Soils and land suitability for the Victoria catchment, Northern Territory

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

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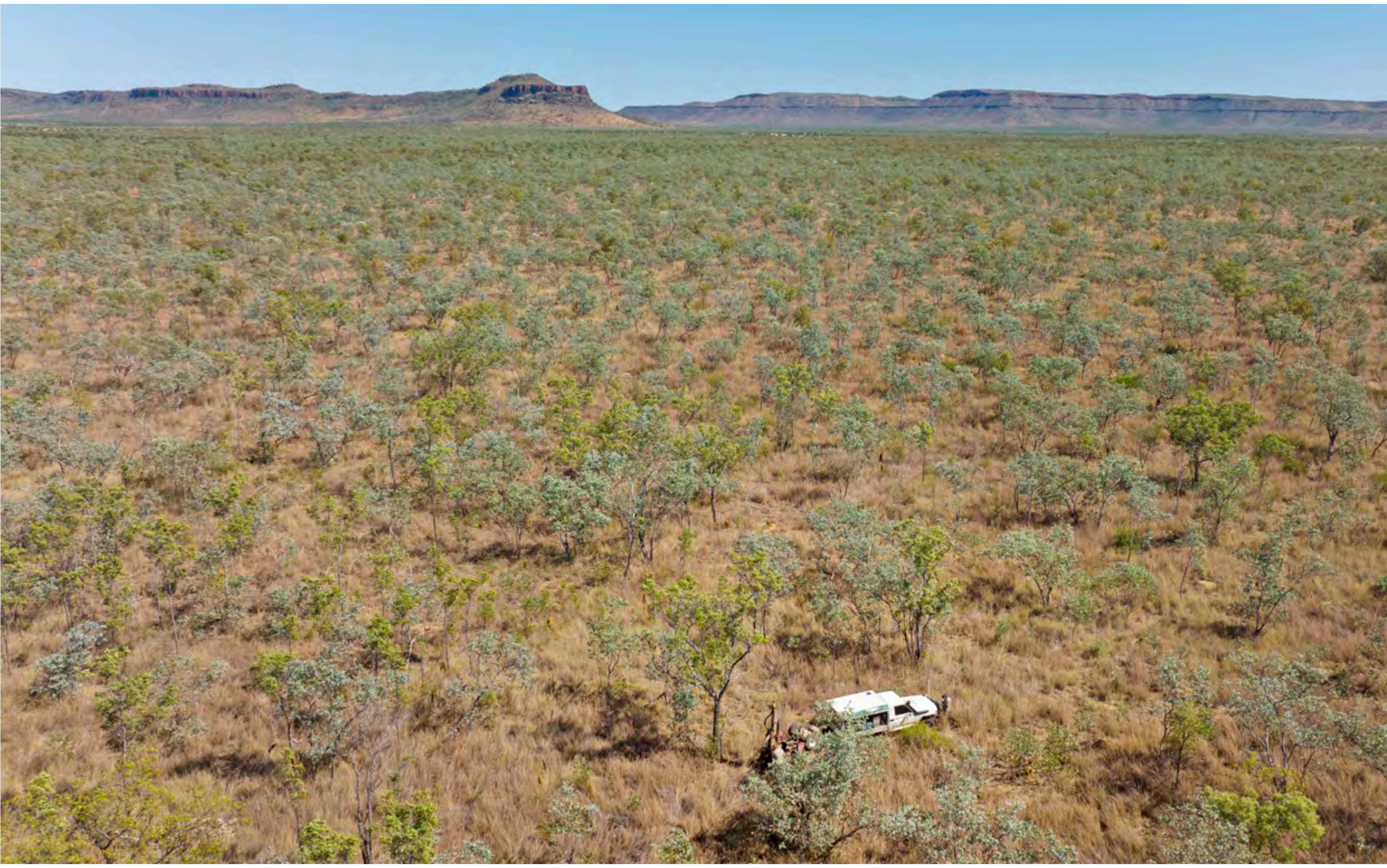

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CSIRO Victoria River Water Resource Assessment acknowledgements

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Aspects of the Assessment have been undertaken in conjunction with the NT 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); Northern Land Council; NT Department of Environment, Parks and Water Security; NT Department of Industry, Tourism and Trade; Office of Northern Australia; Queensland Department of Agriculture and Fisheries; Queensland 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 and Water Security; NT Department of Industry, Tourism and Trade; NT Farmers; NT Seafood Council; Office of Northern Australia; Parks Australia; Regional Development Australia; Roper Gulf Regional Council Shire; Watertrust

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 their release.

This report was reviewed by Mike Grundy (Adjunct Professor, Sydney Institute of Agriculture, The University of Sydney, Australia) and Dr Nathan Robinson (Centre for eResearch and Digital Innovation; Federation University, Australia).

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 extends to local Indigenous organisations and their staff who advised us, gave permission and access for soil sampling, and supervised sampling activity. In particular we would like to thank the Traditional Owners and Rangers of the Judbarra/Gregory National Park and the Northern Land Council. Many CSIRO staff who were 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. The CSIRO staff we wish to thank (in no particular order) include: Bec Bartley, Cuan Petheram, Jon Schatz, Simon Irvin, Tony Webster, Steve Yeates, Arthur Read, Linda Karssies, Georgia Reed 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: Jonathan Burgess and Kaitlyn Andrews (NT government), and Sonya Mork, Angus McElnea and other staff from the Qld DESI Chemistry Centre. Our fieldwork was improved by the support of the local grazing industry. They gave us 'the time of day', shared experiences and on ground knowledge, and provided the local context that is so important for work of this kind. Our documentation, and its consistency were much improved by Joely Taylor who provided great service and patient application of the Assessment's style and convention standards and Nathan Dyer took some wonderful photos and videos. 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: Soil sampling on the alluvial plains of the West Baines River north of Saddle Creek. Source: Nathan Dyer - CSIRO

Director's foreword

Sustainable development and regional economic prosperity are priorities for the Australian and Northern Territory (NT) governments. However, more comprehensive information on land and water resources across northern Australia is required to complement local information held by Indigenous Peoples and other landholders.

Knowledge of the scale, nature, location and distribution of likely environmental, social, cultural and economic opportunities and the risks of any proposed developments is critical to sustainable development. Especially where resource use is contested, this knowledge informs the consultation and planning that underpin the resource security required to unlock investment, while at the same time protecting the environment and cultural values.

