Soils and land suitability for the Roper catchment, Northern Territory

A technical report from the CSIRO Roper River Water Resource Assessment for the National Water Grid

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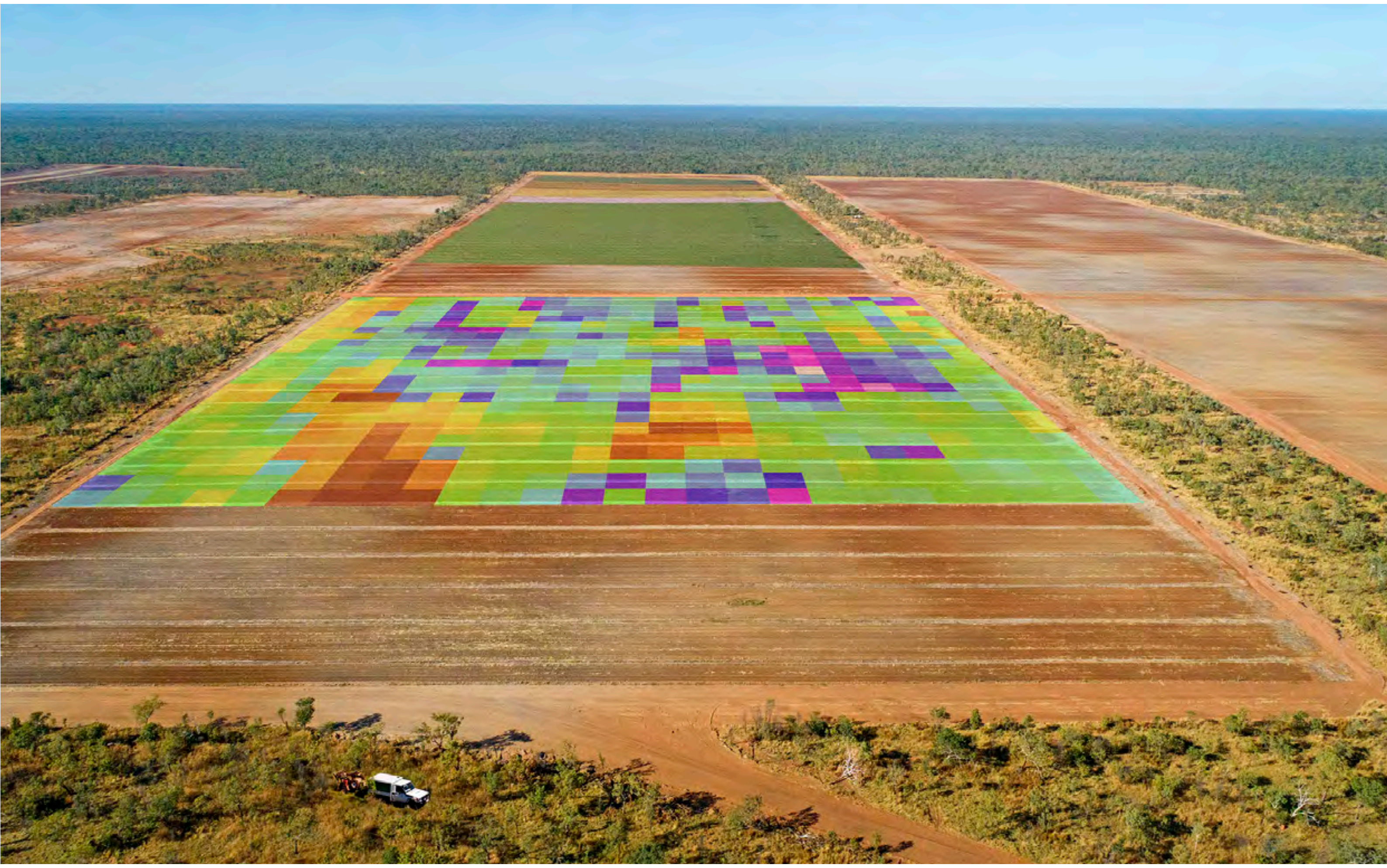

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Aspects of the Assessment have been undertaken in conjunction with the Northern Territory Government.

The Assessment was guided by two committees:

i. The Assessment's Governance Committee: CRC for Northern Australia/James Cook University; CSIRO; National Water Grid (Department of Climate Change, Energy, the Environment and Water); NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Qld Department of Agriculture and Fisheries; Qld Department of Regional Development, Manufacturing and Water

ii. The Assessment's joint Roper and Victoria River catchments Steering Committee: Amateur Fishermen's Association of the NT; Austrade; Centrefarm; CSIRO, National Water Grid (Department of Climate Change, Energy, the Environment and Water); Northern Land Council; NT Cattlemen's Association; NT Department of Environment, Parks Australia; Parks and Water Security; NT Department of Industry, Tourism and Trade; Regional Development Australia; NT Farmers; NT Seafood Council; Office of Northern Australia; Roper Gulf Regional Council Shire

Responsibility for the Assessment's content lies with CSIRO. The Assessment's committees did not have an opportunity to review the Assessment results or outputs prior to its release.

This report was reviewed by David G. Rossiter (Cornell University) and Gerard Grealish (Manaakl Whenua Landcare Research, New Zealand).

The Digital Soil Mapping and Land Suitability analysis reported in this Technical Report would not have been possible without the help, support, encouragement and advice from a large number of people. Our gratitude to local Indigenous organisations and their staff who advised us on access, gave permission for sampling, and supervised sampling activity. In particular we would like to thank the Yugul Mangi Rangers and Northern Land Council. Our fieldwork was improved by the support of the local grazing industry giving access to properties and sharing extensive local knowledge. In particular, Sally and Rohan Sullivan as well as the owners, managers and staff of Lonesome Dove, Flying Fox and Moroak Stations. Many CSIRO people, not part of the immediate team or report authors, provided a range of inputs to the land suitability activity. This includes technical advice, project design, project management oversight, financial controls, administration support, contract management, database and query advice, communications, help with document files and input from other activities such as agricultural viability and aquaculture. The CSIRO people we wish to thank (on no particular order) include: Bec Bartley, Cuan Petheram, Jon Schatz, Ellie Kosta, Jodie Hayward, Simon Irvin, Tony Webster, Steve Yeates, Liz Stower, Mike Grundy, Chris Chilcott, Arthur Read, Linda Karssies, Georgia Reed, Peter Zund and Caroline Bruce. Similarly, a number of people from associated jurisdictions provided valuable input to the project but are not named as part of the team: Jenny Petursson, Mark Sugars, Jim Payne, Henry Smolinski, Jonathan Burgess, Kaitlyn Andrews, Diane Napier, Sonya Mork, Angus McElnea and other staff from the DSITI Chemistry Centre. Finally, we'd like to thank our family, friends and colleagues who picked up the slack when we were away from home or so busy that we (temporarily) forgot that they existed.

Acknowledgement of Country

CSIRO acknowledges the Traditional Owners of the lands, seas and waters, of the area that we live and work on across Australia. We acknowledge their continuing connection to their culture and pay our respects to their Elders past and present.

Photo: CSIRO

Director's foreword

Sustainable regional development is a priority for the Australian and Northern Territory governments. Across northern Australia, however, there is a scarcity of scientific information on land and water resources to complement local information held by Indigenous owners and landholders.

Sustainable regional development requires knowledge of the scale, nature, location and distribution of the likely environmental, social and economic opportunities and the risks of any proposed development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpins the resource security required to unlock investment.

In 2019 the Australian Government commissioned CSIRO to complete the Roper River Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to provide data and insight to support consideration of the use of land and water resources for development in the Roper catchment. While the Assessment focuses mainly on the potential for agriculture, the detailed information provided on land and water resources, their potential uses and the impacts of those uses are relevant to a wider range of regional-scale planning considerations by Indigenous owners, landholders, citizens, investors, local government, the Northern Territory and federal governments.

Importantly the Assessment will not recommend one development over another, nor assume any particular development pathway. It provides a range of possibilities and the information required to interpret them - including risks that may attend any opportunities - consistent with regional values and aspirations.

All data and reports produced by the Assessment will be publicly available.

Chris Chilcott

Project Director

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Shortened forms

SHORT FORM	FULL FORM
AHD	Australian Height Datum
ASC	Australian soil classification
ASS	Acid Sulfate Soils
AVHRR	Advanced Very High Resolution Radiometer
AWC	Available water capacity
BoM	Bureau of Meteorology
CEC	Cation exchange capacity
cLHS	Conditioned Latin Hypercube Sampling
DEM	Digital elevation model
DLCD	Dynamic Land Cover classes
DOI	Digital Object Identifier
DSM	Digital soil mapping
EC	Electrical conductivity
ESP	Exchangeable sodium percent
FAO	Food and Agriculture Organization of the United Nations
FPAR	Fraction of Photosynthetically Active Radiation
GIS	Geographic information system
LiDAR	Light Detection and Ranging
MODIS	Moderate Resolution Imaging Spectroradiometer
NT	Northern Territory
OOB	Out of bag
RF	Random Forest
SGG	Soil Generic Group
UI	Uncertainty index
WII	Weathering Intensity Index

Units

UNIT	DESCRIPTION
ha	Hectares
m	Metres
mAHD	Elevation in metres with respect to the Australian Height Datum
km	Kilometres
°C	Temperature on Celsius scale

Preface

Sustainable regional development is a priority for the Australian and Northern Territory governments. For example, in 2023 the Northern Territory Government committed to the implementation of a new Territory Water Plan. One of the priority actions announced by the government was the acceleration of the existing water science program ‘to support best practice water resource management and sustainable development’.

The efficient use of Australia’s natural resources by food producers and processors requires a good understanding of soil, water and energy resources so they can be managed sustainably. Finely tuned strategic planning will be required to ensure that investment and government expenditure on development are soundly targeted and designed. Northern Australia presents a globally unique opportunity (a greenfield development opportunity in a first-world country) to strategically consider and plan development. Northern Australia also contains ecological and cultural assets of high value and decisions about development will need to be made within that context. Good information is critical to these decisions.

Most of northern Australia’s land and water resources, however, have not been mapped in sufficient detail to provide for reliable resource allocation, mitigate investment or environmental risks, or build policy settings that can support decisions. Better data are required to inform decisions on private investment and government expenditure, to account for intersections between existing and potential resource users, and to ensure that net development benefits are maximised.

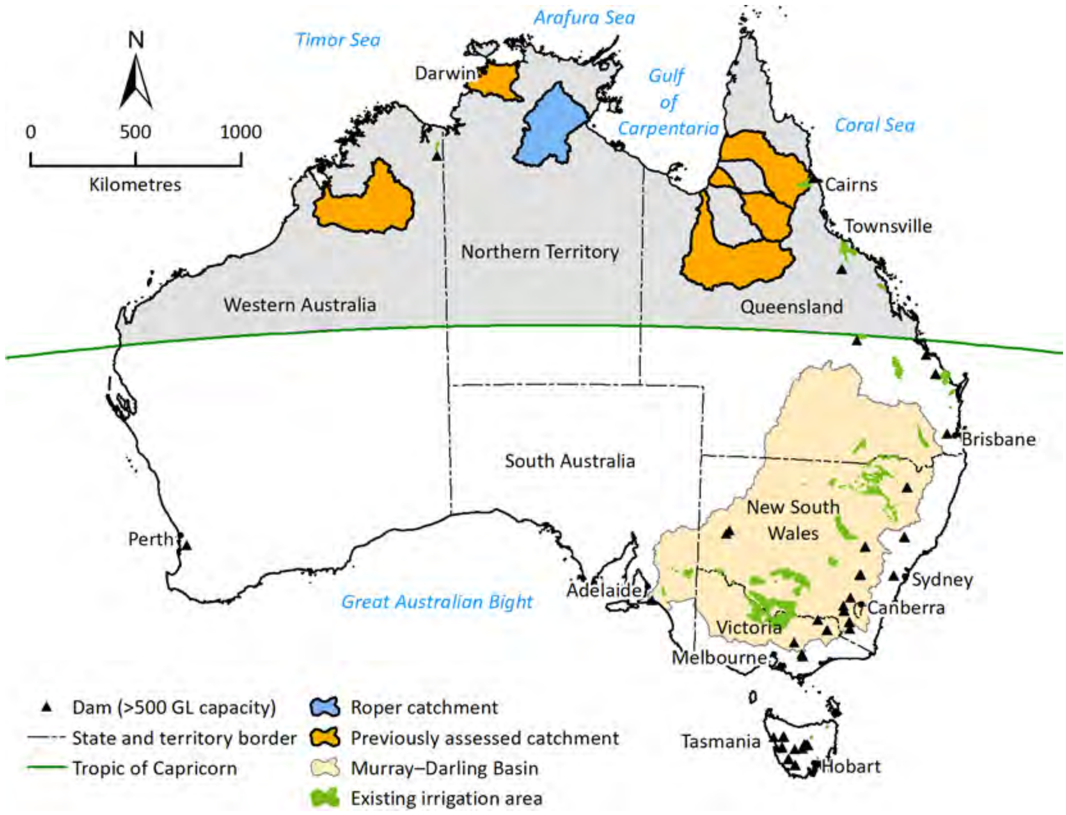
In consultation with the Northern Territory Government, the Australian Government prioritised the catchment of the Roper River for investigation (Preface Figure 1-1) and establishment of baseline information on soil, water and the environment.

Northern Australia is defined as the part of Australia north of the Tropic of Capricorn. The Murray–Darling Basin and major irrigation areas and major dams (greater than 500 GL capacity) in Australia are shown for context.

The Roper River Water Resource Assessment (the Assessment) provides a comprehensive and integrated evaluation of the feasibility, economic viability and sustainability of water and agricultural development.

While agricultural developments are the primary focus of the Assessment, it also considers opportunities for and intersections between other types of water-dependent development. For example, the Assessment explores the nature, scale, location and impacts of developments relating to industrial and urban development and aquaculture, in relevant locations.

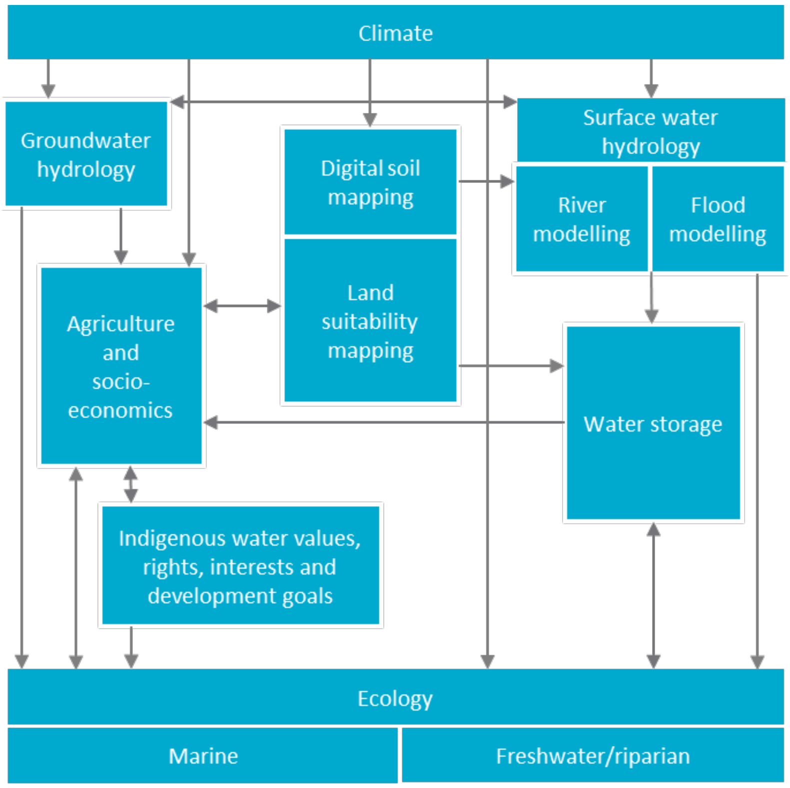
The Assessment was designed to inform consideration of development, not to enable any particular development to occur. As such, the Assessment informs – but does not seek to replace – existing planning, regulatory or approval processes. Importantly, the Assessment does not assume a given policy or regulatory environment. As policy and regulations can change, this enables the results to be applied to the widest range of uses for the longest possible time frame.



Preface Figure 1-1 Map of Australia showing Assessment area

It was not the intention – and nor was it possible – for the Assessment to generate new information on all topics related to water and irrigation development in northern Australia. Topics not directly examined in the Assessment are discussed with reference to and in the context of the existing literature.

Functionally, the Assessment adopted an activities-based approach (reflected in the content and structure of the outputs and products), comprising eight activity groups; each contributes its part to create a cohesive picture of regional development opportunities, costs and benefits. Preface Figure 1-2 illustrates the high-level links between the eight activities and the general flow of information in the Assessment.



Preface Figure 1-2 Schematic diagram of the high-level linkages between the eight activities and the general flow of information in the Assessment.

Assessment reporting structure

Development opportunities and their impacts are frequently highly interdependent and consequently, so is the research undertaken through this Assessment. While each report may be read as a stand-alone document, the suite of reports most reliably informs discussion and decisions concerning regional development when read as a whole.

The Assessment has produced a series of cascading reports and information products:

- Technical reports; that present scientific work at a level of detail sufficient for technical and scientific experts to reproduce the work. Each of the eight activities has one or more corresponding technical report.
- A Catchment report; that for the Roper catchment synthesises key material from the technical reports, providing well-informed (but not necessarily-scientifically trained) readers with the information required to make decisions about the opportunities, costs and benefits associated with irrigated agriculture and other development options.
- A Summary report; that for the Roper catchment provides a summary and narrative for a general public audience in plain English.
- A Summary factsheet; that for the Roper catchment provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable the reader to better access information that is not readily available in a static form. All of these reports, information tools and data products are available online at https://www.csiro.au/roperriver. The website provides readers with a communications suite including factsheets, multimedia content, FAQs, reports and links to other related sites, particularly about other research in northern Australia.

Executive summary

The Roper River Water Resource Assessment (the Assessment) aims to support decision making for sustainable regional development. It does this by clarifying the scale and nature of opportunities (and limitations) for agriculture and other uses of water resources in the catchment of the Roper River in the Northern Territory – an area covering some 7,740,000 ha dominated by extensive cattle grazing. The Assessment was commissioned by the Australian Government and carried out in collaboration with the Northern Territory Government.

A fundamental input to any assessment of water resource development for agriculture is an understanding of the soil and land resources that are present, their spatial distributions, and the limitations to their uses. Specifically, knowledge is needed of the potential suitability of soils for a range of crops, planting seasons and irrigation management.

This report details the digital soil mapping and subsequent land suitability analysis for the catchment. Four major tasks were completed. First, new soil data were collected to cater for important gaps in soils not covered by legacy surveys in the catchment. Second, soil attribute (i.e. soil pH, clay content, A horizon depth, soil thickness, plant available water capacity, permeability, drainage, rockiness, erodibility, exchangeable sodium percentage, surface condition, structure, surface salinity, texture, and microrelief) and soil generic group maps were modelled, each delivered with a spatial resolution of 1 arc-second (i.e. grid cells of approximately 30 m on the ground). Third, the digital maps were incorporated with other publicly available environmental digital maps (e.g. climate) into a digital land suitability modelling framework to determine suitability of land for realistic crop groups under various management scenarios (i.e. planting seasons and irrigation types (land uses)). Dryland was included. Fourth, the reliability of soil attribute and land suitability maps were evaluated following field validation and statistical model testing.

The digital soil mapping for soil attributes and soil generic groups combined legacy and new soil data. Legacy soil data from 5375 sites from the Northern Territory database were augmented by a new soil survey comprising 216 sites. New sites were located using statistical methods to infill gaps in the legacy data. The digital soil mapping applied predictor covariates from various national databases, including the Soil Landscape Grid of Australia. The soil generic groups were developed to support non-expert communication and aligned with the Australian Soil Classification. Methods for map reliability checking included statistical measures as well as generation of reliability maps, which used in companion with the attribute map allows users to visually assess mapping strengths and weaknesses.

The digital land suitability assessment primarily catered for agricultural opportunity, although aquaculture was also included. Suitability assessments were made for crop groups, including horticulture and silviculture. Crop groups feature sets of similar crops with similar growing and management needs. The land suitability assessment followed the standard Food and Agriculture Organization (FAO) schema, which estimates suitability of crops under various management scenarios using a five-class ranking system from ‘land highly suitable with negligible limitations’ (Class 1) to ‘land unsuitable with extreme limitations’ (Class 5). The overall suitability for each

30 m grid of the resulting suitability maps is determined by the most limiting soil and land factor for the grid cell. The land suitability framework does not include flooding as commonly applied in the standard FAO schema; surface water hydrology forms another Assessment activity. The system is flexible enough to be updated to incorporate new data for soils, crop varieties, land management practices, climate etc. as these datasets and knowledge improve.

The suitability of 21 crop groups (>120 individual crops) for 58 land use option combinations (i.e. crop group by season by irrigation type were evaluated) and are presented in the report. However, for report brevity 14 realistic 'exemplar' land use combinations are illustrated. The suitability of land for aquaculture for freshwater and marine species using either earthen or lined ponds are also presented. The report shows the most prospective 'exemplar' land use for the catchment is perennial grass and hay forage crops (e.g. Rhodes grass) (crop group 14) managed by wet-season spray irrigation with 3,947,000 ha, that is 51% of the catchment classed as suitability Class 3 (suitable with limitations) or better. Conversely, cotton (Group 7) under wet season furrow irrigation is suitable over approximately 107,000 ha (1.4%).

The versatility of land for irrigation was also digitally mapped using two different methods. First, irrigation suitability index maps were generated for the 14 'exemplar' land uses by digitally combining the 14; largest index values show where irrigation potential is greatest and lowest values where there was no potential. Second, using the same overlay approach for maps of each irrigation type, maps were generated to show the suitability of land for each irrigation type. In practical terms, versatility maps are a tool to guide policy and developers to the more irrigation (and dryland) prospective lands. The most versatile catchment soils include the cracking clay soils (10% of catchment) and the red loamy soils (35%), with the former associated with alluvial plains and terraces proximal to rivers, and the latter associated with deeply weathered soils mainly on the Sturt Plateau. The least versatile soils of significant area include shallow and rocky soils (33%) associated mainly with upland and central catchment hills and ridges.

The work reported here should be considered within the context of the other activities of the Assessment including: climate; surface water hydrology; groundwater hydrology; agriculture and socio-economics; water storage; Indigenous water values, rights and development goals; and freshwater and marine ecology. These have been reported on individually, along with several catchment summary and individual case study reports.

The report presents key land and soil vulnerabilities to degradation through land development or ongoing agricultural practices. These vulnerabilities relate to the inherent attributes of the land and soil properties.

It is important to emphasise that what is reported is suitable for coarse-scale land appraisal and consistent with a reconnaissance-type of land assessment. As such, the reported outputs are wholly inconsistent with planning and development needs at finer scheme, enterprise or property-type scales. Satisfying those needs requires an appropriate intensity of new investigation for the areas of interest.

Key datasets from this land suitability activity are available to the public via CSIRO's Data Access Portal (https://data.csiro.au/).

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Part I Main report

1 Introduction

Knowledge of soils and the landscapes they occupy is critical for determining the opportunities for land intensification, especially irrigated agriculture. Much of the soil in northern Australia is ancient and highly weathered (Reimann et al., 2012). This means that these soils frequently have low fertility status, that is available phosphorus, total nitrogen, organic carbon, and exchangeable cations. Soils may also be saline (Webb et al., 1974) or have poor structure. The often meagre fertility status of these soils results in naturally sparse vegetation, leaving them prone to erosion (Brooks et al., 2009; Pillans, 1997). However, areas do exist where soils are richer in nutrients and are structured well enough to make them potentially suitable for irrigation; often these are younger soils formed from Quaternary alluvium. There are limited extensive tracts of these and other suitable soils in northern Australia but given the vastness of northern river catchments, areas of good soils may be large enough to make irrigated agriculture a viable proposition. In locating these potentially useful pockets of soil it is necessary to first, understand the location and characteristics of the soils, then second, to assess their suitability in the context of broader water, landscape, environmental and economic factors.

This report describes the approaches used in the land suitability activity of the Roper River Water Resource Assessment, which encompasses the catchment of the Roper River in the Northern Territory. The Assessment represents a next phase in a sequence of catchment assessments in northern Australia, which include: (i) Queensland's Flinders and Gilbert Agricultural Resource Assessment combining the river catchments of the Flinders and Gilbert and completed in 2014, and (ii) the Northern Australia Water Resource Assessment, combining Western Australia's Fitzroy River catchment, Northern Territory's (NT) Darwin river catchments, and Queensland's Mitchell River catchment, completed in 2018 (Figure 1-1). As such, this report can be seen as a companion to the Flinders and Gilbert Agricultural Resource Assessment and the Northern Australia Water Resource Assessment and builds on the legacy of those. In many respects this land suitability activity – as with the activities in the previous assessments – addresses shortcomings identified in the 2009 desktop land evaluation study for northern Australia (Wilson et al., 2009), which showed land intensification opportunities for agriculture to be severely restricted by a lack of appropriate soil and land attribute mapping at suitable mapping scales throughout tropical northern Australia.

The report details approaches applied to ultimately assess the suitability of 58 agricultural land intensification options in the Assessment area that combines groups of crops (21), growing season (wet season, dry season, perennial) and irrigation type (17 flood, 23 spray and 10 trickle) and 8 rainfed (dryland agriculture) farming options. The suitability of land for aquaculture for freshwater and marine species using impoundments or lined ponds is also assessed. Before the suitability for these land use options could be derived and mapped, various activities to map land and soil attributes were undertaken to be incorporated into a land suitability decision-support system to highlight areas of potential agricultural and aquaculture viability.

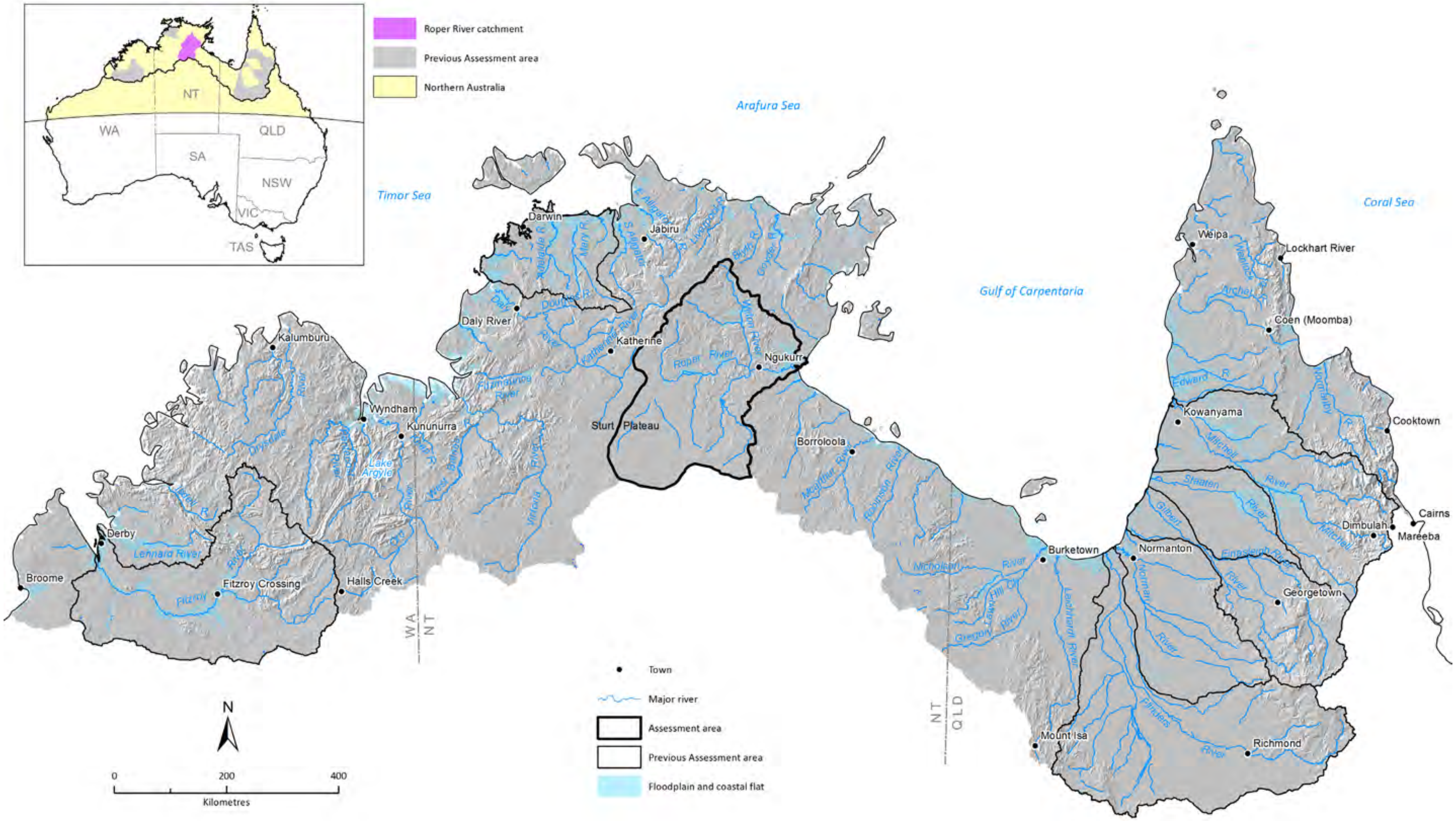


Figure 1-1 Location of Roper River Water Resource Assessment area in northern Australia, including settlements and the major rivers overlaid on hill shaded relief. Previous Assessment boundaries are also shown

1.1 Assessment area

The Roper catchment covers an area of 7,740,000 ha. It includes parts of four physiographic regions described in Plumb (1992) including, (i) the Calcareous Tableland (henceforth, Sturt Plateau) in the south-west, (ii) the Gulf Fall in the centre, (iii) Wilton River Plateau in the north, and (iv), the Coastal Plain, which are shown in Figure 1-2. The Sturt Plateau is a Tableland dominated by Cretaceous sediments and Tertiary lateritic surfaces with interspersed red earthy colluvium and localised clay alluvium (Abbott et al., 2001; Aldrick and Wilson, 1992; Burgess et al., 2015; Day et al., 1984). The dissected Gulf Fall physiographic region occupies most lands from the eastern edge of the Sturt Plateau to the estuarine coastal plain and comprises residual rises and hills, strike ridges, mesas and plateaux and intervening fluvial valleys (Abbott et al., 2001). This province is a complex landscape composed of sandstones, mudstones, siltstone and dolerite lithologies along with extensive areas of colluvium and alluvium (Andrews and Burgess, 2021a). The Wilton River Plateau, located in the northern part of the catchment, is composed of a level to gently undulating sandstone plateau, and the Coastal Plain extends east of the Gulf Fall as an extensive area of salt flats, tidal flats and mangroves.

The climate of the Roper catchment is semi-arid monsoonal with distinctive wet and dry seasons. The wet season (September to April) is characterised by higher temperatures and higher humidity and experiences most of the annual rainfall. The dry season (May to August), in comparison, is cooler, has lower humidity and little to no rainfall (Wilson et al., 1990). Long-term rainfall records in the central Roper valley (Flying Fox) and the Sturt Plateau (Larrimah) indicate mean annual rainfall at 770 to 780 mm per year (BoM, 2020a; 2020b).

Land tenure across the Roper catchment is generally either Pastoral Lease (37,749 km^2) or freehold Aboriginal Land Trusts (35,261 km^2). Other significant tenures include Crown Leases (3,999 km^2) and Vacant Crown Land (229 km^2).

The Roper catchment is sparsely populated but includes the communities of Mataranka, Larrimah, Daly Waters, Beswick, Barunga, Bamyili, and Ngukurr as well as several smaller Indigenous communities, outstations and roadhouses.

Land use mapping (Burgess et al., 2015; Staben and Edmeades, 2020) indicate the predominant land uses in the catchment are grazing native vegetation (35,329 km^2) and managed resource protection and other minimal uses (34,677 km^2). Other substantial land uses include marshes and wetlands (3,273 km^2), nature conservation (3,159 km^2), estuaries (547 km^2), transport and communications (228 km^2), and grazing of modified pastures (76 km^2). Irrigated plantation forests (8.5 km^2, sandalwood) and irrigated seasonal and perennial horticulture and cropping (11.9 km^2; watermelon, mango production in the Mataranka area) and mining (0.8 km^2) account for a small proportion of the total area.

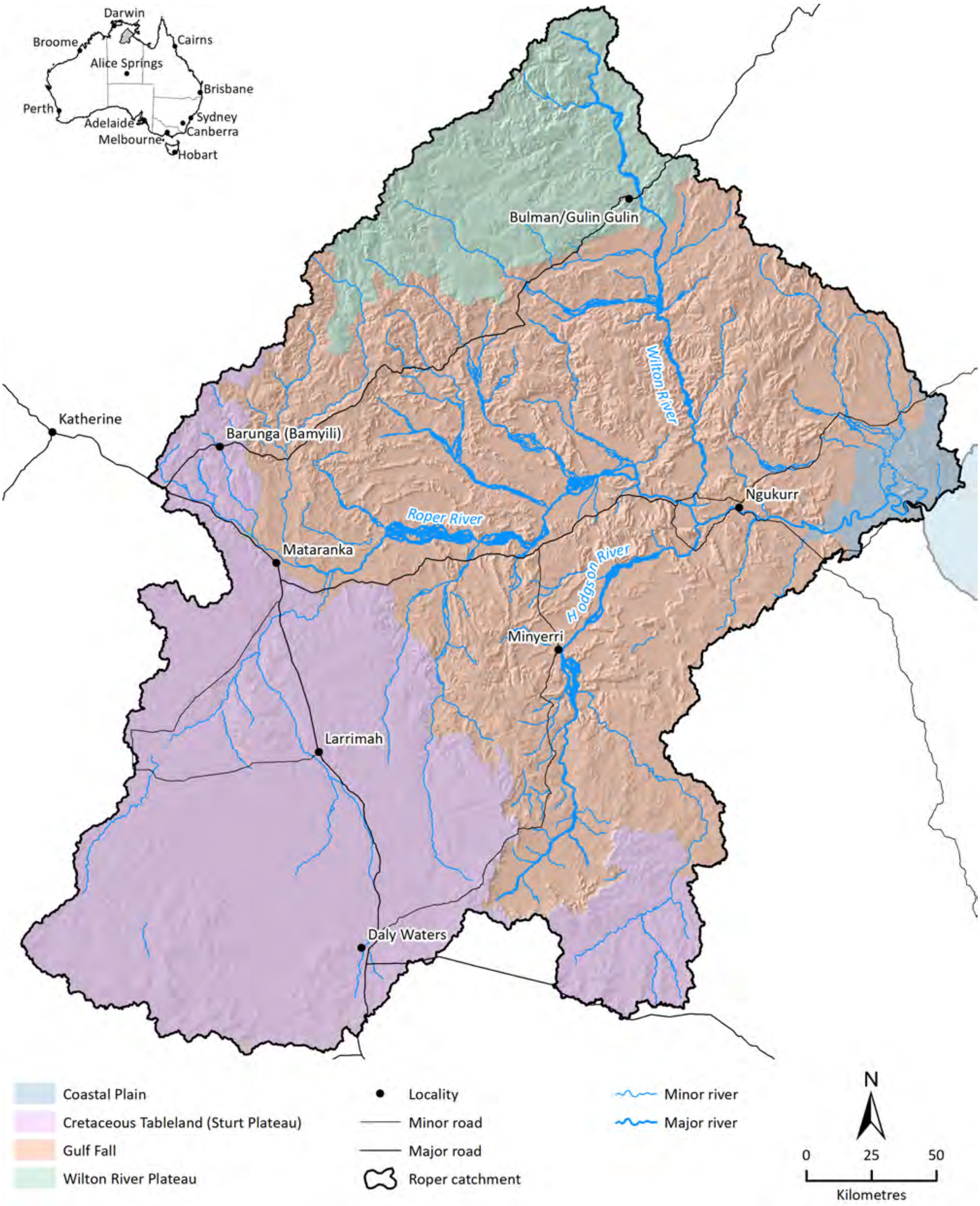


Figure 1-2 Roper River Water Resource Assessment area showing the Roper River and tributaries, physiographic provinces after Plumb (1992), significant settlements and roads overlaid on hill shaded terrain relief

1.2 Summary of previous soil investigations

A broad-scale assessment of the land resources for pastoral opportunities for the whole of the NT was published by Perry (1960). This included general observations on the soils and landscapes, including the Roper catchment. The first soils characterised in the catchment itself were described in the 1970s on the north-west periphery where the catchment straddles the Daly River watershed. These data were collected for two broad-scale land system surveys; Eva Valley (Robinson et al., 1973) and Dry River Station (Day and Forster, 1978), with higher resolution land unit mapping carried out in the vicinity of the Bamyili community (van Cuylenburg, 1975) and Mataranka North Station (Gibbs and van Cuylenburg, 1978).

In the mid-1970s interest in irrigated cropping across parts of the alluvial plains of Moroak Station led to a higher detail soil mapping investigation (Day and Wood, 1976). This survey documented the chemical and physical properties of the cracking clay alluvial soils (Vertosols, according to Australian Soil Classification; Isbell and The National Committee on Soil and Terrain, 2021) of the central Roper River valley. From 1976 to 1989 several surveys were undertaken covering parts of the catchment. These included land system mapping covering the Sturt Plateau (Day et al., 1984) and St Vidgeon Station (Fogarty, 1984) and land unit surveys on Sunday Creek (Day and Henderson, 1985), Wyworrie Station (Lynch and Manning, 1988) and Elsey National Park (Lucas and Manning, 1989).

In 1992 land system mapping (Aldrick and Wilson, 1992) documented the main landform, soil and vegetation communities across the entire catchment, and in 2012 several land system surveys across the northern part of the NT, including the Sturt Plateau (Day et al., 1984), Southern Gulf (Aldrick and Wilson, 1992) and Arnhem Land (Lynch and Wilson, 1992) were consolidated into one dataset. This standardised the broad-scale land resource information across the entire catchment and the northern part of the NT (Lynch et al., 2012).

From 2005 to 2010 field-based soil investigations focused on the collection of soil analytical data for pastoral research on the Sturt Plateau and irrigation efficiency projects on irrigated farms in the Mataranka area (Edmeades, 2011; Hignett, 2010). These investigations documented favourable soil chemical and physical attributes, as well as soil hydraulic properties.

In recent years under the NT Government's Land and Water Program (2014–2018), high-resolution soil and land suitability mapping has been published for the Larrimah area (Burgess et al., 2015; McGrath et al., 2019), part of the Beswick Aboriginal Land Trust (McGrath and Andrews, 2019) and Flying Fox Station (Andrews and Burgess, 2021a; 2021b). The locations of the two Larrimah surveys and the Beswick investigation targeted areas with prospective groundwater supplies, while the Flying Fox survey developed a representative understanding of soil landscapes across the central Roper River valley and the suitability of a range of soils for irrigation. These recent surveys characterised 593 soil sites, providing a comprehensive understanding of the soil resources and their suitability for irrigated agriculture across two key areas in the catchment. Over a 50-year period to 2020, 1524 soils have been characterised in the catchment as a legacy dataset.

1.3 Scientific approach

The scientific approach employed in the report builds on the research legacies of the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013; Harms et al., 2015; Thomas et al., 2015) and Northern Australia Water Resource Assessment (Bui et al., 2020; Thomas et al., 2018a; Thomas et al., 2018b). Both assessments demonstrated the value of modern digital approaches in land suitability analysis, and the benefits accrued through increased operational efficiencies, speed of analyses, utility of digital outputs, and an objective understanding of the quality of outputs. Figure 1-3 shows the broad workflow followed by this activity that closely echoes the methods used in the Flinders and Gilbert Agricultural Resource Assessment and the Northern Australia Water Resource Assessment. The workflow highlights the tasks of soil sampling design, digital soil mapping (DSM) and land suitability analysis, while also showing the dependencies feeding into these, including soil mapping covariates, soil attribute data, map quality assessment, and the land suitability framework that drives the land suitability analysis. As with the Northern Australia Water Resource Assessment, this workflow includes quantitatively mapped estimations of uncertainty.

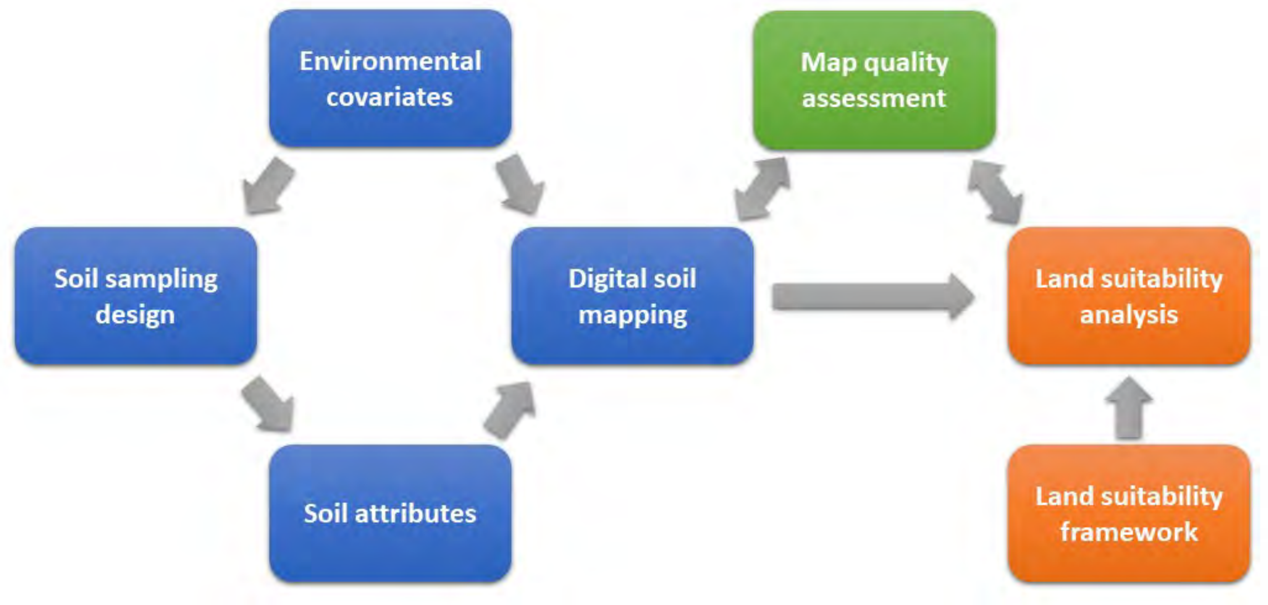


Figure 1-3 Land suitability assessment workflow and key inputs and processes

The following sections summarise the components of the scientific approach captured by the workflow. The section ends with a discussion on acid sulfate soils (ASS), which are limited to the coastal plain of the Assessment area. Although these potential ASS areas are excluded from any possible agricultural development due to acid release and environmental degradation, tidal inundation and saltwater incursion, these areas may still offer prospects for aquaculture, which is also a potential land use. More in-depth discussion on methods is presented in the Methods section (Section 2).

1.3.1 Sampling design

A stratified random sampling approach (McKenzie et al., 2008) removes human bias in the selection of soil sampling sites, and maximises the spread of sites so that the full range of soil variability, as represented by the covariate space, in the study area is sampled. These characteristics of soil sampling design are generally a pre-requisite of reliable DSM (discussed below). The Roper catchment sampling design relied on a form of stratified sampling, conditioned Latin Hypercube Sampling (cLHS), which is described in Minasny and McBratney (2006). cLHS ensures sampling points capture the empirical distribution of the environmental covariates[1] expertly chosen to represent the full variability of soils across the whole study area. In other words, given a gridded study area of N total sites with ancillary variables (X), select X a sub-sample of size n ($n \ll N$) in order that X forms a Latin hypercube, or the multivariate distribution of X is maximally stratified. The number of sampling points, n, is determined *a priori* as a function of operational considerations (i.e. project resourcing and budget).

1.3.2 Digital soil mapping

Digital soil mapping (DSM) has a track record successfully delivering land and soil information to large-area assessments in Australia (Bui et al., 2007; Kidd et al., 2015; Kidd et al., 2014; Thomas et al., 2015; Viscarra-Rossel et al., 2015) and globally (e.g. Behrens and Scholten, 2007; Hartemink et al., 2010; Hartemink et al., 2013), and as such was adopted to map the variability of soils and their attributes in the catchment.

DSM has co-evolved with gains in computing power, adaptation of statistical methods, and increased access to soil mapping covariates (Section 2.4.2) – particularly for the whole of Australia as highlighted by Bui (2007) with routine access to reliable gridded climate, remote sensing, terrain derived from digital elevation models (DEMs), and gamma radiometrics (mineralogy, landscape evolution) layers.

DSM outputs include data and maps of soil attributes and soil types created in geographic information system (GIS) grid data format that follow natural patterns of soil changes across landscapes. These qualities make DSM outputs suitable for direct incorporation with land suitability analysis frameworks, as discussed next. DSM also allows production of companion reliability maps that show where the soil attribute data and maps are more or less reliable for users to make objective decisions on fitness-for-purpose.

Comprehensive texts on DSM are presented elsewhere for readers to follow (e.g. Grunwald, 2006; Hengl and Reuter, 2009; Malone et al., 2017; McBratney et al., 2003).

1.3.3 Land suitability analysis and framework

Land suitability analysis (land suitability) is the process of determining the potential of land for specific land uses on the basis of the local range of environmental attributes and qualities (Rossiter, 1996), collectively termed ‘land use requirements’, for successful implementation that may be restricted by associated ‘limitations’.

[1] Environmental covariates – or simply *covariates* – are spatial geographic information system (GIS) format datasets that bear functional relationship to on-ground soil attributes, and so can contribute to prediction of soil attributes. For example, slope may support prediction of soil depth, relief patterns for soil water accumulation, or remote sensing for soil colour.

