Flow guidelines for water management agencies

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TRaCK

Tropical Rivers and Coastal Knowledge

Water Management Planning					
	Guideline	Summarised scientific findings	TRaCK project	Further info	Project leader or contact
1	Stakeholders and Indigenous communities must be actively engaged throughout water management planning.	Successful water management planning depends on stakeholders being engaged throughout, which in turn depends on genuine inclusiveness, clarity, transparency and equity in decision-making processes. Early engagement is recommended to gather information, determine issues and help prioritise issues which need a participatory approach to problem-solving.	1.3 Collaborative water planning 6.5 Fitzroy River Sustainable Livelihoods	TRaCK website	Poh Ling Tan, Griffith University Anne Poelina, Madjulla Inc.
2	Stakeholder and Indigenous community expectations, and challenges, are consistent across northern Australia.	Challenges which need to be met in the water management planning process across the region relate to 1) stakeholder understanding of technical and planning issues, 2) Indigenous understanding of water planning implications, and 3) robust decision-support systems to understand and manage uncertainty.	1.3 Collaborative water planning	TRaCK website	Poh Ling Tan, Griffith University
3	Valuing and managing water primarily for irrigated agriculture is not a common view.	Australians place a higher value on environmental, recreational and Aboriginal cultural values than production-based services (i.e. irrigated agriculture) provided by tropical rivers.	2.1 Value of Australia’s tropical rivers	TRaCK website	Anna Straton/John Ward, CSIRO
4	The ability for Aboriginal people to use important waterholes for customary activities (e.g. wildlife harvest) must be taken into consideration in planning.	The ecosystem services provided by tropical rivers and valued most highly by Australians is the ability for Aboriginal people to undertake their customary activities at important waterholes.	2.1 Value of Australia’s tropical rivers 2.2 Indigenous socioeconomic	TRaCK website	Anna Straton/John Ward, CSIRO Sue Jackson, CSIRO

			values and river flows		
5	The contribution of the Customary sector (e.g. wildlife harvest) to the Indigenous economy should be recognised in addition to the Market (e.g. employment) and State (e.g. welfare) sectors.	Indigenous people in the Daly River (NT) and Fitzroy River (WA) catchments rely heavily on the harvest and consumption of aquatic species, and the use of these species makes a direct contribution to household income. Reductions in the Indigenous harvest is likely to result in increased expenditure for household budgets. We recommend using a "hybrid economy" approach which recognises the contribution of the Customary sector (e.g. wildlife harvest) in addition to the Market (e.g. employment) and State (e.g. welfare) sectors.	2.2 Indigenous socioeconomic values and river flows	TRaCK website	Sue Jackson, CSIRO
6	The Indigenous economy is unlikely to benefit from growth in the non-Indigenous economy.	Indigenous and non-Indigenous economic systems are asymmetrically divided: growth in the Indigenous economy will benefit the non-Indigenous economy, but growth in non-Indigenous sectors (e.g. agriculture) will generally not flow on through to Indigenous people. The exception is with structural change (i.e. employment, ownership of resources).	3.1 People and the economy	TRaCK website	Natalie Stoeckl, James Cook University
7	Modest growth in water-intensive agricultural activities could rapidly deplete available water resources.	Expansion of the agricultural sector by 5% per annum, particularly if water-intensive practices are employed, could double water use in a short period, e.g. by 2018 in the Mitchell River (QLD), by 2012 in the Daly River (NT).	3.1 People and the economy	TRaCK website	Natalie Stoeckl, James Cook University
8	Cultural flows are important to Indigenous people.	Cultural flows are important to Indigenous people and are distinct from consumptive uses of water.	6.1 Water markets	TRaCK website	Quentin Grafton, Australian National University

9	The trade of environmental and cultural flows is not supported by stakeholders.	While just over half of the surveyed population viewed water as a tradeable commodity, people did not want to see trade in environmental or cultural flows, and a number of these people imposed a caveat that any trading framework must involve Indigenous people. Respondents believed that the ability to trade water would reduce wastage, but wanted unique cultural and ecological values present across the north to be protected. The preservation of certain aquifers and catchments, and that consumptive water use was constrained in these catchments, was also important to respondents.	6.1 Water markets	TRaCK website	Quentin Grafton, Australian National University
10	Land use change can alter sediment sources and loads to northern rivers.	In the Mitchell River, the riverbed sediments are predominantly sourced from alluvial gully erosion, probably initiated or accelerated as a consequence of the switch from Indigenous management to cattle grazing at European settlement. This erosion is occurring predominantly in the riparian zones, which is where the youngest and most productive soils are located, and so is degrading the productivity of alluvial soils for the pastoral industry and the downstream aquatic ecosystem.	4.2 Regional sediment and nutrient budgets 4.4 Bedload transport and alluvial gully erosion	TRaCK website Brooks et al. 2009.	Gary Caitcheon, CSIRO Andrew Brooks, Griffith University
11	Remedial action to reduce sediment delivery in northern catchments should be targeted to riparian zones.	Subsoil erosion in riparian zones contributes a considerably larger proportion of sediments to northern rivers than hillslope erosion from soil surfaces.	4.2 Regional sediment and nutrient budgets	TRaCK website	Gary Caitcheon, CSIRO
12	Flow regimes, riparian zones and catchment land use should be managed to retain aquatic habitat for benthic microalgae.	Benthic microalgae (i.e. biofilm) is a primary energy source supporting fish and food webs in tropical rivers and floodplains. Factors which alter the production of benthic microalgae, e.g. altered dry season flows, altered inundation regimes of floodplains, increased nutrient inputs, altered riparian canopy cover, and disturbance from feral animals or weeds, are likely to alter food web structure and the biomass	5.1 River food webs 5.2 Refugial waterholes	TRaCK website	Michael Douglas, Charles Darwin University Stuart Bunn, Griffith

