Classification of Australian Tropical Rivers to Predict Climate Change Impacts

Wayne Erskine[A,C], M.J. Saynor [B] and J Lowry[B]

[A]Centre for the Sustainable Use of Coasts and Catchments, School of Environmental and Life Sciences, The University of Newcastle, PO Box 127, Ourimbah, NSW 2258, Australia.
[B]Environmental Research Institute of the Supervising Scientist, GPO Box 461, Darwin, NT 0801, Australia
[C]Corresponding author; email: Wayne.Erskine@newcastle.edu.au

Abstract. The preliminary typology of Australian tropical rivers proposed by Erskine *et al.* (2005) was applied 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) using remotely sensed data, topographic and geologic maps and relevant published literature. This work is part of the Tropical Rivers Inventory and Assessment Project funded by Land and Water Australia. Significantly this is the first time that the whole channel network of all three rivers 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.

Introduction

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 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).

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.

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 scales. This work forms part of the Tropical Rivers Inventory and Assessment Project funded by Land and Water Australia and the Natural Heritage Trust.

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.

Methods

Erskine *et al.'s* (2005) preliminary typology was applied 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) using remotely sensed data, topographic and geological maps and relevant published literature (Figure 1). These three drainage basins are called focus catchments. 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).

Erskine *et al.* (2005) proposed the nine preliminary river types outlined in Figure 2. We rapidly found that some river types were too detailed for mapping at a scale of 1:250,000 and that our preliminary scheme needed expansion to include river types that we had thought would not be present. 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 1 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 1. We did not attempt 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. We were careful 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.

Results

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) discuss the channel network, wetlands, hydrology, water balance and environmental water requirements of the catchment. Figure 3 shows the spatial distribution of river types and Table 2 shows the percentage of the mapped drainage occupied by each river type. The total length of channels mapped at 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.

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 4). 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 3 shows the percentage of the mapped drainage occupied by each river type. The total length of 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 4). Except for the estuary, all other river types have a very restricted spatial distribution (Figure 4; Table 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 5 shows the spatial distribution of river types in the Flinders River catchment from the present work and Table 4 shows the percentage of the mapped drainage occupied by each river type. The total length of channels mapped at a scale of 1:250,000 in the Fitzroy River catchment is 29927 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 5, 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.

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 42933 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 maps in the focus catchments.

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.

Conclusion

Application of the preliminary typology of Australian tropical rivers proposed by Erskine *et al.* (2005) 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) using remotely sensed data, topographic and geologic maps and relevant published literature necessitated major revisions. 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 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. 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.

Acknowledgments

We thank Dr C. Taylor and Dr A. Brookes for helpful discussion on methodology and mapped reaches. Erskine gratefully acknowledges the support of the Environmental Research Institute of the Supervising Scientist for his involvement in this project. The research was supported by Land and Water Australia and Natural Heritage Trust.

References

Begg, G. & Lowry, J. (2003) Land capability and topographic data as a surrogate for the mapping and classification of wetlands: a case example from the Daly basin, Northern Territory, Australia. *Water Science and Technology* **48**(7): 49-56.

Begg, G.W., van Dam, R.A., Lowry, J.B., Finlayson, C.M. & Walden, D.J. (2001). *Inventory and risk assessment of water dependent ecosystems in the Daly basin, Northern Territory, Australia*. Supervising Scientist Report 162, Supervising Scientist, Darwin.

Bisson, P.A. and Montgomery, D.R. (1996). Valley segments, stream reaches, and channel units. In: 'Methods in Stream Ecology'. (Eds F.R. Hauer, and G.A. Lamberti.) pp. 23-52. (Academic Press: San Diego, USA.)

Brierley, G.J. and Fryirs, K. (2000). River styles, a geomorphic approach to catchment characterization: implications for river rehabilitation in Bega catchment, New South Wales, Australia. *Environmental Management* **25**, 661-679.

Brierley, G.J. and Fryirs, K.A. (2005). *Geomorphology and River Management. Applications of the River Styles Framework*. Blackwell Publishing, Oxford.