This Assessment defines limitations and builds the analytical framework following the FAO Framework for Land Evaluation (FAO, 1976; 1985). This involves a comprehensive assessment of land suitability that integrates multiple limitations including biophysical (edaphic and climate), social and economic themes (FAO, 2007). The land suitability analysis applied in this Assessment deviates from FAO's integrated framework in that it constrains analysis only to biophysical themes since other aspects are covered in companion Assessment activities (e.g. agriculture and socio-economics). The land suitability approach applied in the Assessment follows a linage of approach first developed in the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013; Harms et al., 2015) and then the Northern Australia Water Resource Assessment (Thomas et al., 2018b).

The edaphic components of the land suitability mostly relate to soil attributes that have a key bearing on the growth and productivity of the irrigated crops, or the amount of land preparation and maintenance of farming infrastructure needed that may affect the financial viability of the irrigation enterprise. For example, soil permeability affects the rate of water application, and rockiness relates to the intensity of rock picking required in land preparation.

1.3.4 Soil landscapes and Soil Generic Groups

Adding to the knowledge base and conceptual understanding of the soil landscapes of the Assessment area allows activity methodologies to be augmented and refined, new investigations to be directed, assumptions to be tested, and ultimately the quality of mapping improved. This was achieved mainly through field-based activities drawing on conventional soil landscape wisdom and paradigms (Hudson, 1992) by applying geomorphic principles to assess the distribution of soils within the landscape. From these, descriptions could be generated of major geomorphic units within the various geological settings. The process provided an estimate of the age of deposits (e.g. Quaternary, Tertiary, Mesozoic, etc.) and degree of weathering – knowledge that is important for identifying deposits likely to be suitable for agriculture (e.g. Quaternary alluvium), or understanding soil–landscape processes such as erosion and deposition, leaching, flooding, waterlogging, and salinity).

As with traditional soil survey, the knowledge gained was formalised into soil-type descriptions encapsulating the key concepts of soil attributes and distributions. The soil-type units arrived at – Soil Generic Groups (SGGs) – were designed to simultaneously cover a number of purposes: to be descriptive so as to assist non-expert communication regarding soil and land resources, to be relatable to agricultural potential, and to align, where practical, to the Australian Soil Classification (ASC, Isbell and The National Committee on Soil and Terrain, 2021). Assessment area SGG mapping from DSM was also used as input into the land suitability framework.

1.3.5 Acid sulfate soils

Acid sulfate soil (ASS) is a broad term given to a range of soils containing sulfurous materials. These soils are either strongly acidic (actual ASS; pH < 4) or have the potential to become strongly acidic (potential ASS; pH > 4) if exposed to atmospheric oxygen, for example when they are unearthed or drained (Fanning and Fanning, 1989; Sullivan et al., 2010). If disturbed or improperly managed and acidification occurs (potential ASS → actual ASS), water can leach the sulfuric acid and dissolved heavy metal contaminants from the ASS posing serious risks to water quality and the health of sensitive aquatic environments (Fältmarsch, 2006; Ljung et al., 2009). The ASS soils in the Assessment area are restricted to the coastal fringes where aquaculture is likely to be the only possible option for land use intensification. As such, land development will attract jurisdictional assessment and legislative guidelines from the NT Government. A simple methodology, consistent with the NT's regulatory guidelines (Dear et al., 2014), was developed to map potential ASS in the Assessment area to guide land use decisions.

1.4 Objectives of the report

The objective of this report is to describe development of digital soil and land products to:

- answer questions regarding the scale of opportunity for agriculture (including tree crops) and aquaculture
- supply land and soil datasets to support other Assessment activities addressing other catchment resource questions, including agronomic and surface hydrology.

To do this, three major tasks were completed. First, new soils data were collected using a statistically robust field sampling strategy. Second, digital soil attribute and Soil Generic Group maps for the Roper catchment were generated using DSM, and the reliability of these maps evaluated statistically. Third, these maps were applied in a customised land suitability framework to identify areas suitable for agricultural intensification (i.e. irrigated agriculture and horticulture) and for aquaculture.

While difficult to directly equate DSM maps to conventional mapping scale, the field sampling intensity provides underpinning evidence that the mapping equates the mapped products to approximately 1:250,000 mapping scale (Gallant et al., 2008) (i.e. consistent to low intensity / reconnaissance types of land evaluation and planning uses). As such, the level of information the data and maps are capable of is only delineating broad areas or tracts of land suitable for intensification, and so not suited to on-ground property scale planning. This means that detailed on-ground soil and land investigations will be necessary to plan specific developments in areas targeted as suitable from these land suitability outputs.

2 Methods

This chapter describes methods used in the land suitability activity and summarised in Figure 1-3. These include field and laboratory methods involved in collecting, collating and analysing soil and land data, and includes legacy data from earlier projects as well as new data collected specifically for the Assessment. The DSM approaches are described including the integration of field and laboratory data into modelling, rationale for selection of covariates, and the attribute modelling algorithm applied. Validation and uncertainty mapping methods are also discussed. Finally, the land suitability analytical framework is presented, the integration of DSM and other limitations in the analytical framework, and methods used to test the quality of land suitability mapping.

2.1 Legacy soil data

A significant amount of soil data are available from numerous previous studies in the Assessment and neighbouring areas. Despite the age and positional accuracy of some of the records, and the various analytical techniques used, much of these legacy data remain usable and valuable for this work. Following a comprehensive review of the data by the then NT Department of Environment and Natural Resources, records were drawn from the NT's corporate Soil and Land Information System (SALInfo, Department of Environment Parks and Water Security, 2000) and the CSIRO managed National Soil Database (NATSoil; Karssies et al., 2011). Data were considered from an area beyond the Roper catchment, that is an area bound by the following extents: south of –12.90° and north of –16.78° latitude, east of 132.00° and west of 135.70° longitude and shown in Figure 2-1. Areas neighbouring the catchment were considered because many of the soils – particularly from the Sturt Plateau – are similar to those inside the catchment; use of the legacy data can boost the DSM predictive capacity.

After extraction from various sources, candidate soil site data were collated in a relational ACCESS database using standard protocols described in Jacquier et al. (2012). In summary the following selection criteria were applied, and records rejected that did not fit these:

- if multiple records existed for one site (e.g. for monitoring), or multiple record identifiers wrongly existed for the same record, the most recent record was accepted
- geographic coordinates had to be to a minimum of four decimal places (decimal degrees) or to tens of metres if the original coordinates were captured as projected coordinates
- where locational accuracy was recorded those of greater than 100 m were rejected
- records included at least some soil profile information (i.e. more than a surface observation)
- additional filtering and cross-checking of the legacy data took place in order to fit specific DSM attribute mapping needs, for example drainage values were checked to ASC to ensure Hydrosols were not well drained.

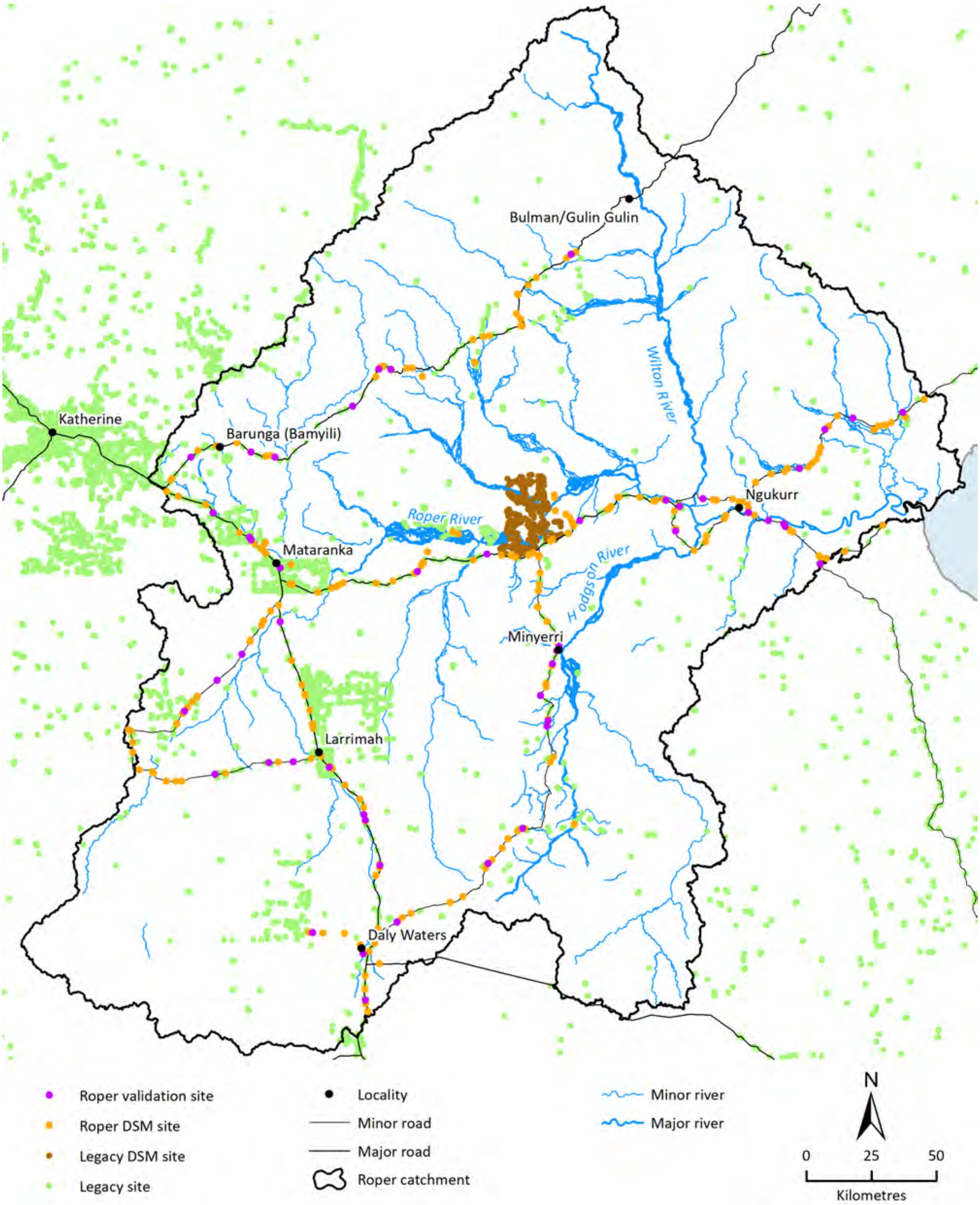


Figure 2-1 Location of legacy and new land and soil sampling sites in and neighbouring the Roper catchment

2.2 New soil data and field methods

This section describes the sampling design for the DSM, the field practices used, and the expert rationale used to define Soil Generic Groups (SGGs). Field methods follow Australian standards for survey guidelines (McKenzie et al., 2008), soil and site description (National Committee on Soil and

Terrain, 2009) and soil classification using ASC (Isbell and The National Committee on Soil and Terrain, 2021).

Fieldwork was dictated by site access so was conducted outside the cyclone season and before soils had set too hard to effectively sample. Field teams were comprised of CSIRO and NT Government staff, and two or more remote field-ready vehicles were used in the work. The timing and scope of soil sample collection was at times impacted by COVID travel restrictions although contingency arrangements successfully minimised impact to the project.

Soil chemical and physical attributes were analysed using conventional laboratory methods (McKenzie et al., 2002; Rayment and Lyons, 2011; Thorburn and Shaw, 1987). All data are stored digitally in the NT Government corporate SALInfo database.

2.2.1 Design of new soil survey

A stratified random sampling design based on conditioned Latin hypercube sampling (cLHS) (Minasny and McBratney, 2006) was used to identify new sampling sites required for the DSM that firstly covered the covariate space, and secondly, infilled geographic gaps in the soil legacy data (Section 2.1). The design produced an unbiased selection of sampling sites covering the full range of soil variables represented by the covariates. The design was implemented in the R computing environment (R Core Team, 2018) using the *clhs* package (Roudier et al., 2012). The soil–landscape variability was captured by selecting covariates to represent the factors of soil formation (Fitzpatrick, 1980; Jenny, 1941) and with low inter-covariate correlation to preserve computational efficiency in the analysis. The seven covariates (Table 2-4) selected in the cLHS sampling design included:

- Prescott Index (soil leaching and formation index)
- DEM (landscape position)
- slope % (mass wasting)
- Dynamic Land Cover classes (DLCD; seasonal vegetation dynamics)
- gamma radiometrics: K-, Th-, U-, and total dose (soil history, age).

The cLHS sampling was constrained using the *cost* condition by forcing sampling sites to within a 300 m buffer each side of mapped roads or tracks. This allowed reduction in field time penalties and made vehicular access more practical. The cLHS sampling design also accounted for legacy sampling sites within the sampled area using the *include* condition of the analytical package.

One hundred and fifty primary and 50 secondary new sampling sites were generated. To check that these sites adequately captured the landscape variability of the catchment, a clustering algorithm implemented in the R statistical software using the *clara* function (Kassambara, 2017) was applied to map areas of soil–landscape similarity. This clustering approach served as an additional qualitative check that the range of soil variability had been representatively captured in the cLHS survey design for the catchment; to be considered an overall success each cluster needed to contain at least one sampling point, while physically larger clusters could contain multiple sampling points. Proportionality was not strictly applied.

A further practical contingency was built into the sampling design to cater for access barriers to sampling sites (e.g. fence lines, locked gates, flood ways, etc.). This involved identifying contingency sites within a radius of 250 m of the primary cLHS sites with similar covariate characteristics to the primary site. This followed the similarity index methodology presented in Brungard and Johanson (2015). For contingency sites to be acceptable, a similarity index of 0.8 was required in reference to the primary sites.

Fieldwork was conducted from August to September 2019, and September 2020. Twenty out of the primary 150 DSM sites were selected for subsequent laboratory analysis. These samples were selected from the 150-sample population to capture the full covariate space range of soils already sampled. Again, selection of the 20 samples was achieved using the R program *clhs* package (Roudier et al., 2012) and involved using the 150-sample as covariates to constrain selections to the original population.

Twenty additional sites were sampled based on free survey (McKenzie and Grundy, 2008) where, from expert opinion, they appeared to hold significant agricultural potential for reference and communication purposes. A further 44 sites added to the collection were selected from the secondary DSM sites prepared by the stratified random sampling design.

2.2.2 New soil sampling

All sampling site locations were recorded using a GPS in WGS84. Samples were taken using a 50 mm diameter vehicle-mounted push corer (Figure 2-2) to a maximum depth of 1.5 m, or to refusal if bedrock or impenetrable layers (e.g. indurated) were encountered. Cores were extruded and described using standard Australian soil survey notation (National Committee on Soil and Terrain, 2009) to 1.5 m and cores divided into samples according to depth intervals: 0–0.1, 0.2– 0.3, 0.5–0.6, 0.8–0.9, 1.1–1.2, and 1.4–1.5 m.

Figure 2-2 Collecting soil cores. A trailer-mounted push core rig was used to collect samples to a maximum depth of 1.5 m

Each depth increment was analysed in the field for:

- pH 1:5 (Raupach, 1957)
- electrical conductivity (EC) 1:5 soil/water
- sodic dispersion, using a modified 'Emerson test' (McKenzie et al., 2002).

Approximately 1 kg from each depth increment was bagged for laboratory analysis (Section 2.3 below). Site and soil descriptions were recorded, transcribed, and uploaded to the NT Government SALInfo database. The field observations taken are listed in Table 2-1.

Table 2-1 Field-based soil attributes and methods of analysis. NCST method equates to National Committee on Soil and Terrain (2009) description systems

QUANTITATIVE SOIL FEATURE	ATTRIBUTE	METHOD	PURPOSE
Location	Unique id, projection, datum, x, y	GPS	Location information for mapping, modelling and data management
Classification	Soil class	ASC in field or office	Defined soil class from the Australian Soil Classification, facilitates communication and correlation
Landscape	Landform element	NCST in field	Describes the landform immediately surrounding the site
Landscape	Landform pattern	NCST in field	Describes the broader landform around the site
Landscape	Slope	Measured in field (clinometer)	Influences runoff, erosion, crop types and management factors
Soil surface attribute	Rock outcrop	NCST in field	Influences crop types and management operations
Soil surface attribute	Surface coarse fragments	NCST in field	Influences crop types and management operations
Soil surface attribute	Surface condition	NCST in field	Influences crop establishment, seedling development and water infiltration
Soil surface attribute	Surface structure	NCST in field	Affects infiltration, erosion and workability
Soil surface attribute	Microrelief	NCST in field	Impact on machinery operation, drainage and irrigation efficiency
Soil water regime	Drainage	NCST in field	Summarises wetness conditions likely to occur at the site
Soil water regime	Permeability	NCST in field	Describes capacity of soil profile to transmit water internally and influences soil wetness and plant root aeration
Soil water regime	Soil mottles	NCST in field	Indication of hydrological attributes of the soil profile
Soil physical depth for plant growth	Rooting depth	Measured in field and laboratory	Indication of chemical or physical barrier to root growth
Soil physical depth for plant growth	Soil depth restriction (before 1.5 m)	Measured in field as depth to impermeable layers or bedrock	Defining characteristic of the soil, driver for a range of other attributes including rooting depth and available water capacity (AWC)

QUANTITATIVE SOIL FEATURE	ATTRIBUTE	METHOD	PURPOSE
Soil profile attributes	Field texture	NCST in field	Influences soil physical attributes and water storage capacity
Soil profile attributes	Structure	NCST in field	Affects infiltration, erosion and workability
Soil profile attributes	Soil colour	NCST in field	Indication of nutrient levels and soil water regime
Soil profile attributes	Segregations	NCST in field	Hard segregations impact on machinery use, other segregations may indicate soil hydrological conditions and depth of water percolation in the soil
Soil chemistry	pH	Measured in field and lab	Affects balance of nutrients in soil, including potential deficiencies and toxicities
Soil chemistry	Electrical conductivity	Measured in field and lab	Indicator of salinity; may restrict root growth
Soil chemistry	Dispersion class	Measured in field	Indicator of potential erosion and permeability
Sample analysis	Bulk density and porosity	Measured in field and lab, and estimated by pedotransfer function†	Affects rooting depth, permeability and drainage and soil workability
Sample analysis	Available water capacity (AWC)	Estimated by pedotransfer function from a range of data	Capacity of soil to store moisture for plant use

†Pedotransfer functions predict soil properties from easily, routinely or cheaply measured data

2.2.3 Validation survey

A two-week field trip was undertaken in May 2021 to collect external validation sites. While the DSM model performance was principally tested through internal validation (Section 2.4.3 below), field validation was undertaken providing the opportunity to expertly test mapping and influence re-modelling parameterisation, if implemented. A cLHS sampling design (Minasny and McBratney, 2006) was employed to select 50[2] validation sites within a 100 m buffer of mapped roads and tracks. Mapped reliability estimates from six DSM soil attribute maps (Section 2.4.4) were used as cLHS covariates to assure against sampling bias towards high-reliability or low-reliability mapped areas. These maps were expertly selected to represent land and soil themes important in land suitability modelling (Section 2.5 below), including drainage, permeability, rockiness, surface pH, surface texture and maximum clay content to 1.5 m depth. Sites with comparative similarity indices (Section 2.2.1) to the primary cLHS validation sites, no further than 250 m away and within the 100 m road buffer, were identified as contingencies for when the primary validation sites could not be practically reached.

[2] Time during the validation survey permitted two more sites to be surveyed. These sites were selected using free survey in agriculturally prospective sites.

Field validation was performed on DSM attributes that could be readily analysed in the field (e.g. pH), or site and soil attributes that could be expertly assessed *in-situ*. These included the following 15 DSM attributes:

- Depth of A horizon
- Microrelief
- AWC 60 cm
- AWC 100 cm
- AWC 150 cm
- Rockiness
- Soil drainage
- Soil Generic Group (SGG)
- Soil permeability
- Soil thickness
- Soil surface condition
- Soil surface pH
- Soil surface structure
- Soil surface texture
- Surface salinity.

AWC maps were tested in the field using the hand texture / AWC look-up Table 2.6 (page 10) in Hazelton and Murphy (2016).

In addition to the DSM soil attribute maps, all draft land suitability maps (Section 3.4) were tested in the field for accuracy assessment. At each validation site, results were scored as either 'correct', 'accept', or 'fail'. The following rationale was used to determine acceptability according to the DSM attribute type:

- continuous attributes – the value was accepted if it fell within the attribute limitation range as long as it was within the suitability class, as the mapped value would have no impact on the land suitability class allocation
- categorical attributes – the value was accepted if it fell in the next attribute class and would have not impacted the suitability (accommodates the variability in the soil), for example drainage Class 3 modelled and Class 4 actual was acceptable but not Class 3 modelled and Class 2 actual as this classification is a suitability cut off.

Time in the field during the validation survey also presented the opportunity to add to the soil sampling from validation locations to boost final DSM modelling with 52 new datasets. This followed the sampling and description protocols described in Section 2.2.2 above.

2.3 Laboratory methods

Soil physical and chemical analytical techniques were used on the newly collected soil samples described in Section 2.2. The analyses are shown in Table 2-2.

Table 2-2 Soil analyses

MEASUREMENT	ELEMENTS AND METHODS	REFERENCE
Particle size (% sand, silt, clay)	Sieve and hydrometer method	Thorburn and Shaw, 1987
Moisture	15-bar moisture, 1/3 bar moisture	Rayment and Lyons, 2011
pH, electrical conductivity (EC), chloride, nitrate	1:5 soil/water	Rayment and Lyons, 2011
Exchangeable cations	Cation exchange capacity (CEC); exchangeable calcium; magnesium; sodium; potassium; exchangeable sodium percent (ESP)	Rayment and Lyons, 2011
Exchange acidity	Exchangeable aluminium, H+	Rayment and Lyons, 2011
Bulk density	Ring method using oven dry weights	Modified from Creswell and Hamilton, 2002
Total elements (total carbon and nitrogen)	Dry furnace	Rayment and Lyons, 2011
Extractable trace elements	Iron; manganese; copper; zinc	Rayment and Lyons, 2011
Surface soil fertility	Organic carbon (Walkley and Black); total nitrogen (Kjeldahl); extractable P (Colwell); extractable potassium; extractable sulfur	Rayment and Lyons, 2011
Dispersion	R1, Dispersion ratio R1 is the ratio of aqueous dispersible silt and clay to total dispersible silt and clay R2, Dispersion ratio R2 is the ratio of aqueous dispersible clay to total dispersible clay. As R1 and R2 are ratios, their values can be unreliable when clay or silt + clay percentages are small (i.e. in sandy soils)	Angus McElnea, Queensland Department of Science, Information Technology and Innovation, pers. comm.

2.4 Digital soil mapping

Many of the modelling approaches applied in modern DSM utilise predictive models that establish relationships between point-based soil observations (i.e. geolocated soil and land attributes) and a set of covariates (McKenzie and Ryan, 1999). These rely on the *scorpan* approach incorporating covariates for soils (*s*), climate (*c*), organisms (*o*), relief (*r*), parent material (*p*), age (*a*), and neighbourhood (*n*) (McBratney et al., 2003). Some of the best performing models use data mining and machine learning to capture spatial distribution of soil properties without prior assumptions about the form of the complex relations between soils and covariates. Here, covariates with a grid resolution of 30 × 30 m were used for the DSM modelling to produce soil attribute data and maps. This resolution is inherited from national datasets (see Table 2-4) and considered suitable being consistent with the Assessment's regional scope.

DSM models can be expressed as statistically based rules representing the relationship between (i) soil observations at the sampling sites and their (ii) geographic intersections of the covariates. Multiple, co-registered covariates are used in environmental correlation – effectively in a stack of gridded covariates (predictors), as represented in Figure 2-3. Applying the model (and its rules) pixel by pixel across the whole mapping extent predicts the target soil attribute at unsampled locations. This process of rule-to-covariate matching progresses through the whole area of interest (i.e. the area covered by the grid stack) to compile the complete final soil attribute data. In essence the environmental correlation approach is a digital analogue of the traditional soil mapping method, which relies on experts to build models (rules) from patterns of relief, drainage or vegetation (i.e. soil covariates) (Hudson, 1992; McKenzie et al., 2008). In the DSM analogue, the 'expert' equates to the statistical model that does the prediction.

A major benefit of DSM compared to traditional soil mapping is that it is possible to statistically quantify and map the reliability – sometimes termed uncertainty – associated with the soil attribute prediction at each pixel. DSM also allows mapping approaches to be consistent so that there is no methodological or operator bias, and users of the mapped outputs can be confident that all areas in the output are systematically comparable. Furthermore, this makes updating maps a straightforward process once new soil observations or better covariates become available.

In addition to mapping soil attributes, DSM was used to map SGGs for the Assessment area directly from SGG site records. These maps predict soil classes, based on soil morphologies and soil–landscape relationships, and used to assist non-expert communication of the soils in the area. The SGG class for sodic clay subsoils is also used as direct input into the land suitability framework. The SGG types, like all soil types, are designed as concepts to capture a suite of soil properties, hence vary from the soil attribute data that much of the DSM generates for the land suitability assessment.

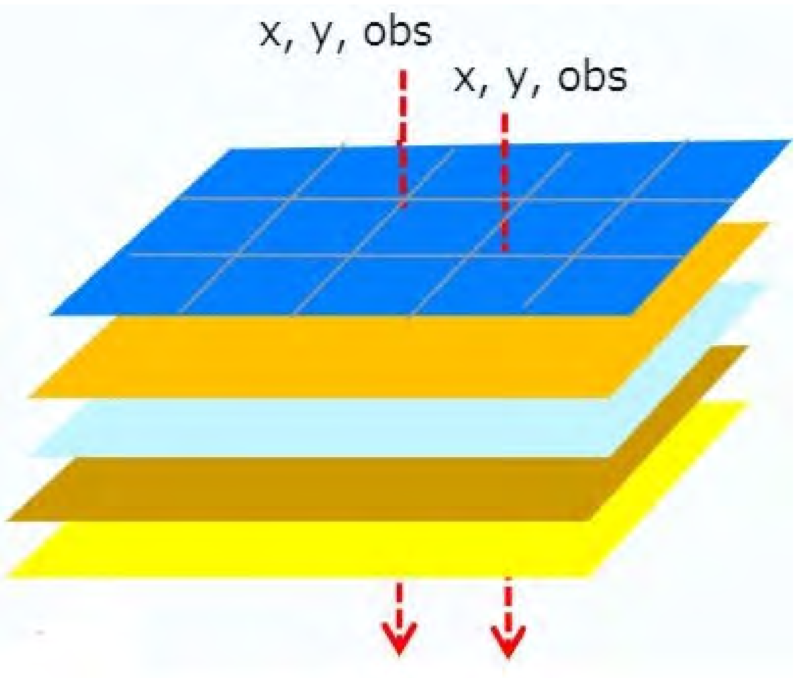


Figure 2-3 DSM models built from the spatial intersection of observations and covariates

2.4.1 Identifying DSM soil attributes

The selection of DSM soil attributes to model and map is principally governed by the needs of the land suitability analysis and the SGG mapping and are listed in Table 2-3. These selections in turn inform the expert knowledge-based selection of covariates used in the DSM process (next section

2.4.2). The needs of the land suitability analysis are informed by the candidate crops and their growth thresholds (i.e. limitations). The land suitability method and land suitability limitations are presented in full detail in Section 2.5. Table 2-7 identifies the limitations served directly by DSM outputs (see column 'Source'), and hence the environmental covariates used – which is discussed more fully next.

Table 2-3 DSM attributes and type

ATTRIBUTE	TYPE
Permeability	Categorical
Drainage	Categorical
Surface condition	Categorical
Surface texture	Categorical
Surface structure	Categorical
Soil Generic Group (SGG)	Categorical
Microrelief	Binary
Rockiness	Binary
Surface salinity	Binary
Depth of A horizon	Continuous
Clay %	Continuous
Surface exchangeable potassium percent (ESP)	Continuous
Soil erodibility (K-factor)	Continuous
Soil thickness (effective rooting depth)	Continuous
Surface pH	Continuous
Available Water Capacity (AWC 60)	Continuous
Available Water Capacity (AWC 100)	Continuous
Available Water Capacity (AWC 150)	Continuous

2.4.2 Environmental covariates used

As outlined in Section 2.4, the covariates were selected as proxies for factors of soil formation (Jenny, 1941). The 40 covariates are presented in Table 2-4 in '*scorpan'* order, a formalisation by McBratney et al. (2003) that puts Jenny's factors of soil formation into a modern and DSM-centric framework. They include covariates used in the Northern Australia Water Resource Assessment (Thomas et al., 2018a), as well as four new climate, one new relief and six new parent material datasets. The six new parent material covariates are 30-year time series of Landsat Thematic Mapper imagery (blue, green, red, near infrared, SWIR1 and SWIR2 wavelength bands) representing the Australian continent with its barest vegetation cover, which were sourced from Roberts et al. (2019). All the covariates used are in the form of digital GIS raster files in GeoTIFF format. They were co-registered to a common datum (WGS84) and re-sampled according to a ground resolution of 1 arc-second (approximately 30 m × 30 m grid resolution). Covariates were used in two tasks covered in this report and shown in Table 2-4: (i) six covariates were used to select new sampling sites, and (ii) 40 covariates were used to predictively model new soil attributes.

Table 2-4 List of covariates used in new soil sampling design for new site selection and in DSM (soil attributes and Soil Generic Groups). ● symbol indicates stage usage

'scorpan' SOIL FORMATION FACTOR	COVARIATE	DESCRIPTION	CUSTODIAN/SOURCES	NEW SOIL SAMPLING DESIGN	DSM SOIL ATTRIBUTE MAPPING
Soil	Kaolinite (%); Illite (%); Smectite (%)	Clay mineral surfaces, 0–0.2 and 0.6–0.8 m depth intervals	CSIRO: Grundy et al. (2015) and Viscarra Rossel (2011)		●
Climate	Prescott Index	Index of soil leaching and effect on soil formation	CSIRO: Gallant and Austin (2015)	●	
	Mean annual aridity index	The monthly ratio of precipitation to potential evaporation (pan, free-water surface)	CSIRO: (Harwood, 2019)		●
	Temperature, annual	Annual mean daily minimum temperature	CSIRO: (Harwood, 2019)		●
	Temperature, winter	Mean minimum daily winter temperature	Bureau of Meteorology: http://www.bom.gov.au/jsp/ncc/climate_averages/temperature/index.jsp		●
	Rainfall, summer	Mean rainfall – summer	Bureau of Meteorology: http://www.bom.gov.au/jsp/ncc/climate_averages/rainfall/index.jsp		●
	Rainfall, annual	Mean rainfall – annual	CSIRO: (Harwood, 2019)		●
	Thunder days	Mean annual thunderstorm days	Bureau of Meteorology: http://www.bom.gov.au/jsp/ncc/climate_averages/thunder-lightning/index.jsp		●
	Rainfall variability	Rainfall variability – annual	Bureau of Meteorology: http://www.bom.gov.au/jsp/ncc/climate_averages/rainfall-variability/index.jsp		●
	Rainfall seasonality	Maximum of differences between successive months	CSIRO: (Harwood, 2019)		●
Organisms	National Dynamic Land Cover dataset	Vegetation community types based on seasonal dynamics in Moderate Resolution Imaging Spectroradiometer (MODIS) data, responding to climate and soil type	Geoscience Australia: Lymburner et al. (2011)	●	
	Mean FPAR	Fraction of Photosynthetically Active Radiation (FPAR) – Mean AVHRR time series	CSIRO: https://remote-sensing.nci.org.au/u39/public/data/avhrr/fpar-clw/v4/Aust_Persistent_fPAR_1km_v4.zip		●

'scorpan' SOIL FORMATION FACTOR	COVARIATE	DESCRIPTION	CUSTODIAN/SOURCES	NEW SOIL SAMPLING DESIGN	DSM SOIL ATTRIBUTE MAPPING
	Mean bare ground fractional cover	Fractional cover Bare Soil-Mean MODIS time series	CSIRO: https://remote-sensing.nci.org.au/u39/public/data/modis/fractionalcover-metrics- abares/v2.2/Userguide_MODIS_FC_V2.2_Metrics.pdf		●
	Mean photosynthetic fractional cover	Fractional cover Photosynthetic vegetation-Mean MODIS time series	CSIRO: https://remote-sensing.nci.org.au/u39/public/data/modis/fractionalcover-metrics-abares/v2.2/Userguide_MODIS_FC_V2.2_Metrics.pdf		●
	Green vegetation persistence	Landsat Thematic Mapper 2000–2010 Persistent Green-Vegetation Fraction	Terrestrial Ecosystems Research Network: http://data.auscover.org.au/xwiki/bin/view/Product+pages/Persistent+Green-Vegetation+Fraction Gill et al. (2017)		●
Relief	Elevation	1 arc sec (~30 m) DEM	CSIRO: Gallant and Austin (2015)	●	●
	Slope (%)	Slope gradient	CSIRO: Gallant and Austin (2015)	●	●
	Slope %, focal median 300 m	Median of slope % in 300 m window	CSIRO: Gallant and Austin (2015)		●
	Relief aspect	Landform solar exposure	CSIRO: Gallant and Austin (2015)		●
	Focal range 1,000 m	Elevation range in 1,000 m window; longer range landform patterns	CSIRO: Gallant and Austin (2015)		●
	Focal range 300 m	Elevation range in 300 m window; longer range landform patterns	CSIRO: Gallant and Austin (2015)		●
	MrVBF	Landscape erosional and depositional zones	CSIRO: Gallant and Austin (2015)		●
	MrRTF	MrRTF is a topographic index designed to identify high flat areas at a range of scales	CSIRO: Gallant and Austin (2015)		●
	Plan curvature	Landform curvature along the contour	CSIRO: Gallant and Austin (2015)		●
	Profile curvature	Landform curvature directly down slope	CSIRO: Gallant and Austin (2015)		●
	Topographic wetness index	Landscape zones of water accumulation	CSIRO: (Gallant and Austin, 2012)		●
Parent material	Potassium (K); Thorium (Th); Uranium (U)	Gamma radiometrics	Geoscience Australia, Minty et al. (2009)	●	●

'scorpan' SOIL FORMATION FACTOR	COVARIATE	DESCRIPTION	CUSTODIAN/SOURCES	NEW SOIL SAMPLING DESIGN	DSM SOIL ATTRIBUTE MAPPING
	Gravity	Geologic Bouguer gravity anomaly	Geoscience Australia		●
	Magnetics	Geologic magnetism	Geoscience Australia		●
	Silica	Total silica concentration	Geoscience Australia		●
	Barest Earth	30-yr time series of Landsat Thematic Mapper blue, green, red, near infrared, SWIR1 and SWIR2 wavelength bands	Geoscience Australia: Roberts et al. (2019)		●
Age	Weathering Intensity Index (WII)	Index of soil-regolith weathering and its effect on soil formation	Geoscience Australia: Wilford (2012)		●

Figure 2-4 shows a selection of covariates (presented in Table 2-4) with each representing an important *scorpan* soil forming factor.

Figure 2-4 (a) shows slope in the Assessment area as an example of a *scorpan* relief soil forming factor. These patterns reflect to a large extent the parent material and landscape history of the area; the flatter region of the Sturt Plateau reflects ancient Cretaceous and Tertiary lateritic surfaces, which since formation have essentially remained geomorphically stable through time, hence show where land is mantled by the deepest soils.

The age and stability of the Sturt Plateau are reflected in Figure 2-4 (b) through gamma radiometrics (*scorpan* parent material factor) and Figure 2-4 (d) Weathering Intensity Index (WII) (*scorpan* age factor); the gamma radiometrics shows strong geochemical patterns associated with deeply weathered, ancient soils and so consistent with the more weathered signal of the WII covariate (Wilford, 2012; Wilford, 1995). The Gulf Fall represents the exposed underlying lithology after progressive westward, northward and southward stripping away of the Sturt Plateau Tertiary surface to reveal a complex geomorphology of strike ridges, residual rises and hills, mesas and plateaux. These elevated relief features are delineated by slope patterns (Figure 2-4 (a)), which contrast the elevated landform features including mesas, plateaux, ridges and rises from the sloping edges and drop-offs, and from the lower flatter fluvial and alluvial areas. Similar complex and high relief patterns are also seen in the Wilton River Plateau dominating the north of the Assessment area, where like the Gulf Fall, gamma radiometric patterns (Figure 2-4 (b)) reflect a Tertiary surface preservation, which contrasts potassium-rich patterns associated with fresher bedrock geochemical signals where the residual surfaces have been stripped away; these residual landscape patterns are also echoed in the WII covariate (Figure 2-4 (d)).

The *scorpan* climate factor of aridity index in Figure 2-4 (c) shows the monthly ratio of precipitation to potential evaporation, that is dryness of the climate at a given place (Stephen, 2005). Across the Assessment area there is a north-to-south trend of increasing aridity, ranging from sub-humid in the north to semi-arid in the southern part. This gradient reflects the prevailing incursions from the coast of cyclones and continental heating/cooling, together imposing on the Assessment area landscape temperature and humidity trends affecting soil forming factors – especially vegetation trends (*scorpan* organisms factor).

Figure 2-4 (e) (mean bare ground fractional cover) represents one of the *scorpan* organisms factors through seasonal vegetation dynamics. This shows occurrence of seasonally most-diminished canopy coverage to be associated with the extensive coastal plain tidal flats near the river's mouth in the coastal plain, and eastern parts of the Gulf Fall area, where relief is particularly incised (Figure 2-4 (a)) leaving large areas of rocky slopes and shallow soils. A similar area of diminished seasonal canopy coverage also exists in the far west of the Gulf Fall area, again where relief patterns are strong and soils shallow. More seasonally prolonged vegetation canopy areas are associated with the Sturt Plateau and parts of the Wilton River Plateau where soils are deeper due to the dominance of Tertiary residual surfaces – as reflected in patterns from Figure 2-4 (b) gamma radiometrics and Figure 2-4 (d) WII. The patterns from the mean bare ground fractional cover reflects the physiological adaptations of various species to the soil and climate influences.

Figure 2-4 (f) (barest earth) shows the long-term trends in soil bareness depicting consistent, inter-annual bare earth patterns. This shows the sparsest vegetation in the Assessment area to be in the extensive tidal flats and along ridges and summits in the Gulf Fall area. The Sturt Plateau and the Wilton River Plateau show some of the least bare soils and reflect more complete canopy coverage in areas where soil is deepest in the residual Tertiary land surfaces.

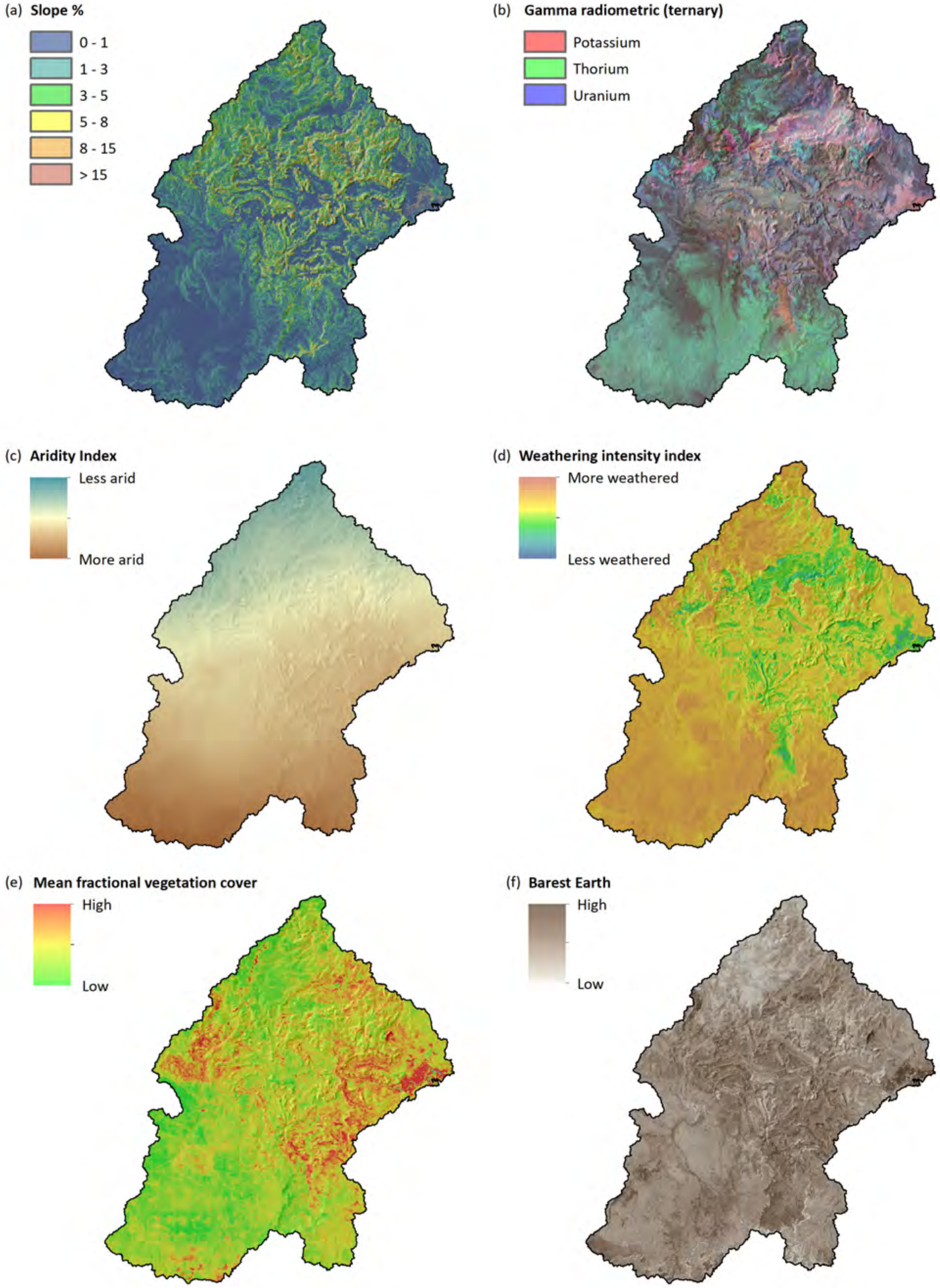


Figure 2-4 Selection of covariates used in DSM with underlying hillshade, including (a) slope %, (b) ternary gamma radiometrics, (c) Aridity Index, (d) Weathering Intensity Index, (e) mean fractional vegetation cover, and (f) bare earth

2.4.3 Soil attribute mapping: categorical, binary, continuous and Soil Generic Groups

The R statistical programming environment (R Core Team, 2018) was used for DSM computing. All soil attributes and SGGs were modelled using a Random Forest (RF) modelling approach (Breiman, 2001) implemented in the *ranger* R package (Wright et al., 2019). Random Forest models have a proven track record in environmental attribute prediction and have little tendency to overfit (Breiman, 1996). The approach constructs a multitude of decision trees during the algorithm training phase. Decision trees are ideally suited for the analysis of high-dimensional environmental data; a mix of continuous and categorical covariates that exhibit non-linear relationships, high-order interactions, and missing values can be used to predict continuous soil attributes (regression trees) or categorical ones (classification trees). Each individual decision tree splits a dataset into more and more homogeneous subsets.

Random Forests are an ensemble learning method that combines the 'bagging' idea (bootstrap aggregation), that is growing each tree from a random selection (with replacement) of samples in the training set, made with random selection of predictors (the covariates) in order to construct a collection of decision trees with controlled variance (Breiman, 1996). Bagging allows estimation of the error rate; some input data points are omitted each time a tree is built, and then these 'out-of-bag' (OOB) sample points are used to test and report the prediction accuracy of the realisation.

Random selection of predictors during RF-building allows the relative importance of individual predictors to be assessed – in other words, if a predictor is left out, how poorly does the model perform? After many trees have been fit, training and test error tend to level off. This means that sub-setting the data into training and test set is not necessary and all the data can be used to grow a RF model (Breiman, 2001).

Random forests output the class that is the mode of the predicted classes (classification) or mean prediction (regression) of the individual trees. The *ranger* package is the fastest and most memory-efficient implementation of RF algorithms available in R (Wright and Ziegler, 2015). The *train* function in the R *caret* package (Kuhn, 2015) was used to select the optimal *mtry* and *splitrule* arguments in the *ranger* algorithm. *Mtry* is the number of variables to possibly split at each node; the default is the rounded down square root of the number of variables or six in this case (√39).

Permeability, drainage, surface condition, surface texture, surface structure, and SGGs are categorical attributes comprising multiple classes, whereas microrelief, rockiness, and surface salinity are binary class attributes (i.e. present or absent) (Table 2-3). All were modelled using RF of 500 classification trees. Beyond the reported OOB prediction error, the kappa coefficient (Cohen, 1960) of the output confusion matrix was used to assess these RF model results; kappa adjusts for chance agreement due to size of classes. While kappa is not a test of mapping accuracy *per se* to inform users, in this case the test is used to test the performance of the model and the categorical allocations.

Depth of A horizon, clay %, surface ESP, soil erodibility (K-factor), soil thickness (effective rooting depth), surface pH, and AWC (AWC 60, which is AWC 60 cm soil depth, AWC 100, to 100 cm soil depth, and AWC 150, to 150 cm soil depth) are continuous attributes (Table 2-3), thus were modelled using RF of 500 regression trees. Model reliability was evaluated two ways: the OOB prediction error and R^2. In all RF models, relative importance of predictors (covariates) was assessed by permutation.

During model development, various point-based observation options were trialled for selection of the best training data:

- all available point-based observations
- only post-year 2000 point-based observations
- only point-based observations deemed to have a reliable source
- only point-based observations derived by stratified random sampling – in effect this Assessment and Flying Fox Station data (Andrews and Burgess, 2021a; 2021b).