In 2021, the Australian Government commissioned CSIRO to complete the Victoria River Water Resource Assessment. In response, CSIRO accessed expertise and collaborations from across Australia to generate data and provide insight to support consideration of the use of land and water resources in the Victoria catchment. The Assessment focuses mainly on the potential for agricultural development, and the opportunities and constraints that development could experience. It also considers climate change impacts and a range of future development pathways without being prescriptive of what they might be. The detailed information provided on land and water resources, their potential uses and the consequences of those uses are carefully designed to be relevant to a wide range of regional-scale planning considerations by Indigenous Peoples, landholders, citizens, investors, local government, and the Australian and NT governments. By fostering shared understanding of the opportunities and the risks among this wide array of stakeholders and decision makers, better informed conversations about future options will be possible.

Importantly, the Assessment does not recommend one development over another, nor assume any particular development pathway, nor even assume that water resource development will occur. 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.

C. Chilcott

Chris Chilcott

Project Director

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Note: Assessment team as at September, 2024. All contributors are affiliated with CSIRO unless indicated otherwise. Activity Leaders are underlined. For the Indigenous water values, rights, interests and development goals activity, Marcus Barber was Activity Leader for the project duration except August 2022 – July 2023 when Kirsty Wissing (a CSIRO employee at the time) undertook this role.

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Shortened forms

SHORT FORM	FULL FORM
ABS	Australian Bureau of Statistics
AHD	Australian Height Datum
ASC	Australian Soil Classification
ASS	acid sulfate soils
AWC	available water capacity
BOM	Bureau of Meteorology
cLHS	Conditioned Latin Hypercube Sampling
DEM	digital elevation model
DSM	digital soil mapping
FAO	Food and Agriculture Organisation of the United Nations
FGARA	Flinders and Gilbert Agricultural Resources Assessment
GIS	geographic information system
NAWRA	Northern Australia Water Resource Assessment
NT	Northern Territory
Qld	Queensland
SGG	Soil Generic Group
UI	uncertainty index

Units

UNIT	DESCRIPTION
ha	hectare
m	metre
km	kilometre
°C	temperature on Celsius scale

Preface

Sustainable development and regional economic prosperity are priorities for the Australian and NT governments and science can play its role. Acknowledging the need for continued research, the NT Government (2023) announced a Territory Water Plan priority action to accelerate the existing water science program 'to support best practice water resource management and sustainable development.'

Governments are actively seeking to diversify regional economies, considering a range of factors. For very remote areas like the Victoria catchment (Preface Figure 1-1), the land, water and other environmental resources or assets will be key in determining how sustainable regional development might occur. Primary questions in any consideration of sustainable regional development relate to the nature and the scale of opportunities, and their risks.

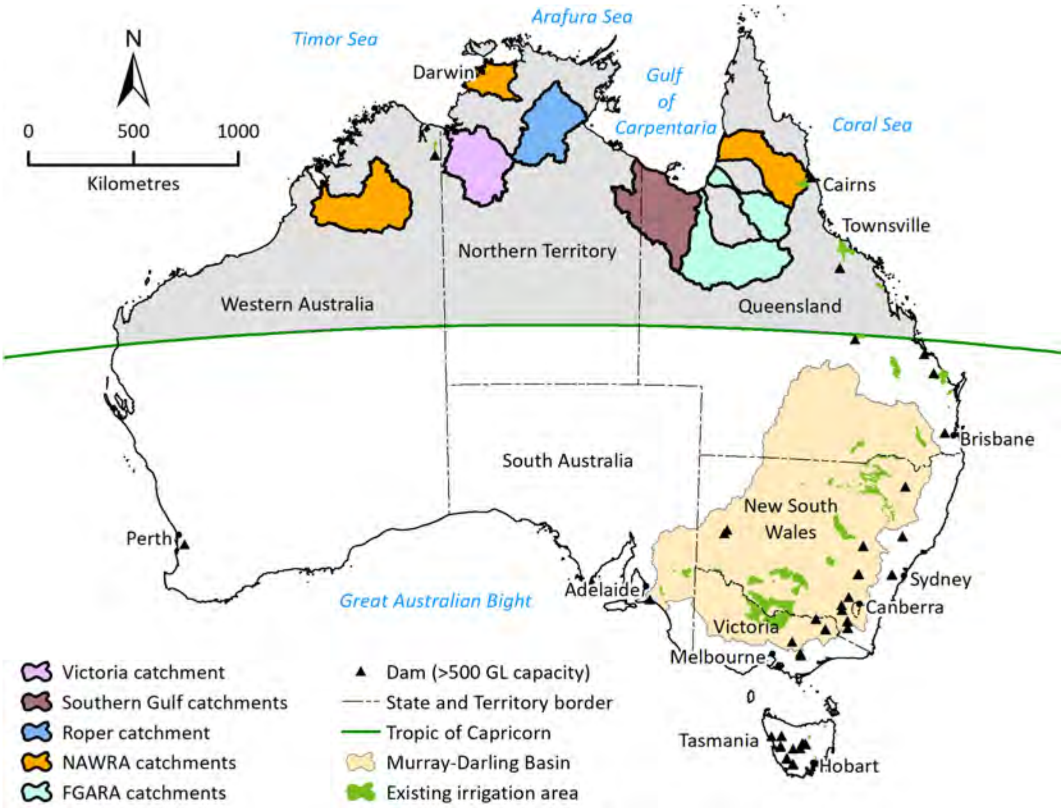
How people perceive those risks is critical, especially in the context of areas such as the Victoria catchment, where approximately 75% of the population is Indigenous (compared to 3.2% for Australia as a whole) and where many Indigenous Peoples still live on the same lands they have inhabited for tens of thousands of years. About 31% of the Victoria catchment is owned by Indigenous Peoples as inalienable freehold.

Access to reliable information about resources enables informed discussion and good decision making. Such information includes the amount and type of a resource or asset, where it is found (including in relation to complementary resources), what commercial uses it might have, how the resource changes within a year and across years, the underlying socio-economic context and the possible impacts of development.

Most of northern Australia's land and water resources have not been mapped in sufficient detail to provide the level of information required for reliable resource allocation, to mitigate investment or environmental risks, or to build policy settings that can support good judgments. The Victoria River Water Resource Assessment aims to partly address this gap by providing data to better 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.

