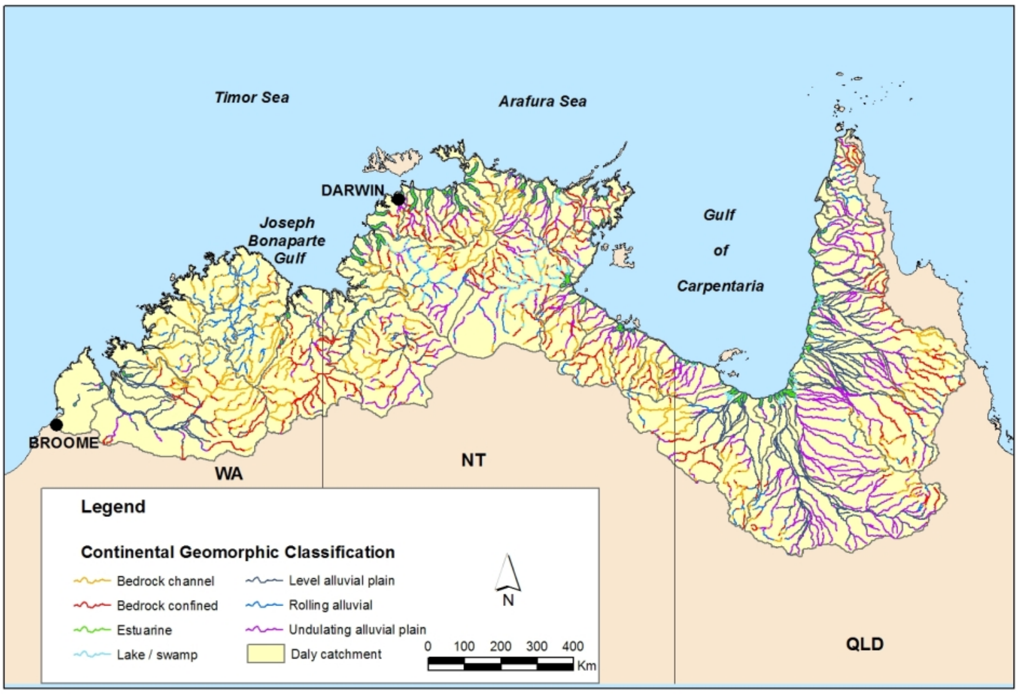

Figure 3: Continental geomorphic classification of rivers across northern Australia