Extra point-based observation datasets were also added to the training data and used in the modelling of some of the soil attributes, including:

- rockiness field observations – observations of locations that fit the 'rocky' limitation criteria captured during fieldwork
- locations dominated by *Acacia shirleyi* (lancewood) extracted from the NT Government vegetation database as it is found on particularly 'rocky' areas
- bare rock – locations captured from satellite imagery of bare rock
- Geoscience Australia rock outcrop data
- post validation sites for Soil Generic Group – an additional 11 sites were added to the SGG model after validation to try to improve predictions in certain catchment areas, 7 sites were collected on the validation trip and 4 sites from legacy data.

All RF models that produced acceptable model statistics (R^2 >0.25, or Kappa >0.35[3]) were applied to map the soil attributes and their uncertainty over the full extent of the mapping area of the Roper catchment, predicting the soil attributes at unsampled locations. This process was conducted using the CSIRO High-Performance Computing environment, given the large size of the dataset and the computational effort involved. The decision on what model and map to use for the final soil limitations to use in the land suitability rules was made qualitatively, collectively by soil surveyors and land resource experts familiar with the area, the match between predicted soil patterns, covariates and satellite imagery (Satellite Pour l'Observation de la Terre – SPOT), and the match between predicted soil patterns and existing land systems mapping and other sources of information (e.g. GoogleEarth™).

2.4.4 Digital soil map compilation and quantifying reliability

The 500 individual trees of the RF models were used to generate 500 datasets of each soil attribute and then used to estimate model reliability for each attribute.

For categorical values, the method for estimating reliability of predictions follows that described in Burrough et al. (1997) following the formula:

$$CI = Pmax-1/Pmax$$

[3] These thresholds draw on expert DSM and soil surveyor experience, and were applied in this instance as an acceptance threshold for maps created from the various model permutations.

where: CI is the confusion index, P_{max} is the probability of the most probable soil class and $P_{max} - 1$ is the probability of the second most probable soil class. A CI of 0 is low confusion or in other words, very reliable. Conversely, a CI of 1 is high confusion or very low reliability.

For continuous soil attributes the estimate of reliability of predicted values is the coefficient of variation (CV), that is, the standard deviation of the 500 predictions divided by the mean, expressed as a percent, at a particular grid location. A CV of 100% is high variability in the model estimates or low reliability, and CV of zero % is no variability in the model estimates or high reliability.

The modal prediction at every grid location was mapped and the resulting soil attribute mapping evaluated by expert soil surveyors and land resource experts familiar with the area. The predictions from the models were assessed for accuracy against new validation observations made in the field (Section 2.2). The DSM models that generated the strongest reliabilities (CI and CV) and conformed to expert opinion on the quality of soil patterns presented in the output maps were selected for land suitability modelling use (Section 2.5).

2.5 Land suitability analysis

Conventional land suitability analysis (land suitability) is a process of determining the potential of land to be used for specific land uses on the basis of the local range of environmental attributes and qualities (Rossiter, 1996), which are collectively termed land use requirements with associated limitations. The output is a 5-class suitability ranking system described in Section 2.5.1.

This Assessment defines limitations and builds the analytical framework following the Food and Agriculture Organization (FAO) approach for Land Evaluation (FAO, 1976; 1985). This involves a comprehensive assessment of land suitability that integrates multiple limitations including biophysical (edaphic and climate), social and economic themes (FAO, 2007). The land suitability analysis applied in this study deviates from FAO’s strict framework to constrain analysis to only biophysical themes.

The edaphic components of the land suitability assessment mostly relate to soil attributes that have a key bearing on the growth and productivity of the irrigated crops, or the amount and cost of land preparation and maintenance of irrigation infrastructure needed that may affect the financial viability of the farming enterprise. For example, soil permeability determines the rate that water can be applied or held, and rockiness relates to the intensity of rock picking required in land preparation and the routine damage to farm machinery that might be expected. The land suitability candidate crops, and application of the framework, are discussed in further detail in the following sections.

2.5.1 Crop suitability classes

In the land suitability framework, the growth performance of each crop for each depth threshold is scored on a limitation subclass 1 to 5 basis. As such, a shallow rooting small crop may be allocated a 1-score on a very shallow soil (the plant is physiologically well suited), whereas a deep rooting horticulture tree crop may be allocated a 5-score (i.e. the plant cannot grow here). When all the limitations deemed to have a production impact are considered simultaneously in the analytical framework, a final suitability 1 to 5 class rating is computed according to the most limiting (i.e. highest scoring) limitation(s) as the underlying assumption applied is that the most limiting factor determines the overall suitability rating. In this simple scenario the horticulture tree crop would not be suitable, simply on the basis of soil thickness alone (i.e. the land would be ranked Class 5). The derivation of limitation thresholds and their scores were either accessed from the literature (e.g. FAO, 1976; 2007), or defined by experts who are familiar with the crops in question and the area limitations.

The standard 5-class land suitability ranking used is based on guidelines developed by the Food and Agriculture Organization (FAO, 1976; 1985) and presented in Table 2-5. The ranking applies a suitability term (suitable (Classes 1 to 3) → currently unsuitable (Class 4) → unsuitable (Class 5)) and a limitations term (negligible (Class 1) → minor (Class 2) → moderate (Class 3) → severe (Class 4) → extreme (Class 5)) to each class. Class 4 (currently unsuitable) acknowledges that there may be future management options to one day make the land currently defined as unsuitable to become suitable. Such shifts to higher suitability may reflect changes to current technology (e.g. new crop varieties, pesticides, machines, and soil ameliorants) or economic (e.g. reduced fertiliser costs, new markets).

Table 2-5 Land suitability classes based on FAO (1976, 1985)

CLASS	SUITABILITY	LIMITATIONS	DESCRIPTION
1	Suitable	Negligible	Highly productive land requiring only simple management practices to maintain economic production.
2	Suitable	Minor	Land with limitations that either constrain production or require more than the simple management practices of Class 1 land to maintain economic production.
3	Suitable	Moderate	Land with limitations that either further constrain production or require more than those management practices of Class 2 land to maintain economic production.
4	Currently unsuitable	Severe	Currently unsuitable land due to severe limitations that preclude successful sustained use of the land for the specified land use. In some circumstances, the limitations may be surmountable with changes to knowledge, economics or technology.
5	Unsuitable	Extreme	The limitations are so severe that the specified land use is precluded. The benefits would not justify the inputs required to maintain production and prevent land degradation in the long term.

Each drop in suitability implies that more management input (thus increasing cost of production) is required to achieve incremental increases in crop production. The limitation term is a proxy for the level of management required to overcome the current level of limitation or the reduction in crop yield / increase in management costs to use the land with the current level of limitation. By convention limiting factors increase from Class 2 through to Class 5 indicating a higher level of management intervention required to elevate the class to the next higher suitability class. For example, if rockiness is identified as the most limiting factor in a given scenario, rock picking overcomes the rockiness limitation to potentially elevate the ranking. However, the ranking will not elevate if the new most limiting factor that emerges, perhaps soil thickness, has the same ranking that rockiness had originally.

2.5.2 Candidate crops

Individual land suitability data and maps were prepared for an extensive set of crops by season by irrigation type[4] (generating >120 land use options) for the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013) and the Northern Australia Water Resource Assessment (Thomas et al., 2018b). These land suitability frameworks were developed with the research partners and stakeholders and represent the state of agronomic knowledge and anticipated market needs at the time. The NT Government recently developed a Katherine region land suitability assessment (Katherine – Daly Waters) (Burgess et al., 2015; McGrath et al., 2019) following investigations in the Larrimah area and the Roper catchment agricultural land suitability framework (Andrews and Burgess, 2021b). The framework used in this Assessment aggregates like-crops and cropping systems into crop groups; these are listed 1 to 21 in Table 2-6. CSIRO has added new crops to this list, many of which have been harmonised into groups 1 to 21. New crops deemed prospective and desirable but not fitting into NT's crop groupings have been added to Table 2-6 in this Assessment – these are the groups 16 to 21.

Table 2-6 Crop groups (1 to 21) and individual land uses evaluated for irrigation potential

Land uses from the Andrews and Burgess (2021b) published list are presented in normal font with overlap of boldface land uses in Crop Groups 1 to 16. Northern Australia Water Resource Assessment land uses (Thomas et al., 2018b) are in boldface font and Crop Groups 17 to 21 are additional to Andrews and Burgess (2021b)

MAJOR CROP GROUP	CROP GROUP	INDIVIDUAL CROPS ASSESSED
Tree crops/horticulture (fruit)	1	Monsoonal tropical tree crops (0.5 m root zone) – **mango**, coconut, dragon fruit, Kakadu plum, bamboo, **lychee**
	2	Tropical **citrus** – lime, lemon, mandarin, pomelo, lemonade, grapefruit
Intensive horticulture (vegetables, row crops)	3	**Cucurbits** – watermelon, honeydew melon, rockmelon, pumpkin, cucumber, Asian melons, zucchini, squash
	4	Fruiting vegetable crops – Solanaceae (**capsicum, chilli**, eggplant, **tomato**), okra, **snake bean**, drumstick tree
	5	**Leafy vegetables** and herbs – kangkong, amaranth, Chinese cabbage, bok choy, pak choy, choy sum, basil, coriander, dill, mint, spearmint, chives, oregano, lemon grass, **asparagus**
Root crops	6	Carrot, onion, **sweet potato**, shallots, ginger, turmeric, galangal, yam bean, taro, **peanut**, **cassava**
Grain and fibre crops	7	**Cotton, grains – sorghum (grain)**, **maize**, **millet (forage)**
	8	**Rice** (lowland and upland)
Small-seeded crops	9	Hemp, **chia**, **quinoa**, **medicinal poppy**
Pulse crops (food legumes)	10	**Mungbean**, **soybean**, **chickpea**, **navy bean**, **lentil**, guar
Industrial	11	**Sugarcane**

[4] Under FAO terms (FAO, 1976) these are 'land utilisation types' (i.e. land use permutations of crop by management)

MAJOR CROP GROUP	CROP GROUP	INDIVIDUAL CROPS ASSESSED
Hay and forage (annual)	12	Annual grass hay/forages – **sorghum (forage), maize (silage)**
	13	Legume hay/forages – blue pea, burgundy bean, cowpea, **lablab**, Cavalcade, forage soybean
Hay and forage (perennial)	14	Perennial grass hay/forage – **Rhodes grass**, panics
Silviculture/forestry (plantation)	15	**Indian sandalwood**
	16	**African mahogany**, *Eucalyptus spp*., *Acacia spp*.
	17	**Teak**
Intensive horticulture (vegetables, row crops)	18	**Sweetcorn**
Oilseeds	19	**Sunflower, sesame**
Tree crops/horticulture	20	**Banana, coffee**
	21	**Cashew, macadamia, papaya**

Each crop group has specific management requirements with respect to plant growth, machinery use and land degradation management and not all crop groups have been assessed for each irrigation method or season (e.g. cucurbits are not assessed for the wet season as they are unlikely to be planted due to high disease risk; African mahogany is not assessed for furrow irrigation). Overall, wet season crops are restricted to crops that can withstand seasonal wetness and/or can be managed (cultivated/harvested) effectively during this time of year in the Roper catchment. Most of the crops can be grown during the dry season under a range of irrigation methods, with many of the small crops grown only during this period. Also, most horticultural crops (are grown under micro irrigation techniques (trickle/drip, micro sprays), whereas grain crops, cotton and sugarcane use spray or furrow irrigation. A limited number of crops (sugarcane, cotton, some grains and forage) have been assessed for potential economic returns under wet season rainfed conditions. The suitability of 17 crops under furrow or flood irrigation was tested, 23 under spray irrigation, 10 under trickle irrigation, and 8 under rainfed conditions. In terms of seasons, the suitability of 21 crop groups were tested under dry season conditions, 22 under wet, and 14 as perennials (Appendix A). The limitations to management are reflected in the rules of the suitability framework and are presented in Appendix B.

The bushfoods jupi (*Antidesma ghaesembilla*), Kakadu plum (*Terminalia ferdinandiana*), and Davidson's plum (*Davidsonia pruriens*) are considered potentially prospective in the catchment given what is understood about where they grow. However, their suitabilities cannot be assessed using the standard land suitability approach because their growing needs and limitation thresholds have yet to be formalised to be translated into a land suitability framework. A trial environmental correlation DSM approach using the *ranger* R package (Wright et al., 2019) was tested based on intersection of the species' known growth locations in the catchment and environmental covariates. However, the results from this preliminary investigation proved inconclusive, probably because of the limited growing location information for the bushfoods, and so the results are not discussed further in this report. This approach could be developed further if botanical and agronomy research were undertaken.

2.5.3 Limitations applied

The 17 limitations and their sources used in the land suitability analysis are presented in Table 2-7. Of these 4 were from national climate data, 12 were derived from DSM land and soil attribute mapping (Section 2.4), and 1 (for ASS) derived directly from the DEM. Limitation rule thresholds are presented in Appendix B.

Some limitations are prepared from a combination of DSM land and soil attributes. For example, the erodibility limitation is determined by combining soil erodibility (*k-factor*, Renard et al., 1991) and slope. Similarly, the soil physical limitation accounts for a range of attributes, including soil surface texture, surface condition, soil structural class and sodicity (exchangeable sodium percentage, ESP). The following sections discuss the limitations in further detail. Areas susceptible to coastal acid sulfate soil (ASS) are mapped by a spatial analysis of the DEM to locate all land within 8 m of Australian Height Datum (AHD), hence those areas under marine tidal influence.

Climate

Annual rainfall

The total amount of rainfall (precipitation) which falls during the growing season has a significant impact on the suitability for rainfed cropping (i.e. grown without supplementary irrigation). Given the expanse of geographic area assessed, and the variability of annual rainfall and soil conditions across the area, a total of eight rainfall categories were identified, ranging from less than 300 to more than 1500 mm. For most of the crops assessed, at least 500 mm is required in combination with suitable soil attributes.

Heat stress

Parts of northern Australia are known for excessive heat over long periods, particularly during the transition periods between the dry and wet seasons. Intensely hot periods, defined as days with the maximum temperature over 40° C, particularly when combined with wind, may damage seedlings as well as the leaves and fruit of many horticultural crops. Dark soil colours, prominent in the north, can become extremely hot and exacerbate damage.

Frost

Low temperatures (<2 °C) can damage sensitive crops and reduce crop yields through damage to flowers and fruits. Generally, there are few frost-prone areas in northern Australia, but they are known in some inland areas, some higher elevated locations and may be localised along low-lying creeks and drainage lines. Dry season and perennial crops are only likely to be affected.

Temperature variation

Northern Australia generally experiences warm daytime temperatures, but overnight minimums can drop regularly by 15 to 20 °C, particularly during the dry season in inland locations. While some crops (e.g. chickpeas and lychees) require cool temperatures for seed/fruit set, other crops do not prefer such conditions.

Land and soil

Water erosion

Soil erosion by water, if not minimised, reduces the productive capacity of the land. Several factors influence the erodibility of the soil including the intensity of rainfall, the gradient and length of slopes, and management practices that reduce surface cover or disturb the soil surface. Different soil types also have an inherent susceptibility to erosion, quantified as a soil erodibility factor (K-factor), which is related to soil permeability, surface structure, particle size (clay, silt and sand content) and the organic carbon content (Rosewell and Loch, 2002). The inherent stability of soils, estimated by K-factor and slope, are used in this limitation.

Table 2-7 Land suitability limitations and source data

LIMITATION	DESCRIPTION	INPUT DATA	SOURCE
Climate – rain	Annual rainfall. Used for rainfed cropping scenarios only	Mean annual rainfall (years 1889–2017)	http://www.bom.gov.au/research/publications/researchreports/BRR-041.pdf
Climate – heat stress	Excessive heat damages crops	Mean number of days >35 °C (years 1889–2017)	http://www.bom.gov.au/research/publications/researchreports/BRR-041.pdf
Climate – frost	Impact on crops due to frost	Mean number of days with minimum temperatures <2 °C (years 1889–2017)	http://www.bom.gov.au/research/publications/researchreports/BRR-041.pdf
Climate – temp variation	Cool seasonal temperatures are required for some crops	Mean minimum monthly temperature <15 °C (years 1889–2017)	http://www.bom.gov.au/research/publications/researchreports/BRR-041.pdf
Water erosion	Soil loss due to water erosion needs to be minimised	K-factor (soil erodibility factor), % slope	DSM from field observations, laboratory measurements and calculated data; CSIRO SRTM
Wetness	Site and soil conditions that result in poor soil aeration and impact on crop growth	Site drainage and soil profile permeability	DSM from field observations
Soil water availability (available water capacity, AWC)	Capacity of a soil to supply water for plant growth; estimated for the soil profile. A critical parameter for rainfed cropping and applied irrigation water efficiency for irrigated land uses	AWC was estimated in the field using equations and field texture tables (Littleboy, 2002) for 0–0.6 m, 0–1.0 m and 0–1.50 m	DSM from field estimates
Nutrient balance	Impact of soil pH on plant ability to utilise soil nutrients	Soil pH in top 10 cm of soil	DSM from field estimates and laboratory analysis
Soil thickness	Adequate soil depth for physical support and plant edaphic requirements	Soil depth (to 1.5 m)	DSM from field observations
Rockiness	Rockiness of soil, including hard rock and significant gravel content impacts on crop growth and farming practices	Rock outcrop, surface gravels and coarse fragments	DSM from field estimates
Gilgai (microrelief)	Indicates the extent of land levelling required; level land is required for even drainage and efficient machinery use	Vertical interval of microrelief	DSM from field estimates
Soil physical restrictions	Physical soil conditions that affect workability, seedling emergence, harvesting (especially for root crops) and water	Thickness of A horizon; surface ESP; Soil Generic Group; soil surface condition; soil surface texture; soil surface structure	DSM from field estimations and laboratory analysis

LIMITATION	DESCRIPTION	INPUT DATA	SOURCE
Irrigation efficiency (furrow and border-check surface irrigation)	Minimise deep drainage	Soil infiltration rate implied from whole soil profile permeability	DSM from field estimates
Irrigation efficiency (spray and trickle irrigation)	Ease of soil profile recharge (wetting up of soil profile)	Soil infiltration rate implied from whole soil profile permeability	DSM from field estimates
Clay content (aquaculture)	Ring tank suitability	% Clay	DSM from laboratory measurements
Salinity (soil surface)	Plant stress due to high levels of salt in the soil profile, salt toxicity	Presence/absence of excessive soil surface salinity	DSM from field observations
Acid sulfate soil potential	Potential for soil sulfides to oxidise to sulfates (forming sulfuric acid) from site disturbance and soil drying	Elevation above mean sea level, < 5 m AHD	Topographic maps, CSIRO SRTM and land system mapping where available

Wetness

Excessive water in the soil profile due to rainfall and local run-on water can reduce crop growth and quality, restrict machinery and irrigation equipment use and may require expensive drainage reclamation works. The wetness limitation considers permeability class (rate of water movement into and through the soil profile) and drainage class (length of time the soil remains saturated).

As wetness can be highly seasonal, drainage and permeability may be considered differently for summer (wet season) and winter (dry season) crops. Although a soil may show signs of wetness, a crop grown in the dry season will usually not experience adverse wetness conditions.

Soil water availability

The available water capacity (AWC) within specified rooting depths (relevant to different crops) represents the volume of water in a soil profile between field capacity (upper limit) and wilting point (lower limit) and is estimated using soil texture (clay, silt and sand content), the percentage of coarse fragments in the soil (that reduce water storage space) and soil thickness. For rainfed cropping, the soil AWC is generally considered to be the maximum amount of moisture stored to grow a crop. For irrigated cropping the AWC relates to the irrigation frequencies required to obtain optimum crop yields. Soil with reduced AWC can be 'topped up' by irrigation, as long as the soil is not too free draining, or infiltration rates are too slow to allow water into the profile.

In this study, suitability subclasses for irrigated land uses are based on the estimated effort and cost required to maintain sufficient moisture in the soil profile for optimum plant growth, which relates directly to the irrigation interval (i.e. days between required irrigations) during the period of maximum water demand. In addition to soil AWC, data used for this estimation are reference crop evapotranspiration (ETo) supplied by SILO (Jeffrey et al., 2001) along with crop-specific factors and equations supplied in the FAO irrigation and drainage paper (Allen et al., 1998).

Nutrient balance (pH)

In addition to the total amount of nutrients within the soil (which is generally low across northern Australian soils in their natural state), chemical processes within the soil can affect the availability of nutrients for plant uptake. Soil acidity or alkalinity may lead to certain nutrient deficiencies and/or toxicities. Soil pH, within the top 0.1 m of soil, has been used as an indicator of conditions that affect the availability of plant nutrients.

Soil thickness

Adequate soil thickness is necessary to provide minimum soil related requirements for supporting plant root development and structural growth. Deeper soils have more water available for plant growth than shallower soils for the same AWC. Shallow soils cause issues with cultivation, seedling establishment and harvesting particularly for root crops. Uprooting of tree crops by strong seasonal winds may be exacerbated by shallow soils that prevent adequate root penetration. In some high-value, intensive cropping systems (e.g. Asian vegetables) shallow gravelly soils may be modified by mounding to provide adequate depth, although this may be a significant management input and therefore reduce the suitability of such shallow soils compared to deeper ones.

Rockiness

Surface gravel, stone and rock outcrop can interfere significantly with planting, cultivation and harvesting machinery used for root crops, small crops, annual forage crops and sugarcane.

Microrelief (gilgai)

Surface microrelief is common in cracking clay soils where wetting and drying cause shrinking and swelling of the soils, resulting in uneven surface features. Microrelief can be substantial, with greater than 30 to 40 cm of vertical displacement in some areas. Gilgai can affect the establishment of irrigation infrastructure and must often be levelled to allow efficient machinery operation and irrigation practices. Levelling may result in inconsistent surface soil characteristics, particularly where sodic and/or saline subsoils close to the surface are exposed.

Soil physical conditions

Several soil physical attributes have impacts on agricultural practices, crop establishment and growth and harvesting operations. Soil surface condition (firm, hard setting, crusting or with a coarse structure) affects seedbed preparation, seedling emergence or the development of root crops. Silty, hardsetting soils reduce infiltration of rainfall and irrigation water. Clayey soils are adhesive and sticky when wet and may be hard and difficult to manage when dry. Cracking types of clay soils can also shear tree roots and impact on infrastructure, for example they can undermine farm infrastructure from heaving. Soils with thin surfaces over sodic and intractable subsoils are generally of low suitability for cropping as the soils are prone to hardsetting and the clay below lacking structure and hostile to roots.

Irrigation efficiency

This relates to the capacity of the soil to facilitate the movement of water into and through the soil profile. For surface irrigation (furrow or border-check methods), surface soils are ideally slowly permeable to allow water to move effectively down furrow or across fields. High infiltration results in uneven rates of water being applied close to the source and minimum or no water being delivered to the ends of furrows. In addition, high rates of deep drainage can occur, resulting in water and nutrient loss below the root zone. For other high application rate irrigation methods, such as overhead spray and pivots, rapid to moderately high infiltration is desirable as more water can enter the soil profile in a shorter period, allowing for quick movement of irrigation infrastructure that may be required to cover large areas with repeat applications to top up the root zone.

Acid sulfate soils

These are soils that contain a high loading of sulfur from marine sources and organic deposits and are particularly prevalent in tidal zones on coastlines and river mouths. When left undisturbed, ASS soils remain in a reduced (sulfidic, pH >4) state and are not noxious. However, when disturbed (e.g. through excavation and exposure to the atmosphere), ASS soils oxidise and become sulfuric (pH <4), releasing sulfuric acid into the environment and causing soil mineral and structural degradation, and release of contaminants. Most of these soils are restricted to coastal areas under marine influence, hence found within 8 m AHD.

2.5.4 Limitations not applied

As with the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013) and the Northern Australia Water Resource Assessment (Thomas et al., 2018b), several limitations that may have bearing on enterprise level land suitability were not assessed as part of this activity. For example, soil temperature may have a limiting effect on crop performance (Abrecht and Bristow, 1996) and was not included. Other limitations that may feature in some land suitability frameworks, although not in scope in the land suitability in this Assessment, include economics and finances (e.g. subsidies and grants, produce market prices, fertilisers and fuel costs, etc.), flooding risk, land management-induced secondary salinity, conservation area exclusions, and proximity to irrigable water. Some of these factors are studied and presented as part of the wider suite of the Roper River Water Resource Assessment and catchment reporting. Caution should be employed when using the land suitability outputs from this activity for planning purposes without wider consideration of these limitations.

2.5.5 Computing land suitability and quantifying reliability

The land suitability modelling in this study applied a set of rules (Appendix B) to the DSM and other attribute layers (Table 2-7). The land suitability assessment analysis follows the process as followed by FAO (FAO, 1976; FAO, 1985). Traditionally, suitability is calculated and mapped spatially by assessing one set of limitation subclass values per pixel to determine the most limiting subclass, which then becomes the overall suitability value for a given pixel.

The processing of translating the limitation layers into crop suitability was done in two stages. The first converted the attribute (e.g. pH) into an attribute code (e.g. Nr1 = pH 5.5–7.0, Nr2 = pH 7.0– 8.5, Nr3 = pH <5.5, Nr4 = pH >8.5). The second then applied the crop specific suitability subclass values to the layers produced in first phase. For example, for rice grown with flood irrigation, raster cells containing values Nr2 become suitability Subclass 1, those containing Nr1 or Nr3 become Subclass 2, and those containing Nr4 become Subclass 3. The different limitation subclasses (e.g. for pH, soil thickness and water erosion) are then assessed to determine the most limiting factor and produce a single suitability class map for each crop group X season X irrigation type combination.

Given the use of DSM attributes to generate suitability attribute/limitation data, estimates of uncertainty are made possible through a method described by Malone et al. (2015) to propagate uncertainty of the soil attribute values through to the suitability assessment process to give an indication of the overall certainty of land suitability predictions.

Each of the DSM attribute data were generated using a RF model comprising 500 trees (Section 2.4.4). Thus, for each pixel on the map there are 500 individual realisations of a given attribute value. On a pixel basis, the calculation of the overall suitability is similar to that of the traditional approach described above, except the calculation has been done 500 times per pixel using the individual DSM realisation values. The overall subclass limitation value is the modal subclass value from the assessment of the 500 individual realisations. An uncertainty index (UI) can be calculated from the distribution of 500 individual subclass values. The UI, for a given pixel, is the degree of confusion between the most probable class and the class immediately less probable in the probability series and is similar to the concept of the confusion index used by Odgers et al. (2014) and Burrough et al. (1997).

The uncertainty index (UI) was calculated as:

$$UI = P_{max-1}/P_{max}$$

where: P_{max} is the probability of the most probable class and P_{max-1} is the probability of the second-most probable class. When UI tends to 0 then one class dominates and there is little confusion in the model and when UI tends to 1 then there is less certainty of the modelled suitability value.

The modal values for each of the relevant limitations for each pixel for each land use is then used to determine the most limiting subclass, thus determining the overall suitability for each of the land uses. The UI assigned to each pixel is that of the corresponding most limiting subclass value. Where two or more subclasses are the most limiting (e.g. a Subclass of 4 for the erosion limitation and a Subclass of 4 for the wetness limitation), the cause of uncertainty assigned to the pixel with the largest UI of the same (and worst) subclasses.

The calculation of the suitability and associated UI maps was undertaken using purpose-written R scripts (R Core Team, 2014). Due to the magnitude of calculations required to assess the uncertainties, the calculations were implemented in a high-performance computing environment.

The land suitability framework implemented 58 unique rules for crop group X season X irrigation type (i.e. 17 furrow/flood, 23 spray and 10 trickle and 8 rainfed) – documented in Appendix A. By aggregating individual crops to crop groups a reduction was achieved, for example from the 126 unique land use options from the Northern Australia Water Resource Assessment (Thomas et al., 2018b), to the 58 unique grouped options reported here.

2.5.6 Landscape complexity

Successful cropping means that management and practices are in tune with the physical constraints of the land parcel size, and minimum contiguous areas of suitable land are necessary to achieve production efficiencies at a scale required to be viable. For example, centre pivots require certain dimensions of land to be available for efficiencies. Land parcel size can be impacted by the juxtaposition of suitable and non-suitable soils, or physical limits to the size of individual parcels caused by anabranching (Taylor, 2002) and incised stream channels. The effect is that, at a coarse scale as reported here, viable areas of apparently suitable land become operationally restricted and potentially not viable for efficient production due to the practicalities of landscape complexity. Two components of landscape complexity are considered here:

1. The contiguous suitable area component was applied to the whole catchment based on crop-specific minimum areas and length/width of contiguous land. Contiguous suitable areas were produced as standalone data products for all Crop Groups (Table 2-8 and Table 2-9). However, the contiguous suitable area mask was not applied to the land suitability maps shown in Section 3.4, in order to make the Assessment products compatible with those found in Bartley et al (2013) and Thomas et al (2018). The technique was developed in this Assessment in a way that can be retrospectively fitted to the Flinders and Gilbert Agricultural Resource Assessment and the Northern Australia Water Resource Assessment data layers if required.

2. The stream dissection component reflects the elaborate pattern of incised (> 1 m depth) anabranched channels in alluvial plains of the Roper River and associated tributaries. Only those areas where Light Detection and Ranging (LiDAR) data were available were considered, rather than the whole catchment. Areas identified with substantial stream dissection are displayed on the land suitability maps presented in Section 3.4.1 (e.g. Figure 3-19).

Contiguous suitable areas

The land suitability 5-class data generated from the combination of DSM attributes, climate data and suitability rules inherently produce a speckled output potentially making it difficult for users to interpret and apply. To address the component of the landscape complexity limitation that relates to this, a spatial filtering method was implemented on the land suitability data to filter out parcels of land unlikely to be operationally viable. The result is data layers where each pixel was deemed to satisfy the rule (value i) or failed the rule (value ii) shown in Table 2-8.

Table 2-8 Rules to satisfy (✓) and or not satisfy (×) for minimum contiguous area and width for each Crop Group (Table 2-6)

CONTIGUOUS AREA AND DIMENSION THRESHOLDS	SUITABILITY FOR CROP GROUPS			
	CATEGORY A	CATEGORY B	CATEGORY C	CATEGORY D
Minimum contiguous area >25 ha and >120m wide	✓	✓	✓	✓
Minimum contiguous area >10 ha and >80m wide	✓	✓	✓	×
Minimum contiguous area >5 ha and >80m wide	✓	✓	×	×
Minimum contiguous area >2.5 ha and >80m wide	✓	×	×	×

To simplify the elaborate landscape of underlying soil attributes, climate and topography reflected in the suitability data, a two-step process was developed and applied across the catchment. First the five FAO suitability classes presented in Table 2-5 were aggregated to two: ‘suitable’ for suitability Classes 1, 2 and 3, or ‘not suitable’ for Class 4 and 5. Second, to further simplify the data, and to reflect the on-ground spatial constraints of farming practices, isolated patches of one or two pixels of ‘not suitable’ within larger ‘suitable’ areas were reclassified as ‘suitable’.

For each crop group, a minimum area and width were defined based on knowledge of farming practices. Depending on the possible land use, minimum areas were deemed as 2.5 ha, 5 ha, 10 ha or 25 ha and minimum widths of 80 m or 120 m, as presented in Table 2-9.

Table 2-9 List of Crop Groups (Table 2-6) for each minimum contiguous area rule from Table 2-8

CATEGORY A	CATEGORY B	CATEGORY C	CATEGORY D
Crop Group 4	Crop Group 1	Crop Group 11	Crop Group 7
Crop Group 5	Crop Group 2	Crop Group 15	Crop Group 8
Crop Group 18	Crop Group 3	Crop Group 16	Crop Group 9
	Crop Group 6	Crop Group 17	Crop Group 10
	Crop Group 20		Crop Group 12
	Crop Group 21		Crop Group 13
			Crop Group 14
			Crop Group 19

The minimum width was imposed by removing parts of the suitable area that are narrower (in any direction) than the required minimum width. The remaining groups of connected cells were then tested to see if they meet the required minimum area and removed if they did not.

Floodplain stream dissection

Figure 2-5 shows examples of heavily anabranched (i.e. dissected) sections of a floodplain (a), Roper River and Maiwok Creek (b). Anabranching intensities shown effectively reduce potential paddock sizes comprising suitable land and puts management restrictions on the movement of agricultural plant and equipment, limiting the potential for agricultural development.

(a) (b)

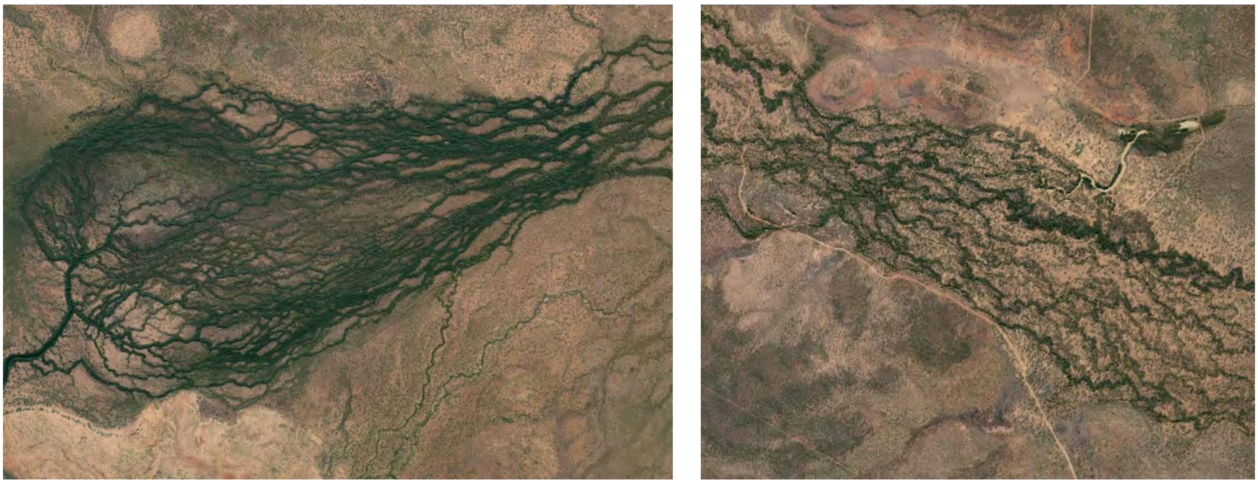


Figure 2-5 Examples of heavily dissected sections of floodplains on (a) the Roper River and (b) Maiwok Creek

A method was adopted to spatially identify these areas to provide a 'flag' on the suitability data outputs. These dissected areas remain classified in the standard Class 1 to 5 land suitability system (Table 2-5) because landscape complexity is not included in the standard land suitability rule set. The stream dissection data applies to all Crop Groups.

The application of this stream dissection component of landscape complexity followed these steps:

- LiDAR flown for the Assessment across the floodplain at 1.0 m ground resolution was used in this analysis and restricted the analysis spatial extent. The existing relief covariates of 30 m resolution across the whole catchment were too spatially coarse to delineate these heavily dissected areas.
- Areas of channel depth greater than 1 m and closer than 100 m to the next greater than 1 m depth channel were identified. The greater than 1 m depth criterion was derived through consultation with producers who reported this depth meant the difference between viable and non-viable irrigation due to the cost of laser levelling required in land preparation.
- Focal Statistics (*focalmean*), over the LiDAR DEM with a 50 m radius circle was applied.
- 'Raster calculator' in Quantum GIS (QGIS) (QGIS project, 2022) was used to extract channels by applying a threshold to the difference between the *focalmean* analysis and the original LiDAR DEM. A difference threshold of 0.9 m was used to identify channels at least 1 m deep because the focal mean represented a slightly lower bank top elevation.

- Using the delineated channels raster, an Euclidean distance grid extracting the areas less than 50 m distant from cells delineated as ‘channel’ was derived.
- Polygon data were created. Manual editing and some filtering removed unwanted areas either as small, isolated units or dissected hills and eliminated 1 m deep sumps in the landscape occurring in otherwise channel-free areas.
- The identified areas of stream dissection were then shown on all land suitability maps.

2.5.7 Versatile agricultural lands

Versatile agricultural lands were determined using the same methods described in the Northern Australia Water Resource Assessment (Thomas et al., 2018b). These products identify where the largest number of the land suitability is mapped as suitable (i.e. suitability Classes 1 to 3). This analysis summarises the suitability of the selected 14 exemplar land management options (see Section 3.4.1) chosen for each pixel and highlights where land is potentially more versatile for agricultural development because the pixels suit a larger range of land uses. Analysis results are displayed as an index ranging between 0 and 1, with the value 0 representing the least versatile land, and the value 1 representing the most versatile.

In addition to the selected set of land uses, an index of versatile agricultural land was also calculated using the subsets of each of the irrigation types and rainfed cropping for the catchment. In this case all the 58 land management options have been assigned to furrow (17 instances), spray (22 instances) and trickle (10 instances) irrigation and rainfed (8 instances) (Appendix A). In this type of versatile agricultural lands analysis, data and maps generated by each irrigation versatility analyses (i.e. furrow, spray, trickle and rainfed) are not suitable for comparing versatility between each irrigation type (i.e. inter-irrigation type versatility) for the Assessment area. However, they are suitable for comparing the distribution of versatility within each irrigation type (i.e. intra-irrigation type versatility).

2.5.8 Aquaculture land suitability

The suitability of areas for aquaculture development were also assessed from the perspective of soil and land characteristics. The limitations considered included clay content, surface pH, soil thickness and rockiness, and mainly relate to geotechnical considerations (e.g. construction and stability of impoundments). Other limitations, including slope, and the likely presence of gilgai microrelief and ASS, infer more difficult, expensive and therefore less suitable development environments, and a greater degree of land preparation effort.

Suitability was assessed for lined and earthen impounded ponds, with earthen ponds requiring soil properties that prevent pond leakage. Soil acidity (pH) was also considered for earthen ponds as some aquaculture species can be affected by unfavourable pH values exchanged into the water column (i.e. biological limitation). In consultation with aquacultural expertise of the agriculture and socio-economics activity, representative and realistic aquaculture species were selected to represent environmental needs of marine species, represented by prawns, and freshwater species. Additionally, barramundi and other euryhaline species, which can tolerate a range of salinity conditions, may be suited to either marine or fresh water, depending on management choices. Except for marine species’ aquaculture, which for practical purposes are restricted by proximity to sea water, no consideration was given in the analysis to proximity to suitable water for fresh and euryhaline species aquaculture. The aquaculture suitability rules, including the limitation classes and suitability subclasses for each species by pond configuration, are presented in Appendix C.

3 Results

This chapter presents the outputs of the DSM and land suitability analyses. It discusses the mapped outputs of SGGs and limitations used in the land suitability analyses, relationship of mapped attributes to the landscapes, as well as mapping reliabilities. There is also discussion on how the limitations affect the land suitability patterns generated by the land suitability framework analysis. The reliability of the land suitability data and maps are also presented. As discussed before, the land suitability analysis for this activity does not consider flooding, secondary salinisation, socio-economics and other limitations.

3.1 Survey data

Soil records were collated from 5641 sites comprising legacy and new soil survey data. Table 3-1 summarises these data (see also Figure 2-1 for geographic distribution). In terms of the legacy data, 5375 records were extracted from SALInfo (Department of Environment, Parks and Water Security, 2000) and NATSoil (Karssies et al., 2011), and all of these records were collected between the years of 1968 and 2020. This activity also sampled 266 new sites – 214 were collected during the 2019 to 2020 field seasons, and 52 more for validation purposes collected during the 2021 field season. In terms of proximity of new sampling sites to target sites (Section 2.2), 51% fell within 30 m (i.e. within 1 pixel) and 21% within 90 m. New and legacy sites were used in the DSM modelling – although not all legacy site records were used for all DSM attribute predictions because some records may have missed one of the soil attributes needed or were excluded because of criteria in Section 2.1.

Table 3-1 Summary of sites collated in the DSM component of the Assessment including new and legacy data within the catchment and legacy data outside the catchment to the modelling extent

DATA TYPE	BOUNDARY	SITE NUMBERS	% OF ALL SITES
Roper Assessment (new data)	Within catchment boundary	214	3.8
Roper Assessment (validation data)	Within catchment boundary	52	< 1
Legacy DSM sites	Within catchment boundary	234	4.2
Legacy data (pre-2021)	Within catchment boundary	1524	27
Legacy data (pre-2021)	Outside catchment boundary, within the model extent	3617	64
Total		5641	100

The distribution of sites used in the DSM is presented in Figure 2-1 and shows a variable density across the catchment. Concentration of sites are apparent around the areas of special development interest (e.g. Mataranka and Larrimah areas), and many fall outside the catchment, (e.g. the Katherine proximity; as discussed in Section 2.1). Many of the sites beyond the catchment of the Roper River were considered useful in the DSM process because they were likely to behave as homosoils, that is similar to other soils inside the catchment boundary – especially on the Sturt Plateau.

The data were used in several ways to provide the values of the attributes to be modelled. A data mining exercise was carried out and extraction queries built to allocate the values. The data extraction rules are explicit in their definition and applied in three methods:

- Actual value – a direct measured value is extracted for the attribute (e.g. permeability, drainage)
- Synthesised value – the final attribute value is a result of interrogating more than one measured attribute (e.g. soil depth derived from depth to R horizon, depth to C horizon, ASC family for soil thickness)
- Calculated value – the final attribute value is a result of a published calculation (i.e. pedotransfer function) that includes values of attributes e.g. AWC calculation including values for % clay, % fine sand, % coarse sand.

During the validation fieldwork a further 52 sites were collected (50 DSM plus the two free survey sites). The SGG and surface salinity models were re-run after validation to improve the DSM; surface salinity applied one new site and SGG, seven new sites.

3.2 Digital soil attribute mapping

This section presents evaluations on the quality of the DSM attribute data. Two methods were applied in testing: the first method is based on internal model validation, whereas the second method followed external validation where new site observations were collected in the field and assessed against mapped soil attributes at these locations. The results of these tests on DSM attribute qualities are presented below.

3.2.1 Model evaluation

Overall, 120 models were generated for the activity and from these 120 digital soil attribute datasets were produced for Assessment area. For all soil attributes, models were generated based on a combination of different soil observation point datasets (see Section 2.4.3) together with model performance testing (e.g. weighting of soil attribute ranges or classes not well predicted in the model, or removing of covariate layers that negatively contributed to the model predictions).

In general, there were no obviously outstanding models in terms of their model performance statistics for any soil attribute. It was therefore difficult to choose models based on their statistics alone. The final decision of which model to use to produce the final map product for any given soil attribute drew strongly on expert knowledge.

The consistency of maps across related soil attributes (e.g. depth of A horizon, soil thickness and rockiness) was also taken into account in the final model selections. A summary of the statistics of the Random Forest models that were selected to produce the final soil attribute maps are presented in Table 3-2 for continuous soil variables and in Table 3-3 for categorical ones. For continuous soil attributes the OOB prediction error is a value in the same units as the attribute, and for categorical attributes it is the proportion of misclassified data points. Final soil attribute data were then used in the land suitability analysis discussed in Section 2.5.

Table 3-2 Random Forest model performances: continuous soil attribute maps products

ATTRIBUTE	SAMPLE SIZE	OOB PREDICTION ERROR	R^2	COMMENTS
A horizon depth	4500 observations	1.27	0.67	Post 2000 observations + Bare rock + Geoscience Australia rock outcrop Log model
AWC 60	236 observations	676	0.66	Roper River Water Resource Assessment observations
AWC 100	236 observations	1933	0.65	Roper River Water Resource Assessment observations
AWC 150	236 observations	4365	0.65	Roper River Water Resource Assessment observations Plan curvature, Profile curvature, Magnetics and Green vegetation persistence covariates negative and removed in model
% clay to 2m	4558 observations	184	0.63	All available observations
ESP	156 observations	1.23	0.46	All available observations Log model, Relief aspect, Focal range 1000m, MrRTF covariates negative and removed in model
K-factor	133 observations	0.00	0.71	All available observations
Surface pH	1434 observations	0.31	0.70	Post year 2000 observations Weighted model (pH > 7.5)
Soil thickness	1541 observations	0.46	0.67	Post year 2000 observations + Bare rock + Geoscience Australia rock outcrop

Table 3-3 Random Forest model performances: categorical soil attribute maps products

ATTRIBUTE	SAMPLE SIZE	OOB PREDICTION ERROR	KAPPA	COMMENTS
Microrelief	5356 observations	0.02	NA	All available observations Modelled as discrete classes – 'Yes' or 'No', Weighted model ('Yes')
Permeability	2677 observations	0.29	0.40	Only observations deemed to have a reliable source
Drainage	2739 observations	0.43	0.36	Only observations deemed to have a reliable source
Rockiness	1751 observations	0.16	0.65	Post year 2000 observations + Rockiness field observations + Lancewood + Bare rock Modelled as discrete classes – 'Yes' or 'No', Weighted model ('Yes')
Surface salinity	1538 observations	0.01	0.85	Post year 2000 observations Modelled as discrete classes – 'Yes' or 'No', Weighted model ('Yes')
SGG	1517 observations	0.38	0.50	Post year 2000 observations + Post validation sites for SGG Weighted model on class 10, 1.1, 1.2
Surface condition	4366 observations	0.25	0.36	All available observations Weighted model (on Class 1 and 5)
Surface structure	2575 observations	0.14	0.53	Only observations deemed to have a reliable source Weighted model on Class 4
Surface texture	4429 observations	0.25	0.47	All available observations Weighted model on Class 3

3.2.2 External validation

Modelled soil attribute data were assessed against the new site validation data (not used in the DSM modelling) using field data acquired during the validation survey (Section 2.2.3). Once the surveyor had arrived at the site, the modelled attribute data was recorded as 'correct', 'accept', or 'fail' at that location. The 'accept' value was recorded against predominantly continuous attributes where the value that was not exactly correct fell within the suitability range for that attribute having no impact on the final suitability, for example at the site if the AWC100 modelled value was 60 mm but the field calculated value was 70 mm, this was deemed acceptable as the AWC100 rule range is 50 to 75 mm.