Brierley, G., Fryirs, K., Outhet, D. and Massey, C. (2002). Application of the river styles framework as a basis for river management in New South Wales, Australia. *Applied Geography* **22**, 91-122.

Erskine, W.D. (1999). Channel morphology. In: '*Geomorphology of the Hawkesbury-Nepean River System. A Review of Landforms, Processes and Management*'. (Ed D. Martens.) pp. 26-48. (Hawkesbury Nepean Catchment Management Trust: Windsor, Aust.)

Erskine, W.D. **(**2005a). SW-966 Stream classification. In: '*Water Encyclopedia: Surface and Agricultural Water*'. (Eds J.H. Lehr, J. Keeley and J. Lehr, J.) pp. 65-71. (Wiley-Interscience, Hoboken.)

Erskine, W.D. (2005b). Gully erosion. In: '*Water Encyclopedia: Surface and Agricultural Water*'. (Eds J.H. Lehr, J. Keeley and J. Lehr, J.), pp. 183-188. (Wiley-Interscience, Hoboken.)

Erskine, W.D., Beggs, G.W., Jolly, P., Georges, A., O'Grady, A., Eamus, D., Rea, N., Dostine, P., Townsend, S. and Padovan, A., 2003. Recommended environmental water requirements for the Daly River, Northern Territory, based on ecological, hydrological and biological principles. *Supervising Scientist Report 175*, Supervising Scientist, Darwin and *National River Health Program Environmental Flows Initiative Technical Report 4*, 50 pp.

Erskine, W.D., Saynor, M.J., Erskine, L., Evans, K.G. and Moliere, D., 2005. A preliminary typology of Australian tropical rivers and implications for fish community ecology. *Marine and Freshwater Research* 56(3): 253-267.

Faulks, F.F. (1998). *Daly River Catchment. Part1 An Assessment of the Physical and Ecological Condition of the Daly River and its Major Tributaries. Part 2 Accompanying*

Sub-Catchment Information. Technical Report No. TR 99/10, N.T. Department of Lands, Planning and Environment, Katherine, Australia.

Faulks, J.J. (2001). *Roper River Catchment. An Assessment of the Physical and Ecological Condition of the Roper River and its Major Tributaries*. Technical Report 36/2001, N.T. Department of Lands, Planning and Environment, Katherine, Australia.

Jolly, P. (2001). *Daly River Catchment Water Balance*. Report 10/2002, N.T. Department of Infrastructure Planning and Environment, Natural Resources Division, Palmerston, Australia.

Jolly, P. (2002). Water Balance for the Daly River catchment, Northern Territory, Australia. *Balancing the Groundwater Budget Conference*, Darwin, 12-17 May 2002. paper published on CD-Rom.

Jolly, P., George, P., Jolly, I. and Spiers, Z. (2000). *Analysis of groundwater fed flows for the Flora, Katherine, Douglas and Daly Rivers.* NT Department of Lands, Planning and Environment, Natural Resources Division Report 36/2000D, Darwin.

Knighton, A.D., Mills, K. and Woodroffe, C.D. (1991). Tidal-creek extension and saltwater intrusion in northern Australia. *Geology* **19**, 831-834.

Knighton, A.D., Woodroffe, C.D. and Mills, K. (1992). The evolution of tidal creek networks, Mary River, northern Australia. *Earth Surface Processes and Landforms* **17**, 167-190.

Mulrennen, M.E. and Woodroffe, C.D. (1998a). Holocene development of the lower Mary River plains, Northern Territory, Australia. *The Holocene* **8.5**, 565-579.

Mulrennen, M.E. and Woodroffe, C.D. (1998b). Saltwater intrusion into the coastal plains of the lower Mary River, Northern Territory, Australia. *Journal of Environmental Management* **54**, 169-188.

Rosgen, D.L. (1994). A classification of natural rivers. *Catena* **22**, 169-199.

Rosgen, D.L. (1996). '*Applied River Morphology*'. (Wildland Hydrology: Pagosa Springs, Colorado.)

Russell-Smith, J. (1985). A record of change: studies of Holocene vegetation history in the South Alligator River region, Northern Territory. *Proceedings of Ecological Society of Australia* **13**, 191-202.

