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Northern rivers and dams: A preliminary assessment of surface water storage potential for northern Australia

Technical Report

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A report to the Australian Government from the CSIRO

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This report was reviewed by Dr Francis Chiew (CSIRO) and Dr Ian Watson (CSIRO).

Summary Photo 1 A potential dam site on Porcupine Creek (Flinders catchment, Queensland) - looking upstream
Source: Reproduced from Petheram et al., (2013a)

Summary

RATIONALE AND METHOD

This short desktop study was commissioned by the Office of Northern Australia to inform decisions relating to evaluation of northern Australia's land and water resources. The rapid appraisal sought to identify catchments with potential surface water storage sites as well as large contiguous areas of soils suitable for irrigated cropping and horticulture, to indicate catchments where future detailed field studies for irrigation potential might be most productive.

More than 2 billion potential dam sites across northern Australian were assessed in a consistent and objective manner, using the DamSite model. Simultaneous consideration was given to surface water storage potential and the proximity of land resources suitable for development of irrigated cropping and horticulture. DamSite modelling is purely biophysical. It is unconstrained by the regulatory environment, does not consider actual or potential controls on dam development and does not take into account other users or uses of water in the catchment.

Although the study identified a large number of potential surface water storage locations and made broad estimates of areas of land that could potentially be irrigated, it was not designed to scope individual promising dams or to design irrigation areas. A study for these purposes would require a different and more detailed analysis. The results of this study are intended to indicate the catchments in which the opportunities for surface water development in support of irrigated agriculture are most likely. In any case, individual water resource developments are best considered within a whole-of-catchment framework.

SCALE OF NORTHERN AUSTRALIA'S IRRIGATION POTENTIAL

Natural resources (soil, surface water and potential large in-stream dams) sufficient to support 1.4 million ha of irrigated agriculture exist in northern Australia. Development of this area would require approximately 90 of the more viable large in-stream storages (including the Burdekin Falls and Ord River dams, which are already constructed) and a large number of reregulating structures (e.g. weirs). Increasing the area under irrigation in northern Australia to 1.4 million ha would result in an increase of around 50% in Australia's total irrigated area. Approximately 40% of this area (600,000 ha) could be secured by around 20 of the more promising large in-stream storages in northern Australia. Clearly, there are declining marginal returns to dam construction—in part because it is attractive to build the best dams first, but also because additional dams may in some places 'compete' for the same water supply.

CATCHMENTS MOST PROSPECTIVE FOR NEW IRRIGATION DEVELOPMENT

The greatest opportunity for 'greenfield' development to increase surface water storage and broad scale irrigation occurs in the following catchments. Each would require detailed catchment-scale studies to become 'bankable' water development opportunities:

- Mitchell catchment (60,000 to 80,000 ha) in Queensland
- Fitzroy catchment (60,000 to 80,000 ha) in Western Australia
- Archer, Wenlock and Normanby catchments (up to 60,000 ha combined) on Cape York Peninsula in Queensland
- Victoria (20,000 ha to 40,000 ha, potentially more) and Roper (20,000 to 40,000 ha) catchments in the Northern Territory
- a number of small catchments surrounding Darwin, for which multi-purpose (urban, industry, agriculture) water developments may be attractive. Multiple surface water storages in the

Adelaide, Finniss, Mary and Wildman river catchments may be able to support up to 30,000 ha of irrigated agriculture, in addition to the small-scale groundwater-based irrigation currently practised.

The opportunity exists for supplemental irrigation of the approximately 200,000 ha of predominantly rainfed sugarcane currently grown on the narrow coastal plains of the Wet Tropics region (Cardwell to Mossman). The high rainfall in this region means that a small amount of water storage can supplement a relatively large irrigation area. In the drier, upper Herbert catchment, large in-stream storages could potentially irrigate an estimated 20,000 ha of land.

There is also potential for broad scale irrigation development based on large in-stream storages in protected areas within the South Alligator (Kakadu National Park), East Alligator (Arnhem Land) , Daly (Nitmiluk National Park or Katherine Gorge) and Herbert (Girringun National Park) catchments. These areas have not been highlighted as being prospective for new irrigation development because of their current protected status.

LOCATIONS MOST PROSPECTIVE FOR EXPANDED IRRIGATION DEVELOPMENT

Of all the catchments in northern Australia, the Ord and Burdekin appear to offer the most immediate opportunities for irrigation expansion because they currently have large scale water storage that can be more fully used, as well as potential for further storages. The Daly and Fitzroy (Queensland) catchments currently support irrigation; expansion of irrigation in these catchments would require development of new water storage infrastructure.

The existing Ord River Dam is planned to support four distinct irrigation areas:

- Stage 1 of the Ord River Irrigation Area has an area of about 14,000 ha.
- Stage 2 (about 13,400 ha) is currently under development.
- Stage 3 comprises 6,000 ha of land in Western Australia and 14,500 ha in the Northern Territory.

Concerns about soil and groundwater salinity, and flood risk need to be addressed for the Northern Territory component of Stage 3 development if this is to constitute a ‘bankable’ development opportunity.

The Burdekin catchment has both large existing uncommitted water allocations and capacity for construction of additional storage capacity. By raising the existing Burdekin Falls Dam and constructing new in-stream and off-stream storages, an additional ~100,000 ha of irrigated agriculture could be supported. This would more than double the catchment’s current area of irrigated agriculture (about 90,000 ha).

Raising the Burdekin Falls Dam appears to be the most cost-effective way of increasing water allocations in the catchment. This could enable expansion of irrigation in the Lower Burdekin (about 10,000 ha) and along the Elliot Main Channel to Bowen (about 50,000 ha); salinity and erosion risks would need to be addressed for this to become a ‘bankable’ proposition. Raising the Burdekin Falls Dam would also meet future urban demand from Townsville, and enable water to be supplied via pipeline to the Galilee and Bowen basins to support future mining operations.

There are also opportunities for irrigation development in the upper Burdekin catchment (potentially more than 40,000 ha). This would require new large water infrastructure along the Bowen River and upper Burdekin River, and/or an expansion of water harvesting and off-stream storages in the Belyando–Suttor subcatchment.

The Daly catchment has an estimated 2200 ha of irrigated agriculture, with the majority of irrigation water sourced from groundwater. Groundwater in the Daly Basin is fully allocated. Potential in-stream dams in the Daly catchment may support more than 20,000 ha of additional irrigated land. The conjunctive use of groundwater and surface water may present opportunities to manage climate risks, and depletion of groundwater and river baseflow.

The Fitzroy catchment (Queensland) currently has approximately 65,000 ha of irrigated agriculture. Further development of water infrastructure could potentially enable an additional 40,000 to 60,000 ha of irrigated agriculture. The water infrastructure required would include the Nathan dam on the Dawson River and other unspecified structures.

OTHER WATER SOURCES AND STORAGE AND IRRIGATION OPTIONS

Groundwater could support approximately 100,000 to 150,000 ha of irrigated land in northern Australia. This is approximately 10% of the land that could potentially be irrigated using large in-stream storages in northern Australia.

Although large in-stream storages are able to support a greater area of irrigation development, groundwater will often be a more cost-effective option where it is available in sufficient volumes. Groundwater is often overlooked as a source of water for irrigation, largely because the process of characterising groundwater is comparatively expensive and uncertain. When the costs of groundwater characterisation are amortised across a development, however, groundwater will frequently prove more cost-effective than large in-stream storages.

Some parts of northern Australia may lend themself to water harvesting and off-stream storage of water, and managed aquifer recharge. In some cases, there may also be opportunities to augment and extract water from natural waterholes and wetlands to supply farm-scale irrigation developments. Although each of these approaches is capable of supplying far smaller (5–100 times lower) volumes of water than large in-stream dams, each may have a role to play in maximising the cost-effectiveness of water supply.

IMPORTANT CONSIDERATIONS

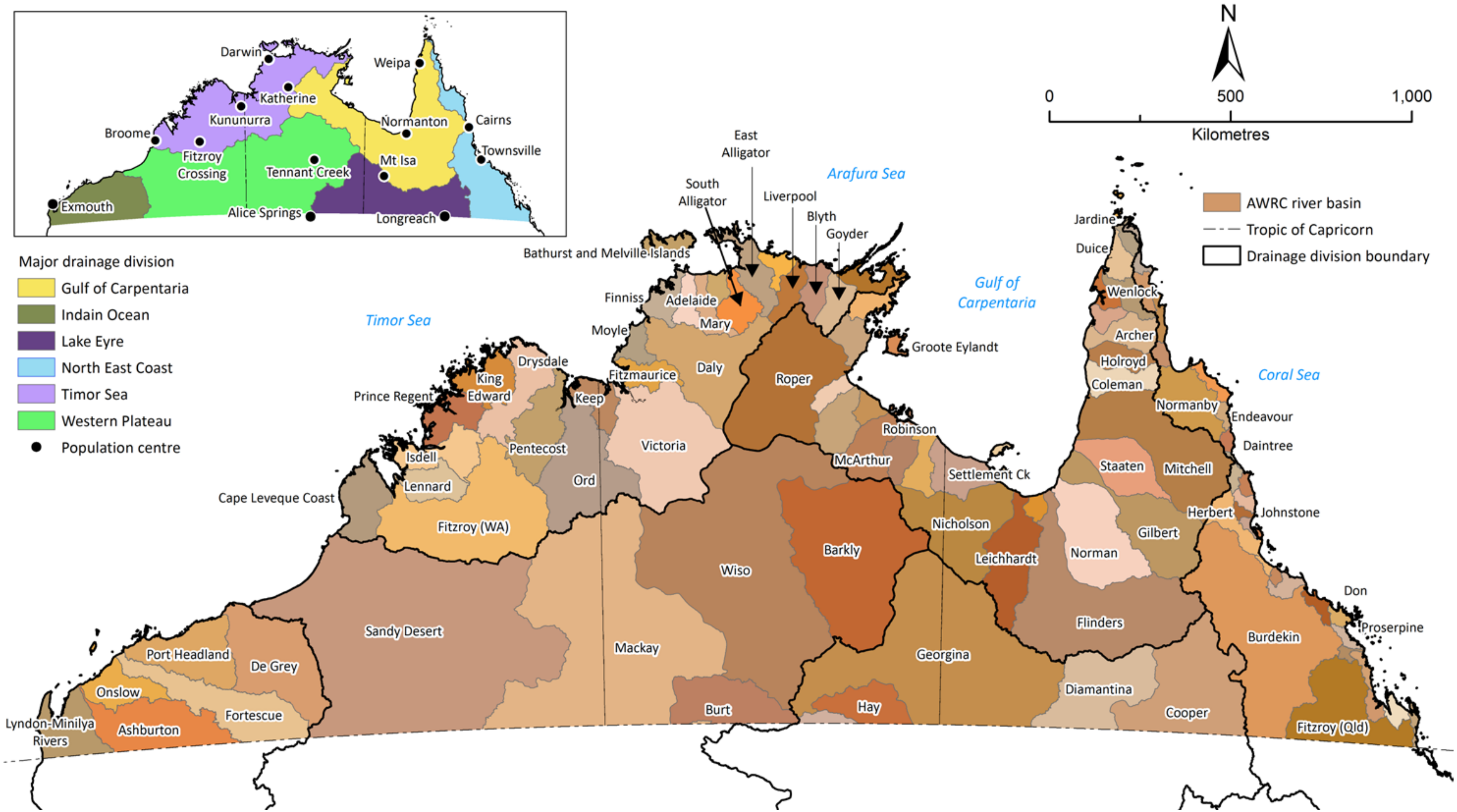
Although this study has used the availability of soil and surface water resources as primary criteria for identifying the potential for irrigated agriculture, other factors are also very important in determining opportunity. These include market opportunities and value chains to meet them, current and potential industries, existing hard (e.g. roads, power) and soft (e.g. schools, hospitals) infrastructure, and local social and cultural conditions. These factors are also likely to inform decisions about priorities for future, more detailed studies.

Changes in water demand can sometimes be met without the need for new water infrastructure. A range of regulatory and market-based approaches to allocating water can ensure that water moves to where it is needed most.

Changes in water demand can be difficult to predict. For this reason, planning for water infrastructure projects should take into account a range of potential and shifting future combinations of water demand, use and pricing, each of which affects the design requirements and investment profile for water infrastructure. Even where a storage development may be conceived solely to meet one demand, such as mining, the potential for other uses, such as irrigation post-mining, should always be contemplated.

Preliminary dam costing, informed by site visits and assessment of the local geology, is a critical component of pre-feasibility studies. To assist with short-listing of dams, pre-feasibility analyses are ideally undertaken within the context of a broader assessment of the soils and agricultural potential of the area, local aspirations and values, and views of existing water users. Such an integrated analysis helps decision makers to take a long-term view of water resource development in a catchment, and to make future water allocation decisions. For example, incremental releases of water for consumptive use or the development of inappropriate large-scale water storages may preclude the development of appropriate large water storages in the future.

Once a dam site has been adopted for feasibility analysis, an iterative process of increasingly detailed investigative studies is typically undertaken. Occasionally, this takes as few as 2 or 3 years, but it may often take more than 10 years. Geotechnical investigations alone sometimes cost several million dollars. At the feasibility stage, it is important that funding for geotechnical investigations is 'front-loaded'. Failure to invest adequately in geotechnical investigations before detailed planning or construction commences can be very costly.



Summary Figure 1 Australian Water Resources Council (AWRC) river basins in northern Australia

The larger AWRC river basins in northern Australia are named. The inset shows the major drainage divisions and key population centres in northern Australia.

Shortened forms

ANCOLD	Australian National Committee on Large Dams
ASC	Australian Soil Classification
AWRA	Australian Water Resource Assessment System
ASRIS	Australian Soil Resource Information System
AWRC	Australian Water Resources Council
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	digital elevation model
DLRM	Northern Territory Department of Land Resource Management
EPA	Environmental Protection Authority
FSL	full supply level
GAB	Great Artesian Basin
HP	High Priority
MAR	managed aquifer recharge
MODIS	Moderate Resolution Imaging Spectroradiometer
MP	Medium Priority
NASY	Northern Australia Sustainable Yields
ONA	the Australian Government Office of Northern Australia
PE	potential evaporation
QLD	Queensland
ROP	Resource Operation Plan
SILO	Database of climate data
WA	Western Australia
WRP	Water Resource Plan

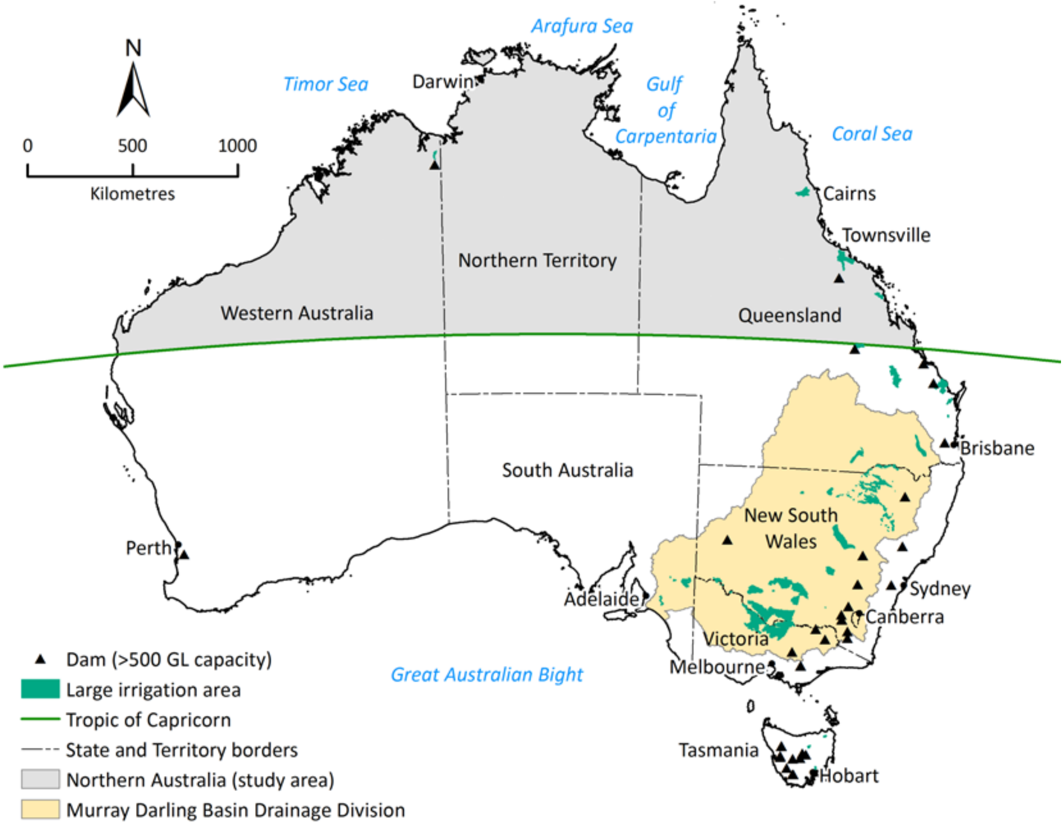
Units

MEASUREMENT UNITS	DESCRIPTION
GL	gigalitres, 1,000,000,000 litres
km	kilometres, 1000 metres
m	metres
mAHD	metres above Australian Height Datum
ML	megalitres, 1,000,000 litres

Preamble

Northern Australia—the area north of the Tropic of Capricorn—comprises approximately 40% of Australia's land mass but remains relatively undeveloped, accommodating around 5% of the total Australian population. Of Australia's irrigated land, only about 8% lies north of the Tropic of Capricorn; the majority (around 50%) is located in the Murray–Darling Basin (Preamble Figure 1).

Recent focus on the shortage of water, and on climate-based threats to food and fibre production in the nation's south have redirected attention towards the possible use of northern water resources and the development of agricultural potential in northern Australia. Broad analyses of northern Australia as a whole have indicated that it is capable of supporting significant additional agricultural and pastoral production, based on more intensive agricultural use of its land and water resources. The same analyses also identified that land and water resources across northern Australia are already being used to support a wide range of highly valued cultural, environmental and economic activities. As a consequence, pursuit of new agricultural development opportunities would inevitably affect existing uses and users of land and water resources.



Preamble Figure 1 Major dams (greater than 500 GL capacity) and large irrigation areas across Australia

Most of northern Australia's land and water resources have not been mapped in sufficient detail to support reliable resource allocation or investment decisions, or to provide policy settings that can support such decisions. More detailed data are required to enable private investment and government expenditure on development to be soundly targeted and designed, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.

The recently completed Flinders and Gilbert Agricultural Resource Assessment[1] in north Queensland developed fundamental soil and water datasets, and provided a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of agricultural development in two catchments of northern Australia. It identified several opportunities for large-scale (>10,000 ha) irrigation development, based on the coincidence of suitable soils and new water storage capacity. It provides a blueprint of the data and analysis required to identify and support actionable development opportunities in northern Australia.

That work covered 155,000 km^2 (approximately 5%) of northern Australia. Acquiring a similar level of data and insight across northern Australia's more than 3 million km^2 would require more time and resources than are currently available. Determining where such effort can be most productively spent is an important priority being considered by the Northern Australia Taskforce that is charged with preparing the Northern Australia White Paper.

To inform this deliberation, the Office of Northern Australia commissioned the current study, which seeks to identify those catchments in northern Australia in which there is a coincidence of large contiguous areas of soils suitable for cropping and horticulture (i.e. >10,000 ha), and potential surface water storages. Although these are used as primary selection criteria, other factors are also important in determining opportunity. These include market opportunities and value chains to meet them, current and potential industries, existing hard (e.g. roads, power) and soft (e.g. schools, hospitals) infrastructure, and local social and cultural conditions. These factors are also likely to inform decisions about priorities for future, more detailed studies.

This study complements recent studies that found that around 600 GL of renewable groundwater is likely to exist across northern Australia (CSIRO 2009a), and recent studies into livestock industry logistics (Higgins 2013), irrigation mosaics (Grice et al., 2013) and food and fibre supply chains (Ash et al., 2014) in northern Australia.

We emphasise that the analyses in this report are purely biophysical. They are unconstrained by the regulatory environment, do not consider actual or potential controls on dam development, and do not take into account other uses or users of water in the catchments considered. These factors are appropriately considered in distinct policy and other forums.

Preamble Photo 1 Cattle being loaded onto trucks at a station near Hughenden (Flinders catchment, Queensland)
Photo: CSIRO

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[1] http://www.csiro.au/en/Research/LWF/Areas/Water-resources/Assessing-water-resources/Flinders-Gilbert

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1 Introduction

Overview of large dams in Australia

Dams have profoundly influenced the nation's rural development. In southern Australia, large reservoirs have been an effective means of providing reliable water supplies in a dry and variable climate. Without the elaborate series of dams and tunnels constructed as part of the Snowy Mountain scheme, much of the irrigated land in the Murray Darling Basin, Australia's major food bowl, could not be watered. Today there are over 560 large dams (i.e. >10m height) on the Australian National Committee for Large Dams (ANCOLD) register, but only about 5% occur north of the Tropic of Capricorn (Figure 1-1).

Collectively Australia's dams generate about 6.2% of the nation's 's electricity (World Bank http://data.worldbank.org/indicator/EG.ELC.HYRO.ZS) and meet 75% of Australia's ~25,000 GL annual water use. They also provide services such as tourism, flood protection and recreation. These dams have also regulated flow in many of Australia's rivers and often contributed to complex and unpredictable environmental and social changes. Further, large dams are costly in terms of capital expenditure and maintenance, and there is compelling evidence that the budgets of large dams are systematically biased below actual costs (Ansar et al., 2013).

It is a commonplace in public discourse that there have been no dams built recently in Australia. This ignores Wyaralong Dam (Queensland), completed in 2011, and Cotter Dam (Australian Capital Territory), completed in 2014. Each is considerable: Wyaralong Dam has a height of 48 metres, a length of 490 metres and cost $348 million, while Cotter Dam has a height of 87 metres, a length of 330 metres and cost $411 million. The location of the major constructed dams (>500 GL storage capacity) and main irrigation areas in Australia are shown in Preamble Figure 1.

The large, often public, capital expenditure requirements and potential environmental and social changes have led some sectors of the public to question whether dams are an appropriate pathway for development. Figure 1-1 shows that the number of dams constructed in Australia started to plateau in the mid-1990s, despite the backdrop of the Millennium drought from 1996 to 2008 in south-eastern Australia. This decline is in part due to a change in community attitudes and values regarding dams and the environment in general. It may also reflect the fact that, especially where there has been considerable development of water resources, there are declining marginal returns to additional water storage. Similar trends occurred in other developed countries (WCD 2000) - where there has been a general move away from planning and construction of large water resource systems consisting of large dams and associated works, towards managing and operating current systems more efficiently.

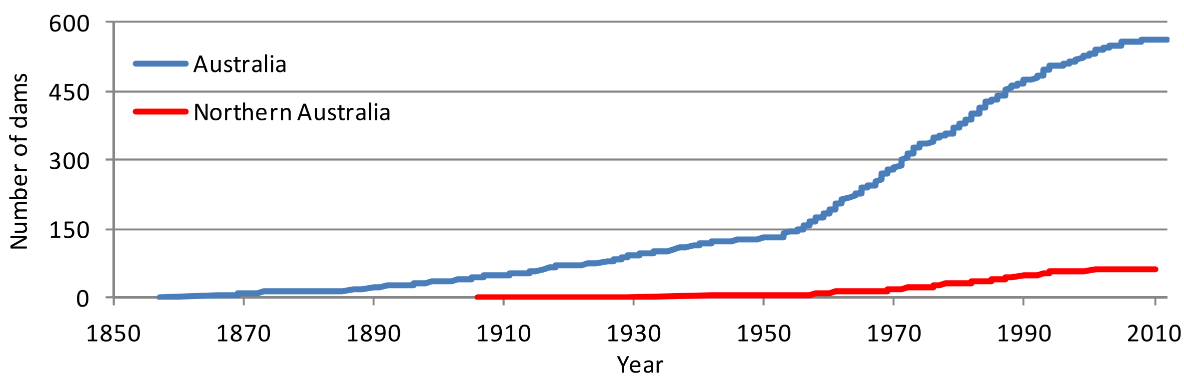

Figure 1-1 Cumulative number of large dams (>10m wall height) in Australia and northern Australia over time since European settlement
Source: Data sourced from ANCOLD

Northern Australia, however, may present a different situation, as there are few existing large dams (Figure 1-1), access to reliable water is a key constraint to development and groundwater is limited in many parts to stock and domestic supplies (CSIRO 2009a,b,c,d). There is therefore considerable interest in exploring the potential for surface water storages in northern Australia, and the provision of reliable information for strategic planning of agricultural developments, including where the water could be used, is seen as crucial.

Past assessments of divertible surface water resources in northern Australia

Past assessment of surface water storages in northern Australia has been largely adhoc. The majority of studies focus on individual locations (e.g. Morwood 1983, Maunsell McIntyre 2000), have been undertaken by a range of different public and private organisations, and use a variety of methods applied with different degrees of rigour. Furthermore, many of the studies were not published, or only exist as hardcopy reports in Government archives.

There are no studies that have examined the potential for surface water storages across each of the Australian Water Resource Council (AWRC) river basins of northern Australia, using a consistent and rigorous set of methods and in sufficient detail to enable the proximity of likely storage locations to soils suitable for irrigation to be examined.

Several publications have set out to provide an overview of potentially divertible surface water volumes across Australia. In 1976 the Department of Natural Resources (DNR 1976) collated information from each jurisdiction based on their best estimates of the potential divertible volumes of surface water for each of AWRC river basins across Australia – irrespective of the availability of soils suitable for irrigation and ignoring social, environmental and economic considerations.

This work was revisited in the 1985 Australian Water Resources Review (AWRC 1988), following a similar approach. While those two studies provide continental scale estimates of potentially divertible water, there is no supporting documentation justifying how these estimates were derived or which potential dams were assessed in each AWRC river basin, so as to allow examination of the proximity of these dams to areas with soil suitable for irrigation.

In 2000 the National Land and Water Resources Audit (NLWRA 2000) also collated estimates of 'sustainable' surface water diversions from the jurisdictions. However, estimates of divertible water were not provided for all AWRC river basins and the jurisdictions adopted different definitions of 'sustainable diversions', some of which incorporated ecological values. This made it particularly difficult to compare estimates in different jurisdictions.

In 2008 the CSIRO undertook the Northern Australia Sustainable Yields (NASY) project, a comprehensive hydrological assessment of catchments in the Timor Sea, Gulf of Carpentaria and northern North-East Coast Drainage Divisions under current and future climate and current and future development scenarios (CSIRO 2009b,c,d). Under the terms of reference of the NASY project only those potential dams and future development options nominated by the three northern jurisdictions were assessed. Consequently future development scenarios were limited to assessing Ord Stage 2 and raising the existing Darwin River Dam.

In a continental scale assessment comparing northern and southern Australia's potential for irrigation, Petheram et al., (2010) aggregated the NLWRA (2000) estimates of surface runoff and the AWRC (1988) proportions of divertible yield for each AWRC river basin to obtain broad scale estimates of potentially divertible yield and potential irrigable area for each of the twelve major drainage divisions across Australia (Figure 1-2). They found that, despite more than 60% of Australia's surface runoff being generated there, northern Australia only had approximately 45% of Australia potentially divertible yield. Taking into consideration the higher crop water requirements in northern Australia, Petheram et al., (2010) estimated that northern Australia has about 38% of Australia's potentially irrigable area (ignoring social, environmental and economic considerations and availability of suitable soil). The authors concluded that, while there are opportunities for irrigation in northern Australia, the majority of Australia's irrigation would always be located in the south.

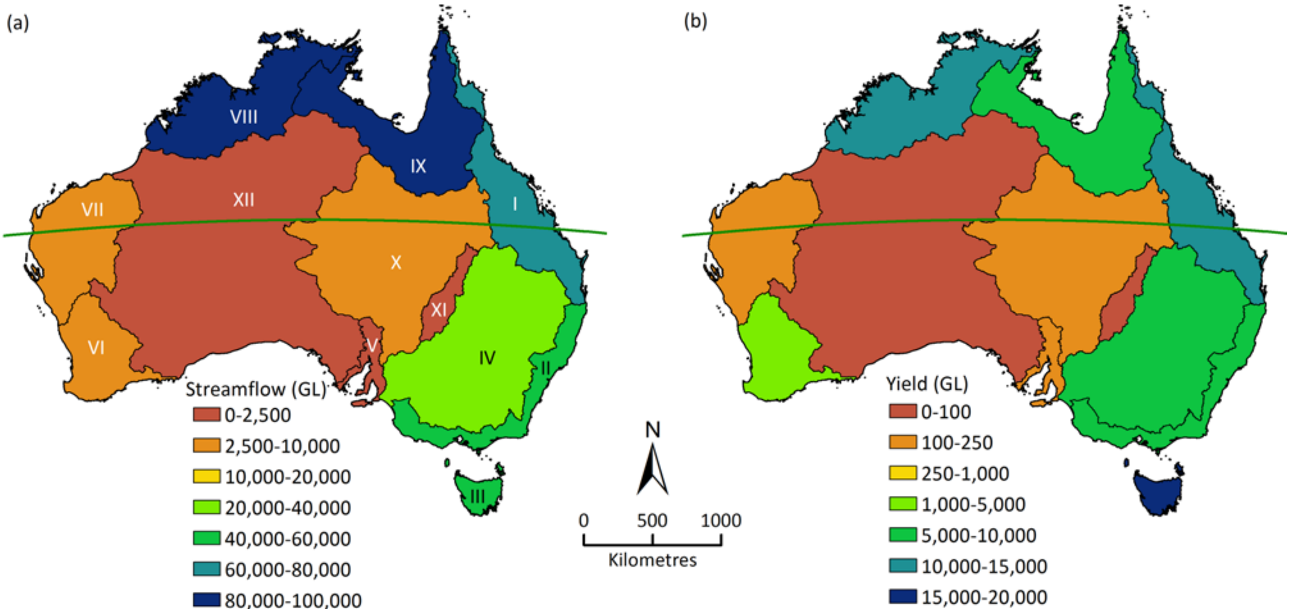

Figure 1-2 Prior estimates of streamflow and potentially divertible yield for the major drainage divisions of Australia
Broad scale exploitable yield estimates assume 64% efficiency of conveyance and delivery to field. They do not account for environmental, social or economic considerations or the availability or proximity of soil suited to irrigated agriculture. The roman numerals in figure (a) indicate the AWRC drainage division number. These are: I) North-East Coast; II) South-East Coast; III) Tasmania; IV) Murray Darling Basin; V) South Australian Gulf; VI) South West Coast; VII) Indian Ocean; VIII) Timor Sea; IX) Gulf of Carpentaria; X) Lake Eyre; XI) Bulloo-Bancannia; XII) Western Plateau. Source: Data sourced from Petheram et al., (2010)

Challenges and considerations in assessing potential dam sites in northern Australia

The investigation of a potential dam site involves an iterative process of increasingly detailed studies, sometimes occurring over as few as 2 or 3 years but often over 10 or more years. It is not unusual for the cost of the geotechnical investigations for a potential dam site, alone, to exceed several million dollars. Given the large costs and time involved and the likelihood of many potential dam sites in a catchment, an important stage of developing the surface water resources of a catchment is a 'pre-feasibility assessment'. This involves a detailed desktop investigation and site visit to acquire the more significant information requirements for numerous potential dam sites in an area, including whether:

- the topography favours the creation of a large storage volume by a dam of height and length likely to be economically viable;
- the regional and local geology are likely to impose constraints or additional cost to construction;
- the streamflow characteristics at the site are appropriate for a storage to meet the forecast demand;
- the dam site location is in the vicinity of the forecast demand for water or soils suitable for irrigation;
- the storage would impact existing land uses, existing infrastructure or environmental, social or cultural values and whether the impacts are likely to be acceptable to investors and other stakeholders . This is particularly relevant to the coastal Queensland (QLD) regions (i.e. Wet Tropics, Burdekin and Fitzroy) where there is already a large degree of regulation.

The geological assessment should include a visit to each site.

It is common in pre-feasibility analysis for the better potential sites to be short-listed for a more detailed desktop analysis, including more time demanding analyses such as preliminary flood design assessment (e.g. to assess the additional height above the full supply level (FSL) (or freeboard), that can significantly impact on dam cost and a detailed desktop costing). An example of such a preliminary assessment was recently undertaken in northern Australia in the Flinders and Gilbert catchments by Petheram et al., (2013a). Through this process it is possible to confidently select the most appropriate dam sites on which to undertake more detailed and costly ground based investigations. Such site specific investigations are referred to as feasibility analysis.

One of the challenges in undertaking even a preliminary assessment of surface water storage locations across northern Australia is the vast land area, much of which is remote and for which data on hydro-climate, geology and soil is sparse. While some parts of northern Australia have seen numerous dam investigations (e.g. surrounding Darwin, and in the Flinders catchment), others have seen little activity (e.g. Kimberley region, Roper catchment). Furthermore, in many areas the existing preliminary investigative studies were typically undertaken three to five decades ago and many reports were either unpublished or only exist in Government archives. Consequently the process of establishing an objective, initial list of potential dam locations for a pre-feasibility assessment is fraught with uncertainty.

To address this challenge, in 2010 CSIRO developed the DamSite model (Read et al., 2012), a series of algorithms that utilises a digital elevation model (DEM) and hydrological data to automatically identify and assess every potential dam site in a catchment. This model was further refined and successfully applied as part of the Flinders and Gilbert Agricultural Resource Assessment (Petheram et al., 2013a). The advantage of the DamSite model is that it enables an objective preliminary assessment of potential surface water storages to be made relatively rapidly, and using a consistent set of methods. Previously, preliminary surface water storage assessments were made by manually selecting sites for assessment, based on visual examination of a DEM and satellite imagery or aerial photography. Then hydrological models and/or data would be developed to assess the performance of a dam at the selected locations - inevitably a time consuming and somewhat subjective process.