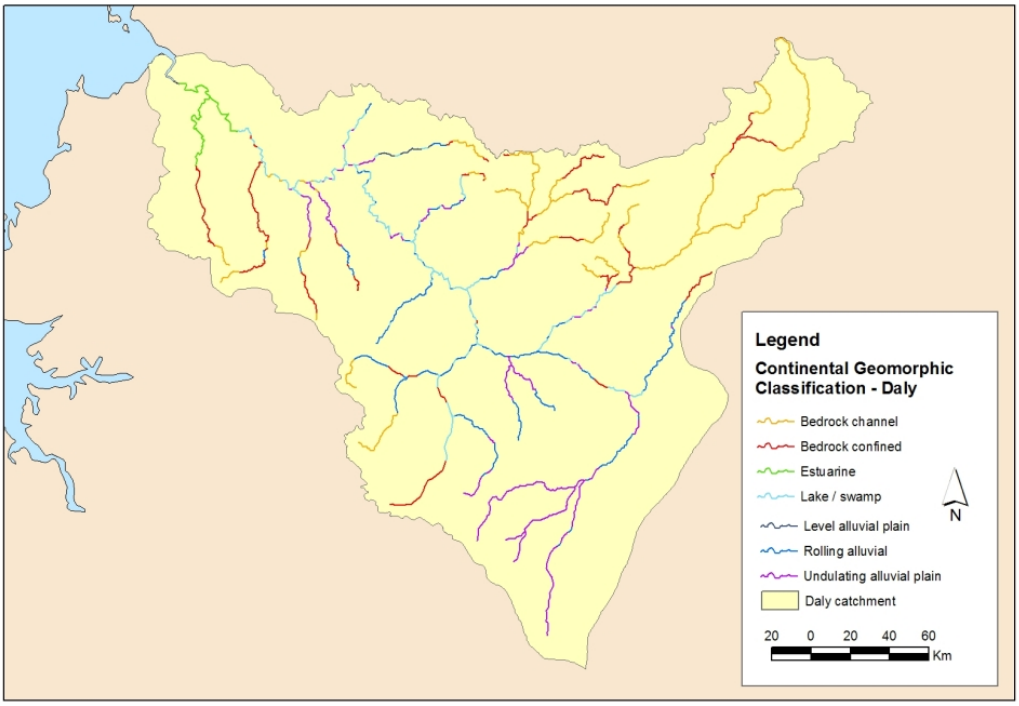

Figure 4: Continental classification (7 classes) for the Daly River, NT

4. Tropical Rivers Geomorphic Classification: Focus Catchment Scale

It is essential to know what river types currently exist in catchments if they are to be managed effectively and if appropriate actions are to be proposed and implemented to address current and future threats, such as land development and climate change. The work reported below can be completed in about 2 days for a 110,000 km^2 catchment if topographic and geological maps and remotely sensed data are readily available.

The approach adopted here is that a simple descriptive name based on the distinguishing geomorphic characteristics of the reach is used, such as ‘Meandering River’. Greater terminological precision can be used when the unique characteristics of each type are determined (Erskine, 1999). This will allow subdivision of major types into more homogeneous categories as more information is obtained and as mapping progresses to larger scale. Channel reaches are the appropriate spatial scale to map specific river types, such as those defined by Rosgen (1994; 1996), Brierley and Fryirs (2000; 2005), Brierley *et al* (2002) and Erskine *et al* (2005). The Erskine *et al* (2005) typology applies to reaches at least 5 km but usually greater than 10 km long. Previous assessments of stream condition in the Daly and Roper catchments in the Northern Territory were based on stream order as shown on 1:250,000 topographic maps (Faulks, 1998; 2001) which are of an appropriate scale for application of the present typology.

Erskine *et al*’s (2005) preliminary typology (Figure 2) was applied to the complete channel network which had been classified as either a named and/or a major river) extracted from the 1:250,000 GeoData digital topographic datasets for the three large drainage basins in northern Australia (Daly River, NT; Fitzroy River, WA; Flinders River, Qld) which had been previously identified as so-called ‘focus catchments’ for the TRIAP program. Remotely sensed data, topographic and geological maps and relevant published literature were used to supplement and enhance the delineation of these channels. Significantly this is the first time that the whole mapped channel network of all three rivers has been classified into homogeneous river reaches. Previous river classification exercises on these rivers have not investigated the total channel network but only a subjectively determined subset (Faulks, 1998; Brennan & Gardiner, 2004).

However, it was found that some of the river types illustrated in Figure 2 were too detailed for mapping at a scale of 1:250,000 and that the preliminary scheme needed expansion to include river types that had not been incorporated into the initial typology. Therefore, the initial scheme shown in Figure 2 was revised by additions, amalgamations and deletions to 12 river types to accommodate the full range of river types present. The 12 river types mapped as homogeneous river reaches were: (1) bedrock rivers; (2) confined and constrained rivers; (3) low sinuosity rivers; (4) meandering rivers; (5) wandering rivers; (6) anabranching rivers; (7) chain of ponds; (8) gullies; (9) floodouts; (10) lakes, swamps or billabongs; (11) non-channelised valley floors; and (12) estuarine rivers. The floodplains associated with each river type are also different and are included in the classification. Table 4 outlines the revised classification. At scales larger than 1:250,000, subdivision of each river type is recommended, as shown by the variants in Table 4. However, no attempt was made to map the variants for this project. As with Brennan and Gardiner (2004), this was a desktop exercise that did not involve any field work.