Saynor, M.J., Erskine, W.D., Evans, K.G. and Eliot, I. (2004). Gully initiation and implications for management of scour holes in the vicinity of the Jabiluka mine, Northern Territory, Australia. *Geografiska Annaler* **86A**, 191-203.

Schumm, S.A. (2005). *River Variability and Complexity*. Cambridge University Press, Cambridge.

Taylor, C.F.H. (1999). The role of overbank flow in governing the form of an anabranching river: the Fitzroy River, northwestern Australia. *International Association of Sedimentologists* Spec. Publ. **28**, 77-91.

Wasson, R.J. (1992). *Modern Sedimentation and Late Quaternary Evolution of the Magela Creek Plain*. Supervising Scientist for the Alligator Rivers Region Research Report 6, Australian Government Publishing Service, Canberra, Australia.

Woodroffe, C.D., Chappell, J.M.A., Thom, B.G. and Wallensky, E. (1989). Depositional model of a macrotidal estuary and flood plain, South Alligator River, northern Australia. *Sedimentology* **36**, 737-756.

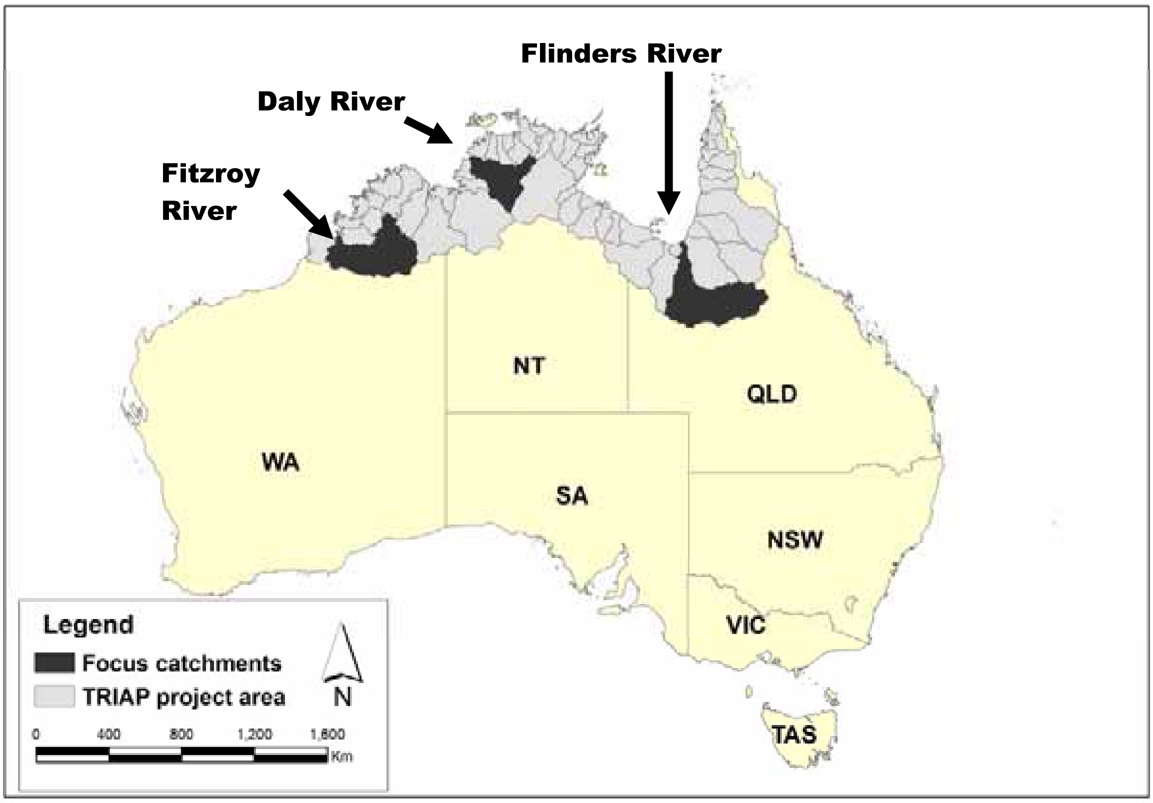

Figure 1. Location of the three focus catchments for the Tropical Rivers Inventory and Assessment Project.