		of key fish species such as black bream and barramundi. While algae is consumed by fish and invertebrates, nutrients have stronger effects on the biomass of algae than grazing animals. These impacts can be disproportionately greater in disconnected pools of intermittent rivers during the dry season, and in all rivers when flows recommence with storm runoff events in the early wet season.			University
13	Human impacts on Darwin Harbour are minor and localised, and depend on flushing.	Most of the nutrient load in Darwin Harbour comes from the ocean rather than from river or urban inputs. This is due to the large tidal exchange and the relatively low-nutrient inputs from unimpacted rivers. However, sewage inputs in tidal creeks with less flushing (e.g. Buffalo Creek) increase nutrient inputs, which promote algal growth, which in turn increase sediment and nutrient loads, reduce dissolved oxygen, and release nutrients which promote algal growth.	5.4 Catchment development and estuarine health	TRaCK website Burford et al. 2008. Smith et al. 2011.	Michele Burford, Griffith University
14	Managing flows for selected widespread and common species (rather than rare and threatened species) will sustain the economic contribution of aquatic species to Indigenous livelihoods.	Some of the most economically valuable aquatic species harvested by Indigenous communities in the Daly River (NT) and Fitzroy River (WA) catchments are also among the most common and widespread species across these northern catchments. Furthermore, the top five species harvested in each catchment contribute the majority (up to 90%) of the economic value of the total aquatic harvest. However, this contribution is spread across the landscape, and is not necessarily from a subset of sites. In the Daly River catchment these species are long- and short-necked turtles, barramundi, black bream and magpie geese. In the Fitzroy River catchment these species are black bream, fork-tailed catfish, freshwater sawfish, barramundi and cherabin.	2.2 Indigenous socioeconomic values and river flows	TRaCK website	Sue Jackson, CSIRO
15	In the Fitzroy River catchment (WA), freshwater sawfish (a threatened species) comprise an economically	Freshwater sawfish are among the top five species harvested by local Indigenous communities in the Fitzroy River (WA). While this species has listed conservation status, only small	2.2 Indigenous socioeconomic values and river	TRaCK website	Sue Jackson, CSIRO

	valuable species for Indigenous harvesting.	numbers of sawfish are harvested, their relatively large body size provides a substantial and economically valuable food source. A long history of Indigenous harvest combined with the continuing health of sawfish populations suggests that the Indigenous harvest should not necessarily be the focal point of conservation concern.	flows		

Water monitoring					
	Guideline	Summarised scientific findings	TRaCK project	Further info	Project leader or contact
16	Before water quality monitoring is implemented, it should be preceded by a clear plan developed within a framework which incorporates all aspects of monitoring.	In developing plans for water quality (and ultimately river health) monitoring, there is considerable benefit in beginning with a framework to: 1) explicitly link water and land use impacts with their effects on water quality (e.g. by using a pressure/threat – stressor – ecological response model) and ensure the monitoring is integrated , collaborative and linked to management, 2) manage water quality for the multiple beneficial uses of water, 3) provide a basis for continual review and improvement (i.e. adaptive management), 4) provide clear and accessible communication of the purposes and aims of monitoring, and 5) acknowledge that water quality monitoring is more than data collection and includes understanding, design, data storage, management, assessment, reporting and communication.	4.5 Water quality monitoring framework	TRaCK website	Simon Townsend, Charles Darwin University
17	There are constraints on the capacity to successfully apply the Framework for the Assessment of River and Wetland Health (FARWH) in northern Australia.	The Framework for Assessment of River and Wetland Health (FARWH) relies on a sound knowledge of the “reference state” as a comparison against which the degree of impact can be measured, but these sites are often lacking in northern Australia. The FARWH relies on the random selection of sites with equitable spatial coverage and stream order; this is not possible due to the remote location of sites and lack of vehicular access, and occasional failure to secure landholder access to sites. Finally, the FARWH trial conducted in tropical NT and WA was applied to perennially-flowing streams and rivers and in the dry season only; its application to wet season	4.6 Trial of the FARWH	TRaCK website	Simon Townsend, Charles Darwin University

		conditions and wetlands has not been tested.			
18	Site selection for river health assessment should include small streams, and should approximate their contribution to the river network.	Small streams are more vulnerable to health degradation than large rivers. River health monitoring tools, which are based on model predictions from reference site data, need to include small streams and in a proportion that approximates their contribution to the river network under assessment.	4.6 Trial of the FARWH	TRaCK website	Simon Townsend, Charles Darwin University
19	The Flows Stress Ranking (FSR) is a suitable monitoring tool to assess deviations in flow regimes.	The Flow Stress Ranking (FSR) procedure to assess deviations from the natural flow regime was successfully applied to the Ord River (WA) and Darwin River (NT) hydrographic data sets, and also to the Katherine River (NT) where the effect of groundwater extraction on river discharge could be modelled.	4.6 Trial of the FARWH	TRaCK website	Simon Townsend, Charles Darwin University
20	The Tropical Rapid Assessment for Riparian Condition (TRARC) approach is not sensitive to the detection of cattle disturbance in riparian zones.	The Tropical Rapid Assessment for Riparian Condition (TRARC) was applied to the physical form and fringing zones themes in trialling the FARWH (the Framework for Assessment of River and Wetland Health). The results were not strongly correlated to cattle disturbance possibly because there was no impact, the impact was only a small proportion of stream length, and/or the TRARC is not sensitive to small scale, localised disturbances when the scale in question is considerably less than the assessed area. Therefore, alternative methods for riparian zones should be considered such as using the raw data for a subset of TRARC indices rather than the use of categories, or a more focussed effort on the most likely impact, e.g. plot seedling recruitment assessments.	4.6 Trial of the FARWH	TRaCK website	Simon Townsend, Charles Darwin University
21	The Catchment Disturbance index in the FARWH includes a fire component to link fire management with river health assessment.	The catchment disturbance index included a fire component, in recognition of the damage fire can do to fringing zone vegetation and canopy cover, and its contribution to increased catchment erosion.	4.6 Trial of the FARWH	TRaCK website	Simon Townsend, Charles Darwin University