The change from one river reach to another can be abrupt but can also be transitional. Care was taken to check boundaries in bedrock confinement for changes in geology, where possible. Nevertheless, it must be realised that better quality data on topography, landforms and geology may necessitate revisions of the present reach boundaries. Importantly, it should be recognised that all classes may not be present in every catchment. The results of the classification of the individual focus catchments are described below:

4.1 Daly River

The total catchment area of the Daly River drainage basin is 52577 km^2 and Faulks (1998), Jolly (2001; 2002), Jolly *et al* (2000), Begg et al. (2001), Begg and Lowry (2003) and Erskine *et al* (2003) all discuss the channel network, wetlands, hydrology, water balance and environmental water requirements of the catchment. Figure 5 shows the spatial distribution of river types and Table 5 shows the percentage of the mapped drainage occupied by each river type. The total length of channels classified as 'named or major' at a scale of 1:250,000 in the Daly River catchment is 4861 km.

In the Daly River catchment, confined and constrained rivers dominated (48.5 % of the total length of the channel network), with anabranching rivers (17.4 %), chain of ponds (9.33 %), meandering rivers (8.88 %) and bedrock rivers (7.66 %) subdominant. Only short reaches of low sinuosity rivers, non-channelised valley floors, billabongs and estuarine rivers were mapped. Wandering rivers, floodouts and gullies were absent.

The Katherine, Fergusson, Edith and Daly Rivers are either bedrock channels or bedrock confined and constrained channels for most of their length. The low relief catchment of the Dry River is characterised by low energy river types with non-channelised valley floors, chain of ponds and anabranching rivers dominating. Billabongs and non-channelised valley floors are common on the estuarine floodplain.

Table 4: River types identified in the Daly River catchment, NT, Fitzroy River catchment, WA and Flinders River catchment, Qld and mapped as homogeneous river reaches in each catchment. See Figures 3, 4 and 5 for the spatial distribution of river types in each catchment.

River type	Characteristics	Variants
1. Bedrock River	Channel excavated into bedrock with essentially no floodplain.	iv) Upland Bedrock Channel ii) Steep Bedrock Cascades iii) Deep Bedrock Gorge
2. Confined and Constrained River	Channel impinges against and/or flows across materials of limited erodibility, such as colluvium, bedrock or terrace sediments (Schumm, 2005). Limited development of floodplain as pockets in localised expansions. Bars and benches often form where it is too narrow for a floodplain.	iv) Close lateral confinement ii) Close lateral and vertical confinement iii) Close Vertical Confinement iv) Partial Lateral Confinement v) Partial Lateral and Vertical Confinement vi) Partial Vertical Confinement
3. Low Sinuosity River	Single channel with a sinuosity < 1.35. Floodplain usually has a well-developed natural levee with crevasses and splays.	i) Straight channels with a sinuosity <1.05 ii) Low sinuosity channel with a sinuosity between 1.05 and 1.4.