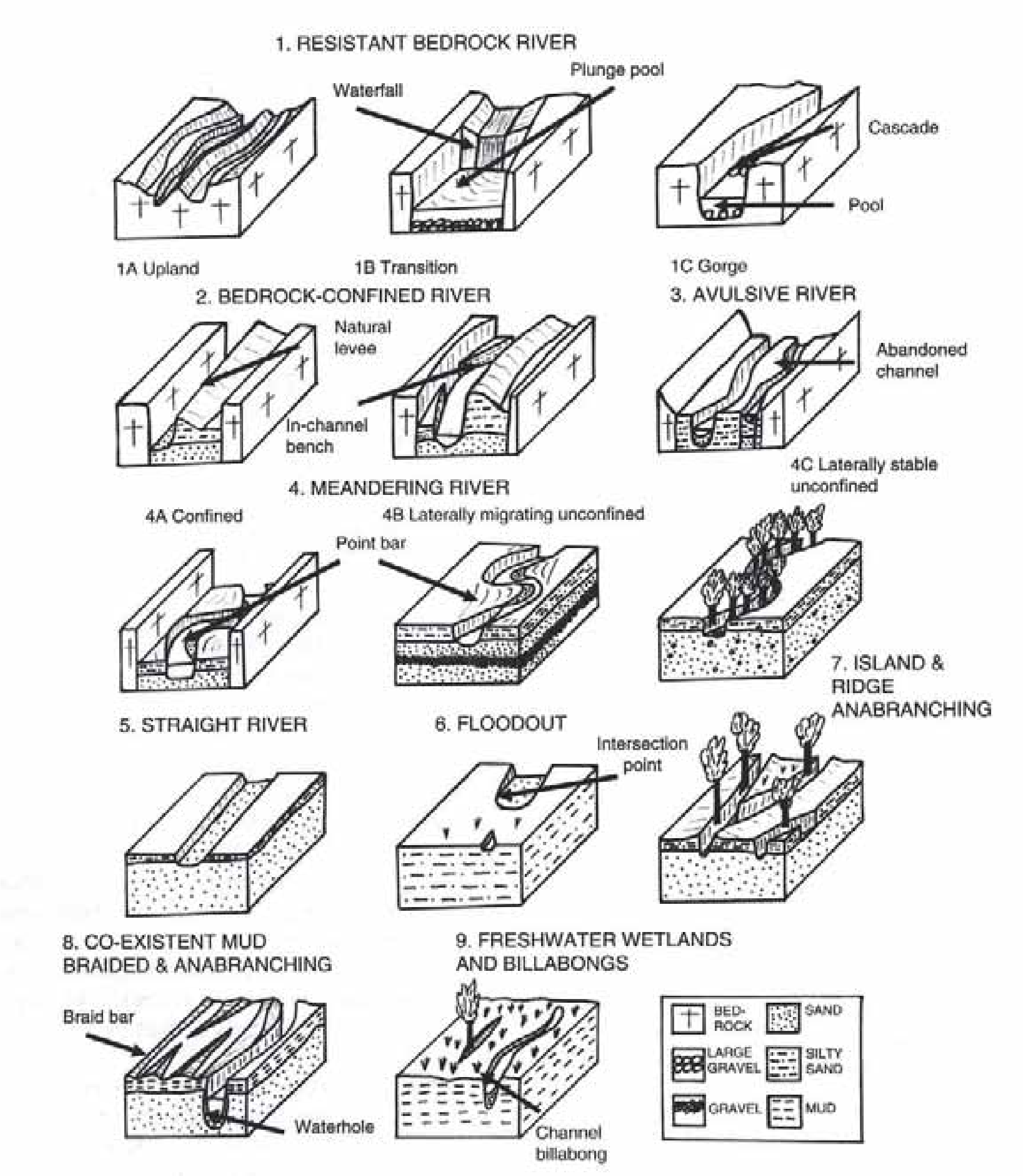

Figure 2. Preliminary typology of Australia's tropical rivers proposed by Erskine *et al.* (2005).