22	The Water Quality index in the FARWH may not be suitable for northern Australian rivers.	The application of the FARWH water quality theme is problematic because it requires a zero score for “polluted” waters and relies on subjective judgement. It also requires knowledge of the ecological impact of water pollution which, with the exception of mine pollution, is poorly understood.	4.6 Trial of the FARWH	TRaCK website	Simon Townsend, Charles Darwin University
23	Open-system diurnal oxygen curves provide a good measure of total photosynthesis.	Photosynthesis as measured by the diurnal oxygen curve method is responsive to light and the *biomass* of primary producers in clear, low-nutrient tropical rivers such as the Daly River (NT).	4.3 Nutrient flux and fine sediments	TRaCK website Townsend et al. 2011.	Simon Townsend, Charles Darwin University
24	Photosynthesis (as measured by diurnal oxygen curves) does not provide a good measure of the production *rate* of plant and algal biomass in clear, low-nutrient tropical rivers such as the Daly River	Photosynthesis (as measured by diurnal oxygen curves) substantially over-estimates primary production by algal and plant biomass in nutrient-limited tropical rivers. Photosynthesis is not inhibited at high light intensities in clear, low-nutrient rivers such as the Daly River (NT), and therefore diurnal oxygen curves are not an effective way to measure the gross *rate* of production of biomass in these types of rivers. (Most carbon fixed by photosynthesis is extruded to the water by algae and plants as dissolved organic material, rather than incorporated into plant biomass.)	4.3 Nutrient flux and fine sediments	TRaCK website Webster et al. 2005.	Barbara Robson, CSIRO
25	Dry season nutrient *concentrations* should be routinely monitored, including both soluble and insoluble forms.	The growth and accumulation of primary producers is constrained, in part, by available nutrients. Nutrients in the water column may be monitored in their soluble form or as a total amount (which includes both soluble and insoluble forms). Both have advantages and disadvantages, but monitoring for both provides the best information. Both organic and inorganic soluble forms should be monitored.	4.3 Nutrient flux and fine sediments	TRaCK website	Simon Townsend, Charles Darwin University Barbara Robson, CSIRO
26	Nutrient *loads* (both organic and inorganic species) should be monitored in low-nutrient rivers such	Increased nutrient loads are a common consequence of changes in land use. Nutrient addition to low-nutrient rivers such as the Daly River (NT) is likely to alter aquatic vegetation	4.3 Nutrient flux and fine	TRaCK website	Barbara Robson, CSIRO

	as the Daly River (NT) to allow early detection of changes to nutrient loads.	assemblages, particularly algae. The Daly River is adapted to low nutrient (nitrogen and phosphorus) concentrations in the dry season, and nitrogen and/or phosphorus limit the biomass of primary producers. Inorganic nutrients are rapidly taken up by aquatic algae, so increased nutrient *loads* may not immediately be reflected in increased nutrient *concentrations*. Any increase in dry-season nutrient stores in the river is likely to result in increased production of fast-growing algae such as *Spirogyra*, possibly at the expense of slower-growing aquatic plants.	sediments		
27	Nutrient loads should be monitored during the dry and at the end of the wet season as flows recede.	In perennial reaches of the Daly River (NT), and possibly other perennial rivers (although this remains to be tested), primary productivity increases over the dry season. During the early dry season, growth of plant biomass (e.g. fast-growing plants like periphyton and *Spirogyra*) is supported by the direct uptake of nutrients from the water column. Later in the dry season, plant biomass (e.g. slower-growing plants like *Vallisneria*) is supported by the recycling of nutrients within benthic communities (e.g. the trapping of nutrients by fast-growing *Spirogyra*), and possibly also by releases from sediment stores. Consequently, nutrient loads towards the end of the wet season are "driving" subsequent dry season production.	4.3 Nutrient flux and fine sediments	TRaCK website	Barbara Robson, CSIRO
28	Water quality monitoring in intermittent rivers should include waterhole volume with nutrient loads.	In low-nutrient intermittent rivers such as the Flinders River (QLD), primary production is dominated by water column algae (phytoplankton) and is nitrogen-limited, so both nitrogen and phosphorus inputs should be considered in their management. Nutrient concentrations and algal biomass in waterholes increase over the dry season as a result of evaporative concentration: nutrient stores do not increase.	4.3 Nutrient flux and fine sediments	TRaCK website	Barbara Robson, CSIRO
29	Despite some consistent patterns in	Vegetation, fish and macroinvertebrate assemblages show	5.1 River food	TRaCK	Michael

	biotic assemblages, there appears to be little capacity for using “surrogates” to represent multiple assemblages.	concordant patterns of spatial variation across river landscapes, but are organised along different sets of environmental gradients and filters. While flows regime and ecosystem size are important in describing the distribution of each assemblage type, there are also other environmental variables which contribute to their distributions. This means one assemblage type cannot be used as a surrogate for either of the other assemblage types. Genetic analyses further indicate that across northern Australia, biodiversity is higher, and species distributions narrower, than previously thought, and that there are distinct areas of high genetic diversity and high endemism.	webs 5.8 Biodiversity & HCVAE	website	Douglas, Charles Darwin University Jane Hughes, Griffith University