Study objectives

This rapid study sought to identify catchments with both potential surface water storages and large contiguous areas (i.e. > 10,000 ha) of soils suitable for cropping and horticulture, to help indicate catchments where future detailed field studies for irrigation potential may be most productive.

Specifically, this study sought to:

- Use the DamSite model to identify and undertake a relative assessment of all potential dam locations within northern Australia.
- Undertake a preliminary yield assessment of 10,000 of the more promising potential dam locations across northern Australia.
- Undertake a regional scale geological assessment of the likely geological suitability of a selection of potential dam locations in northern Australia.
- Examine the proximity of the better storage locations to soils suited for irrigation development.
- Provide a regional scale perspective on which AWRC river basins have land suitable for farm scale off-stream storage structures (e.g. ring tanks).

This study does not constitute a ‘pre-feasibility assessment’ and the results cannot be used to nominate specific dam sites for construction or to plan the location of potential irrigation schemes.

Report structure

This report is organised as follows. The remainder of Chapter 1 describes key terminology and concepts associated with northern Australia and surface water storages. Chapter 2 presents information on geology, climate and surface water resources of northern Australia. A brief summary of groundwater resources in northern Australia is also provided. Chapter 3 outlines the results of the DamSite modelling and land suitability analysis across the entire study area. Chapter 4 provides a brief integrated summary on the potential opportunities for broad scale irrigated agriculture for each region based upon a consideration of potential surface water storages and their likely geological and hydrological suitability, productive groundwater systems and land suitability analysis.

A companion report contains five appendices (i.e. Appendices to the Technical Report).

Appendix A provides location maps (e.g. river and town names) and maps of potential surface water storages, preliminary plots of yield versus reliability for selected potential dams and maps and tables of land suitability for each of the 21 reporting regions.

Appendix B provides a summary of the Water Resource Plans (WRP) and Resource Operation Plans (ROP) for the regulated catchments draining the east coast of Queensland. These are the more heavily regulated catchments in northern Australia. It also provides brief comment on selected potential dam sites in these Queensland regions.

Appendix C describes the methods used to undertake the DamSite modelling, assess the suitability of off-stream storage suitability and assess the scale of northern Australia’s irrigation potential.

Appendix D presents modelled pre-development discharge characteristics for the AWRC river basins in the 13 more northerly reporting regions (i.e. Timor Sea and Gulf of Carpentaria drainage divisions and the North East Coast Drainage Division north of Cairns).

Appendix E is a geological timeline.

1.1 Key terminology and concepts

1.1.1 NORTHERN AUSTRALIA, STUDY AREA AND REPORTING REGIONS

Northern Australia is defined in this study as that part of Australia north of the Tropic of Capricorn (Preamble Figure 1) and comprises all or part of 100 AWRC river basins. The water resources of northern Australia have been assessed and broadly documented by a number of authors (e.g. McMahon et al., 2008, Petheram and Bristow 2008, Petheram et al., 2008, CSIRO 2009b,c,d, Creswell et al., 2009, Petheram et al., 2010, Petheram et al., 2012, Turnadge et al., 2013, CSIRO 2014).

The study area was broken into 21 reporting regions (Figure 1-3). This was to enable information to be provided at a finer resolution than all of northern Australia, but without being too onerous on the reader. Furthermore, provision of information at a finer scale would be inconsistent with the level of detail of information that is available for many parts of northern Australia. The more northerly 13 regions situated in the Timor Sea and Gulf of Carpentaria Drainage Divisions and the North-East Coast Drainage Division north of Cairns (shown by green polygon in the inset in Figure 1-3) are the same as those used by the Northern NASY project. The location of the ‘central’ eight regions is shown by the orange polygon in the inset in Figure 1-3.

1.1.2 WATER YEAR AND WET AND DRY SEASONS

Northern Australia experiences a highly seasonal climate, with the majority of rain falling between November and April (Petheram and Bristow 2008). Unless specified otherwise the wet season is defined as the six-month period from 1 November to 30 April and the dry season is the six-month period from 1 May to 31 October. All results in the study are reported over the ‘water year’, defined as the period 1 September to 31 August and which allows each individual wet season to be counted in a single 12-month period, rather than split over two calendar years (i.e. counted as two separate seasons). This is considered the best option for reporting climate statistics in northern Australia from a hydrological and agricultural assessment viewpoint. All hydro-climatic analysis were undertaken between the period 1 September 1930 to 31 August 2007 (i.e. 77 years), which is consistent with the timeframe used by the NASY project (2009b, c, d), and for which readily available runoff data were available.

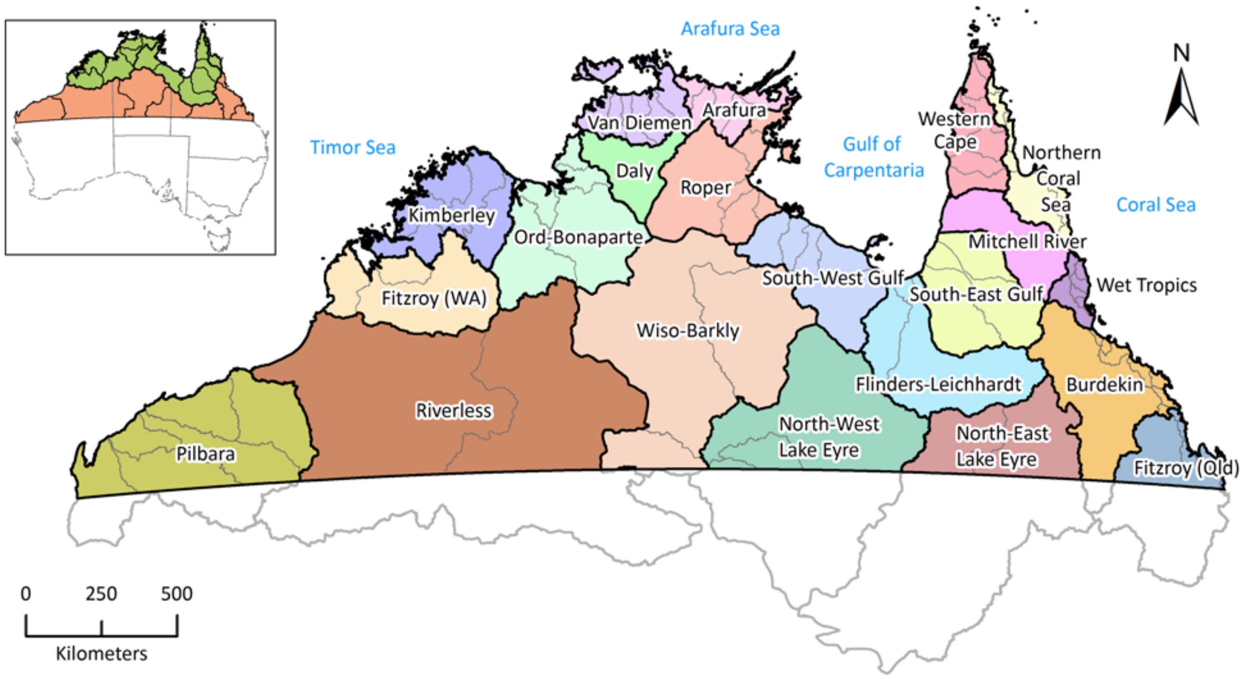

Figure 1-3 Reporting regions of the study area
Black lines in study area show extent of reporting regions. Grey lines inside study area indicate AWRC river basin boundaries. Inset shows location of study area. Green polygon shows location of the 13 more northerly regions. Orange polygon shows location of the 8 'central' regions.

1.1.3 ASSESSING DAM PERFORMANCE – STORAGE, WATER YIELD AND RELIABILITY

Storage, yield and reliability are three inter-related terms.

The performance of a dam is often assessed in terms of yield or demand. Yield is the controlled release of water from a reservoir. Yield values are accompanied by a reliability value. Increasing the yield from a reservoir reduces the reliability of meeting the increased yield. Reliability is typically expressed as a time (i.e. monthly or annual) or volumetric based measure (McMahon and Adeloyte 2005). Other terms that are used synonymously with yield are release, draft and regulation. Unless stated otherwise all yield estimates in this report are the amount of water that could be supplied in 85% of years.

Storage volume or dam capacity is an inappropriate indicator of dam performance, because it is possible to have a dam with a very large capacity that is situated on a very small creek and consequently never fills. In this instance, the amount of water that can be supplied from the dam would be significantly less than the storage volume. Similarly, mean annual streamflow is a poor indicator of likely dam performance because i) the mean annual flow could greatly exceed the dam storage capacity; or ii) if there is large variability in annual inflows the reliability of supply is adversely affected, particularly if there are long runs of dry years.

In an assessment of 15 potential dam configurations in the Flinders catchment and 7 potential dam configurations in the Gilbert catchment Petheram et al., (2013a) found that the median percentage yield (at 85% annual time reliability) as a proportion of storage capacity was 19% and 76% respectively.

In existing regulated river systems, water allocations established under the relevant resource operation plans are described as High Priority (HP) or Medium Priority (MP), rather than reporting yields for a dam. This is because allocations are held by users in schemes which often include multiple storages (e.g. the Burdekin Haughton Water Supply Scheme is based on the supply of water from the Burdekin Falls Dam, Gorge Weir, Blue Valley Weir and Clare Weir). Where multiple storages exist in a catchment they are usually modelled and operated as a system. In these systems reporting individual yields can be both difficult and meaningless. See Section 0 for definitions of HP and MP water.

1.1.4 TYPES OF SURFACE WATER STORAGES

This study examined two types of surface water storages: (i) large dams, which supply water to multiple properties; and (ii) on-farm dams, which supply water to a single property. The former are typically used to supply water to broad-scale irrigation schemes such as those common in southern Australia, while the latter are typically used to supply water for stock and domestic purposes or for mosaics of small-scale irrigation.

Both large dams and on-farm dams can be further classified as in-stream or off-stream water storages. In this study in-stream water storages are defined as structures that intercept a drainage line (creek or river) and are not supplemented with water from another drainage line. Off-stream water storages are defined as structures that (i) do not intercept a drainage line; or (ii) intercept a drainage line and are supplemented with water from another drainage line. Ring tanks and turkey nest tanks are examples of off-stream storages with a continuous embankment. Re-regulating structures, such as weirs and sand dams are also briefly discussed below.

Large in-stream dams

Large in-stream dams are usually constructed from earth, rock or concrete materials, as a barrier wall across a river so as to store water in the reservoir created. They need to be able to safely discharge the largest flood flows likely to enter the reservoir and the structure has to be designed so that the dam meets its purpose, generally at least for 100 years. Large dams are sometimes referred to as carry-over storages. That is, they are large enough relative to the demands on the dam (i.e. water supplied for consumptive use, evaporation and seepage) so that, when full, water can last two or more years. This has the advantage of militating against years with low inflows to the dam. An advantage of large in-stream dams is that they provide a very efficient way of intercepting the flow in a river, effectively trapping all flow until FSL is reached. For this reason, however, they also provide a very effective barrier to the movement of fish and other species within a river system and can inundate large areas of land.

Two types of dams are particularly suited to northern Australia, embankment dams and concrete gravity dams. Embankment dams are usually the most economical, provided suitable construction materials can be found locally, and are best suited to smaller catchment areas where the spillway capacity requirement is small. Concrete gravity dams with a central overflow spillway are generally more suitable where a large capacity spillway is needed to discharge flood inflows.

Off-stream water storages

Off-stream water storages were among the first man made water storages because people initially lacked the capacity to build structures that could block rivers and withstand large flood events. For example the 12th Dynasty of Ancient Egypt diverted water from the Nile River into the El Fayyum Depression (Nace 1972), while one of the Maya's largest cities was constructed around off-stream water storages (Scarborough and Gallopin 1991). In Australia there is evidence that Indigenous people engineered structures to divert river flows prior to European settlement (Barber and Jackson 2012).

Off-stream water storages can take the form of farm scale ring tanks (e.g. 3000 to 8000 ML storage capacity) or large dam structures. One of the advantages of off-stream storages is that, if properly designed, they can cause less disruption of the natural flow regime than large in-stream dams, provided that water is extracted from the river using pumps, or if there is a diversion structure it has raiseable gates to allow water and aquatic species to pass when not in use. However, raiseable gates are typically expensive to operate and maintain, particularly in remote areas, and the structures supporting the gates need to be designed to withstand large flood events, which increases the cost of the diversion structure considerably.

An often overlooked aspect of off-stream storages is that the amount of water that can be diverted into an off-stream storage using a diversion structure in a river is related to the relative difference of the height of water in the river and the height of water in the storage; water must be made to run downhill from the point of diversion to the storage location. To achieve adequate flow rates in the diversion channel, the diversion structure has to be sufficiently high to generate the required head of water. This is particularly the case in northern Australia where the water levels rise and fall very rapidly (Petheram et al., 2008a) and there is relatively little time for extraction or diversion. Kim et al., (2013) provide an example of a ‘hydraulic’ analysis for an off-stream storage and diversion structure in the Flinders catchment.

Reregulating structures

Downstream regulating structures allow for more efficient releases from the storages and for some additional yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems.

Weirs are a commonly used reregulating structure and differ from dams in that they are lower barriers located entirely within stream banks and are totally overtopped during flood events (Photo 1-1). As a rule of thumb, weirs are constructed to half the bank height. Weirs are typically used as regulating structures downstream of large dams to allow for more efficient releases from the storages and for some additional yield from the weir storage itself, thereby reducing the transmission losses normally involved in supplemented river systems. Suitable weir locations were not explicitly examined in this study.

As many of the large rivers in northern Australia are very wide (e.g. >300 m), weirs are likely to be impractical and expensive at many locations. An alternative structure is sand dams, which are low embankments built of sand constructed at the start of each dry season during periods of low or no flow when heavy earth moving machinery can access the bed of the river. They are constructed to form a pool of depth sufficient to enable pumping (i.e. typically greater than 4-m depth). They are widely used in the Burdekin River near Ayr, where the river is too wide to construct a weir. Although sand dams are cheap to construct relative to a weir, they require annual rebuilding and have much larger seepage losses beneath and through the dam wall.

Weirs, sand dams and diversion structures can obstruct the movement of fish and other species in a similar way to dams.

Photo 1-1 Clare Weir on the Burdekin River (Queensland)
15.6 GL capacity. Photo: CSIRO

1.1.5 TERMINOLOGY USED IN REGULATED RIVER SYSTEMS

This section describes terminology used in this report to characterise regulated river systems and describe water trading. Because the more heavily regulated river systems in northern Australia are located on the east coast of Queensland only the key terminology used by Queensland Government and used in this report are described here. It should be noted, however, terminology varies from one jurisdiction to another.

Water resource plan (WRP) - a statutory plan for a river basin that provides the management framework for a sustainable balance between the consumptive share and environmental share of a water resource. The plan may also identify any additional water available for allocation.

Resource operations plan (ROP) - a plan that provides the rules and processes to implement a water resource plan. A ROP may contain specific detail about infrastructure operating rules; trading rules; water sharing rules; converting entitlements tied to land to tradeable water allocations; processes for granting of additional water allocations; and monitoring of and reporting on water and ecosystems.

Supplemented water -a water supply in which reliability is enhanced by releases of stored water from infrastructure. A regulated water supply.

Unsupplemented water - a water supply in which reliability is not enhanced by releases of stored water from infrastructure. An unregulated water supply.

Allocation - an authority established under a WRP/ROP to take water. It is separate from land and can be held and traded as personal property by non-landholders.

Uncommitted allocation – a water allocation established under a WRP/ROP available from a water supply scheme that has not been purchased by a user.

High priority (HP) water - a group of water allocations from a supplemented supply that have a high reliability of supply (i.e. 95% or higher). HP water is typically purchased by users who require a high reliability e.g. for town water supply, horticulture, mining and industry.

Medium priority (MP) water - a group of water allocations from a supplemented supply that has a lower reliability of supply and cost than HP water. The actual reliability of MP water varies from scheme to scheme. MP water is often purchased by irrigators growing annual crops.

General reserve – a volume of water set aside in a WRP which may be made available.

Strategic reserve - a volume of water set aside in a WRP for a specified or unspecified future purpose. Examples of a strategic reserve include volumes set aside for an identified potential dam (e.g. Connors dam and Nathan dam in the Fitzroy WRP and Urannah dam and raising Burdekin Falls Dam in the Burdekin WRP).

2 Study area

This section provides a summary of key characteristics of the geology, soils, climate and surface and groundwater resources, for the catchments of northern Australia. More detailed descriptions can be found in the references provided herein.

2.1 Geology

A dam site is regarded here as ‘prospective’ if it has inflows of sufficient volume and frequency, topography that provides a physiographic constriction of the river channel, and critically, favourable foundation geology. Favourable foundation conditions include a relatively shallow layer of unconsolidated materials such as alluvium, and underlying rock which is relatively strong, resistant to erosion, and non-permeable or capable of being grouted. Geological features that make dam construction challenging or prohibitively expensive include the presence of faults, weak geological units, karstic rock, landslides and deeply weathered zones.

A limited regional scale desktop geological assessment was undertaken of northern Australia using 1:250,000 geological maps, Google Earth imagery and DEMs. The primary purpose was to assess the likely geological suitability of general areas with more favourable topography for storing water. No site visits were undertaken as part of this ‘pre-‘ pre-feasibility analysis.

For any of the locations identified in this report to advance to construction, a pre-feasibility analysis would be required to establish a short-list of suitable local sites, based on visits by an experienced dam geologist and water infrastructure engineer or planner to each potential dam site within the area. Once the most appropriate dam site has been determined as part of the pre-feasibility analysis, a ‘feasibility analysis’ is then undertaken at the selected site. This investigation generally involves an iterative process of increasingly detailed studies over a period of years, occasionally as few as 2 or 3 years, but often over 10 or more years and can cost several million dollars.

An overview of the geological features of the parts of the study area in Western Australia (WA), Northern Territory (NT) and Queensland that are important with respect to large dams is provided below. Figure 2-1 shows a broad scale surface geology map of northern Australia. Broad scale geological summaries within the context of surface water storage infrastructure are provided for each region in Appendix A. A geological timeline is provided in Appendix E.

2.1.1 WESTERN AUSTRALIA

Fitzroy, Kimberley, Ord-Bonaparte regions

The majority of the Kimberley and the north-eastern third of the Fitzroy regions are made up of dissected plateaus and ranges underlain by sedimentary, igneous and metamorphic rocks of Proterozoic age. These rocks are characterised by flat bottomed, steep sided valleys underlain by near horizontal or gently dipping sandstone, and these areas are likely to provide suitable foundation conditions for dams. Some carbonate rocks and calcareous sandstone, which can be extremely permeable, occur in the region. Alluvium underlain by soft estuarine sediments to below present sea level occurs in the lower reaches of the river valleys. These are poorly suited to dam construction.

The extensive alluvium, which occurs along the mid-to-lower reaches of the Fitzroy River, presents few opportunities for large in-stream dams. Embankments would have to be very long to provide adequate storage capacity. Also, construction and operation of a spillway to cope with the large flood events would entail significant risk and cost.

Pilbara, Riverless regions

The Pilbara Region is formed of ancient Archaean and Proterozoic rocks with a Cenozoic landscape, infilled mainly by chemical sediments. The Archaean granite-greenstone terrane is characterised by low-relief areas of granite, surrounded by vertically or steeply dipping volcanic and metasedimentary rocks typically forming spine backed ridges broken by narrow gorges where drainage lines pass through. The Proterozoic Hamersley and Ashburton basins comprise flat lying to moderately dipping sediments consisting of volcanic, shale, dolomite and banded iron formation, which form the Hamersley and Chichester Ranges in the north and Capricorn Range to the south. Residual iron rich capping occurs on the Proterozoic iron formations, but generally both Archaean and Proterozoic rocks are fresh and not deeply weathered. Cenozoic valleys are filled with channel iron deposits, calcrete and alluvium which either underlie present day drainage lines, or are cross-cut and dissected by later Cenozoic streams which have cut into the bedrock. A coastal plain formed by flood plain deposits of the major rivers occurs east of the Harding River, and south west of the Fortescue River where it overlies Cretaceous sediments of the Carnarvon Basin. Most of the major rivers have deposited significant alluvial aquifers of sand and gravel where they cross the coastal plain.

The Riverless region is covered by the Great Sandy Desert and a narrow coastal plain, and is underlain by the sedimentary Canning Basin. The desert sand dunes are derived from Permian, Jurassic and Cretaceous sandstones, which occur as isolated outcrops in low hills. Drainage in the area is uncoordinated, but there is a network of palaeodrainage lines, probably developed in the early Cenozoic, which became inactive in the Quaternary. The main palaeodrainages, namely the Percival and Mandora systems, are occupied by discontinuous salt lakes and calcrete outcrops, while others such as the Wallal Palaeodrainage are dry valleys traversed by sand dunes, with deep water tables.

2.1.2 NORTHERN TERRITORY

Victoria, Daly, Van Diemen, Arafura and Roper regions

The geology of the ‘Top End’ (which encompasses the Victoria and Daly catchments and the Van Diemen, Arafura and Roper regions) is dominated by Proterozoic and Early Palaeozoic aged sedimentary rocks of the Victoria, Daly, Arafura and McArthur Basins and the Pine Creek Orogen. They comprise sandstone, siltstone, shale and dolomitic rocks and they vary from flat lying to moderately strongly folded. Plateaus and strike ridges of sandstone form the main positive topographic features, whereas siltstone, shale and dolomite areas tend to have low relief with limited outcrop.

Geological conditions likely to influence the suitability of potential dam sites include the strength and permeability of the rock for the foundations, abutments and spillway, the depth of alluvium and the absence of cavernous rocks beneath the reservoir. Of the potential dam sites identified in the NT, sandstone is the most common rock. In general it is hard with little or no primary porosity. The degree of fracturing varies considerably from area to area and needs to be assessed during on-site investigations. Some sandstone strike ridges are bound on one side by faults running parallel to the bedding. The potential for more intense fracturing in those situations is obviously higher than in un-faulted rocks.

Alluvial sequences are in general poorly developed in the ‘Top End’. In major rivers such as the Daly and Victoria, bedrock is frequently exposed along long stretches of the river and in most cases alluvium is likely to extend to depths of less than ten meters below the river bed. On and adjacent to the coastal plains thicker sections of alluvium and estuarine deposits may be encountered.

Dolomitic rocks including dolostone, dolomitic siltstone and dolomitic sandstone occurs sporadically across the ‘Top End’. They are cavernous in some areas, notably in the Daly Basin and in the Robinson River area. If such rocks are present either at the site of the dam wall or beneath the reservoir there is potential for leakage to occur.

Wiso-Barkly, North-West Lake Eyre

All sites overlie Lower Palaeozoic aged basins. The rocks are dominated by carbonates, are near flat lying and are regionally extensive. Sites west of the Stuart Highway overlie the Wiso Basin while those to the east overlie the Georgina Basin.

Partially vegetated dunefields cover broad areas of the Wiso Basin, limiting the availability of suitable sites for surface water storages. Most of the sites identified are associated with areas of clay soil exposed between dunes. They lie along the courses of buried Cenozoic river systems, termed palaeovalleys. The three easternmost sites of the Barkly-Wiso region are associated with the clayey floodplain sediments of the Newcastle Creek.

2.1.3 QUEENSLAND

South-West Gulf, Flinders-Leichhardt, South-East Gulf, Mitchell, Western Cape, Northern Coral Sea regions

The best geological unit for location of dams in north-western Queensland (i.e. the Flinders-Leichhardt region) is the Mt Isa Inlier. Here the rock consists of metamorphosed sedimentary and igneous intrusive types, which are strong and often provide suitable foundation conditions for large dams. In the South-East Gulf and Mitchell regions the most geologically favourable dam sites occur where rivers have eroded through ignimbrites within the metamorphic and igneous intrusive rocks of the Georgina Inlier. Other suitable sites in the Mitchell region occur within resistant granite and meta-sediment rocks of the Hodgkinson Province.

The western part of the Mitchell and Western Cape regions are large areas of low topographic relief underlain by weathered rocks of the Rolling Downs Group and Bulimba Formation. These units are characterised by deep profiles of bauxite and ferricrete that are highly permeable and unsuitable for dam construction or off-stream storages, except where underlain by clay.

Further south in the Flinders catchment, the gentle rolling downs topography of the Rolling Downs Group that makes up much of the region presents few opportunities for on-stream dams. Embankments have to be very long to provide adequate storage capacity. In this unit, off-stream storages offer the best prospect for water storage.

Some carbonate rock occurs in the South-West Gulf region and within a northwest to north trending belt between the Georgetown Inlier and Hodgkinson Province in the Mitchell region. These rocks would have to be assessed for karstic conditions.

Basalt flows have adversely affected numerous potential sites along the Einasleigh and the Lynd rivers in the South-East Gulf and Mitchell regions respectively. Basalt flows can cause problems in dam and diversion structure foundations because they often overlie alluvium which acts as a leakage path below or around the dam.

Eastern Lake Eyre, Wet Tropics, Burdekin, Fitzroy

In the Wet Tropics region the dominant geological provinces in terms of area are the Hodgkinson and Kennedy Provinces. There are smaller areas of late Cenozoic age basalt, which nonetheless have important implications for dam construction. Much of the Hodgkinson Province consists of multiple deformed, steeply dipping strata comprising sandstone, siltstone and mudstone with subordinate chert and mafic volcanic rocks. The age ranges from Silurian to Devonian. The Kennedy Province contains predominantly felsic intrusive and extrusive rocks of Carboniferous to Permian age. It includes intrusive granitic rocks and extrusive felsic ignimbrites. In the late Cenozoic, large basaltic lava eruptions formed extensive lava fields such as Undara. Some of the lava flowed down existing stream valleys such as the Mulgrave River. Because of its high strength and resistance to weathering, ignimbrite within the Kennedy Province often forms the best dam sites.

A large part of the Burdekin catchment falls within the Clarke River Province. The rocks in this province include both deep water marine sedimentary rocks and shallow marine sedimentary rocks. The former contain steeply dipping sandstones and mudstones such as the Wairuna Formation and Pelican Range Formation. The shallow marine sedimentary rocks contain both carbonate rich rocks and siliciclastic rocks. To the south of the Clarke River Province are metamorphic, granitic and mildly deformed sedimentary rocks of the Charters Towers Province. These range in age from Neoproterozoic to early Palaeozoic age. Both the Clarke River Province and Charters Towers Province are overlain by later sedimentary basins such as the Burdekin Basin, Drummond Basin and Sybil Graben. The latter contains The Hells Gate Rhyolite. Rocks of the Kennedy Province are also scattered throughout the catchment. This province includes intrusive granitic rocks and extrusive felsic ignimbrites. Late Cenozoic basalt eruptions have affected the Burdekin catchment in a similar way to the Wet Tropics catchments. Flood basalts have formed lava fields in the northern part and lava has also flowed down parts of the major streams such as the Burdekin River and Clarke River. Dam sites with good geological characteristics form in a variety of geological provinces within this catchment.

In the western part of the Fitzroy catchment (Queensland), coal-bearing sedimentary rocks of the Bowen Basin predominate. In the late Cenozoic, basaltic lava fields formed and these overlie the sedimentary rocks in some areas. The Fitzroy River and its sub-basins also contain extensive alluvial deposits. In the eastern part of the catchment, rocks of the Yarrol Province predominate. These consist of volcanic, volcaniclastic and sedimentary rocks ranging in age from Silurian to Permian. A small area of the Marlborough Province occurs within the catchment to the north-west of Rockhampton. This contains metamorphic rocks and the Princhester Serpentinite. Because of the subdued topography, there are few dam sites in the western part of the catchment. Prospects for dam construction are better in the east where there are more resistant rock types.

Photo 2-1 Hinchinbrook Island (Wet Tropics region, Queensland)
Photo: CSIRO

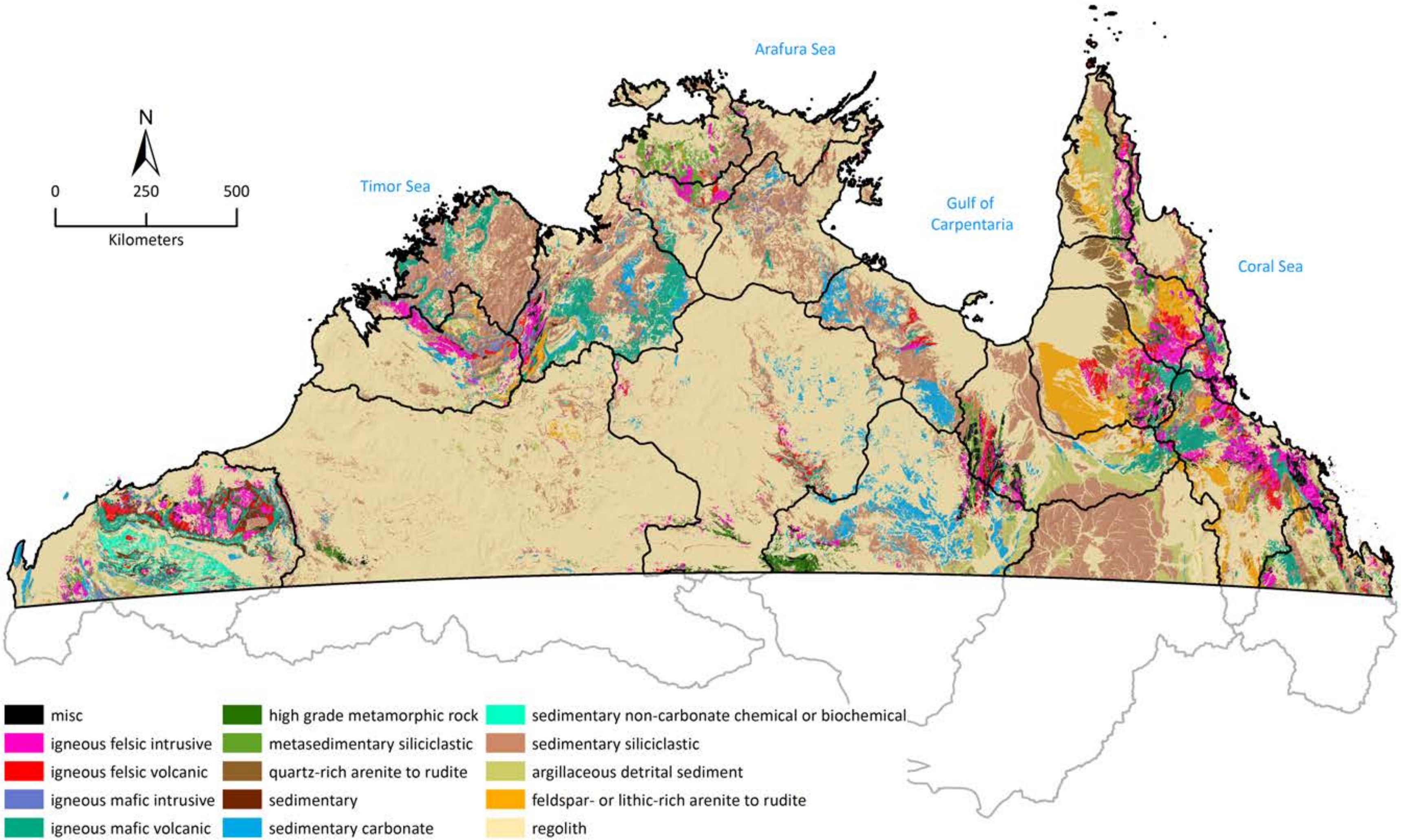

Figure 2-1 Surface geology in northern Australia (1:1000,000 scale)
Black lines delineate the reporting regions

2.2 Land and soil resources

Land and soil resources underpin agricultural development and productivity and the likely sustainability of business enterprises. In most parts of Australia, but especially in northern Australia, soils are ancient, strongly weathered and infertile by world standards. This is particularly the case in the western and central parts of northern Australia, where desert sands, dune fields and shallow rocky outcrops predominate. Areas of suitable agricultural soils exist throughout the north, but are not always found in close proximity to available irrigation water resources and their location and extent has not been adequately mapped.

In the east, some younger volcanic soils occur, as do areas of deeper more productive alluvial soils on coastal lowlands. Historically, this variability of soils and water has provided different opportunities for agricultural development. Almost all soils in northern Australia require high fertiliser inputs to ensure good crop yields. Organic matter is typically low and many of the soils have inherently low to moderate water holding capacity. Evidence from across Australia suggests that soils of ancient landscapes, like those across the north, are less resilient to change and once disturbed by agricultural practices, are more likely than younger landscapes to decline in condition (McKenzie et al., 2004). Therefore, developing irrigated agriculture in northern Australia will require careful planning and management to both obtain the best from the available soils and ensure that the soils do not sustain damage that would lead to lower crop yields, environmental degradation and loss of ecosystem services.

Notwithstanding this, CSIRO estimates that there are at least 16 million hectares of soil that are at least moderately suitable for irrigated annual agriculture in northern Australia, an area comprising >5% of the landscape (Wilson et al., (2009)).

Figure 2-2 shows the distribution of the dominant Orders of the Australia Soil Classification (Isbell 2002) across northern Australia. The mapping is derived from a collation of different datasets, which range in scale from less than 1:10,000 in the Lower Burdekin Irrigation Area to greater than 1:2,000,000 in the Riverless region. It is important to note that at scales greater than 1:250,000 the mapping is of land systems and soil associations, not specifically soil types. Table 2-1 provides estimates of the area of each soil Order. The uncertainty in these estimates may be greater than 50% for some soil areas due to the scale of available mapping. Table 2-2 provides a general description of the Orders and a description of the agricultural use, of those soils that occur in greater than 10% of northern Australia. Appendix A provides a brief description of the soils that occur within each region. An overview of the land and soil resources across northern Australia is provided by Wilson et al., (2009) and Wilson et al., (2013).