Recorded results were assessed as a proportion of the total number of new validation sites. For most attributes the external validation results show that the modelled data are better than would be expected based on the model statistics alone. This finding underscores the importance of the collection of new independent, external validation data to evaluate the attribute mapping and surveyor knowledge.

The validation accuracy results for the 'correct' class are presented in Table 3-4. These results indicate that the strongest predictions (>75% correctly predicted) were seen in surface salinity (100%), microrelief (98%), rockiness (87%), surface condition (81%) and surface structure (78%). Weaker predictions (<75% correct) were seen in surface pH (73%), SGG (72%), permeability (69%), surface texture (64%), soil thickness (64%) and drainage (62%). The AWC predictions were generally weak with predictions of 56% (AWC60), 46% (AWC100), and 50% (AWC150) and likely to reflect model estimations and validation error; fewer model input model data points are likely to have diminished model quality in the first place, while quality of validation estimates may have been hampered by quality of *in-situ* field estimations compounded by error estimations in the multivariate criteria used in the AWC look-up tables from Hazelton and Murphy (2016). Depth of A horizon predictions were also weak (48%).

No continuous data attributes were in the strongest predictions with three of the five attributes being presence or absence (only two categories). The four weakest attributes predicted were all continuous data (AWC60, AWC100, AWC150 and depth of A horizon). AWC had the most variable results either predicting too high or too low reflecting an inability to handle the shallow and/or rocky soils, and sandy soils.

In Table 3-4 the results of the combined 'correct' and 'accept' classes show all but AWC60, AWC100 and AWC150 to be greater than 75% correctly predicted, the strongest prediction class.

The original SGG model was satisfactory, but a better model run post-validation incorporating the seven additional sites improved mapping of one SGG class – SGG 2, discussed in 3.2.5 below – in the upper Hodgson River area and in the north along the Central Arnhem Road.

Table 3-4 Roper catchment external validation results

DSM ATTRIBUTE	CORRECT	ACCEPT	FAIL	TOTAL	DSM ATTRIBUTE	CORRECT	ACCEPT	FAIL	TOTAL
Depth of A horizon	25	23	4	52	Soil permeability	36	7	9	52
%	48	44	8	100	%	69	14	17	100

DSM ATTRIBUTE	CORRECT	ACCEPT	FAIL	TOTAL	DSM ATTRIBUTE	CORRECT	ACCEPT	FAIL	TOTAL
Microrelief	51	0	1	52	Soil thickness	33	13	6	52
%	98	0	2	100	%	64	25	11	100
AWC60	29	6	17	52	Soil surface condition	42	6	4	52
%	56	11	33	100	%	81	11	8	100
AWC100	24	5	23	52	Soil surface pH	38	11	3	52
%	46	10	44	100	%	73	21	6	100
AWC150	26	2	24	52	Soil surface structure	40	6	6	52
%	50	4	46	100	%	78	11	11	100
Rockiness	45	3	4	52	Soil surface texture	33	11	8	52
%	87	6	7	100	%	64	21	15	100
Soil drainage	32	11	9	52	Surface salinity	52	0	0	52
%	62	21	17	100	%	100	0	0	100
SGG	37	4	10	51					
%	72	8	20	100					

3.2.3 Soil and landscape descriptions and Soil Generic Groups

Soils often occur in complex patterns (Fridland, 1974) resulting from the short-range interplay between soil forming factors (Jenny, 1941). Consequently, soils can be highly variable across a landscape with different soils having different attributes that determine their suitability for growing different crops and their management needs. Data and maps of soil and their attributes provide a spatial representation of how soils vary across a landscape and are fundamental to regional-scale land use planning by providing an overview of the distribution of land resources. To that end, soils in the Assessment area were categorised into SGGs and described in Table 3-5. These soil units provide a means of grouping together soils that have broadly similar attributes and management considerations. The distribution of these soils and their attributes closely reflects the geology and landform of the immediate and surrounding areas.

The following sections describe the major landscapes and distribution of SGGs across the Roper catchment, along with a brief discussion of the opportunities and limitations for agricultural intensification offered by the SGGs. Soil classes of the ASC (Isbell and National Committee on Soil and Terrain, 2021), generally shown in parentheses, are also highlighted in the discussions to facilitate better interpretation of soils typically found in these SGGs.

3.2.4 Landscape descriptions

The geology and landforms of the Roper catchment are complex, being dominated by the Proterozoic sediments in the centre of the catchment (Gulf Fall), the deeply weathered Cretaceous sediments of the Sturt Plateau to the west, and the recent alluvial plains of the Roper River and its tributaries draining east to the Gulf of Carpentaria. Figure 3-1 shows an example of a typical Roper catchment landscape featuring sandstone plateaux and escarpments that give way to alluvial plains formed by the river and its tributaries.

Figure 3-1 Sandstone plateaux and escarpments along the Central Arnhem Road with gentle footslopes (foreground) grading to alluvial plains

The Proterozoic rocks comprise mainly sandstones, siltstones, shales, volcanics (with dolerite sills prominent) and some limestones. These folded very old rocks form the linear steep hills and ridges with a dominant north–south orientation throughout the central and northern part of the catchment.

Overlying the Proterozoic geologies is a series of sediments and volcanics comprising mainly Cambrian sandstones, basalt and limestone. Landform is mainly undulating to gently undulating rises. The extensive Nutwood Downs Volcanics comprised mainly of basalt occur high in the Hodgson River catchment, while springs from the Tindall Limestone at Mataranka have a major influence on the hydrology of the Roper River.

Cretaceous sandstone, siltstone and mudstone sediments overlie the older geologies in the west and north of the catchment. These sediments have been deeply weathered during the Tertiary and now form extensive plains, plateaux, escarpments and gentle footslopes. The Sturt Plateau is a prominent landscape of the western part of the catchment.

Erosion of the various geologies and landforms have been deposited as alluvial plains. Relict Tertiary / Quaternary alluvial clay deposits occur extensively over the Sturt Plateau as plains and drainage depressions. Subsequent erosion of the deeply weathered Cretaceous sediments on the Sturt Plateau have deposited sandy and loamy sediments over the Sturt Plateau, and partly over the relict clay deposits and as alluvial plains associated with the current river systems. The alluvial plains associated with the Roper River are perpendicular to the linear north–south orientated hills in the centre of the catchment, which contrasts with the tributaries that are tightly controlled by the orientation of the hills. In the catchment below Ngukurr, the seasonally wet broad alluvial plains adjoin the coastal marine plains. These broad landscapes generally comprise a range of SGGs.

3.2.5 Soils and Soil Generic Groups

The SGGs and soil attributes in the Roper catchment are modelled from field observations, laboratory analysis data and covariates (Sections 2.1 and 2.3) while also drawing on previous surveys conducted in the area by the NT Government outlined in Section 1.2. Table 3-5 describes the SGGs, correlations to ASC and generalised management considerations, while their mapped distributions are shown in Figure 3-2. The corresponding areas for each SGG and their proportions as a percentage are presented in Table 3-6.

Table 3-5 Soil Generic Groups, descriptions, management considerations, and correlations to Australian Soil Classification (ASC)

SGG	SGG OVERVIEW	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS	ASC CORRELATION
1.1	Sand or loam over relatively friable red clay subsoils	Strong texture contrast between the A and B horizons, A horizons generally not bleached. B horizon not sodic and may be acid or alkaline. Moderately deep to deep well-drained red soils	Undulating plains to hilly areas on a wide variety of parent materials	The non-acid soils are widely used for agriculture; the strongly acid soils are generally used for native and improved pastures	Red Chromosols and Kurosols except those with strongly bleached A horizons (the AT, AV, AY, AZ, BA or BB subgroups)
1.2	Sand or loam over relatively friable brown, yellow and grey clay subsoils	As above but moderately well-drained to imperfectly drained brown, yellow and grey soils	As above	As above but may be restricted by drainage related issues	Brown, yellow and grey Chromosols and Kurosols except those with strongly bleached A horizons (the AT, AV, AY, AZ, BA or BB subgroups)
2	Friable non-cracking clay or clay loam soils	Moderate to strongly structured, neutral to strongly acid soils with little or only gradual increase in clay content with depth. Grey to red, moderately deep to very deep soils	Plains, plateaux and undulating plains to hilly areas on a wide variety of parent materials	Generally high agricultural potential because of their good structure, their moderate to high chemical fertility and water-holding capacity. Ferrosols on young basalt and other basic landscapes may be shallow and rocky	Ferrosols and Dermosols without sodic B horizons (EO HA HC HO BA or HB subgroups)
3	Seasonally or permanently wet soils	A wide variety of soils grouped together because of their seasonal or permanent inundation. No discrimination between saline and fresh water	Coastal areas to inland wetlands, swamps and drainage depressions. Mostly unconsolidated sediments, usually alluvium.	Require drainage works before development can proceed. Acid sulfate soils and salinity are associated problems in some areas	Hydrosols and Aquic Vertosols and Podosols with long-term saturation
4.1	Red loamy soils	Well-drained, neutral to acid red soils with little or only	Level to gently undulating plains and	Moderate to high agricultural potential with spray or trickle	Red Kandosols

SGG	SGG OVERVIEW	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS	ASC CORRELATION
		gradual increase in clay content at depth. Moderately deep to very deep red soils	plateaux, and some unconsolidated sediments, usually alluvium	irrigation due to their good drainage. Low to moderate water-holding capacity, often hard-setting surfaces	
4.2	Brown, yellow and grey loamy soils	As above but moderately well-drained to imperfectly drained brown, yellow and grey soils	As above	As above but may be restricted by drainage related issues	Brown, yellow and grey Kandosols
5	Peaty soils	Soils high in organic matter	Predominantly swamps	Low agricultural potential due to very poor drainage	Organosols
6.1	Red sandy soils	Moderately deep to very deep red sands. May be gravelly	Sandplains and dunes; Aeolian, fluvial and siliceous parent material	Low agricultural potential due to excessive drainage and poor water-holding capacity. Potential for irrigated agriculture	Red Tenosols and Red Rudosols
6.2	Brown, yellow and grey sandy soils	Moderately deep to very deep brown, yellow and grey sands. May be gravelly	As above	Low agricultural potential due to poor water-holding capacity combined with seasonal drainage restrictions. May have potential for irrigated agriculture	Brown, yellow and grey Tenosols. Rudosols and Podosols without long-term saturation
7	Shallow and/or rocky soils	Very shallow to shallow <0.5m. Usually sandy or loamy but may be clayey. Generally weakly developed soils that may contain gravel	Crests and slopes of hilly and dissected plateaux in a wide variety of landscapes	Negligible agricultural potential due to lack of soil thickness, poor water-holding capacity and presence of rock	Most soils <0.5 m, mainly very shallow to shallow Rudosols, Tenosols, Calcarosols and Kandosols
8	Sand or loam over sodic clay subsoils	Strong texture contrast between the A and B horizons; A horizons usually bleached. Usually alkaline but occasionally neutral to acid subsoils. Moderately deep to deep	Lower slopes and plains in a wide variety of landscapes	Generally low to moderate agricultural potential due to restricted drainage, poor root penetration and susceptibility to gully and tunnel erosion. Those with thick to very thick A horizons are favoured	Sodosols; bleached Chromosols and Kurosols (those with AT, AV, AY, AZ, BA or BB subgroups) Dermosols with sodic B horizons (EO HA HC HO BA or HB subgroups)
9	Cracking clay soils	Clay soils with shrink-swell properties that cause cracking when dry. Usually alkaline and moderately deep to very deep	Floodplains and other alluvial plains. Level to gently undulating plains and rises (formed on labile sedimentary rock). Minor occurrences in basalt landscapes.	Generally moderate to high agricultural potential. The flooding limitation will need to be assessed locally. Many soils are high in salt (particularly those associated with the treeless plains). Gilgai and coarse structured surfaces may occur	Vertosols
10	Highly calcareous soils	Moderately deep to deep soils that are calcareous throughout the profile	Plains to hilly areas	Generally moderate to low agricultural potential depending on soil thickness and presence of rock	Calcarosols

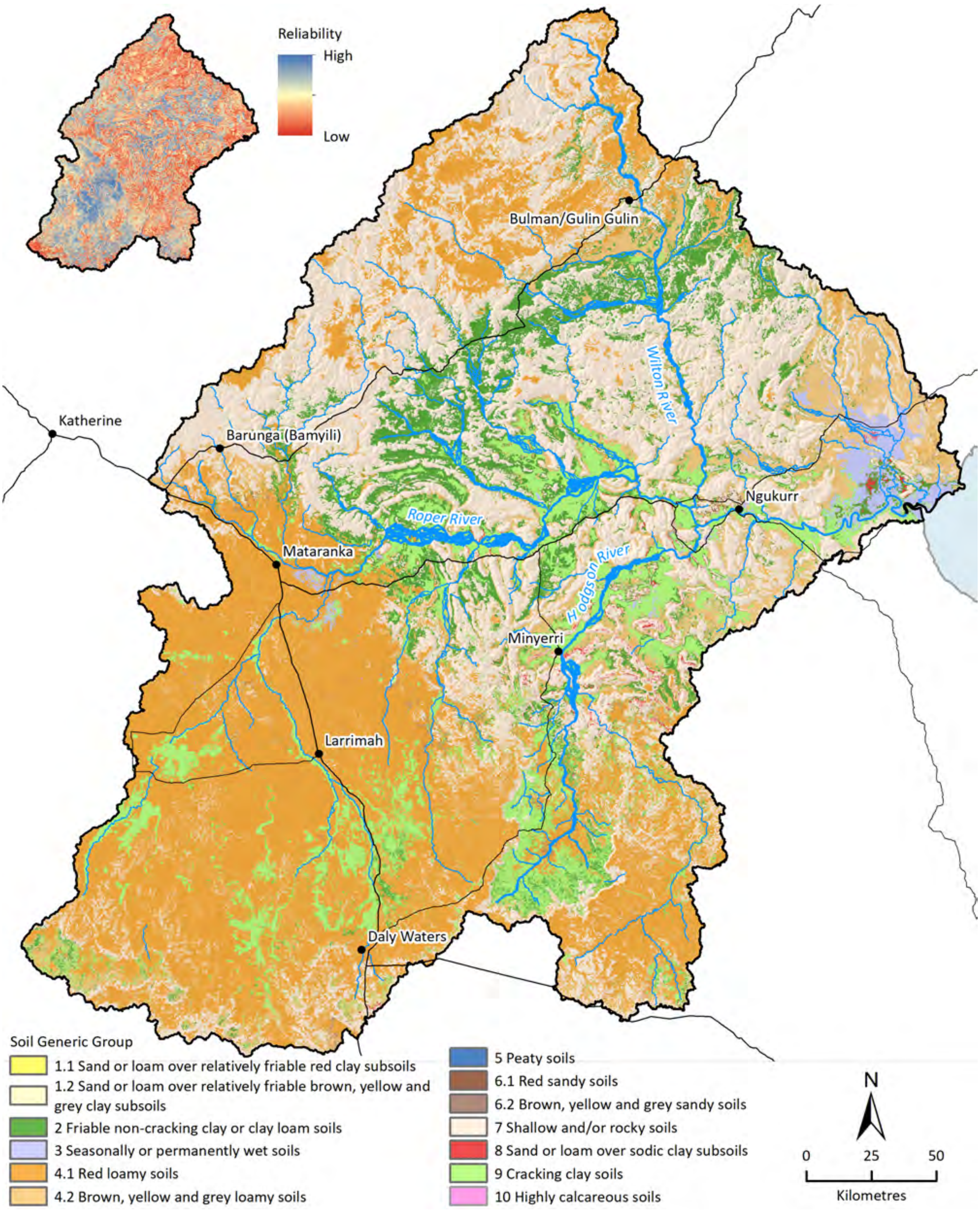


Figure 3-2 The Soil Generic Groups of the Roper catchment produced by DSM. The inset map shows the data reliability, based on the confusion index as described in Section 2.4.4

Table 3-6 Area and proportions covered by each Soil Generic Groups for the Roper catchment

SGG	DESCRIPTION	AREA (HA)	% OF STUDY AREA
1.1	Sand or loam over relatively friable red clay subsoils	100	0.0
1.2	Sand or loam over relatively friable brown, yellow and grey clay subsoils	760	0.0
2	Friable non-cracking clay or clay loam soils	710,000	9.2
3	Seasonally or permanently wet soils	113,800	1.5
4.1	Red loamy soils	2,717,290	35.1
4.2	Brown, yellow and grey loamy soils	633,300	8.3
5	Peaty soils	n/a	n/a
6.1	Red sandy soils	2,850	0.0
6.2	Brown, yellow and grey sandy soils	17,900	0.2
7	Shallow and/or rocky soils	2,741,000	35.3
8	Sand or loam over sodic clay subsoils	23,000	0.3
9	Cracking clay soils	783,000	10.1
10	Highly calcareous soils	200	0.0

SGG 1.1 and 1.2 occupy very minor areas of the Roper catchment (<1%). The sand or loam over friable clay (Chromosols, Kurosols) are associated with the gentle lower slopes of hills and rises on the less resistant Proterozoic geologies and Cambrian limestone in the high to middle parts of the catchment. This group is divided by colour reflecting their landscape position and soil properties. Soils are moderately suited to a range of grain and horticultural land uses. However, these soils are frequently in narrow, ribbon form in the landscape or have abundant rock from upper slopes, therefore limiting opportunities for agricultural development.

SGG 2 the friable clays and clay loam soils (Ferrosols, Dermosols) occur on Cambrian mudstones and limestones, Proterozoic to Cambrian basalts, Proterozoic dolerites, Cretaceous siltstones, and Cenozoic alluvium (9.15%). Deep (1.0–1.5 m) hardsetting loamy surfaced soils over friable mottled yellow and brown clay subsoils (Dermosols) developed on limestone, dolomitic siltstone, mudstone and siltstone occur in the Elsey Creek and Hodgson Creek sub catchments and to a limited extent on the Cretaceous sediments on the Sturt Plateau. Large areas of seasonally wet brown friable clay loam soils (Figure 3-3) occur in the north of the catchment on alluvial plains. The soils are suitable for irrigated agriculture and horticultural crops depending on soil wetness, slope and amount of rock.

Figure 3-3 Brown friable clay loam soils (Dermosols, SGG 2 soil) on alluvial plains in the north of the catchment

Moderately deep (0.5–1.0 m) red friable clays (Ferrosols), for example shown in Figure 3-4, are limited to basic rocks (basalt and dolerite) in the undulating to steep rises and hills of the southern catchment. Scattered stone and boulders often occur. The soils are suitable for cropping and horticultural tree crops. Moderately deep to deep soils (0.5–1.5 m) with few stones or boulders occur on gentle plains, rises and pediments but are usually highly fragmented due to drainage lines and short slope lengths between rock outcrops. Relatively large areas (e.g. 100 ha) are usable for cropping and horticultural land uses.

Figure 3-4 Gently undulating plains and rises with red friable clay soils – a SGG 2 soil – and scattered surface rock on basalt (Ferrosols)

Very deep gilgaied soils (>1.5 m) with clay loam to clay surfaces over mottled structured brown vertic (shrink-swell properties) clay subsoils (Dermosols) also occur adjacent to and in association with the Tertiary/Quaternary alluvial clay plains on the Sturt Plateau. These gilgaied soils, often with sink holes (small vertical depressions), frequently have large deep (>0.3 m) gilgai depressions that limit development due to excessive levelling that is required for efficient irrigation practices.

SGG 3 the seasonally wet or permanently wet soils (Hydrosols and aquic Vertosols, 1.5%) occur extensively on a range of swamps, drainage lines, internal drainage depressions and low-lying alluvial coastal and marine plains (Figure 3-5). The low-lying seasonally wet non-saline alluvial plains of the lower Roper River downstream of Ngukurr are suited to dry season irrigated agriculture. All other seasonally wet to permanently wet soils have limited potential for agricultural development. The coastal alluvial plains and very poorly drained saline coastal marine plains subject to tidal inundation have very deep strongly mottled grey non-cracking and cracking clays, with potential acid sulfate deposits in the profile (Section 1.3.5) and are subject to storm surge from cyclones.

Figure 3-5 The wet saline marine plains have no cropping potential, although may have use in aquaculture. A Hydrosol (SGG 3)

Closed drainage depressions in the deeply weathered Tertiary plains often have sands and loams deposited over poorly drained clay (Figure 3-6). The dark clay surfaced grey clay soil associated with the drainage lines and mound springs of the Tindall Limestone around Mataranka usually have no agricultural development potential due to extremely high salt levels and prolonged waterlogging.

SGG 4 are the moderately deep to very deep loamy soils, divided by colour reflecting their landscape position and soil properties. The red loamy (SGG 4.1; Kandosols, 35.21%, Figure 3-7) and brown, yellow and grey loamy (SGG 4.2; Kandosols, 8.16%), occur extensively on the deeply weathered Cretaceous mudstones, siltstones and sandstones of the Sturt Plateau and a variety of other sandstone geologies and landforms throughout the Roper catchment. Lateritised rock and ferricrete on subtle relief reflect a complex arrangement of these soils. The level to gently undulating deeply weathered Cretaceous sediments in the Roper catchment usually have sandy to loamy surfaced well-drained red (SGG 4.1) soils on the lower slopes and level infilled plains while moderately well-drained to imperfectly drained brown and yellow (SGG 4.2) soils occur on the plains or drainage depressions where water tends to accumulate, and on lower slopes to upper landscape positions due to subsurface duricrusts restricting internal drainage. The depth to iron pans and the amount of iron nodules relates to position in the landscape. Generally, the intact deeply weathered surface has moderately deep to deep (0.5–1.5 m) red (SGG 4.1) and brown or occasionally yellow (SGG 4.2) soils with large to moderate amounts of iron nodules

Figure 3-6 Seasonally wet internal drainage depression on the Sturt Plateau, a Hydrosol (SGG 3)

throughout the profile grading to shallow (<0.5 m) soils with abundant iron nodules and iron pans on the eroded edges of the plains and upper slopes of rises. Exposed laterite (Stoops and Marcelino, 2010) is common. Deep to very deep (>1.0 m) soils with few iron nodules frequently occur on the level infill plains and valley flats. Deeper soils with little rock or ironstone gravels that have resulted from the redistribution of erosion products into the lower landscape positions are highly suited to irrigated agriculture and horticulture. In some locations, narrow or small areas in the landscape may limit infrastructure layout and consequently agricultural opportunities. All SGG 4 soils are usually nutrient deficient, hence irrigated cropping requires very high fertiliser inputs when soils are initially cultivated. After the initial high application, fertiliser rates follow recommended crop requirements. Irrigation potential is limited to spray and trickle irrigated crops on the moderately deep to deep soils with low to high soil water storage (70 to 140 mm) and fewer iron nodules.

Figure 3-7 Red loamy soil (SGG 4.1; Kandosol) on the Sturt Plateau

Narrow levees adjacent to the major rivers, tributaries and prior streams on the alluvial plains throughout the catchment have very deep (>1.5 m) well-drained massive soils with sandy and loamy surfaces over red (SGG 4.1), brown and yellow (SGG 4.2) loam to clay subsoils. Soils are highly suited to irrigated agriculture but the narrow, ribbon form in the landscape may limit infrastructure layout and consequently agricultural opportunities. The lower slopes (<5%) of pediments derived from sandstones and siltstones of the Proterozoic and Cambrian hills and rises in the upper catchment usually have moderately deep (0.5–1 m), moderately well-drained to imperfectly drained, sandy to loamy surfaced, yellow and brown (SGG 4.2) massive soils with abundant rock fragments occurring frequently throughout the profile. Iron nodules in the profile also frequently occur, especially on lower slopes. However, as these units usually occupy small areas, development potential is limited. Moderately deep to very deep (0.5 – >1.5 m), well-drained to imperfectly drained, red (SGG 4.1) and mottled yellow (SGG 4.2), loose sandy to hard-setting loamy surfaced massive soils occur in association with friable loamy soils (SGG 2; Dermosols, Figure 3-8) on the gently undulating rises and plains developed over the Tindall Limestone around Mataranka extending north-west towards Katherine. Soils occur as a mosaic over the landscape, probably reflecting the depth to the underlying rock with red soils on the deeper areas. This group of soils overlying limestone probably originated from the redistribution of erosion products from the Sturt Plateau. These moderately permeable soils have moderate to high (100 to 140 mm) soil water storage and are highly suited to a broad range of irrigated crops.

SGG 5, the peaty soils, do not occur in the Roper catchment.

Figure 3-8 The very deep, well-drained, sandy surfaced red massive loamy soils (Kandosol, SGG 4.1) overlying limestone in the Mataranka area are suited to a wide range of irrigated crops

SGG 6 are deep sandy soils, divided by colour reflecting their landscape position and soil properties. These sandy soils occur to a limited extent (<1%) as very deep (>1.5 m) sands on the beach ridges along the coast (SGG 6.2; Rudosols, Tenosols, Podosols); as moderately deep to deep (>0.5–1.5 m) moderately well-drained to imperfectly drained yellow, brown or bleached sands (SGG 6.2; Tenosols) on pediments of Proterozoic quartz sandstones and the deeply weathered sediments throughout the Sturt Plateau; and as very deep (>1.5 m) red (SGG 6.1; Tenosols), yellow and grey (SGG 6.2, Tenosols) sand on levees and prior streams on alluvial plains. These highly permeable soils with very low soil water storage (<70 mm) have potential for irrigated horticulture utilising trickle or drip systems, otherwise the agricultural potential is low. The sands on the sandstones and deeply weathered sediments grade to shallow (<0.5 m) and/or stony soils (SGG 7) on upper slopes.

SGG 7 is the shallow (<0.5 m) and/or stony soils (mainly Rudosols, Tenosols, Calcarosols and Kandosols, but includes some Vertosols, Chromosols and Dermosols) occurring extensively (35.33%) throughout the mid- to upper catchment on Proterozoic to Cambrian sandstones, siltstones, mudstones, basalts, dolerites and limestones; and exposed lateritic and duricrust surfaces of the deeply weathered Cretaceous sediments on the Sturt Plateau. All shallow and gravelly/stony soils have very low to low soil water storage (<70 mm), predominantly slopes subject to erosion, a fragmented landscape due to intense drainage patterns and have limited potential for agricultural development (Figure 3-9 (a)). Very shallow (<0.25 m) Tenosols, Rudosols and Kandosols also occur extensively as sandy and loamy soils with abundant sandstone or lateritic gravels and rock outcrop on the rises and scarp areas (Figure 3-9 (b)) of the dissected quartz sandstone hills and dissected plateaux of the deeply weathered sediments. Very shallow (<0.25 m) Kandosols and Tenosols with abundant iron nodules, iron pans and exposed laterite also occur on the eroded edges of the plains and upper slopes of rises of the deeply weathered Tertiary sediments. Most of the Calcarosols on the limestones are shallow (<0.5 m) with abundant rock outcrop including the mound springs associated with the Tindall Limestone around Mataranka.

Occasionally, the mudstones of the Proterozoic and Cambrian geologies in the mid- catchment have gilgaied brown Vertosols (SGG 9) and vertic Dermosols on lower slopes with abundant lag gravels and stone on the steep upper slopes and are included in this group.

a)

b)

Figure 3-9 The shallow and/or rocky soils (SGG 7) occur extensively throughout the catchment and have no agricultural potential. These include (a) shallow gravelly red Kandosols on deeply weathered sediments and (b) shallow stony soils on slopes of the Proterozoic sediment

SGG 8 is scattered in minor areas throughout the Roper catchment (<1%). These soils are characterised by sodic subsoils and are typically sand or loam over sodic and intractable clays (Sodosols, sodic Dermosols). Agricultural potential is low to moderate with management required for irrigation timing, structural amelioration (gypsum rates) and erosion. Soils are dominated by hard-setting sandy loam, clay loam to silty clay loam surfaced mottled brown and yellow gradational and texture contrast soils with strongly sodic, dispersive, structured clay subsoils usually at <0.3 m. All soils are slowly permeable and moderately well-drained to imperfectly drained predominantly with low to high soil water storage (70 to 140 mm). They are subject to regular flooding throughout the lower parts of the catchment and are subject to erosion on slopes, particularly gully erosion adjacent to deeply incised stream channels. These soils on the alluvial plains grade to seasonally wet soils (SGG 3) lower parts of the catchment. Sand and loam over mottled yellow or grey sodic clay are associated with lower slopes (foot slopes and pediments) of rises and low hills often with abundant stone. The agricultural potential of this latter group is low due to low soil water storage (<70 mm) and erosion on slopes, particularly gully erosion.

SGG 9, the slowly permeable cracking clay soils (Vertosols, 10.09%), occur on the alluvial plains associated with the Roper River and major rivers draining to the Roper River in the north (Figure 3-10) and as Tertiary/Quaternary relict alluvium throughout the Sturt Plateau often occurring as internal drainage depressions. These very deep (>1.5 m), predominantly imperfectly drained, slowly permeable brown to grey cracking clays are usually strongly sodic at depth with soft self-mulching or hardsetting surfaces. Soils have high to very high water-holding capacity (>140 mm) but may have a restricted rooting depth due to very high salt levels in the subsoil. The self-mulching and structured brown and grey cracking clay soils are suited to a variety of dry-season grain, forage and pulse crops. The clay plains of the Roper catchment are subject to regular flooding and frequently have small (<0.3 m) gilgai depressions and numerous flood channels. These soils on the alluvial plains grade to seasonally wet soils (SGG 3), including aquic Vertosols, in the lower parts of the catchment below Ngukurr. The Tertiary/Quaternary clay plains of the Sturt Plateau often have large deep gilgai (>0.3 m) up to 0.8 m deep that will limit development potential due to excessive levelling that is required for efficient irrigation practices. Gravels frequently occur on the mounds. This Tertiary/Quaternary relict alluvium appears to be overlaid in part by the redistribution of erosion products from the surrounding deeply weathered sediments.

Figure 3-10 Large areas of brown Vertosols (SGG 9) on alluvial plains along the major rivers are suited to irrigated grain and pulse crops, forage crops, sugarcane and cotton

SGG 10, the highly calcareous soils (<1%), occur in small areas on the Cambrian Tindall Limestone around Mataranka, and other limestones and dolomites in the upper Wilton River subcatchment and south of Ngukurr. These red soils have abundant soft carbonate at depth. Soils are suitable for spray or trickle irrigated cropping, particularly horticultural crops, but nutrient disorders are likely due to the strongly alkaline soil profile.

3.2.6 General land suitability observations

In addition to the quantified land evaluation completed using statistical sampling, DSM and land suitability analysis, as presented above, a number of qualitative land evaluation observations were made by the expert soil scientists when conducting field investigations (Section 2.2). These observations of regionally extensive and prospective areas are presented in Table 3-7 and relate to the potential development of land for agricultural use identified in the field and from the land suitability outputs. The remoteness of the study area meant that these 'opportunistic' qualitative land observations made during the soil sampling and validation surveys offered increased general appreciation of the scale and distribution of agricultural opportunity in the study area and added to the wider agricultural 'narrative' for reporting and Assessment communication. Comments are restricted to the larger areas of these soils; there will be numerous instances of smaller, localised occurrences of these soils that may also be agriculturally viable on some properties and not discussed here.

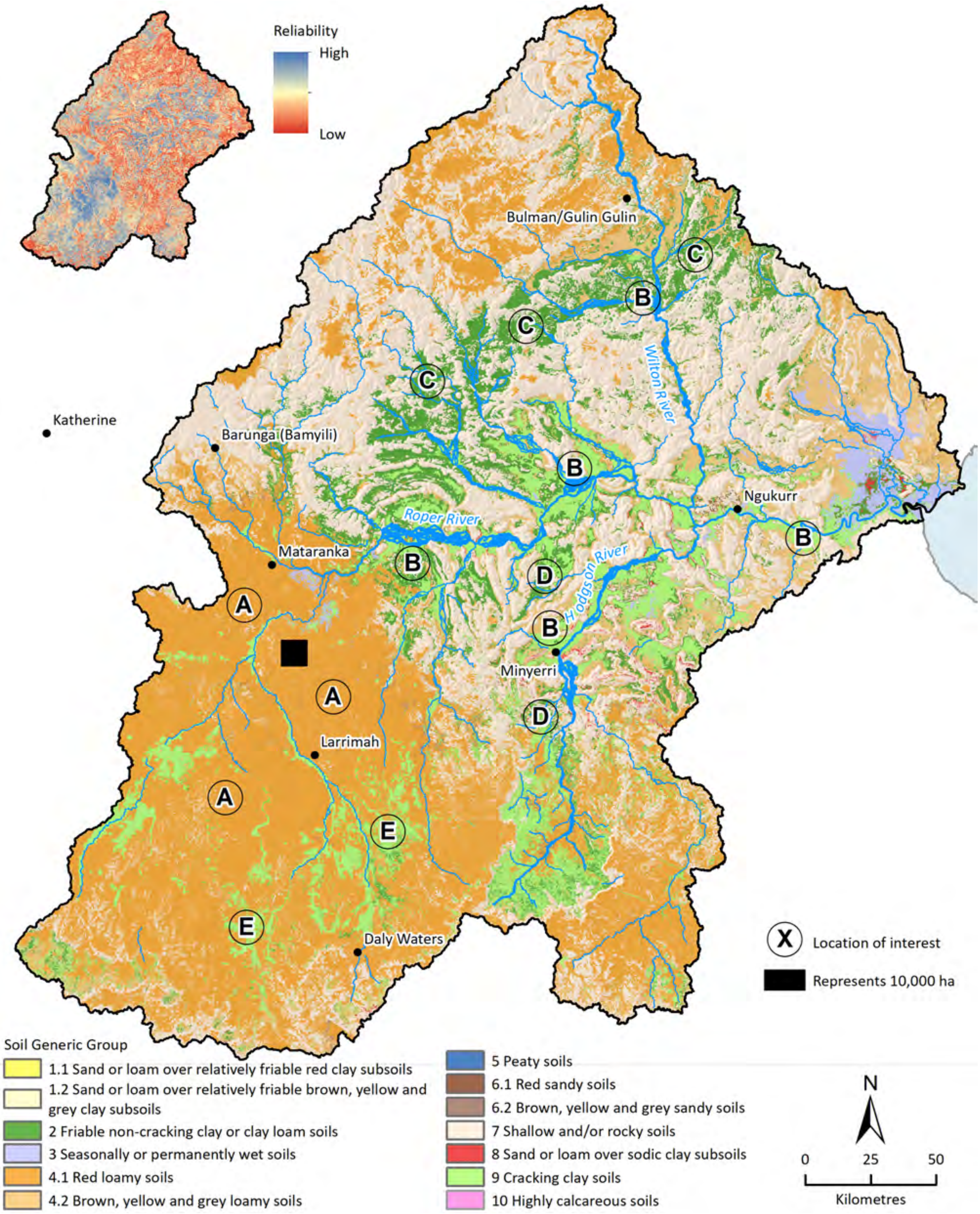


Figure 3-11 Soil Generic Group (SGG) map showing areas (A–E) referenced in Table 3-7. The inset map shows the data reliability, based on the confusion index as described in Section 2.4.4

Table 3-7 Qualitative land evaluation observations for soils of the Roper catchment

AREA	LOCALITY/LOCATION NAME	COMMENT
A	Loamy soils of the Sturt Plateau	Moderately permeable red and brown loamy soils (SGG 4.1 and 4.2). Deep to very deep loamy soils are suitable for a diverse range of irrigated horticulture and spray-irrigated grain and pulse crops, forage crops, timber crops, sugarcane and cotton. Extensive areas of soils with hard iron nodules may be suitable for small crops but abundant amounts of nodules will restrict the amount of available soil water for crop growth. Very shallow soils are generally unsuitable for cropping due to very low available soil water and restricted rooting depth.
B	Cracking clays soils on broad alluvial plains of the major rivers, particularly the Roper River, upper Wilton and mid-Hodgson rivers	Comprises floodplains often with numerous flood channels and narrow levees. Soils are mainly brown cracking clay soils (SGG 9) with coarse surface structure on the floodplains and brown friable loams and clays (SGG 2) on the levees. Most of the alluvium is subject to frequent flooding. The cracking clay soils are suitable for furrow or spray-irrigated sugarcane, cotton, dry-season grain and pulse crops, and forage crops. The main limitations are flooding on the floodplains during the wet season, workability, and landscape complexity due to the complex distribution of flood channels, resulting in small and/or narrow areas limiting paddock size and irrigation infrastructure layout. Management of wet season cropping needs to consider crop tolerance to seasonal wetness and flood duration, depth and frequency. The narrow levees are suitable for a range of spray-irrigated grain and forage crops and trickle irrigated horticultural crops, but the generally long thin units restrict irrigation layout and machinery use in most areas.
C	Brown non-cracking clay soils along the Central Arnhem Road	Deep to very deep hard-setting brown gradational soils with structured friable clay subsoils (SGG2) on alluvial plains, mainly in the northern part of the catchment. Soils are suitable for irrigated horticulture and a range of spray-irrigated grain and pulse crops, mainly dry-season cropping. Wet season cropping may be restricted by seasonal wetness. Extents are generally minor resulting in small and/or narrow areas limiting paddock size and irrigation infrastructure layout.
D	Red friable loamy clay soils in the Hodgson River area	Predominantly deep red friable loams developed on basic rocks (SGG 2), frequently with scattered stone and cobble. Soils are mainly suitable for irrigated horticultural tree crops depending on the amount of surface stone and cobble. Extents are generally minor resulting in small and/or narrow areas limiting paddock size and irrigation infrastructure layout.
E	Grey cracking clay soils of the Sturt Plateau	Very deep, gilgaied, self-mulching, grey and occasionally brown, cracking clay soils subject to seasonal wetness occur in the lower landscape positions of the Sturt Plateau (SGG 9). Suitable for dry-season furrow or spray-irrigated grain and pulse crops, forage crops and cotton. Deep gilgai microrelief may restrict land levelling operations in some areas.

3.2.7 Land degradation of potential irrigated agricultural land

Roper catchment landscapes are generally in a stable condition. The dominant form of land degradation occurring under existing land uses is erosion with hillslope water erosion a part of the land suitability assessment in this catchment. Other forms of erosion such as gully erosion have not been assessed. Also, secondary salinisation, soil acidification, soil structural decline, nutrient loss and soil organic carbon decline, have not been assessed (mainly due to lack of data and time restraints).

From field observation, severe gully erosion is an uncommon feature of the cracking clays (SGG 9) on alluvial plains in riparian areas of the Roper River and major tributaries. This erosion has resulted in minor sediment and nutrient loads to the Roper River and coastal marine environments. Gully erosion is usually associated with strongly sodic subsoils (SGG 8), however, these soils are generally not suitable for agricultural development. Severe gullying may result in a dissected landscape that restricts irrigation infrastructure layout, paddock size and access, as well as removing nutrients and organic matter from the site and contaminating water ways. These riparian areas require appropriate buffers of native vegetation to separate development and erosion prone areas, and require the implementation of appropriate run-off management into sensitive areas. Rehabilitation is prohibitively expensive.

Soil acidification is associated with crop productivity decline and nutrient disorders mainly caused by prolonged fertiliser application and the removal of basic cations in the harvested produce. Naturally acidic soils mainly associated with the red, brown and yellow loamy soils (SGG 4.1 and 4.2) and sandy soils (SGG 6.1 and 6.2) on the Sturt Plateau, pediments derived from sandstones and on alluvial plains are most susceptible to soil acidification.

Soil structure decline and associated productivity decline is associated with reduced soil health (reduced organic matter and associated microbial and faunal activity and nutrient cycling; erosion of the top soil; cultivation resulting in loss of soil structure, reduced surface water infiltration and surface porosity, and compaction resulting in reducing root growth and soil drainage). Management to moderate these impacts is mainly associated with reduced cultivation, maintaining or improving organic matter levels, retaining crop residues, good nutrient management, efficient irrigation management, and controlling erosion. Soil structure decline is mainly a problem on soils with a high proportion of fine sand and silt with clay loam textures and in rigid clay soils (soils that do not have shrink-swell properties) low in organic matter, which mainly includes the friable non-cracking clays or clay loam soils (SGG 2) of the alluvial plains, and small areas of Cambrian basalts and Proterozoic dolomites.

3.3 Soil attribute data and maps

A selection of the DSM attribute data (Section 2.4.4) more heavily relied on for the land suitability analysis are presented below. These layers include surface pH, rockiness, surface texture classes, permeability, soil thickness and AWC100, that is, cumulative soil profile AWC to 100 cm depth. Interpretation of the soil patterns in the soil attribute layers is assisted by referencing the SGG mapping (Figure 3-11) and the soil landscape and SGG discussions Section 3.2.3 above. Further context to the descriptions that follow may be gleaned from discussions in Section 2.4.2 where relationships to covariate *scorpan* soil forming factor attributes and soil and landscape properties are presented. References to biophysical provinces in the discussion below relate to those shown in Figure 1-2.

The surface soil pH attribute map in Figure 3-12 shows that most surface soils are in the pH range 5.5 to 7.0 and would not present a limitation to crop growth in almost all instances. There are instances of alkaline soils (pH >8.5) associated with limestone formations and associated springs in the Mataranka area on the Sturt Plateau, and in the central north at the Gulf Fall and Wilton River Plateau transition (Figure 3-11). Some acidic soils (pH <5.5) are found with the shallow, rockier soils associated with the hills and ranges in the west, centre and east in the Assessment area, typically SGG 7 (shallow and/or rocky) soils. Mapping reliability is strongest in the Roper River alluvium and the Sturt Plateau.

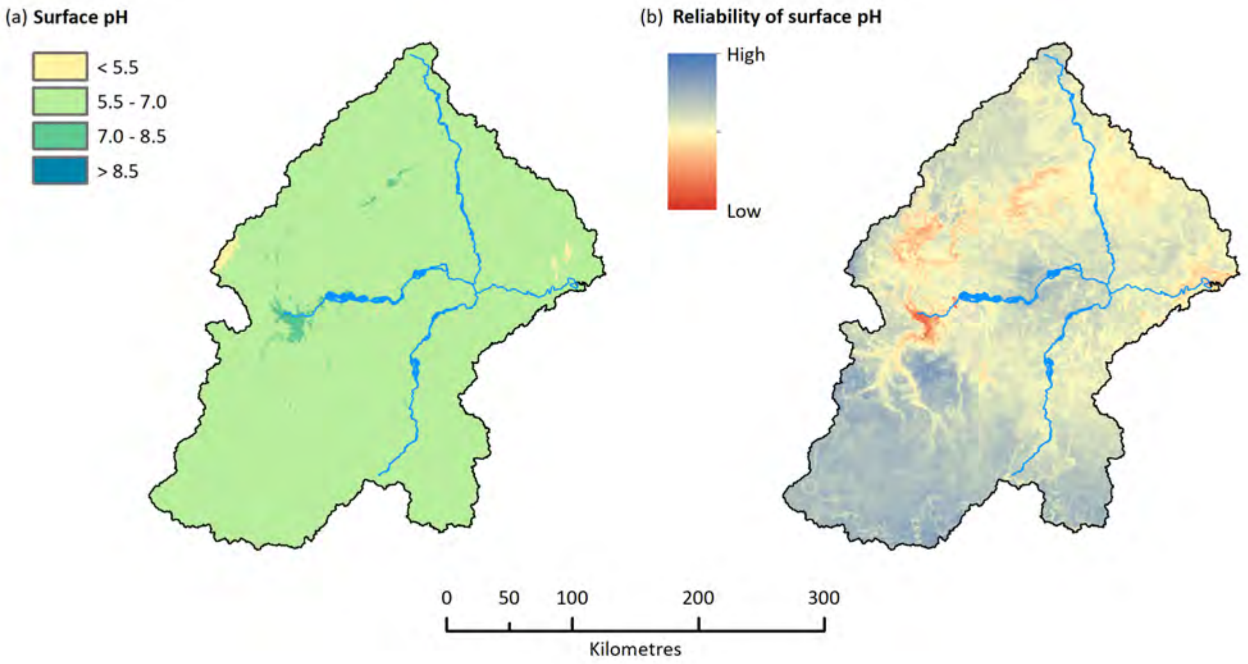


Figure 3-12 Distribution in the Roper catchment of (a) surface soil pH and (b) companion reliability mapping

Figure 3-13 shows the distribution of rocky soils to closely match the more freshly exposed lithologies, that is the hills and ranges mantled by SGG 7 shallow and/or rocky soils in the Gulf Fall and areas of the Wilton River Plateau. Non-rocky soils are associated with parts of the deeply weathered soils (SGG 4.1; red loamy soils) on the Sturt Plateau, and along river and tributary margins (SGG 9, cracking clays and SGG 2; friable non-cracking clay or clay loam soils) and on the coastal marine plains (SGG 3; seasonally or permanently wet soils). Mapping reliability is strongest over much of the Sturt Plateau and on the alluvium associated with the Roper River.

The catchment soil textures are presented in Figure 3-14 This shows the soils to be dominated by sandy surfaced soils, especially the sandstone geologies of the Sturt Plateau, Proterozoic geologies in the central parts of the catchment, and massive sandstones of the Wilton River Plateau. The alluvial plains of the Wilton River Plateau show localised examples of loamy soils (SGG 2), and clay alluvium (SGG 9, cracking clay soils) associated with drainage lines of the Roper River and major tributaries and coastal marine plains. Clay soils (SGG 9) are also associated with fine-grained sedimentary rocks and basalts in the Hodgson River catchment in the south and east of Mataranka. Sandy soils dominate northern part of the Sturt Plateau, whereas the southern part is dominated by loamy soils (SGG 4.1, red loamy soils). This southern area of the catchment also features Tertiary Quaternary clay deposits (SGG 9, cracking clay soils) in drainage depressions on the plateau, especially in the headwaters. In terms of mapping reliability, reliability is strongest in the Sturt Plateau and the central areas of the Roper catchment.