Water Assessment and eFlows					
	Guideline	Summarised scientific findings	TRaCK project	Further info	Project leader or contact
30	Rivers of northern Australia can be characterised and grouped according to flow regime type. Flow components which distinguish individual rivers can be identified.	There are six distinct flow regime types in northern Australia, distinguished by perenniality/intermittency, predictability, and the timing of major floods. Most rivers are in one of two flow types: predictable summer highly intermittent (most common, e.g. Fitzroy (WA), Mitchell (QLD)), or stable summer baseflow (i.e. perennial, e.g. Daly (NT)).	3.3 Classification of northern Australian riverine flow regimes	Digital atlas TRaCK website Kennard et al. 2010.	Mark Kennard, Griffith University
31	Flow-ecology relationships and insights relating to ecological function may be transferred between catchments within the same flow type.	The flow regime classification provides a spatial context for individual rivers and a valid foundation for extrapolating findings between catchments. The classification therefore promotes the identification of ecological patterns associated with particular flow regimes and particular flow components.	3.3 Classification of northern Australian riverine flow regimes	Digital atlas TRaCK website Kennard et al. 2010.	Mark Kennard, Griffith University
32	River flows during the early dry season can be sustained by local groundwater stores in the riverbanks; flows can be sustained from deeper aquifers in the later dry season.	In the lower Fitzroy River (WA), river flow over the weeks and months of the early dry season are sourced from local groundwater sources in the river banks. As the dry season progresses, flows are sourced from regional and deeper aquifers. In the Daly River (NT), regional aquifers can sustain flow throughout the year.	4.1 Water budgets	TRaCK website	Richard Cresswell, SKM
33	Altering catchment vegetation can alter hydrology: native savannah vegetation maintains relatively constant water use year-round.	In the Daly (NT), pastoral vegetation uses more water in the wet season and less in dry season, whereas native savannah vegetation uses water comparatively constantly year-round. In areas vegetated by native savannah, soils dry out more during the dry season, hence groundwater recharge is lower during the wet season.	4.1 Water budgets	TRaCK website	Richard Cresswell, SKM

34	Long-term flow regime patterns can affect channel morphology.	The lower Daly River (NT) has experienced channel widening and extensive bank erosion since the 1970s, supporting the hypothesis that the channel is adjusting to a wetter hydrologic regime over this period. While there has been no net sediment accumulation during this period, the eroded bank sediments appear to have been exported from the reach (and potentially deposited in the estuary), and the riverbed sediments in the lower Daly River appear to have been sourced from upstream (but this remains to be investigated).	4.2 Regional sediment and nutrient budgets 4.4 Bedload transport and alluvial gully erosion	TRaCK website Wasson et al. 2010.	Gary Caitcheon, CSIRO Andrew Brooks, Griffith University
35	Wet season flows are important in structuring channel morphology from year to year.	In the Daly River (NT), greater magnitude wet season flows due to wetter conditions since 1966 have contributed to greater bank erosion and channel widening. In the Mitchell River (QLD), wet season flows can move large amounts of bed sediments, e.g. 50 million m^3/yr between 1988-2007. The bed sediments of the Mitchell River are highly dynamic, e.g. about 40% of the suspended sediments consist of sands, which results in a highly dynamic distribution of permanent pools from year to year despite the total pool area being constant.	4.4 Bedload transport and alluvial gully erosion	TRaCK website	Andrew Brooks, Griffith University
36	Hydraulic and hydrodynamic models of perennial rivers should appropriately model the impact of hydraulic breaks.	Dry season flows in perennial rivers such as the Daly River (NT) are controlled by hydraulic breaks, i.e. relatively sharp drops in water surface levels along the river channel. The choice of hydraulic or hydrodynamic models for the Daly River must be guided by the capacity of the model to include the impact of hydraulic breaks (not all models do so). Accurate modelling of river hydraulics and water surface levels under different flow conditions will require detailed bathymetry that is capable of properly defining the hydraulic breaks.	4.3 Nutrient flux and fine sediments	TRaCK website	Barbara Robson, CSIRO

37	Dry season baseflows in perennial rivers should be protected to maintain instream habitat diversity, particularly gravel runs and pools, for algal communities.	In perennial rivers, the hydraulic environment during the dry season is dependent on river flow and bathymetry. Gravel runs and pools are maintained by dry season baseflows and are key habitats for benthic microalgae which contribute to most primary production in the Daly River (NT). A reduction in baseflow will alter the hydraulic environment, therefore will alter the distribution and abundance of velocity "patches", and will generally reduce the area of riverbed subject to relatively high velocities and shear stress. The ecological significance of this is poorly understood, although there is evidence that it will negatively affect primary production. Small reductions in dry season baseflows could have disproportionately large effects on productivity and habitat availability.	4.3 Nutrient flux and fine sediments	TRaCK website Townsend & Padovan 2009.	Barbara Robson, CSIRO
38	Dry season baseflows in perennial rivers should be protected to maintain the movement of fine sediments over the dry season and prevent infilling of pools.	Sediments are highly dynamic during the dry season in perennial rivers such as the Daly River (NT). Continual reworking of the bed sediments moves fine sediments into pools and gravel beds, increasing the organic content of gravel beds over the course of the dry season. Water flows through sand ripples, penetrating 5-10 cm before being advected back into the water column. Sand ripples are potentially important zones for bacterial breakdown of organic material and nutrient recycling, but this remains a knowledge gap.	4.3 Nutrient flux and fine sediments	TRaCK website	Barbara Robson, CSIRO
39	Seasonal flow patterns should be preserved to maintain aquatic plant community structure.	Plant biomass (including algal biomass) is strongly affected by seasonal changes in flows. Sloughing or scouring of benthic plant material occurs under higher flows, and nutrient transfer rates decrease under low flows, both of which play an important role in the seasonal distribution and relative abundance of different species.	4.3 Nutrient flux and fine sediments	TRaCK website	Barbara Robson, CSIRO