Photo 2-2 Irrigated fields along the Gilbert River (Qld)
Irrigation water sourced from Gilbert River bedsands. Photo: CSIRO

Table 2-1 Australian soil classification Orders in northern Australia

General suitability for agriculture is categorised as (U)sually, (S)ometimes and (R)arely. Most soils are classified 'S' because the grouping of soils in the ASC are too broad to assign a definitive suitability. For example Vertosols (cracking clays) are classified 'S' because some Vertosols can be well suited for irrigated agriculture, while others have high salinity, sodicity and alkalinity levels, making them generally unsuited for irrigated agriculture. Furthermore the suitability of a soil can be crop and climate dependent. For example for some crops grown on Vertosols in wetter parts of northern Australia vehicle access can be limited when the soils are saturated, which can make them generally unsuitable. Error in area values in table may be greater than 50%. Source: Data sourced from Wilson et al., (2009)

AUSTRALIAN SOIL CLASSIFICATION ORDER	SHORT DESCRIPTION	AREA ('000 ha)	PERCENTAGE OF TOTAL AREA (%)	GENERAL SUITABILITY FOR IRRIGATED AGRICULTURE
Calcarosols	Soils with pedogenic carbonate throughout	4,349	2%	S
Chromosols	Neutral to alkaline soils with sharp increases in clay in the sub-soil	12,741	5%	U
Dermosols	Structured sub-soils and minor changes in texture	8,194	3%	U
Ferrosols	Soils with a high free iron content	1,929	1%	S
Hydrosols	Soils that are saturated for at least 2-3 months in most years	8,945	3%	S
Kandosols	Weakly structured soils with minimal changes in texture	70,176	26%	S
Kurosols	Soils with sharp increases in clay in the strongly acidic sub-soil	130	0%	S
Podosols	Soils with sub-soil dominated by accumulation of organic matter, aluminium and/or iron	697	0%	S
Rudosols	Very minimally developed soils	80,675	29%	S
Sodosols	Alkaline and sodic soils with sharp increases in texture	6,572	2%	S
Tenosols	Soils with only weak pedologic development	37,900	14%	S
Vertosols	Cracking clays	40,182	15%	U

Photo 2-3 Inspecting a Red Kandasol (Oolloo) in the Daly catchment (NT). Photo: CSIRO

Table 2-2 General descriptions of main Australian Soil Classification Orders (>10% by area) mapped in northern Australia and some agricultural use descriptions.
Source: Modified from Wilson et al., (2013)

AUSTRALIAN SOIL CLASSIFICATION – SHORT DESCRIPTION	GENERAL DESCRIPTION	AGRICULTURAL USE
Kandosols – *Weakly structured soils with minimal changes in texture*	Kandosols are widespread throughout the study region. Massive or only weakly structured red, yellow and grey earths with clay content in the part of the sub-soil exceeding 15%. A feature of many Kandosols is their reasonable depth. In northern Australia, Kandosols appear to have formed under a previous, much wetter climate.	Kandosols may be gravelly, but are generally moderately deep and well drained, although there are examples that have impeded sub-surface drainage. The surface is often hard setting and crusting even when the level of use is low. They are used to grow cereals in NSW and south-west WA. Much of the irrigation in the NT is on Red Kandosols. Areas of Kandosols potentially suitable for irrigation can be found in the Pilbara and Riverless regions (WA), the Wiso-Barkly region (NT) and North-West Lake Eyre region (Qld).
Rudosols – *very minimally developed soils*	Rudosols are widespread throughout the NT and WA, less so in Qld. They occupy large areas of the desert and hilly upland parts of northern Australia. Rudosols also include many alluvial soils and sands with little horizon organisation or development.	Rudosols are extremely diverse. There are many small areas, mostly alluvial, which may be suited to cropping. Other areas are too shallow and stony.
Tenosols – *slightly developed soils*	Tenosols are widespread throughout the study region, particularly in the NT and WA. Tenosols have only weak pedologic development apart from the A horizons. Often siliceous and earthy sands and alluvial soils.	Tenosols are extremely diverse. They can be shallow to deep, but generally with low water holding capacity and low nutrient status. Limited areas of Tenosols are used for hardwood timber production in southern Australia and cereal growing in limited areas of south-west WA. There are large areas of Tenosols mapped in the Riverless region (WA), the Barkly-Wiso region (NT) and NW Lake Eyre region (Qld)
Vertosols – *cracking clays*	Vertosols are found extensively throughout the study region in western Qld, the Barkly Tablelands, the east Kimberley, frontages of the west Kimberley and along parts of the Pilbara coast. Vertosols are cracking clay (i.e. shrink-swell) soils with more than 35% clay throughout. When dry, these soils often crack to considerable depth. They are often found on extensive floodplains of inland streams which regularly flood.	Vertosols are used extensively for crop production in eastern Qld and NSW. They are also extensively irrigated, for example on the Riverine Plain of south-east Australia. High salt levels are found in some Vertosols and they sometimes restrict irrigation water entry. Vehicular access to Vertosols can be difficult when wet which is particularly an issue during the north Australian wet season. Their deep cracking when dry makes them unsuitable for tree crops and can damage infrastructure (e.g. roads, fences and irrigation). Sub-soils can be strongly acid or strongly alkaline and/or strongly sodic.

As discussed earlier most of the ‘soil’ mapping across northern Australia is land system mapping and soil association mapping (i.e. a scale of 1:250,000 or greater). Irrigation developments require paddock scale mapping, typically a minimum of 1:25,000, or a minimum of 1:10,000 for precision agricultural operations. The cost of mapping soil at 1:25,000 is 4 times that of mapping soil at 1:50,000 and 16 times that of mapping soil at 1:100,000.

An example of the investment required is seen in the Lower Burdekin, the largest irrigation scheme north of the Tropic of Capricorn, with approximately 80,000 ha of cultivated land. Total government investment (Federal and State) in soil survey data (e.g. capturing, collating, analysing and visualising) in the Lower Burdekin is estimated to have comprised about $25 m over 25 years (D. Brough 2014 pers. comm.). There would also have been significant additional investment by private sector developers, farmers and community groups.

New statistically based approaches to soil mapping and attribute estimation (referred to as digital soil mapping, e.g. see Bartley et al., 2013, Wilson et al., 2013) have the potential to provide more cost effective soil and land suitability assessment, but significant on-ground investment would still be required.

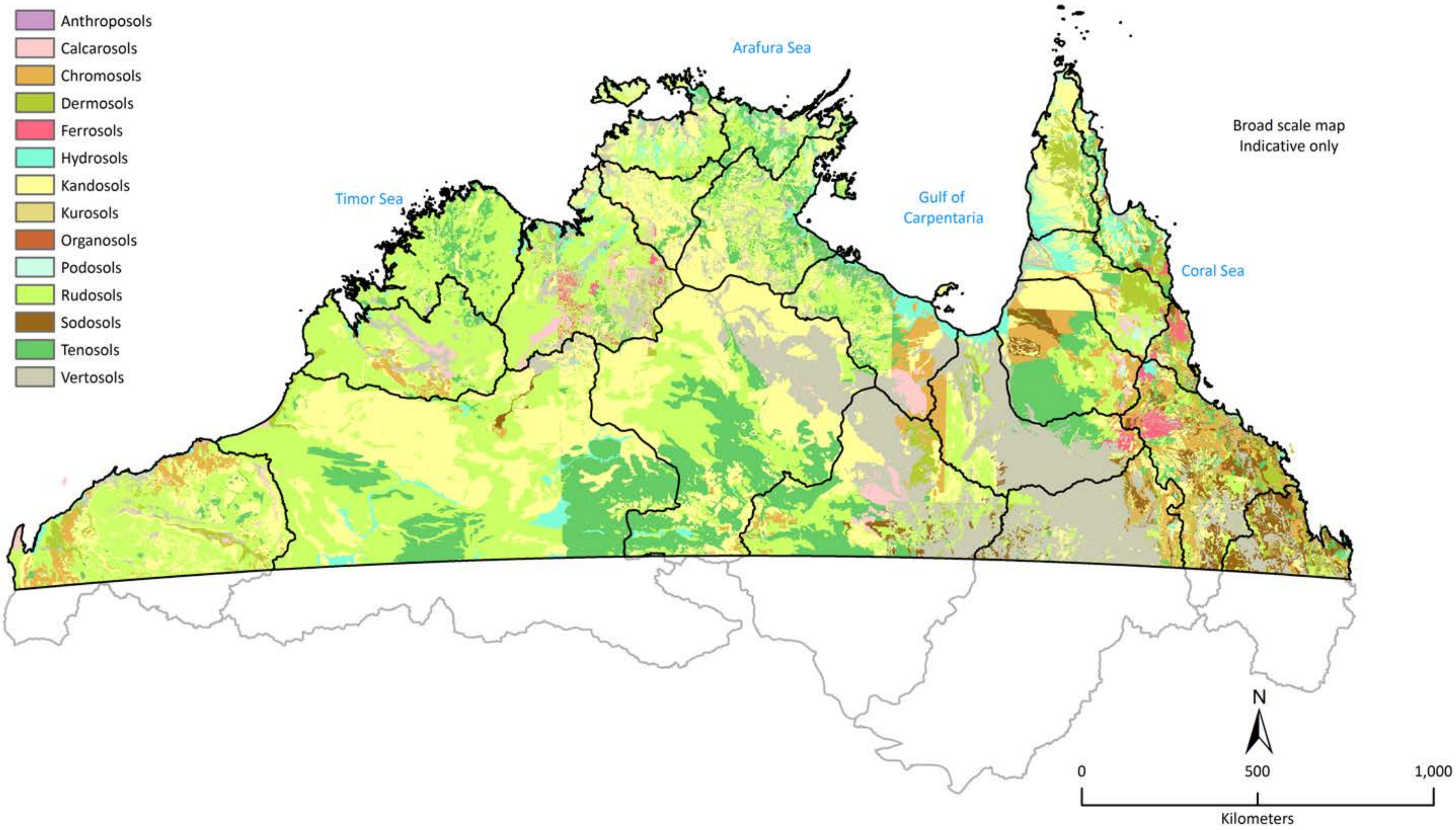

Figure 2-2 Australian soils classification map for northern Australia
Black lines delineate the reporting regions.
Source:Soil data sourced from ASRIS

2.3 Climate

Mean annual rainfall across northern Australia varies from less than 200 mm in the Riverless region to over 4000 mm in the Wet Tropics region (Figure 2-3). One of the defining traits of northern Australia's climate is the high seasonality of rainfall, which is considerably more pronounced than in southern Australia. Most parts of northern Australia receive more than 90% of their rainfall during the wet season (Petheram and Bristow 2008, CSIRO 2009b, c, d), defined in this report as being between November and April (inclusive). Along the east coast of Queensland orographic uplift of moist south-east trade winds results in some dry season rainfall (see Petheram and Bristow 2008). An implication of the low rainfall during the dry season is that irrigation would require water storage infrastructure, except in the limited areas where suitable groundwater is available.

In addition to its high seasonality, rainfall across northern Australia exhibits large variation from one year to the next (inter-annual variation). The variability in rainfall is amplified in runoff (Petheram et al., 2008a), and the larger the variability of inflows to a dam the less reliable it is in supplying a given demand. Petheram et al., (2008a) observed that the inter-annual variability of rainfall and inter-annual variability of runoff in northern Australia is about 30% higher and 200 to 300% higher respectively than that observed in other 'wet-dry' tropical parts of the world.

Northern Australia's climate is also characterised by irregular periods of consistently low rainfall, i.e. when successive wet seasons fail while dry seasons remain characteristically dry. Runs of wet and dry years occur when the rainfalls of consecutive years are above or below the median respectively. Petheram et al., (2008a) and Petheram and Yang (2013) showed that the runs of dry years in northern Australia were not unusual but the magnitude of dry years (i.e. how dry it gets during the dry spells) was greater than for other areas of Australia and parts of the world of the same mean annual rainfall.

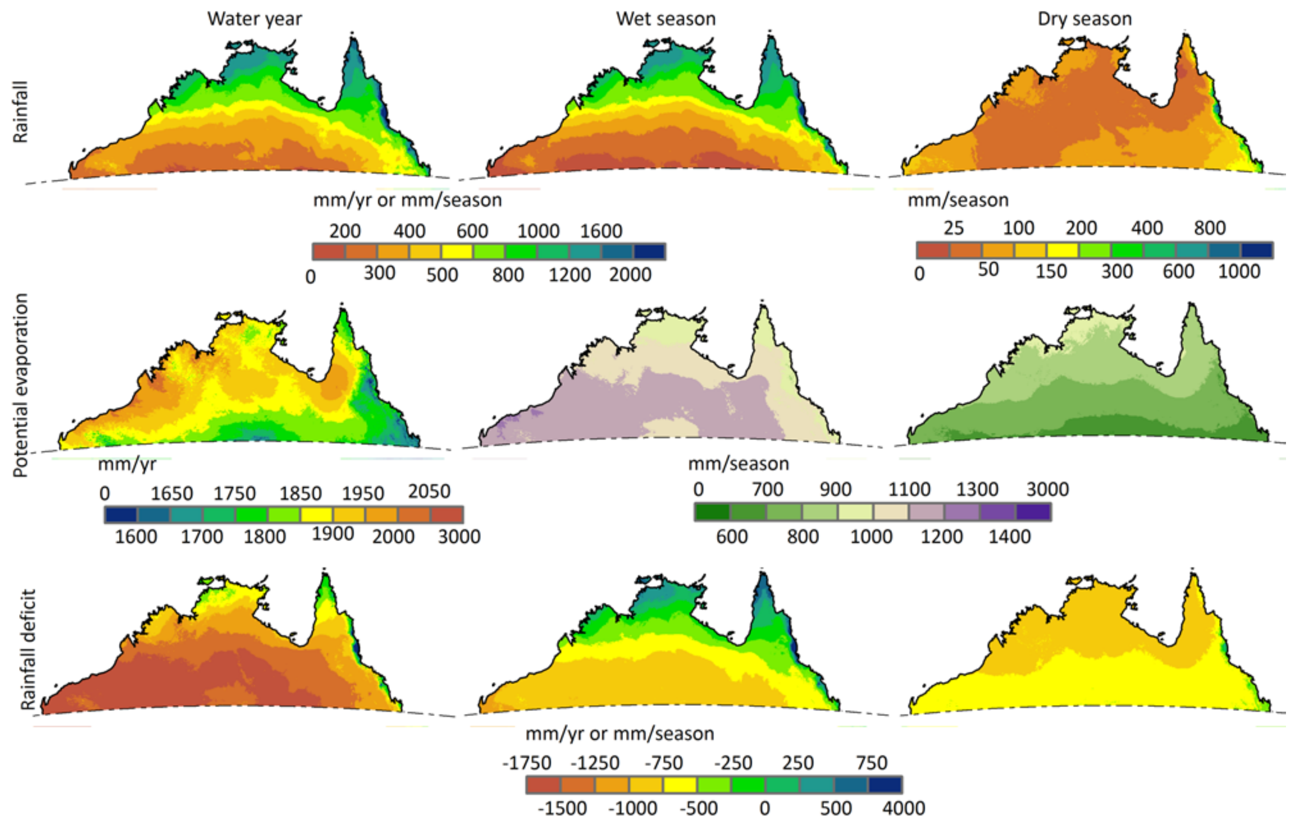

Figure 2-3 Mean annual and mean seasonal rainfall, potential evaporation and rainfall deficit (1930 to 2007)
Potential evaporation calculated using Morton's areal potential (Morton 2003). Rainfall deficit is the rainfall minus potential evaporation.

Across northern Australia potential evaporation rates are relatively high all year round (Figure 2-3). Although evaporation rates are high across northern Australia, net evaporation (i.e. the difference between evaporation and rainfall) is the more relevant parameter to large carry-over surface water storages. This is because evaporation in large dams in the most northerly parts of northern Australia is largely offset by the high rainfall totals. Figure 2-3 illustrates the mean annual rainfall deficit (i.e. difference between mean annual evaporation and mean annual rainfall), or mean annual net evaporation, that would occur from a surface water storage. This figure indicates that mean annual net evaporation in the more northerly regions of northern Australia is relatively low, and some regions (e.g. Wet Tropics region) even experience a 'negative' mean annual net evaporation (i.e. mean annual rainfall exceeds mean annual evaporation).

The more southerly regions of northern Australia have high mean annual net evaporation. Mean annual net evaporation is highest in the Pilbara region.

Together with the high seasonality of rainfall the high potential evaporation rates result in many inland areas having semi-arid landscapes (Figure 2-4). In the north of the study area (e.g. NT) the semi-arid zone roughly corresponds to 800 mm rainfall isohyte, in the south eastern part of the study area the semi-arid area roughly coincides with areas with mean annual rainfalls of up to 600 mm. In southern Australia, where potential evaporation and the seasonality of rainfall is generally lower, semi-arid landscapes coincide more closely with mean annual rainfall of 400 mm or less.

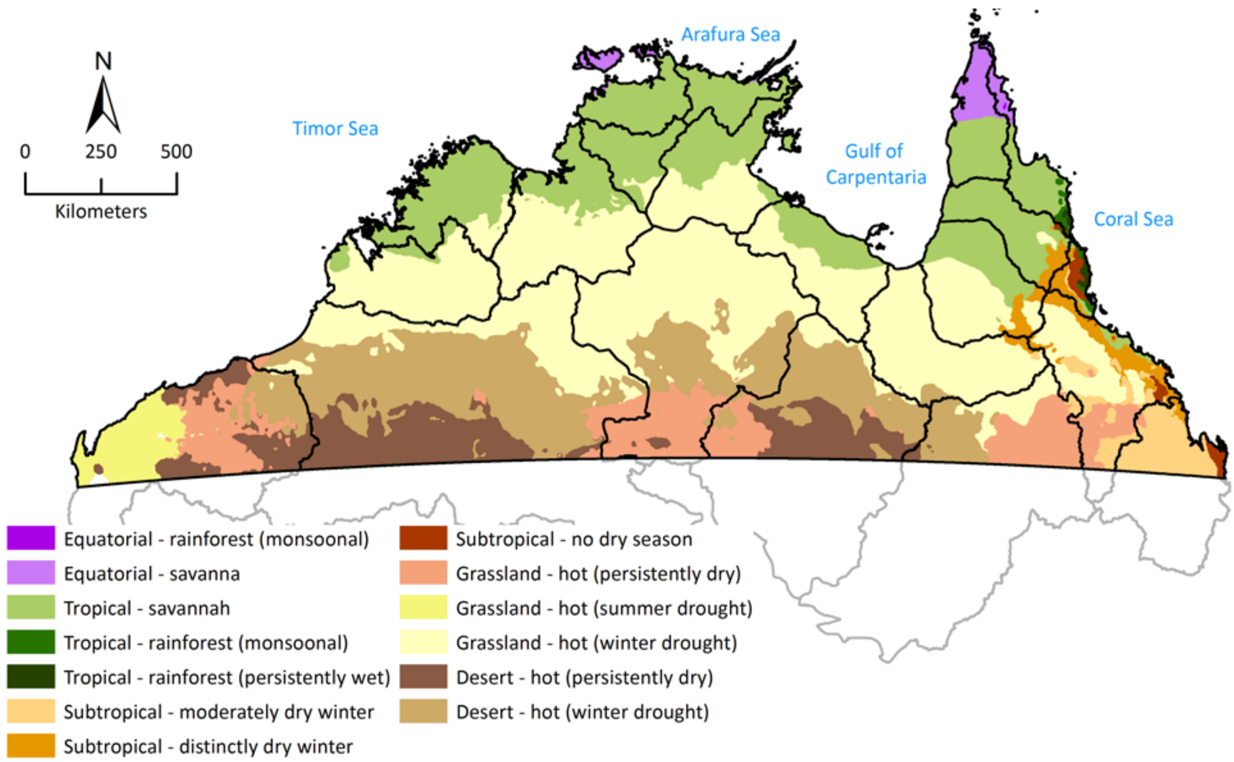

Figure 2-4 Köppen-Geiger classification map for northern Australia
Black lines delineate the reporting regions
Source: Australian Government Bureau of Meteorology (BoM 2014)

2.4 Groundwater resources of northern Australia

The northern Australia Land and Water Science Review estimated that approximately 60,000 ha of land could potentially be irrigated using groundwater in the Timor Sea and Gulf of Carpentaria Drainage Divisions. Extending the same analysis to the Tropic of Capricorn it is estimated that between 100,000 and 150,000 ha of land could potentially be irrigated using groundwater in northern Australia (this includes the Wet Tropics region and the Lower Burdekin, but noting that water for the managed aquifer recharge scheme in the Lower Burdekin is supplied by the Burdekin Falls Dam).

Irrigation developments using groundwater will be more economically viable than those utilising surface water. This is because the initial capital cost of infrastructure is typically lower for groundwater than surface water developments, and provided groundwater is carefully allocated the reliability of water supply tends to be higher than surface water developments. Investigation costs for groundwater, however, tend to be considerably higher than surface water and the overall area of northern Australia that could potentially be irrigated with groundwater is likely to be about 10 times less than that of surface water.

Across northern Australia the intermediate to regional scale basins with the largest estimated extractable groundwater volumes are the (i) central Daly-Wiso and Georgina; (ii) coastal section of the Canning basin; and (iii) Great Artesian Basin (GAB) (Table 2-3 and Figure 2-5). Each is estimated to have extractable groundwater volumes of greater than 100 GL/year (Turnadge et al., 2013). The remainder of the Daly-Wiso and Georgina and the inland portion of the Canning basin have estimated extractable groundwater volumes of between 10 and 100 GL/year. Elsewhere the estimated extractable groundwater volumes are estimated to be less than 10 GL/year. These figures suggest that, based on the limited data that are available, there may be approximately 600 GL/year of extractable groundwater available in the intermediate to regional scale systems in northern Australia. The groundwater prospectivity map shown in Figure 2-5 was developed by Turnadge et. al. (2013) by refining the groundwater prospectivity map produced as part of the Northern Australia Land and Water Science Review (CSIRO 2009a, Cresswell et al., 2009) in order to provide estimates of the variability of intra-basin prospectivity.

Perhaps the most noteworthy local to intermediate scale groundwater system in northern Australia is the Burdekin Delta in the Lower Burdekin (Burdekin catchment). The Lower Burdekin is one of Australia's most intensive groundwater use areas, containing more than 2000 extraction bores (Arunakumaren et al., 2001), and with a sustainable yield estimated to be 350 GL/yr (NLWRA 2000). The alluvial groundwater system in the Burdekin Delta is managed using aquifer enhanced recharge, using water released down the Burdekin River from the Burdekin Falls Dam. The coastal alluvial deposits associated with the other large east flowing rivers draining the Great Dividing Range and steep coastal escarpments also contain groundwater that may also support small scale irrigation. These deposits are also likely to have the best prospects for managed aquifer recharge for irrigation in northern Australia. West of the Great Dividing Range, depositional environments are different (Petheram and Bristow 2008) and opportunities for managed aquifer recharge in such alluvial systems are likely to be considerably smaller in scale (see Section 5.2).

Other noteworthy local to intermediate systems in northern Australia are the Fitzroy River (WA) alluvium (Harrington et al., 2011, Lindsay and Commander 2006) and the Koolpinyah Dolomite (CSIRO 2009b), which underlies the Adelaide and Mary catchments, east of Darwin. Recent drilling by Queensland Government in the McBride and Chudleigh basalt provinces in the Gilbert catchment has identified a promising groundwater resource (Bruce Pearce pers. comm. 2013), which may be able to support small scale irrigation.

The groundwater resources of the northerly draining catchments of northern Australia were described by the NASY project (CSIRO 2009b, c, d), and those reports remain the most comprehensive collation of material on groundwater in northern Australia. Turnadge et al., (2013) provide an overview of the published studies that occurred subsequent to the NASY project.

The sustainable allocation and management of groundwater resources in northern Australia requires sufficient understanding of recharge locations, processes and rates, aquifer flow paths and flow rates, and discharge locations, mechanisms and rates. This can only be attained through on-ground studies.

The groundwater systems for selected regions are briefly described in Appendix A.

Table 2-3 Estimates of annual groundwater availability from northern Australia at the intra-basin scale
Source: Modified from Turnadge et al., (2013)

GROUNDWATER RESOURCE		DEVELOPMENT POTENTIAL	ESTIMATED AVAILABLE EXTRACTION (GL/Y)
(1)	Daly, Wiso and Georgina basins (central)[*]	high	> 100
(2)	Canning Basin (coastal)[#]	high	> 100
(3)	Great Artesian Basin	high	> 100
(4)	Daly, Wiso and Georgina basins, excluding (1) [%]	moderate	10 - 100
(5)	Canning Basin, excluding (2) [^]	moderate	10 - 100
(6)	Fitzroy River alluvium[## ^]	moderate	10 - 100
(7)	Koolpinyah Dolomite	Moderate	10 - 100
(8)	Other groundwater resources	low	< 10

[*]refers to the area encompassing the southern region of the Daly Basin and the northern regions of both the Wiso and Georgina basins;

[#]refers to the area of the Canning Basin located less than 100 km from the coast;

[%]refers to the combined area of the Daly, Wiso and Georgina basins excluding (1);

[^]refers to the area of the Canning Basin located more than 100km from the coast

[##] under normal flood conditions it has been estimated the alluvium may be able supply 200 GL of water, but actual yield will be limited by the quality of groundwater and low flow years in the Fitzroy River (i.e. need to maintain dry season waterholes).

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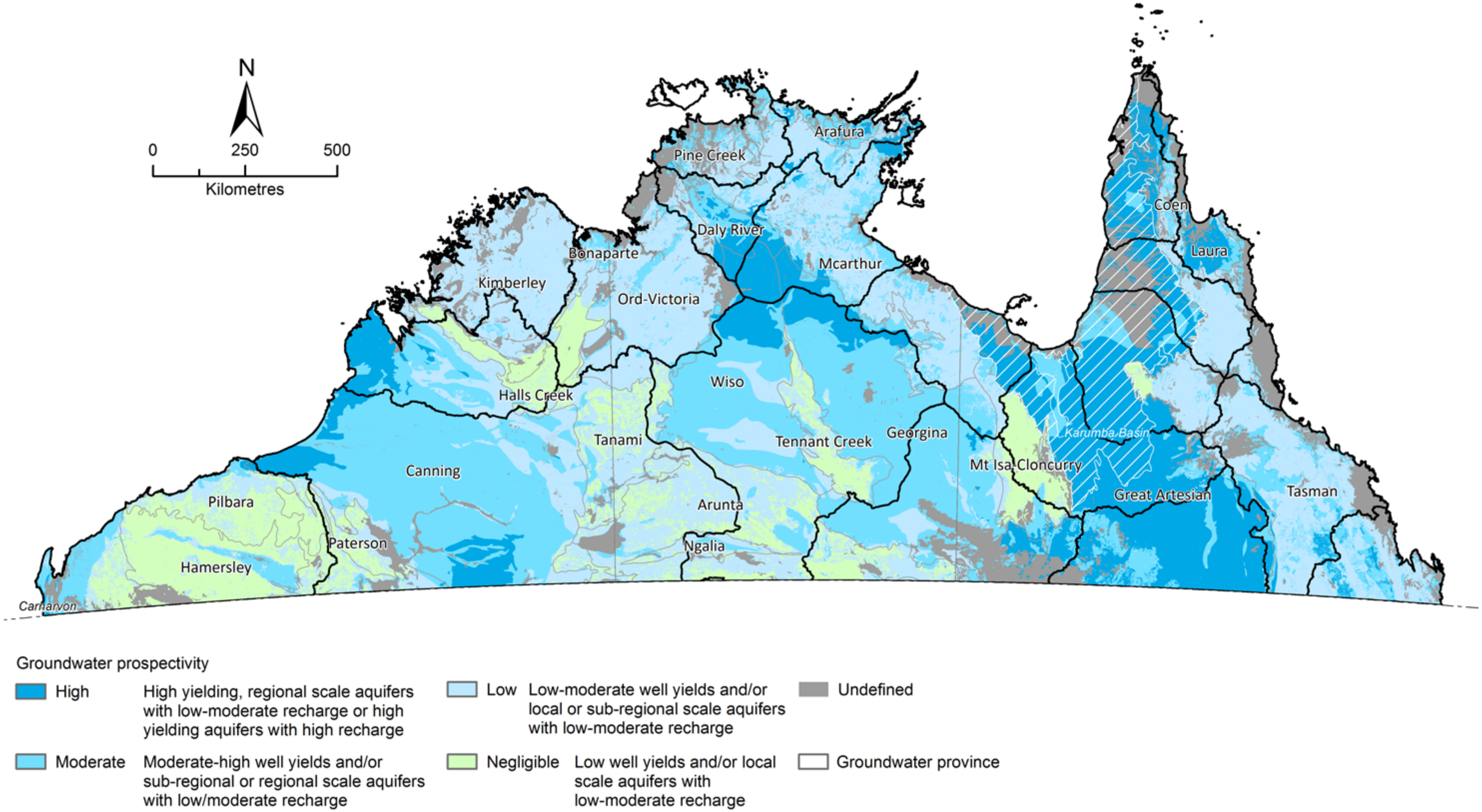

Figure 2-5 Revised map of groundwater prospectively for northern Australia

Blue tones indicate the degree of prospectivity. Hatching indicates the Karumba basin. In these areas, Karumba Basin aquifers are more likely to be used as a groundwater source, because they are shallower. The prospectivity of Karumba Basin aquifers is not shown in this figure. Black lines indicate reporting regions. This figure shows that major groundwater provinces do not align with surface water catchment boundaries. Local scale groundwater systems not shown. Source: Adapted from Turnadge et al., (2013)

2.5 Surface water resources of northern Australia

Northern Australia encompasses 100 AWRC river basins, and whose rivers are more seasonal and variable from year to year than rivers elsewhere in the world of the same climate type (Petheram et al., 2008). Across most of northern Australia the flow of water in rivers and streams is intermittent. For example many streams in the Pilbara region as well as larger rivers in the Wiso-Barkly region and the Lake Eyre basin have periods without flow that may extend to multiple years. In the Lake Eyre Basin rivers often flow less than 10% of the time and only in times of heavy rain, after which large areas may be inundated because of the flat terrain and interlacing nature of the channel network (McMahon et al., 2008). The largest region in the study area, the Riverless region, has negligible surface water resources, and groundwater is the main source of supply for stock and domestic purposes. This region, also known as the Western Plateau Division, is essentially an area of uncoordinated drainage. Streams, where they do exist, are seldom of length, disappearing in flat lands or shallow, narrow salt encrusted lakes (DNR 1976). In many places the ground is so sandy and porous that any rainfall in excess of evaporation is rapidly lost to infiltration.

The modelled median annual discharge and coefficient of variation of annual discharge from each AWRC river basin in northern Australia is shown in Figure 2-6 and Figure 2-7 respectively. It should be noted that the modelled median annual streamflow shown in Figure 2-6 is likely to represent an upper estimate, as the modelling did not include large scale transmission losses, which would be particularly prevalent in the semi-arid and arid Pilbara, Wiso-Barkly and Lake Eyre regions. The catchments with the largest streamflow are typically the larger basins on the east coast of Queensland, i.e. the Burdekin and Fitzroy, followed by the small, but very wet catchments in the Wet Tropics region. Partly because of the higher runoff and longer periods of streamflow, the catchments along the east coast of Queensland have higher and more stable human populations and many of the larger rivers are already regulated. These catchments also have a greater incidence of previous investigations of potential dam sites (see Section 3.1).

The actual amount of water that can be extracted or diverted for consumptive use from the river basins shown in Figure 2-6 will in many cases be considerably less than the median annual discharge. In addition to the quantity of streamflow, the amount of water than can be extracted for consumptive use will be dependent on the existence of favourable sites for in-stream or off-stream storages and the variability of streamflow. These issues are examined in Section 4. Many rivers in northern Australia also experience localised and extensive flooding. Figure 2-8 shows those areas that experience widespread inundation. Parts of northern Australia that experience the most extensive inundation are flat and have large contributing areas i.e. the southern Gulf (i.e. Flinders, Norman, Gilbert, Staaten catchments) and depressions in the Wiso-Barkly and Riverless regions, which drain the southern Barkley Tablelands. Appendix A provides satellite derived flood inundation maps for each of the reporting regions.

For further reading, McMahon et al., (2008) provide a comprehensive analysis of the surface hydrology of the Lake Eyre Basin. CSIRO (2014) provide a detailed analysis of the surface (and groundwater) resources of the Pilbara region. CSIRO (2009b, c, d) provide a detailed analysis of the hydrology of the Timor Sea and Gulf of Carpentaria Drainage Divisions. Petheram and Bristow (2008) and Petheram et al., (2008a) provide an overview of the hydrology of northern Australia.