The Assessment differs somewhat from many resource assessments in that it considers a wide range of resources or assets, rather than being a single mapping exercise of, say, soils. It provides a lot of contextual information about the socio-economic profile of the catchment, and the economic possibilities and environmental impacts of development. Further, it considers many of the different resource and asset types in an integrated way, rather than separately. The Assessment has agricultural developments as its primary focus, but it also considers opportunities for and intersections between other types of water-dependent development.

The Assessment was designed to inform consideration of development, not to enable any particular development to occur. The outcome of no change in land use or water resource development is also valid. 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. Policy and regulations can change, so this flexibility enables the results to be applied to the widest range of uses for the longest possible time frame.



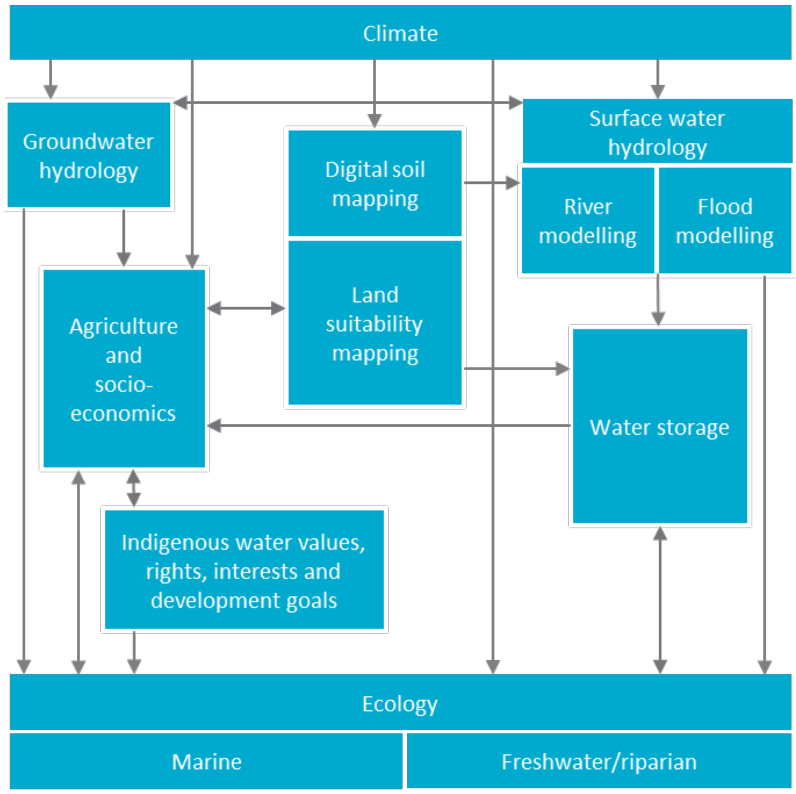
Preface Figure 1-1 Map of Australia showing Assessment area (Victoria catchment and other recent CSIRO Assessments

FGARA = Flinders and Gilbert Agricultural Resource Assessment; NAWRA = Northern Australia Water Resource Assessment.

It was not the intention of – 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.

CSIRO has strong organisational commitments to reconciliation with Australia's Indigenous Peoples and to conducting ethical research with the free, prior and informed consent of human participants. The Assessment consulted with Indigenous representative organisations and Traditional Owner groups from the catchment to aid their understanding and potential engagement with its fieldwork requirements. The Assessment conducted significant fieldwork in the catchment, including with Traditional Owners through the activity focused on Indigenous values, rights, interests and development goals. CSIRO created new scientific knowledge about the catchment through direct fieldwork, by synthesising new material from existing information, and by remotely sensed data and numerical modelling.

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



Preface Figure 1-2 Schematic of the high-level linkages between the eight activity groups 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 for each Assessment 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 present scientific work with sufficient detail for technical and scientific experts to reproduce the work. Each of the activities (Preface Figure 1-2) has one or more corresponding technical reports.
- A catchment report, which synthesises key material from the technical reports, providing well-informed (but not necessarily scientifically trained) users with the information required to inform decisions about the opportunities, costs and benefits, but also risks associated with irrigated agriculture and other development options.
- A summary report provides a shorter summary and narrative for a general public audience in plain English.
- A summary fact sheet provides key findings for a general public audience in the shortest possible format.

The Assessment has also developed online information products to enable users to better access information that is not readily available in print format. All of these reports, information tools and data products are available online at https://www.csiro.au/victoriariver. The webpages give users access to a communications suite including fact sheets, multimedia content, FAQs, reports and links to related sites, particularly about other research in northern Australia.

Executive summary

The Victoria River Water Resource Assessment (the Assessment) was commissioned by the Australian Government and carried out by CSIRO in collaboration with the Northern Territory Government. The Assessment aims to support decision making for sustainable regional development for the Victoria catchment in the Northern Territory by clarifying the scale and nature of opportunities and limitations for agriculture and other uses of water resources. The catchment covers some 82,400 km^2 and is dominated by extensive cattle grazing.

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 distribution, 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 (DSM) and subsequent land suitability analysis for the catchment. Four major tasks were completed, namely:

1. New soil data were collected to cater for important gaps in soils not covered by pre-existing surveys in the catchment.
2. Soil attribute (i.e. soil pH, clay content, A horizon depth, soil thickness, available water capacity, permeability, drainage, rockiness, erodibility, exchangeable sodium percentage, surface condition, structure, surface salinity, texture, and microrelief) and soil generic group data were modelled, each delivered with a spatial resolution of one arc-second (i.e. grid cells of approximately 30 m on the ground).
3. The digital data and maps were incorporated with other publicly available environmental digital data (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). Rainfed agriculture was also included as a land use.
4. The reliability of soil attribute and land suitability data were evaluated following field validation and statistical testing.

The DSM for soil attributes and soil generic groups (SGGs) combined pre-existing and new soil data. Pre-existing soil data from 6463 sites from the Northern Territory database were augmented by a new soil survey comprising 136 sites. New sites were located using statistical methods to infill geographic gaps in the pre-existing data. The digital soil mapping applied predictor covariates from various national databases, including the Soil Landscape Grid of Australia. The SGGs were developed to support non-expert communication and aligned with the Australian Soil Classification (ASC). Methods for map reliability checking included statistical measures as well as generation of reliability maps, which allow users to visually assess mapping strengths and weaknesses when used in companion with the attribute map.