40	Dry season baseflows in perennial rivers should be protected to maintain instream habitat diversity, particularly gravel runs and riffles, for instream biota.	Rocky riffles and gravel runs in perennial rivers are key areas for the growth of benthic microalgae (i.e. biofilm), which is a primary food source supporting fish and food webs in tropical rivers. Riffles are key areas for the emergence of adult aquatic insects, which are an important link to terrestrial food webs by providing food for fauna such as spiders, birds and bats. Aquatic insect emergence peaks in the dry season. Riffles are also key areas for the juveniles of numerous fish species where they are safe from predation and can access food resources (e.g. black bream, Butler’s grunter).	4.3 Nutrient flux and fine sediment 5.1 River food webs 5.5 Flow-ecology relationships	TRaCK website	Simon Townsend, Charles Darwin University Michael Douglas, Charles Darwin University Brad Pusey, Griffith University
41	Permanent waterholes in intermittent rivers and on floodplains are critical aquatic refugia and should be preserved.	Waterholes remaining in intermittent river channels and on floodplains are critical habitats for aquatic biota during the dry season, as well as for terrestrial biota which rely on aquatic resources (e.g. birds). Wet season flows inundate floodplains, which influences the persistence of permanent waterholes throughout the dry season (there is little evidence for groundwater inputs sustaining waterholes across most of northern Australia). These waterholes are refugia for aquatic biota, such as algae, vascular plants, invertebrates and fish, during the dry season. They also provide food resources, e.g. plants, invertebrates, adult insect emergence and fish, for terrestrial consumers such as birds, bats and other biota that rely on aquatic food resources. Predation and competition can become more intense over the course of the dry season as these habitats retract; similarly, physical conditions can also become harsh as dissolved oxygen decreases and turbidity increases. Refugial habitats also provide the biotic resources for recolonising newly inundated and connected habitats once flows resume in the wet season. Local impacts such as nutrient inputs and disturbance from feral animals and	5.1 River food webs 5.2 Refugial waterholes	TRaCK website Pettit et al. 2011.	Michael Douglas, Charles Darwin University Stuart Bunn, Griffith University

		weeds, can have disproportionately greater effects in these isolated waterholes.			
42	Wet season flows should be preserved to maintain instream habitat supply.	Wet season flows are important for redistributing instream habitat, e.g. wood aggregations, sediment turnover, scouring rockbars, all of which provide habitat for benthic algae, invertebrates, fish, birds and crocodiles during the dry season. Wet season flows move large amounts of wood in the Daly River (NT), redistributing around 50% of aggregated wood and resulting in a high degree of habitat turnover and heterogeneity for instream biota from year to year. Modifications to wet season flows can reduce instream habitat and turnover.	5.1 River food webs 5.5 Flow-ecology relationships	TRaCK website	Michael Douglas, Charles Darwin University Peter Davies, University of Western Australia
43	Wet season flows should preserve hydrological connectivity between rivers and floodplains.	Wet season flows are necessary for reconnecting floodplains (and their waterholes) with the river, allowing nutrient and sediment exchange, providing opportunities for fish, invertebrate and plant growth (including algae), and critical food sources and nesting habitats for waterbirds. There is good evidence that the growth of microalgae on inundated floodplains during the wet season is consumed by fish, even during relatively short inundation periods. Macroinvertebrates and small fish (e.g. bony bream, eel-tailed catfish) are then responsible for transferring this energy by being key prey items for “higher-value” species such as barramundi and fork-tailed catfish. Fish put on considerable, and rapid, tissue growth during this time and carry this floodplain “signal” back to refugial areas such as rivers, waterholes and coastal areas during the dry season. It appears that the strength of this reliance is positively related to the period of floodplain inundation. Thus the provision of food resources and habitats during wet season inundation of floodplains can have far-reaching effects on biotic populations and communities, well into the following	5.1 River food webs 5.2 Refugial waterholes 5.3 Floodplain food webs	TRaCK website Jardine et al. *In review a*.	Michael Douglas, Charles Darwin University Stuart Bunn, Griffith University

		dry season. Reduced flows which reduce the extent of floodplain inundation are most likely to adversely affect small off-channel waterholes on the lower floodplain, and can exacerbate harsh physical conditions in waterholes at the end of the dry season.			
44	Riparian zones provide a critical link between aquatic and terrestrial food webs.	Terrestrial inputs from the riparian zone contribute to the diets of aquatic fauna. Terrestrial leaves can be utilised by microbial communities and benthic macroinvertebrates, particularly when canopy cover is heavy and reduces light inputs for algal growth. Terrestrial arthropods contribute to the diets of a range of aquatic fauna such as invertebrates, fish and crocodiles.	5.1 River food webs	TRaCK website	Michael Douglas, Charles Darwin University
45	Flow regime plays a key role in structuring biodiversity and species distributions.	Vegetation (both riparian and aquatic), fish and invertebrate assemblages display spatial concordance in their distributions: each assemblage differs between the Daly (NT) and Fitzroy (WA) catchments, and between main channels, tributaries and waterholes within catchments, in the same way as the other two assemblage types. Vegetation, fish and invertebrate assemblages are structured along a particular set of environmental gradients (meaning one assemblage type cannot be used as a surrogate for overall biodiversity), but flow regime and ecosystem size are important for all three assemblage types. Species diversity is higher in hydrologically connected, perennial systems. In particular, there is distinct genetic diversity in some fish species of the Daly River, and the northern Kimberley has a high degree of endemism (i.e. species not found anywhere else).	5.1 River food webs 5.8 Biodiversity & HCVAE	TRaCK website	Michael Douglas, Charles Darwin University Jane Hughes, Griffith University
46	Flow regime influences the strength of consumer-resource coupling within food webs.	Strength of coupling between fish consumers and their energy sources is related to hydrological connectivity: coupling is stronger in food webs which are more	5.1 River food webs	TRaCK website Jardine et	Michael Douglas, Charles Darwin