Photo 2-4 Einasleigh River looking upstream to Mount Noble (Gilbert catchment) December 2012
Photo CSIRO

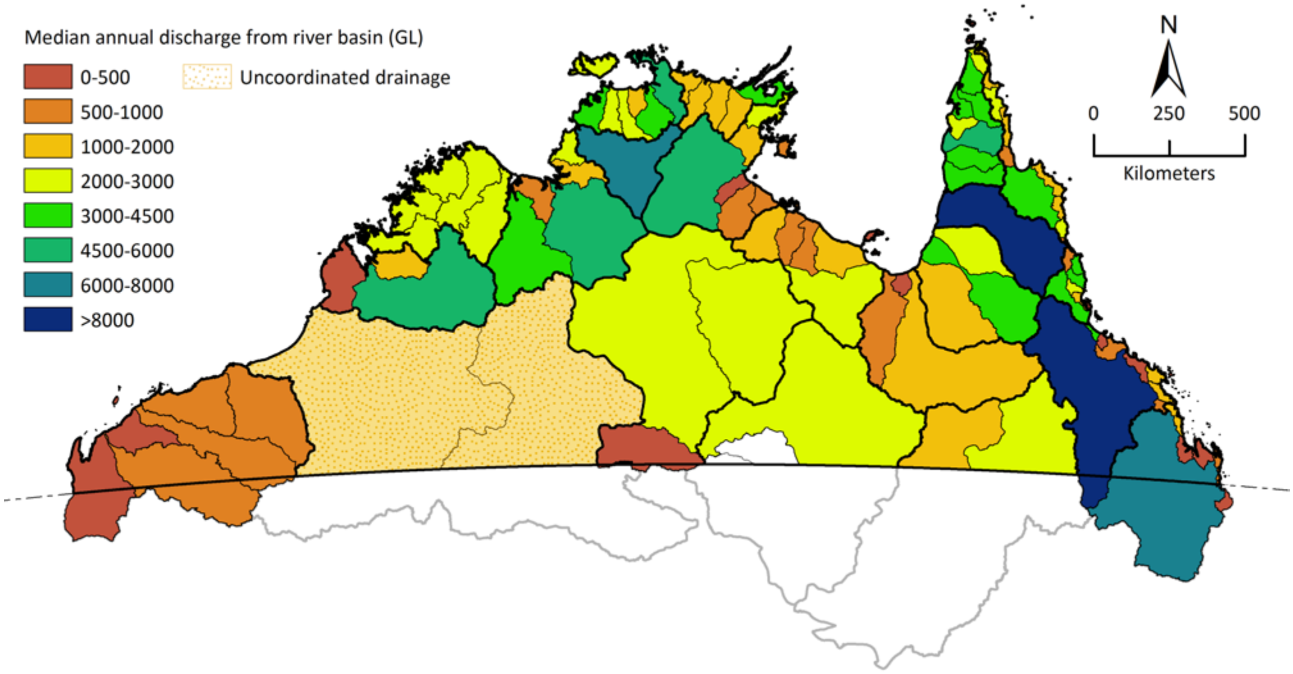

Figure 2-6 Modelled median annual discharge (1930 to 2007) from each of the AWRC river basins in northern Australia

Note when calculating discharge for the north draining catchments that straddle the Tropic of Capricorn, the entire catchment area was used, and in the case of coastal AWRC river basins the estimates include not just the major river within that basin but also the small coastal rivers and streams adjacent to the major river. When calculating discharge for south draining catchments that straddle the Tropic of Capricorn only that part of the catchment north of the Tropic of Capricorn was used. These estimates do not consider transmission losses, which are likely to be considerable, particularly in the larger internal semi-arid/arid catchments and others with internal sinks such as the Fortescue river basin (WA). Source: Data sourced from Petheram et al., (2012) and Australian Water Resource Assessment System (AWRA) Version 4.5 (Vaze et al., 2013).

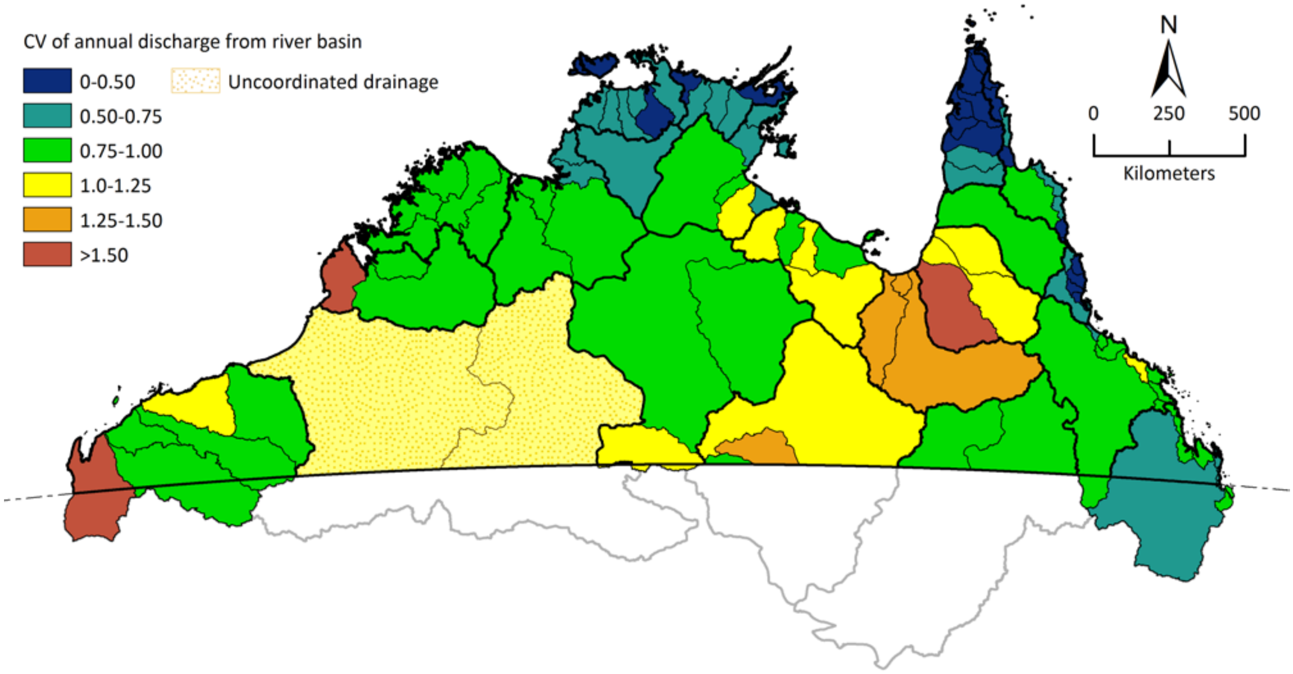

Figure 2-7 Modelled coefficient of variation of annual discharge under the historical climate (1930 to 2007) in each of the AWRC river basins in northern Australia

Data in this figure were calculated in a similar manner to data in Figure 2-6. Source: Data sourced from Petheram et al., (2012) and AWRA Version 4.5 (Vaze et al., 2013).

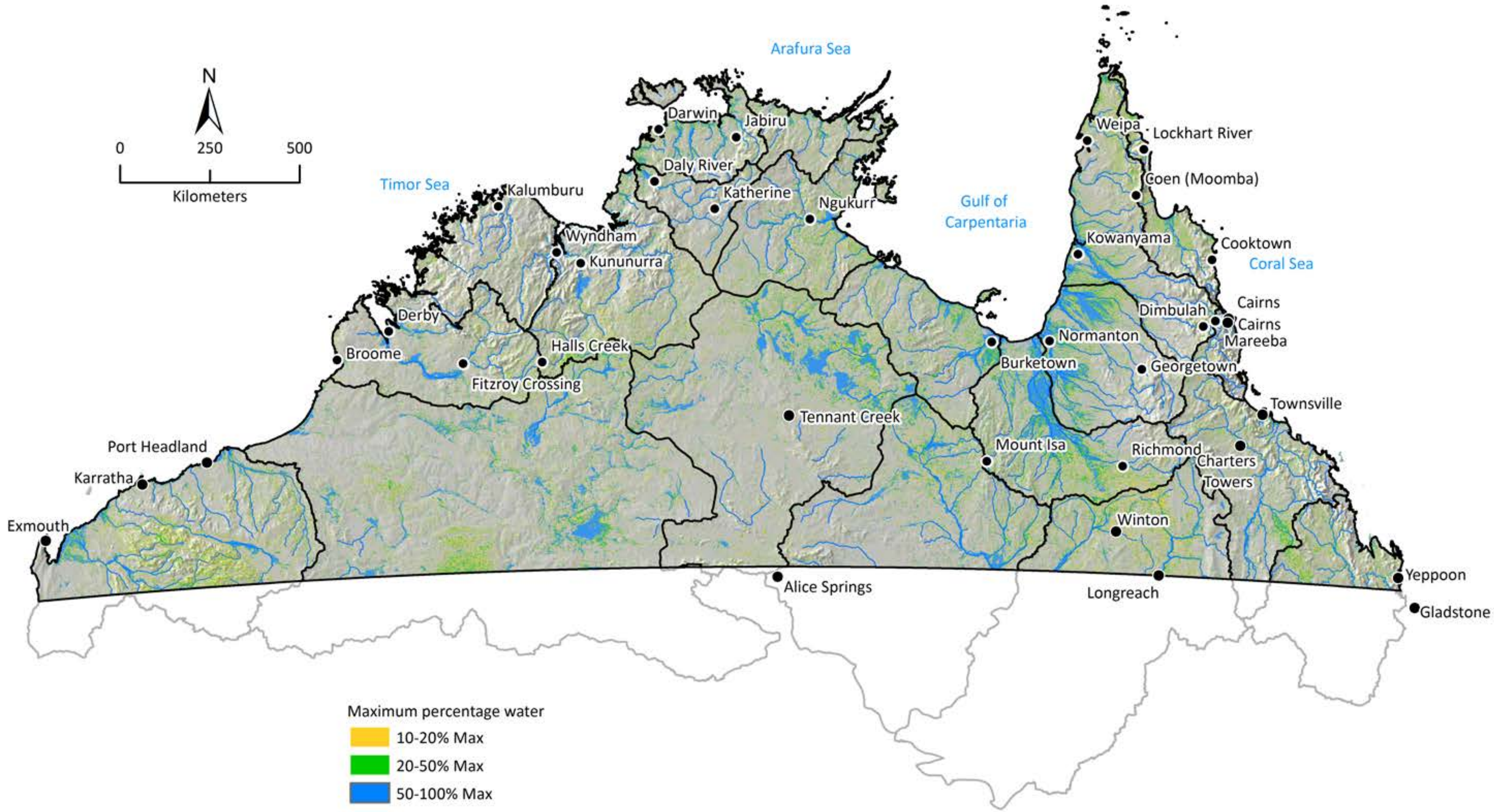

Figure 2-8 Major rivers, towns and flood inundation map for northern Australia

Background is a shaded relief map, which indicates areas of higher and lower topographic relief. Flood inundation data captured using MODIS satellite imagery (data sourced from Turnadge et al., 2013). This figure illustrates the maximum percentage of MODIS pixel inundated between 2000 and 2010. MODIS data were not locally calibrated and as a result some artefacts are evident in the image e.g. yellow shading on the Hamersley Ranges in the Pilbara region and yellow-green shading on vertosol soils in the Burdekin and Fitzroy regions

3 Regulated river systems in northern Australia

Many of the catchments along the north east coast of Queensland (i.e. between Rockhampton and Cairns) are regulated systems containing existing water storages. In some of these catchments uncommitted water allocations are available for purchase or lease, which would generally be less expensive than water from the construction of a new storage. Furthermore the construction of new water storages will need to access available reserve volumes and not impact on the reliability of water supplied to existing users or compromise environmental values. For these reasons it is essential to examine the nature and extent of regulation and quantities of general and strategic reserves in river systems before potential dam sites or other forms of water diversion are considered.

3.1 Constructed dams in northern Australia

The existing storage capacity in northern Australia is about 15,500 GL. Figure 3-1 shows existing large dams in northern Australia recorded by the ANCOLD database. Relatively few large dams are located north of the Tropic of Capricorn (Figure 3-1) and most of those are located along the Queensland coast. A notable exception is the Ord River Dam, which supplies water to the Ord River Irrigation Area, but also hydro power to Kununurra and Wyndham townships and the Argyle Mine.

In the sparsely populated northerly draining catchments of northern Australia there are few opportunities to repurpose existing dams for irrigation. The reservoirs are usually too small (irrigation requires substantially more water than mining, industry or urban uses) and many dam walls would require refitting for irrigation supply purposes. Further dams suppling water to mines located in hard rock areas are not usually constructed near soils suitable for irrigated agriculture. Major ore bodies are generally limited to very old igneous and metamorphic rocks, where hot fluids have been transported from great depths and minerals in the fluids precipitated in the joints and fractures of these rocks. The formation of major ore bodies is facilitated by cracking of the crust, folding and mountain building activity, where the older the rock the greater the chance that it would have been exposed to these activities. The soils in these areas are typically shallow and poorly developed.

Some of the existing large dams in northern Australia were constructed by mining companies to supply water to nearby mines (e.g. Corella Dam in the Flinders catchment, Kidston Dam (officially known as Copperfield River Gorge Dam)in the Gilbert catchment). These dams were designed to be constructed to a very tight time frame and to provide water to mines with an expected operational life of only 15 to 20 years. With the closure of the mines, ownership of the dams was transferred to the Queensland Government, which has had to pay for the upkeep and maintenance of the structures. Neither Corella nor Kidston dams can currently be used to supply water for irrigation. In the case of Corella Dam, embankment settlement led to extensive cracking of the face slab, which has worsened as the slab reinforcing mesh corroded (Petheram et al., 2013a). Repairing and refitting this dam for irrigation would be expensive, possibly as expensive as constructing a new dam at the same location (Petheram et al., 2013a).

The situation is different in the more densely populated catchments along the east coast of Queensland (i.e. Burdekin and Fitzroy catchments). These catchments host intensive and multiple land uses, and there has been, and will continue to be competition for additional water supplies between urban, mining, industrial and rural users. Permanent trading in water allocations introduced as part of the Council of Australian Government (COAG) water reform agenda is a mechanism which allows water to move between sectors to meet new demands and for water to move to the highest value uses such that new water demands do not always require new storage development.

It is also important to recognise that the demands of different water users changes over time, as will their capacity to pay for or ‘compete’ for water. In addition, different water users require water with differing levels of reliability. As such, it is important that planning for water infrastructure projects takes into account a range of potential and shifting combinations of water use, that will affect water demand, use and pricing and, hence, the design requirements and investment profile of the infrastructure.

Whilst planning for changing patterns of multiple-sector water use is most necessary where multi-sector demand is already apparent through intensive water use, a multiple-sector approach can profitably inform all water infrastructure planning. Even where a storage development may be conceived solely to meet one demand, such as mining, the potential for other uses such as irrigation post-mining should always be contemplated.

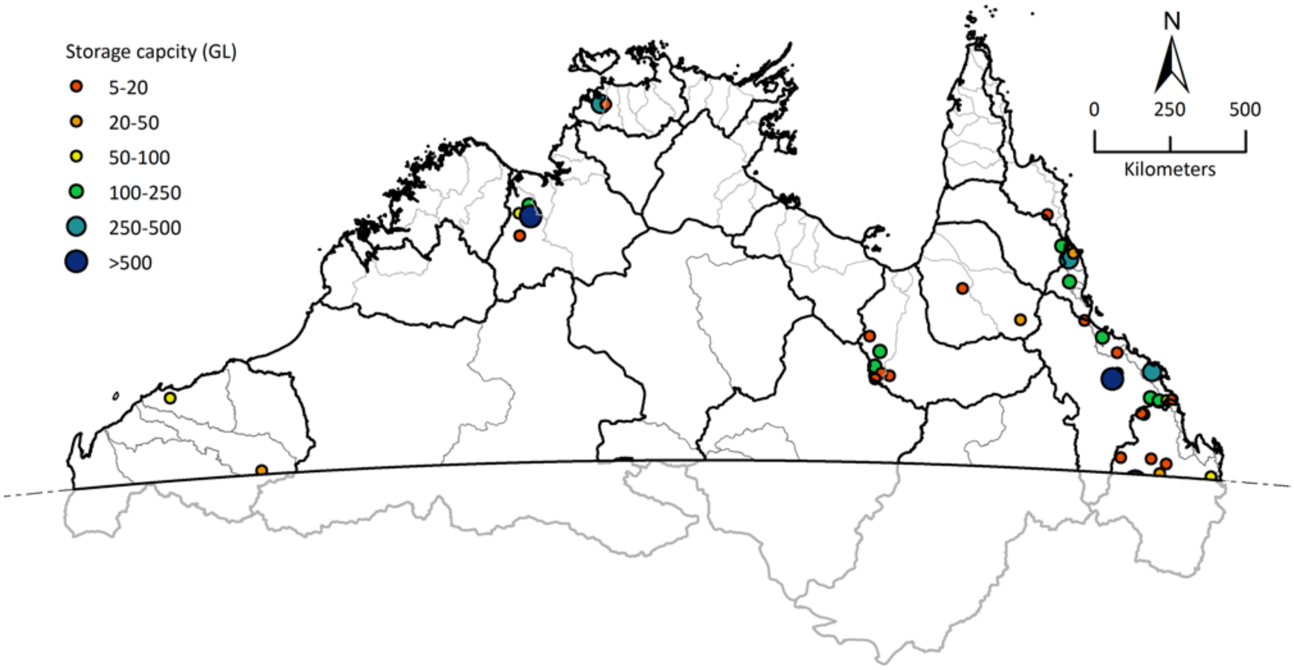

Figure 3-1 Storage capacity of existing surface water storages greater than 5 GL and with a dam wall greater than 10 m in height

Black lines delineate reporting regions. Grey lines delineate AWRC river basins. Note dam capacity is usually considerably greater than the yield (i.e. water that can be supplied from a dam). Source: Data sourced from the ANCOLD database of large dams in Australia.

3.2 Uncommitted water in the regulated river basins of north east Queensland

In this section, Table 3-1 provides a summary of water resource and operation plans and uncommitted water in the more heavily regulated catchments of northern Australia. The largest quantities of uncommitted water are in the Burdekin Haughton Water Supply Scheme, Pioneer Valley Water Supply Scheme and the Proserpine River Water Supply Scheme, though in the latter case the water is expected to be used for future urban growth. The volume of uncommitted water in the Burdekin Haughton Water Supply Scheme is considerably larger than the yield from any of the potential storages recently investigated in the Flinders catchment (see Petheram et al., 2013a).

Significant strategic reserve volumes have been set aside in the Fitzroy Basin WRP, for Connors River dam (56.4 GL/yr) and for the Nathan dam (90 GL/yr) proposals, and in the Burdekin Basin WRP for raising the Burdekin Falls Dam (150 GL/yr) and for the Urannah dam (150 GL/yr) proposals. Significant volumes of general reserves have also been set aside in these basins.

Appendix B provides further detail for each of the more heavily regulated catchments along the north east coast of Queensland. It also provides a brief comment on selected potential dam options in Queensland.

Table 3-1 Summary of water resource and resource operations plans and uncommitted water in the regulated river basins in north east Queensland

REGION	CATCHMENT	SUMMARY
Wet Tropics	Barron	**Water resource plan:** Water Resource (Barron Basin) Plan 2002 **Resources operations plan**: Barron Basin Resource Operations Plan, finalised 6/2005. Amended 5/2013. **Current allocations:** HP - 14,028 ML/yr; MP - 190,937 ML/yr, 30,625 ML/yr no priority specified. **Water availability:** 4,000 ML/yr at Lake Placid. **Existing storage capacity**: 476,000 ML
Wet Tropics	Herbert	**Water resource plan:** The Herbert River catchment area is included in the Water Resource (Wet Tropics) Plan 2013 **Resources operations plan**: A resource operations plan for the Wet Tropics area is in preparation **Current allocations:** **Water availability** Strategic reserves – 12,450 ML/yr **Existing storage capacity**: < 1000 ML
Wet Tropics	Tully	**Water resource plan:** Water Resource (Wet Tropics) Plan, 2013 **Resources operations plan**: Under preparation **Current allocations:** Maximum diversion to power station 3,024 ML/day **Water availability:** Water is used for power generation, and the regular water releases also support a white water rafting industry **Existing storage capacity**: 205,000 ML
Burdekin	Burdekin	**Water resource plan:** Water Resource (Burdekin Basin) Plan 2007 **Resources operations plan**: Burdekin Basin Resource Operations Plan, finalised 12/2009 **Current allocations:** HP -133,252 ML/yr; MP – 985,268 ML/yr. **Water availability:** It is considered there are potentially 50,158 ML/yr of uncommitted HP allocations and 44,593 ML/yr of uncommitted MP allocations available in the Burdekin Haughton Water Supply Scheme. **Water availability:** Strategic reserve volumes of 150,000 ML/yr are available for a raising of Burdekin Falls Dam (Photo 3-1) and for development of the Urannah dam proposal. General reserve volumes are available as detailed in the appendix. **Existing storage capacity**: 2,022,977 ML
Burdekin	Don	**Water resource plan:** A water resource plan has not been prepared for the Don River catchment **Resources operations plan**: A water resource plan has not been prepared for the Don River catchment **Current allocations:** Water used in the lower Don River area is groundwater from the Don River delta aquifers. This resource is considered to be fully allocated. Urban supply to Bowen is supplemented by a pipeline from the Proserpine River Water Supply Scheme. The Water for Bowen proposal involved diversion from the Burdekin Haughton Water Supply Scheme **Water availability:** 0 **Existing storage capacity**: 0
Burdekin	O'Connell	**Water resource plan:** The Water Resource (Whitsunday) Plan 2010 covers the O'Connell and Andromache River catchments. A water resource plan has not been prepared for the St Helens Creek catchment **Resources operations plan**: The Whitsunday Resource Operations Plan was finalised in December 2011. **Current allocations:** Existing license entitlements have not been converted to allocations. **Water availability:** Strategic reserves 1,000 ML/yr: General reserves 19,000 ML/yr. **Existing storage capacity**: 0
Burdekin	Pioneer	**Water resource plan:** Water Resource (Pioneer Valley) Plan 2002 **Resources operations plan**: Pioneer Valley Resource Operations Plan was released in June 2005 and amended in 2007

REGION	CATCHMENT	SUMMARY
		Current allocations: HP – 30,753 ML/yr; MP - 98,927 ML/yr **Water availability:** SunWater report that 11,000 ML of uncommitted HP water allocations are available for lease in the Pioneer Valley Water Supply Scheme. **Existing storage capacity**: 228,880 ML
Burdekin	Proserpine	**Water resource plan:** Water Resource (Whitsunday) Plan 2010 **Resources operations plan**: Whitsunday Resource Operations Plan, Finalised December 2010 **Current allocations:** HP – 21,445 ML/yr; MP – 38,075 ML/yr **Water availability:** Approximately 10,000 ML/yr of uncommitted HP water allocations are available in the Proserpine River Water Supply Scheme to meet expected growth in urban demands. **Existing storage capacity**: 491,400 ML
Burdekin	Ross	**Water resource plan:** A water resource plan has not been prepared for the Ross River catchment **Resources operations plan**: A resource operations plan has not been prepared for the Ross River catchment **Current allocations:** 75,000 ML/yr – reliability not specified. **Water availability:** No water other than that held by the Townsville City Council is available from the Ross River catchment **Existing storage capacity**: 238,247 ML
Fitzroy	Fitzroy	**Water resource plan:** Water Resource (Fitzroy Basin) Plan 2011 **Resources operations plan**: Fitzroy Basin Resource Operations Plan, September 2014. **Current allocations:** HP - 130,636 ML/yr; MP – 274,012 ML/yr. **Water availability:** SunWater advertise that approximately 1,600 ML/yr of uncommitted water allocations are currently available for lease in the Nogoa Mackenzie Water Supply Scheme. The Fitzroy Basin water resource plan sets aside strategic reserve volumes which could be accessed by development of the Connors River and Nathan dams and the lower Fitzroy River weirs. General reserve volumes are available as detailed in the appendix. **Existing storage capacity**: 1,605,626 ML

Photo 3-1 Burdekin Falls Dam (Burdekin catchment)
February 2009. Photo: CSIRO

4 An assessment of surface water storage potential

4.1 Potential surface water storages previously investigated by the northern jurisdictions

In the 1960s and '70s the northern jurisdictions investigated numerous potential dam sites in northern Australia, the majority of investigations occurring along the east coast of Queensland, and in the vicinity of Darwin (Figure 4-1). It is difficult to compare the outcomes of those studies because they were undertaken by a wide range of organisations, at different times, using different methods and with varying degrees of rigour. Some reports were never officially published or only exist as hardcopy documents in Government archives. Consequently it was not possible to locate, review and summarise all previous studies in the timeframe available for this rapid assessment. With the exception of information on dam location, and for some sites an estimate of potential storage capacity, no information in a summarised form was readily available. (It should be noted that the jurisdictions are endeavouring to make many of their hardcopy reports available on-line.)

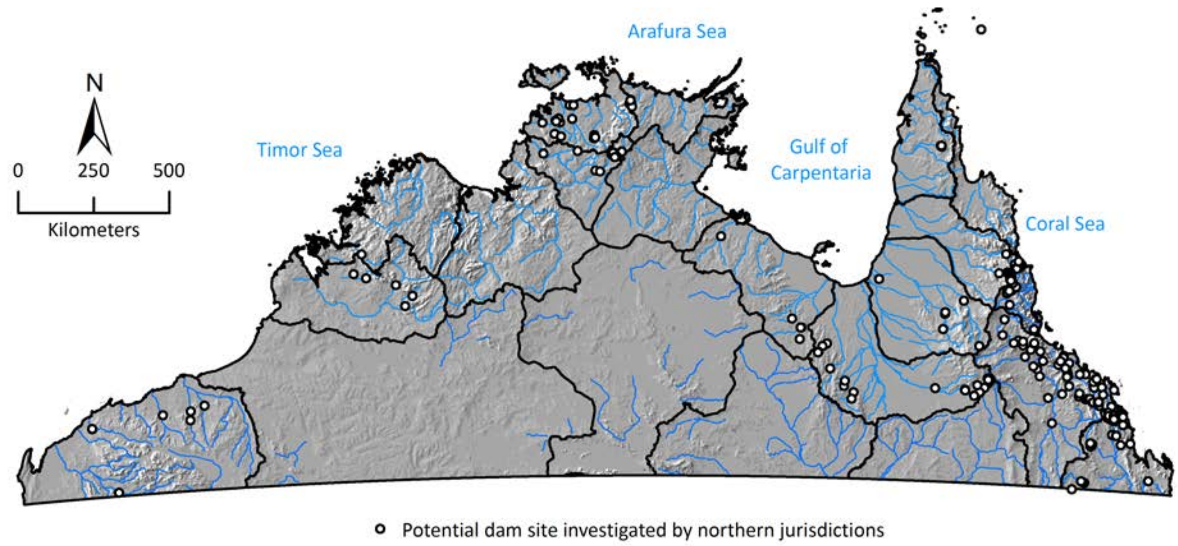

Figure 4-1 Map of potential surface water storage options in northern Australia previously investigated by the northern jurisdictions.
Source: Data were supplied by the Department of Energy and Water Supply (Queensland) and Northern Territory Department of Land and Resource Management. This was supplemented with additional sites known to be previously investigated by the authors.

4.2 A consistent assessment of the potential for large in-stream dams

4.2.1 OVERVIEW OF DAMSITE MODELLING METHOD

To ensure that the entire study area was objectively and consistently assessed for potential sites for dams, the DamSite model was applied to the area. This model is a series of algorithms that automatically determines favourable locations in the landscape as sites for intermediate to large water storages. Over 2 billion sites across northern Australia were assessed at 1 m increments, up to a height of over 100 m at some sites. A dam cost function developed by Petheram and McMahon (2012) was used to generate an approximate unit cost for each potential dam structure. This was used to help identify the optimal height at a given site and the optimal sites in each reporting region.

No dollar costs are presented in this report. Ultimately, dam costs are highly site specific, and without detailed locally-derived knowledge cost estimates can be in error by more than 50%. The purpose of the cost function used in this study was to distinguish between potential dam sites requiring a large dam wall (i.e. higher likely cost) from those sites requiring smaller dam walls (i.e. lower likely cost). Despite the uncertainty in using a generic cost function, the approach proved effective in the Flinders and Gilbert catchments and in testing in the catchments around Darwin, where the DamSite model identified many of the existing potential dam sites as well as several other better locations.

Broadly, the approach involves calculating the potential dam and reservoir dimensions of every potential site in northern Australia at 1 m increments. The cost effectiveness of each reservoir was evaluated by calculating the ratio of the storage volume to cost (i.e. the approximate cost of constructing the dam wall). A summary of the results is presented in Figure 4-2 and is discussed in Section 4.5.

The next step involved calculating an approximate yield (at 85% annual time reliability) using a computationally efficient method (i.e. Gould-Dincer-Gamma algorithm) for each site and for each 1 m increment dam height, i.e. up to 100 times, at over 2 billion sites. For each region, the 500 potential dam sites with the best yield per unit cost were then re-evaluated using a more accurate but time consuming method (i.e. a behaviour analysis model). The cost effectiveness of each reservoir in terms of yield was evaluated by calculating the ratio of yield to cost. The yield results are presented in Figure 4-3, Figure 4-4 and Figure 4-5, and are discussed in Section 4.2.3. Runoff data for the 13 more northerly reporting regions were sourced from Petheram et al., (2009 and 2012) and runoff data for the eight central reporting regions were sourced from the Australian Water Resource Assessment System (AWRA) Version 4.5 (Vaze et al., 2013).

It should be noted that the Riverless region was not assessed using the DamSite model: the lack of suitable topography, low runoff and uncoordinated drainage patterns mean that this region is highly unlikely to be suitable for in-stream or off-stream water storages (see Section 2.5). Furthermore, the analysis methods as they stand now are not able to properly handle the uncoordinated drainage patterns and the prevalence of landscape depressions, so assessment of this region would be difficult without further development of the DamSite method.

Detailed figures of the results are provided for each region in Appendix A. A more detailed description of the methods is provided in Appendix C.

4.2.2 OPTIMAL STORAGE PER UNIT COST

A prospective dam site depends on the existence of a physiographic constriction of the river channel immediately downstream of a broad valley, the dimensions of which determine the storage volume. Figure 4-2 displays the optimal storage volume per unit cost for all sites in northern Australia with a ratio of storage per unit cost greater than 20. This figure (expressed as volume stored in GL per unit cost) gives an indication of those parts of northern Australia that have favourable topography for dams.

The figure indicates that the best topography for large dams is in the western half of northern Australia (i.e. Timor Sea Drainage Division and the Roper catchment), in particular the Fitzroy, Ord, Victoria and Roper catchments. The optimal FSL of these dams is generally more than 50 m above the river bed. The eastern half of northern Australia (i.e. Queensland in general) has generally unfavourable topography for siting large dams.

Despite the lack of relief, Figure 4-2 indicates (counter intuitively) that the upper Wiso-Barkly region has suitable topography for large storages. This is because long (i.e. > 15 km), low (< 10m height) dam walls could create impoundments that could potentially store very large volumes of water, simply because the landscape is so flat the impounded area would extend a long distance (e.g > 80 km in some instances). However, these shallow, sandy storages would lose excessive water to evaporation and seepage, and runoff is very low (i.e. < 15 mm/yr) and highly variable. Consequently when inflows and evaporation are taken into consideration (i.e. Figure 4-3) these sites no longer appear promising. A similar phenomenon appears to occur in the Fortescue River catchment, downstream of the Fortescue Marshes, where long (i.e. >10 km), low (i.e. < 15 m) dam walls could potentially create large storage volumes, because the remarkably flat topography upstream of the reservoir. However, the Fortescue River effectively terminates at the Fortescue Marsh and consequently yields at these locations would in reality be severely limited by inflows to and evaporation from the shallow reservoir.

Elsewhere in northern Australia parts of the Pilbara region and Burdekin catchment have favourable topography for storing water. The FSL of these storages would generally be between 20 and 40 m above the river bed. The steep and rugged terrain of the Wet Tropics region means this region has very few sites that are topographically suitable for large in-stream dams.

Figure 4-3 shows that large parts of northern Australia comprises Indigenous land or has been set aside for conservation or other protection (e.g. nature parks, flora, historical and coastal reserves, state conservation areas, nature refuges and heritage agreements). Some of the better potential dam sites in terms of storage per unit cost, but also yield per unit cost, occur in these areas. Many conservation areas are located in fairly rugged landscapes with a limited number of other uses, and these landscapes often have locations topographically favourable for siting dams.

The best DEM across northern Australia is the Shuttle Radar Topography Mission (SRTM) DEM (grid cell resolution of 30 m) and this was used in this analysis. It should be noted that the SRTM DEM considerably underestimates the volume of large water bodies that existed at the time the SRTM was flown (i.e. February 2000). These large, existing waterbodies resulted in voids in the SRTM DEM and theswere infilled by NASA using various means. Hence the DamSite modelling results for dams associated with these waterbodies (e.g. reservoir impounded by the Burdekin Falls Dam) are likely to be underestimated e.g. storage per unit cost and yield per unit cost will most likely be higher than that calculated by the DamSite model based on the SRTM DEM data.

4.2.3 YIELD AND OPTIMAL YIELD PER UNIT COST

In addition to having suitable topography and geology (i.e. see Section 2.1), dams require sufficient inflows to meet a potential demand (i.e. from a town, an irrigation district or mine) and in those areas where evaporation greatly exceeds rainfall, they cannot be so shallow that large amounts of water are lost to evaporation. Dams that command smaller catchments with lower runoff (see inset in Figure 4-4) have smaller yields. The results presented in Figure 4-3 take into consideration dam and reservoir dimensions but also the quantity and variability of inflows to the reservoir, and the concept that for a given potential dam, the larger the variability of inflows the lower the yield. Figure 4-3 also takes into consideration net evaporation. Only those sites with an optimum yield per unit cost greater than five are displayed in Figure 4-3.

In terms of yield per unit cost, the better potential dam locations occur in the western half of northern Australia, where there are topographically favourable potential dam sites with large catchment areas (i.e. large inflows) (Figure 4-3). Other favourable potential dam locations in terms of yield per unit cost are found in the wetter, more northerly regions. While these regions have only moderately favourable topography for dams they have high and relatively reliable inflows. The more northerly regions include the Van Diemen, Western Cape and the Northern Coral Sea regions. However, the western half of much of the Western Cape region is underlain by bauxite, which is highly permeable and generally unsuitable for water storages.

The regions in the Gulf, which are topographically relatively unfavourable for large dams, are even less favourable in terms of yield per unit cost because many of these areas also have low runoff relative to the rest of northern Australia.

The insets in Figure 4-3 indicate the approximate height and width of the FSL at the optimal yield per unit cost. In the western regions, the Fitzroy, Kimberley, Ord and Victoria, many of the better locations have an ‘optimum’ FSL 30 to 50 m above the river bed. These same locations had an optimal FSL of greater than 50 m in terms of storage per unit cost. This indicates that while larger dams could be constructed at these sites their performance starts to be limited by inflows to the dam reservoir. In the Gulf of Carpentaria Drainage Division, the Gilbert and Mitchell catchments have several potential dams with an 'optimum' FSL at 30 to 40 m at the optimal yield per unit cost. In the northerly regions, such as Van Diemen, Arafura and Western Cape the height of the 'optimum' FSL is typically less than 20 m, in part a reflection of the subdued topography.