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 comprise similar sets of 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 hydrology is covered by another Assessment activity. The system is flexible enough to accommodate new data for soils, crop varieties, land management practices, climate etc. as datasets and new knowledge is derived.

The suitability of 21 crop groups (>120 individual crops) for 58 land use combinations (i.e. crop group by season by irrigation type were evaluated) and presented in the report. However, for report brevity, 14 realistic ‘exemplar’ land use combinations are illustrated. The suitability of land for aquaculture (freshwater and/or marine species) using either earthen or lined ponds are assessed. The report shows the most prospective ‘exemplar’ cropping land use for the catchment is crop group 3, intensive horticulture under dry season trickle irrigation covering 37.1 % (3,066,400 ha) of the catchment with suitability class 3 or better. The most agriculturally versatile lands in the catchment were associated with the alluvial plains, the Limestone gentle plains, and the Basalt gentle plains where friable clays and loams (SGG 2) and cracking clay soils (SGG 9) dominate. These soils are suited to spray and trickle irrigation due to their favourable soil water characteristics, e.g. larger water holding capacity. The Tertiary sedimentary plains with red loamy soils (SGG 4.1) were also assessed has being favourable for spray or trickle irrigation for their generally suitable drainage attributes. Low to zero irrigation versatility areas coincide with shallow and/or stony soils on sloping lands. These soils are featured in hilly physiographic units of Basalt hills, Sandstone hills and Limestone hills.

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 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 not suitable for planning and development needs at scheme, property or paddock level. Satisfying those needs requires new investigation at commensurate intensity.

Given the system-wide approach to assessing opportunity and constraints to intensification of agriculture in the region, this report should be considered within the context of the other Assessment activity reports. These activities include climate; surface water hydrology; groundwater hydrology; agriculture and aquaculture viability; water storage; socioeconomics; Indigenous water values, rights and development aspirations; and aquatic and marine ecology. These companion studies are also published.

All data from the Assessment is publicly available to the public via CSIRO’s Data Access Portal (https://data.csiro.au/).

Contents

Figures

Tables

1 Introduction

Knowledge of soils and the landscapes they occupy is critical for determining the opportunities for land intensification, especially for 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 i.e., 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 well structured 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 extensive enough to make irrigated agriculture a viable proposition. In locating these potentially useful pockets of land it is necessary to firstly, understand the location and characteristics of the soils, then secondly, 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 (the activity) of the Victoria River Water Resource Assessment (the Assessment), which encompasses the Victoria catchment of the Northern Territory (NT). This Assessment is the next phase in a sequence of catchment Assessments in Northern Australia (Figure 1-1) including:

1. Queensland's (Qld) Flinders and Gilbert Agricultural Resource Assessment combining the river catchments of the Flinders and Gilbert and completed in 2014 (Bartley et al., 2013).
2. The Northern Australia Water Resource Assessment, combining Western Australia's Fitzroy River catchment, NT's Darwin river catchments, and Qld's Mitchell River catchment, completed in 2018 (Thomas et al., 2018a; Thomas et al., 2018b).
3. The Roper River Water Resource Assessment (Thomas et al., 2022) in the Northern Territory.

In many respects this activity, as with the previous Assessments, captures the meaning of earlier studies on soil and land resources of the North (e.g. Wilson et al., 2009) that were based on limited pre-existing soil data. This data constraint has substantially limited its usefulness and applicability of those studies, so hence the need for new data to deliver new knowledge and insights to the land and utility of the North.

The report details approaches applied to assess the suitability of 58 agricultural land intensification options in the Assessment area that combines plausible land use and management scenarios (land uses) for the agricultural environment. This includes 21 crops, growing season (wet season, dry season, perennial), and irrigation type. Irrigation type combines flood, spray and trickle irrigation methods. Rainfed farming is also included in the list of land uses. The suitability of land for aquaculture for freshwater and marine species is also assessed. Before the suitability for these land use options could proceed, various activities to map land and soil attributes were undertaken, and the maps then incorporated into a land suitability decision support system to identify areas of potential agricultural and aquaculture viability of the various land use options.