The soil permeability data are presented in Figure 3-15 and show much of the catchment to be moderately permeable. Notably the Sturt Plateau is dominated by these soils, coinciding with the red loams of SGG 4.1. Highly permeable soils dominate much of the Wilton River Plateau with distributions aligned to shallow sandy soils (SGG 7) developed on quartz sandstones. There are significant areas of slowly permeable soils in the central Gulf Fall areas associated with the cracking clays of SGG 9 of the Roper River and major tributaries and the Tertiary Quaternary clay deposits of the Sturt Plateau, and also around the mouth of the river in the coastal plain where seasonally wet or permanently wet soils dominate (SGG 3 soils). Mapping reliability is patchy throughout but strongest in parts of the Sturt Plateau and some areas of the Gulf Fall region.

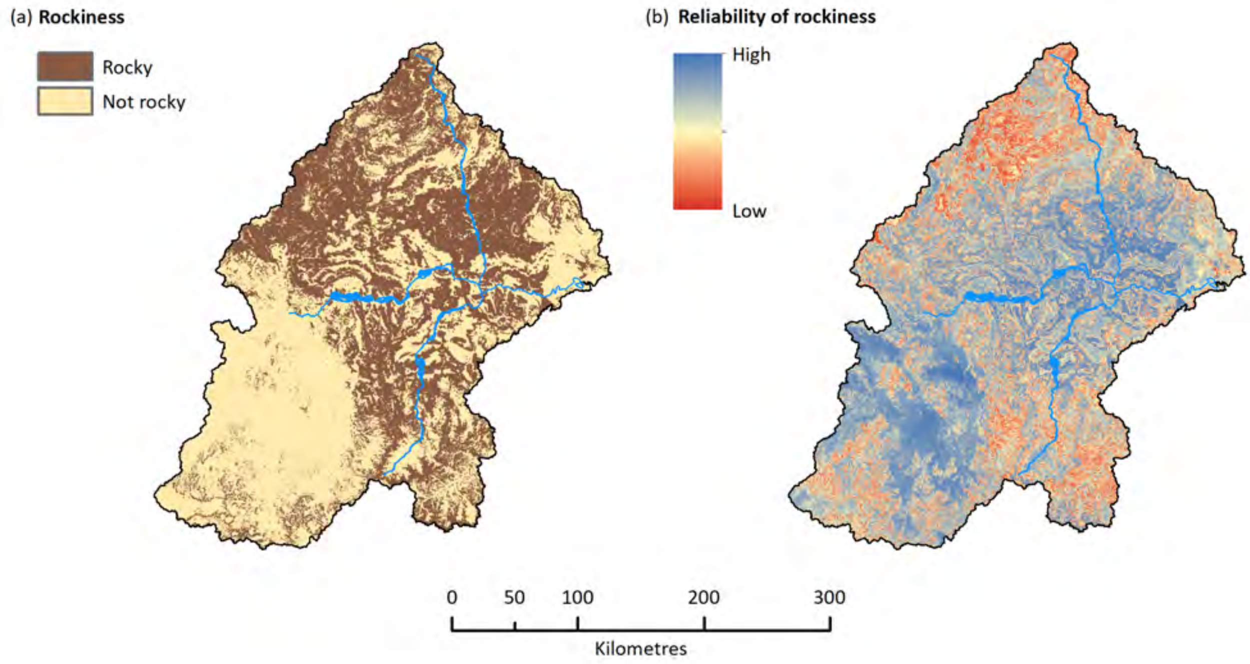


Figure 3-13 Distribution in the Roper catchment of (a) soil rockiness and (b) companion reliability mapping

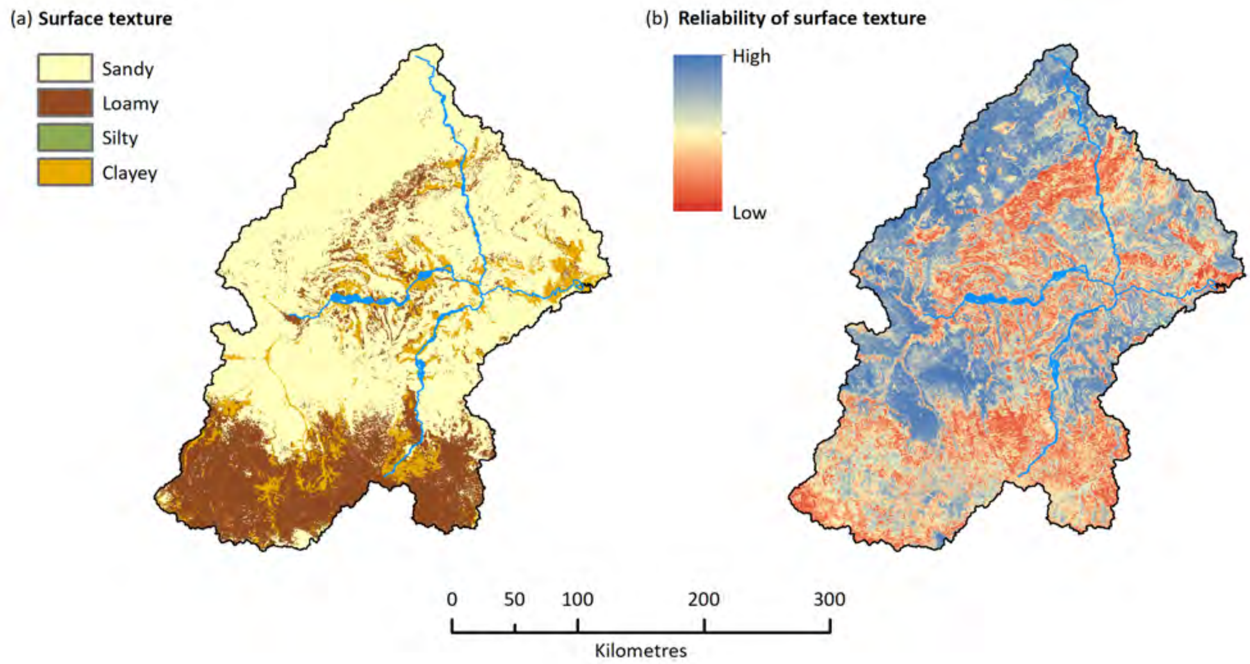


Figure 3-14 Distribution in the Roper catchment of (a) surface soil textural class and (b) companion reliability mapping

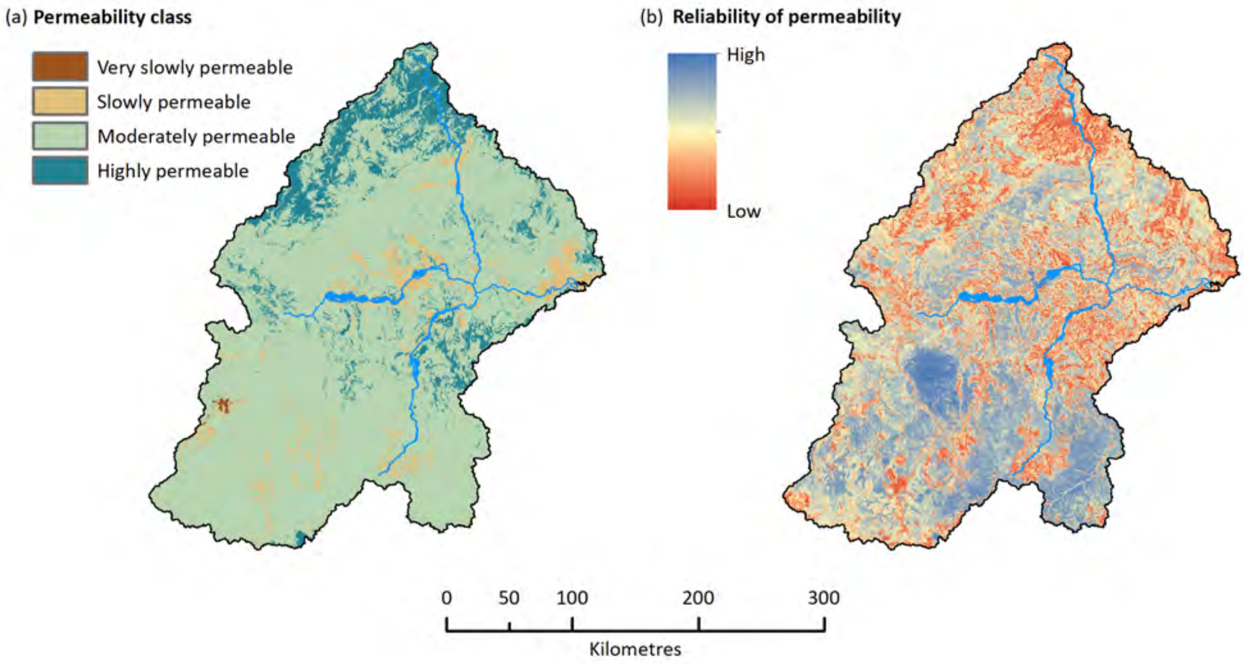


Figure 3-15 Distribution in the Roper catchment of (a) soil permeability and (b) companion reliability mapping

The soil thickness map for the Assessment area is presented in Figure 3-16. This shows the deepest trend in the Sturt Plateau where soils often exceed 1.5 m depth, especially in lower landscape positions on the plains, and on the Tertiary Quaternary clay deposits (SGG 9, cracking clay soils). Soils are also particularly deep near the mouth of the river in the coastal plain (SGG 3 seasonally wet or permanently wet soils) and on the alluvial plains (SGG 9, cracking clay soils). The shallower soils strongly coincide with SGG 7 (the shallow and/or rocky soils) in the Gulf Fall country. Mapping reliability is generally strongest on the central Roper catchment and parts of the Sturt Plateau.

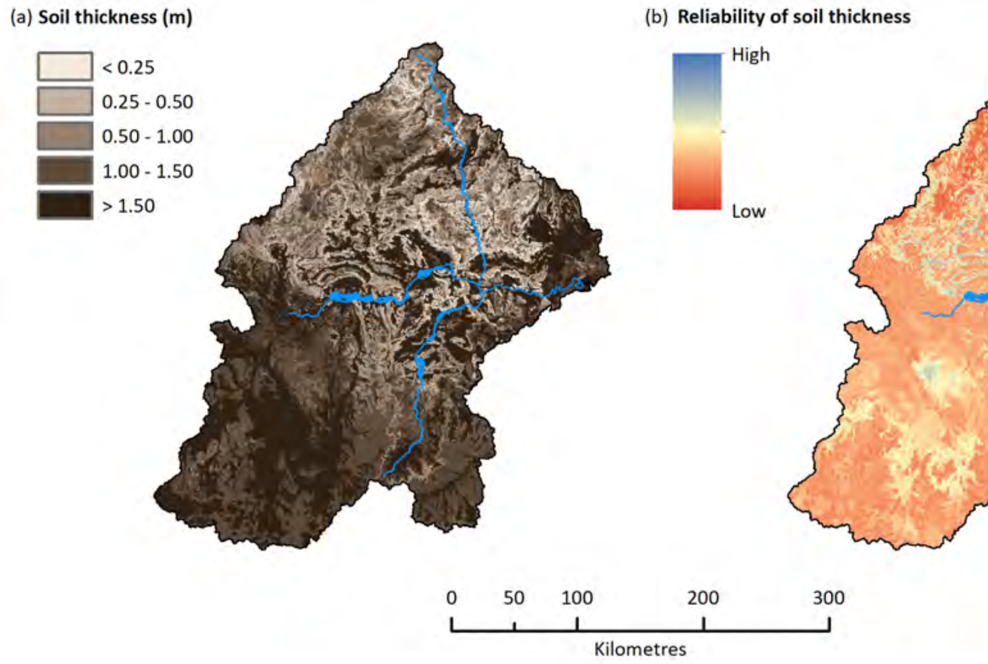


Figure 3-16 Distribution in the Roper catchment of (a) soil thickness and (b) companion reliability mapping

The AWC patterns shown in Figure 3-17 naturally match the soil surface texture class (Figure 3-14) and soil thickness (Figure 3-16) mapping. The largest AWC values are associated with the cracking clays soils (SGG 9) on the alluvium around the main watercourses and tributaries, especially in the Gulf Fall country. Also, extensive areas of larger AWC values are evident on the deep loams (SGG4.1) and clay deposits (SGG 9) of the Sturt Plateau (Figure 3-16). The lowest value AWC areas coincide with the shallow or rocky soils (SGG 7) along ridges and rises in the Gulf Fall and Wilton River Plateau. Mapping reliability is generally strongest throughout the Sturt Plateau and weaker throughout the remaining areas.

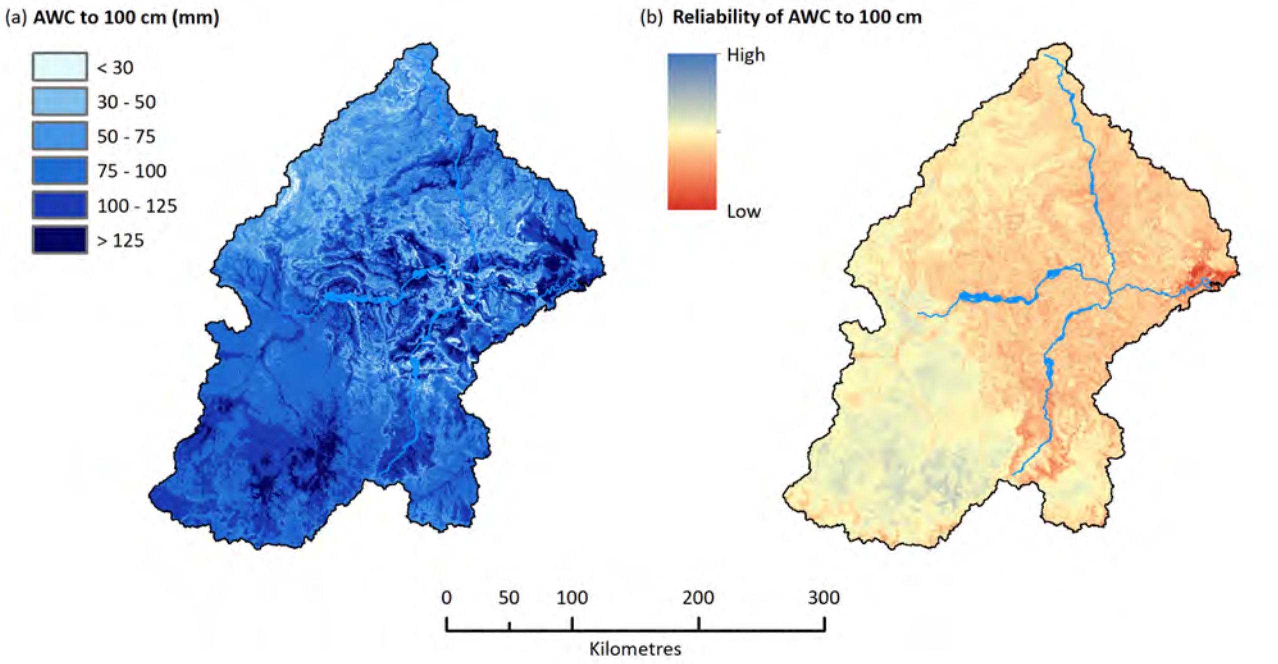


Figure 3-17 Distribution in the Roper catchment of (a) available water capacity and (b) companion reliability mapping

3.3.1 Acid sulfate soils

The distribution of potential ASS in the Roper catchment is shown in Figure 3-18, and indicates the soils to be restricted to the coastal marine plains below the 8 m AHD. The area of land affected by ASS is approximately 125,000 ha, and these areas will significantly limit development opportunities for agriculture. It also affects building infrastructure considerations due to seasonal or permanent wetness, natural salinity and the requirement to manage potential degradation from ASS. However, with correct site management of ASS these soils may be suited to aquaculture (e.g. lined ponds).

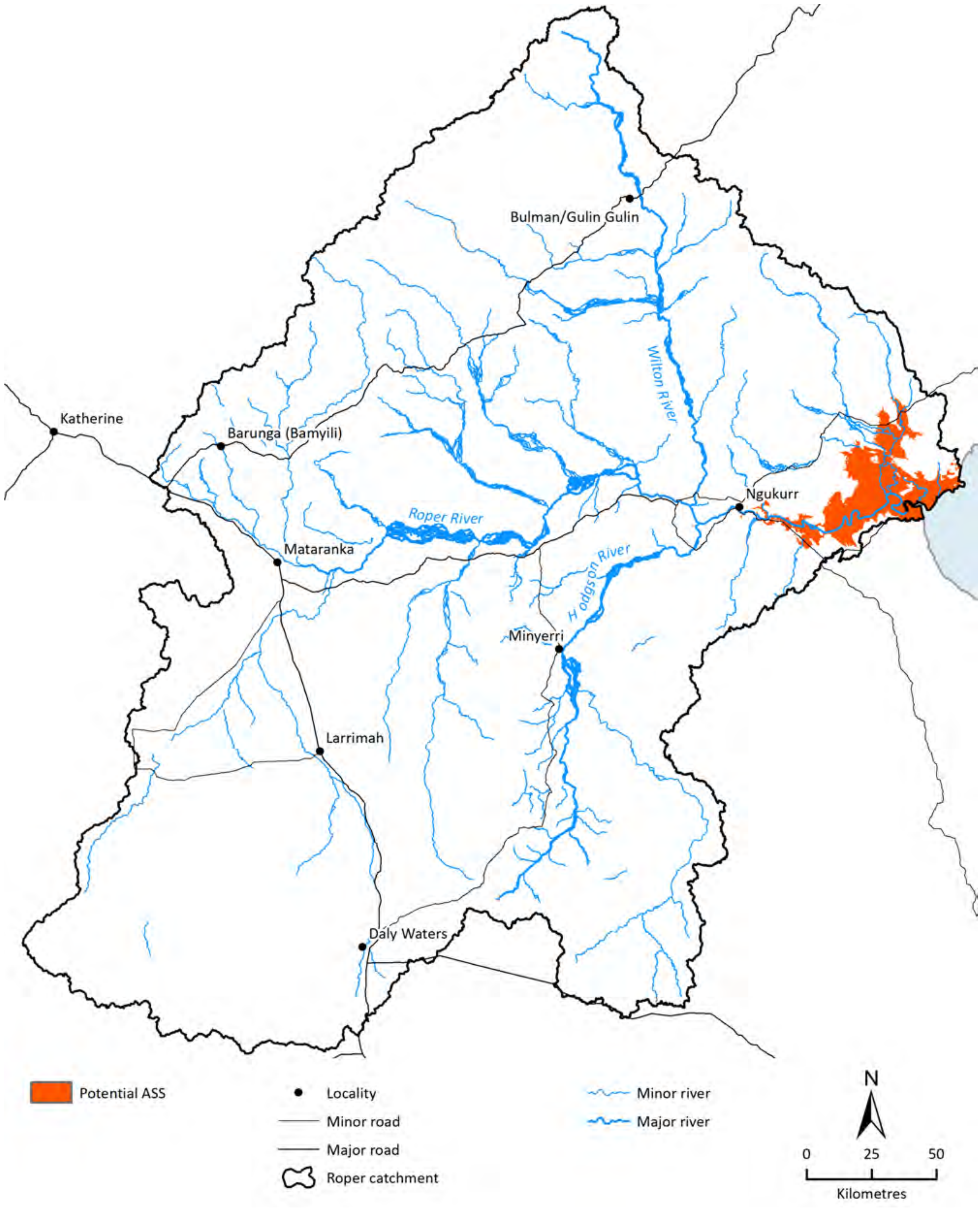


Figure 3-18 Distribution of potential acid sulfate soils in the Roper catchment

3.4 Land suitability

The following presents a selection of example land suitability data and maps (with accompanying reliability mapping) for cropping and aquaculture in the Assessment area. Versatile agriculture (i.e. cropping) indices are also discussed, along with methods to address landscape complexity that may impose additional farm management limitations on cropping land use options.

3.4.1 Land suitability distributions

The following section presents irrigated and rainfed crop group suitability (Section 2.5.2) distributions. For this discussion, 14 exemplar land uses have been selected, including two rainfed crops of interest. These selections have been expertly chosen from the 58 possibilities that were modelled (listed in Appendix A). The exemplar crop/management options are considered at this time to show a plausible variety of crops (Crop Groups) X season X irrigation type considered to align to the catchment's growing conditions (land, soils and climate) and market desirability. Readers are referred throughout to SGG mapping and soil–landscape explanatories in Section 3.2.3, and particularly Section 3.2.6, where links to the inherent qualities of the soils and their generic agricultural opportunities are made (see Figure 3-11). Comment is also made around the reliability of the land suitability mapping (Section 2.5.5) with presentation of companion mapping reliability maps with the land suitability maps. Hectarage calculations for the land suitability classes for the various land uses discussed in this Section are summarised in Figure 3-26, which is accompanied by general observations around the size (hectarage) of opportunity for each of the land suitability combinations. The biophysical provinces referred to in the following discussions are presented in Figure 1-2.

Figure 3-19 (a) shows the suitability for Crop Group 7 (grain and fibre crops e.g. cotton) under wet season furrow irrigation. Most of the catchment is suitability Class 4 or 5, so generally not suited for this purpose. However, there are minor areas in the Gulf Fall country that are Class 3, moderately suitable. The level deep slowly permeable cracking clay soils (SGG 9) on the river and tributaries are Class 3 (moderately suitable) and coincide with 'B' areas from Figure 3-11. There are also minor areas of Class 3 associated with the clay deposits on the Sturt Plateau, again associated with the cracking clays (SGG 9). In total there are approximately 107,000 ha (1.4% of catchment) of Class 3 lands for this land use (Figure 3-26). The mapping reliability is variable throughout the catchment, although better in areas of the Sturt Plateau.

Suitability for Crop Group 7 (grain and fibre crops, e.g. cotton) under wet season, rainfed is shown in Figure 3-19 (b). Again, most of the catchment is unsuitable for this land use being Class 4 or worse. However, there are minor areas in the Gulf Fall country of moderately suitable Class 3 along the drainage lines in the cracking clays (SGG 9, areas 'B', Figure 3-11) and friable non-cracking clay or clay loam soils (SGG 2, areas 'D', Figure 3-11) – soils that have higher water-holding capacity). On the Sturt Plateau there are significant areas of Class 3 – often associated with 'A' and 'E' areas from Figure 3-11. In these areas are dominated by level very deep non-rocky soils like SGG 4.1 (red loamy soils), SGG 4.2 (brown, yellow and grey loamy soils) and SGG 9 (cracking clays) with high AWC. Notably there are areas of Class 2 (suitable land with minor limitations) along drainage lines in the north-east of the Sturt Plateau, again associated with areas of SGG 9 (cracking clay) soils. Catchment wide for Group 7 crops, under wet season, rainfed there are approximately 7,800 ha (0.1%) of Class 2 and 436,000 ha (5.6%) of Class 3 lands (Figure 3-26).

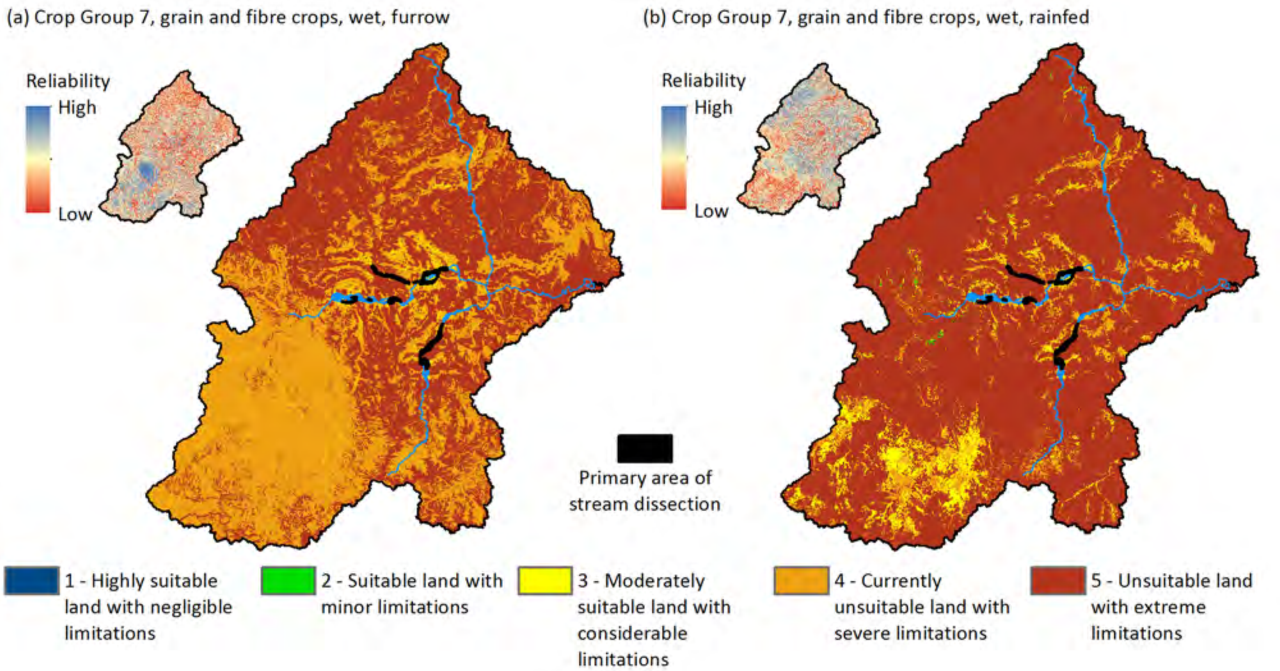


Figure 3-19 Modelled land suitability for Crop Group 7, 'grain & fibre crops' such as cotton or sorghum (grain), grown using (a) furrow irrigation in the wet season and (b) rainfed over the wet season

Insets illustrate reliability of land suitability mapping. Note that these land suitability maps do not take into consideration flooding, risk of secondary salinisation or availability of water. More detail for the crop groups can be found in Table 2-6

The land suitability for Crop Group 12 hay and forage crops (e.g. sorghum (forage), maize) under wet season rainfed management is shown in Figure 3-20 (a). This shows similar trends to Group 7 crops (grain and fibre crops, e.g. cotton) under wet season, rainfed, that a small proportion of the catchment is Class 3 or better (suitable), and these areas are to be found on the Sturt Plateau associated with SGG 4.1 (red loamy soils) and SGG 9 (cracking clays). These areas coincide with some 'A' and 'E' areas shown in Figure 3-11; these are soils with high water-holding capacity. There are also minor examples of Class 3 lands fringing the rivers and tributaries in the Gulf Fall country associated with some 'B' areas (Figure 3-11); these areas are associated with SGG 9 (cracking clay) soils. There are also some minor examples of Class 2 soils in the north of the Sturt Plateau (SGG 9, cracking clay) soils and in the extreme north of the Wilton River Plateau where SGG 4.1 (red loam) soils are present. Approximately 393,000 ha (5.1%) are mapped as Class 3 and 16,500 ha (0.2%) as Class 2 (Figure 3-26). Mapping reliability is strongest in areas of the Wilton River Plateau in the north of the catchment.

Land suitability for Group 14 perennial grass and hay forage crops (e.g. Rhodes grass) managed by wet-season spray irrigation is shown in Figure 3-20 (b), shows a very significant proportion of the catchment to be suitable with large areas of Class 3 and Class 2 to be present. Class 2 areas are strongly associated with the distribution of SGG 4.1 (red loamy) soils; greater than half of the Sturt Plateau, and here much of the SGG 9 (cracking clays) and SGG 2 (friable non-cracking clay or clay loam soils) soils are mapped as Class 3. Much of the northern parts of the Wilton River Plateau are mapped as Class 2, as are eastern and southern areas of the Gulf Fall country. These areas coincide with SGG 2 (friable loams), SGG 4.1 (red loamy soils) and SGG 9 (cracking clays) soils.

Significant areas of the Gulf Fall country around the alluvial soils dominated by SGG 9 cracking clays soils are mapped as Class 3 suitability. Approximately 2,252,800 ha (29.1%) of catchment lands are mapped as Class 3 and approximately 1,694,500 ha (21.1%) are mapped as Class 2 – meaning that greater than 50% of the catchment is suitable for group 14 crops (e.g. Rhodes grass) under wet-season spray irrigation (Figure 3-26).

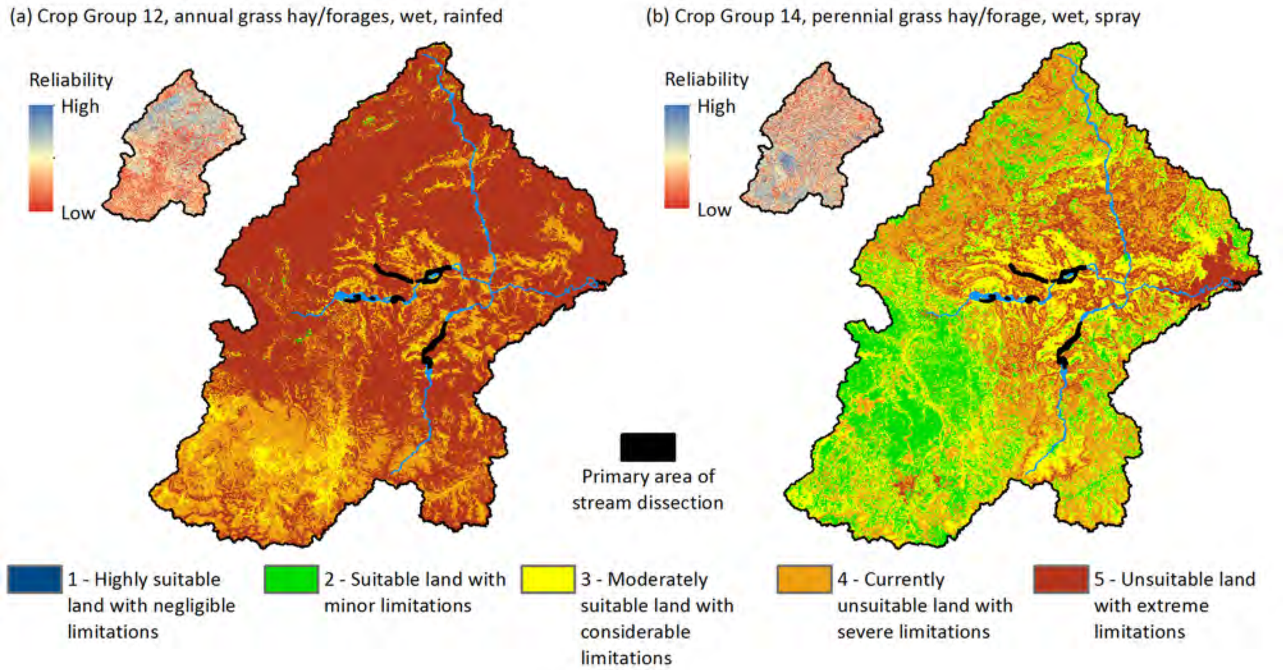


Figure 3-20 Modelled land suitability for (a) Crop Group 12, 'grass hay/forage (annual)' such as sorghum (forage), rainfed in the wet season and (b) Crop Group 14 'grass hay/forage (perennial)' such as Rhodes grass, under spray irrigation

Insets illustrate reliability of land suitability mapping. Note that these land suitability maps do not take into consideration flooding, risk of secondary salinisation or availability of water. More detail for the crop groups can be found in Table 2-6

Figure 3-21 (a) shows the land suitability distribution for Crop Group 10 pulse crops (e.g. Mungbean) under dry season spray irrigation management. There are significant areas of both Class 2 and 3 land suitabilities throughout the catchment. Much of the Class 2 areas are in the northern areas of the Sturt Plateau and associated with SGG 4.1 (red loamy) soils; these areas coincide with area 'A' (Figure 3-11). Smaller areas of Class 2 suitability areas occur in the Wilton River Plateau, again associated with SGG 4.1 (red loamy) soils. There are also some Class 2 areas and these often coincide with areas 'B' and 'C' from Figure 3-11. Class 3 areas cover much of the remaining catchment and are concentrated in the Sturt Plateau on SGG 4.1 (red loamy) and SGG 9 (cracking clay) soils. These Class 3 patterns repeat on the Wilton River Plateau with areas 'B' and 'C' (Figure 3-11) and in the Gulf Fall country with areas 'B' and 'D' (Figure 3-11) in the alluvial soils (SGG 9, cracking clay soils), the east of the coastal plain associated with SGG 4.2 soils (brown, yellow and grey loam), and the southern Gulf Fall where SGG 4.1 (red loam) and SGG 9 (cracking clays) soils dominate. In terms of areas covered, approximately 2,641,700 ha (34.1%) of the catchment is mapped as Class 3 and approximately 496,700 ha (6.4%) mapped as Class 2 (Figure 3-26). Mapping reliability is variable throughout the catchment with areas of stronger prediction in the southern Sturt Plateau and central Gulf Fall areas.

The land suitability of Crop Group 13, legume hay / forages (e.g. lablab) under dry-season furrow irrigation is shown in Figure 3-21 (b). This shows the most prospective areas to be in the middle of the Gulf Fall country associated with Roper River and Wilton River alluvium dominated by SGG 9 (cracking clay) soils, mapped as suitability Class 3. These areas are linked to 'B' and 'C' areas in Figure 3-11. There are lesser areas of Class 3 on the clay deposits (SGG 9, cracking clay soils) on the Sturt Plateau. Class 3 areas occupy approximately 303,600 ha (3.9%) of the catchment (Figure 3-26) Sturt Plateau. Mapping reliability is strongest in the eastern parts of the Sturt Plateau and the coastal plain near the river mouth, and reasonably strong in the rest of the Sturt Plateau.

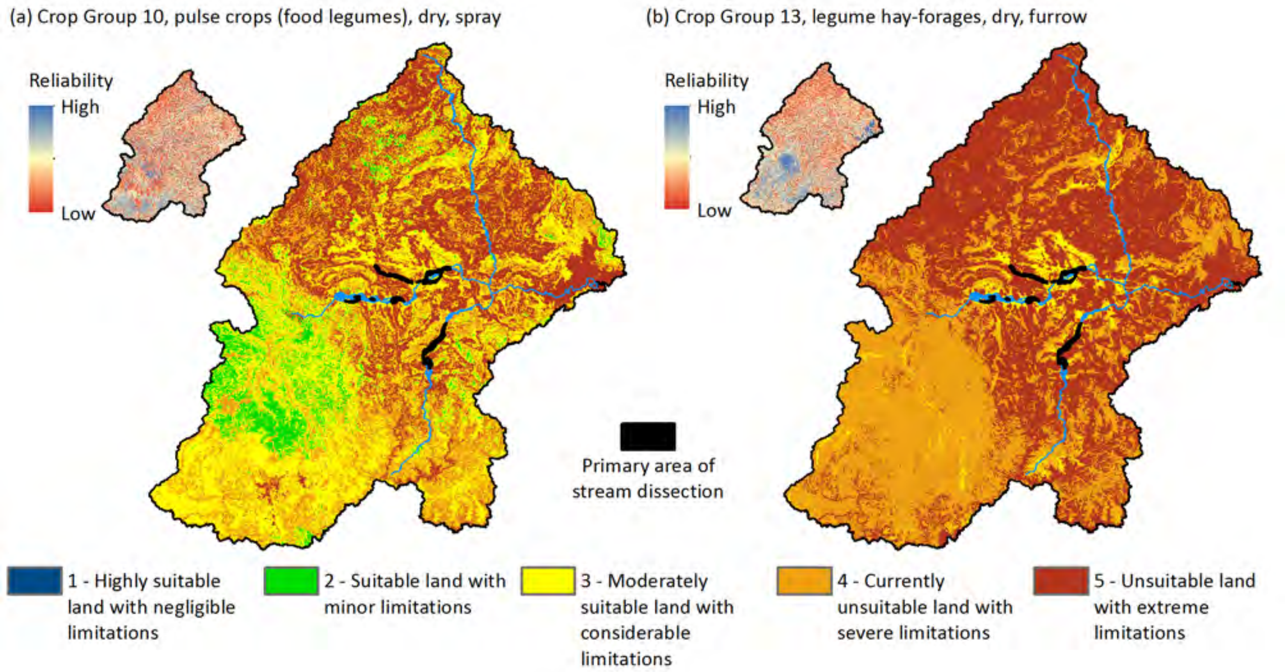


Figure 3-21 Modelled land suitability for (a) Crop Group 10, 'pulse crops (food legumes)' such as soybean, dry-season spray irrigation and (b) Crop Group 13 'legume hay/forages' such as Cavalcade, dry-season furrow irrigation

Insets illustrate reliability of land suitability mapping. Note that these land suitability maps do not take into consideration flooding, risk of secondary salinisation or availability of water. More detail for the crop groups can be found in Table 2-6

Crop Group 1 monsoonal tropical tree crops/horticulture (fruit), monsoonal perennial tropical tree crops (e.g. mango) under trickle irrigation land suitability mapping is shown in Figure 3-22 (a). This shows the suitability of land under this management to be widespread across the catchment – with exclusion of shallow soils and soils with potential ASS. Much of the Class 2 areas are associated with the level to gently undulating, deep to very deep, well drained soils (SGG 4.1 red loam) soils in the northern Sturt Plateau (see 'A' areas, Figure 3-11), while there are also significant areas in the northern areas on the Wilton River Plateau. Minor areas of Class 2 on well drained friable loams (SGG 2) are found throughout the central areas of the Gulf Fall country, around 'D' areas in Figure 3-11. Class 3 soils are found throughout the catchment, especially in the southern Sturt Plateau 'A' areas (Figure 3-11), mainly in SGG 4.1 (red loam) soils. Other clusters of Class 3 soils area are noted in the southern areas of the Gulf Fall country (mainly SGG 4.1, red loamy soils). Approximately 2,983,600 ha (38.6%) of the catchment is mapped as Class 3 and 526,000 ha (6.8%) as Class 2 (Figure 3-26). Mapping reliability is greatest in the north and south sectors of the Sturt Plateau and in the north of the Wilton River Plateau.

Figure 3-22 (b) presents the land suitability map for Crop Group 2 tree crops/horticulture (fruit), tropical citrus (e.g. lime) under trickle irrigation. In many respects the suitability patterns match those discussed above for mango under trickle irrigation (Figure 3-22 (a)) with significant areas of Class 2 and 3 lands revealed in the northern Sturt Plateau. Again, the northern Sturt Plateau dominates the Class 2 suitability distribution where SGG 4.1 (red loamy) soils dominate, as well as in areas of the northern Wilton River Plateau, again coinciding with SGG 4.1 soils. Class 3 soils are less widespread in the central drainage basin (cf. mango, trickle irrigation) due to the higher sensitivity to soil wetness on the imperfectly drained clay soils of the Roper River alluvium, but are well represented in the southern Sturt Plateau where deep well drained SGG 4.1 (red loamy) soils dominate; and the Gulf Fall country where SGG 4.1 (red loamy) soils, red friable loams (SGG 2) and moderately well drained SGG 9 (cracking clay) soils dominate. Figure 3-22 Class 3 areas cover approximately 2,160,600 ha (27.9%) for Group 2 tree crops, and 442,000 ha (5.7%) for Class 2 (Figure 3-26). The reliability of mapping is best in the northern and southern Sturt Plateau and north-most areas of the Wilton River Plateau.

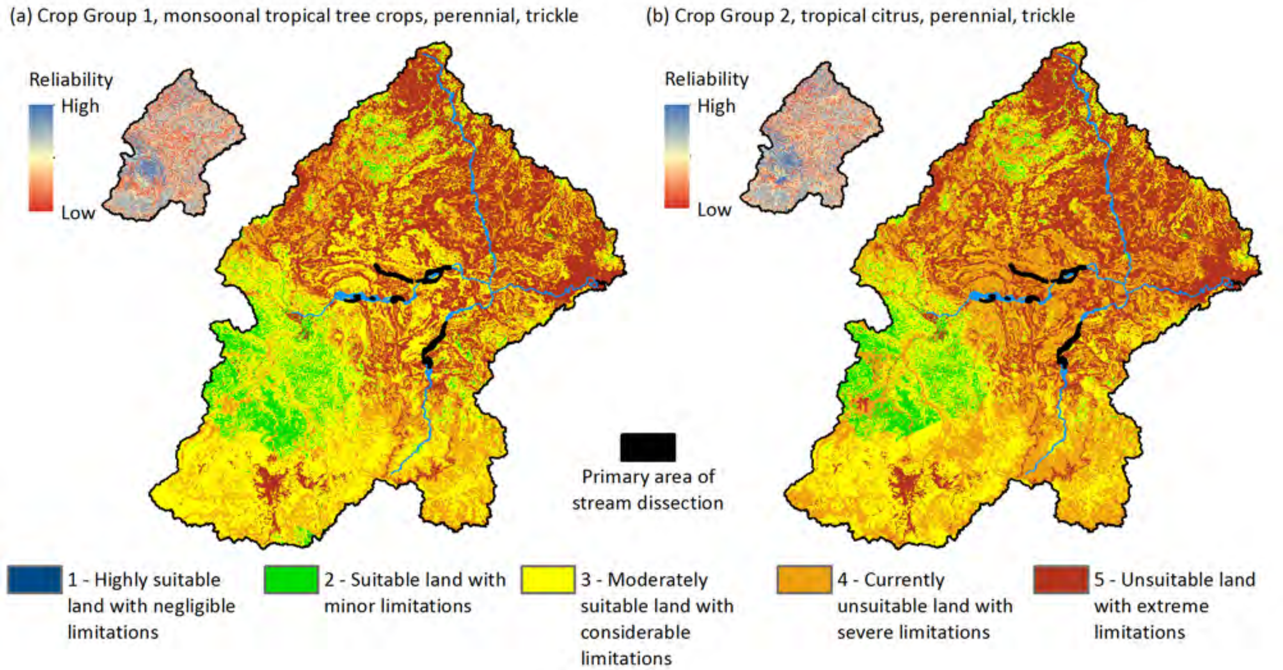


Figure 3-22 Modelled land suitability for (a) Crop Group 1, 'monsoonal tropical tree crops' such as mango, under trickle irrigation and (b) Crop Group 2 'Tropical citrus' such as lemon, under trickle irrigation

Insets illustrate reliability of land suitability mapping. Note that these land suitability maps do not take into consideration flooding, risk of secondary salinisation or availability of water. More detail for the crop groups can be found in Table 2-6

Figure 3-23 (a) shows that there is little opportunity in the catchment for Crop Group 19, oilseed crops (e.g. sunflower, sesame) under wet season furrow irrigation management. Areas of viability (i.e. Class 3) can be found in the SGG 9 (cracking clay) soils closely flanking drainage lines in the central Gulf Fall country, and minor examples on the Sturt Plateau, again SGG 9 (cracking clay) soils. Approximately 105,800 ha (1.4%) of the catchment is mapped with Class 3 suitability (Figure 3-26). Mapping reliability is variable throughout the catchment, although generally stronger on the Sturt Plateau.

As shown in Figure 3-23 (b) for Crop Group 9, small-seeded crops (e.g. chia, quinoa) under dry season spray irrigation there are significant areas of the catchment that are suitable. Large areas of the Sturt Plateau's level, moderately deep to very deep, non-gravelly SGG 4.1 (red loam) soils are mapped as Class 2 (areas 'A', Figure 3-11) and in the northern parts of the Wilton River Plateau, again corresponding to SGG 4.1 soils. There are also examples of Class 2 soils corresponding to some SGG 9 (cracking clays) soils in the southern Gulf Fall country, as well as in SGG 4.2 (brown, yellow and grey loam) soils in the extreme east of the coastal plain north of the river's mouth. Class 3 areas are widespread on the southern Sturt Plateau associated with SGG 4.1 (red loam) soils and SGG 9 (cracking clay) soils. The catchment features 580,900 ha (7.5%) of Class 2 soils and 2,734,800 ha (35.3%) of Class 3 soils (Figure 3-26). Mapping reliability is variable throughout the catchment but generally strongest in the Sturt Plateau.

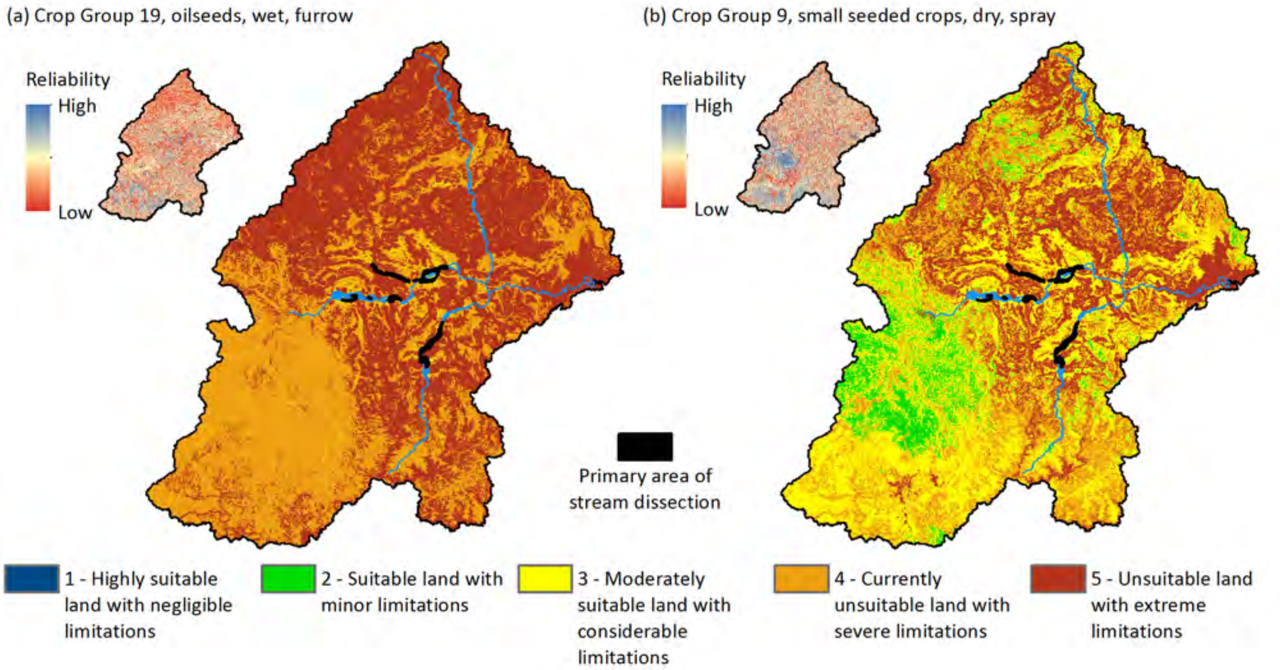


Figure 3-23 Modelled land suitability for (a) Crop Group 19, 'oilseeds' such as sesame. under wet-season furrow irrigation and (b) Crop Group 9 'small-seeded crops' such as hemp, under dry-season spray irrigation

Insets illustrate reliability of land suitability mapping. Note that these land suitability maps do not take into consideration flooding, risk of secondary salinisation or availability of water. More detail for the crop groups can be found in Table 2-6

Figure 3-24 (a) shows the land suitabilities for Crop Group 3, intensive horticulture (vegetables, row crops, e.g. cucurbits) under dry season trickle irrigation. On the Sturt Plateau there are significant areas of Class 2 soils that are linked to level, moderately deep to very deep, non-gravelly SGG 4.1 (red loam) soils. Other significant areas of Class 2 are found in the Wilton River Plateau where SGG 4.1 (red loam) soils are found. There are also lesser areas of Class 2 in the southern Gulf Fall country on alluvial plains (i.e. SGG 9 (cracking clay) soils). Class 3 soils are widespread in the southern Sturt Plateau (SGG 4.1 (red loamy) and SGG 9 (cracking clay) soils. Other soils contributing to Class 3 include SGG 2 (friable loams) and SGG 4.2 (brown, yellow and grey loams) soils, particularly in the eastern areas of the Gulf Fall. Class 2 areas represent approximately 2,801,400 ha (36.2%) of the catchment, and Class 3, 588,900 ha (7.6%) (Figure 3-26). Mapping reliability is variable throughout the catchment, although strongest in the southern and northern parts of the Sturt Plateau, and near to the river mouth on the coastal plain.