4. Meandering River	Single channel with a sinuosity generally >1.5. Short sections of straighter channel with a sinuosity of >1.35 are included. Point bars usually well=developed on the inside of bends. Floodplain formed dominantly by lateral accretion and often consists of floodplain ridges.	iv) Confined Meandering River ii) Laterally Migrating Unconfined Meandering River iii) Laterally Stable Unconfined Meandering River
5. Wandering River	Usually gravel-bed but can be sand-bed. Intermediate form between meandering and braided rivers with islands and bars.	Overseas results may not be applicable to Australia because there are few braided rivers.
6. Anabranching River	Multiple channels separated by ridges, islands and/or floodplain. Diversity of different anabranching rivers and floodplains, many of which have still not been investigated.	iv) Ridge Anabranching River ii) Island Anabranching River iii) Co-existent Mud-Braided and Anabranching River iv) Floodplain Anabranching River v) Multiple Main Channels Anabranching River
7. Chain of Ponds	A diverse drainage form ranging from disconnected pools/ponds in valley floors to large pools in small continuous channels to extensive wetlands.	Requires further investigation.
8. Gully	Relatively deep, recently formed , eroded channels that are cut into unconsolidated materials where no well-defined channel previously existed.	i) Valley Floor Gully ii) Valley Head Gully iii) Valley-Side Gully
9. Floodout	Form of channel failure where bedload is deposited. Discussed by Erskine *et al.* (2005).	i) Terminal Floodout ii) Intermediate Floodout
10. Lakes, Swamps and Billabongs	Pools in former channels of estuaries and rivers, backswamps and dammed tributary valleys. Discussed by Erskine *et al.* (2005)	i) Channel Billabongs ii) Floodplain Billabongs iii) Backflow Billabongs iv) Backswamps
11. Non-Channelised Valley Floors	Swampy, unchanneled valley floors that can extend upslope into alluvial fans, hillslope hollows and percolines. Usually well vegetated and characterised by high water tables, at least during the wet season. Mud sheets characterise the floodplain.	Requires further investigation
12. Estuarine Rivers	Woodroffe *et al.* (1989) define four reaches for macrotidal estuaries which are included as examples i) to iv) in the next column. Floodplains differ between different reaches. Newly developing tidal channels are called ‘Developing Saline Channels’ and are discussed by Knighton *et al.* (1991; 1992)	i) Estuarine Funnel ii) Sinuous Meandering Reach iii) Cuspate Meandering Reach iv) Upstream Reach v) Developing Saline Channels

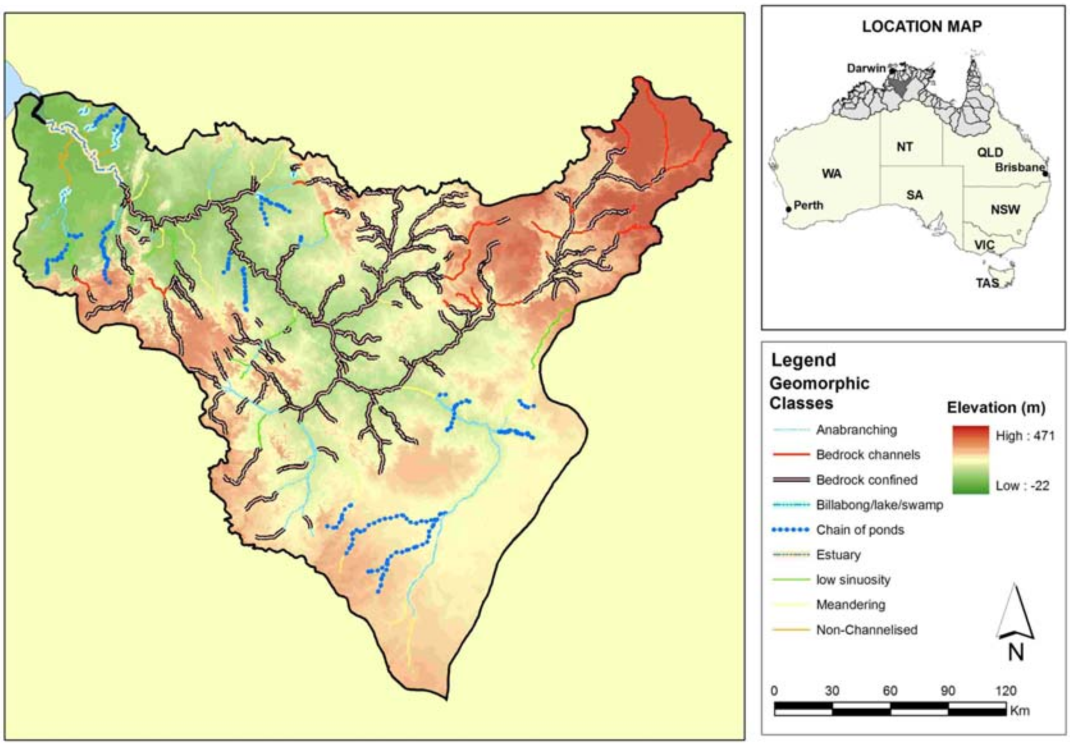

Figure 5: Mapped river types for river reaches of the Daly River catchment, NT.