The best existing or potential dam sites in northern Australia in terms of yield per unit cost are the Ord River and Burdekin Falls dams, which have already been constructed. The best large potential dam sites in northern Australia in terms of yield per unit cost are 'Mount Nancar in the lower Daly catchment, the lower Victoria catchment and the lower Roper catchment. However, unlike the Ord River and Burdekin Falls dam, there appear to be limited soils suitable for irrigated agriculture below these potential dam sites.

In terms of yield per unit cost, other potential dam locations of note occur along the Burdekin River up and downstream of the existing Burdekin Falls Dam (e.g. Hells Gates Mount Foxton), the Fitzroy catchment (WA) (e.g. Dimond Gorge) and in the Herbert River Gorge in the Wet Tropics region.

Unlike the catchments in the Timor Sea and Gulf of Carpentaria Drainage Division and the Pilbara region, the DamSite modelling of the Queensland coastal catchments indicated weir structures to be generally the most cost effective form of water storage (i.e. see small dam heights shown in inset in Figure 4-3). This is probably because the large easterly draining rivers are more deeply incised than the rivers in northern Australia west of the Great Dividing Range. Incised rivers can enable modest storage of water (e.g. 10 GL) behind relatively narrow (i.e. 100 to 200 m), 10 m high weir structures. Furthermore, unlike most of the rivers west of the divide, many of the large east draining rivers flow for a large proportion of the year, which has the effect of continually replenishing the weir reservoir.

Figure 4-4 shows the yield (at 85% annual time reliability) at the dam height at which the optimum yield per unit cost occurs. Note it is possible that a dam constructed at each site could have a higher or lower yield than displayed in this figure, if the dam wall was constructed higher or lower than the height of the dam wall at the optimum yield per unit cost (see yield – reliability charts for selected potential dam sites in Appendix A).

It should be noted, however, that all yields are expressed at the 'dam wall'. The amount of water that could actually be used by an irrigated crop will be considerably less than this amount, depending upon the distance of the dam to the irrigation scheme, the method of conveyance, on-farm storage and the technology used to apply water to the crop. Conveyance, on-farm and field application losses combined typically range between about 40% and 60% of the value stated at the dam wall (Petheram et al., 2013b,c). However, conveyance losses alone can be greater than 50% in both natural and constructed channels (ANCID 2001). Typically the greater the distance water needs to be conveyed, the larger the loss.

Figure 4-5 explores the maximum yield for all potential sites with a yield per unit cost value greater than 10. This figure shows that many of the previously identified potential dam sites along the Burdekin River upstream of Burdekin Falls Dam (e.g. Hells Gate, Mount Foxton) as potentially high yielding (i.e. yields between 600 and 1500 GL/yr).

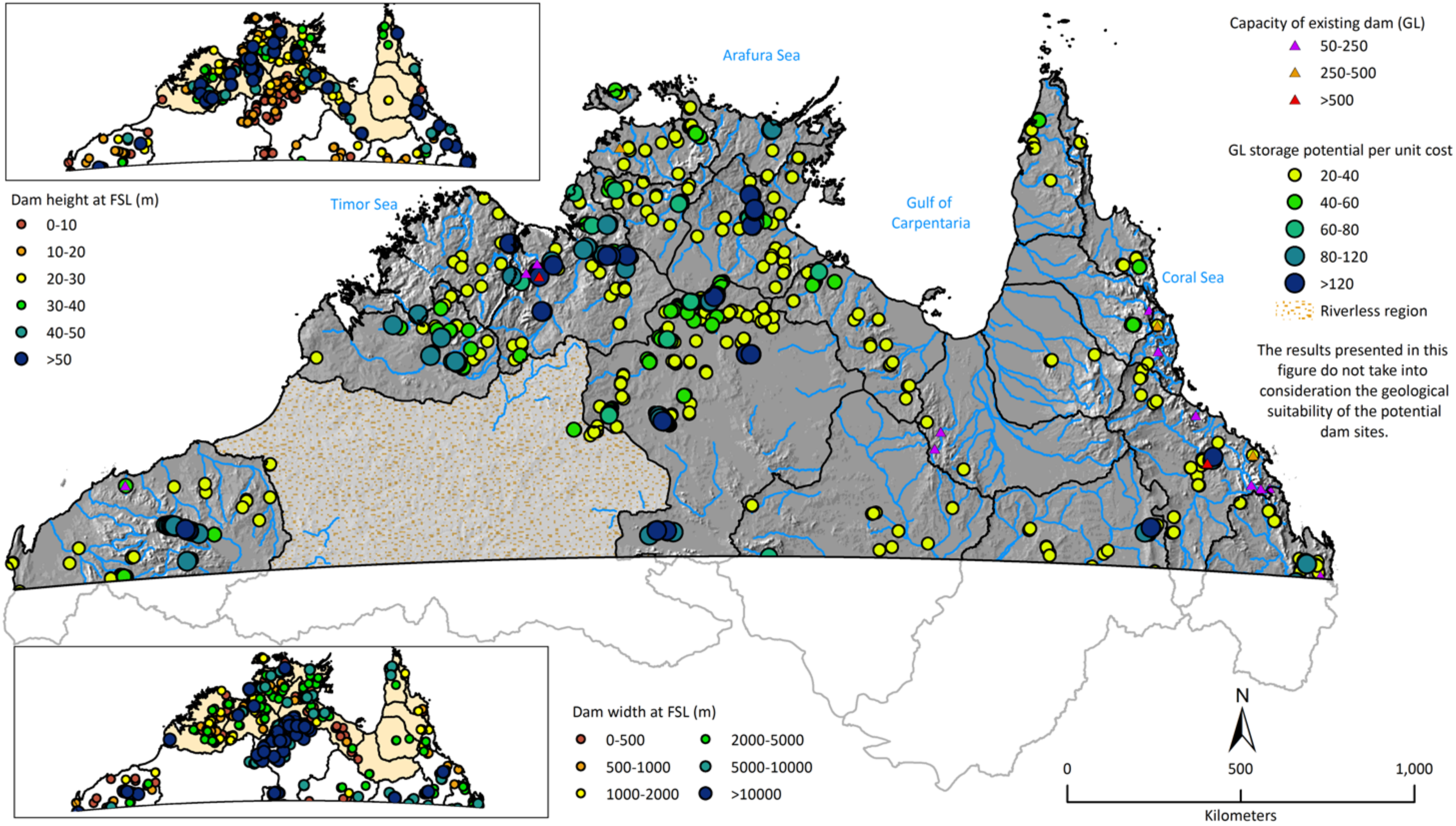

Figure 4-2 Modelled optimal storage per unit cost and land tenure of northern Australia

Only those potential dam sites with greater than 20 GL storage per unit cost are shown. Sites may not be geologically suitable. Triangles indicate storage capacity of existing dams and weirs (Source: ANCOLD). Note the actual yield from the existing storages will generally be considerably less than the storage capacity. Insets shows the approximate height (top) and width (bottom) of the dam FSL above the river bed at which the optimum storage volume to cost occurs.

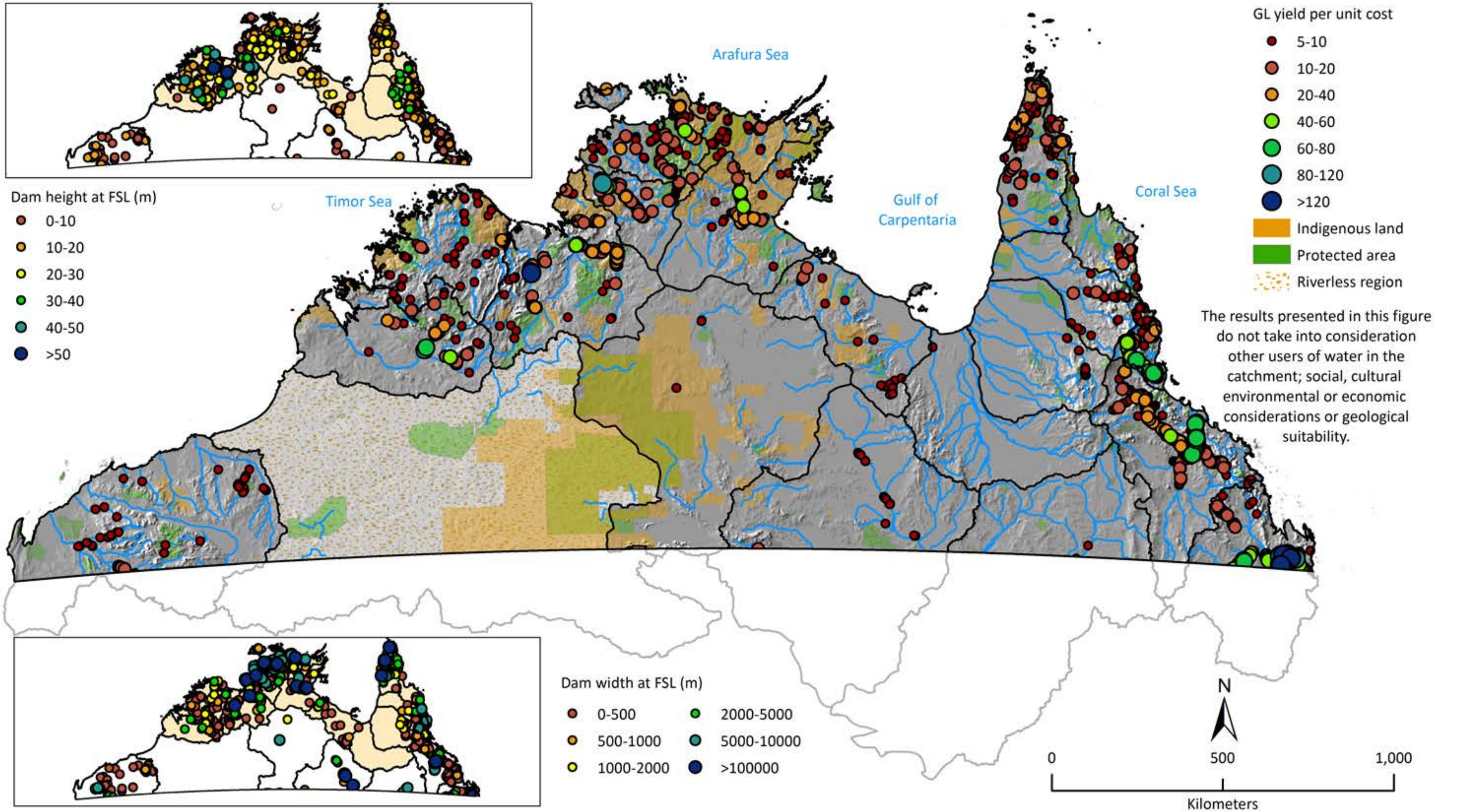

Figure 4-3 Modelled optimal yield per unit cost and protected areas of northern Australia
Only those potential dam sites with greater than 5 GL yield per unit cost are shown. Yield estimates do not account for up or downstream users of water and assume no other regulatory structures exist upstream of the site. Insets shows the approximate height (top) and width (bottom) of the dam FSL above the river bed at which the optimum yield to cost occurs. Indigenous land shown in brown (NLWRA 2002). Other protected areas are shown in green and include national, conservation and nature parks, flora, historical and coastal reserves, state conservation areas, and heritage agreements (Source: Collaborative Australian Protected Areas Database 2012). Sites may not be geologically suitable.

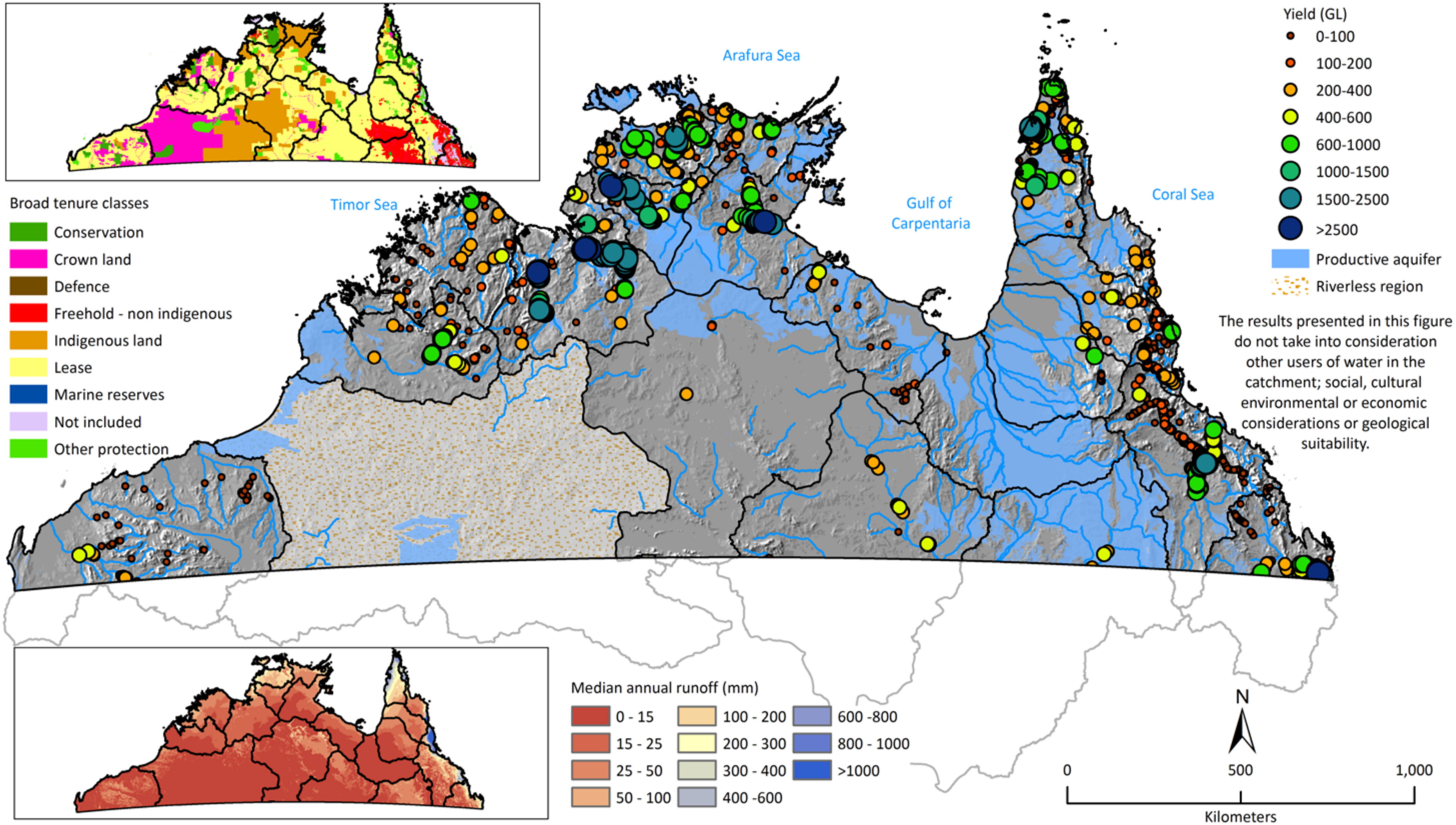

Figure 4-4 Modelled yield at the optimal dam height and productive aquifer map of northern Australia

Yield estimates based on 85% annual time reliability and yield is reported at the dam height at which the optimal yield per unit cost occurs. Only those potential dam sites with greater than 5 GL yield per unit cost are shown. Yield estimates are approximate only and calculations do not i) consider other users of water and ii) assume no other regulatory structures exist upstream of the site. Sites may not be geologically suitable. Productive aquifers shown in blue - based on Turnadge et al., 2013. Insets show i) broad tenure classes (top); and ii) median annual runoff (bottom) (data sourced from Petheram et al., (2012) and AWRA Version 4.5 (Vaze et al., 2013).

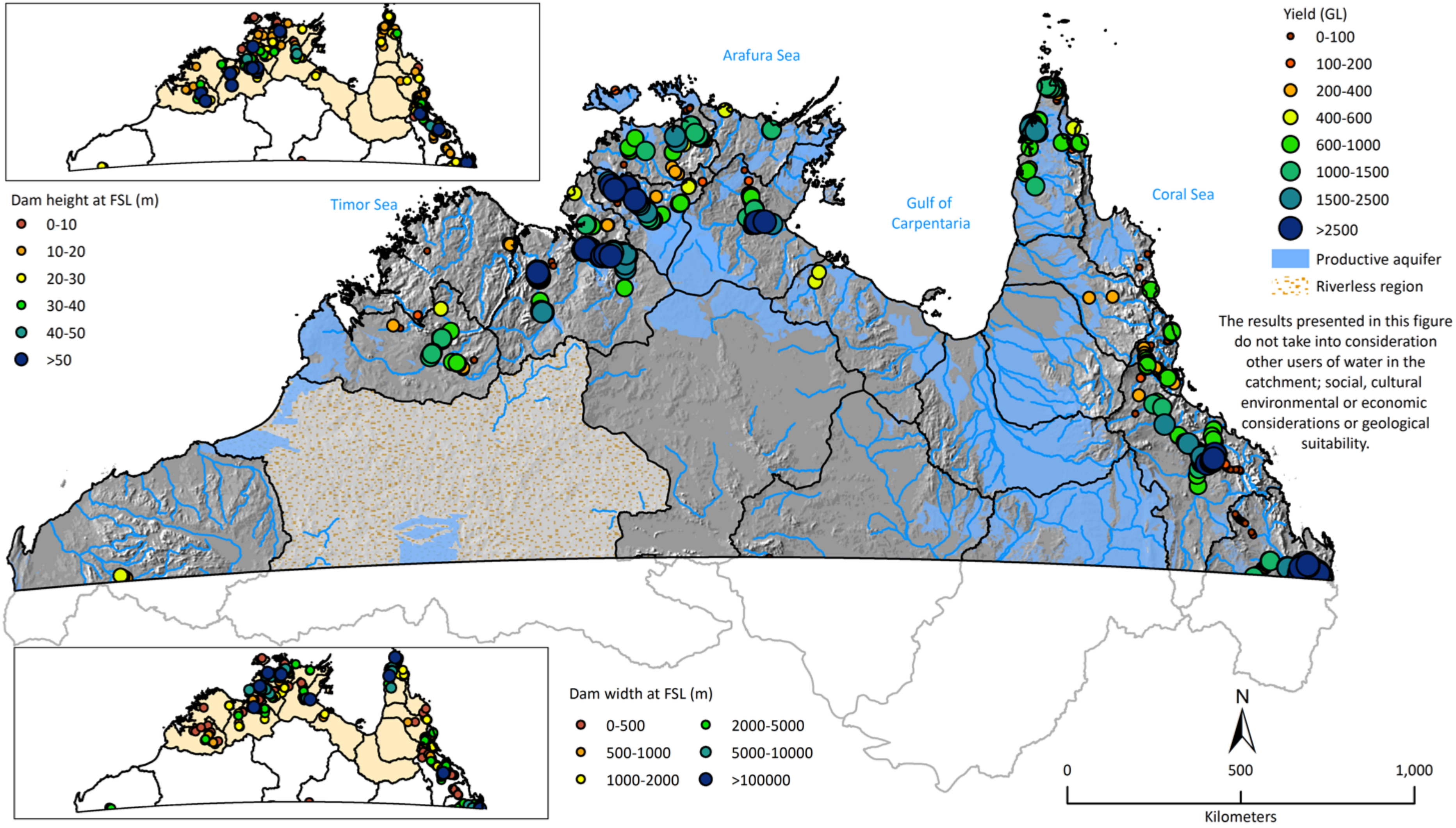

Figure 4-5 Maximum modelled yield for those sites with a yield (GL) per unit cost greater than 10

Yield estimates based on 85% annual time reliability and yield is reported at the dam height at which the maximum yield occurs with a yield per unit cost greater than 10. Only those potential dam sites with greater than 10 GL yield per unit cost are shown. Yield estimates are approximate only and calculations do not i) consider other users of water and ii) assume no other regulatory structures exist upstream of the site. Insets show the approximate height (top) and width (bottom) of the dam FSL above the river bed at which the maximum yield occurs. Sites may not be geologically suitable.

4.3 Potential for off-stream storages

The aim of this section is to provide a broad scale assessment of the suitability of physical conditions across northern Australia for farm scale off-stream water storage locations. Figure 4-6 indicates the general suitability for off-stream storage across the north. It does not take into consideration the availability of water or geological considerations below 2 m. The analysis for assessing the potential suitability of farm scale off-stream storages is documented in more detail in Appendix C.

Unlike large dams, farm scale off-stream water storages (e.g. ring tanks: Photo 4-1) need neither favourable topographic constrictions, nor to be situated on a river or drainage line (see Section 1.1.4 for types of water storages). For this reason and because they tend to be small structures (typically between 3000 and 8000 ML storage volume), a different type of analysis was used to assess their suitability.

Areas identified as being 'likely to be suitable' for off-stream storage occur in the coastal floodplains of the Daly (6), Adelaide and Mary (7) river catchments, the ephemeral freshwater lakes in the Barkley Wiso region (10) and the Belyando and Suttor rivers (18) in the upper Burdekin catchment, where some water harvesting using ring tanks for irrigation already occurs. The largest contiguous areas of land that are 'possibly suitable' for farm scale off-stream water storage are found in the Flinders catchment (10 in Figure 4-6), lower Leichhardt (13), lower Nicholson (12), the Sturt plateau in the upper Roper (9) upper Georgina (11), upper Diamantina (15) and upper Thompson (16) and upper Daly catchments (8). The latter five areas are semi-arid and streamflow is highly intermittent. Other smaller contiguous areas of land classified as 'possibly suitable' for off-stream water storage are the alluvial floodplains adjacent to the Fitzroy River (2) (WA), the alluvial floodplains of the West Baines River in the Victoria catchment (5) and the lower floodplains of the Normanby catchment (17). All three of these areas are susceptible to flooding. Other smaller contiguous areas possibly suitable for off-stream storage also occur in the in the Fitzroy (19) (Qld) catchment and in the Riverless region Sturt Creek (3) and Lake Mackay (4), an ephemeral salt lake. The majority of the western half of northern Australia is unlikely to be suitable for off-stream storage because the soils are too sandy.

Based on the rules used in this analysis the Fortescue Marsh (1) in the Pilbara region and the Sturt Plateau (8 and 9) were identified as being 'possibly suitable' for off-stream storage. However, the Fortescue Marsh is hypersaline and has a high conservation value and in reality is unlikely to be suitable for off-stream storage. The Sturt Plateau has a high gravel content (not captured in this analysis) and these areas are thought unlikely to be suitable for off-stream water storage.

Note the areas in Figure 4-6 classified as 'unlikely to be suitable' may have local scale opportunities for siting farm scale off-stream storage, but based on the data available, are unlikely to support a district of multiple farms in close proximity for harvesting water. Hence these results are indicative of the broad locations where off-stream storages are likely to be suitable and should not be used as the sole basis for siting individual farm storages. The investigation and design of an off-stream storage should be undertaken by a suitability qualified professional.

Photo 4-1 Rectangular ring tank in the Flinders catchment (Queensland). Photo CSIRO

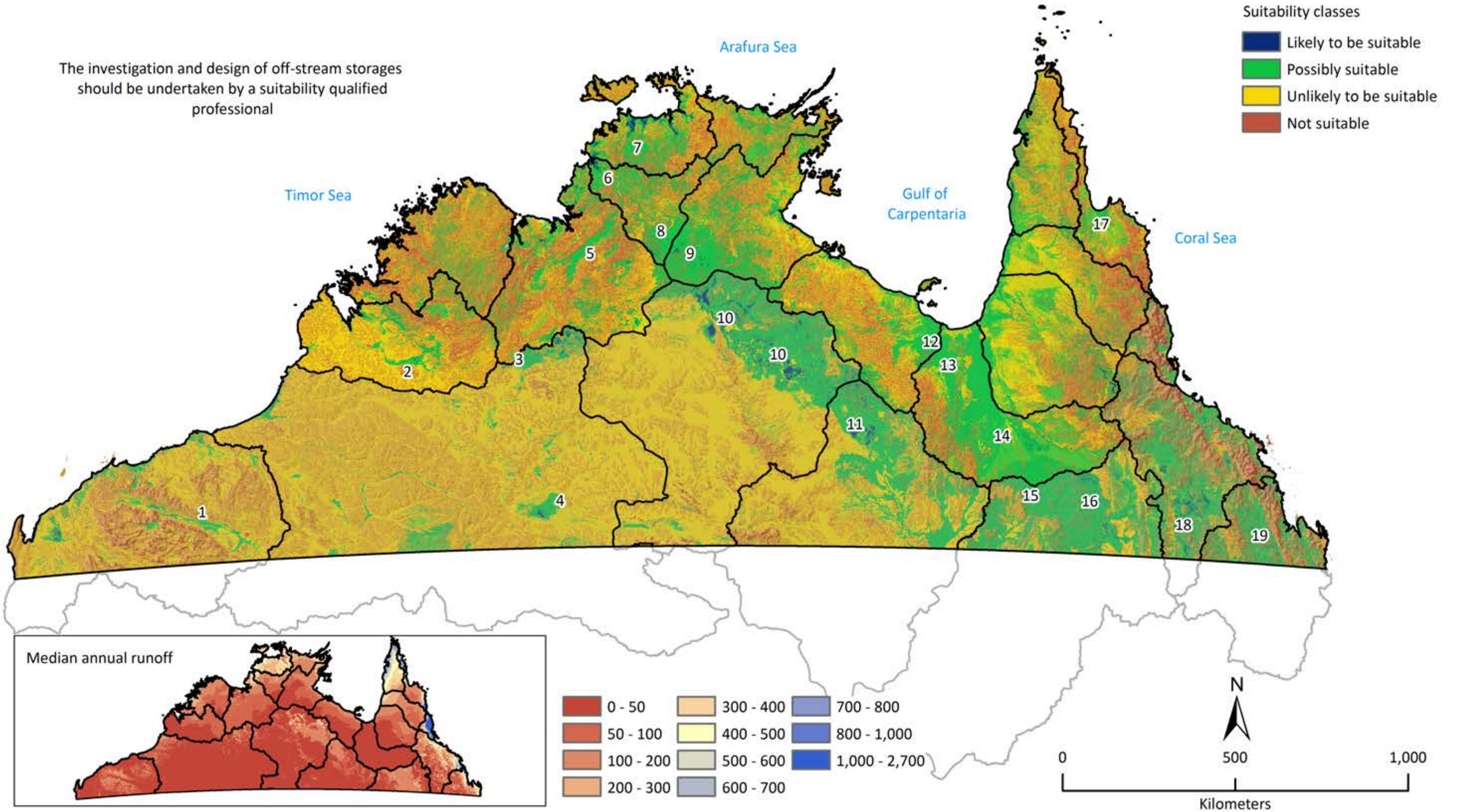

Figure 4-6 Suitability of off-stream water storages in northern Australia

This analysis was limited to using continental scale datasets (see Appendix C). Soil information below 2 m was not available, thus the nature of subsurface material below that depth is not considered, with the exception of general information from broad-scale geological mapping. Soil sodicity, flood risk and water availability are not considered. Black lines delineate reporting regions. The investigation and design of off-stream storages should be undertaken by a suitability qualified professional. Inset shows median annual runoff across northern Australia. Source: Data sourced from Petheram et al., (2012) and AWRA Version 4.5 (Vaze et al., 2013).

4.4 Land suitability analysis

The results for three broad land suitability assessments are presented; improved pastures (Figure 4-7), irrigated annual crops (Figure 4-8) and irrigated perennial crops (Figure 4-9). These broad scale generalised land suitability maps cannot be used to plan the location of an irrigation scheme. That also requires a different and more detailed analysis. Figure 4-10 presents the land suitability assessment for irrigated annuals overlain by those potential dam sites in northern Australia with a yield (GL) per unit cost greater than 10.

This report utilises an extension of the land suitability analysis undertaken by Wilson et al., (2009), part of the Northern Australia Land and Water Science Review. Although limited amounts of soil data exist for the southern half of the NT, it has yet to be compiled in a nationally compatible form. As a result it was not included in this assessment.

Soils receive a score of 1 (most suited) to 5 (least suited) based on their ability to cost-effectively support a given agricultural enterprise. The scoring system is outlined in Table 4-1. Note that a large proportion of Australia's agricultural soils are classified as Class 3. Table 4-2 presents broad scale estimates of the amount land classified as Group A1 through C2 for improved pastures, annual crops and perennial crops. The groups indicate the proportion of different classes that fall within a polygon.

Table 4-1 Land suitability classification

CLASS	DESCRIPTION
Class 1	**(Highly) Suitable land with negligible limitations**. This is highly productive land requiring only simple management practices to maintain economic production.
Class 2	**Suitable land with minor limitations** which either reduce production or require more than the simple management practices of class 1 land to maintain economic production.
Class 3	**Moderately suitable land with considerable limitations** which either further lower production or require more than those management practices of class 2 land to maintain economic production.
Class 4	**Marginal land which is presently considered unsuitable due to severe limitations**. The long-term significance of these limitations on the proposed land use is unknown. The use of this land depends on undertaking additional studies to determine whether the effects of the limitation(s) can be reduced to achieve sustained economic production.
Class 5	**Unsuitable land with extreme limitations that preclude its use**. Class 5 is considered unsuitable, having limitations that in aggregate are so severe that the benefits would not justify the inputs required to initiate and maintain production in the long-term. It would require a major change in economics, technology or management expertise before the land could be considered suitable for that land use.

The extended land suitability assessments (using rules from Wilson et al., (2009) shown in Figure 4-7 to Figure 4-9 and Table 4-2) were made using a generic set of rules across the entire study area and hence do not consider local agronomy or local differences in soils of the same Order in the Australian Soil Classification (e.g. Vertosols in different parts of the study area have different properties and therefore different suitability for growing different crops, but in the absence of better data, Wilson et al., 2009 applied a standard set of rules to all Vertosols). This land suitability assessment does not consider factors such as flooding and salinity risk, water availability or economic, social or environmental offsite impacts. It is not possible to quantify the uncertainty associated with these values, but as a result of the coarse scale of soil mapping alone, it is possible that the uncertainty with some of the land suitability area estimates may be greater than 80% at the regional reporting scale. At the scale of the entire study area, assuming no systematic error, errors are likely to cancel out to an extent, hence the uncertainty in land suitability area estimates is likely to be lower (i.e. greater than 50%). The extension of this analysis south of the Timor Sea and Gulf of Carpentaria Drainage Divisions to the Tropic of Capricorn, requires particular caution as input datasets and data used for some of the limitations have not been rigorously quality controlled and in some cases are missing.

Table 4-2 Generalised land suitability assessment for northern Australia

Does not take into consideration local agronomy, flooding, salinity risk, water availability or economic, social and environmental offsite impact considerations. As a result of the coarse scale soil mapping alone the uncertainty associated with some of the land suitability area estimates may be greater than 50%. Source: Data sourced from Wilson et al., (2009)

GROUP NUMBER	SHORT DESCRIPTION	IMPROVED PASURE		ANNUAL		PERENNIAL	
		('000 ha)	(%)	('000 ha)	(%)	('000 ha)	(%)
A1	>70% of the area is Class 1 or 2	17,162	6%	48,849	17%	5,103	2%
A2	>50-70% of the area is Class 1 or 2	7,136	3%	7,436	3%	3,772	1%
B1	>70% of the area is Class 1, 2 or 3	154,376	57%	52,544	19%	103,902	38%
B2	>50-70% of the area is Class 1, 2 or 3	5,735	2%	9,798	4%	10,484	4%
C1	>50-70% of the area is Class 4 or 5	6,261	2%	11,496	4%	11,113	4%
C2	>70% of the area is Class 4 or 5	28,945	11%	90,225	33%	84,039	31%
Not assessed	Urban, water body etc	348	0%	386	0%	386	0%
Null	No data	52,566	19%	53,796	20%	53,739	20%

Large parts of northern Australia may be at least moderately suitable for improved pastures (Figure 4-7), although with considerable limitations that require management input. Large contiguous areas of land potentially suitable for irrigated annuals (Figure 4-8) and irrigated perennials (Figure 4-9) appear in the Fitzroy region (WA), the upper Victoria catchment, the Daly catchment, particularly on the Sturt Plateau, the upper Blyth catchment, Nicolson catchment, Leichhardt catchment, Norman catchment, Staaten catchment, catchments of the Western Cape region and the Pilbara and Riverless regions in WA. Large contiguous areas of suitable land are also thought likely to occur in the Barkly-Wiso region in the NT. Care should be taken to recognise that the large contiguous nature of these areas reflects the broad scale of the input soils data, and that more appropriate scales of assessment will show the true nature of soil suitability and availability. A recent study as part of the Flinders and Gilbert Agriculture Resource Assessment (Bartley et al., 2013) identified some large areas of land suitable for irrigated cropping in the Flinders and mid-reaches of the Gilbert catchments. Similar intensity of investigation is required in other regions identified as having likely areas of suitable soils coincident with potential water resources.

New statistically based approaches to soil mapping and attribute estimation (referred to as digital soil mapping), such as those recently used in the Flinders and Gilbert catchments of Queensland (Bartley et al., 2013), have the potential to be more cost effective methods of soil and land suitability assessment for agricultural purposes than those traditionally used. Unlike traditional methods of mapping soils, digital soil mapping has the additional benefit of being able to quantify the uncertainty in mapped attributes (e.g. soil water holding capacity, soil depth, clay content, electrical conductivity etc) and resulting land suitability maps.

A description of the soils and maps of the suitability of land in each region are presented in Appendix A.