The land suitability patterns for Crop Group 6, root crops (e.g. cassava and peanut) under dry-season spray irrigation management (Figure 3-24 (b)) are similar to the Group 3 crops under dry-season trickle irrigation (Figure 3-24 (a)). Class 2 areas dominate the northern Sturt Plateau and the northern areas of the Wilton River Plateau, and these areas are associated with deep non-gravelly sandy surfaced SGG 4.1 (red loamy) soils. There is also a significant area of Class 3 soils in the southern Sturt Plateau and southern drainage areas of the Gulf Fall country corresponding to non-gravelly loamy surfaced SGG 4.1 (red loamy) soils. Suitability Class 2 covers approximately 2,309,600 ha (29.8%) of the catchment, and Class 3 covers approximately 589,500 ha (7.6%) (Figure 3-26). The reliability of mapping is strongest in the north-east and the southern areas of the Sturt Plateau.

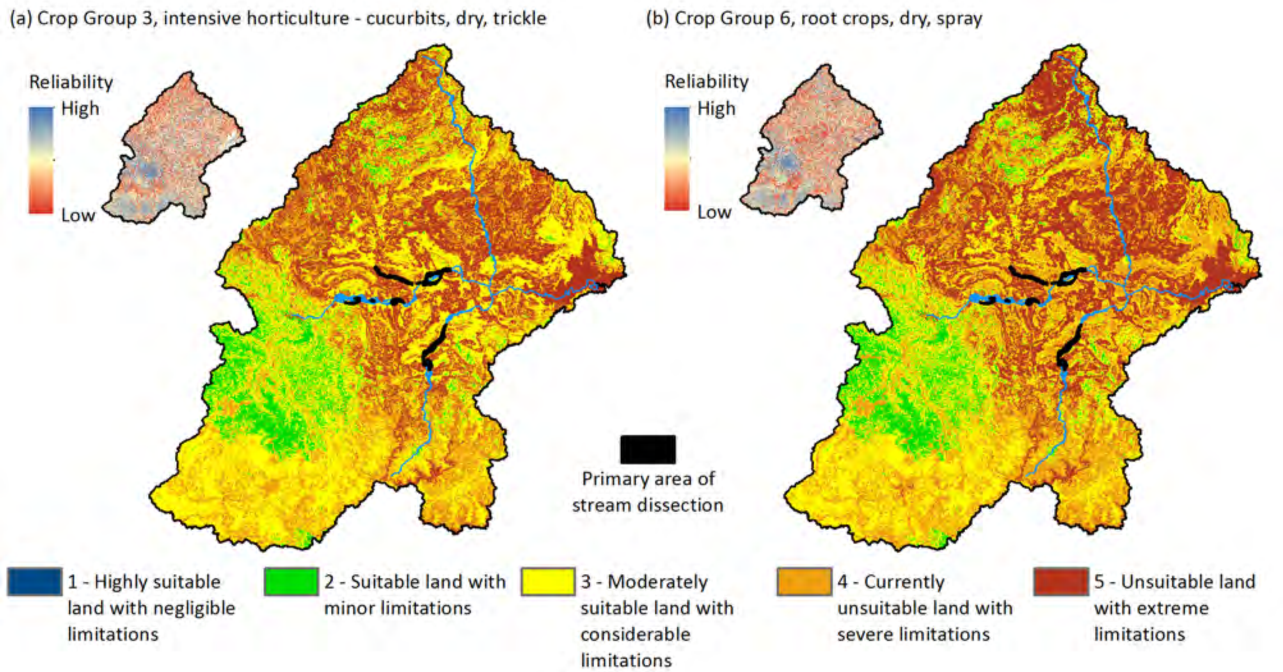


Figure 3-24 Modelled land suitability for (a) Crop Group 3, 'intensive horticulture – cucurbits' such as melons under dry-season trickle irrigation and (b) Crop Group 6 'root crops' such as cassava, under dry-season spray irrigation

Insets illustrate reliability of land suitability mapping. Note that these land suitability maps do not take into consideration flooding, risk of secondary salinisation or availability of water. More detail for the crop groups can be found in Table 2-6

Figure 3-25 (a) shows the land suitability distribution for Crop Group 15 (Indian sandalwood) under trickle irrigation. As with other trickle irrigated crops, this shows a large proportion of the northern Sturt Plateau (areas 'A', Figure 3-11), areas of the north Wilton River Plateau (areas 'C', Figure 3-11), and the southern drainage areas of the Gulf Fall country (areas 'D', Figure 3-11) are mapped as Class 2. These areas are closely aligned to occurrences of SGG 4.1 (red loam) soils and friable loams (SGG 2). Figure 3-24 Class 3 areas cover approximately 3,047,400 ha (39.4%), Class 2 areas cover approximately 488,000 ha (6.3%) and Class 1, approximately 3,800 ha (<0.1%) (Figure 3-26). Mapping reliability is strongest in the north of the Sturt Plateau and weakest in the centre of the Gulf Fall country.

The Crop Group 16 (African mahogany) under trickle irrigation management land suitability is shown in Figure 3-25 (b). The patterns closely follow those of Indian sandalwood shown in Figure 3-25 (a) with the most prospective growing areas (Class 1) too small in area to be shown at the display scale. Class 2 soils are associated with SGG 4.1 (red loam) soils in the northern Sturt Plateau and areas of the northern Wilton River Plateau. Areas of Class 3 are also common throughout the catchment, especially in the Sturt Plateau SGG 4.1 (red loam) soils and minor examples of SGG 9 (cracking clay) soils along the drainage line, and in the friable loams (SGG 2) on the upper Wilton alluvial plains and on basic rocks scattered throughout the centre of the catchment in the Gulf Fall. Other areas dominated by Class 3 include soils fringing the drainage network in the central Gulf Fall country associated with SGG 9 (cracking clay) soils along the Roper River and major tributaries and on the sedimentary rocks of the upper Hodgson River catchment, and in the southern fringes of this country where SGG 4.1 (red loam) soils are more common. Approximately 3,700 ha (<0.1%) of the catchment is highly suited (Class 1) to African mahogany under trickle irrigation, approximately 552,000 ha (7.1%) is covered by Class 2, and approximately 3,114,700 ha (40.3%) is covered by Class 3 (Figure 3-26). Mapping reliability is strongest in north and south areas of the Sturt Plateau, and in much of the northern areas of the Wilton River Plateau and coastal plain.

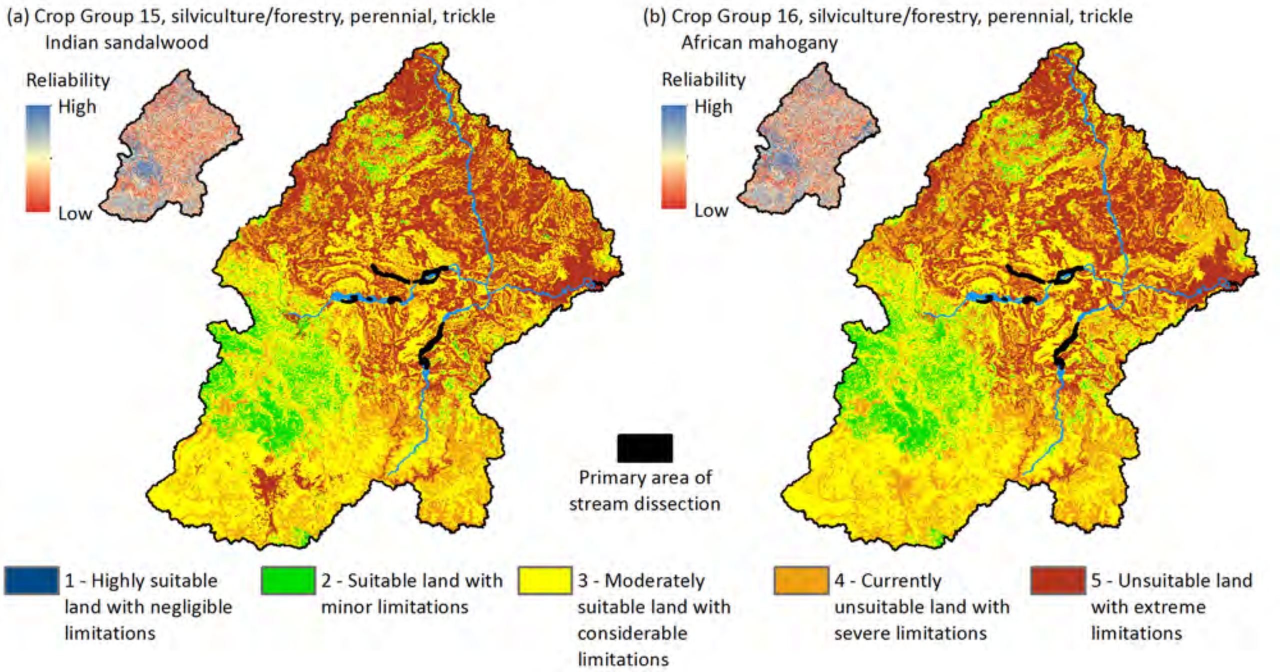


Figure 3-25 Modelled land suitability for (a) Crop Group 15, 'silviculture/forestry', such as Indian sandalwood, under trickle irrigation and (b) Crop Group 16 'silviculture/forestry' such as African mahogany, under trickle irrigation

Insets illustrate reliability of land suitability mapping. Note that these land suitability maps do not take into consideration flooding, risk of secondary salinisation or availability of water. More detail for the crop groups can be found in Table 2-6

The suitability class distributions for the Roper catchment for each of the 14 land uses discussed above are summarised in Figure 3-26. This shows the most prospective crop group / management option for the catchment to be Crop Group 14 perennial grass and hay forage crops (e.g. Rhodes grass) managed by wet season spray irrigation. This option proves to be suitable (Class 3 or better) in approximately 3,947,000 ha, that is 51% of the catchment. Contrasting this, cotton (Group 7) under wet season furrow irrigation is suitable over approximately 107,000 ha, which corresponds to 1.4% of the catchment. However, being only Class 3 suitability class (i.e. moderately suitable with considerable limitations), cotton grown under these management conditions is likely to present moderate challenges and inputs to achieve production targets and will require careful management. Wet season furrow crops are limited to wetness tolerant crops on mainly impermeable soils.

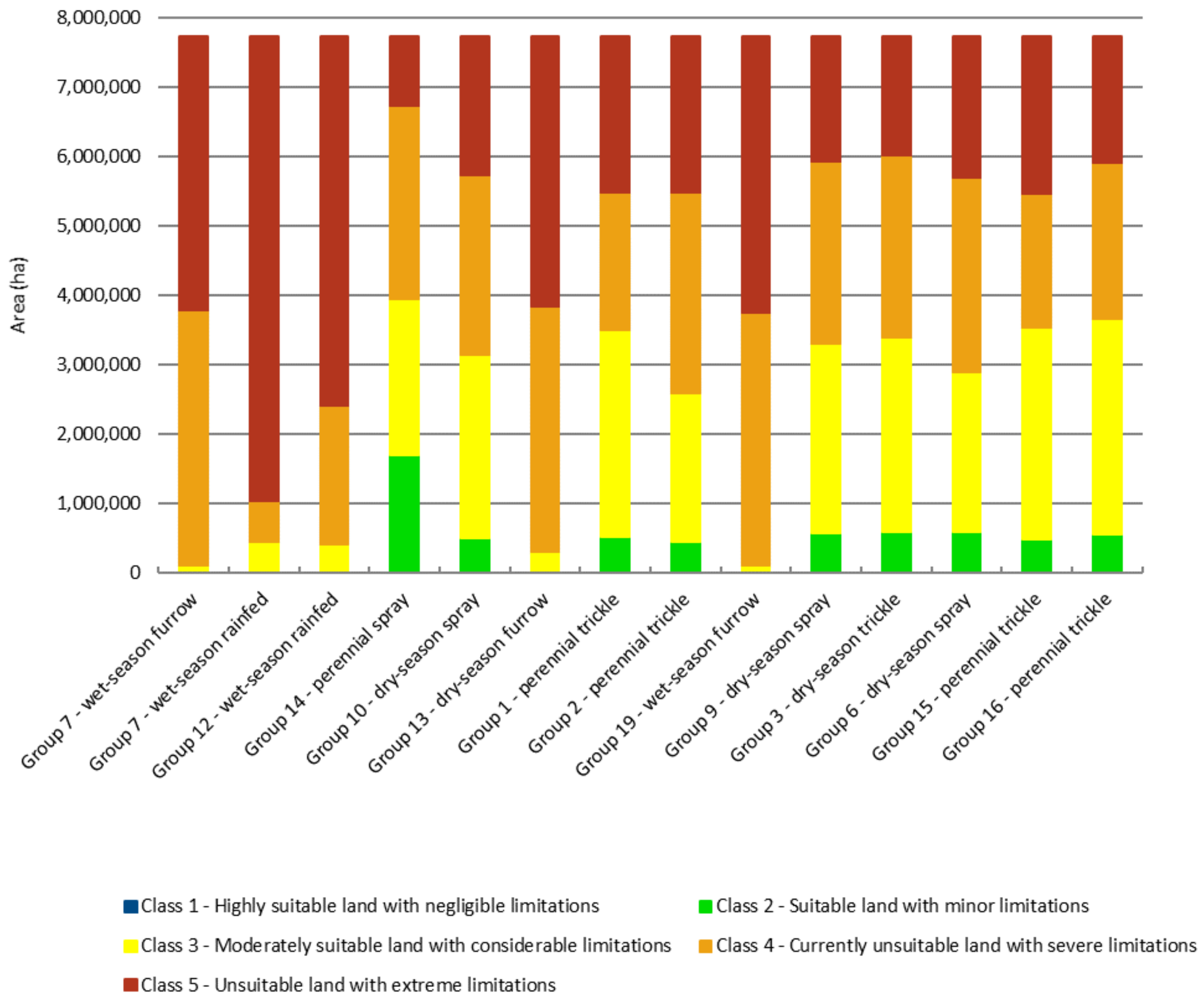


Figure 3-26 Area (ha) of the Roper catchment mapped in each of the land suitability classes for the 14 selected land use options

A description of the five land suitability classes is provided in Table 2-5. More detail on the 21 crop groups, and example crops, is found in Table 2-6 and Section 3.4.1

3.4.2 Landscape complexity

As discussed in Section 2.5.6, methods were tested to assess the contiguousness of parcels of suitable cropping lands based on natural distributions of soil and land variability. This need comes from operational farming constraints imposed on parcels of suitable land being too small either because of natural variability of land and soil attributes, or physical limits on suitable farming land parcel sizes caused by land dissection through anabranching caused by close alignment of streamlines and channelling. Examples of analytical results are presented below.

Contiguous suitable areas – an example

The final product of the contiguous suitable area analysis is shown in Figure 3-27 (c) illustrating the combination of crop suitability classes, having a mixture of suitability Classes 2, 3 and 4 (Figure 3-27 (a)) that satisfies the contiguous area rules. The processing steps follow Figure 3-27 (b) the result of combined Classes 1 to 3 and combined Classes 4 and 5 to create a binary map on ‘suitable’ versus ‘non-suitable’. Next, Figure 3-27 (c) shows the result of the ‘nibbling’ process to incorporate small areas of 'non-suitable' into 'suitable' to provide larger, more operationally viable areas. Figure 3-27 (d) shows the final output from Figure 3-27 (c) overlayed on the original suitable areas. This illustrates the process applied and residual areas, now coded 'not suitable', the original suitability Class 4 and 5 areas, as well as some Class 2 and 3 areas deemed unsuitable by virtue of their small (i.e. non-viable) on-ground dimensions.

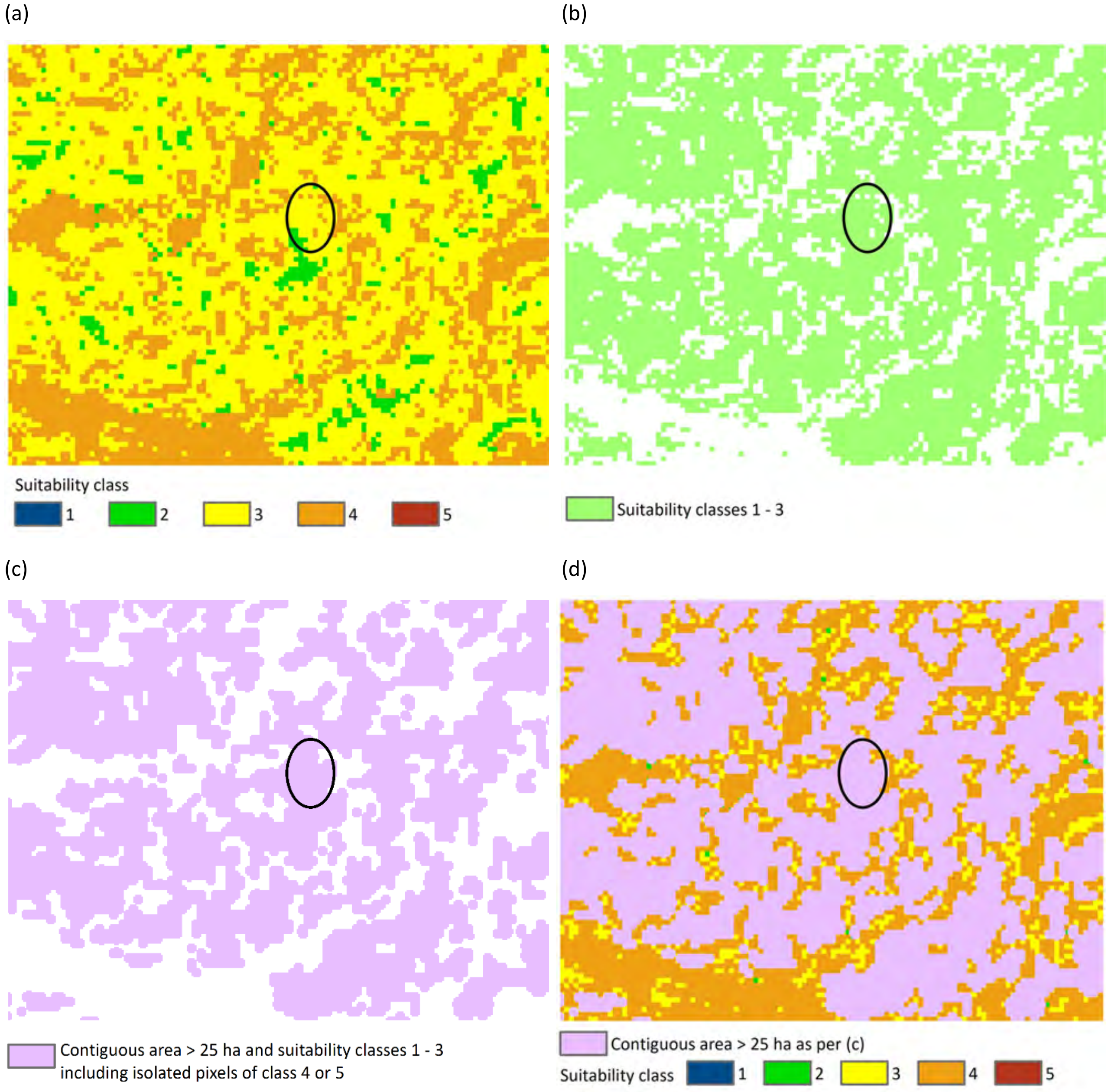
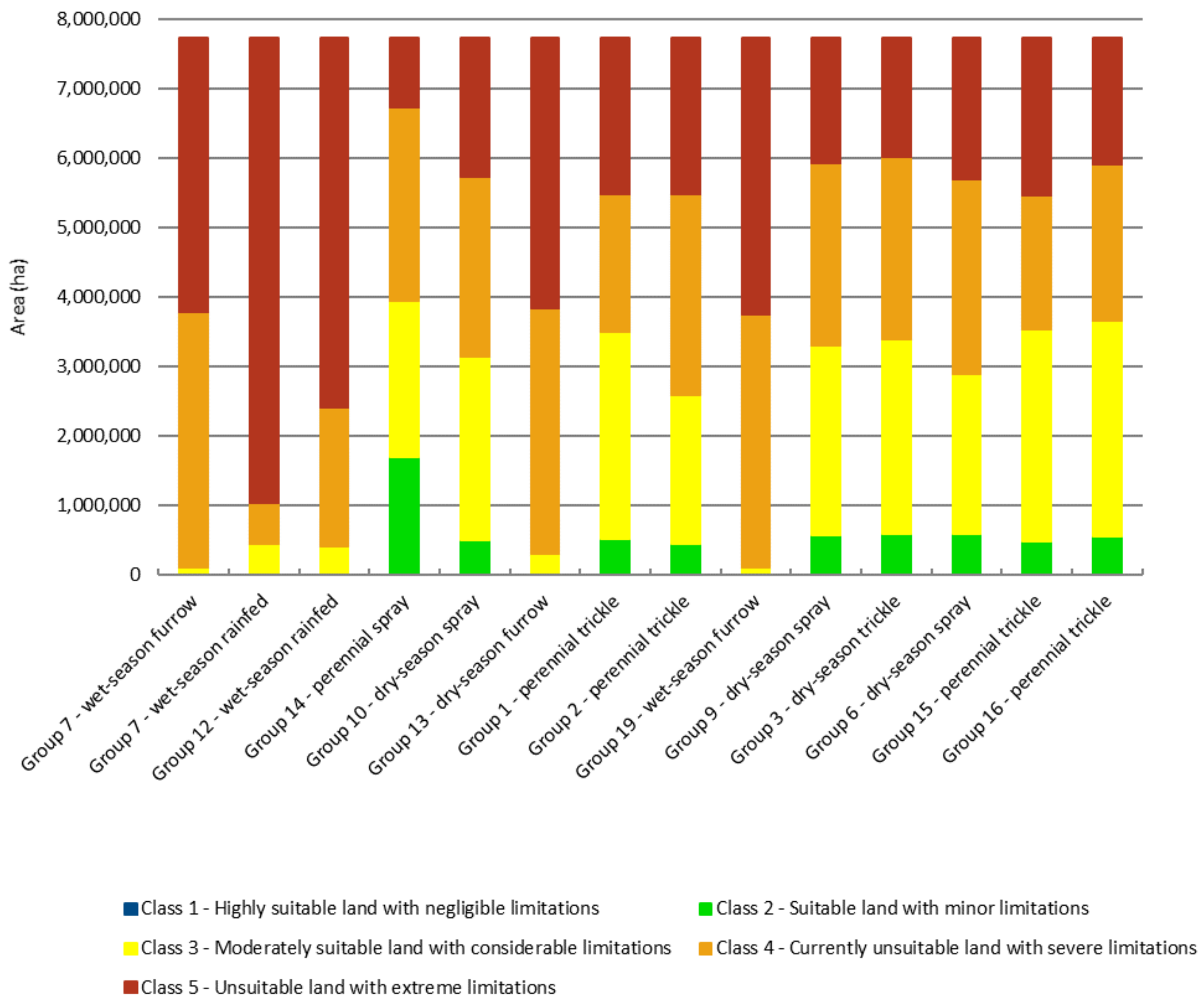


Figure 3-27 Example of the application of the contiguous areas processing, the black ellipse is used to highlight agriculturally unsuitable single and double pixels that get included into the suitable contiguous area data reflecting on-ground management

Data were simplified from (a) original suitability data to (b) Class 1 – 3 combined to be 'suitable'. Then minimum length and area rules applied for the final output (c) with the inclusion of several isolated pixels previously categorised as Class 4 or 5, and (d) final output overlying the original data management. Wet season furrow crops are limited to wetness tolerant crops on mainly impermeable soils.



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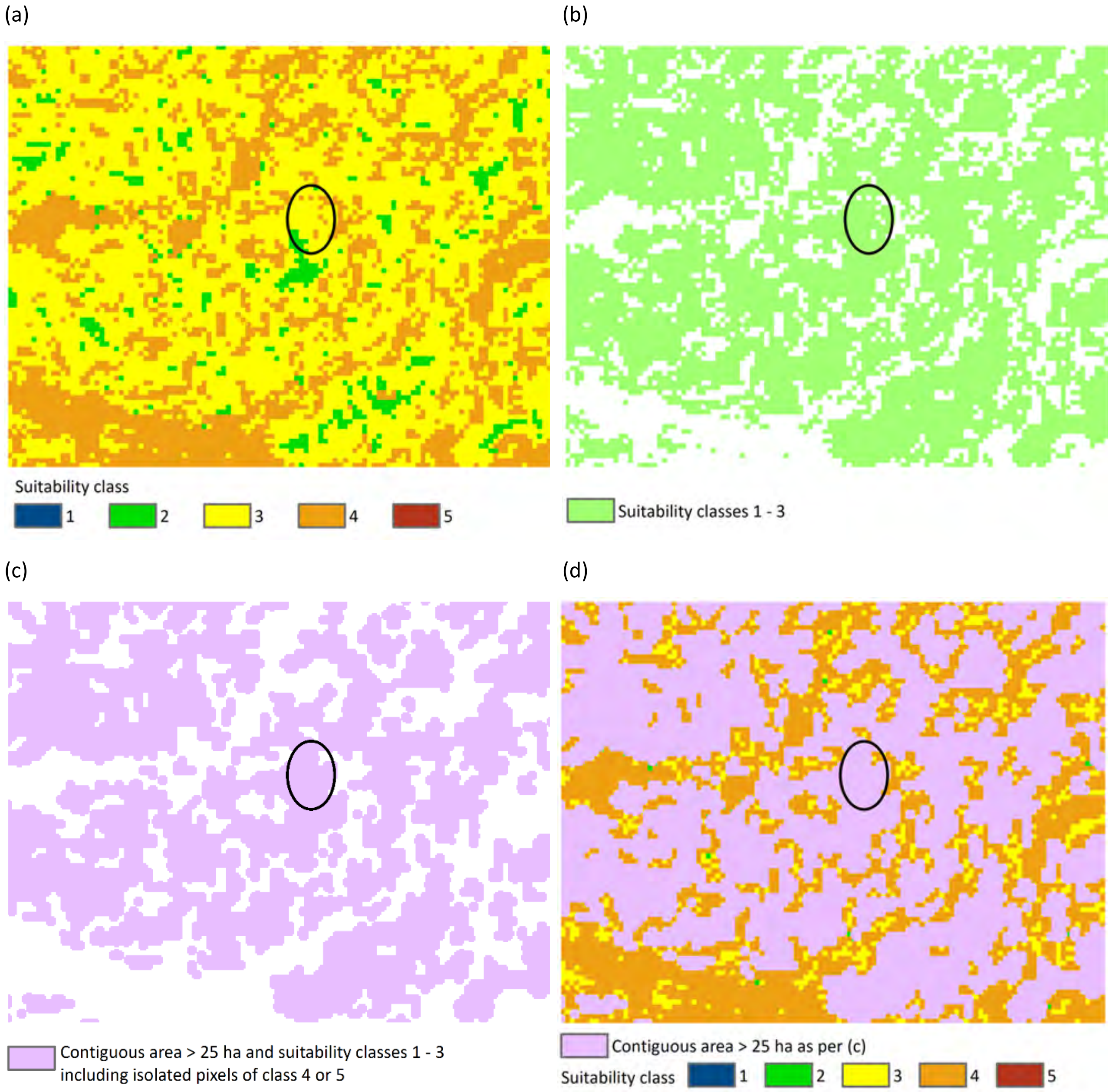

Figure 3-27 Example of the application of the contiguous areas processing, the black ellipse is used to highlight agriculturally unsuitable single and double pixels that get included into the suitable contiguous area data reflecting on-ground management

Data were simplified from (a) original suitability data to (b) Class 1 – 3 combined to be ‘suitable’. Then minimum length and area rules applied for the final output (c) with the inclusion of several isolated pixels previously categorised as Class 4 or 5, and (d) final output overlying the original data

Floodplain stream dissection – an example

Figure 3-28 shows an example of the results of analysis of stream dissection along a heavily dissected section of the Roper River with LiDAR coverage. This is a result of the rules described in Section 2.5.6 that areas within the coloured buffers were deemed too affected by drainage dissection of the potential land to be practically viable for farming because of the insufficiently large parcels. Acceptable results were achieved in the flat terrain containing well-defined channels, although the analysis proved more problematic where local high points occur within the search radius, but these fell largely outside the floodplain.

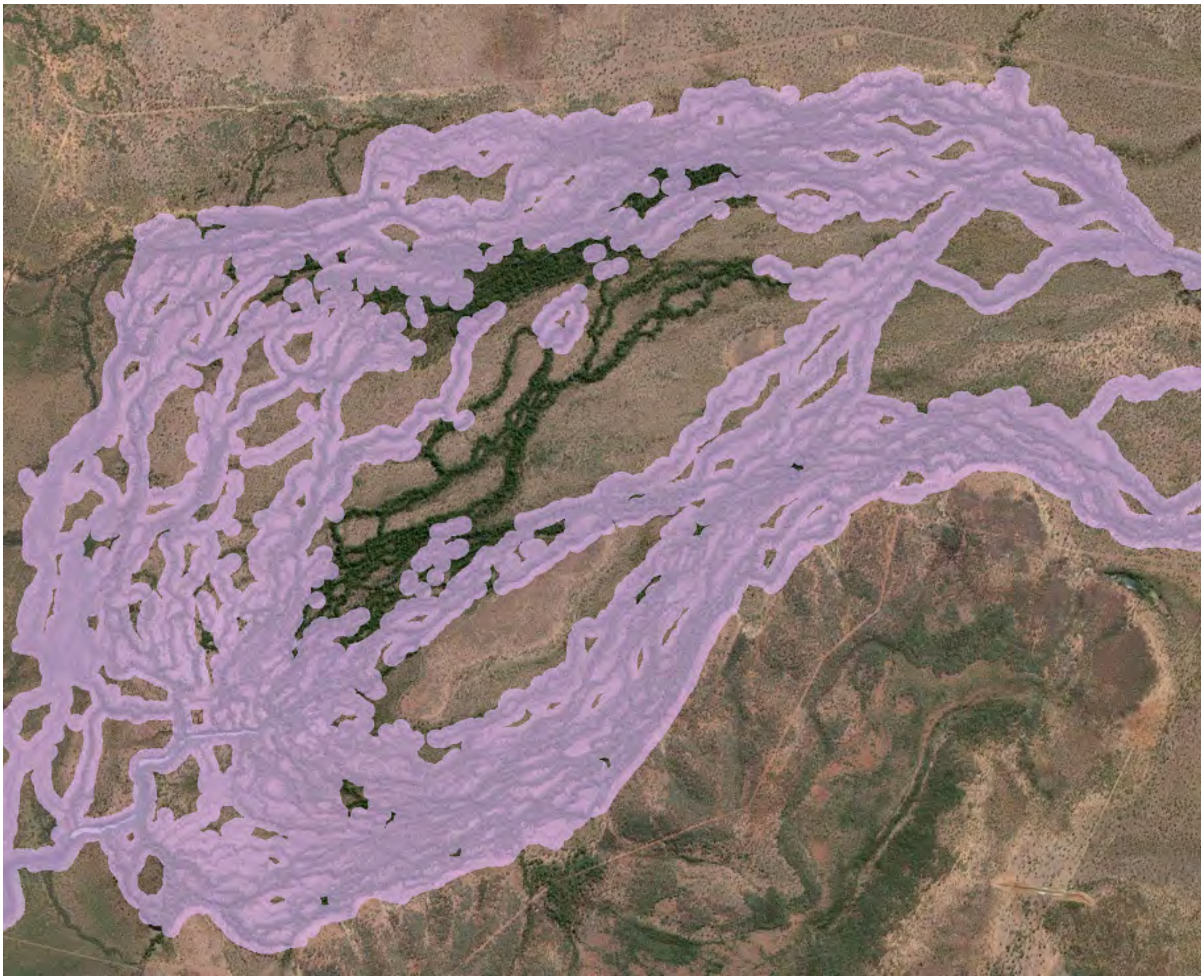

Figure 3-28 A section of the Roper River floodplain alluvium showing the mapped extent (purple) of the stream dissection

Streams running through the centre section of the floodplain have not been identified because the channels were less than 1 m deep.

As discussed, the methods worked through here to address landscape complexity were not imposed in the land suitability framework. This is because it is not considered appropriate in this Assessment to impose these limitations on farming opportunity because each developer will have different investment thresholds and expectations on financial returns, and each concern is likely to apply their own rules as to how the land is parcelled and managed during the set-up phase. However, the examples presented here outline some methods that can be applied to address these landscape complexity issues – issues that are likely to be more significant to this Assessment area than others because of the high degree of dissection observed along the drainage courses in the catchment.

3.4.3 Versatile agricultural land

This section displays the agricultural versatility of lands in the Roper catchment and captures the two approaches outlined in Section 2.5.7.

Figure 3-29 shows the versatility of agriculture lands from the perspective of the 14 exemplar land uses as per above representing a range of crop groups X season X irrigation type. Most of the Sturt Plateau displays a moderate to high level of versatility, coinciding with the combination of favourable soil attributes, notably AWC (Figure 3-17), permeability (Figure 3-15) and soil depth (Figure 3-16). These versatile soils strongly coincide with SGG 4.1 (red loamy) soils and area ‘A’ from Figure 3-11. Other areas of higher versatility are found in the Wilton River Plateau associated with the alluvium of the drainage margins, typically SGG 2 (friable non-cracking clay or clay loam soils) and SGG 9 (cracking clay soils), and in many instances coinciding with areas ‘B’ and ‘C’ from Figure 3-11. Much of the Roper River alluvium in the Gulf Fall country also shows higher levels of versatility, especially in the headwaters of the Hodgson River (areas ‘B’ and ‘D’, Figure 3-11). Much of the SGG 4.2 (brown, yellow and grey loam) soils found in the east, north of the river mouth also show a moderate to high level of versatility.

Figure 3-30 shows the versatility of agriculture under four management systems, namely furrow, spray, trickle irrigation and rainfed. In terms of irrigation-type versatility, a large proportion of the Assessment area shows high to moderate versatility for spray irrigation (Figure 3-30 (a), 23 land uses). Much of the Sturt Plateau is highly versatile (see ‘A’ areas, Figure 3-11). These areas tend to coincide with moderately permeable (Figure 3-15), loamy soils (SGG 4) (Figure 3-11) with larger AWC values (Figure 3-17). Other areas of high versatility for spray irrigations are found throughout the alluvial soils of the Wilton River Plateau (SGG 2, friable non-cracking clay or clay loam soils, and SGG 9, cracking clay soils), and similarly in the Gulf Fall country. These areas coincide with areas ‘B’, ‘C’ and ‘D’ in Figure 3-11.

The versatility of land for trickle irrigation shown in Figure 3-30 (b) (10 land uses) closely mirrors the versatility distribution for spray irrigation (Figure 3-30 (a)) previously discussed. Much of the catchment shows high to moderate versality with greatest versatility coinciding with SGG 4.1 (red loamy), SGG 2 (friable non-cracking clay or clay loam) and SGG 9 (cracking clay) soils (Figure 3-11). These soils have favourable attributes for this form of irrigation, in particular suitable permeability (Figure 3-15) and soil depth (Figure 3-16).

The versatile furrow irrigated lands (Figure 3-30 (c), 17 land uses) are less extensive and mostly associated with the heavier alluvial soils (SGG 9, cracking clays) – typically areas ‘B’ (Figure 3-11) on river and drainage margins in the central areas of the Gulf Fall country and the upper Wilton River. Isolated patches of moderately versatile lands for furrow irrigation are also found on the Sturt Plateau on impermeable cracking clays soils (SGG 9) (Figure 3-15).

Under the rainfed system (Figure 3-30 (d), 8 land uses) areas of high to moderate versatility are found on the Sturt Plateau where larger AWC values (Figure 3-17) dominate, that is where soil depth (Figure 3-16) and suitable soil textures (Figure 3-14) combine. Here, soils are dominated by SGG 4.1 (red loam) and GSS 9 (cracking clay) soils (Figure 3-11). Some concentrations of versatile rainfed lands are also found in the alluvium (typically on SGG 9 (cracking clay)) soils in the Gulf Fall area as well as in the Wilton River Plateau. These more versatile areas typically coincide with ‘A’, ‘E’, ‘B’ and ‘C’ in Figure 3-11.

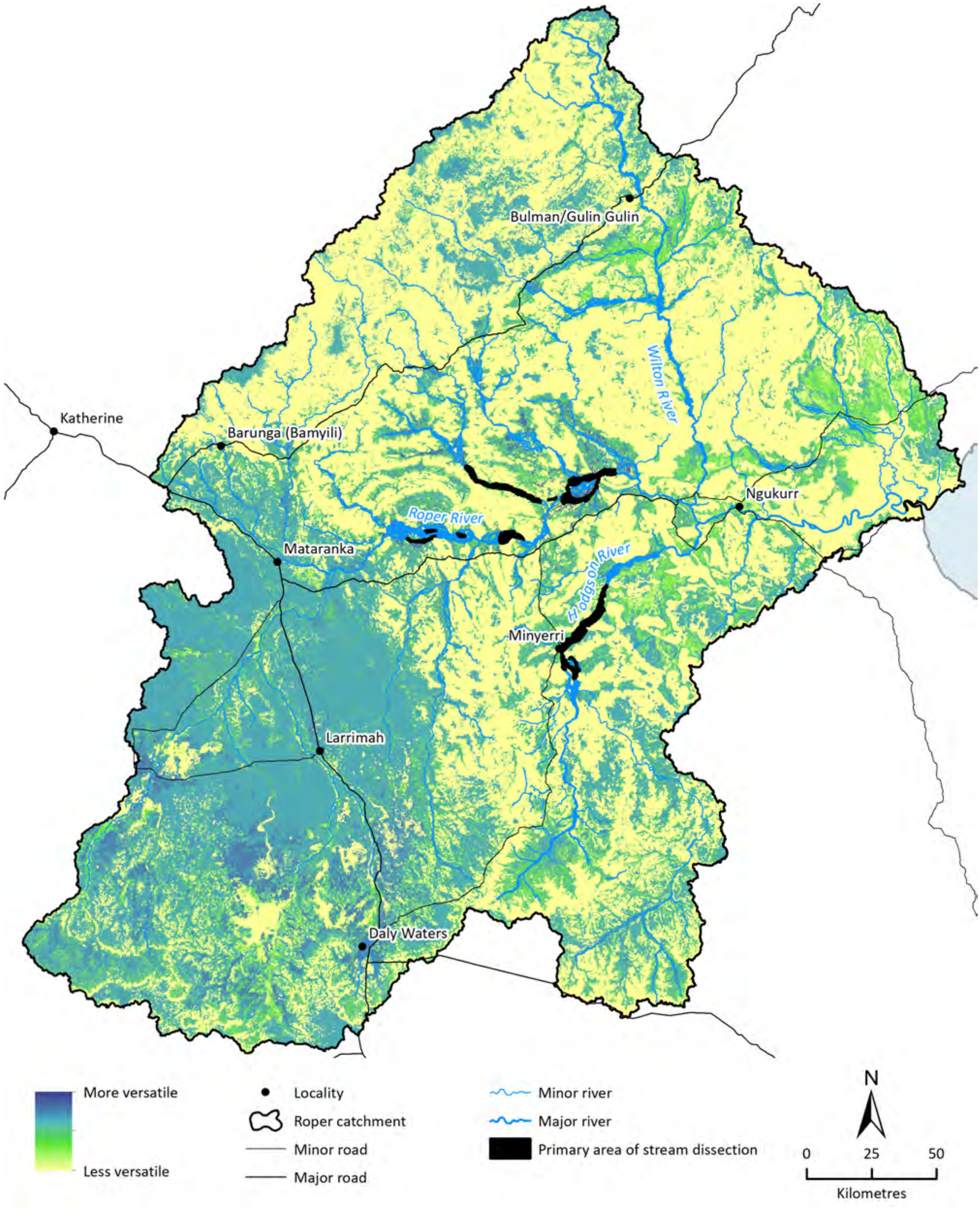

Figure 3-29 Agricultural versatility index map combining 14 unique land use options

Higher index values denote land that is likely to be suitable for more of the 14 selected land use options

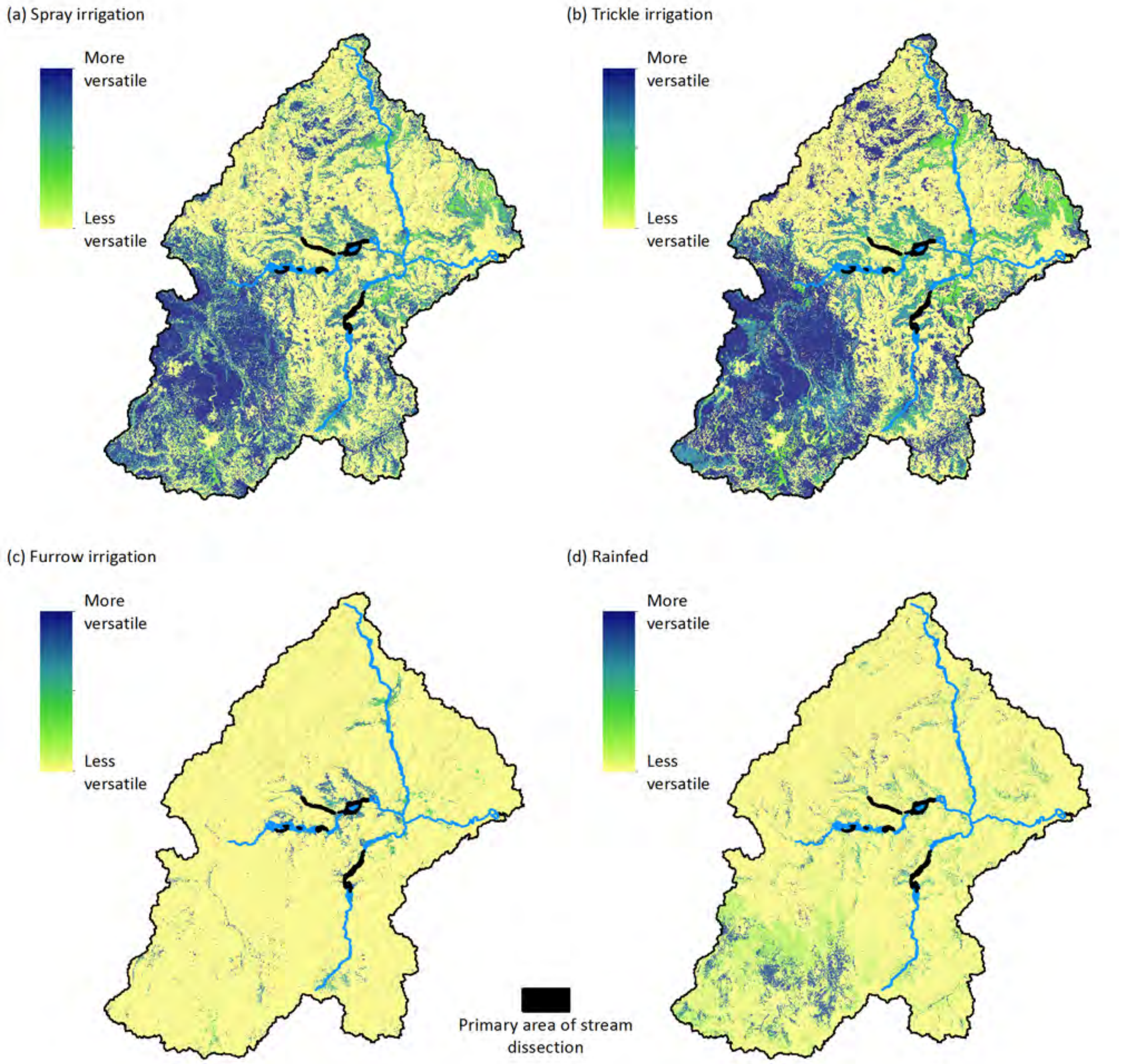

Figure 3-30 Agricultural versatility for each irrigation type and rainfed showing (a) spray, (b) trickle, (c) furrow irrigation, and (d) rainfed

Higher index values indicate greater versatility for each irrigation option. Displays are not suited to inter-irrigation type comparisons, rather should be used for intra-irrigation type comparisons

The versatility maps help to identify land where types of irrigation investment may be best targeted, or to guide where land can be most flexibly used if and as markets and technologies shift to provide farming resilience. Caution should be applied in comparing the versatility of certain areas across the range of irrigation types as the type and number of crops used for the assessment of each study area varies. The scale of mapping presented here is not suitable for identifying the potential of small parcels of land that may be sufficiently large enough on their own or closely clustered to be viable for farming on a case-by-case basis. The mapping as presented is only capable of providing a coarse impression of the scale of opportunity in the Assessment area. Finally, it has been noted that that versatility comparisons shown in Figure 3-30 are only suitable for intra-irrigation type assessments.