		hydrologically isolated (e.g. the Fitzroy River (WA)), and weaker in food webs which are more hydrologically connected, or perennial (e.g. The Daly River (NT)). Hydrological connectivity promotes the movement of fish and higher-order consumers, so they can access and integrate energy sources across a range of locations across the riverine landscape and thus weaken coupling to site-specific resources. Local impacts on benthic algae can have disproportionately greater effects on food webs in hydrologically isolated systems because consumers, being unable to move between locations, are more strongly coupled to site-specific resources.		al. *In review b*.	University
47	Flow regime, and the consequent degree of hydrological connectivity, plays a role in structuring aquatic food webs.	Food web structure, as described using community-wide metrics, can vary between catchments. While much of this variation is unexplained, it appears that facets of food web structure (e.g. diversity of basal resources, average trophic diversity, and total niche space) are explained by difference in flow regime and the degree of hydrological connectivity: all are greater in more hydrologically-connected systems. This suggests that hydrological connectivity promotes the movement of high-order consumers throughout river landscapes, thereby integrating signatures from numerous locations and resulting in greater trophic diversity. Instream habitat and nutrients also contribute to the observed spatial variation in food web structure. Together, these findings suggest that factors which may disrupt food web stability (such as altered flows, riparian canopy cover, nutrient inputs, instream barriers) can affect energy sources underpinning food webs and consequently resources for fisheries and Indigenous livelihoods.	5.1 River food webs	TRaCK website	Michael Douglas, Charles Darwin University
48	Water quality in disconnected waterholes can be naturally	Seasonal effects on water quality and primary production in disconnected waterholes appear to be as strong as	5.1 River food webs	TRaCK website	Michael Douglas,

	highly variable.	ecological effects. That is, waterholes in the late dry season have vastly different physical (e.g. turbidity) and chemical (e.g. nutrients, chlorophyll) properties compared to the same waterholes early in the dry season after floodwaters recede. This is true for sites with and without major disturbances from cattle and feral pigs, so any efforts to quantify the effects of these introduced animals or other pressures must take into account the large and natural seasonal variation. However, there exist few locations that are truly pristine that could allow determination of pre-European conditions.	5.2 Refugial waterholes		Charles Darwin University Stuart Bunn, Griffith University
49	Floodplain residence times can be highly variable across northern Australia.	Western Cape York (QLD) rivers are dominated by large distributary fan systems that have a low inundation frequency and are generally only inundated for a short time (e.g. around two months in a wet year). In these distributary fan systems the floods recede in a “wedge” manner such that waterbodies in the upper fan are inundated for a relatively short period compared to the lower more coastal part of the distributary fan. Similarly, the vast floodplains of the Southern Gulf (QLD) have extensive floods occurring across complex anabranching drainage networks but with relatively short inundation periods. The Fitzroy (WA) floodplain is the most dominant floodplain in the western part of the TRaCK study area and has large but short duration floods (less than two months in a wet year); flood inundation is more confined to the areas adjacent to the main channel and the flood events occur as ‘pulse’ such that most waterbodies on the floodplain are inundated for approximately the same period regardless of catchment position. The areas of highest inundation frequency and longest flood residence times in the TRaCK study area occur across the northernmost parts of the NT and include Alligator (Kakadu wetlands), Goyder (Arafura Swamp), and	5.3 Floodplain food webs	TRaCK website	Stuart Bunn, Griffith University

		Daly-Douglas river systems. The Daly floodplain differs significantly from the Mitchell and the Fitzroy with long flood residence times (greater than 6 months), the majority of the floodplain being dominated by aquatic vegetation, and floods gradually recede to large perennial waterbodies. It appears that food webs in catchments with longer flood and flow periods have weaker coupling between fish consumers and their local, site-specific resources, but are more connected between locations due to the movements of fish across the river landscape.			
50	Wet season floods affect estuarine and coastal productivity.	Experiments in the Norman River (QLD) estuary indicate that freshwater inundation of saltflats can release nutrients and increase chlorophyll *a*, thereby increasing coastal productivity. But sustained flooding in the Southern Gulf coincided with reduced salinity, reduced algae and meiofauna on the mudflats, and a migration of banana prawns out of the Norman River estuary. Post flooding, there is evidence that mudflat productivity is enhanced, but not water column productivity. Floodplumes from the Norman River result in large areas of freshwater in the coastal areas, with freshwater fish and crustacean species replacing estuarine species.	5.4 Catchment development and estuarine health	TRaCK website Burford et al. 2009.	Michele Burford, Griffith University
51	Modifications to dry season flows in perennial rivers which narrow the range of, or alter, current velocities will impact benthic communities.	Benthic algal biomass is highly variable over different current velocities, resulting in heterogeneous patchiness of growth over the riverbed, which has been shown to support high abundance and diversity of instream fauna. Macroinvertebrate assemblages differ between patches of low and high current velocity, with high velocity areas (about 0.8 m/s) supporting unique species which are not found in other areas. However, once velocities increase beyond 1 m/s, there appears to be a decline in macroinvertebrate abundance and diversity.	5.5 Flow-ecology relationships	TRaCK website	Peter Davies, University of Western Australia