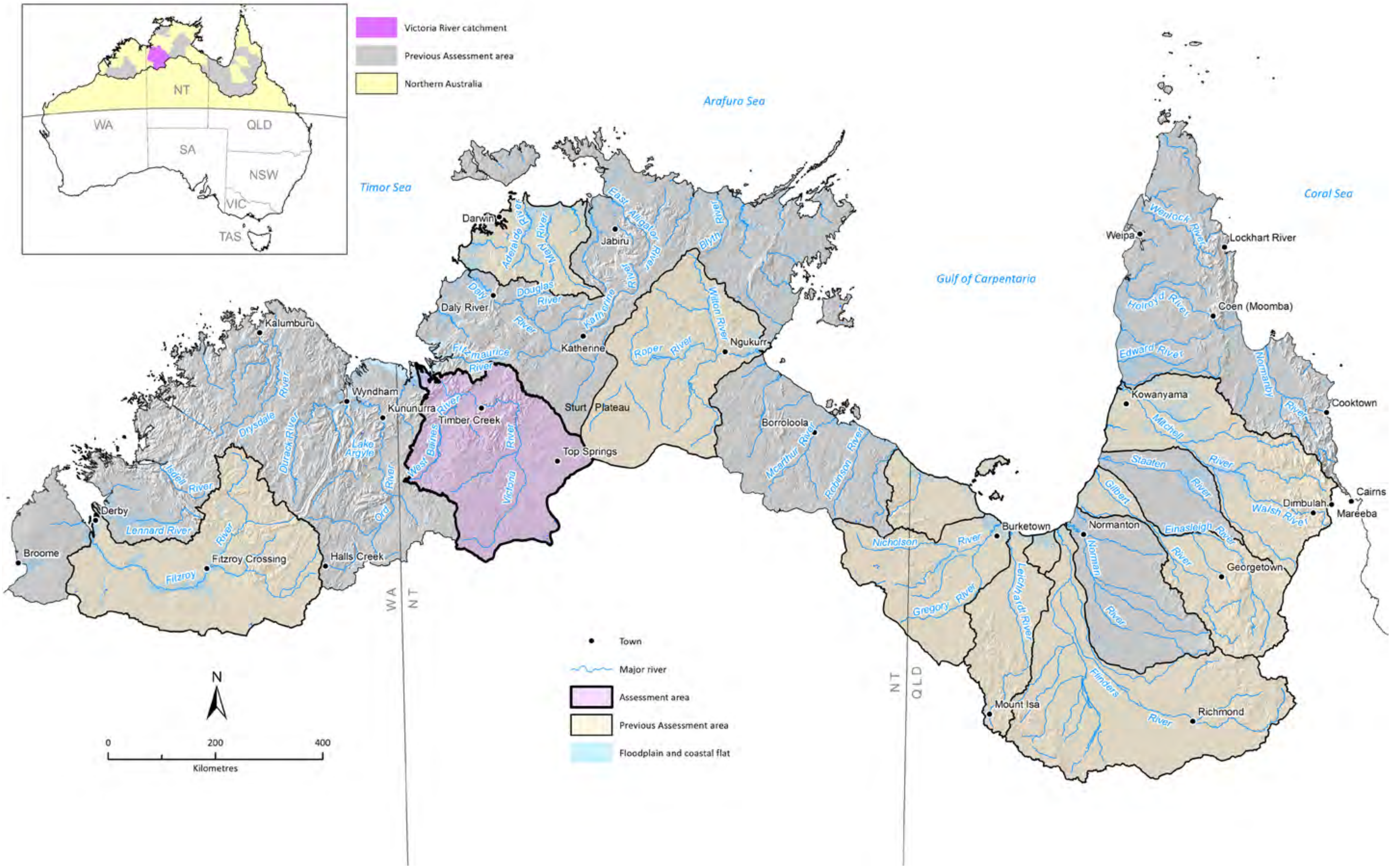


Figure 1-1 Location of Victoria River Water Resource Assessment area in northern Australia, including settlements and the major rivers overlaid on hill shaded relief. Previous Assessment boundaries are also shown

1.1 Assessment area

The Victoria catchment, covering some 82,400 km^2, defines the boundary of the Assessment area and is shown in Figure 1-2. The catchment is located in the far northwest of the Northern Territory on the Western Australian border adjacent to the North Kimberly region. At approximately 510 km in length the river is the longest in the Northern Territory (Geoscience Australia, 2022) and flows into the Joseph Bonaparte Gulf in the Timor Sea.

In terms of the earliest post-colonial exploratory accounts, on 12 September 1819 Philip Peter King formally recorded the mouth of the Victoria River. In 1839 Captain J. C. Wickham on one of the HMS Beagle expeditions formally named the river after Queen Victoria, and members of the expedition navigated nearly 200 km up stream. In 1855 Augustus Gregory sailed to the river mouth and from there staged exploratory inland surveys before sailing back to Brisbane.

The Victoria catchment has a summer rainfall dominant climate showing marked wet summers and dry winters. Much of the catchment has hot humid summers and shifts to warm humid summers southwards. The climate is characterised by tropical cyclonic weather systems that build in the Indian Ocean and Coral Sea and deliver rain typically from November to April. These systems often deliver rain during extremely intense events, and because cyclones track inland the intensity and quantity of rain delivered correlates to distance from the coast. Hence there is a strong north-south rainfall trend, and inland (southern) rainfall may be significantly less than that delivered in coastal areas in many years (Stewart et al., 1970).

Contemporary long-term Bureau of Meteorology (2022) records confirm the north-south rainfall trend in the catchment; for example at Auvergne Station near the gulf (Lat 15.68° S, Lon 130.01° E) the mean annual rainfall is 850 mm. The Victoria River Downs Station (Lat 16.40° S, Lon 131.01° E) lies approximately mid catchment, and here the mean annual rainfall is 651 mm. On the southern watershed at Lajamanu (Lat 18.33° S, Lon 130.64° E) the mean annual rainfall is 506 mm. While mean annual maximum and mean annual minimum temperatures vary little across these weather stations (max: 35.2 - 33.9 °C; min: 19.6 °C for all), mean annual evaporation increases on trend towards the south of the catchment (Stewart et al., 1970).

The physiography of the Victoria catchment is shown in Figure 1-2 with descriptions in Table 1-1. These eight units identified[1] are listed with shortened names in parentheses below:

- coastal marine plains (*Marine plains*)
- alluvial plains of rivers and creeks (*Alluvial plains*)
- level lateritic plains, plateaux and escarpments (*Tertiary sedimentary plains*)
- gently undulating plains and rises on Basalt (*Basalt gentle plains*)
- undulating rises to steep hills on Basalt (*Basalt hills*)
- dissected plateaux, escarpments, steep hills and ridges on Sandstones, Siltstones and Shales (*Sandstone hills*)

[1] Physiographic units have been refined in this study using method outlined in Section 2.2.4 and reported in Section 3.3

- gently undulating plains and pediments on Dolomite and Limestone, minor Shales/Mudstones/Siltstones (*Limestone gentle plains*)
- hills and ridges on Dolomite (*Limestone hills*).

The physiographic units serve as a useful framework to understand the potential agricultural lands and soils in terms of qualities and limitations, given each unit is derived from a distinct group of lithologies and landforms that give rise to a particular set of soil types and geomorphic patterns. Links between physiographic units and soils are expanded further in Section 3.3 below.