3.4.4 Aquaculture land suitability

As discussed in Section 2.5.8, the land suitability for aquaculture takes into account proximity to seawater for marine species but there is no proximity consideration for freshwater species. Soil and land limitations for lined and earthen ponds vary, for example pH relating to the physiological tolerances of species, sodicity for integrity of soil for impoundment maintenance and sustainability, and permeability for water retention, whereas limitations like slope, soil thickness and rockiness are pertinent to lined ponds. The land suitability frameworks for aquaculture are presented in Appendix C. Figure 1-2 presents the physiographic provinces that are referenced in discussions below.

The aquaculture land suitabilities for freshwater species are shown in Figure 3-31. This shows that a significant proportion of the catchment is suitable for freshwater lined aquaculture (Figure 3-31 (a)). Much of the Sturt Plateau is highly suitable (Class 1) or suitable with minor limitations (Class 2). This is because low slope gradient and low surface rockiness (Figure 3-13) correspond in the SGG 4.1 (red loam) soils, meaning that the need for intensive land preparation would be limited. Other areas of Class 1 and 2 are found in the alluvial areas of the Wilton River Plateau, and alluvial areas throughout the Gulf Fall country on SGG 2 (friable non-cracking clay or clay loam) and SGG 9 (cracking clay) and SGG 4.1 (red loam) soils, which are generally Class 2. In the Gulf Fall country there are significant instances of Class 1 soils associated with the alluvial soils along the major watercourses where SGG 2 (friable non-cracking clay or clay loam) and SGG 9 (cracking clay) soils dominate, including in the headwaters of the Hodgson River where SGG 9 (cracking clay) soils dominate. Near to the river mouth in the coastal plain, SGG 3 (seasonally or permanently wet) soils coincide with Class 1 suitability and in the same area, SGG 9 (cracking clay) and SGG 8 (sand or loam over sodic clay subsoils) soils contribute to Class 2 and 3 suitabilities. Approximately 2,476,000 ha (32%) is highly suited (Class 1) for freshwater lined aquaculture, and 1,695,500 ha (22%) is mapped as Class 2, and 162,500 ha is mapped as Class 3.

In comparison, opportunities for freshwater species in earthen ponds in the Assessment area are less (Figure 3-31 (b)). There are minor areas of Class 2 associated with SGG 9 (cracking clay) soils on the Sturt Plateau. The moderately to highly permeable soils (Figure 3-15) are unsuited to earthen water impoundments. Areas of Class 3 suitability on slowly permeable clays (SGG 9, cracking clay soils) are found on the Wilton River Plateau and in the Gulf Fall country (slowly permeable, or less, Figure 3-15). There are also significant areas of the coastal plain near the river mouth of Class 3 suitability on slowly permeable (Figure 3-15) seasonally or permanently wet soil (SGG 3), sodic soils (SGG 8, sand or loam over sodic clay subsoils) and cracking clay soils (SGG 9). These coastal plains have potential ASS that would require appropriate management. Fresh water using earthen ponds shows a very small proportion of Class 2 suitability totalling 8,500 ha (0.11%) and 537,000 ha (7%) as Class 3.

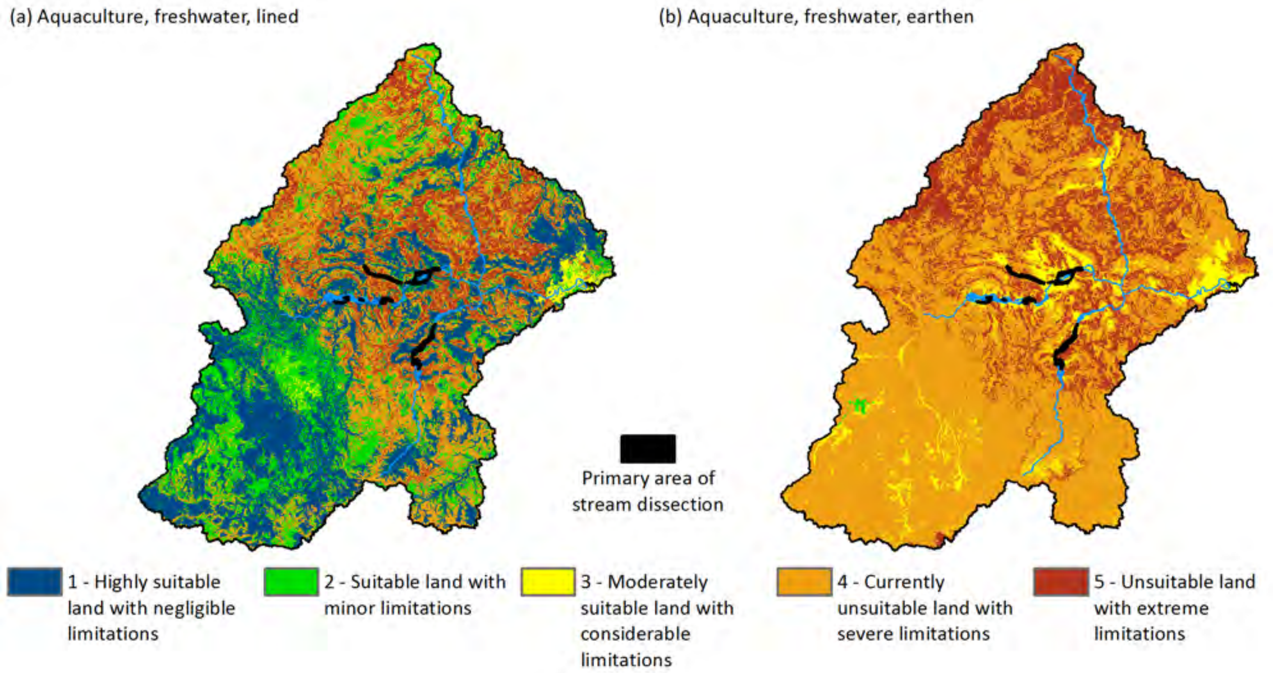

Figure 3-31 Land suitability for freshwater aquaculture in (a) lined ponds and (b) earthen ponds

The suitability for marine aquaculture has been restricted to a distance of 2 km to marine water source. Aquaculture land suitability in lined ponds is shown in Figure 3-32 (a) and shows suitability restricted to the areas under tidal influence and the river margins where SGG 9 (cracking clay) and SGG 3 (seasonally or permanently wet) soils dominate. These soils show the desired land surface characteristics such as no rockiness (Figure 3-13), and suitable slope (Figure 2-4) and soil thickness (Figure 3-16). However, these soils have the potential to produce ASS and so need to be managed accordingly. Approximately 4,500 ha (0.06%) of the catchment is highly suited (Class 1) to marine aquaculture in lined ponds, 7,700 ha (0.1%) as Class 2, and 48,000 ha (0.62%) as Class 3.

The land suitability patterns for marine species in earthen ponds (Figure 3-32 (b)) closely mirror those of the marine in lined ponds (Figure 3-32 (b)), although areas are restricted to slowly permeable soils (Figure 3-15, i.e. SGG 9 (cracking clay) soils). Approximately 43,000 ha (0.56%) of the catchment is mapped as suitability Class 3.

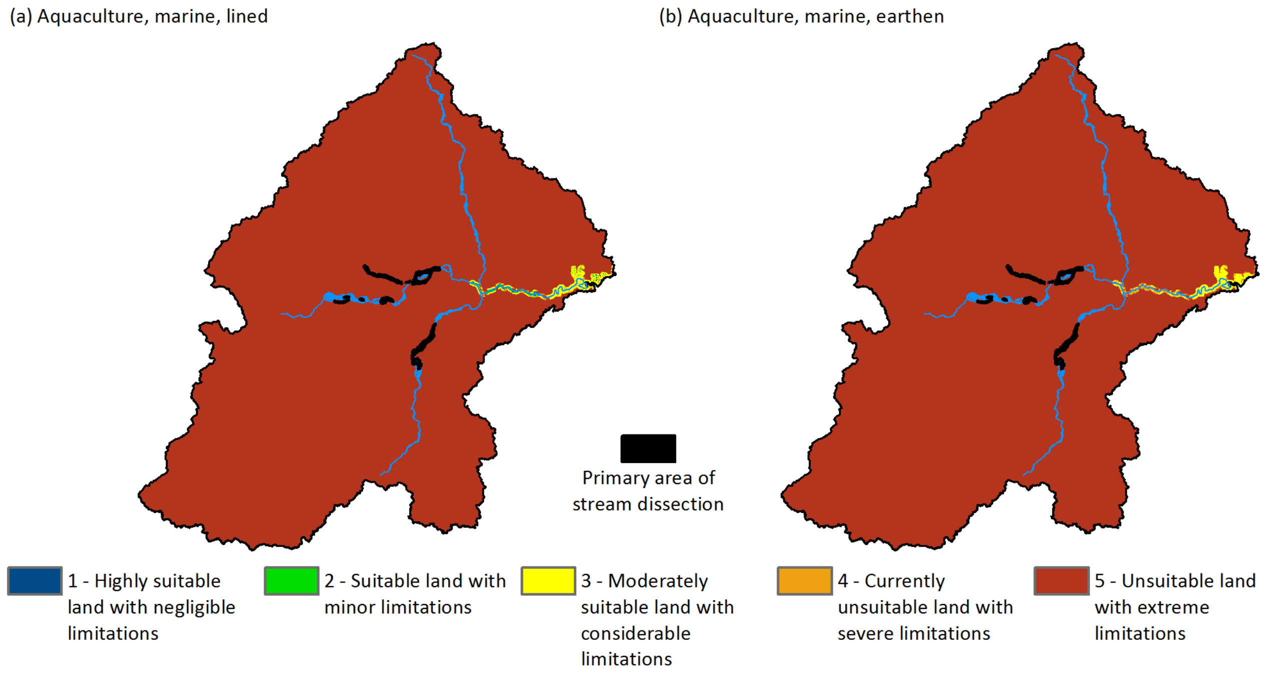

Figure 3-32 Land suitability for marine aquaculture in (a) lined ponds and (b) earthen ponds

3.4.5 Propagation of artefacts from DSM and land suitability data

As a footnote to the land suitability analysis, there will be instances of visible spatial artefacts in some mapped results inherited from the covariates and climate data. Artefacts are observed as unnaturally crisp edges in maps with no clear physiographic rationale. Artefacts may be inherited from the covariates used in the DSM (Section 2.4.2) and carried through into the DSM products. In this study there are likely to be three sources of artefacts: first, inherited from binary covariates (e.g. vector-based geological mapping). Second, created by the decision tree algorithm reflecting data decision points for threshold splits in continuous covariates (Section 2.4.4). Third, from raster-based covariates reflecting cultural land patterns, for example remote sensing showing the overprint of land use at boundaries like urban/rural interfaces, or paddock boundaries with different crops on each side.

While mapped artefacts sometimes draw the eye they are accepted as inherent data features and overall mapping quality is best judged against the quantitative data suite (i.e. statistical error and reliability mapping discussed in Sections 3.2.1 and 3.2.2). Due diligence by prospective land developers – as advocated in Section 3.4.2 – involving on-ground assessments prior to decision making can either identify or put context to mapped artefacts.

An example of artefact propagation flow from a DSM input covariate data through to land suitability mapping is shown in Figure 3-33. The origin of an apparent artefact, a cleared paddock with crisp edges is shown in the satellite remote sensing image in Figure 3-33 (a). The imagery is not used as a covariate input to the model however the Landsat Thematic Mapper Bare Earth covariate is (Figure 3-33 (b)). The resulting DSM correctly models the land that surrounds the cleared land as SGG 4.1, red loamy soils, whereas it incorrectly models the cleared land as SGG 9, cracking clay soils. Figure 3-33 (d) shows the bare earth covariate as highly influential in modelling the SGGs. The SGG classification error is propagated through to error in the land suitability modelling as shown in Figure 3-33 (e), where for dry-season spray-irrigated root crops the bare patch is classified as unsuitable when it should be suitable actually being SGG 4.1. With suitable permeability characteristics, and suitable for dry-season furrow-irrigated forage crops (Figure 3-33 (f)) because DSM mapped as cracking clay, when it is in practice unsuitable for this land use option – correctly being a permeable red loamy soil.

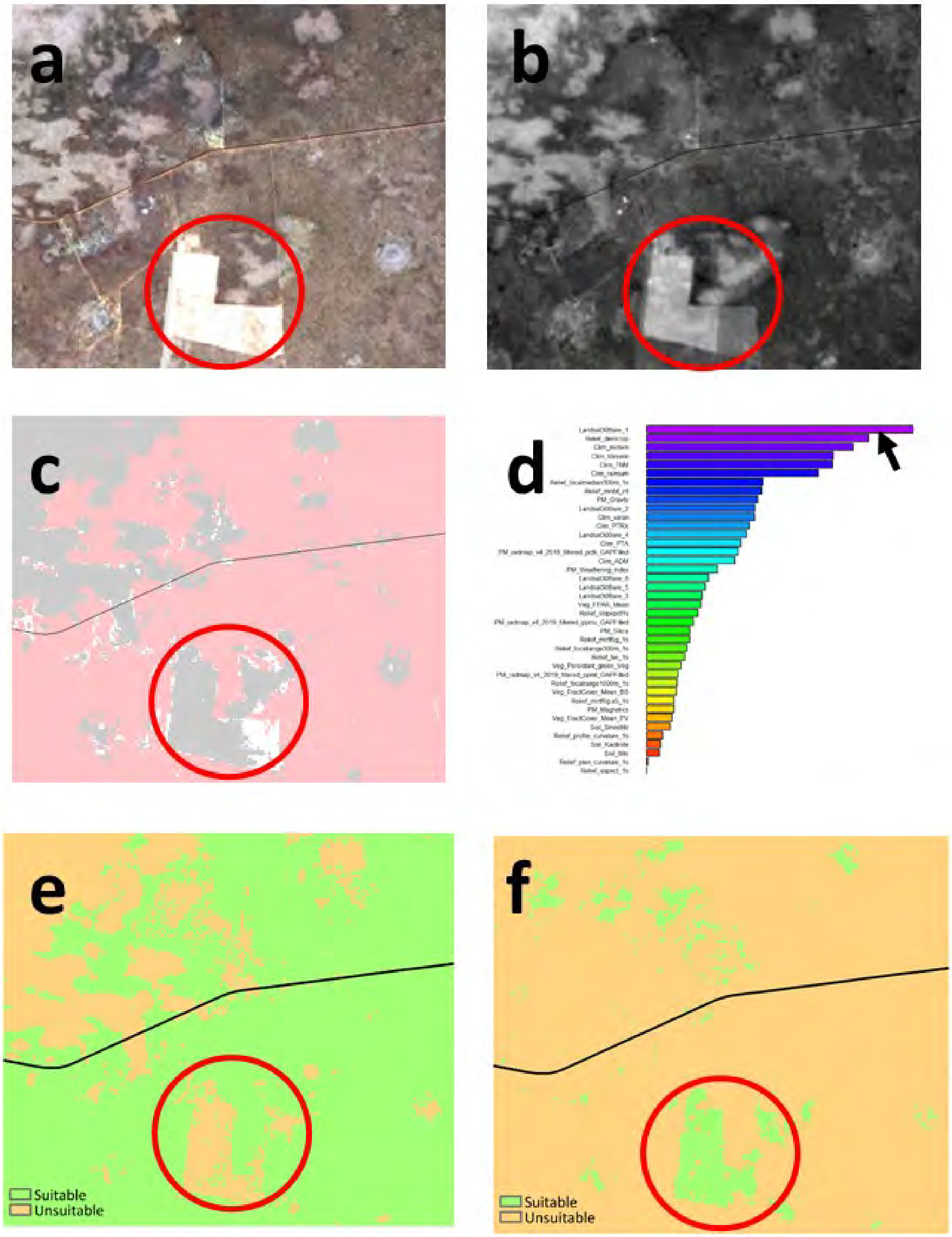

Figure 3-33 Propagation of an apparent artefact caused by cleared land for area circled red shown in satellite image from the Sturt Plateau

(a) The land is dominated by SGG 4.1 (red loamy) soil); (b) the bare earth covariate coverage of the area; (c) shows DSM to have incorrectly mapped the SGG 4.1 soil as SGG 9 (cracking clay) soil caused by the bare earth covariate; (d) shows that the bare earth covariate (arrowed) dominates the SGG DSM. Propagation of error caused by the SGG DSM mismatch is shown the land suitability mapping for dry-season furrow-irrigated forage crops (e). Soils that should be suitable are classed not suitable because of this SGG error; (f) shows another example in which dry-season furrow-irrigated forage crops are incorrectly mapped as suitable, which is incorrect because of unsuitable permeability of SGG 4.1 soils

4 Synthesis

This land suitability activity has applied digital land resource assessment methods to generate 58 agriculture and four aquaculture themed land suitability datasets and maps for the Roper River Water Resource Assessment. The Assessment area incorporates the catchment of the Roper River in the Northern Territory, which covers an area of 7,740,000 ha. The activity's main objective was to produce crop and aquaculture suitability data and maps to assist the Australian community and developer interests, land use policy, and to offer a broad appraisal of land intensification options for the Assessment area.

To achieve this aim, two major tasks were completed. First, new land and soil attribute data and maps were created using DSM techniques that incorporated new soil survey and legacy (pre-existing) soil data. Second, these newly acquired land and soil attribute maps were then integrated into a digitally-based land suitability analysis framework, based on the conventional land suitability assessment approach (FAO, 1976; 1985), to test and map land suitability for an expert determined set of crops grown under plausible management options (irrigated and non-irrigated) summarised in Appendix A. A land suitability analysis was also conducted for aquaculture for freshwater and marine species.

The methods used in this study have been adapted from those previously used in land suitability assessments from northern Australia, namely the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013; Harms et al., 2015; Thomas et al., 2015) and more recently the Northern Australia Water Resource Assessment (Thomas et al., 2018a; Thomas et al., 2018b).

The land suitability assessment is framed around crop 'limitations' for land and soil attributes supplied through the DSM and other publicly available datasets like climate, presented in Appendix B. In terms of cropping, these frameworks matched instances of crop group X season X irrigation type (and rainfed), and environmental conditions (soils, landscape and climate). Accompanying data showing mapping reliability were also delivered as part of the study, so users can objectively judge the quality of outputs. The land suitability rules for aquaculture for marine and freshwater species in earthen or lined ponds is presented in Appendix C. In a departure from previous assessments for simplicity purposes, individual crops were not assessed, rather groupings of crops ('crop groups') arranged to include a suite of crops requiring very similar growing, machinery and land degradation needs and so subject to the same limitations. In this case 21 crop groups were identified.

The 21 Crop Groups (see Table 2-6) comprising the 58 land use groupings of crop group X season (wet, dry and perennial) X irrigation type (17 furrow/flood, 23 spray, 10 trickle, and 8 rainfed) options represent over 120 individual crops that are listed in Appendix A and were modelled through the land suitability assessment. Based on the Food and Agriculture Organization land suitability system of analysis, the results are presented in a 5-class system that ranks the land suitability for each land use from highly suitable with negligible limitations (Class 1) to unsuitable land with extreme limitations; Classes 1 and 3 are marked as suitable. The 58 land uses that were modelled in this way are presented in Appendix D. It was not practical to discuss in the main body of this report all modelled outcomes, rather a selection of 14 realistic 'exemplar' combinations were selected for discussion.

A further interpretation of the land suitability data used a methodology to create indices capturing the versatility of cropping lands. These indices essentially combine crop land suitability mapping to discriminate areas coinciding with a high degree of land suitability in multiple crops (i.e. highly versatile lands) versus those areas where few or none were suitable (low or no versatility lands). Two types of agricultural versatility maps were generated: the first showing crop versatility for 14 plausible 'exemplar' cropping combinations, and the second showing irrigation versatility for each irrigation type (spray, trickle and furrow) and also rainfed agriculture. In practical terms, the indices may be used as a tool to guide government policy makers and developers to prioritise areas to focus the next phases of land evaluation, which must be the next step prior to any development.

Limitations that may feature in some land suitability frameworks – although not in scope this analysis – include economics and finances (e.g. subsidies and grants, produce market prices, fertilisers and fuel costs, etc.), flooding risk, land management-induced secondary salinity, conservation area exclusions, and proximity to irrigable water. Policy and land tenure limitations were not imposed in recognition that these socio-economic and political attributes of the landscape are non-permanent and may shift as economic, technological, community aspiration and values, legal and policy climates shift, at times quite rapidly. Some of these are reported with other activities in the Assessment. Caution should be employed when using the land suitability outputs from this activity for planning purposes without wider consideration of these limitations.

To summarise the outputs of the agricultural versatility maps, overall (i.e. simultaneously considering the 14 exemplar land uses), the most versatile lands in the Roper catchment were associated with the SGG soils of 4.1 (red loam) soils associated with deep lateritic soils on the Sturt and the Wilton River Plateaux, and the clays (SGG 2, friable non-cracking clay or clay loam soils, and SGG 9, cracking clay soils) that are found along the main river and significant tributaries on the plateaux and the Gulf Fall region. These soils are suited to irrigation because they are deep, level, rock free and have good water retention or drainage when needed for each type of irrigation. For example, the clays are suitable for furrow irrigation because they limit drainage whereas the deep loams are suitable for spray and trickle irrigation, particularly for horticultural crops, because of their suitable water holding (AWC), good drainage and permeability to limit waterlogging. In some cases, the scale of cropping opportunity appears significant in the Assessment area – subject to the availability of suitable water. Reflecting these soils, the results show that spray and trickle irrigation is likely to be prospective over much of the catchment where the SGG 4.1 (red loam) soils are widespread, whereas furrow irrigation is likely to be more suitable in the alluvial clays.

The outputs of the aquaculture land suitability show opportunity for freshwater species in lined ponds to be widespread throughout the catchment due to the extensive distribution of favourable soil and land characteristics (flat land, non-rocky, deep), whereas for fresh water with earthen pond, options are restricted to the impermeable alluvial clays to allow retention of water. Marine aquaculture's range is obviously restricted to the tidal zones of the catchment on the coastal plain.

The outputs of this activity inform users of the reliability of the land suitability mapping, so that they can determine for themselves the level of confidence they should apply when using the outputs. It is recommended that the maps and products generated by the activity be used at a printed map scale of approximately 1:250,000 (i.e. a low intensity or reconnaissance-type survey). It is therefore important to realise that the information provided here characterises land suitability over a broad area and thus is best suited for gaining a regional-scale overview. Additional, detailed on-ground soil and land investigations must be followed prior to planning development at the scheme or property scale, and assessment made in accordance with jurisdictional legislation (e.g. relating to acid sulfate soils).

Finally, the land suitability frameworks (crops and aquaculture) developed offer a systematic, quantitative framework to analyse land development opportunity in the Assessment area. This allows for realistic comparisons of the scale of opportunity to be made before development should continue. As knowledge grows and conditions change (e.g. land tenure, technology, climate) in the Assessment area, modifications can be made to the framework and the analyses re-run and updated. Modifications to the framework can include changed thresholds (e.g. to reflect new crop varieties), changing climate, or the supply of new datasets (e.g. finer scale DSM attribute maps) to allow finer scale investigations to be carried out.

Key datasets generated through this activity, including land suitability and soil attribute maps, and companion reliability maps, are publicly available from the CSIRO Data Access Portal (https://data.csiro.au/).

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Part II Appendices

Appendix A Land use combinations for crop groups and suitability analyses

To enable ease of compilation, the land use combinations for the land suitability analysis are presented in a coded form in the land suitability rules in Appendix B. The expanded forms are presented below. The structure of the code is ‘crop group’ then underscore ‘season’ then underscore ‘irrigation type’ (e.g. land use combination code ‘CropGrp3_D_S’ is ‘Crop group 3 dry-season spray-irrigated’). The ‘crop’ list below is from the Northern Australia Water Resource Assessment and carried into this Assessment. For the full list of crops in the Assessment refer to the Crop Groups in Table 2-6.

Apx Table A-1 Land use combinations for crop suitability analyses

LAND USE CODE	CROP	SEASON	IRRIGATION TYPE
CropGrp1_P_S	Mango, lychee	Perennial	Spray
CropGrp1_P_T	Mango, lychee	Perennial	Trickle
CropGrp2_P_T	Citrus	Perennial	Trickle
CropGrp3_D_S	Cucurbit	Dry	Spray
CropGrp3_D_T	Cucurbit	Dry	Trickle
CropGrp4_D_S	Capsicum, chilli, tomato, snake bean	Dry	Spray
CropGrp4_D_T	Capsicum, chilli, tomato, snake bean	Dry	Trickle
CropGrp5_D_T	Asian greens, asparagus	Dry	Trickle
CropGrp6_D_S	Sweet potato, peanut, cassava	Dry	Spray
CropGrp6_W_S	Sweet potato, peanut, cassava	Wet	Spray
CropGrp7_D_F	Cotton, sorghum (grain), maize, millet (forage)	Dry	Furrow
CropGrp7_D_S	Cotton, sorghum (grain), maize, millet (forage)	Dry	Spray
CropGrp7_W_F	Cotton, sorghum (grain), maize, millet (forage)	Wet	Furrow
CropGrp7_W_S	Cotton sorghum (grain), maize, millet (forage)	Wet	Spray
CropGrp7_W_R	Cotton, sorghum (grain), maize, millet (forage)	Wet	Rainfed
CropGrp8_D_F	Rice lowland	Dry	Furrow/flood
CropGrp8_W_F	Rice lowland	Wet	Furrow/flood
CropGrp8_D_S	Rice upland	Dry	Spray
CropGrp8_W_S	Rice upland	Wet	Spray
CropGrp8_W_R	Rice upland	Wet	Rainfed
CropGrp9_D_F	Chia, quinoa, medicinal poppy	Dry	Furrow
CropGrp9_D_S	Chia, quinoa, medicinal poppy	Dry	Spray
CropGrp9_W_R	Chia, quinoa, medicinal poppy	Wet	Rainfed
CropGrp10_D_F	Mungbean, soybean, chickpea, navy bean, lentil	Dry	Furrow

LAND USE CODE	CROP	SEASON	IRRIGATION TYPE
CropGrp10_D_S	Mungbean, soybean, chickpea, navy bean, lentil	Dry	Spray
CropGrp10_W_R	Mungbean, soybean, chickpea, navy bean, lentil	Wet	Rainfed
CropGrp11_P_F	Sugarcane	Perennial	Furrow
CropGrp11_P_S	Sugarcane	Perennial	Spray
CropGrp11_P_R	Sugarcane	Perennial	Rainfed
CropGrp12_D_F	Sorghum (forage), maize (silage)	Dry	Furrow
CropGrp12_D_S	Sorghum (forage), maize (silage)	Dry	Spray
CropGrp12_W_F	Sorghum (forage), maize (silage)	Wet	Furrow
CropGrp12_W_S	Sorghum (forage), maize (silage)	Wet	Spray
CropGrp12_W_R	Sorghum (forage), maize (silage)	Wet	Rainfed
CropGrp13_D_F	Lablab	Dry	Furrow
CropGrp13_D_S	Lablab	Dry	Spray
CropGrp13_W_F	Lablab	Wet	Furrow
CropGrp13_W_S	Lablab	Wet	Spray
CropGrp13_W_R	Lablab	Wet	Rainfed
CropGrp14_P_F	Rhodes grass	Perennial	Furrow
CropGrp14_P_S	Rhodes grass	Perennial	Spray
CropGrp15_P_F	Indian sandalwood	Perennial	Furrow
CropGrp15_P_T	Indian sandalwood	Perennial	Trickle
CropGrp16_P_T	African mahogany	Perennial	Trickle
CropGrp17_P_T	Teak	Perennial	Trickle
CropGrp18_D_F	Sweetcorn	Dry	Furrow
CropGrp18_D_S	Sweetcorn	Dry	Spray
CropGrp18_W_F	Sweetcorn	Wet	Furrow
CropGrp18_W_S	Sweetcorn	Wet	Spray
CropGrp19_D_F	Sunflower, sesame	Dry	Furrow
CropGrp19_D_S	Sunflower, sesame	Dry	Spray
CropGrp19_W_F	Sunflower, sesame	Wet	Furrow
CropGrp19_W_S	Sunflower, sesame	Wet	Spray
CropGrp19_W_R	Sunflower, sesame	Wet	Rainfed
CropGrp20_P_S	Banana, coffee	Perennial	Spray
CropGrp20_P_T	Banana, coffee	Perennial	Trickle
CropGrp21_P_S	Cashew, macadamia, papaya	Perennial	Spray
CropGrp21_P_T	Cashew, macadamia, papaya	Perennial	Trickle

Appendix B Land suitability rules for land uses

Climate – frost

Low temperatures (<2°C) affect frost sensitive crops and reduce crop yields through damage to flowers and fruits. Generally, there are few frost prone areas in northern Australia, but they are known in some inland areas, some higher elevated locations and may be localised along low-lying creeks and drainage lines.

Apx Table B-1 Climate – frost – wet-season land uses not included

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES			
		A	B	C	D
Cf1	Frost free	1	1	1	1
Cf2	Occasional frost <2° (<2 days)	1	1	2	3
Cf3	Regular light frost <2° (≥2 days)	2	3	3	4
		CropGrp3_D_S, CropGrp11_P_R	CropGrp4_D_S	CropGrp1_P_S	CropGrp21_P_S
		CropGrp3_D_T, CropGrp12_D_F	CropGrp4_D_T	CropGrp1_P_T	CropGrp21_P_T
		CropGrp7_D_F, CropGrp12_D_S	CropGrp5_D_T	CropGrp2_P_T	
		CropGrp7_D_S, CropGrp13_D_S	CropGrp6_D_S	CropGrp13_D_F	
		CropGrp9_D_F, CropGrp18_D_F	CropGrp8_D_F	CropGrp15_P_F	
		CropGrp9_D_S, CropGrp18_D_S	CropGrp8_D_S	CropGrp15_P_T	
		CropGrp10_D_F, CropGrp19_D_F		CropGrp16_P_T	
		CropGrp10_D_S, CropGrp19_D_S		CropGrp17_P_T	
		CropGrp11_P_F		CropGrp20_P_S	
		CropGrp11_P_S		CropGrp20_P_T	

Climate – heat stress

Excessive heat damages crops impacting on seedlings, fruit, flowers and leaves. Parts of northern Australia are noted for exceptionally hot temperatures that occur over long periods.

Apx Table B-2 Climate – heat stress, table 1 of 2

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES					
		A	B	C	D	E	F
Ch1	Low heat stress (<5 35°days) – Dry season						
Ch2	Moderate heat stress (5-50 35°days) – Dry						
Ch3	Severe heat stress (≥50 35°days) – Dry season						
Ch4	Low heat stress (<5 40°days) – Wet season	1	1	1	1	1	1
Ch5	Moderate heat stress (5-50 40°days) – Wet	1	1	2	2	2	3
Ch6	Severe heat stress (≥50 40°days) – Wet season	2	3	2	3	4	4
		CropGrp6_W_S	CropGrp1_P_T	CropGrp7_W_F	CropGrp17_P_T	CropGrp20_P_T	CropGrp2_P_T
		CropGrp8_W_F	CropGrp1_P_S	CropGrp7_W_S		CropGrp20_P_S	CropGrp21_P_T
		CropGrp8_W_S		CropGrp7_W_R			CropGrp21_P_S
		CropGrp8_W_R		CropGrp12_W_F			
		CropGrp13_W_F		CropGrp12_W_S			
		CropGrp13_W_S		CropGrp12_W_R			
		CropGrp14_P_F		CropGrp13_W_R			
		CropGrp14_P_S		CropGrp18_W_F			
		CropGrp15_P_T		CropGrp18_W_S			
		CropGrp15_P_F		CropGrp19_W_F			
		CropGrp16_P_T		CropGrp19_W_S			
				CropGrp19_W_R			

Apx Table B-3 Climate – heat stress, table 2 of 2

C	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES					
		G	H	I	J	K	L
C	Low heat stress (<5 35° days) – Dry-season	1	1	1	1	1	1
C	Moderate heat stress (5 to 50 35°days) – Dry-season	1	1	2	1	2	2
C	Severe heat stress (≥50 35°days) – Dry-season	2	3	3	2	2	3
C	Low heat stress (<5 40°days) – Wet-season	1	1	1			
C	Moderate heat stress (5-50 40°days) – Wet-season	1	1	2			
C	Severe heat stress (≥50 40°days) – Wet-season	2	3	3			
		CropGrp11_P_F	CropGrp10_W_R	CropGrp9_W_R	CropGrp3_D_S	CropGrp7_D_F	CropGrp5_D_T
		CropGrp11_P_S			CropGrp3_D_T	CropGrp7_D_S	CropGrp9_D_F
		CropGrp11_P_R			CropGrp4_D_S	CropGrp12_D_F	CropGrp9_D_S
					CropGrp4_D_T	CropGrp12_D_S	CropGrp10_D_F
					CropGrp6_D_S	CropGrp18_D_F	
					CropGrp8_D_F	CropGrp18_D_S	
					CropGrp8_D_S	CropGrp19_D_F	
					CropGrp10_D_S	CropGrp19_D_S	
					CropGrp13_D_F		
					CropGrp13_D_S		

Climate – annual rainfall – rainfed land uses only

The amount of rainfall that falls during the growing season has a significant impact on the suitability for rainfed cropping (i.e. grown without supplementary irrigation). The suitability subclasses shown below identify the different rainfall zones and assume the soils have a high soil water storage capacity (i.e. AWC > 180 mm to 1.0 m soil thickness).

Apx Table B-4 Climate – annual rainfall, rainfed land uses only

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES		
		A	B	C
Cp1	Annual rainfall >1500 mm	1	1	1
Cp2	Annual rainfall 1000–1500 mm	1	1	3
Cp3	Annual rainfall 800–1000 mm	1	2	4
Cp4	Annual rainfall 600–800 mm	2	3	4
Cp5	Annual rainfall 500–600 mm	3	4	5
Cp6	Annual rainfall 400–500 mm	4	5	5
Cp7	Annual rainfall 300–400 mm	5	5	5
Cp8	Annual rainfall <300 mm	5	5	5
		CropGrp12_W_R	CropGrp7_W_R	CropGrp11_P_R
		CropGrp19_W_R	CropGrp8_W_R	
			CropGrp9_W_R	
			CropGrp10_W_R	
			CropGrp13_W_R	

Climate – temperature variation

Northern Australia generally experiences warm daytime temperatures, but overnight minimums can drop regularly by 15 – 20°C, particularly during the dry season in inland locations. While some crops (e.g. chickpeas and lychees) require cool temperatures for seed/fruit set, other crops (e.g. cassava) do not prefer such conditions.

Apx Table B-5 Climate – temperature variation

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES					
		A	B	C		D	E
Ct1	Mean minimum monthly temperature <15° for 4 months or more	1	1	2		3	3
Ct2	Mean minimum monthly temperature <15° for 3 months or less	1	2	1		1	2
		ALL	CropGrp2_P_T	CropGrp1_P_T	CropGrp8_W_S	CropGrp7_D_F	CropGrp21_P_T
		OTHER	CropGrp5_D_T	CropGrp1_P_S	CropGrp11_P_F	CropGrp7_D_S	CropGrp21_P_S
		LAND		CropGrp3_D_S	CropGrp15_P_T	CropGrp8_D_F	
		USES		CropGrp3_D_T	CropGrp15_P_F	CropGrp8_D_S	
				CropGrp4_D_S	CropGrp16_P_T		
				CropGrp4_D_T	CropGrp17_P_T		
				CropGrp7_W_F	CropGrp20_P_T		
				CropGrp8_W_F	CropGrp20_P_S		

Gilgai microrelief – all land uses

Severe gilgai microrelief affects machinery use and irrigation efficiency.

Apx Table B-6 Gilgai microrelief – all land uses

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES
Tm1	No gilgai or no significant gilgai (vertical interval <0.3m)	1
Tm2	Gilgai significantly present (vertical interval >0.3 m)	4

Acid sulfate soil potential – all land uses

Potential for soil sulfides to oxidise to sulfates (forming sulfuric acid) from site disturbance and soil drying.

Apx Table B-7 Acid sulfate soil potential – all land uses

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES
Da1	No significant ASS potential	1
Da2	Significant ASS potential	5

Surface salinity – all land uses

Seed establishment is hindered due to high levels of salt in the soil surface.

Apx Table B-8 Surface salinity

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES
Sa1	No evidence of surface salinity	1
Sa2	Existing soil surface salinity	5

Irrigation efficiency – furrow and flood irrigated land uses

Soil infiltration characteristics need to deliver water evenly and efficiently down furrows and across paddocks to minimise water loss. Inefficiencies arise from high infiltration rates and waterlogging at upper end of furrows if furrows are too long.

Apx Table B-9 Irrigation efficiency – furrow and flood irrigated land uses

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES
		A
If1	Very slowly permeable – Permeability Class 1	1
If2	Slowly permeable soils – Permeability Class 2	3
If3	Moderately permeable soils – Permeability Class 3	4
If4	Highly permeable soils – Permeability Class 4	5

CropGrp7_D_F	CropGrp11_P_F	CropGrp15_P_F
CropGrp7_W_F	CropGrp12_D_F	CropGrp18_D_F
CropGrp8_D_F	CropGrp12_W_F	CropGrp18_W_F
CropGrp8_W_F	CropGrp13_D_F	CropGrp19_D_F
CropGrp9_D_F	CropGrp13_W_F	CropGrp19_W_F
CropGrp10_D_F	CropGrp14_P_F	

Irrigation efficiency – high application method irrigated land uses (spray, trickle, mini-spray)

Soil infiltration characteristics need to deliver water effectively from high application rate irrigation methods to wet up the soil profile. Rapid to moderately high infiltration is desirable as more water can enter the soil profile in a shorter period. Quick movement of irrigation infrastructure may also be required to cover large areas with repeat applications to top-up the root zone.

Apx Table B-10 Irrigation efficiency – other high application method irrigated land uses (spray, trickle, mini-spray) and rainfed

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES
		A
Ir1	Highly permeable soils – Permeability Class 4	1
Ir2	Moderately permeable soils – Permeability Class 3	2
Ir3	Slowly permeable soils – Permeability Class 2	2
Ir4	Very slowly permeable soils – Permeability Class 1	3
		CropGrp1_P_S CropGrp1_P_T CropGrp2_P_T CropGrp3_D_S CropGrp3_D_T CropGrp4_D_S CropGrp4_D_T CropGrp5_D_T CropGrp6_D_S CropGrp6_W_S CropGrp7_D_S CropGrp7_W_S CropGrp7_W_R CropGrp8_D_S CropGrp8_W_S CropGrp8_W_R CropGrp9_D_S CropGrp9_W_R CropGrp10_D_S CropGrp10_W_R CropGrp11_P_S CropGrp11_P_R CropGrp12_D_S CropGrp12_W_S CropGrp12_W_R CropGrp13_D_S CropGrp13_W_S CropGrp13_W_R CropGrp14_P_S CropGrp15_P_T CropGrp16_P_T CropGrp17_P_T CropGrp18_D_S CropGrp18_W_S CropGrp19_D_S CropGrp19_W_S CropGrp19_W_R CropGrp20_P_S CropGrp20_P_T CropGrp21_P_S CropGrp21_P_T

Soil water availability – irrigated land uses

Available water capacity (AWC) estimates the capacity of a soil to store water for plant use (volumetric soil water between field capacity and wilting point). Subclasses relate to irrigation efficiency, that is the frequency of water applications required during the period of maximum water demand.

Apx Table B-11 Soil water availability – irrigated land uses AWC to 1.0 m, table 1 of 2

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES						
		A	B	C	D	E	F	G
M1	AWC to 1 m >215 mm	1	1	1	1	1	1	1
M2	AWC to 1 m 180–215 mm	1	1	1	1	1	1	1
M3	AWC to 1 m 140–180 mm	1	1	1	1	1	1	1
M4	AWC to 1 m 110–140 mm	1	1	1	1	1	1	1
M5	AWC to 1 m 70–110 mm	1	1	1	1	1	1	1
M6	AWC to 1 m 40–70 mm	1	1	2	2	2	2	3
M7	AWC to 1 m 20–40 mm	3	4	3	4	4	5	5
M8	AWC to 1 m <20 mm	5	5	5	4	5	5	5
		CropGrp16_P_T	CropGrp17_P_T	CropGrp21_P_T	CropGrp1_P_T CropGrp2_P_T	CropGrp20_P_T	CropGrp1_P_S CropGrp15_P_T	CropGrp15_P_F

Apx Table B-12 Soil water availability – irrigated land uses AWC to 1.0 m, table 2 of 2

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES							
		H	I	J	K	L	M	N	O
M1	AWC to 1 m >215 mm	1	1	1	1	1	1	1	1
M2	AWC to 1 m 180–215 mm	1	1	1	1	1	1	1	2
M3	AWC to 1 m 140–180 mm	1	1	1	1	2	2	2	2
M4	AWC to 1 m 110–140 mm	1	2	2	2	2	3	3	3
M5	AWC to 1 m 70–110 mm	2	3	3	3	3	3	4	4
M6	AWC to 1 m 40–70 mm	3	3	4	4	4	4	4	4
M7	AWC to 1 m 20–40 mm	4	5	4	5	5	4	5	5
M8	AWC to 1 m <20 mm	5	5	5	5	5	5	5	5
		CropGrp6_W_S	CropGrp10_D_S	CropGrp7_W_F	CropGrp8_D_S	CropGrp12_D_F	CropGrp8_W_F	CropGrp10_D_F	CropGrp19_D_F
		CropGrp6_D_S	CropGrp18_D_S	CropGrp7_D_F	CropGrp12_W_F	CropGrp13_D_F	CropGrp8_D_F	CropGrp18_D_F	
		CropGrp7_W_S	CropGrp19_W_S	CropGrp9_D_F	CropGrp19_D_S	CropGrp18_W_F		CropGrp19_W_F	
		CropGrp7_D_S		CropGrp11_P_F		CropGrp20_P_S			
		CropGrp8_W_S		CropGrp13_W_F		CropGrp21_P_S			
		CropGrp9_D_S		CropGrp14_P_F					
		CropGrp11_P_S							
		CropGrp12_W_S							
		CropGrp12_D_S							
		CropGrp13_W_S							
		CropGrp13_D_S							
		CropGrp14_P_S							
		CropGrp18_W_S							

Apx Table B-13 Soil water availability – irrigated land uses AWC to 0.6 m (shallow rooted crops)

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES			
		A	B	C	D
M9	AWC to 0.6 m >140 mm	1	1	1	2
M10	AWC to 0.6 m 110–140 mm	1	1	2	3
M11	AWC to 0.6 m 70–110 mm	1	2	3	3
M12	AWC to 0.6 m 40–70 mm	2	2	3	4
M13	AWC to 0.6 m 20–40 mm	3	3	5	5
M14	AWC to 0.6 m <20 mm	5	5	5	5
		CropGrp3_D_T CropGrp4_D_T	CropGrp5_D_T	CropGrp3_D_S	CropGrp4_D_S

Nutrient balance

Surface soil pH affects the availability of nutrients for plant use. Strong acidity or alkalinity may lead to certain nutrient deficiencies and/or toxicities.

Apx Table B-14 Nutrient balance

CODE	DESCRIPTION	SUITABILITY SUBSLASSES FOR LAND USES					
		A	B	C	D	E	F
Nr1	pH 5.5–7.0	1	1	1	1	2	3
Nr2	pH 7.0–8.5	1	1	1	2	1	1
Nr3	pH <5.5	2	2	3	2	2	4
Nr4	pH >8.5	2	3	2	3	2	2
		ALL	CropGrp20_P_S	CropGrp7_D_F	CropGrp1_P_S	CropGrp5_D_T	CropGrp17_P_T
		OTHER	CropGrp20_P_T	CropGrp7_D_S	CropGrp1_P_T	CropGrp9_D_F	
		CROP	CropGrp21_P_S	CropGrp7_W_F	CropGrp2_P_T	CropGrp9_D_S	
		GROUPS	CropGrp21_P_T	CropGrp7_W_S	CropGrp6_D_S	CropGrp9_W_R	
				CropGrp7_W_R	CropGrp6_W_S		
				CropGrp10_D_F			

Physical restrictions – soil surface condition

Soil surface condition can cause problems with a range of management activities, especially seedbed preparation, germination and crop establishment and the fruiting/harvesting of root crops.