Table 5: Percentage of total river length for each river type in each focus catchment.

River type	% of total channel length – Daly River	% of total channel length – Fitzroy River	% of total channel length – Flinders River	% of total channel length – Overall
1. Bedrock River	7.65	7.48	1.94	3.64
2. Confined and Constrained River	48.45	38.52	13.22	22.01
3. Low Sinuosity River	4.17	2.14	1.50	1.93
4. Meandering River	8.88	3.70	2.63	3.54
5. Wandering River	0	0	0.9	0.63
6. Anabranching River	17.41	44.68	77.77	64.66
7. Chain of Ponds	9.33	0.49	0.32	1.38
8. Gully	0	0.30	0	0.06
9. Floodout	0	0.49	0	0.09
10. Lakes, Swamps and Billabongs	0.96	0.07	0	0.12
11. Non-Channelised Valley Floors	1.50	0.76	0.80	0.87
12. Estuarine Rivers	1.65	1.37	0.92	1.09

4.2 Fitzroy River

The total catchment area of the Fitzroy River catchment is about 90,000 km^2 and the catchment is composed of bedrock uplands in the upper one-third of the catchment and lowlands in the lower two-thirds of the catchment (Figure 6). Taylor (1999) discusses the anabranching reaches in the lowlands but anabranching reaches also occur in parts of the uplands. Figure 4 shows the spatial distribution of river types and Table 5 shows the percentage of the mapped drainage occupied by each river type. The total length of major/named channels mapped at a scale of 1:250,000 in the Fitzroy River catchment is 8145 km.

In the Fitzroy River catchment, anabranching rivers (44.68 %) and bedrock confined and constrained rivers (38.52 %) dominate, with bedrock (7.48 %), meandering (3.70 %) and low sinuosity rivers (2.15 %) subdominant. Only short reaches of non-channelised valley floors, billabongs, chain of ponds, gullies, floodouts and estuarine rivers were mapped. Wandering rivers were not present.

Anabranching rivers dominate in the lower catchment, and bedrock and bedrock confined and constrained rivers dominate in the upper catchment (Figure 6). Except for the estuary, all other river types have a very restricted spatial distribution (Figure 6; Table 5).