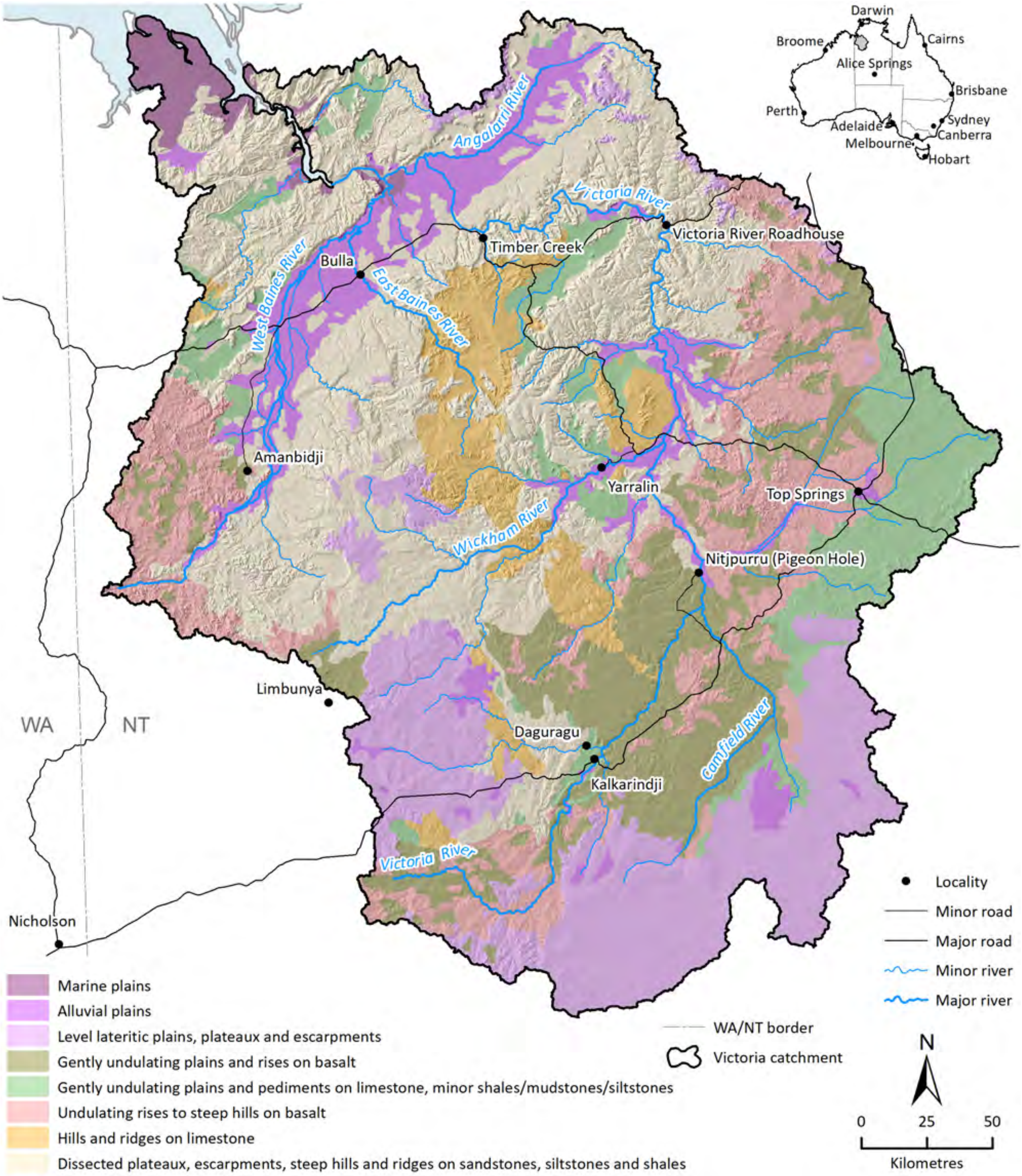


Figure 1-2 Victoria River Water Resources Assessment catchment (82,400 km^2), featuring the Victoria River and tributaries, physiographic units after Sweet (1977), significant settlements and roads overlaid on hill shaded terrain relief

Table 1-1 cross-references the physiographic unit descriptions from the legend in Figure 1-2.

Table 1-1. Victoria catchment physiographic unit description, shortened names used in the report from Figure 1-2, and area coverages (ha)

PHYSIOGRAPHIC UNIT DESCRIPTION	SHORTENED NAME	AREA (ha)	% OF SUDY AREA
Coastal marine plains	Marine plains	143,000	1.8
Alluvial plains of rivers and creeks	Alluvial plains	643,000	7.8
Level lateritic plains, plateaux and escarpments	Tertiary sedimentary plains	1,320,000	16
Gently undulating plains and rises on basalt	Basalt gentle plains	1,031,000	12.5
Undulating rises to steep hills on basalt	Basalt hills	1,100,000	13.3
Dissected plateaux, escarpments, steep hills and ridges on sandstones, siltstones and shales	Sandstone hills	2,722,000	33
Gently undulating plains and pediments on dolomite and limestone, minor shales/mudstones/siltstones	Limestone gentle plains	741,000	9
Hills and ridges on dolomite	Limestone hills	540,000	6.6

1.2 Summary of previous soil investigations

A broad scale assessment of the land resources for pastoral opportunities for the Northern Territory, including observations of the soil landscapes of the Victoria catchment, was published in Perry (1960). The first soils characterised in the catchment itself were described in the late 1960s for a broad scale (1:10 M mapping scale) land system survey (Stewart et al., 1970). This mapping documented the main landforms, soils and vegetation communities across the Ord and Victoria River regions.

During the 1970s, higher resolution land unit mapping was carried out on the Victoria River Research Station (Forster and Laity, 1972) and in the Timber Creek Township area (Wells and Van-Cuylenburg, 1976).

Following evidence of land degradation across parts of the catchment in the 1970s, land resource and erosion studies were initiated. Land system mapping undertaken across parts of Humbert River Station (Wood et al., 1979) identified some soils were highly susceptible to severe water erosion. Around this time similar studies were undertaken across parts of the upper Ord River catchment, immediately west of the current study area (Aldrick et al., 1978; Robinson, 1971). These investigations were followed by a reconnaissance erosion survey of nine pastoral leases in the Victoria River locality (Condon, 1986), which documented erosion extent, relationships between soil type and erosion susceptibility and an overall plan for regeneration. In the late 1980s, parts of Coolibah, Innesvale and Delamere Stations in the north and eastern parts of the catchment were assessed in two studies (Raine, 1989a; Raine, 1989b).

Following the establishment of Keep River and Gregory (now Judbarra–Gregory) National Parks, the Conservation Commission of the Northern Territory undertook integrated land resource assessments of both parks (Brocklehurst et al., 1996; Siverten and van-Cuylenburg, 1986). This information would assist both general land management and the development of conservation strategies.

Small-scale investigations in the 1980s further characterised soils for pastoral research on the Victoria River Research Station as well as establishing an understanding of the pastoral and cropping soils along the western boundary of the catchment in the east Kimberley region (Isbell et al., 1986).

During the 1990s, soil research focussed on developing quantitative methodologies for estimating sustainable carrying capacities of the region's major land types (Cobiac, 2006). Although small in scale, these investigations continued to build the knowledge base on soil physical and chemical properties of this region.