Table 1. 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 Figues 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.	i) 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.	i) 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.	i) 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.	i) 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

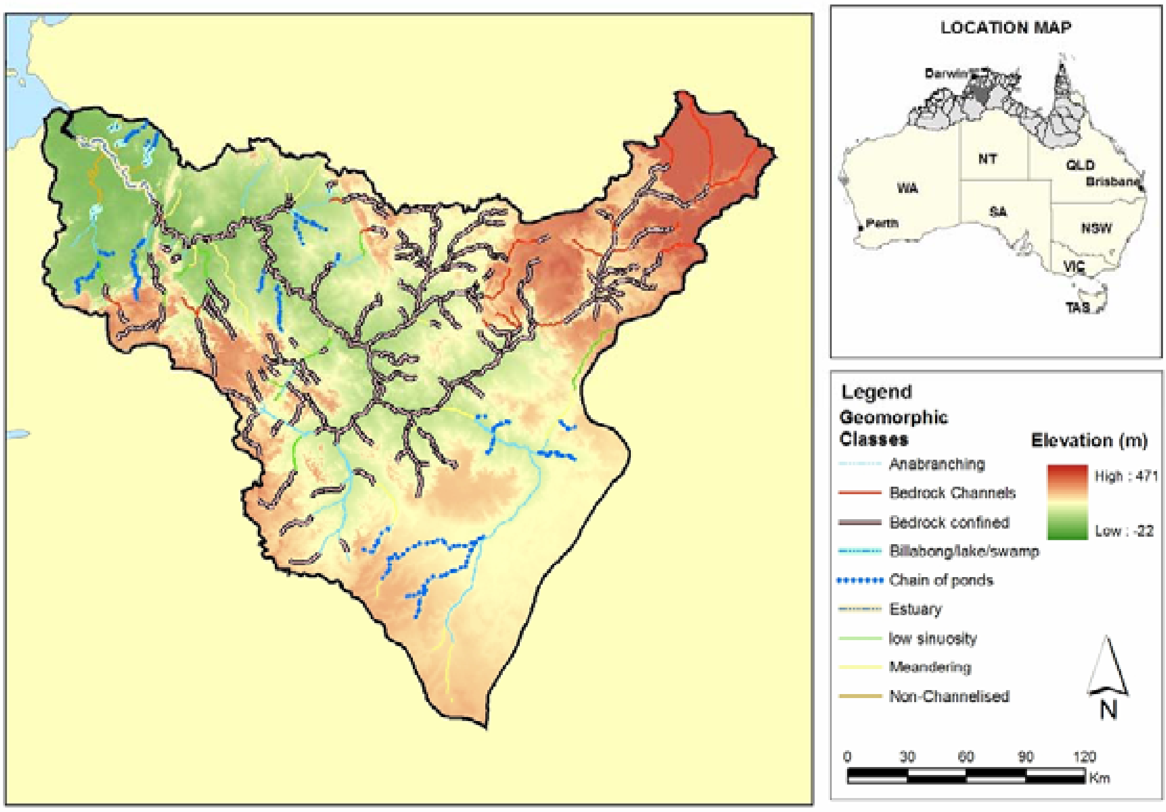

Figure 3. Mapped river types for river reaches of the Daly River catchment, NT.

Table 2. Percentage of total river length for each river type in the Daly River catchment, NT. For distribution of river types, see Figure 3.

RIVER TYPE	**PERCENTAGE OF TOTAL CHANNEL LENGTH**
1. Bedrock River	7.65
2. Confined and Constrained River	48.45
3. Low Sinuosity River	4.17
4. Meandering River	8.88
5. Wandering River	0
6. Anabranching River	17.41
7. Chain of Ponds	9.33
8. Gully	0
9. Floodout	0
10. Lakes, Swamps and Billabongs	0.96
11. Non-Channelised Valley Floors	1.50
12. Estuarine Rivers	1.65