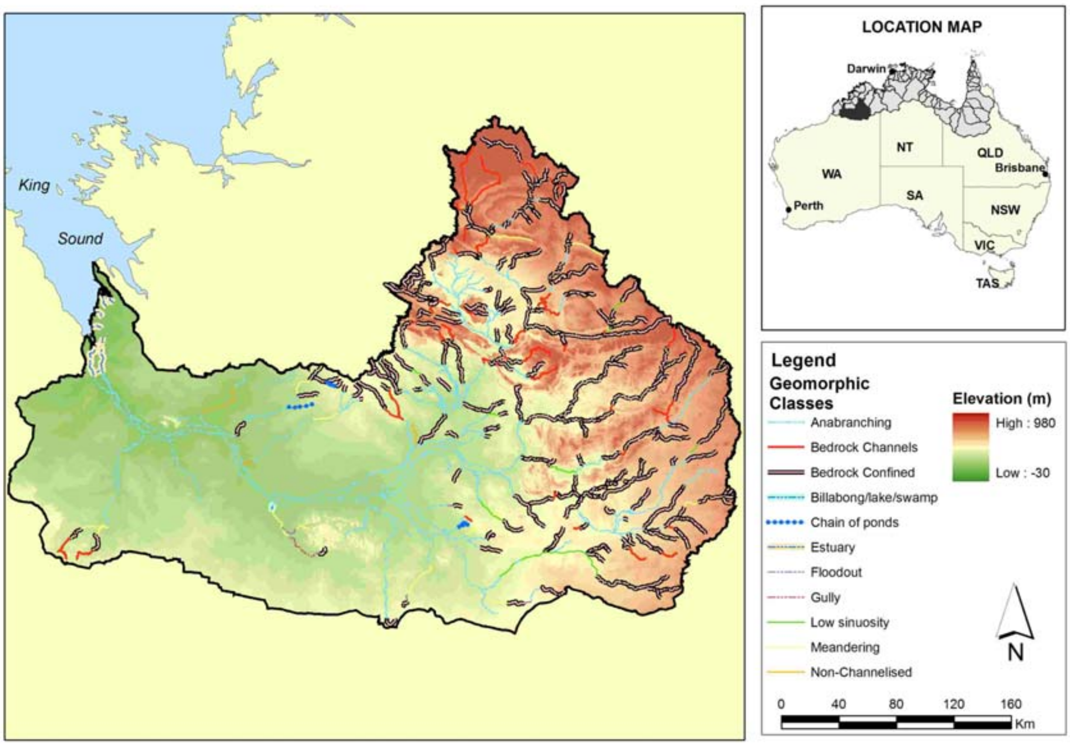

Figure 6: Mapped river types for river reaches of the Fitzroy River catchment, WA.

4.3 Flinders River

The total catchment area of the Flinders River catchment is about 109,400 km^2. Brennan and Gardiner (2004) mapped river styles on the Flinders, Stawell, Cloncurry, Corella, Dugald and Williams rivers and Julia Creek. Figure 7 shows the spatial distribution of river types in the Flinders River catchment from the present work and Table 5 shows the percentage of the mapped drainage occupied by each river type. The total length of major/named channels mapped at a scale of 1:250,000 in the Fitzroy River catchment is 29,927 km.

In the Flinders River catchment, anabranching rivers predominate (77.77 %), with bedrock confined and constrained (13.22 %), meandering (2.63 %) bedrock (1.94 %) and low sinuosity rivers (1.50 %) also present. Wandering rivers, chain of ponds, non-channelised valley floors and estuarine rivers were rare for the 1:250,000 mapped channel network.

As shown in Figure 7, anabranching rivers dominate throughout the catchment, except for the uplands in the southwestern corner and the eastern part of the catchment. In the uplands, bedrock confined and constrained and bedrock channels dominate. Except for the estuary, all other five river types have a restricted distribution.