Following salinity concerns, a soil investigation was carried out on Legune Station in 2001. The investigation identified naturally high levels of soil salinity across the delta (Tickell and Hill, 2001).

Vegetation and flora surveys of Auvergne Station and part of Spirit Hills (Brocklehurst et al., 1998), and Bullo River Stations (Lewis et al., 2010) generated reconnaissance soil information across the northern part of the catchment.

In 1990, the Northern Territory Government initiated its largest integrated land resource-mapping project. Encompassing 74,502 km^2 across 23 pastoral leases and Aboriginal Land Trusts, this project collected an extensive new soil dataset, and for the first time delivered consistent 1:100,000 land unit mapping across a large part of the Victoria River pastoral district (Napier and Hill, 2012). The project was published in 2012 and later extended to encompass Auvergne Station (Napier et al., 2018).

Over a 50-year period, soil information collected from 3,154 sites has underpinned an appreciation of the region's land resources and the associated implications for rangeland, grazing and conservation land management.

1.3 Land resource assessment design, data and inference system

The land resource assessment approach described by this report builds on research legacies of the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013; Harms et al., 2015; Thomas et al., 2015), the Northern Australia Water Resource Assessment (Bui et al., 2020; Thomas et al., 2018a; Thomas et al., 2018b) and the Roper Water Resource Assessment (Thomas et al., 2022). These 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 that has been adopted. This highlights phases 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 previous Assessments this workflow includes quantitatively mapped estimations of uncertainty. These phases are described more fully below.

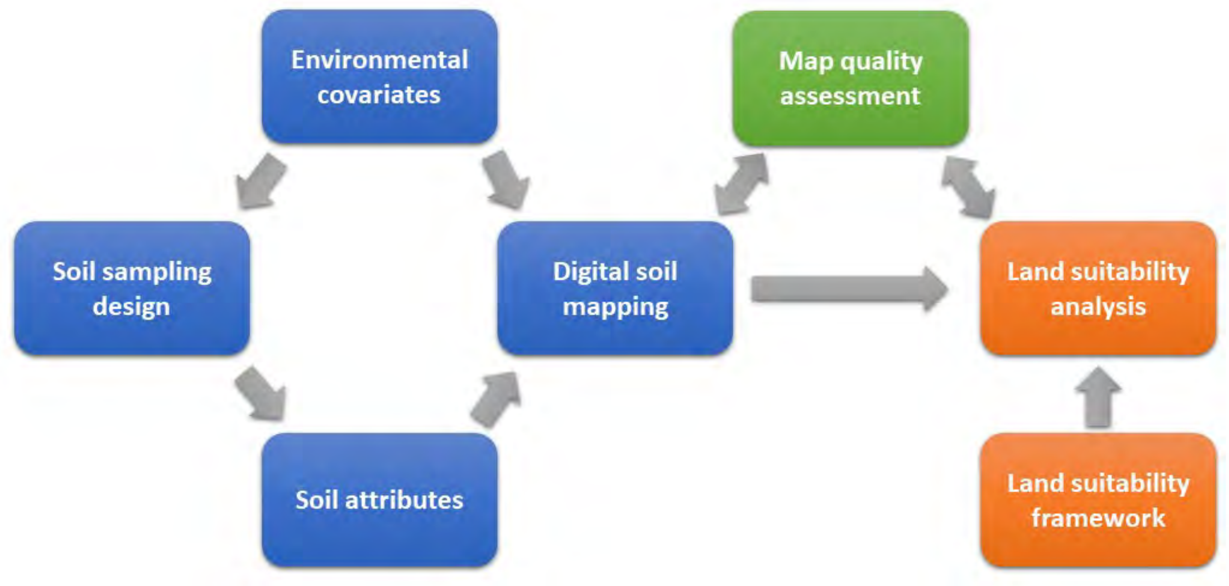


Figure 1-3 Land suitability assessment workflow and key inputs and processes

1.3.1 Sampling design

Reliable DSM requires a sampling approach (McKenzie et al., 2008) that minimises bias in the selection of soil sampling sites and maximises the spread of sites so that the full range of soil variability in the study area is sampled (at least to the extent suggested by the covariate space). The sampling design used conditioned Latin Hypercube Sampling (cLHS), a form of digital stratified random sampling described in Minasny and McBratney (2006). cLHS ensures sampling points capture the distribution of the environmental covariates[2] chosen to represent the drivers of soil variability in the area of interest. Thus, 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 from operational considerations like project resourcing and budget.

1.3.2 DSM

DSM has a successful track record in delivering land and soil information to large-area assessments in Australia and the region (Bui et al., 2007; Grundy et al., 2020; Kidd et al., 2015; Kidd et al., 2020; Kidd et al., 2014; Searle et al., 2021; Thomas et al., 2015; Viscarra-Rossel et al., 2015), and elsewhere (e.g. Behrens and Scholten, 2007; Hartemink et al., 2010; Hartemink et al., 2013). The success of the approach lies in the fact that DSM has co-evolved with gains in computing power and adaption of statistical methods. Australia is well positioned to undertake DSM for catchment-wide studies because of a legacy of reliable covariates including climate, remote sensing, terrain derived from digital elevation models (DEMs), and gamma radiometrics (mineralogy, landscape evolution) data layers (Bui, 2007).

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[2] Environmental covariates – or simply *covariates* – are spatial geographic information system (GIS) format datasets that, based on the principles of soil formation, are expected to have functional relationships 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.

DSM outputs include maps of soil attributes and soil types created in GIS grid data format that follow natural patterns of soil change across landscapes. These qualities make DSM outputs suitable for direct incorporation with land suitability analysis frameworks discussed next. DSM also enables production of companion mapping reliability maps showing where the DSM mapping are more or less reliable; these companion maps are useful to users who make objective decisions on fitness-for-purpose of the mapping.

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 agricultural qualities (Rossiter, 1996). Land suitability assessment considers the attributes and qualities that limit the maximum potential yield of a land use and terms these factors 'limitations'.

This Assessment defines limitations and builds the analytical framework following the FAO Framework for Land Evaluation (FAO, 1976; FAO, 1985). The Framework involves a broad assessment of land suitability that integrates multiple limitations including biophysical (edaphic and climate), social and economic themes (FAO, 2007). This Assessment, however, deviates from FAO's integrated framework as it constrains analysis only to edaphic and biophysical themes; other aspects are covered in companion Assessment activities, e.g., surface water hydrology, socioeconomics, Indigenous water values, rights and development aspirations, and aquatic and marine ecology.