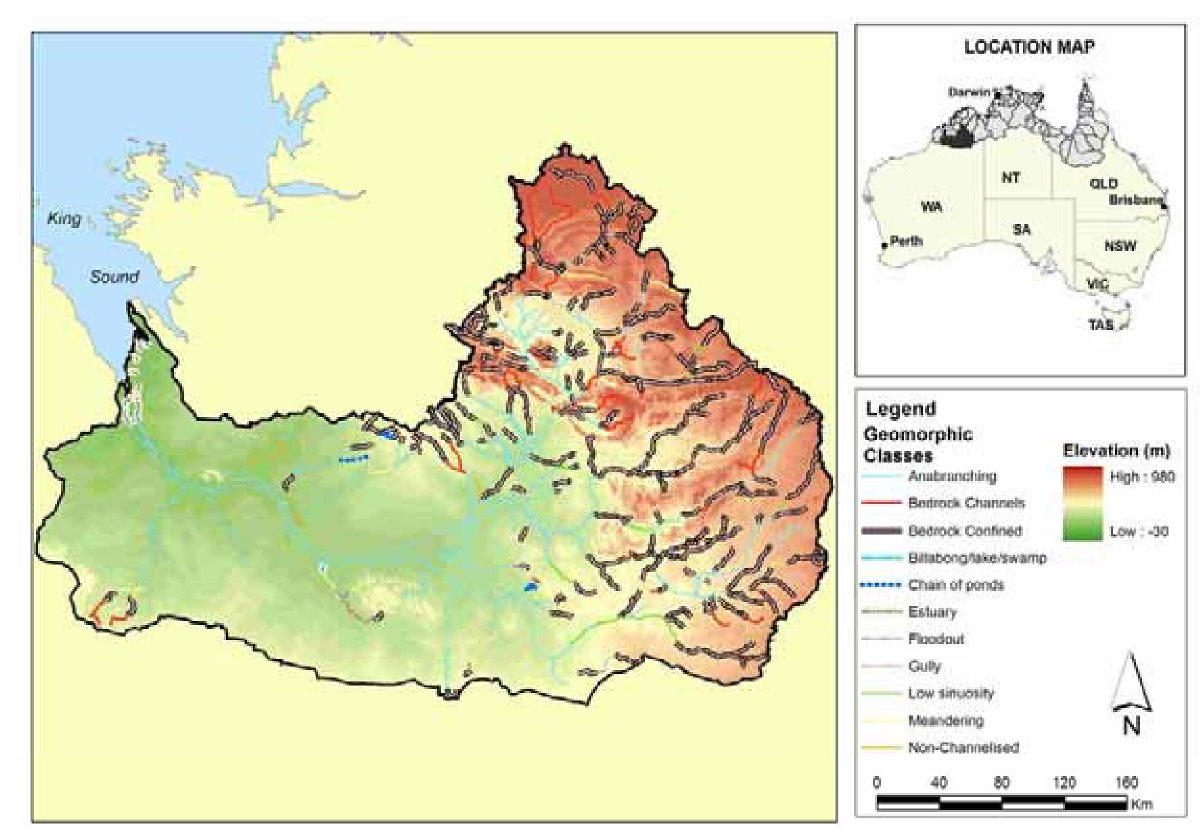

Figure 4. Mapped river types for river reaches of the Fitzroy River catchment, WA.

Table 3. Percentage of total river length for each river type in the Fitzroy River catchment, WA. For distribution of river types, see Figure 4.

RIVER TYPE	**PERCENTAGE OF TOTAL CHANNEL LENGTH**
1. Bedrock River	7.48
2. Confined and Constrained River	38.52
3. Low Sinuosity River	2.14
4. Meandering River	3.70
5. Wandering River	0
6. Anabranching River	44.68
7. Chain of Ponds	0.49
8. Gully	0.30
9. Floodout	0.49
10. Lakes, Swamps and Billabongs	0.07
11. Non-Channelised Valley Floors	0.76
12. Estuarine Rivers	1.37