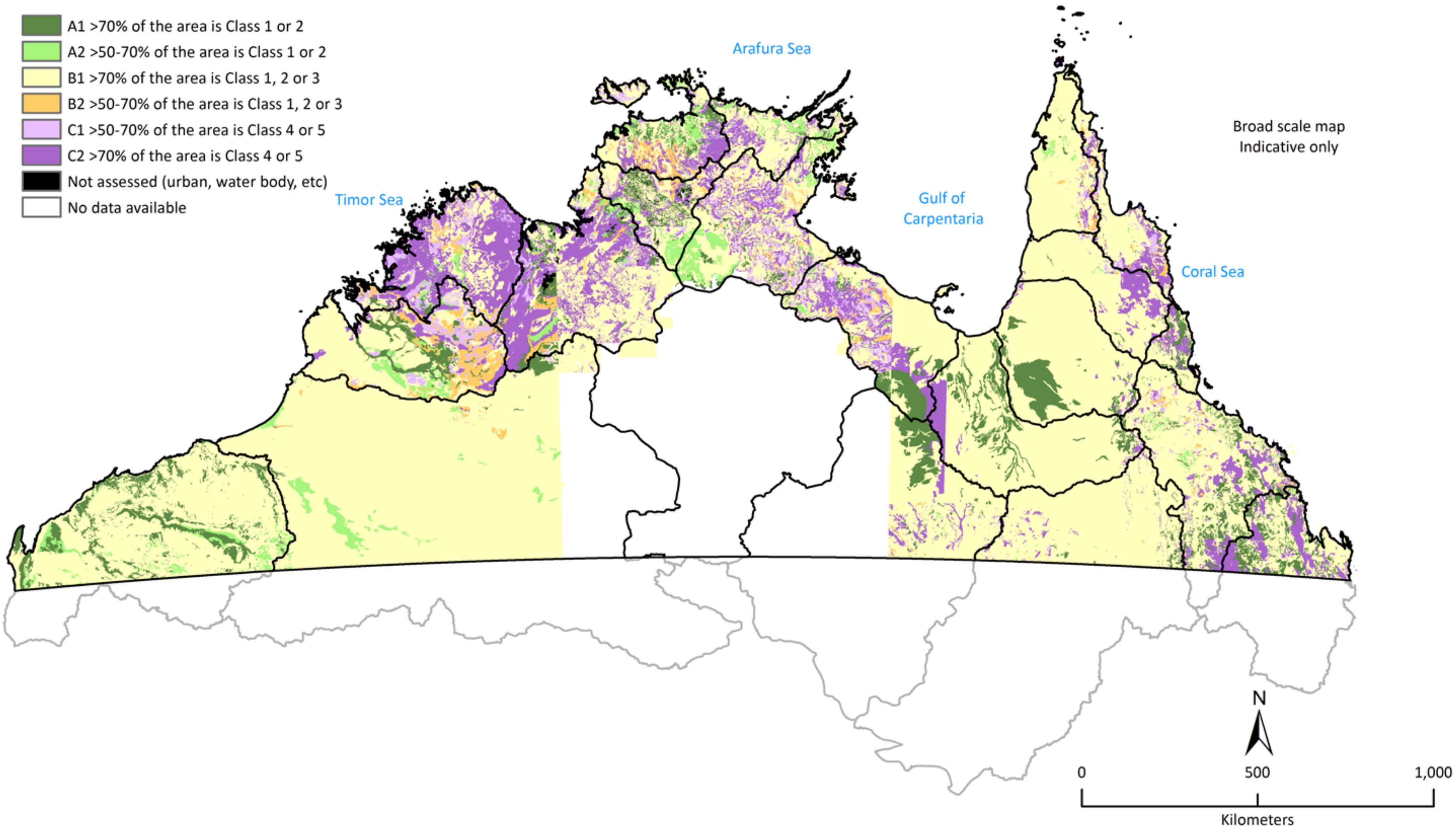

Figure 4-7 Broad scale land suitability for improved pastures in northern Australia
Inset indicates approximate scale of soil mapping. Note that this broad scale suitability map does not take into consideration flooding, salt lakes or risk of secondary salinisation availability of water for irrigation or local agronomy. The southern half of the NT was not included in this assessment - although limited amounts of soil data exist for the southern half of the NT, it has yet to be compiled in a nationally compatible form. Source: Data sourced from Wilson et al., (2009).

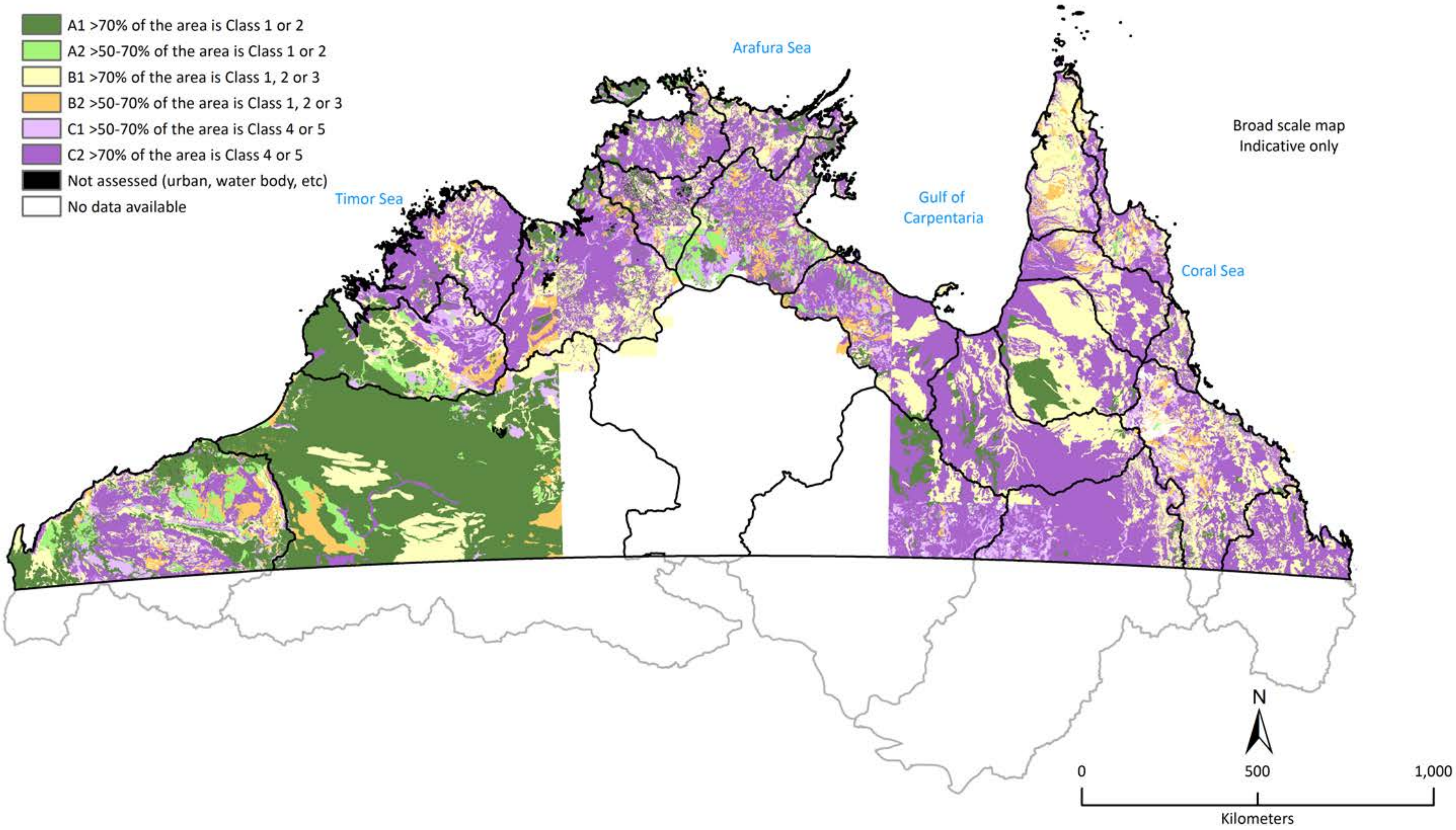

Figure 4-8 Broad scale land suitability for irrigated annual crops in northern Australia

Inset indicates approximate scale of soil mapping. Note that this broad scale suitability map does not take into consideration flooding, salt lakes or risk of secondary salinisation availability of water for irrigation or local agronomy. The southern half of the NT was not included in this assessment - although limited amounts of soil data exist for the southern half of the NT, it has yet to be compiled in a nationally compatible form. Source: Data sourced from Wilson et al., (2009)

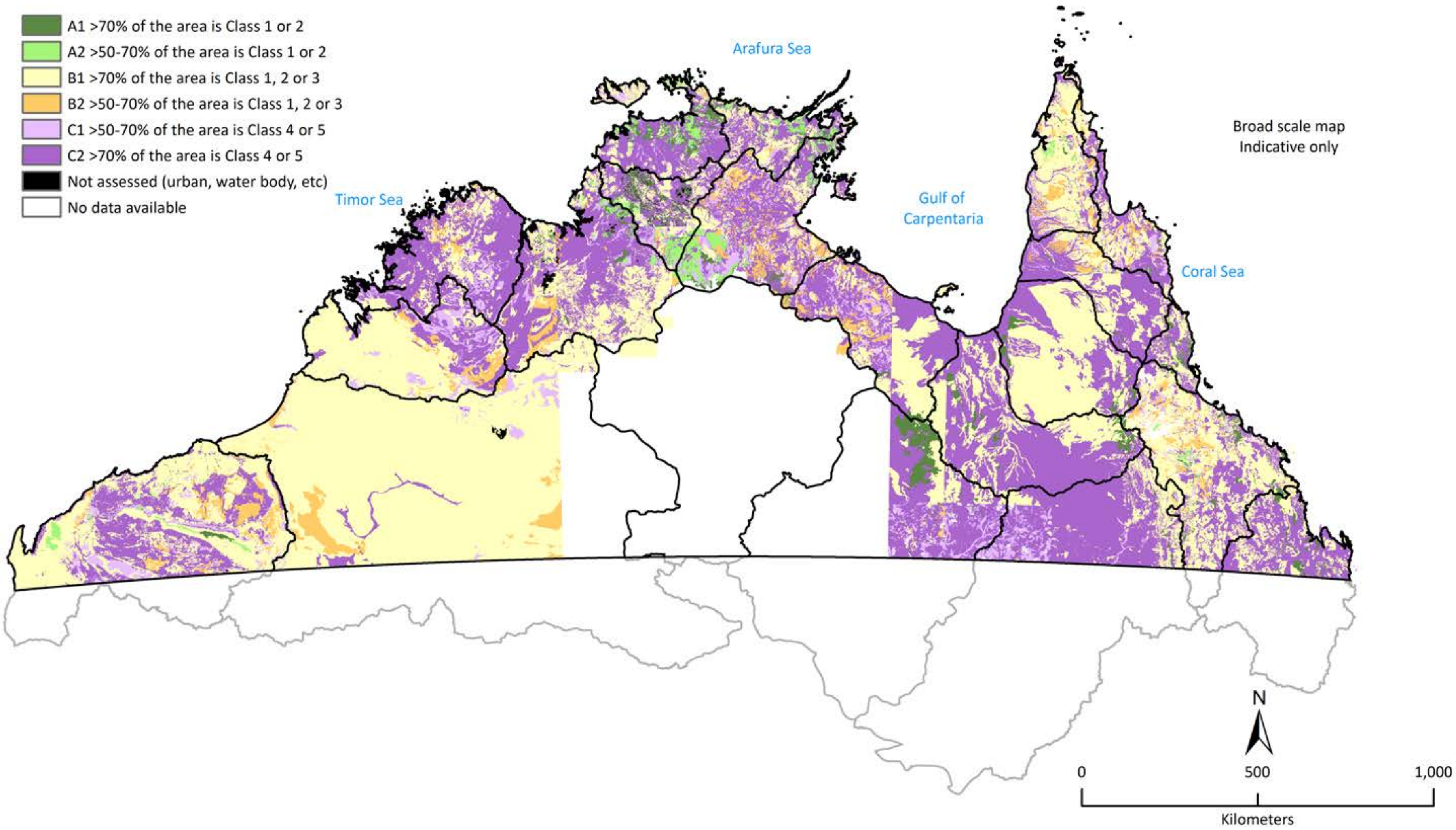

Figure 4-9 Broad scale land suitability for irrigated perennial crops in northern Australia

Inset indicates approximate scale of soil mapping. Note that this broad scale suitability map does not take into consideration flooding, salt lakes or risk of secondary salinisation availability of water for irrigation or local agronomy. The southern half of the NT was not included in this assessment - although limited amounts of soil data exist for the southern half of the NT, it has yet to be compiled in a nationally compatible form. Source: Data sourced from Wilson et al., (2009)

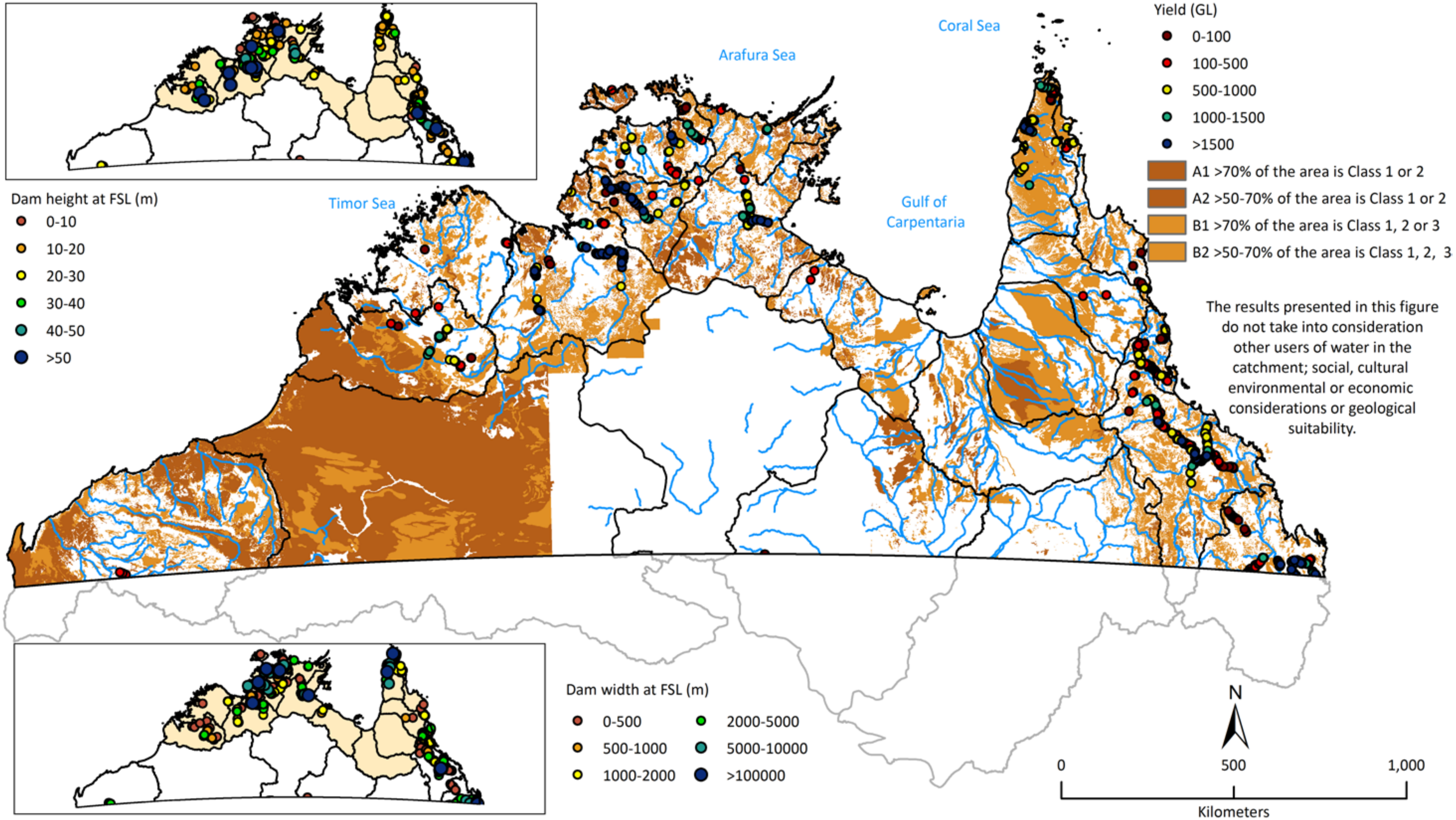

Figure 4-10 Maximum modelled yield for those sites with a yield (GL) per unit cost greater than 10 and land suitability map for irrigated annual crops in northern Australia
Yield estimates based on 85% annual time reliability and yield is reported at the dam height at which the maximum yield occurs with a yield per unit cost greater than 10. Only those potential dam sites with greater than 10 GL yield per unit cost are shown Yield estimates are approximate only and calculations do not i) consider other users of water and ii) assume no other regulatory structures exist upstream of the site. Sites may not be geologically suitable. Land suitability classes C1 and C2 not shown. Data were not available for the southern half of the NT.

4.5 Potential opportunities for large scale irrigated agriculture

This section provides a brief integrated summary of the potential opportunities for broad scale irrigated agriculture for each region in northern Australia, based upon consideration of potential surface water storages and their likely geological and hydrological suitability, productive groundwater systems and land suitability analysis. Central to this discussion is Figure 4-3, Figure 4-10, Figure 4-11 and their underlying data. Section 4.5.1 provides an estimate of the amount of land that could potentially be irrigated in northern Australia using water sourced from large in-stream storages. Section 4.5.2 and Section 4.5.3 provide an overview of the soil and water resources and surface water storage opportunities in the 13 northern and 8 central regions of northern Australia, respectively.

This section does not address local, farm scale opportunities (e.g. irrigation mosaics) that are likely to be scattered throughout northern Australia (e.g. less than 200 ha of irrigation for every 500,000 ha) and could utilise land and water resource features that are currently too small to be mapped given the available data. Irrigation mosaics in a northern Australia context were comprehensively examined in Grice et al., (2013).

Additional information for each region is provided in Appendix A and B.

- Appendix A contains regional scale location maps and maps of surface water storage potential and land suitability and yield – reliability charts for selected potential dams.
- Appendix B provides a brief description of selected potential dams and summarises WRPs and ROPs for the regulated river basins on the east coast of Queensland.

The geological suitability descriptions provided in Appendix A are based on a limited assessment of regional scale datasets. No site investigations were undertaken. Because every potential dam site is geologically unique, increasingly detailed geotechnical investigations are required before construction of a dam can proceed. An important point is that geotechnical investigations should receive adequate funding at the feasibility stage (Fell et al., 2005). Inadequately funded geotechnical investigations at the feasibility stage could result in:

- the adoption of less satisfactory of various alternative sites;
- the adoption of a site which later proves to be unfeasible, or for which large cost over-runs occur to address unforseen conditions;
- the abandonment of a suitable site (or possibly a whole project) which would not have happened had a well conceived (but expensive) geotechnical investigation being undertaken (Fell et al., 2005).

4.5.1 THE SCALE OF NORTHERN AUSTRALIA'S IRRIGATION POTENTIAL

Natural resources (soil, surface water and potential large in-stream dams) sufficient to support 1.4 million ha of irrigated agriculture exist in northern Australia. Development of this area would require approximately 90 of the more viable large dams (including the Burdekin Falls and Ord River dams, which have already been constructed). Approximately 40% of this area, 600,000 ha of irrigated agriculture, could be secured by ~20 of the most promising large dams in northern Australia. Clearly, there are declining marginal returns to dam construction; in part because it is attractive to build the best dams first, but also because additional dams may in some places 'compete' for the same water supply.

Excluding protected areas, approximately 1.1 million ha of land could be irrigated in northern Australia using water from ~75 of the more viable existing or potential large dams. Approximately 30% of this area, 350,000 ha of irrigated agriculture, could be secured by ~15 of the most promising large dams (including the existing Burdekin Falls and Ord River dams) outside of protected areas.

Figure 4-11 provides estimates of the amount of land that could potentially be irrigated in each AWRC river basin. It is important to note that these areas are indicative and that in data sparse environments, such as much of northern Australia, catchment scale resource assessments would be required to fully understand the opportunities for irrigated agriculture and the risks that attend those opportunities.

Areas were calculated assuming a relatively high conveyance and application efficiency of 55% from dam to crop, and year round irrigation of a pasture (taking into consideration crop water requirements specific to the general climate of each region). Broad estimates of the amount of land that could potentially be irrigated in each region were based upon the coincidence of suitable soil and surface water storage and the more limiting of these two factors. If pasture, crops or annual horticultural produce was not grown all year, it may be possible to irrigate larger areas in those river basins where soil suitable for irrigation is not limiting. Only surface water storages with a yield (GL) per unit cost greater than 5 were considered. See methods in Appendix C for more detail.

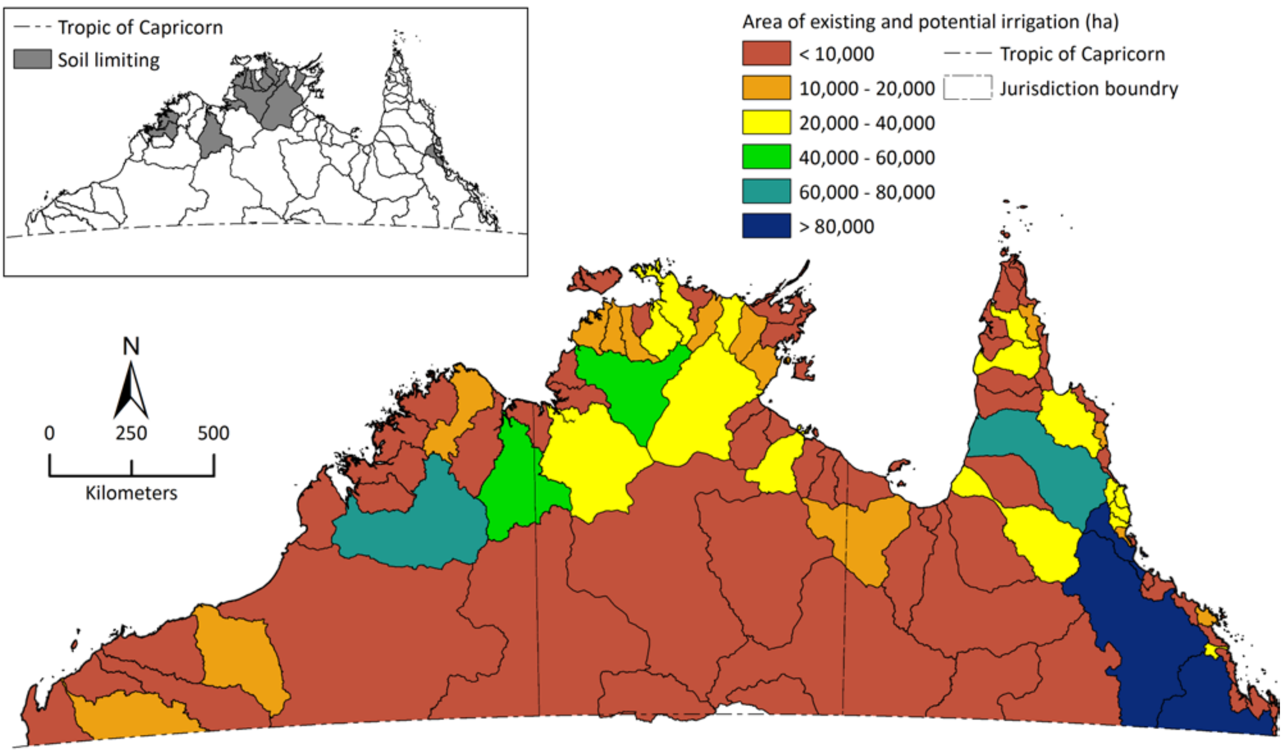

Figure 4-11 Potential area of land that could be irrigated using water from large dams in each AWRC river basin
Area values include existing irrigation schemes and large in-stream dams. Based on a sub-continental scale assessment of the coincidence of soil and large in-stream potential surface water storages (dams) and the more limiting of these two factors. Only considers those dams with a yield per unit cost greater than 5. Inset shows those AWRC river basins for which the area of soil suitable for irrigation downstream of large dams was deemed to be less than the amount of land that could be irrigated using water sourced from the dam. Assumes pasture and/or crops grown in all months (see Appendix C for detail about methods). Does not assume a given regulatory environment (i.e. protected areas were not excluded from the analysis).

In 2012-13 it was estimated that there was approximately 2.4 million ha of irrigated land in Australia, of which 1.2 million ha was situated in the Murray Darling Basin (ABS 2014). In northern Australia it is estimated that there is approximately 200,000 ha of irrigated land (including parts of the Fitzroy catchment just south of the Tropic of Capricorn e.g. Emerald), or 8% of Australia's irrigated area. Increasing the area under irrigation in northern Australia to 1.4 million ha would result in a ~50% increase in Australia's total irrigated area and the controlled release of about 25,000 GL of water from dams in northern Australia. This is equivalent to one third of the water that was extracted in Australia in 2000-01 (~75,000 GL), of which two thirds (i.e. ~50,000 GL) was returned to river, mainly being used for hydroelectric power generation and one third (~25,000 GL) was consumed by industry, households and agriculture (CSIRO 2011).

4.5.2 NORTHERLY REPORTING REGIONS OF NORTHERN AUSTRALIA

This section provides an overview of the soil and water resources and surface water storage opportunities in the 13 more northerly regions of northern Australia (Figure 1-3). Key rivers and geographic areas referenced in this section are shown in (Figure 4-12). Regions are reported west to east.

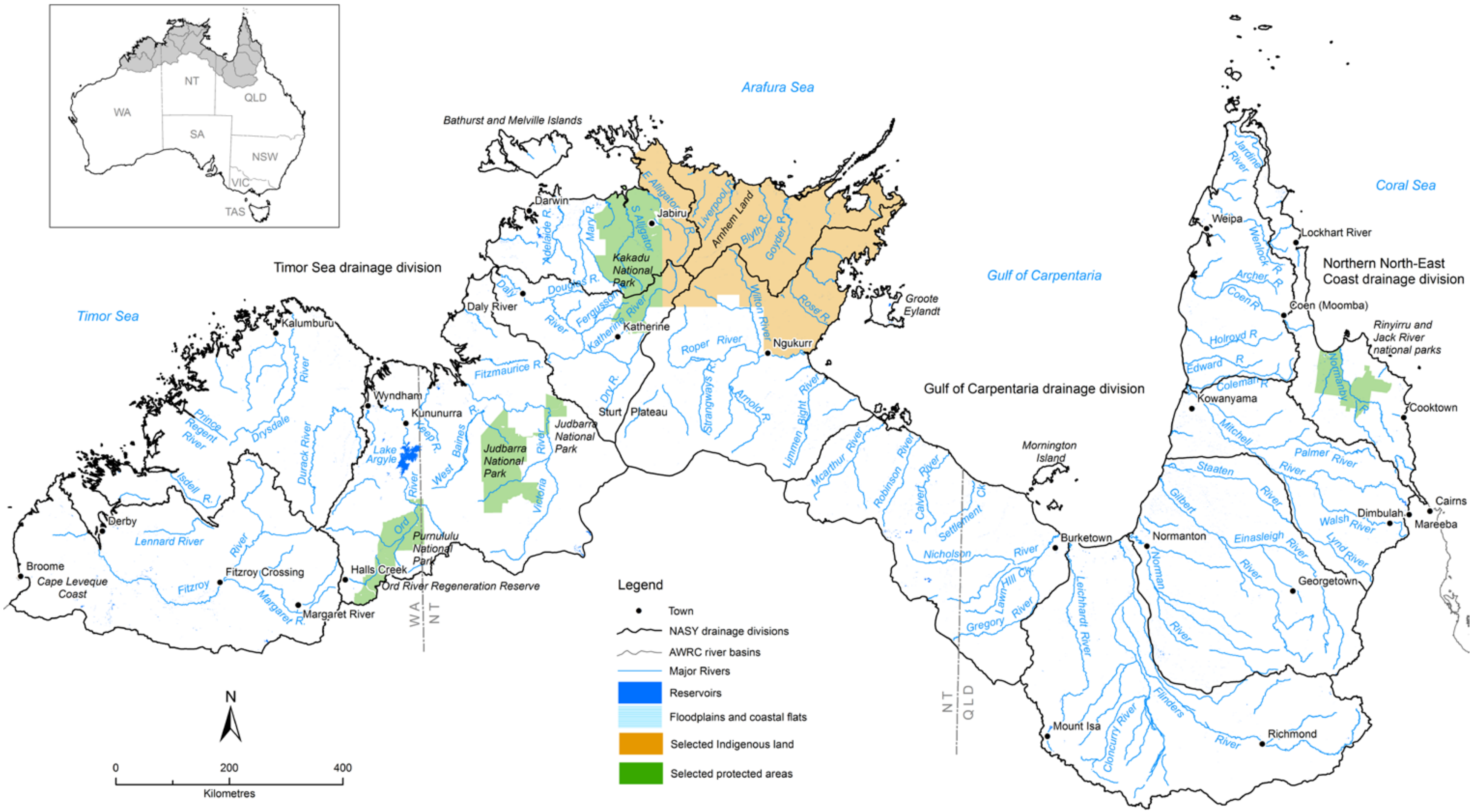

Figure 4-12 Location map of the 13 northern most regions

This figure shows key rivers and geographic areas referenced in the text. The inset shows the geographic extent of the 13 more northerly regions in northern Australia.

Fitzroy region (WA)

The Fitzroy region (WA) has considerable potential for broad scale irrigated agriculture. It is estimated that large in-stream storages could be used to irrigate nearly 80,000 ha of land in 85% of years.

The Fitzroy catchment has several moderate to high yielding potential dam sites (i.e. approximately 600 to 1200 GL at the dam wall in 85% of years) that are likely to be geologically suitable for a dam and situated upstream of large contiguous areas potentially suitable for irrigated agriculture (Figure 4-4 and Figure 4-8). The alluvial floodplains of the Fitzroy River are also thought to contain a significant groundwater resource (estimated to be approximately 200 GL under 'normal' flood years, but actual yields will be limited by low flow years and spatial variability in groundwater quality; Lindsay and Commander 2006) with yields of about 5 L/s, which may be sufficient to support small scale irrigation. Similar alluvial aquifers are thought to exist in the Lennard catchment (CSIRO 2009b). Approximately two-thirds of the region is underlain by the aquifers of the Canning Basin, a large groundwater store with individual bore yields ranging from about 2 to 20 L/s (Laws 1990). Consequently there are opportunities for broad scale irrigated agriculture from surface water or conjunctive use of surface and groundwater. The main limitations to irrigated agriculture along the Fitzroy River would appear to be flooding (Figure 2-8) and the distance of the potential water storages upstream of the suitable soils. Large dams upstream of the Fitzroy River alluvium may reduce the risk of flooding.

Smaller areas of contiguous soils occur on the Hann River and the lower reaches of the Leopold River and minor areas on the Lennard River. In the west of the region, the Cape Leveque Coast catchment is characterised by deep sandy soils. It has very limited surface water resources but is underlain by productive aquifer systems (Searle 2012), for which further investigations are required to determine the limits of the resource. Immediately to the south of the Fitzroy region and extending into the Riverless region is the La Grange groundwater area (Paul et al., 2013) with an annual allocation limit of 60 GL, of which about 70% is still available for licensing (DoW 2013a).

Kimberley region

The Kimberley region is one of the most data sparse parts of Australia. The potential for broad scale irrigated agriculture is thought to be fairly limited. It is estimated that large in-stream storages across the Kimberley region could potentially be used to irrigate up to 20,000 in 85% of years, with the Drysdale catchment having the greatest potential.

Irrigated agricultural development in the Kimberley region is likely to be limited to the better developed soils. Potential surface water storages of small to moderate yield are scattered throughout the region, and in many cases are downstream of potentially suitable soils. The dam with the highest yield per unit cost is located at the downstream end of the Pentecoast River catchment (Figure 4-3) and is unlikely to be geologically unsuitable. Areas suitable for further investigation based on the coincidence of suitable soils and potential water storages include the Kandosols and Tenosols of the valleys and lowlands particularly around the central and northern reaches of the Drysdale River and the upper reaches of the Isdell River. It is likely, however, that the better potential dam sites on the Isdell River may inundate large areas of the more suitable soil.

The Kimberley region is predominantly composed of fractured rock aquifers. The typical bore yields are between 0.5 and 2 L/s (CSIRO 2009b) and have no potential for irrigated agriculture. No regional scale alluvial aquifers exit in the region, but there are numerous small and disconnected aquifers dotted along stretches of most rivers. These appear to be mostly small and isolated but some aquifers have a thickness of greater than 6 m and have potential for providing stock and domestic supplies.

Ord-Victoria region

The Ord catchment has one of the largest existing irrigation developments in northern Australia and there are considerable opportunities for future expansion. The soil and water resources in the Ord catchment could potentially support between 40,000 and 60,000 ha of irrigated agriculture, while large in-stream storages in the Victoria catchment could potentially be used to irrigate between 20,000 to 40,000 ha in 85%

of years. It may be possible to irrigate additional land in the mid-to-lower reaches of the Victoria catchment (i.e. greater than 80,000 ha of additional land), but this would depend upon the geological suitability of high yielding potential dam sites, the suitability of downstream clay soils for irrigated agriculture and the ability to mitigate against flooding (which may require the construction of levees and additional dams). Because of the considerable uncertainty associated with the potential of this downstream area, the smaller more conservative area of potential irrigation (i.e. 20,000 to 40,000 ha) was adopted. A catchment scale resource assessment would be required to more clearly understand the opportunities for irrigated agriculture in the Victoria catchment and the risks that attend those opportunities.

Stage 1 of the Ord River Irrigation Area (ORIA) has an area of about 14,000 ha and there is considerable opportunity to expand irrigated agriculture. Stage 2 of the ORIA (~13,400 ha) is currently under development and (in a Stage 3) an additional 14,500 ha are being considered on the NT side of the border and a further 6500 ha in WA on lighter soils. In total these planned expansion phases would establish approximately 50,000 ha of farming land in production in the next decade (Ash et al., 2014). The Ord River Dam impounds Lake Argyle, which can yield more than 2000 GL in 85% of years. Currently, however, most of the water from Lake Argyle is being used for the generation of hydroelectric power (CSIRO 2009b). DoW (2006) details how the waters of the Ord River are shared between the riverine environment and the commercial needs of irrigation and hydro-power generation.