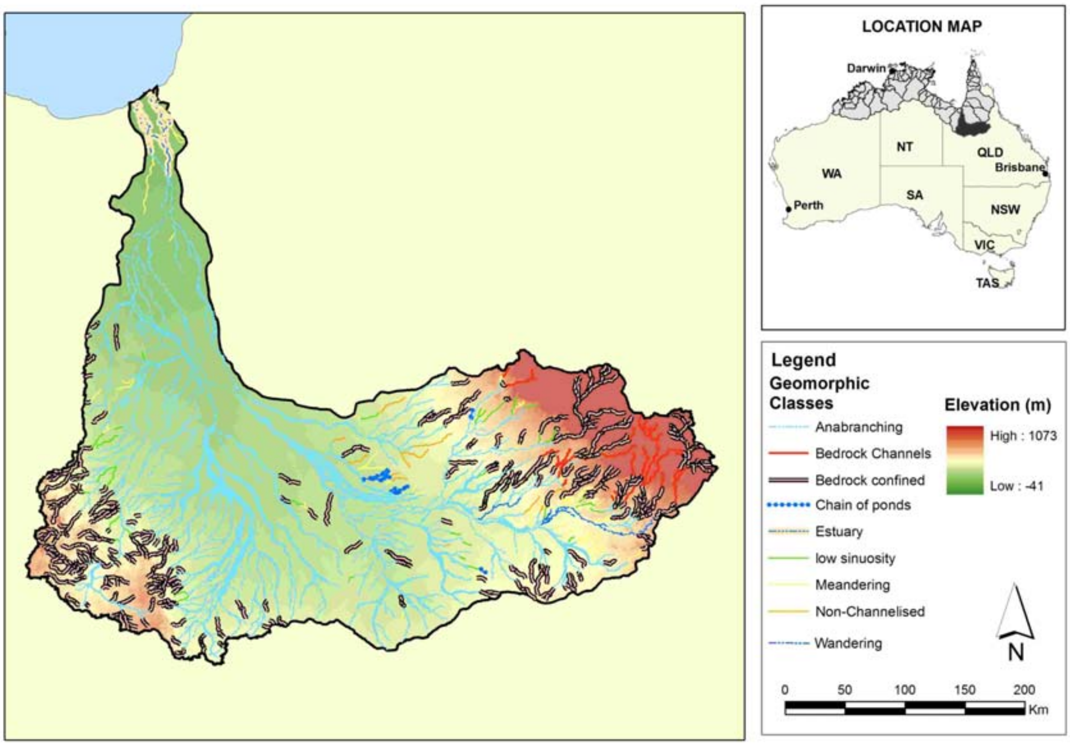

Figure 7: Mapped river types for river reaches of the Flinders River catchment, Qld.

4.4 All Focus Catchments

Table 5 shows the percentage of the mapped drainage occupied by each river type for all three focus catchments combined. The total length of channels mapped at 1:250,000 in the three focus catchments is 42,933 km. Anabranching rivers clearly dominate occupying 64.66 % of the total length of mapped drainage in all three catchments. Confined and constrained rivers occupy the next greatest length of mapped drainage at 22.01 %. Bedrock (3.64 %) and meandering channels (3.54 %) are the next most significant, with low sinuosity rivers (1.93

%), chain of ponds (1.38 %) and estuarine rivers (1.09 %) being the only others to occupy more than 1 % of the total mapped drainage length. Therefore, billabongs, non-channelised valley floors, floodouts, gullies and wandering rivers are relatively rare river types for the mapped drainage on the 1:250,000 datasets in the focus catchments.

5. Predicted Climate Change Impacts

Predicted climate change for the Australian tropics includes higher temperatures, a more intense monsoon, general increase in rainfall intensities, possible marked increase in heavy rains, more floods and dry spells, increased potential evaporation and enhanced topographic effects on rainfall. Irrigated agriculture is also changing focus from temperate to tropical Australia where there are currently many proposed developments. To predict river response to climate change and agricultural development it is essential to benchmark the location and condition of existing river types in the Australian tropics and to understand their structure and function. The river classification scheme used for the present study enables the identification of the major river types present and the prioritisation of research on the structure and function of the dominant river types. Clearly, our results indicate that anabranching and bedrock confined and constrained rivers are the most import river types in the focus catchments. It is unlikely that these dominant river types in tropical Australia are sensitive to climate change because of either extensive floodplains (anabranching rivers) to dissipate flood power or resistant channel boundaries (bedrock confined and constrained rivers). The effects of more variable streamflows on their resilience and sensitivity requires further investigation. Nevertheless, riparian vegetation is an important control on channel stability and climate-induced changes in riparian vegetation will have significant implications for the characteristics of the identified river types.

River classification is also important for the identification of rare river types that should be conserved and/or protected from known threats, such as climate change. Our results indicate that billabongs, non-channelised valley floors, floodouts, gullies and wandering rivers are relatively rare river types that should be assessed for targetted conservation efforts. While gullies and floodouts are hardly significant landforms and ecosystems, non-channelised valley floors and billabongs are more important in terms of preventing the onset of gully erosion which can generate high sediment yields (Erskine, 2005b) and drain billabongs. Saynor *et al* (2004) have emphasised that it is possible to reverse gully initiation if the early stages are identified and appropriate corrective measures are taken.