52	Alterations to flow regimes which introduce, or increase, intermittency, will reduce fish habitat and diversity and alter fish assemblages.	Fish assemblages are structured by the interaction of landscape, instream habitat and flow regime. Fish assemblages in intermittent rivers and reaches are a subset of assemblages found in perennial reaches; intermittent reaches have fewer species, fewer large-bodied species, fewer large individuals and fewer predators.	5.5 Flow-ecology relationships	TRaCK website	Brad Pusey, Griffith University
53	Many tropical fish species require hydrological connectivity to be able to move between reaches.	Many fish species need to move between riverine reaches for migration, spawning and dispersal: one third of species recorded in the Daly River (NT) need to move between estuarine and freshwater reaches for spawning (e.g. barramundi, freshwater sole), and one third need to move between different freshwater reaches for spawning (e.g. black bream, plotosid catfish). The distance of movement upstream appears to be limited only by flow intermittency, so flow alterations which introduce intermittency will affect fish movement. Instream barriers will also disconnect river reaches and impede fish movement.	5.5 Flow-ecology relationships	TRaCK website	Brad Pusey, Griffith University
54	Seasonal hydrology and timing is important for fish migration and spawning.	There are four migration "guilds" of fish: 1) fish species whose juveniles migrate upstream from estuaries during the wet season (e.g. barramundi, freshwater sole), 2) species who migrate between freshwater reaches to spawning sites in the wet season (e.g. black bream, plotosid catfish), 3) species who migrate between freshwater reaches during the dry season (e.g. longtom, bony bream), and 4) species that move and spawn all year round (e.g. rainbowfish, hardyheads). Modifications to either wet season or dry season flows can affect the movement and spawning of numerous fish species.	5.5 Flow-ecology relationships	TRaCK website	Brad Pusey, Griffith University
55	The transition periods between the wet and the dry seasons (and vice versa) are key times	In perennial reaches of the Daly River (NT), flows go through a clearwater phase during the transition periods between the wet and dry seasons due to groundwater inputs. The	5.5 Flow-ecology	TRaCK website	Peter Davies, University of Western

	for biotic production and movement.	timing of this clearwater phase depends on the ratio of surface water volume to groundwater volume. The clearwater phase promotes the growth of aquatic plants (e.g. benthic algae and vascular plants) which provide food and habitat for macroinvertebrates, fish and turtles. In tributaries of the Daly River, these transition periods coincide with increases in algal biomass and the abundance of aquatic invertebrates. The transitions between the wet and dry seasons are also key times for the movement of fish in Daly River tributaries: fish move upstream during the early wet season, and downstream in the late-wet/early-dry season. The abundance of fish moving downstream during the late-wet season is greater in intermittent tributaries without permanent water, suggesting the movement is related to finding refuge for the dry season. Flow modifications which disrupt the timing of these transition periods, or alter their duration, can negatively affect benthic production and fish movement.	relationships	Warfe et al. *In review*.	Australia
56	Interannual variability in wet season flows influences variation in fish assemblages.	Sampling over longer time periods (i.e. more years) provides a far more complete picture of interannual changes in fish assemblages: for example, the abundance of predators in the Daly River (NT) has been considerably greater in years 3 and 4 of sampling compared to the first two years. It is possible that fish assemblages are returning to pre-flood conditions after major flooding in 2006. Multiple years of sampling are required to properly understand variation in fish assemblage structure.	5.5 Flow-ecology relationships	TRaCK website	Brad Pusey, Griffith University
57	Dry season water extraction in perennial rivers can increase the risk of habitat loss for numerous fish species.	Qualitative modelling of fish habitat under future water use scenarios indicates that dry season water extraction in the Daly River catchment (NT) will increase the risk of habitat loss for 40 species, although some species are at considerably higher risk than others, e.g. black bream,	5.5 Flow-ecology relationships	TRaCK website	Mark Kennard, Griffith University

		barramundi, both of which are species of socioeconomic importance.			
58	Dry season water extraction in perennial rivers can reduce the abundance of key fish species.	Modelling of future water use scenarios indicates that flow reduction in the Daly River (NT) during the dry season will double the risk of “extremely low” abundances of black bream and barramundi. Both species are among the most economically important species harvested by local Indigenous communities, and barramundi are also an important recreational fishery in the Daly River.	5.5 Flow-ecology relationships 2.2 Indigenous socioeconomic values and river flows	TRaCK website	Mark Kennard, Griffith University Sue Jackson, CSIRO
59	Commercial and recreational fisheries catch is linked with the scale of freshwater flows.	Freshwater flows flush estuarine species of commercial interest into deep waters, making them accessible to commercial and recreational fisheries. Freshwater species, or species tolerant of freshwater, replace estuarine species in the estuaries during the wet season, increasing food availability and hence recreational fisheries stocks.	5.4 Catchment development and estuarine health	TRaCK website	Michele Burford, Griffith University
60	Altered wet season flows, both magnitude and timing, are likely to reduce the recruitment and catch of coastal fisheries.	Coastal finfish production (i.e. catch) is positively correlated with wet season flows, with increased catchability within the year of the flow. Recruitment of barramundi is positively correlated with early wet season flows (i.e. in December). This appears to be fairly consistent between tropical estuaries.	5.6 Flow impacts on estuarine finfish	TRaCK website	Ian Halliday, Fisheries Queensland
61	Flow modifications which reduce the abundance and diversity of aquatic species can negatively affect household incomes of local communities.	Indigenous people in the Daly River (NT) and Fitzroy River (WA) catchments rely heavily on the harvest and consumption of aquatic species, and the use of these species makes a direct contribution to household income. Reductions in the Indigenous harvest is likely to result in increased expenditure for household budgets. However, a lack of information on customary fisheries (e.g. harvest impact versus harvest success) makes it difficult to specify	2.2 Indigenous socioeconomic values and river flows	TRaCK website	Sue Jackson, CSIRO

		exactly how the Indigenous harvest may be affected by flow alterations.			
62	Both wet season and dry season flows sustain the few species that are of most economic value to Indigenous households.	The top five species harvested by local Indigenous communities in the Daly River (NT) and Fitzroy River (WA) catchments, which contribute up to 90% of the total aquatic harvest, span the entire flow regime. Barramundi and black bream require dry season flows to be maintained, especially over shallow riffle areas, cherubin require late wet season flows for upstream migration, and turtles and magpie geese have nesting requirements met by wet season flows.	2.2 Indigenous socioeconomic values and river flows	TRaCK website	Sue Jackson, CSIRO
63	Indigenous harvest of aquatic resources is strongly seasonal and can vary between catchments due to the strong dependence on accessibility to aquatic habitats.	Patterns of Indigenous use of aquatic resources can be spatially and seasonally variable. For example, in the Fitzroy River (WA) catchment the frequency of harvesting trips is at its highest during the wet season, whereas in the Daly River (NT) it is at its lowest during the wet season. In the Fitzroy catchment, harvesting activities are concentrated on the main river channel; more than 70% of harvesting trips are to the main channel regardless of season. In the Daly catchment, the main channel is the focus for harvesting activities during the wet season, but during the dry season harvesting activities are focussed on floodplain waterholes; up to 70% of trips during the late dry season are to billabongs. This switch does not occur in the Fitzroy River catchment.	2.2 Indigenous socioeconomic values and river flows	TRaCK website	Sue Jackson, CSIRO