Smaller, less contiguous areas of suitable soils appear to occur in the south west of the region along the upper reaches of the Ord River, which are immediately downstream of several low yielding potential dams that are likely to be geologically suitable. However, this area is situated in the Purnululu National Park and the Ord River Regeneration Reserve. Many of the better soils in the Ord River Regenerative Reserve are badly degraded (Payne et al., 2004).

In the Victoria catchment, high yielding potential dam sites (i.e. > 2000 GL at the dam wall in 85% years) occur within the Judbarra (Gregory) National Park in the mid and downstream reaches of the Victoria River. There are potentially some concerns with the foundations at these sites. A large area of black cracking clays occurs along the West Baines River, which may be suitable for some annual cropping (although land suitability mapping indicates this area is generally poor for irrigated agriculture this may be misleading on these clay soils due to the use of broad soil groupings). This area is downstream of the high yielding potential dam sites in the mid-reaches of the Victoria River. However, the West Baines River is susceptible to flooding (Figure 2-8) and it is likely that water infrastructure (e.g. levees or dams) on the West Baines River would be required to mitigate against flooding.

The largest areas of soils suitable for irrigated agriculture appear to occur along the Victoria River in the south east of the catchment. There are several small to moderate yielding potential dam sites that may be geologically suitable in the vicinity of these soils, however, most of this area has very low runoff and limited topographic relief.

There are limited groundwater resources in the Ord-Bonaparte region. The more productive aquifers are the dolomitic shales in the central portion of the Victoria River catchment, which are estimated to yield between 5 and 10 L/s and could potentially support some small scale irrigation. The Cainozoic sediments which underlie part of the Keep River floodplain where expansion of the Ord River Irrigation Area is proposed to occur can yield up to 25 L/s (CSIRO 2009b). Elsewhere in the Ord-Bonaparte region groundwater yield from fractured rock and Palaeozoic and Cretaceous aquifers are typically less than 5 L/s and have no potential for irrigated agriculture.

Daly region

The Daly region or catchment has an estimated 2200 ha of irrigated agriculture (Petheram et al., 2008b), with the majority of water sourced from groundwater. Groundwater in the Daly Basin is fully allocated. There are small to moderate opportunities to increase irrigated agriculture through conjunctive use of surface and groundwater. Excluding sites along the Katherine River in Nitmiluk National Park, it is estimated that large in-stream storages could potentially be used to irrigate between 20,000 and 40,000 ha in 85% of years. Including sites in Nitmiluk National Park, large in-stream storages could potentially be used to irrigate up to 60,000 ha in 85% of years.

The Daly catchment is arguably the most well studied catchment in northern Australia, being one of the focus catchments of the Tropical Rivers and Coastal Knowledge (TRaCK) program. The agricultural soils in the Daly Basin have also been well studied by NT government agencies. Areas of soil with suitability for irrigated agriculture are scattered throughout the region. Main areas for further investigation could be considered in the north west along the lower reaches of the Daly River and in the north east around Katherine. Gravelly red earth Kandosols on the Sturt Plateau, in the south of the region, appear suitable for some agriculture although no significant water resources are known in this area. A large proportion of the Daly catchment is underlain by the Daly Basin (Figure 4-4). The Daly Basin contains karstic carbonate rocks within which major aquifers occur (i.e. the Tindall Limestone and Oolloo Dolostone aquifers). Bores in these aquifers can yield greater than 50 L/s from relatively shallow depths (CSIRO 2009b). These aquifers are fully allocated and supply dry season base flow to the Daly River and a number of its tributaries.

In the lower reaches of the Daly catchment at Mount Nancar (Figure 4-4) is a very high yielding potential dam site (i.e. > 4000 GL at the dam wall in 85% of years) that is likely to be geologically suitable. However, there are no large areas of soil suitable for irrigated agriculture below this site. Other large potential dam sites occur along the Daly River upstream of Mount Nancar and upstream of soils potentially suitable for irrigated agriculture. However, most of these sites are likely to be situated in karstic carbonate rock, which is generally unsuitable for siting large dams. Smaller but more geologically suitable potential dam sites (i.e. between 500 GL and 1000 GL at the dam wall in 85% of years) occur along the Katherine River in the Nitmiluk National Park. Smaller, geologically suitable potential dam sites occur along the Fergusson River (i.e. between about 300 GL and 400 GL at the dam wall in 85% of years) and in the upper reaches of the Douglas River (i.e. < 100 GL in 85% of years). Although the yield from these potential dam sites is modest they may present an opportunity to manage climate risk and depletion of groundwater and river baseflow through the conjunctive use of groundwater and surface water.

Van Diemen region

The Van Diemen region has moderate potential for broad scale irrigated agriculture. Large in-stream storages in the Adelaide and Mary river catchments east of Darwin and the Finniss river catchment south of Darwin could be used to potentially irrigate up to 30,000 ha of land in 85% of years. The Wildman River catchment appears to have relatively large contiguous areas of soil that may be potentially suitable for irrigated agriculture, but potential surface water storages in the catchment are low yielding (i.e. less than 100 GL). An additional 40,000 to 60,000 ha of land could potentially be irrigated in Kakadu National Park in the South Alligator River catchment and Arnhem Land in East Alligator River catchment. It should be noted, however, that the majority of the higher yielding dam sites in this region were identified as potentially having geological considerations that may require costly remediation.

The better potential dam sites in terms of yield and yield per unit cost are situated in the South Alligator and East Alligator catchments in the eastern proportion of the region (Figure 4-3). These catchments form part of either Kakadu National Park or Arnhem Land. Small to moderate yielding potential dam sites (i.e. between about 100 and 600 GL at the dam wall in 85% of years) are found scattered elsewhere throughout the region. Soils with agricultural suitability are generally confined to the sandy Kandosols in the central section of the region and some of these appear coincident with some potential dam sites. Further investigation may be warranted in areas between the Adelaide and Mary rivers, the Wildman River catchment and in the north east around the upper reaches of Cooper Creek between Oenpelli and the Coburg Peninsula.

Large proportions of the Van Diemen region are underlain by productive clastic sedimentary or karstic carbonates. In particular the Adelaide River and Mary River catchments to the east of Darwin are underlain by a major karstic aquifer, the Koolpinyah Dolomite. West of the Adelaide River this aquifer may already be fully allocated (groundwater plan currently under development). East of the Adelaide River this aquifer may be able to support additional small scale irrigation. This part of the Koolpinyah Dolomite has been studied in less detail. If there was an available groundwater resource east of the Adelaide River, it could potentially be used in conjunction with the small to moderate yielding potential surface water storages in the mid reaches of the Adelaide and Mary rivers. Surface water could also potentially be diverted into off-stream storages or extracted directly from the wetlands in the lower reaches of these two catchments. This would require more detailed investigation. An advantage of establishing irrigation in the Adelaide, Mary and Wildman river catchments are their proximity to Darwin. The Cretaceous/Tertiary sandstones on Bathurst and Melville Islands and the Coburg Peninsula are likely to have fairly limited prospects for irrigation.

Arafura region

The Arafura region has small to moderate opportunities for broad scale irrigated agriculture based on surface water in the Liverpool, lower Blyth and Goyder catchments and groundwater from the Dook Creek Formation in the upper Blyth catchment. The highest yielding potential dam site in the region would be to enhance the storage capacity of the Arafura Swamp in the Goyder catchment. If geologically feasible, enhancing the storage capacity of the Arafura Swamp could potentially enable 60,000 ha to 80,000 ha of land to be irrigated. However, it would appear that there is insufficient area of soil suitable for irrigated agriculture in the vicinity of the Arafura Swamp.

Areas of deeper, sandy Kandosols and Tenosols in the north east of the region and extending across the dissected inland plains towards the west are likely to have the best potential suitability for agricultural development. There appears to be some small to moderate potential surface water storage sites in the Liverpool and Blyth catchments that are adjacent to or immediately upstream of soils potentially suitable for irrigated agriculture. The upper reaches of the Blyth catchment appears to have the largest area of contiguous soils that are potentially suited for irrigated agriculture. However, there are no suitable potential dam sites in this part of the catchment and although the land appears suitable for off-stream storages, streamflow in these upper reaches is likely to limit the scale of development. These soils, however, are underlain by the most productive aquifer in the region, the dolomitic Dook Creek Formation, which contributes considerable dry season flow to the Goyder and Blyth rivers (CSIRO 2009b). The Goyder River is the main source of water during the dry season for the Arafura Swamp. There is little information on the Dook Creek Formation, but it is likely that bores in this formation could yield between 5 and 25 L/s, and may be sufficient to support small scale irrigation.

Roper region

The Roper region is likely to have small to moderate opportunities for broad scale irrigated agriculture. There are numerous high yielding potential dam sites in the Roper catchment, however, soils suitable for irrigation downstream of these sites appear to be heavily dissected. It is estimated that multiple dams could be used to potentially irrigate between 20,000 ha and 40,000 ha in 85% of years. Large areas of contiguous soil suited for irrigated agriculture would appear to be the limiting factor. Groundwater sourced from the Tindall Limestone aquifer in the south-west of the Roper catchment could potentially enable several thousand hectares of broad scale irrigation.

There are a number of high yielding potential dam sites in the lower and middle reaches of the Roper River (i.e. greater than 1000 GL at the dam wall in 85% of years) and on the Wilton River (i.e. approximately 600 GL at the dam wall in 85% of years). However, downstream of these sites, soils suitable for irrigated agriculture are limited by the complexity of the dissected landscape (Figure 4-8 and Figure 4-9). A large contiguous area of Kandosols, which appears suitable for irrigated agriculture, is situated on the Sturt Plateau in the south-western part of the region. There are no potential dam sites in this part of the Roper region, and although the land appears suitable for off-stream storages (Figure 4-6), streamflow is highly intermittent in these upper reaches. This part of the Roper region is, however, underlain the by the Tindall Limestone aquifer, which is capable of supporting broad scale irrigation (Pascoe-Bell et al., 2011). The dolomitic Dook Creek Formation in the northern part of the Roper catchment is little known but it is thought likely that bores in this formation could yield between 5 and 25 L/s, and may be sufficient to support small scale irrigation. Small areas of soil suitable for irrigated agriculture may overlie parts of the Dook Creek Formation in the Roper catchment, but it is likely that the suitable soils are dissected. Elsewhere the more productive aquifers have local scale importance but are unlikely to support irrigated agriculture.

South-West Gulf region

There is low to moderate potential for broad scale irrigated agriculture in the South-West Gulf region, largely based on surface water resources. It is estimated that large in-stream storages could be used to potentially irrigate between 30,000 and 60,000 ha of land across the entire region.

The best potential dam sites in this region in terms of yield per unit cost are situated in the McArthur catchment (Figure 4-3). Downstream of these sites appear to be coastal Tenosols between the McArthur and Robinson rivers that appear to be suitable for irrigated agriculture (Figure 4-8 and Figure 4-9). Significant aquifers occur within the Proterozic carbonate rocks of the McArthur Basin, which underlies part of the McArthur catchment (CSIRO 2009c). To the south-east are lowland Chromosols and Vertosols around Doomagee; and along the mid reaches of the Gregory River in Queensland. The Gregory and Nicholson rivers have potential surface water storage locations that are likely to be geologically suitable for the construction of low yielding dams (e.g. 100 to 300 GL at the dam wall in 85% of years) (Figure 4-4). The lower parts of the Nicholson catchment appear to be susceptible to flooding (Figure 2-8). In addition to soils potentially suitable for irrigated agriculture in the lower reaches of the Nicholson catchment, there are also potentially soils suitable for irrigated agriculture in the lower reaches of the adjacent Leichhardt catchment. It is possible that a dam on the Gregory River may be able to supply water to either the lower Nicolson or the lower Leichhardt. However, soil and land suitability mapping in the east of this region is some of the poorest resolution and most uncertain in Australia so care should be taken with interpretation of this information (e.g. see Figure 2-2 and Figure 4-8).

Between the Nicholson and Gregory rivers are the karstic carbonate rocks of the Georgina Basin (Camooweal Dolostone and Thorntonia Limestone), a major aquifer with very high permeability (CSIRO 2009c). Yields from these aquifers could potentially support small to broad scale irrigation. It should be noted that discharge from the Thorntonia Limestone aquifer is occurring in the form of dewatering for the Century Zinc Mine (NASY 2009c). This mine is, however, due to close in 2016. Regional groundwater discharges from the aquifers developed in the Camooweal Dolostone and Thorntonia Limestone provide dry season flow to the Gregory River and Lawn Hill Creek.

Flinders-Leichhardt region

There is limited potential for irrigated agriculture in the Flinders catchment based on large in-stream storages. The Flinders and Gilbert Agricultural Resource Assessment identified that between 10,000 and 20,000 ha of land could be irrigated in the Flinders catchment based on water harvesting and farm scale off-stream water storages (Holz et al., 2013). Similar but smaller opportunities are likely to exist in the Leichhardt catchment, where there appear to be soils suitable for off-stream water storage along the lower reaches of the Leichhardt River.

There are limited opportunities for large in-stream dams in the Flinders (Petheram et al., 2013a) and Leichhardt catchments. This is because of a lack of topographic relief. Where there is topographic relief the catchment areas are small and runoff is low and hence inflows to the potential dams are small. There are already several dams in the Leichhardt catchment that supply Mount Isa and the mining industry. If the water from these dams were used for irrigation it is likely that less than 10,000 ha of land could be irrigated.

The best opportunities for irrigated agriculture are based on water harvesting and farm scale off-stream storages (Figure 4-6). Soils suitable for irrigated agriculture are likely to be found throughout most of the Flinders catchment adjacent to the major drainage lines. There are likely to be local farm scale opportunities in some parts of the Flinders catchment to irrigate small areas using groundwater in the alluvial aquifers. The Flinders catchment was studied in detail as part of the Flinders and Gilbert Agricultural Resource Assessment (Petheram et al., 2013b).

South-East Gulf region

The greatest potential for irrigated agriculture in the South-East Gulf region is adjacent to the Gilbert and Einasleigh rivers in the mid-reaches of the Gilbert catchment. It is estimated that large in-stream dams could potentially irrigate between 20,000 and 40,000 ha in the Gilbert catchment. There are limited opportunities for irrigated agriculture based on large in-stream dams in the adjacent Norman and Staaten catchments.

The Gilbert catchment has a moderately yielding potential dam site (i.e. approximately 400 GL at the dam wall in 85% of years) along the Einasleigh River that is likely to be geologically suitable, and upstream of soils suitable for irrigated agriculture (Figure 4-4). A lower yielding potential dam site (i.e. approximately 200 GL at the dam wall in 85% of years) is situated on the Gilbert River, immediately upstream of about 15,000 ha of soils that are moderately suited to spray or trickle irrigated agriculture (Petheram et al., 2013c). The site with the highest yielding potential dam shown on Figure 4-4 (Mount Noble) has been adversely affected by basalt flows and is unlikely to be geologically suitable (Petheram et al., 2013a). A number of potential dam sites along the mid to upper reaches of the Einasleigh River have been adversely affected by basalt flows, where basalt infilled former river valleys can form potential leakage paths around dams. Basalt has flowed down the former river valleys and floodplains forming lava fields and, in some cases, blocking former river channels. The most northern part of the flow is about 24 km north of Einasleigh. The Undara basalt flow of the McBride province has affected the middle reaches of the Einasleigh River downstream of its confluence with Junction Creek to its confluence with Parallel Creek – a distance of about 60 km (Petheram et al., 2013a). Remedial measures are generally expensive and can require extensive excavation of basalt and alluvial material, and cement grouting.

A relatively extensive area of sandy Tenosols in the south west of the region (Figure 2-2) appears to be suitable for irrigated agriculture (Figure 4-8), but there are no large potential surface water storages and there are likely to be limited opportunities for water harvesting. This area is susceptible to extensive flooding. In the Gilbert catchment small quantities of water are sourced from the bedsands of the Gilbert River and used for irrigation. The Gilbert catchment was studied in detail as part of the Flinders and Gilbert Agricultural Resource Assessment (Petheram et al., 2013c).

Mitchell region

The Mitchell region appears to have considerable potential for broad scale irrigated agriculture, largely based on surface water supplies. It is estimated that large in-stream dams could potentially irrigate between 60,000 ha and 80,000 ha in 85% of years.

The Mitchell catchment has the largest discharge of all AWRC river basins in northern Australia (~10,000 GL in 50% of years; Petheram et al., 2012). However, it is likely that only a modest percentage of the median annual discharge could potentially be diverted for consumptive use. Nevertheless several small to moderate yielding potential dam sites (i.e. between 200 and 600 GL at the dam wall in 85% of years), which appear likely to be geologically suitable, occur in the mid to upper reaches of the Mitchell catchment (Figure 4-4). There are also currently four major existing water storages in the Mitchell catchment, with a combined capacity of over 140 GL (CSIRO 2009c). Soils in the uplands east of the Mitchell River region are dominated by Dermosols and Rudosols with some Calcarosols around Chillagoe. Sandy Kandosols occur in the centre of the region with the western lowlands dominated by seasonally inundated Vertosols and Hydrosols (Figure 2-2). The agricultural suitability of the central Kandosols, which are located downstream of some of the better potential dam sites in the catchment, could be further investigated. The lack of potential dam sites and soils suitable for irrigated agriculture limit the opportunities for irrigated agriculture in the mid to lower reaches of the Mitchell catchment. Irrigated agricultural developments in the headwaters of the Mitchell catchment would be close to Mareeba and Cairns and may supplement production from the existing Mareeba-Dimbulah irrigation area.

Western Cape region

The Western Cape region has small to moderate potential for broad scale irrigated agriculture. Large in-stream dams in the mid-to-upper reaches of the Archer and Wenlock catchments could potentially support up to 40,000 ha in the Western Cape region, although a quick desktop analysis indicate that there may be some geological concerns with these potential sites. There is an unquantified potential to extract water for irrigation from the GAB under Cape York Peninsula, it could potentially enable up to 10,000 ha. However, as with most groundwater systems in northern Australia, there are insufficient data to adequately quantify the amount of water stored, recharge rates or sustainable extraction yields.

Although there appear to be large areas of land potentially suited to irrigated agriculture, and there are a number of potential dam sites in the Western Cape region (Figure 4-3) that have moderate yield to unit cost ratios (largely a result of the high runoff), the higher yielding potential dam sites are situated in the lower parts of the landscape, which are generally geologically unsuitable for large dams or off-stream water storages due to the high permeability of the substrata (i.e. bauxite). The agricultural suitability of the region, at least at a broad regional scale, was documented as part of the Cape York Peninsula Land Use Study (CYPLUS) investigation. The Gilbert River Formation is a major sandstone aquifer that occurs across the entire region. Large supplies (> 60 L/s) of medium quality groundwater can be obtained from the Gilbert River Formation aquifer from bores that intersect the entire sandstone sequence (CSIRO 2009c). Shallow bores that intersect the unconfined Gilbert River Formation typically provide yields of 1 to 5 L/s of good quality groundwater (DNRM 2005).

Northern Coral Sea region

There is small to moderate potential for irrigated agriculture in the Northern Coral region. Large in-stream dams in the Normanby and Endeavour catchments could be used to potentially irrigate approximately 20,000 ha and up to 10,000 ha of land respectively.

The catchment with the greatest potential for irrigated agriculture in the Northern Coral Sea region is the Normanby catchment, which is largely underlain by the Laura Basin. Several potential dam sites situated in rock that is likely to be geologically suitable occur on the upper Normanby River (Figure 4-3). Below these potential dam sites there are soils that appear suitable for irrigated agriculture. However, a large part of this area forms part of Rinyirru (Lakefield) and Jack River national parks. Nearly 4000 ha of horticulture already occurs on rich basaltic soils around Lakeland Downs on the upper reaches of the Laura River in the Normanby catchment. Groundwater yields from the Laura Basin are variable and range from approximately 2 to 15 L/s (CSIRO 2009d), and could potentially support small scale irrigation. As with many groundwater systems in northern Australia, there are insufficient data to adequately quantify the amount of water stored, recharge rates or sustainable extraction yields.

4.5.3 REGIONS OF CENTRAL NORTHERN AUSTRALIA

This section provides an overview of the soil and water resources and surface water storage opportunities in the eight central reporting regions of northern Australia (Figure 1-3). Key rivers and geographic areas referenced in this section are shown in Figure 4-13. Regions are reported west to east and then north to south.

Pilbara region

The Pilbara region has low potential for broad scale irrigated agriculture based on surface water. Collectively multiple large dams could be used to potentially irrigate about 40,000 ha of land. In the Pilbara region yields are limited by low and highly variable inflows to potential reservoirs and high net evaporation rates. There is potential for small scale irrigation developments based on groundwater in the Pilbara region (~2500 ha), although mine dewatering may provide large initial but non-sustainable quantities.

In the De Grey and Port Hedland Coast basins, there are several low yielding potential dam sites (e.g. yields of 50 to 150 GL/yr) that are likely to be geologically suitable and relatively close to land that may be suitable for irrigated agriculture, and which is not particularly susceptible to flooding (i.e. F5, F7, F8 and F9 in Appendix A). While the yields at these potential dam sites are likely to be limited by low and variable inflows to the reservoirs, collectively they could potentially reliability irrigate about 40,000 ha of land. Off-stream storages are unlikely to be suitable in the Pilbara region because of the sandy texture of the soils.

Soils likely to be suited to irrigated agriculture are also found in the lower Onslow Coast and Lyndon-Minilya Rivers AWRC river basins. However, potential surface water sites with sufficient topographic relief and which are also geologically suitable are limited.

No surface water allocation plan currently exists for the Pilbara. Harding Dam operates through a water licence in the context of the conjunctive scheme (as specified in the groundwater allocation plan), and conditions and commitments through the Environmental Protection Authority (EPA) approval for the dam. Ophthalmia Dam (used to enhance recharge) also operates through a water licence, which is in the context of the original state agreement. Surface water recharge to alluvial aquifers is covered through groundwater allocation plans and licences (pers. comm. Susan Worley 2014).

There is potential for small scale irrigation developments based on groundwater in the Pilbara region (~2500 ha). Mine dewatering may provide additional initially large but non-ongoing quantities of water for irrigation. The largest groundwater resources in the Pilbara region are associated with deep sedimentary basins in the east (Canning Basin) and west (Carnarvon Basin). The West Canning Basin is by far the most promising because abundant fresh groundwater is contained in the confined Wallal Formation and there are few existing users of this resource. Recharge in the region is poorly quantified and discharge is mainly offshore. Because of its location on the coast, near roads and not too far from Port Hedland, the West Canning Basin is being actively investigated for both public and private water supplies.

Groundwater in the Carnarvon Basin to the west is less abundant and much more saline than the West Canning Basin resources, and is therefore not considered a viable resource without desalination.

Very high yielding aquifers are associated with Channel Iron Deposits (CIDs) within paleochannels in the Hamersley Basin. These are usually associated with economic iron ore deposits. The most notable reuse scheme in operation is Marandoo, which is used to irrigate Rhodes Grass for producing hay for cattle in the Hamersley Range. Including water from fractured rock and alluvial aquifers, 250 to 300 GL/yr is expected to be discharged from iron ore mining below the watertable in the coming years. Much of this water is not replenished in the short term so the current yields cannot be assumed to be sustainable.

There are large but unquantified water supplies associated with the Wittenoom and Carawine dolomite formations in the Hamersley Basin. Upper parts of these dolomites are karstic and their weathering forms calcrete deposits downstream which can also form high yielding aquifers (e.g. Millstream Calcrete). Water in these formations is ‘hard’ and hydraulic properties are very variable due to dissolution and precipitation.

Current allocation limits were set for nine 'target groundwater resources' (major sedimentary aquifers) totalling 90.5 GL per year (DoW 2013). Allocations for 'non target groundwater resources' (mainly fractured rock aquifers and paleochannels) were set at 137.4 GL/y. There is currently considerable work being undertaken in the Pilbara by the Western Australian Government and CSIRO (CSIRO 2014). Groundwater allocation plans will be updated as new information becomes available.

For more information on the surface and groundwater resources of the Pilbara region see CSIRO (2014).

Riverless region

The Riverless region has no potential for irrigated agriculture based on surface water resources. Some of the region is, however, underlain by aquifers of moderate to high potential. Soils appear to be broadly suitable for agriculture due to their flat landscape positions and relatively deep, non-rocky, sandy nature However, the scale of mapping for this region is very broad (i.e. ~1:2 million) and does not adequately reflect soil and landscape variations that could affect potential agricultural development.

The Permian and Mesozoic sandstones are high-yielding aquifers, and generally contain low salinity groundwater. Along the coastal plain, in the south, groundwater from the Jurassic Wallal Sandstone is used for irrigation of fodder crops, while in the northern LaGrange area, groundwater from the Cretaceous Broome Sandstone has been used to irrigate melons and used for cotton trials. Further investigation of the irrigation potential of this area is being carried out by the Western Australian State Government under the Royalties of Regions and Water for Food programs.

Wiso-Barkly region

There is very limited potential for in-stream or off-stream water storage in the Wiso-Barkly region.

The landscapes of this region are ancient and deeply weathered, formed on some of the oldest parts of the Earth's crust. The landscape is mostly level plains with some areas of low undulating to rolling hills south-east of Tennant Creek. For this reason the region has limited topography for siting large dams and in many places the drainage is either uncoordinated or flows to large depressions in the landscape, forming large ephemeral freshwater lakes, which are considered important bird areas (Birdlife International 2014). No water from this region discharges to the ocean.

In the most northerly parts of the region, construction of low (i.e. 10 m), very long (i.e. >15 km) dam walls has the potential to create impoundments that could potentially store very large volumes of water, simply because the landscape is so flat the impounded area would extend a long distance (e.g > 80 km in some instances). However, these shallow, sandy storages would lose a lot of water to evaporation and seepage, and runoff is very low (i.e. < 15 mm/yr) and highly variable. These factors combine to result in low yields. Furthermore the geology of the region is generally suitable for large in-stream storages and in many places there may not be suitable material to construct an embankment.

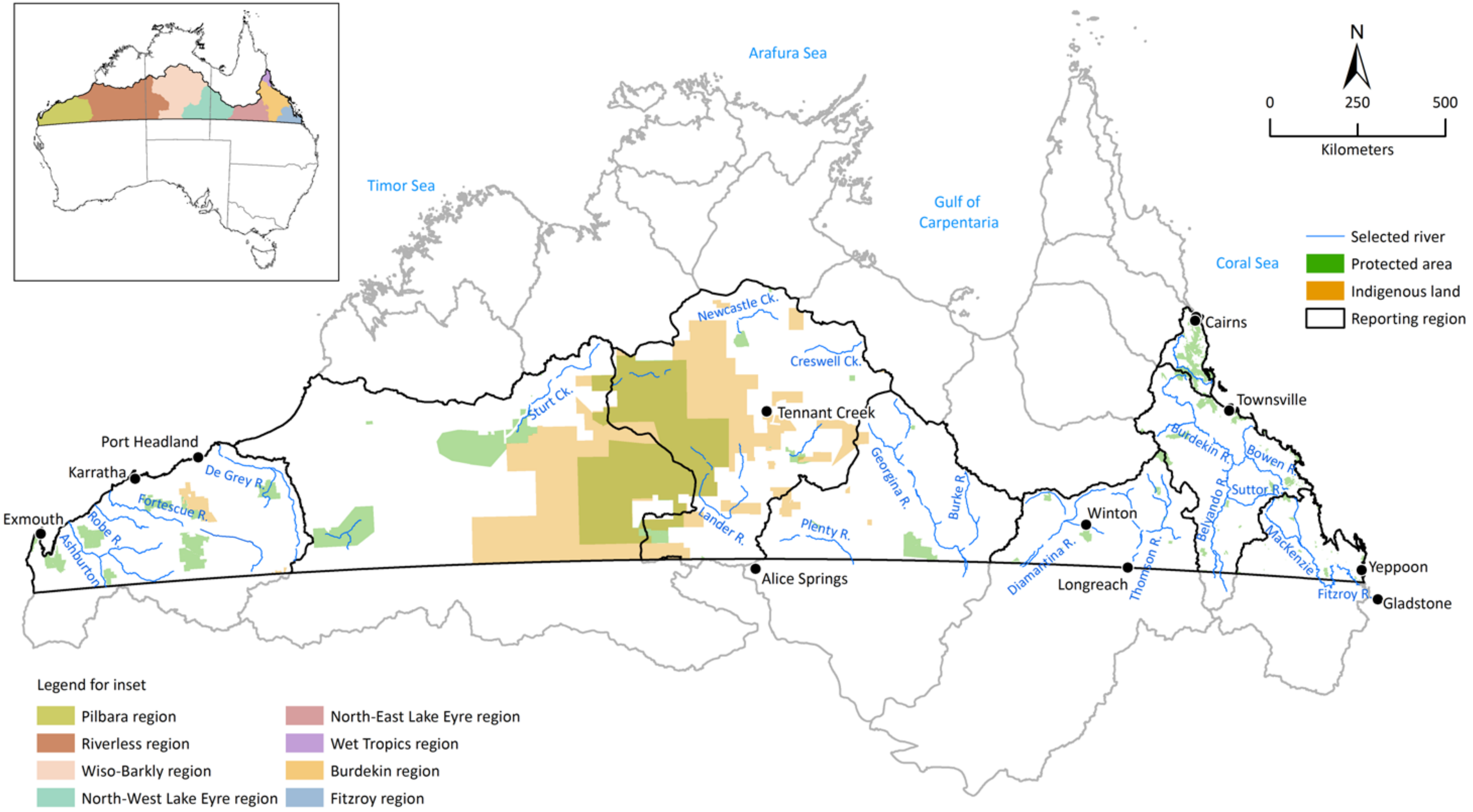

Figure 4-13 Location map of the eight central reporting regions of northern Australia

This figure shows key rivers and geographic areas referenced in the text. The inset shows the geographic extent of the 8 central reporting regions of northern Australia

North-West Lake Eyre region

The North West Lake Eyre region comprises mostly level to gently inclined plains with small areas of more undulating and dissected county in the north-east. There is limited potential for in-stream water storages in the region. The most likely form of water storage would be low weirs, but these structures would need to be very wide and they would be problematic to construct in the braided rivers that typify many of the larger river systems in the region.

Soils possibly suitable for off-stream storages occur along the upper Georgina River. However, mean annual runoff is relatively low and is highly seasonal.

In the NT, parts of the region are underlain by aquifers of the Georgina Basin. They are mostly carbonate rocks that form fractured and karstic aquifers. They are widely utilised as a source of stock water with bore yields commonly up to 5 L/sec. One unit, the Camooweal Dolostone, is potentially higher yielding and may locally produce irrigation quantities.

Soil mapping in this region is old and very broad scale, and further preliminary studies should be conducted to verify the likely soils and suitability in this region before any additional investigations or developments are considered.

North-East Lake Eyre region

The North-East Lake Eyre region encompasses the flat plains and broad, braided river channels of the upper reaches of Thompson and Barcoo Rivers. The eastern section of the region includes the western slopes, undulating rises and hills of the Great Dividing Range. There is very limited potential for in-stream water storages in the region. The most likely form of water storage would be low weirs (e.g. Longreach waterhole) but, as in the North-West Lake Eyre region, in many places these structures would need to be very wide and they would be problematic to construct in the braided rivers that typify many of the larger river systems in the region.

Soils possibly suitable for off-stream storages occur along the Diamantina and Thompson rivers. However, mean annual runoff is relatively low and is highly seasonal.

The North-East Lake Eyre region is underlain by the GAB, a productive aquifer extensively used for supplying water for stock and domestic purposes. The potential to use groundwater from the GAB in the North-East Lake Eyre region for irrigation is not well known, though water from much of the GAB is generally unsuitable for irrigation because it is incompatible with the dominantly montmorillonitic swelling clay soils chemically (i.e. due to the groundwater having high alkalinity and sodium) (Smerdon and Ransley 2012). If an additional source of water were available it may be possible to shandy (i.e. mix) it with GAB water for irrigation purposes. Nevertheless the potential to use water from the GAB in the North East Lake Eyre region for irrigation is likely to be limited by groundwater quantity and quality. Further research would be required.

Wet Tropics region

The Wet Tropics region has a low to modest potential for expansion of irrigated agriculture. Although runoff is very high in most places (i.e. > 1000 mm/yr), the steep landscape means there are relatively few potential dam sites commanding large storage volumes. The most promising potential dam sites in the Wet Tropics region are in the Herbert catchment. Large in-stream dams in the remote Herbert River gorge (within Girringun National Park) could be used to potentially irrigate 60,000 ha to 80,000 ha of land. However, the gorge is remote and dryland sugarcane is already been grown on the coastal plains downstream. Dams in the more accessible upper catchment could be used to potentially irrigate approximately 20,000 ha of land.

Unlike most of northern Australia, the Wet Tropics region experiences high and year round, albeit highly seasonal, rainfall. As a consequence of the high year round rainfall demand for irrigation supplies in many parts of the Wet Tropics is minimal. Although the wet tropical climate with its high humidity, high intensity rainfall, cyclonic events and, in some places, extreme temperatures, can prove challenging for many agricultural enterprises, along the coastal floodplains of the Wet Tropics region a dryland sugarcane industry has existed for over 100 years. In 2008-09 it was calculated that sugarcane was grown on about 200,000 ha of land in the region (Queensland Government 2009).

The largest water storages in the Wet Tropics region are Tinaroo Falls Dam (439 GL storage capacity) in the upper Barron catchment and Koombooloomba Dam (205 GL storage capacity) in the upper Tully catchment (Figure 4-14), making these the two most regulated catchments in the region. Releases from the Koombooloomba Dam are used for hydroelectric power generation, which significantly regulates flow in the Tully River. There is limited demand for water for irrigation downstream of Koombooloomba Dam. Tinaroo Falls Dam and reregulating structures supply the Mareeba Dimbulah Water Supply Scheme with 14 GL of HP and 191 GL of MP water allocations. Although these supplies are fully allocated, approximately 70 GL/yr of MP water is consistently underutilised and, if traded, would be available for other users. In 2012 the water pricing structure changed to increase the relative proportion of the access cost (to about 90% of the total cost), which appears to have caused a sharp increase in water usage (~80% in 2013) (pers. comm. David Morrison). Although this appears to have encouraged an increase in water usage and production it also potentially sends a market signal discouraging water use efficiency.