The extensive freshwater wetlands (220 km^2) on lower Magela Creek were formed at least in part by sedimentation during the late Holocene raising the Magela wetlands above the level of tidal inundation, hence causing atrophy of estuarine channels, the remnants of which still exist as billabongs in some places (Wasson, 1992). Russell-Smith (1985) and Mulrennen and Woodroffe (1998a) also documented a similar dismemberment of the South Alligator and Mary rivers, respectively, immediately upstream of their estuaries during the late Holocene. However, in the latter cases, there has been recent saline intrusion into the freshwater wetlands, for reasons that are still unclear (Mulrennen and Woodroffe, 1998b) but probably include short period changes in sea level. Nevertheless, on the Mary River, the atrophied former tidal channels have rapidly extended back into the wetlands by a combination of headward extension along main channels and by tributary development (Knighton *et al* 1991; 1992). We did not identify saline intrusion in our focus catchments. Nevertheless, billabongs, lakes and swamps are sensitive landforms and ecosystems that will respond to any changes in tidal hydrodynamics and water balance, both of which can be influenced by climate change.

6. Summary and Conclusions

A preliminary nine-class typology of Australian tropical rivers was proposed by Erskine *et al* (2005) to provide a geomorphic classification for Australia's tropical rivers. However, at the broad, continental scale it became apparent that it was not possible to identify or delineate each of the individual classes using existing, available data sets. Through a process of consultation, the typology was revised to produce a seven-class typology. Consequently, this typology was applied to all the all rivers represented on the 1:2,500,000 digital drainage dataset in the 51 catchments in the study area. The classification was based on querying existing soils and landform datasets in a GIS environment. No ground surveys were undertaken to validate the typology and there has not been any on the ground validation.

When applied at the focus catchment scale, specifically to the complete channel network (named and major rivers) extracted from digital 1:250,000 hydrological datasets for the three focus catchments (Daly River, NT; Fitzroy River, WA; Flinders River, Qld), the preliminary typology proposed by Erskine et al. (2005) required major revisions. The initial nine river types were revised by additions, amalgamations and deletions to 12 to accommodate the full range of river types present. The 12 river types mapped as homogeneous river reaches were: (1) bedrock rivers; (2) confined and constrained rivers; (3) low sinuosity rivers; (4) meandering rivers; (5) wandering rivers; (6) anabranching rivers; (7) chain of ponds; (8) gullies; (9) floodouts; (10) lakes, swamps or billabongs; (11) non-channelised valley floors; and (12) estuarine rivers. The floodplains associated with each river type were also included in the classification. At scales larger than 1:250,000, subdivision of each river type is recommended. In the Daly River catchment, confined and constrained rivers dominate, with bedrock, meandering and anabranching rivers subdominant. In the Fitzroy River catchment, confined and constrained rivers and anabranching rivers dominate, with bedrock, meandering and low sinuosity rivers subdominant. In the Flinders River catchment, anabranching rivers predominate, with confined and constrained rivers also present. Wandering rivers, floodouts and non-channelised valley floors were rare for the 1:250,000 channel network.

The geomorphic classifications at both the continental and focus-catchment scale are an essential and integral element of a GIS which has been compiled as part of the inventory of data used in the development of an ecological typology for north Australian rivers.

Predicted climate change for the Australian tropics is significant. To predict river response to climate change and agricultural development it is essential to benchmark the location and condition of existing river types in the Australian tropics and understand their structure and function. The modified river classification scheme enables the identification of the major river types present and the prioritisation of research on the structure and function of the dominant river types. It is unlikely that the dominant river types in tropical Australia are sensitive to climate change because of either extensive floodplains (anabranching and meandering rivers) to dissipate flood power or resistant channel boundaries (confined and constrained rivers and bedrock rivers). Nevertheless, riparian vegetation is an important control on channel stability and climate-induced changes in riparian vegetation will have significant implications for the characteristics of the identified river types.

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