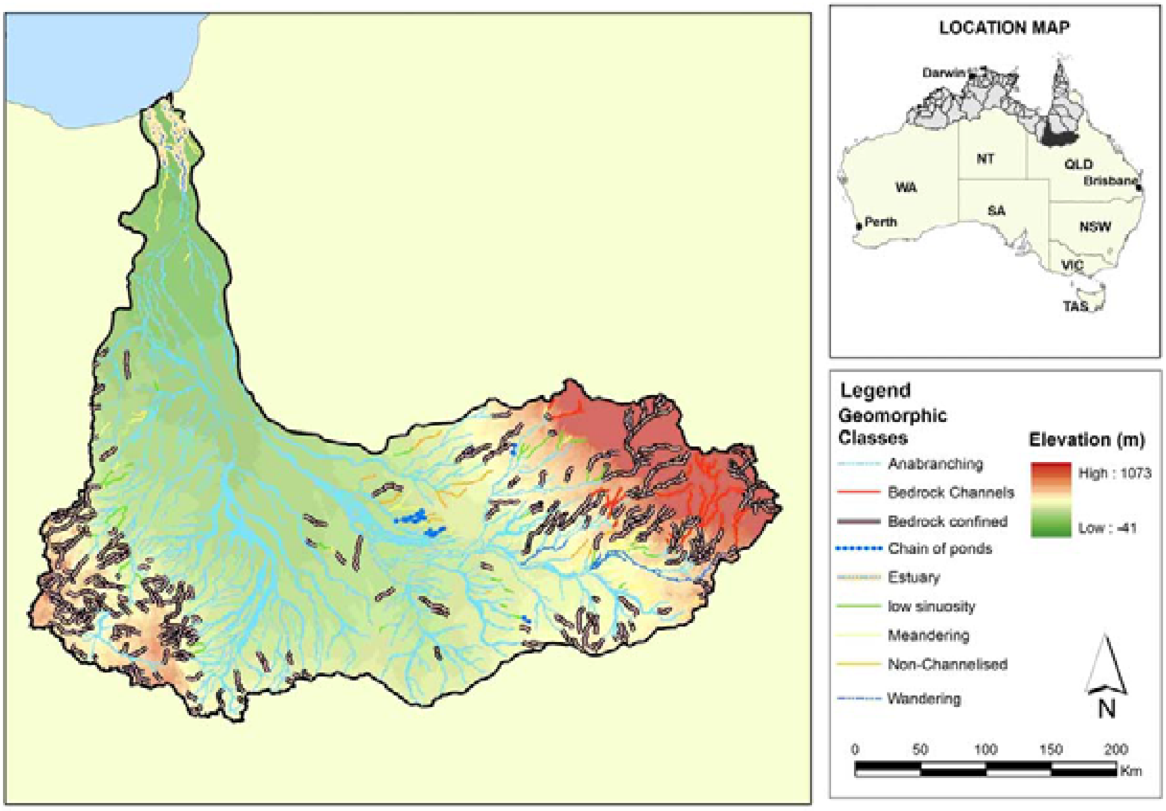

Figure 5. Mapped river types for river reaches of the Flinders River catchment, Qld.

Table 4. Percentage of total river length for each river type in the Flinders River catchment, Qld. For distribution of river types, see Figure 5.

RIVER TYPE	**PERCENTAGE OF TOTAL CHANNEL LENGTH**
1. Bedrock River	1.94
2. Confined and Constrained River	13.22
3. Low Sinuosity River	1.50
4. Meandering River	2.63
5. Wandering River	0.9
6. Anabranching River	77.77
7. Chain of Ponds	0.32
8. Gully	0
9. Floodout	0
10. Lakes, Swamps and Billabongs	0
11. Non-Channelised Valley Floors	0.80
12. Estuarine Rivers	0.92

Table 5. Percentage of total river length for each river type for all three focus catchments, the Daly, Fitzroy and Flinders catchments.

RIVER TYPE	**PERCENTAGE OF TOTAL CHANNEL LENGTH**
1. Bedrock River	3.64
2. Confined and Constrained River	22.01
3. Low Sinuosity River	1.93
4. Meandering River	3.54
5. Wandering River	0.63
6. Anabranching River	64.66
7. Chain of Ponds	1.38
8. Gully	0.06
9. Floodout	0.09
10. Lakes, Swamps and Billabongs	0.12
11. Non-Channelised Valley Floors	0.87
12. Estuarine Rivers	1.09