Water impacts and management					
Guideline		Summarised scientific findings	TRaCK project	Further info	Contact
64	Land use change can alter sediment sources and loads to northern rivers.	In the Mitchell River, the riverbed sediments are predominantly sourced from alluvial gully erosion, probably initiated or accelerated as a consequence of the switch from Indigenous management to cattle grazing at European settlement. This erosion is occurring predominantly in the riparian zones, which is where the youngest and most productive soils are located, and so is degrading the productivity of alluvial soils for the pastoral industry and the downstream aquatic ecosystem.	4.2 Regional sediment and nutrient budgets 4.4 Bedload transport and alluvial gully erosion	TRaCK website Brooks et al. 2009 *Earth Surface Processes and Landforms* 34:1951	Gary Caitcheon, CSIRO Andrew Brooks, Griffith University
65	Remedial action to reduce sediment delivery in northern catchments should be targeted to riparian zones.	Subsoil erosion in riparian zones contributes a considerably larger proportion of sediments to northern rivers than hillslope erosion from soil surfaces.	4.2 Regional sediment and nutrient budgets	TRaCK website	Gary Caitcheon, CSIRO
66	Flow regimes, riparian zones and catchment land use should be managed to retain aquatic habitat for benthic microalgae.	Benthic microalgae (i.e. biofilm) is a primary energy source supporting fish and food webs in tropical rivers and floodplains. Factors which alter the production of benthic microalgae, e.g. altered dry season flows, altered inundation regimes of floodplains, increased nutrient inputs, altered riparian canopy cover, and disturbance from feral animals or weeds, are likely to alter food web structure and the biomass of key fish species such as black bream and barramundi. While algae is consumed by fish and invertebrates, nutrients have stronger effects on the biomass of algae than grazing animals. These impacts can be disproportionately greater in disconnected pools of intermittent rivers during the dry season, and in all rivers when flows recommence with storm runoff events in the early wet season.	5.1 River food webs 5.2 Refugial waterholes	TRaCK website	Michael Douglas, Charles Darwin University Stuart Bunn, Griffith University
67	Human impacts on Darwin Harbour are minor and localised, and depend on flushing.	Most of the nutrient load in Darwin Harbour comes from the ocean rather than from river or urban inputs. This is due to the large tidal exchange and the relatively low-nutrient inputs from unimpacted rivers. However, sewage inputs in tidal creeks with less flushing (e.g. Buffalo Creek) increase nutrient inputs, which promote algal growth, which in turn increase sediment and nutrient loads, reduce dissolved oxygen, and release nutrients which promote algal growth.	5.4 Catchment development and estuarine health	TRaCK website Burford et al. 2008 *ECSS* 79:440	Michele Burford, Griffith University

Water assessment and planning tools					
	Tool	Purpose	TRaCK project	Further info	Project leader or contact
68	Interactive GIS system for classifying tropical rivers according to individual requirements.	Users can develop classifications of tropical rivers according to user-defined input variables from a range of geophysical data, thus allowing tailor-made outputs for specific purposes.	3.2 Classifying river landscapes	Digital atlas TRaCK website	Andrew Brooks, Griffith University
69	Classification of river flow regimes.	The classification can be used to describe a river's flow regime, and to promote and identify ecological patterns associated with particular flow regimes.	3.3 Classification of northern Australian riverine flow regimes	Digital atlas TRaCK website Kennard et al. 2010.	Brad Pusey, Griffith University
70	Qualitative risk assessment of dry season water abstraction on fish assemblages of the Daly River (NT)	Uses habitat and life history information to rank 40 fish species according to their relative risk from dry season water extraction in the Daly River (NT).	5.5 Flow-ecology relationships	TRaCK website	Mark Kennard. Griffith University
71	Bayesian Belief Networks for dry season barramundi and black bream abundances in the Daly River (NT).	Bayesian Belief Networks for barramundi and black bream abundances under future water use scenarios in the Daly River (NT).	5.5 Flow-ecology relationships	TRaCK website	Mark Kennard. Griffith University
72	Map-based metadatabase comprising all TRaCK research.	A map-based database containing all the TRaCK research projects, where they occurred, their associated metadata (i.e. descriptions of data files), and contact details for further information.	1.4 Knowledge integration & science delivery	Digital atlas TRaCK website	Francis Pantus, Griffith University

73	Management Strategy Evaluation (MSE) application.	Application which provides integration between TRaCK science domains and resource management knowledge domains. Delivers the capability to evaluate different water-use scenarios to water resource managers and stakeholders	1.4 Knowledge integration & science delivery	TRaCK website	Francis Pantus, Griffith University
74	Conceptual models of northern riverine structure and function	Conceptual models of how northern Australian river, estuary and floodplain ecosystems are structured and how they function, with an emphasis on seasonal differences.	1.4 Knowledge integration & science delivery 5.7 Flow tools	TRaCK website Warfe et al. *In review*.	Peter Davies, University of Western Australia.

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(all references can also be found on the TRaCK website at www.track.gov.au).

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