Apx Table B-15 Physical restrictions – soil surface condition

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES							
		A	B	C		D	E	F	G
Ps1	Surface condition loose or soft (sandy or loamy surface texture)	1	1	1		1	1	1	1
Ps2	Surface condition firm/hard setting or crusting and sandy or loamy surface texture	1	1	1		1	2	2	2
Ps3	Surface texture silty	1	1	2		2	2	2	3
Ps4	Clayey surface texture and single grain surface structure	1	1	2		2	2	2	3
Ps5	Clayey surface texture and fine surface structure	1	1	2		2	2	2	3
Ps6	Clayey surface texture and cloddy (massive) surface structure	2	3	3		4	3	4	4
Ps7	Clayey surface texture and coarse surface structure	2	3	3		4	3	4	4
		CropGrp1_P_S	CropGrp3_D_T	CropGrp3_D_S	CropGrp19_D_F	CropGrp10_W_R	CropGrp7_D_F	CropGrp10_D_F	CropGrp6_W_S
		CropGrp1_P_T	CropGrp4_D_T	CropGrp4_D_S	CropGrp19_D_S		CropGrp7_D_S	CropGrp10_D_S	CropGrp6_D_S
		CropGrp2_P_T	CropGrp5_D_T	CropGrp8_D_F	CropGrp19_W_F		CropGrp7_W_F		
		CropGrp15_P_F	CropGrp16_P_T	CropGrp8_D_S	CropGrp19_W_S		CropGrp7_W_S		
		CropGrp15_P_T	CropGrp17_P_T	CropGrp8_W_F	CropGrp19_W_R		CropGrp7_W_R		
		CropGrp20_P_S	CropGrp18_D_F	CropGrp8_W_S			CropGrp12_D_F		
		CropGrp20_P_T	CropGrp18_W_F	CropGrp8_W_R			CropGrp12_D_S		
		CropGrp21_P_S		CropGrp9_D_F			CropGrp12_W_F		
		CropGrp21_P_T		CropGrp9_D_S			CropGrp12_W_S		
				CropGrp9_W_R			CropGrp12_W_R		

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES						
		A	B	C	D	E	F	G
				CropGrp11_P_F CropGrp11_P_S CropGrp11_P_R CropGrp13_W_R CropGrp18_D_S CropGrp18_W_S		CropGrp13_D_F CropGrp13_D_S CropGrp13_W_F CropGrp13_W_S CropGrp14_P_F CropGrp14_P_S		

Physical restrictions – surface infiltration

Silty and surface sealing (hard-setting) soils have reduced infiltration of rainfall and irrigation water.

Apx Table B-16 Physical restrictions – surface infiltration

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES		
		A	B	C
Pi1	Silty surface texture and surface ESP >= 6	2	3	4
Pi2	All other soils	1	1	1
		CropGrp3_D_T CropGrp4_D_T CropGrp5_D_T CropGrp15_P_F CropGrp16_P_T CropGrp17_P_T CropGrp18_D_F CropGrp18_W_F	CropGrp1_P_T CropGrp2_P_T CropGrp7_D_F CropGrp7_W_F CropGrp8_D_F CropGrp8_W_F CropGrp8_W_R CropGrp9_D_F CropGrp9_W_R CropGrp10_D_F CropGrp10_W_R CropGrp11_P_F CropGrp12_D_F CropGrp12_W_F CropGrp13_D_F CropGrp13_W_F CropGrp13_W_R CropGrp14_P_F CropGrp15_P_T CropGrp19_D_F CropGrp19_W_F CropGrp20_P_T CropGrp21_P_T	CropGrp1_P_S CropGrp3_D_S CropGrp4_D_S CropGrp6_D_S CropGrp6_W_S CropGrp7_D_S CropGrp7_W_S CropGrp7_W_R CropGrp8_D_S CropGrp8_W_S CropGrp9_D_S CropGrp10_D_S CropGrp11_P_S CropGrp11_P_R CropGrp12_D_S CropGrp12_W_S CropGrp12_W_R CropGrp13_D_S CropGrp13_W_S CropGrp14_P_S CropGrp18_D_S CropGrp18_W_S CropGrp19_D_S CropGrp19_W_S CropGrp19_W_R CropGrp20_P_S CropGrp21_P_S

Physical restrictions – soil surface texture

Factors relating to soil surface texture and the type of soil affect crop growth in a range of different ways, for example the recoverability (harvest difficulties) and condition of root crops, the establishment of tree crops (vertic effects). Soils with a sodic subsoil and only a thin surface soil (A horizon) are difficult to manage for all cropping applications and also pose a significant land degradation hazard.

Apx Table B-17 Physical restrictions – soil surface texture

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES			
		A	B	C	D
Pa1	Sandy or loamy surface texture	1	1	1	1
Pa2	Clayey or silty surface texture and non-cracking surface condition	1	1	2	2
Pa3	Clayey surface texture and self-mulching surface condition	2	3	2	3
Pa4	Clayey surface texture and ONLY cracking surface condition	2	3	2	3
Pa5	Soils with sodic subsoils and A horizon thickness < 20 cm	3	4	3	4
		CropGrp8_W_S CropGrp11_P_F CropGrp11_P_S CropGrp11_P_R	CropGrp1_P_S CropGrp1_P_T CropGrp2_P_T CropGrp15_P_F CropGrp15_P_T CropGrp20_P_S CropGrp20_P_T CropGrp21_P_S CropGrp21_P_T	ALL OTHER CROP GROUPS	CropGrp6_D_S CropGrp6_W_S CropGrp16_P_T CropGrp17_P_T

Rockiness

Surface rockiness affects machinery and harvesting operations and reduces crop growth.

Surface gravel, stone and rock outcrop can interfere significantly with planting, cultivation and harvesting machinery used for root crops, small crops, annual forage crops and sugarcane. Sites were assigned as being rocky or not based on the thresholds below, or where the combined total of any of the field observations had an abundance greater than 50% at the surface or in the top 0.1 m of soil: (i) rock outcrop or boulders >2%; (ii) cobbles or stones (60–600 mm) >20%; (iii) coarse gravel (20–60 mm) >50%; (iv) medium gravel (6–20 mm) >90%, and; (v) hard segregations >50%.

Apx Table B-18 Rockiness

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES A	B
R1	Not rocky or not significantly rocky	1	1
R2	Rocky	4	5
		CropGrp1_P_S CropGrp1_P_T CropGrp2_P_T CropGrp3_D_S CropGrp3_D_T CropGrp4_D_S CropGrp4_D_T CropGrp5_D_T CropGrp6_D_S CropGrp6_W_S CropGrp7_D_S CropGrp7_W_S CropGrp7_W_R CropGrp8_D_S CropGrp8_W_S CropGrp8_W_R CropGrp9_D_S CropGrp9_W_R CropGrp10_D_S CropGrp10_W_R CropGrp11_P_S CropGrp11_P_R CropGrp12_D_S CropGrp12_W_S CropGrp12_W_R CropGrp13_D_S CropGrp13_W_S CropGrp14_P_S CropGrp15_P_T CropGrp16_P_T CropGrp17_P_T CropGrp18_D_S CropGrp18_W_S CropGrp19_D_S CropGrp19_W_S CropGrp19_W_R CropGrp20_P_S CropGrp20_P_T CropGrp21_P_S CropGrp21_P_T	CropGrp7_D_F CropGrp7_W_F CropGrp8_D_F CropGrp8_W_F CropGrp9_D_F CropGrp10_D_F CropGrp11_P_F CropGrp12_D_F CropGrp12_W_F CropGrp13_D_F CropGrp13_W_F CropGrp13_W_R CropGrp14_P_F CropGrp15_P_F CropGrp18_D_F CropGrp18_W_F CropGrp19_D_F CropGrp19_W_F

Soil thickness

Soil thickness generally relates to the requirements for plants for physical support, in supporting plant root development and structural growth. Additional soil thickness is required to fulfil the requirements for certain crops (e.g. avocado, African mahogany). Additional soil thickness is required for efficient harvesting of root crops.

Apx Table B-19 Soil thickness

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES						
		A	B	C	D	E	F	G
Pd1	Very deep (>=1.5 m)	1	1	1	1	1	1	1
Pd2	Deep (1.0–<1.5)	1	1	1	1	1	1	1
Pd3	Moderate (0.5–<1.0 m)	1	1	1	1	1	2	3
Pd4	Shallow (0.25-<0.5 m)	2	2	3	3	4	4	4
Pd5	Very shallow (<0.25 m)	4	5	4	5	5	5	5
		CropGrp3_D_S CropGrp3_D_T CropGrp4_D_S CropGrp4_D_T CropGrp14_P_S CropGrp18_D_F CropGrp18_D_S	CropGrp5_D_T	CropGrp13_D_S CropGrp13_W_S CropGrp13_W_R CropGrp18_W_F CropGrp18_W_S	CropGrp7_D_F CropGrp7_D_S CropGrp7_W_F CropGrp7_W_S CropGrp7_W_R CropGrp8_D_F CropGrp8_D_S CropGrp8_W_F CropGrp8_W_S CropGrp9_D_F CropGrp9_D_S CropGrp9_W_R CropGrp10_D_F CropGrp10_D_S CropGrp10_W_R CropGrp11_P_F CropGrp11_P_S CropGrp11_P_R CropGrp12_D_F CropGrp12_D_S CropGrp12_W_F CropGrp12_W_S CropGrp12_W_R CropGrp13_D_F CropGrp13_W_F CropGrp14_P_F CropGrp19_D_F CropGrp19_D_S CropGrp19_W_F CropGrp19_W_S CropGrp19_W_R CropGrp20_P_S CropGrp20_P_T	CropGrp8_W_R	CropGrp1_P_S CropGrp1_P_T CropGrp2_P_T CropGrp6_D_S CropGrp6_W_S	CropGrp15_P_F CropGrp15_P_T CropGrp16_P_T CropGrp17_P_T CropGrp21_P_S CropGrp21_P_T

Water erosion

Soil loss from water erosion needs to be minimised to reduce land degradation risk and productivity decline.

Apx Table B-20 Water erosion

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES					
		A	B	C	D	E	F
E1	Low erodibility, K <0.02, <0.5% slope	1	1	1	1	1	1
E2	Low erodibility, K <0.02, 0.5–1% slope	2	2	2	2	2	2
E3	Low erodibility, K <0.02, 1–2% slope	2	3	3	3	3	3
E4	Low erodibility, K <0.02, 2–3% slope	3	3	3	3	4	4
E5	Low erodibility, K <0.02, 3–5% slope	3	4	4	4	4	4
E6	Low erodibility, K <0.02, 5–8% slope	4	4	4	5	5	5
E7	Low erodibility, K <0.02, 8–12% slope	4	5	5	5	5	5
E8	Low erodibility, K <0.02, 12–15% slope	5	5	5	5	5	5
E9	Low erodibility, K <0.02, 15–20% slope	5	5	5	5	5	5
E10	Low erodibility, K <0.02, >20% slope	5	5	5	5	5	5
E11	Moderate erodibility, K 0.02–0.04, <0.5% slope	2	2	2	2	2	2
E12	Moderate erodibility, K 0.02–0.04, 0.5–1% slope	2	3	3	3	3	3
E13	Moderate erodibility, K 0.02–0.04, 1–2% slope	3	3	3	3	3	4
E14	Moderate erodibility, K 0.02–0.04, 2–3% slope	3	3	4	4	4	4
E15	Moderate erodibility, K 0.02–0.04, 3–5% slope	4	4	4	4	4	5
E16	Moderate erodibility, K 0.02–0.04, 5–8% slope	4	4	5	5	5	5
E17	Moderate erodibility, K 0.02–0.04, 8–12% slope	5	5	5	5	5	5
E18	Moderate erodibility, K 0.02–0.04, 12–15% slope	5	5	5	5	5	5
E19	Moderate erodibility, K 0.02–0.04, 15–20% slope	5	5	5	5	5	5

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES					
		A	B	C	D	E	F
E20	Moderate erodibility, K 0.02–0.04, >20% slope	5	5	5	5	5	5
E21	High erodibility, K 0.04–0.06, <0.5% slope	2	3	3	3	3	3
E22	High erodibility, K 0.04–0.06, 0.5–1% slope	3	3	3	3	3	4
E23	High erodibility, K 0.04–0.06, 1–2% slope	3	3	4	4	4	4
E24	High erodibility, K 0.04–0.06, 2–3% slope	4	4	4	4	4	5
E25	High erodibility, K 0.04–0.06, 3–5% slope	4	4	5	5	5	5
E26	High erodibility, K 0.04–0.06, 5–8% slope	5	5	5	5	5	5
E27	High erodibility, K 0.04–0.06, 8–12% slope	5	5	5	5	5	5
E28	High erodibility, K 0.04–0.06, 12–15% slope	5	5	5	5	5	5
E29	High erodibility, K 0.04–0.06, 15–20% slope	5	5	5	5	5	5
E30	High erodibility, K 0.04–0.06, >20% slope	5	5	5	5	5	5
E31	Very high erodibility, K >0.06, <0.5% slope	2	3	3	3	3	3
E32	Very high erodibility, K >0.06, 0.5–1% slope	3	4	4	4	4	4
E33	Very high erodibility, K >0.06, 1–2% slope	4	4	4	4	4	4
E34	Very high erodibility, K >0.06, 2–3% slope	5	5	5	5	5	5
E35	Very high erodibility, K >0.06, 3–5% slope	5	5	5	5	5	5
E36	Very high erodibility, K >0.06, 5–8% slope	5	5	5	5	5	5
E37	Very high erodibility, K >0.06, 8–12% slope	5	5	5	5	5	5
E38	Very high erodibility, K >0.06, 12–15% slope	5	5	5	5	5	5
E39	Very high erodibility, K >0.06, 15–20% slope	5	5	5	5	5	5
E40	Very high erodibility, K >0.06, >20% slope	5	5	5	5	5	5
		CropGrp14_P_S	CropGrp1_P_S CropGrp1_P_T CropGrp2_P_T CropGrp15_P_T	CropGrp3_D_S CropGrp3_D_T CropGrp4_D_S CropGrp5_D_T	CropGrp4_D_T	CropGrp7_D_F CropGrp8_D_F CropGrp9_D_F CropGrp10_D_F	CropGrp6_W_S CropGrp7_W_F CropGrp7_W_S CropGrp7_W_R

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES A	B	C	D	E	F
			CropGrp16_P_T	CropGrp6_D_S		CropGrp12_D_F	CropGrp8_W_F
			CropGrp17_P_T	CropGrp7_D_S		CropGrp13_D_F	CropGrp8_W_S
			CropGrp20_P_S	CropGrp8_D_S		CropGrp14_P_F	CropGrp8_W_R
			CropGrp20_P_T	CropGrp9_D_S		CropGrp15_P_F	CropGrp9_W_R
			CropGrp21_P_S	CropGrp10_D_S		CropGrp18_D_F	CropGrp10_W_R
			CropGrp21_P_T	CropGrp11_P_S		CropGrp19_D_F	CropGrp11_P_F
				CropGrp11_P_R			CropGrp12_W_F
				CropGrp12_D_S			CropGrp12_W_S
				CropGrp13_D_S			CropGrp12_W_R
				CropGrp18_D_S			CropGrp13_W_F
				CropGrp19_D_S			CropGrp13_W_S
							CropGrp13_W_R
							CropGrp18_W_F
							CropGrp18_W_S
							CropGrp19_W_F
							CropGrp19_W_S
							CropGrp19_W_R

Wetness

Site and soil conditions that result in poor soil aeration. Excess water on the soil surface or in the soil profile caused from inadequate site drainage reduces crop growth and quality and restricts machinery use. Crops grown entirely in the dry season are less affected by this limitation as they will not generally experience very wet conditions.

Apx Table B-21 Wetness, table 1 of 3

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES								
		A	B	C	D	E	F	G	H	I
W1	Rapidly drained	1	1	1	1	1	1	1	1	1
W2	Well drained and highly permeable	1	1	1	1	1	1	1	1	1
W3	Well drained and moderately permeable	1	1	1	1	1	1	1	1	1
W4	Well drained and slowly permeable	1	1	2	2	2	2	2	2	2
W5	Well drained and very slowly permeable	2	2	2	2	3	3	3	3	3
W6	Moderately well drained and highly permeable	2	2	1	1	1	1	1	1	1
W7	Moderately well drained and moderately permeable	2	2	2	2	2	2	2	2	2
W8	Moderately well drained and slowly permeable	2	2	3	3	2	2	3	3	3
W9	Moderately well drained and very slowly permeable	3	3	3	3	3	3	3	3	3
W10	Imperfectly drained and highly permeable	2	2	2	2	2	2	2	2	2
W11	Imperfectly drained and moderately permeable	2	2	2	3	3	3	2	2	3
W12	Imperfectly drained and slowly permeable	2	2	3	4	3	4	3	3	4
W13	Imperfectly drained and very slowly permeable	3	3	3	4	4	4	3	3	4
W14	Poorly drained and highly or moderately permeable	3	4	3	5	4	4	3	4	5

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES								
		A	B	C	D	E	F	G	H	I
W15	Poorly drained and slowly or very slowly permeable	4	4	4	5	4	4	4	4	5
W16	Very poorly drained	4	4	5	5	5	5	5	5	5
		CropGrp8_D_F CropGrp8_D_S CropGrp8_W_F	CropGrp8_W_R CropGrp8_W_S	CropGrp3_D_S CropGrp3_D_T CropGrp4_D_S CropGrp4_D_T	CropGrp20_P_S CropGrp20_P_T	CropGrp16_P_T	CropGrp13_W_R CropGrp13_W_S	CropGrp18_D_S	CropGrp7_D_S CropGrp12_D_S CropGrp19_D_S	CropGrp1_P_S CropGrp1_P_T

Apx Table B-22 Wetness, table 2 of 3

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES								
		J	K	L	M	N	O	P	Q	R
W1	Rapidly drained	1	1	1	1	1	1	1	1	1
W2	Well drained and highly permeable	1	1	1	1	1	1	1	1	1
W3	Well drained and moderately permeable	1	1	1	1	1	1	1	2	2
W4	Well drained and slowly permeable	2	2	2	2	2	2	2	2	2
W5	Well drained and very slowly permeable	3	3	3	3	3	3	4	3	3
W6	Moderately well drained and highly permeable	1	1	2	2	2	2	2	2	2
W7	Moderately well drained and moderately permeable	2	2	2	2	2	2	3	2	2
W8	Moderately well drained and slowly permeable	3	3	2	2	3	3	4	2	2
W9	Moderately well drained and very slowly permeable	4	4	3	3	3	3	4	3	3
W10	Imperfectly drained and highly permeable	3	3	2	2	2	2	4	2	2
W11	Imperfectly drained and moderately permeable	3	4	2	3	2	2	4	2	3

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES								
		J	K	L	M	N	O	P	Q	R
W12	Imperfectly drained and slowly permeable	4	4	3	3	3	3	5	3	3
W13	Imperfectly drained and very slowly permeable	4	5	3	4	3	4	5	3	4
W14	Poorly drained and highly or moderately permeable	5	5	4	4	3	3	5	4	4
W15	Poorly drained and slowly or very slowly permeable	5	5	4	5	4	4	5	4	5
W16	Very poorly drained	5	5	5	5	5	5	5	5	5
		CropGrp15_P_F CropGrp15_P_T	CropGrp2_P_T CropGrp17_P_T	CropGrp13_D_S	CropGrp9_D_S CropGrp10_D_S	CropGrp5_D_T	CropGrp11_P_F CropGrp11_P_R CropGrp11_P_S	CropGrp21_P_S CropGrp21_P_T	CropGrp13_D_F	CropGrp9_D_F CropGrp10_D_F

Apx Table B-23 Wetness, table 3 of 3

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES						
		S	T	U	V	W	X	Y
W1	Rapidly drained	1	1	1	1	1	1	1
W2	Well drained and highly permeable	1	1	1	1	1	1	1
W3	Well drained and moderately permeable	2	2	2	2	2	2	2
W4	Well drained and slowly permeable	2	2	2	2	2	2	2
W5	Well drained and very slowly permeable	3	3	3	3	3	3	3
W6	Moderately well drained and highly permeable	2	2	2	2	2	2	2
W7	Moderately well drained and moderately permeable	2	2	2	2	2	2	3
W8	Moderately well drained and slowly permeable	3	3	3	3	3	3	3
W9	Moderately well drained and very slowly permeable	3	3	3	3	3	3	4
W10	Imperfectly drained and highly permeable	2	2	2	2	3	3	4
W11	Imperfectly drained and moderately permeable	2	2	3	3	3	3	4
W12	Imperfectly drained and slowly permeable	3	3	3	4	4	4	5
W13	Imperfectly drained and very slowly permeable	3	3	4	4	4	4	5
W14	Poorly drained and highly or moderately permeable	3	4	4	4	4	4	5
W15	Poorly drained and slowly or very slowly permeable	4	4	5	5	4	5	5
W16	Very poorly drained	5	5	5	5	5	5	5
		CropGrp18_D_F	CropGrp7_D_F	CropGrp14_P_F	CropGrp6_D_S	CropGrp13_W_F	CropGrp7_W_F	CropGrp6_W_S

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES						
		S	T	U	V	W	X	Y
			CropGrp12_D_F	CropGrp14_P_S			CropGrp7_W_S	
			CropGrp19_D_F				CropGrp7_W_R	
							CropGrp9_W_R	
							CropGrp10_W_R	
							CropGrp12_W_F	
							CropGrp12_W_R	
							CropGrp12_W_S	
							CropGrp18_D_F	
							CropGrp18_W_F	
							CropGrp18_W_S	
							CropGrp19_W_F	
							CropGrp19_W_R	
							CropGrp19_W_S	

Soil water availability – rainfed land uses

Available water capacity (AWC) estimates the capacity of a soil to store water for plant use (volumetric soil water between field capacity and wilting point). For rainfed cropping, suitability subclasses are determined by a combination of annual rainfall and AWC to various depths.

Three rainfall zones have been identified for the Roper catchment.

Apx Table B-24 Soil water availability – rainfed land uses, table 1 of 3

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES		
		A	B	C
MR1-1	Rainfall 1000–1500 mm, AWC to 1.0 m >215 mm	1	1	1
MR1-2	Rainfall 1000–1500 mm, AWC to 1 m 180–215 mm	1	1	1
MR1-3	Rainfall 1000–1500 mm, AWC to 1 m 140–180 mm	2	2	2
MR1-4	Rainfall 1000–1500 mm, AWC to 1 m 110–140 mm	3	3	3
MR1-5	Rainfall 1000–1500 mm, AWC to 1 m 70–110 mm	3	4	4
MR1-6	Rainfall 1000–1500 mm, AWC to 1 m 40–70 mm	4	4	5
MR1-7	Rainfall 1000–1500 mm, AWC to 1 m <40 mm	5	5	5
		CropGrp11_P_R	CropGrp9_W_R	CropGrp7_W_R
			CropGrp10_W_R	CropGrp8_W_R
			CropGrp12_W_R	CropGrp13_W_R
			CropGrp19_W_R	

Apx Table B-25 Soil water availability – rainfed land uses, table 2 of 3

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES			
		A	B	C	D
MR2-1	Rainfall 800–1000 mm, AWC to 1.0 m >215 mm	1	1	1	1
MR2-2	Rainfall 800–1000 mm, AWC to 1 m 180–215 mm	1	1	2	2
MR2-3	Rainfall 800–1000 mm, AWC to 1 m 140–180 mm	2	2	2	2
MR2-4	Rainfall 800–1000 mm, AWC to 1 m 110–140 mm	3	3	3	3
MR2-5	Rainfall 800–1000 mm, AWC to 1 m 70–110 mm	4	4	4	4
MR2-6	Rainfall 800–1000 mm, AWC to 1 m 40–70 mm	4	5	4	5
MR2-7	Rainfall 800–1000 mm, AWC to 1 m <40 mm	5	5	5	5
		CropGrp11_P_R	CropGrp7_W_R CropGrp8_W_R	CropGrp9_W_R CropGrp10_W_R CropGrp12_W_R CropGrp19_W_R	CropGrp13_W_R

Apx Table B-26 Soil water availability – rainfed land uses, table 3 of 3

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES		
		A	B	C
MR3-1	Rainfall 600–800 mm, AWC to 1.0 m >215 mm	1	2	3
MR3-2	Rainfall 600–800 mm, AWC to 1 m 180–215 mm	2	2	4
MR3-3	Rainfall 600–800 mm, AWC to 1 m 140–180 mm	3	3	4
MR3-4	Rainfall 600–800 mm, AWC to 1 m 110–140 mm	4	4	5
MR3-5	Rainfall 600–800 mm, AWC to 1 m 70–110 mm	5	5	5
MR3-6	Rainfall 600–800 mm, AWC to 1 m 40–70 mm	5	5	5
MR3-7	Rainfall 600–800 mm, AWC to 1 m <40 mm	5	5	5
		CropGrp7_W_R	CropGrp19_W_R	CropGrp11_P_R
		CropGrp8_W_R		
		CropGrp9_W_R		
		CropGrp10_W_R		
		CropGrp12_W_R		
		CropGrp13_W_R		

Appendix C Land suitability rules for aquaculture

Apx Table C-1 Land suitability rules for aquaculture

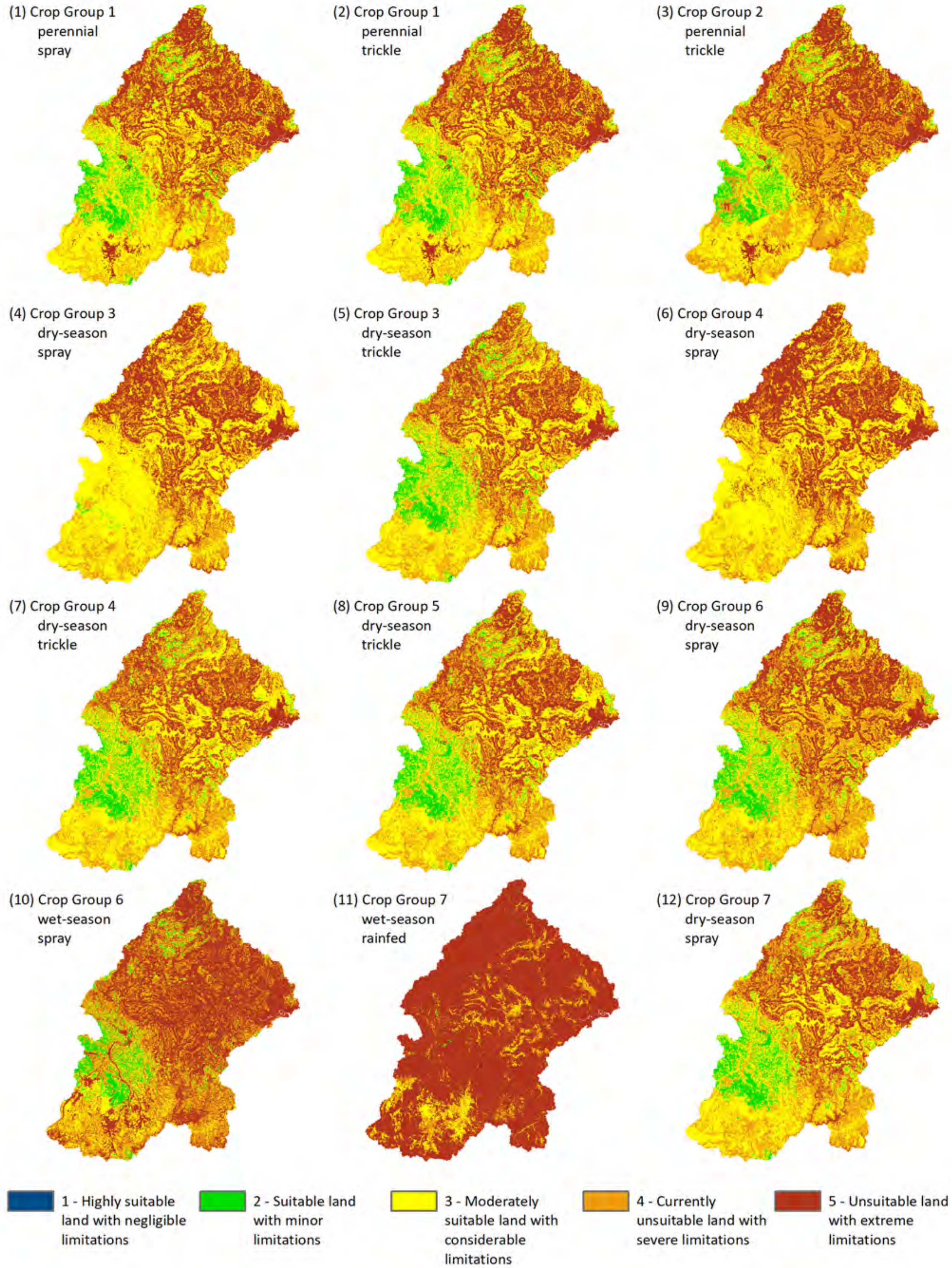
ATTRIBUTE	RULE	MARINE EARTHEN	MARINE LINED	FRESH WATER EARTHEN	FRESH WATER LINED
Distance to marine water	<500m	1	1		
	500–1000m	2	2		
	1000–2000m	3	3		
	>2000m	5	5		
Elevation	0–5m	3	3		
	5–15m	1	1		
	15–20m	2	2		
	20–25m	4	4		
	>25m	5	5		
Slope % (STRM)	Slope <2%	1	1	1	1
	>2% and <4% slope	2	2	2	2
	>4% and <5% slope	3	3	3	3
	>5% slope	5	5	5	5
Clay (%) to 2m depth	>30%	1	1	1	1
	20–30%	2	1	2	1
	10–20%	4	2	4	2
	<10%	4	3	4	3
pH mean to 1m depth	6.0–7.0			2	1
	7.0–8.8			1	1
	>8.8			3	1
	<6.0			3	1
Acid sulfate soils (STRM <5 mAHD)	High probability occurrence	3	3	3	3
	Low probability occurrence	2	1	2	1
	No known occurrence	1	1	1	1
Soil thickness	<0.5	5	5	5	5
	0.5–1	3	3	3	3
	1.0–1.5	2	2	2	2
	>1.5	1	1	1	1
Permeability	Very slowly	1		1	
	Slowly	3		3	
	Moderately	4		4	
	Rapidly	5		5	
Rockiness	Not rocky or significantly rocky	1	1	1	1
	Rocky	4	4	4	4
Microrelief (Gilgai)	No gilgai or significant gilgai	1	1	1	1
	Gilgai significantly present	2	2	2	2

Appendix D Maps of land suitability options

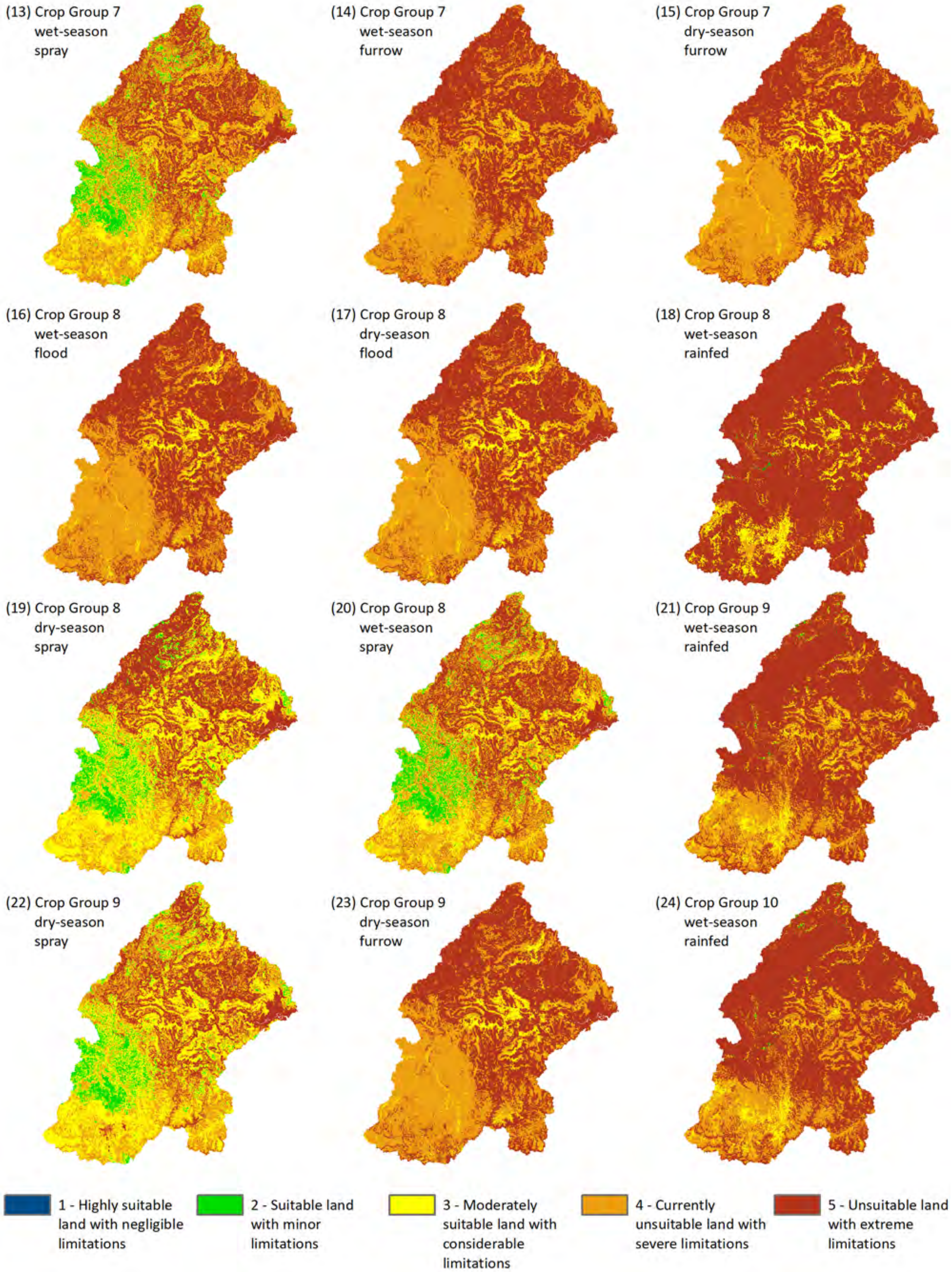
Full suite of land suitability maps for crop groups X season X irrigation type, as presented in Appendix A.

The following land suitability maps do not consider economics and finances (e.g. subsidies and grants, produce market prices, fertilisers and fuel costs, etc.), land tenure, conservation area exclusions or factors such as flooding, secondary salinisation risk or availability of irrigable water. A quantitative assessment of the reliability of the suitability data although not shown here is available for each land use.

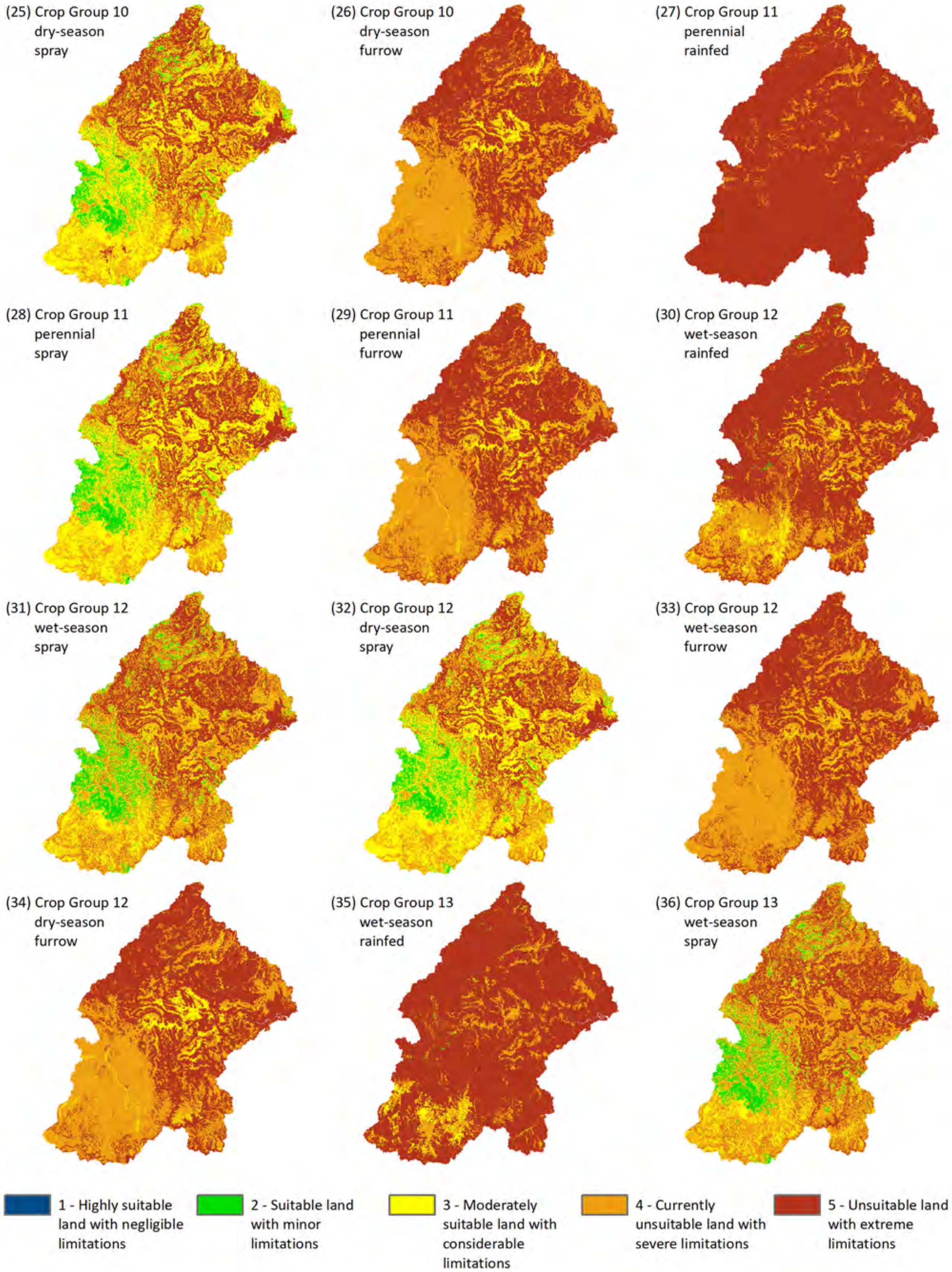
All datasets from this activity including land suitability and the companion reliability maps are publicly available from the CSIRO Data Access Portal (https://data.csiro.au/).



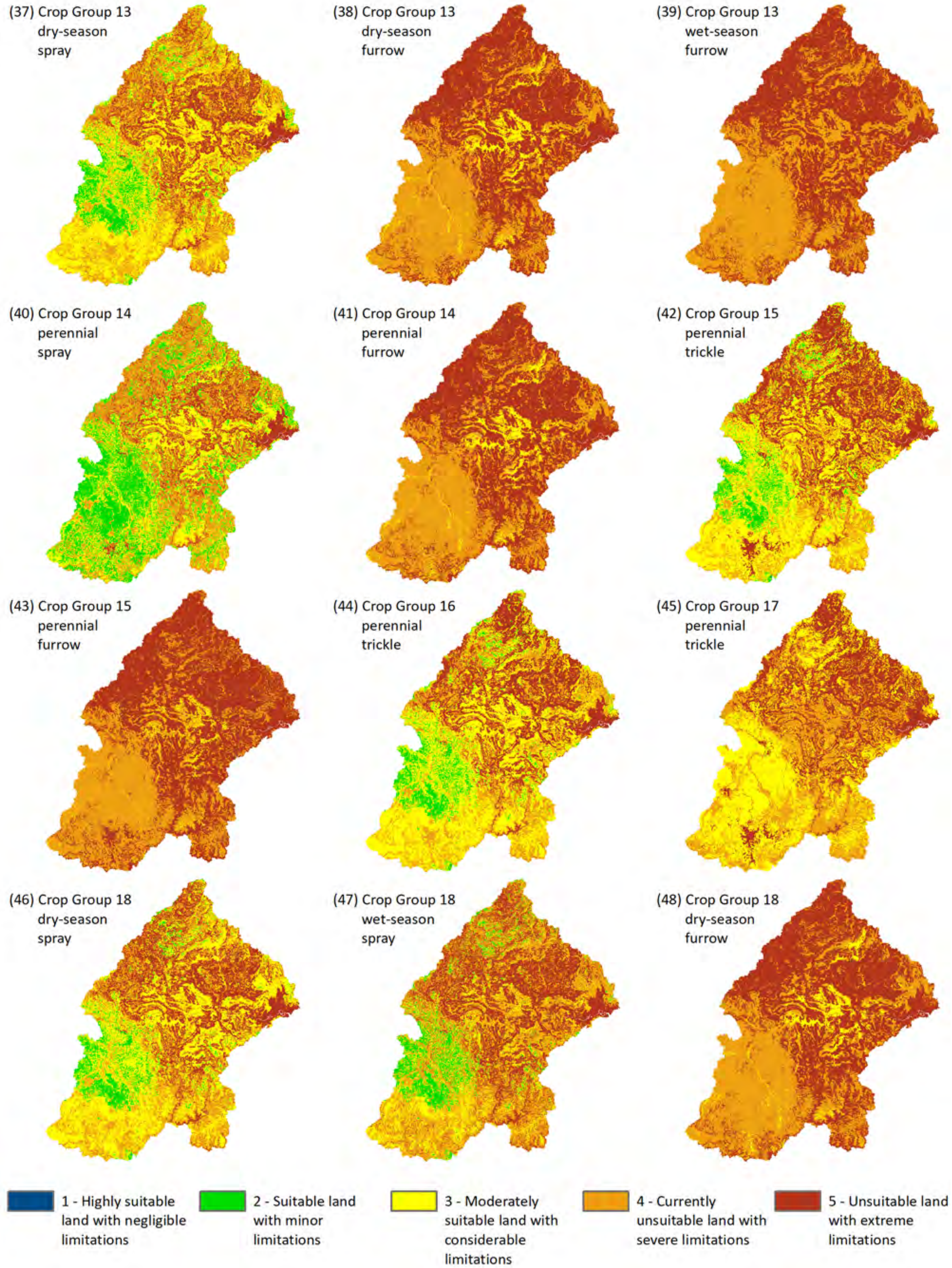
Apx Figure D-1 Suitability for land use options 1 to 12 from Appendix A



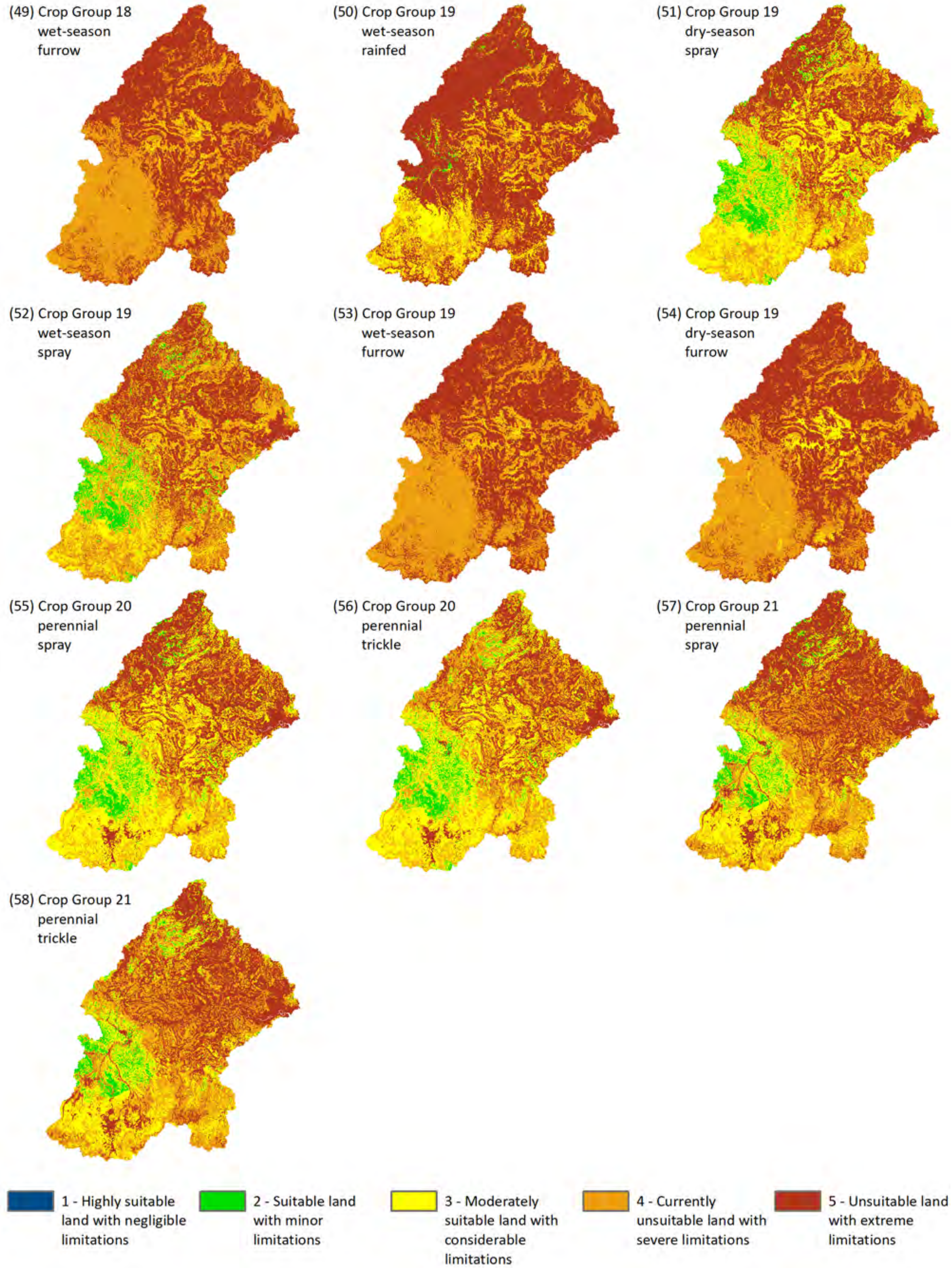
Apx Figure D-2 Suitability for land use options 13 to 24 from Appendix A



Apx Figure D-3 Suitability for land use options 25 to 36 from Appendix A



Apx Figure D-4 Suitability for land use options 37 to 48 from Appendix A



Apx Figure D-5 Suitability for land use options 49 to 58 from Appendix A

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