The upper Herbert catchment has several potential dam sites capable of yielding between 100 to 200 GL/yr (e.g. W1 and W2 in Appendix A), and which may be geologically suitable. Small off-stream storage options have been proposed in the area on the Herbert River and Blunder Creek (DNRW 2007). Further downstream there are potential dam sites within the Herbert River Gorge with large yields (i.e. 600 to 1000 GL/yr), but these sites are very remote, difficult to access (e.g. W4 in Appendix A) and are a considerable distance upstream (~100 km) of soils suitable for irrigated agriculture. Furthermore dryland sugarcane is already extensively grown on the coastal plains of the Herbert River and currently there is little demand for irrigation supplies.

Soils in the Wet Tropics region are variable, reflecting the different parent materials, geomorphological processes and landscapes that occur across the region. The soils have been well studied by the Queensland Government and the agricultural suitability and high productivity of some soils is well known and industry is well established. In particular, the deeper, less-rocky, better areas of Ferrosols on the Atherton Tableland, and the productive, less flood-prone areas of the coastal river flats are well utilised. The upper Herbert catchment appears to have more than 50,000 ha of land suitable for irrigated agriculture (Enderlin and Neenan 2000). However, it is likely that there would only be sufficient water to reliability year-round irrigate in the order of 20,000 ha.

Some of the coastal alluvial aquifers in the Wet Tropics region could potentially support small scale irrigation (e.g. Herbert River) or augment town water supplies (e.g. Mulgrave River aquifer).

Burdekin region

For three reasons, the Burdekin catchment offers one of northern Australia's greatest opportunities for expanding irrigation. First, it has the largest existing uncommitted water allocations (40 GL/yr HP water and 19 GL/yr MP water). Second, it has considerable potential for newly constructed water storage capacity. Thirdly, 300 GL/yr has already been set aside as strategic reserves in the Burdekin Resource Operation Plan (ROP) for future water allocation from potential storages. It is estimated that there are sufficient soil and water resources in the Burdekin catchment for irrigation to expand by an additional 100,000 ha.

The Burdekin catchment currently contains about 90,000 ha of irrigated agriculture (Photo 4-2), the majority (~80,000 ha) being located in the Lower Burdekin (Photo 4-2) adjacent to the Burdekin and Haughton rivers, with smaller areas of irrigation situated in Belyando and Suttor subcatchments (~6500 ha), along the upper Burdekin River (~2500 ha) and in the Bowen Broken subcatchment (~1000 ha) (NRMW 2006). There are a number of potential large in-stream storages that could be used to expand irrigation in the catchment. Of these raising the Burdekin Falls Dam (Figure 4-14) appears to be the most cost effective water storage development in the Burdekin region and this could potentially enable an expansion of irrigation in the Lower Burdekin, meet an anticipated increase in demand for water from Townsville and/or enable water to be supplied via pipeline to the Galilee and Bowen basins (Figure 4-14) to support future mining operations.

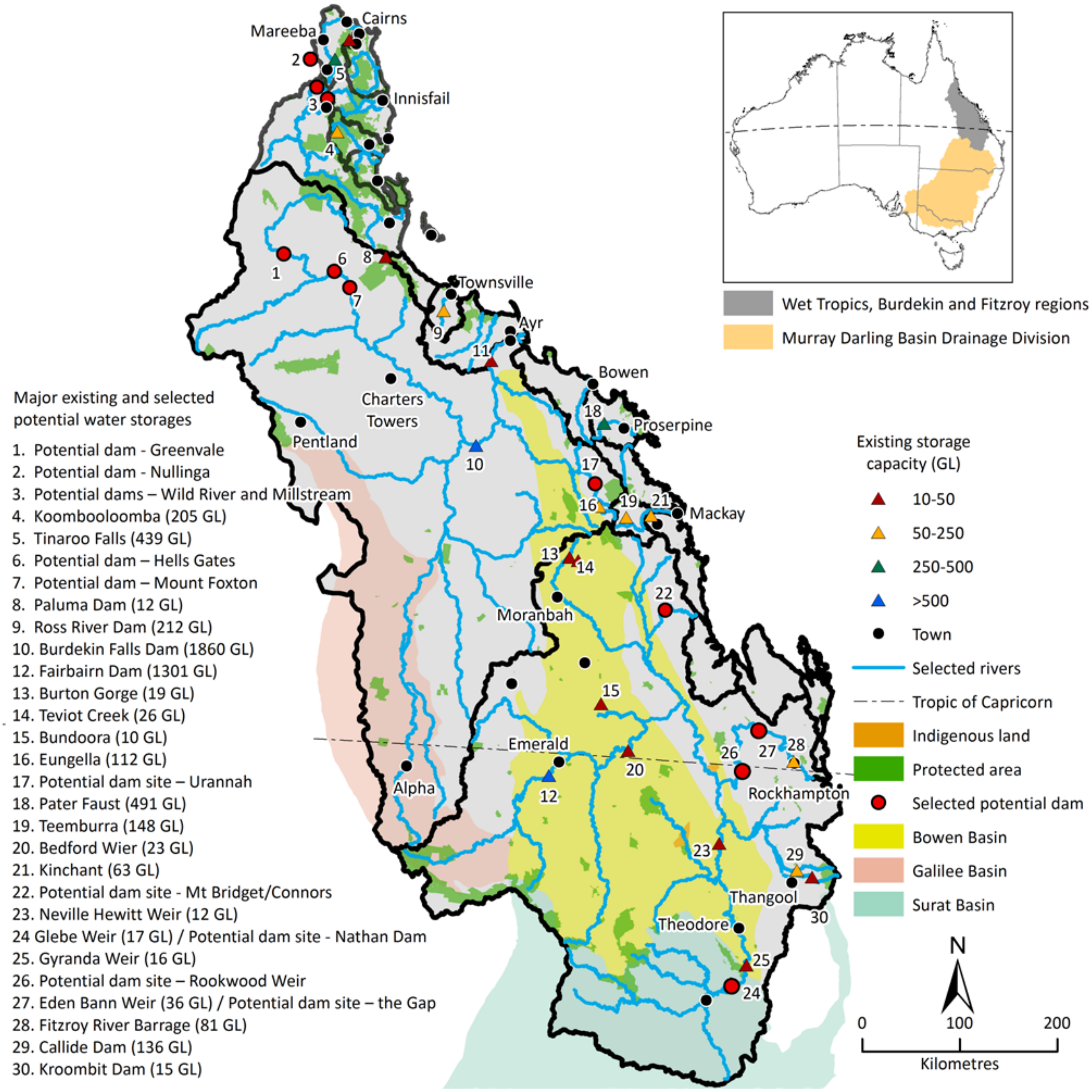

Figure 4-14 Location map of the Wet Tropics, Burdekin and Fitzroy regions

This figure shows major existing storages and population centres and selected potential storages and key river systems. The inset shows the geographic extent of the area in comparison to the Murray Darling Basin Drainage Division.

The Burdekin region comprises eight AWRC river basins, the largest being the Burdekin catchment. In the Lower Burdekin, surface water and groundwater are used for irrigation, and water for both surface and groundwater is supplied from the Burdekin Falls Dam (1860 GL storage capacity) and its downstream reregulating structures (e.g. Clare Weir) – groundwater levels in the Lower Burdekin Delta are maintained by aquifer enhanced recharge using water releases from the Burdekin Falls Dam. In the upper Burdekin catchment, along the Belyando and Suttor rivers there are some small scale irrigation based on water harvesting and off-stream storage.

The soils of the Burdekin region are spatially complex, reflecting various parent materials, geomorphic and landscape processes. Outside of the Lower Burdekin, areas of potentially suitable soils exist in isolated inland areas, particularly on Kandosols in the southern sections of the region in higher landscape positions surrounding the clay plains around the Belyando River. The agricultural suitability of the Burdekin region has been well studied by the Queensland Government, relative to most other parts of northern Australia.

Within the Lower Burdekin, an existing irrigation area, soil surveys are typically 1:50,000 scale or better. Elsewhere in the Burdekin catchment soil survey data is mostly at 1:250,000 scale (DNRM North Region – land resource and soil survey overview map).

The best dam site in the Burdekin region is the site of the existing Burdekin Falls Dam (1860 GL storage capacity). There is capacity to raise the Burdekin Falls Dam, which could potentially meet an anticipated increase in demand for water from Townsville, enable an increase in irrigated area in the Lower Burdekin and/or enable water to be supplied via pipeline to potential future mining operations in the Galilee and Bowen basins. There is already a strategic reserve of 150 GL for a future raising of the Burdekin Falls Dam in the Burdekin WRP. It has been estimated there is potentially 140,000 ha of land suitable for irrigation in the Lower Burdekin, including an additional 10,000 ha adjacent to the Haughton River and up to 50,000 ha along the existing Elliot Main Channel to Bowen (DERM 2010). Some of these currently undeveloped areas, particularly in the proposed Inkerman and Right Bank areas appear to have considerable constraints to irrigated agricultural development (Thompson 1977, Donnollan 1994a,b). Soils in these areas are particularly susceptible to erosion, salinity and sodicity issues and have complex landscape patterns, which would require significant inputs and careful management.

The best potential new dam sites in the Burdekin region are along the Burdekin River, upstream of Burdekin Falls Dam reservoir. Over many years numerous potential dam sites have been investigated (Figure 4-1), some of which along the upper Burdekin River were recently reviewed by GHD (2014). Large in-stream dams constructed at some of the better potential sites along the upper Burdekin River (e.g. Hells Gates; Figure 4-14) may yield in excess of 1000 GL/yr. Construction of these storages would, however, reduce the inflows to the Burdekin Falls Dam reservoir, and because there is an ill defined (e.g. GHD 2014, DERM 2010) but only modest area of soil suitable for irrigated agriculture along the Burdekin River upstream of the Burdekin Falls Dam (i.e. between 10,000 and 50,000 ha), raising Burdekin Falls Dam would likely be the preferred water storage development, unless there was a demand for water in the upper catchment for mining or some other non-agricultural enterprise. Furthermore the Burdekin Falls Dam spillway needs upgrading by 2035 to meet the new ANCOLD guidelines, and it could be cost effective to raise the dam at the same time.

Based on regional scale soil survey data (1:250,000), along the Bowen River there appear to be more than 100,000 ha of land suitable for irrigated agriculture (DERM 2010). Within the vicinity of this area of land is the proposed Urannah dam (Figure 4-14). Although its storage capacity (~1500 GL) is 80% of the Burdekin Falls Dam reservoir its yield is only 177 GL/yr (after environmental releases; BCEG 2002), sufficient to reliability irrigate approximately 10,000 to 15,000 ha. As with other dam development options in the region, Urannah dam has the potential for multi-purpose use. The Burdekin ROP has a strategic reserve of 150 GL for a volume of water, for water infrastructure for the Bowen and Broken subcatchments, which is primarily intended for industrial use.

In the southern Burdekin, along the Belyando and Suttor rivers there are very limited opportunities for large in-stream dams. However, there are soils suitable for water harvesting and off-stream storage of water, and regional scale soil mapping (DERM 2010) suggest that there are large areas of land potentially suitable for irrigated agriculture (> 200,000 ha). In the Burdekin WRP there are 130 GL/yr of general reserves in the Belyando Suttor subcatchment and 20 GL/yr of strategic reserves. The highly seasonal river flows and rapid rise and fall of water levels in these rivers can pose challenges for irrigation enterprises based on water harvesting.

Elsewhere in the Burdekin region, the Pioneer catchment has about 15,000 ha of irrigated agriculture and there is 11 GL/yr of HP water available for lease in the Pioneer Valley Water Supply Scheme. The catchment has several low yielding potential dam sites (i.e. 0 to 100 GL/yr).

Photo 4-2 Furrow irrigation in the Burdekin Haughton Water Supply Scheme (Lower Burdekin, Queensland)
Photo: CSIRO

Fitzroy region (Queensland)

The Fitzroy catchment has moderate potential for the expansion of irrigated agriculture and already contains more than 65,000 ha of irrigated land and about 800,000 ha of dryland agriculture (DERM 2009). It is estimated that multiple dams in the Fitzroy catchment (including those parts of the catchment south of the Tropic of Capricorn) could potentially expand the area under irrigation between 40,000 ha and 60,000 ha, if the water were used for this purpose. The Nathan dam proposal on the Dawson River, upstream of an existing irrigation area at Theodore (Figure 4-14), offers the largest potential for an expansion of irrigated production in the catchment.

There are three particularly prominent potential water storage options in the Fitzroy catchment (Queensland), no one of which is clearly preferred because they are geographically separate and have different potential demands.

Of the more viable options the Connors River dam proposal (56.4 GL/yr HP water) (Figure 4-14 and F2 in Appendix A) is intended solely to provide urban and mining supplies to the Bowen and Galilee basins. No other purpose is envisaged. It was proposed that Connors River dam and pipelines project would supply 25 GL/yr of HP water to Moranbah in the Bowen Basin with a pipeline extension to Alpha in the Galilee Basin supplying 25 GL/yr to that area. However, if two or more mines in Galilee Basin were to commence operation, then it is likely that it would be necessary to access water from another source such as the Burdekin Falls Dam. If the Burdekin Falls Dam were raised (i.e. resulting in an additional 121 GL HP water at Clare Weir in the Lower Burdekin) it could potentially meet the peak demand from a fully developed Galilee Basin.

The Nathan dam (66 GL/yr HP water) (Figure 4-14 and F4 in Appendix A), which is immediately south of the Tropic of Capricorn, is intended to increase urban, mining and industrial supplies along the Dawson River and potentially, to the lower Fitzroy River and or southwards to the Surat Basin. It is possible, however, that the Nathan dam project will develop later than previously expected given that substantial volumes of coal seam gas water are now expected to be produced in the Surat Basin over the next 25 to 30 years with up to 35.6 GL/yr being delivered by the Woleebee Pipeline from the basin to Glebe Weir on the Dawson River (QCMD 2014).

The third potential option, the lower Fitzroy River weir developments (i.e. constructing a weir at Rockwood and raising the Eden Bann Weir) (~76 GL/yr HP water) (Figure 4-14 and existing dam near F5 in Appendix A) would be the preferred option to meet additional urban and industrial demands in Rockhampton, the Capricorn Coast and the Gladstone areas. More details of these proposals are provided in Appendix B.

While there are numerous potential weir sites located across the catchment, the generally subdued relief means there are relatively few large potential dam sites in the vicinity of soils suitable for irrigation. It is possible to construct a very large dam at 'The Gap' (Figure 4-14 and F5 in Appendix A) about 140 km upstream of Rockhampton, which could potentially have a storage volume greater than 10,000 GL and a yield greater than 2000 GL/yr (in 85% of years). The modest demand for water in the Rockhampton area and limited area of suitable soils available for irrigated agriculture below the dam site has meant that the construction of a dam at 'The Gap' has not been seriously examined for a number of decades. There has been some local interest in construction of a dam at 'The Gap' for flood mitigation purposes, however, it should be noted that the maximum recorded annual flow at 'The Gap' was about 38,000 GL and hence despite the potential volume of the reservoir it would have a modest ability to mitigate large flood events in wet years.

The Nathan dam proposal on the Dawson River offers the largest potential for an expansion of irrigated production in the catchment. If the HP supply from the proposed Nathan dam were not fully taken up for urban, mining and industrial development as expected, irrigation along the Dawson River could expand to take up any available MP supply. This could potentially irrigate ~20,000 ha along the banks of the Dawson River, possibly more if only a single crop such as cotton were grown each year.

Soil mapping across the Fitzroy region is at 1:500,000 scale (DERM 2010), with the exception of the coastal strip (1:50,000) and a couple of smaller areas at 1:100,000 and 1:250,000 scale mapping. There are likely to be small areas of alluvial soil suitable for irrigated agriculture scattered throughout the catchment.

5 Other considerations

5.1 Ecological and cultural considerations

The regulation of river systems through Australia and the world has brought about what in many cases have been complex and unpredictable changes in ecological, geomorphological, cultural and social parameters. Some of the issues that can arise as a result of the construction of dams and diversion structures and irrigation areas are briefly discussed below. If water resource or irrigation development were to proceed, site specific studies would be required to understand the likely ecological and cultural impacts. Across northern Australia the absence of good baseline information and datasets makes it difficult to establish developments and then adaptively manage ('learn as you go') any resulting development impacts.

While dams, water regulation and water extractions can result in considerable ecological changes as briefly detailed below, it is also important to note that the reservoir created by a dam can provide highly valued amenity for local communities and new and potentially valuable ecological assets.

Reductions in flow

Freshwater flows have a profound influence on coastal ecosystems (Gillanders and Kingsford 2002), affecting circulation patterns and vertical stability of marine waters, mixing and nutrient exchange processes and the delivery of particulate organic and inorganic compounds that form part of the marine food chain (Drinkwater and Frank 1994). In large river systems the effect of freshwater has been observed to extend many hundreds of kilometres into the ocean beyond the river mouth (e.g. Moore et al., 1988). Ecologically, freshwater flow has been strongly linked to the health and production of certain estuarine and marine fish and shellfish (Robins et al., 2005), with most studies showing a positive relationship between fish abundance and river discharge (Drinkwater and Frank 1994).

Changes in seasonality of flow

Dams, diversion structures and other forms of river regulation not only reduce the flow downstream but can also result in changes to the seasonality of flow, which can lead to considerable ecological change. The construction of the Ord River Dam and Ord River Irrigation Area has changed the lower Ord River from an ephemeral to a perennial river (Petheram et al., 2008b). This has been accompanied by a change to the in-stream and riparian ecology. Similarly in the Lower Burdekin, the rivers and creeks that receive tail water drainage from the Burdekin Haughton Water Supply Scheme (e.g. Barattas Creek and Sheep Station Creek) have changed from ephemeral to perennial water courses, resulting in ecological changes (Burrows and Butler 2007).

Change in water quality

In rivers in northern Australia affected by irrigation development (e.g. in the irrigation districts of the lower Burdekin coastal floodplain and the upper Walsh River) reduction in water quality has been identified as a key reason for reductions in existing ecosystem health (e.g. Burrows, 2004; Burrows and Butler, 2007; Butler, 2008; Butler et al., 2007; Perna, 2003). The higher temperature and turbidity (the clarity of water: low turbidity represents clear water, high turbidity represents low clarity) and decreased dissolved oxygen (Butler et al., 2007; Butler et al., 2009) of the tail water combine to further restrict ecological processes and to affect aquatic fauna.

In the case of the Lower Burdekin, the construction of the Burdekin Falls Dam and subsequent regulation of the lower Burdekin River resulted in highly turbid dry season flows, contrary to original expectations. The change from clear to turbid flow occurred not just in the Burdekin River, but also in the adjacent creeks, rivers and wetlands (Burrows and Butler 2007), which receive the tail water drainage from the Burdekin Haughton Water Supply Scheme area.

The effect of river barriers and reservoir inundation

A well documented effect of in-stream structures (small and large) is the blockage of migration routes as well as the movement of plants and energy, potentially disrupting connectivity of populations and ecological processes. Even in locations where fish ladders have been known to work, large delays in migration can occur below the dam (Drinkwater and Frank 1994). Water pooling behind storages changes up stream currents, which may further exacerbate this problem (Brett 1957). The water impounded by a dam or diversion structure also inundates an area of land, drowning not only in-stream habitat but surrounding flora and fauna communities. The large, deep lake lake-like environment created by a dam favours some species over others and will function completely differently to natural rivers and streams, which are usually shallow and flowing.

Reservoir stratification

Stratification of water within reservoirs can also be potentially problematic. A long duration of stratification can result in long periods of low dissolved oxygen concentration and the release of nutrients and methane from the sediments at the base of the reservoir. Persistence of shallow surface mixing layer depths can provide suitable light conditions to support algal blooms.

Sediment transport and sedimentation

Rivers carry fine and coarse sediment eroded from hill slopes, gullies, banks and sediment stored within the channel. Sediment delivery to dams can be a major problem for water storage capacity since infilling progressively reduces the volume available for active water storage. Coarse sediment is often deposited where rivers flow into the reservoir, which can result in or exacerbate localised flooding in these areas. In trapping the sediment, dams can alter downstream river and coastal geomorphology.

Based on a desktop assessment of ten sediment yield studies from across northern Australia (Tomkins, 2013), sediment yield to catchment area relationships for northern Australia were developed and found to predict slightly lower sediment yield values than global relationships. This was not unexpected given the antiquity of the Australian landscape (i.e. it is flat and slowly eroding under 'natural' conditions).

Reliable estimation of sediment infill rates requires analysis of specific dam proposals. These would need to be completed if any of the potential dams in northern Australia were considered further.

Indigenous cultural heritage considerations

There is much evidence of the importance of rivers and water to Indigenous Australians. Indigenous people traditionally situated their campsites and subsistence activities along major watercourses and drainage lines. Consequently dams are more likely to impact on areas of high cultural significance than most other infrastructure developments (e.g. irrigation schemes, roads). Consequently the cost and time required for cultural heritage investigations associated with dam sites is high relative to other development activities.

It is highly likely that many of the large drainage lines in northern Australia contain a large number of Indigenous cultural sites, including archaeological pre-colonial sites, some of which are likely to be of national scientific significance. If any potential dam sites in northern Australia were to progress, an archaeological survey would be required to understand the potential Indigenous archaeological impact of the dam and reservoir. It is commonly recommended that such investigation be undertaken in consultation with relevant Indigenous parties and, should works proceed in the area, that a Cultural Heritage Management Plan or Agreement be developed. Research with Indigenous parties should include the collection and review of oral information from knowledgeable people and discussion regarding contemporary use of water sources in the area.

Indigenous water values

Tens of thousands of years of tenure by Indigenous people in Australia has resulted in very strong custodial connections to important places and significant knowledge of the wider landscape. Indigenous people particularly across northern Australia assert and maintain important cultural, historical, and emotional ties to these areas (Barber and Jackson 2011, Barber et al., 2012, Jackson et al., 2012). In many cases, people also rely on these lands for a range of physical, biological and food resources to which they attach significant spiritual and economic values. Consequently these areas can become a major focus for contemporary social and economic development ideas and aspirations.

5.2 Alternative methods for storing water

Large in-stream storages are not the only methods of storing water, they do, however, present the greatest opportunity for broad scale irrigated agriculture. In northern Australia it is broadly estimated that large in-stream storages could enable 5 to 20 times more land to be irrigated than water harvesting and off-stream storages, 10 to 40 times more land to be irrigated than managed aquifer recharge and 50 to 100 times more land to be irrigated than large wetland systems and natural waterholes. Further research would be required to better understand the absolute and relative magnitude of these alternative water storage methods across northern Australia, these numbers, however, provide a likely order of magnitude. Though each approach is capable of supplying far smaller volumes of water than in-stream dams, each may have a role to play in maximising the cost-effectiveness of water supply.

In Section 2 groundwater in northern Australia was discussed, and Section 3 presented the results of an analysis on large dams and off-stream storages. In this section the potential for other forms of water storage in northern Australia are outlined.

5.2.1 OPPORTUNITIES FOR MANAGED AQUIFER RECHARGE IN NORTHERN AUSTRALIA

Managed aquifer recharge (MAR) is defined as the purposeful recharge of water to aquifers for subsequent recovery or for environmental benefit (Dillon et al., 2009). It can be used to replenish depleted aquifers, remove pathogens and prevent sea water intrusion. Forms of MAR that enhance infiltration to relatively shallow unconfined aquifers (e.g. infiltration ponds) are the only form of MAR currently economically suitable for irrigated agriculture. Where water has a higher value (e.g. mining, energy operations, town water supply), other more expensive, but versatile forms of MAR, such as aquifer storage and recovery, can be economically viable and should be considered. The extra area of irrigation that could be irrigated in northern Australia using MAR is likely to be between 10 to 40 times less than the area that could be potentially irrigated using large in-stream dams.

The best opportunities for infiltration based MAR schemes to increase the area of land under irrigation in northern Australia is likely to be in the prograding alluvial deltas and coastal floodplains of the rivers along the north east coast of Queensland. There may also be potential to use infiltration based MAR in the karstic carbonate systems of northern Australia. However, these karstic systems would have to be thoroughly investigated because there is a reasonable likelihood that the infiltrated water could, in many situations, discharged or ‘leak’ immediately to the river. Elsewhere the potential to use MAR for irrigation is likely to be largely opportunistic and would have most advantage over surface water storages in the more southerly semi-arid/arid parts of northern Australia, where rainfall deficits (i.e. rainfall minus evaporation) are highest, runoff is most variable and the topography generally favours broad, shallow surface water storages.

Opportunities for managed aquifer recharge for irrigation in northern Australia

The aquifers in northern Australia that are most suitable for MAR are likely to be the unconsolidated sediments on the coastal floodplains of large rivers on the north-east Queensland coast. This is because of its unique environmental setting where large volumes of surface water (i.e. a result of large catchment areas) discharge off steep coastal escarpments, which ensure appropriate hydraulic conditions for the delivery of coarse sediment to the coastal floodplain. As the rivers enter the narrow, flat coastal areas there is a marked reduction in fluvial energy and the coarse sediments are deposited. As a result the Burdekin, Herbert and Fitzroy (Qld), for example all have prograding alluvial deltas of relatively coarse sedimentary material. The Lower Burdekin Irrigation Area has the largest and one of the only MAR schemes supplying water for irrigation in Australia (Photo 5-1). MAR has been successfully used in the Lower Burdekin to manage sea water intrusion since the mid-1960's. It should be noted, however, that water is reliability supplied to the Lower Burdekin MAR scheme from the Burdekin Falls Dam and associated reregulating structures.

West of the Great Divide (i.e. the majority of northern Australia), unconsolidated sediments associated with current and prior streams may have prospects for MAR. However, in many places the scale of these MAR developments would most likely lend themselves to property scale developments (i.e. < 500 ha). In the wet, northerly parts of northern Australia (e.g. around Darwin, Cape York) unconfined groundwater systems are 'spill' and 'fill' systems, that is, the aquifers consistently fill during the wet season, and so under 'natural' conditions there is no additional storage capacity to enable MAR (CSIRO 2009b, c). Further south/inland, rainfall decreases, the monsoon becomes less reliable (Petheram and Bristow 2008), and so unconfined groundwater systems are less likely to exhibit 'spill' and 'fill' behaviour. In these lower, less reliable rainfall areas MAR has the potential to be more economically viable than surface water storage options. However, streamflow also becomes increasingly ephemeral and intermittent with distance south and inland, potentially requiring larger off-stream storages to temporarily hold surface water prior to infiltration. In many places the size of irrigation would most likely be limited to property scale developments.

Photo 5-1 Managed aquifer recharge infiltration pit in the Lower Burdekin Irrigation Area
Photo: CSIRO

In the Gilbert River, Queensland, small volumes of water (< 25 GL in total) are extracted by some landowners for irrigation of small fields from river bedsands (QDNR 1998; AGE 1999), which are comprised of coarse sands and gravels. There may be similar opportunities for small scale irrigation based on extractions from bedsands in other rivers in northern Australia of similar sediment composition. These opportunities could potentially be enhanced in some circumstances by the construction of a barrier across the river within the bedsands. In developing countries, small (i.e. 1 to 5 m high) reinforced concrete walls are increasingly being built across seasonal rivers, to provide a reliable potable water supply in water scarce environments. However, storage capacities are typically small (e.g. 2 to 20 ML), and suited to supply water for domestic purposes and small food gardens. While there may be opportunities to enhance bedsand storage in some river reaches in northern Australia this technology is unlikely enable broad scale irrigation across the north.

Considerations in using managed aquifer recharge for irrigation in northern Australia

The main advantages of infiltration based MAR schemes over large carry-over surface water storages for irrigation in northern Australia are the lower capital costs. Further in the southerly semi-arid/arid parts of northern Australia net evaporative losses (i.e. difference between evaporation and rainfall) are considerably lower from MAR schemes compared to equivalent sized surface water schemes. In the more northerly parts of northern Australia, net evaporative losses from large carry-over storages are relatively low and in some cases negative (i.e. annual rainfall exceeds annual evaporation), and the comparative 'evaporative' advantage of MAR over large carry-over storage is considerably diminished.

The advantage of low net evaporation rates is that it enables water to be stored for multiple years allowing water to be 'banked' during wetter years and used during drier years. This provides a much more reliable supply of water than could be achieved using shallow on-farm storages (i.e. ring tanks) and could also enable double cropping or perennial crops, thereby achieving greatest return from land development costs. Double cropping or growing perennial crops using water from shallow on-farm storages is seldom likely to be feasible because of large evaporation losses (> 50% per year). Having a reliable supply of water enables reliable crop production, which in turn provides an opportunity to secure finance and long term market contracts.

Disadvantages of MAR are that the site specific investigation costs are more specialised and considerably higher than required for farm scale off-stream storages and even large carry-over storages. The high cost of initial investigation is likely to be a major deterrent for individual land holders, unless they could be reasonably confident of success.

In northern Australia, river levels rise and fall more quickly than southern Australia (Petheram et al., 2008a), and because infiltration rates are often orders of magnitude lower than runoff rates, reasonably large off-stream storages may need to be constructed to temporarily hold the water before it can be transferred into an infiltration pit.

Another consideration is that if an area suitable for MAR was identified one or two demonstration sites would probably need to be developed within the vicinity of an agricultural precinct before the technology was proved and adopted by local landholders.

5.2.2 OPPORTUNITIES TO STORE WATER IN NATURAL WATERHOLES AND WETLANDS

Wetland systems and waterholes that persist throughout the dry season are natural waterbodies characteristic of large parts of the northerly draining catchments of northern Australia. It is roughly estimated that large in-stream dams could irrigate between 50 and 100 times more land than large wetland systems and persistent waterholes. Both wetlands and persistent waterholes have considerable ecological significance (Kingsford 2000, Waltham et al., 2013). In this section the potential to extract water from these natural sources for irrigation is briefly discussed.

Wetlands

Wetlands in northern Australia are seasonally replenished during flood events, when they become temporarily connected to nearby streams and rivers. This allows the transfer of material fluxes and movement of aquatic species. Due to the high biodiversity value of wetlands and the demand for water for irrigation in southern Australia, several studies have examined the potential for using wetlands in regulated river systems as a means conjunctively storing water for irrigation and conserving wetland health (e.g. Ning et al., 2012, Watkins et al., 2012). In the Roper catchment, there is evidence that prior to European settlement Indigenous people engineered diversion structures on perennial rivers during the dry season to divert water into adjacent wetlands, from which they acquired food resources (Barber and Jackson 2012).

No other published studies on the use of wetlands as a means of storing water in the unregulated river systems of northern Australia have been identified.

It is thought likely that the potential to use wetlands for storing water for irrigating short season crops in northern Australia would be mostly limited to the larger natural wetlands found in the wetter, more northerly and coastal regions. Elsewhere it is likely that the volume of water available from a wetland relative to the requirement for irrigation would be small (i.e. less than 20%), even if the wetland volume is enhanced through engineering structures. This was found to be the case in the lightly regulated Broken River system in Victoria (Sammond et al., 2013). In some northern jurisdictions there may be regulatory impediments to extracting water from or using wetlands for storing water for irrigation purposes.

Dry season waterholes

The extended dry season in northern Australia means that the majority of rivers in the north are ephemeral, with many flowing for less than 50% of the time (Petheram et al., 2008a). As a result, during the dry season, most rivers break up into a series of waterholes (e.g. see McJannet et al., 2013). Some waterholes receive groundwater discharge all year round, but many are only replenished during the wet season by surface water flows (Jolly et al., 2013). Many homesteads across northern Australia are located near a waterhole from which water is sourced for stock and domestic supply. However, the volume of water required for irrigation is many orders of magnitude greater than that required for stock and domestic supply. In most cases waterholes are unlikely to have sufficient storage capacity to be used for irrigation - except perhaps for very small fodder or horticultural plantings.

In the Flinders catchment for example, most waterholes were less than 2.5 ha in area (McJannet et al., 2013). Assuming an average depth of 5 m and an area of 2.5 ha, a 2.5 ha waterhole would contain 125 ML of water. A small area (e.g. 200 ha), planted to a short season crop like mungbeans in the Flinders catchment would require approximately 400 ML of water (not including conveyance, on-farm and application losses). Crops with longer growing season (e.g. cotton, rice) would need considerably more water than mungbeans. In the wetter, more northerly parts of northern Australia, where waterholes are likely to be larger and short season crops require less water than in the Flinders catchment, in some circumstances it may be economically viable to irrigate small areas using water from waterholes. However, dry season waterholes will not support broad scale irrigation across northern Australia.

A further consideration to using waterholes or connected bedsands as sources of water for irrigation is that these waterbodies are particularly important refugial habitat for aquatic biota during the extended dry season (e.g. Waltham et al., 2013).

Photo 5-2 Persistent waterhole in the Fitzroy River (WA)
Source: CSIRO

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7 Appendices

The appendices to the main technical report are contained in a companion report. The companion report contains five appendices and must be read in conjunction to the main technical report.

Appendix A (page 80) provides location maps (e.g. river and town names) and maps of potential surface water storages, preliminary plots of yield versus reliability for selected potential dams and maps and tables of land suitability for each of the 21 reporting regions.

Appendix B (page 353) provides a summary of the Water Resource Plans (WRP) and Resource Operation Plans (ROP) for the regulated catchments draining the east coast of Queensland. These are the more heavily regulated catchments in northern Australia. It also provides brief comment on selected potential dam sites in these Queensland regions.

Appendix C (page 380) describes the methods used to undertake the DamSite modelling, assess the suitability of off-stream storage suitability and assess the scale of northern Australia's irrigation potential.

Appendix D (page 393) presents modelled pre-development discharge characteristics for the AWRC river basins in the 13 more northerly reporting regions (i.e. Timor Sea and Gulf of Carpentaria drainage divisions and the North East Coast Drainage Division north of Cairns).

Appendix E (page 396) is a geological timeline.

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