The land suitability approach applied in the Assessment follows the lineage of approaches first developed in the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013; Harms et al., 2015), and was further refined through the Northern Australia Water Resource Assessment (Thomas et al., 2018b) and the Roper Water Resource Assessment (Thomas et al., 2022).

The edaphic components of the land suitability mostly relate to soil attributes - or limitations - that have a key bearing on the growth and productivity of irrigated land uses, 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.

1.4 Report objectives

The objective of this report is to describe the methods and outputs used to

- address questions around the scale of opportunity for agricultural land use intensification of the Victoria catchment
- support other Assessment Activities with land and soil datasets addressing other catchment resource questions, including agronomic and surface hydrology.

2 Methods

2.1 Pre-existing soil data

A significant amount of soil data are available from numerous prior studies that have been carried out in the Assessment and neighbouring areas. Despite the age of data and possible inconsistencies caused by prior less precise analytical methods or changes in land use in the intervening years, much data remains usable and valuable for this work subject to selection criteria described.

Following a comprehensive review of the data by the 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 included from areas beyond the Victoria catchment bound by the following extents: south of -14.69° and north of -18.40° latitude, east of 129.00° (the West Australian border) and west of 132.55° longitude. The extent is shown in Figure 2-1. These areas are sufficiently close to the catchment that they share the soil development conditions and so the soils are the same, and so their inclusion in the Assessment boosts the DSM models.

After extraction from various sources, candidate soil site records were collated in a relational database using standard protocols described in Jacquier et al. (2012). The following criteria were applied to select suitable records. Where duplicate records were discovered for each site, the most recent record was accepted. If a record was captured in geographic coordinates to >4 decimal places, the record was accepted. If the record is tagged with a positional accuracy of 50 m or better, the record as accepted. Only records that had some below-surface soil description or data were accepted. Where numerous clustered records existed e.g. from an intense land development survey, one representative record was selected to reduce modelling bias. Quality checks were conducted to only accept sites that demonstrate logical consistency according to the modelling need. For example, a record classifying a site as an ASC Hydrosol but described as well drained thus inaccurate was rejected for use in drainage mapping.

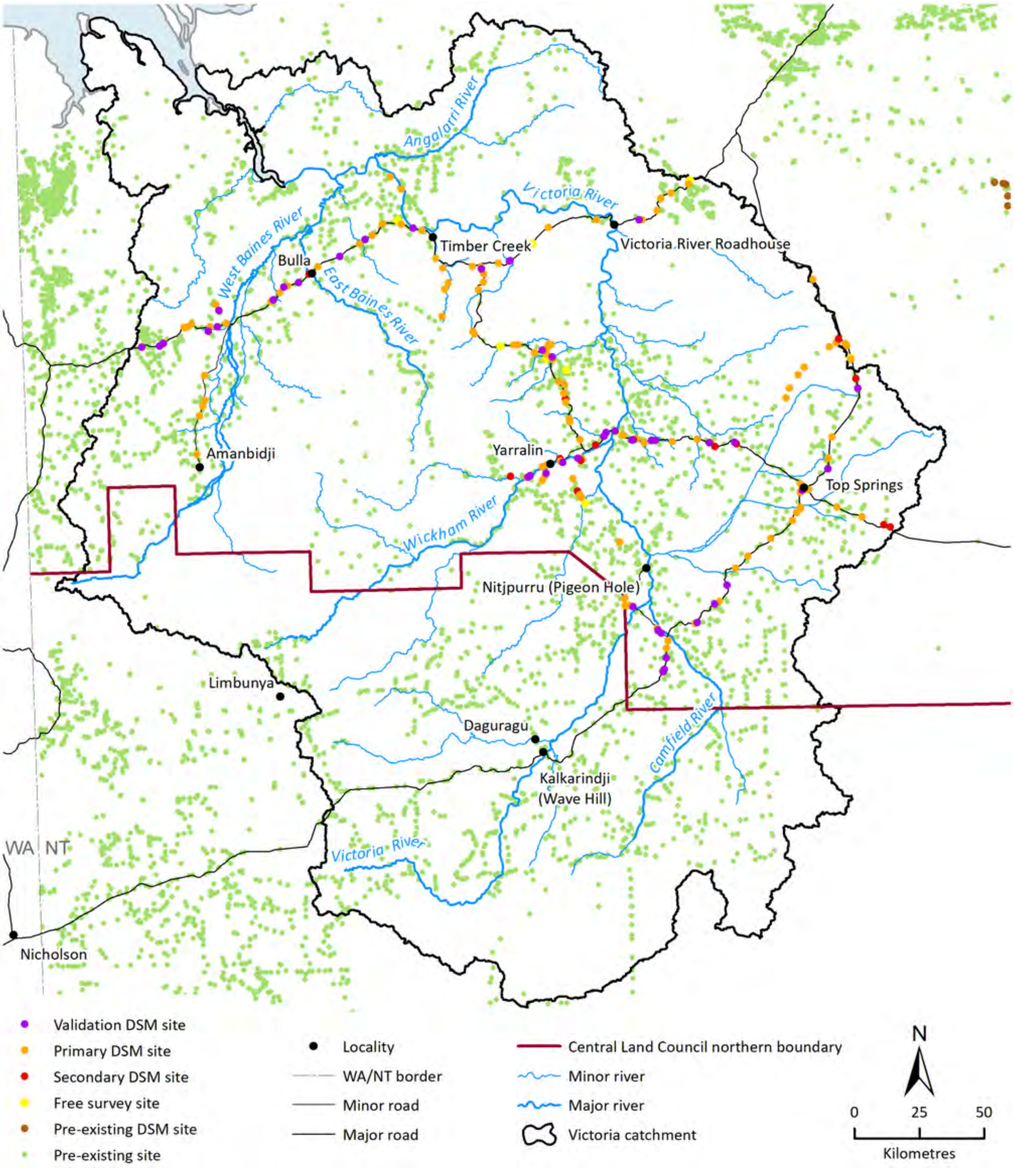

Figure 2-1 Location of pre-existing and new land and soil sampling sites in and neighbouring the Victoria catchment

2.2 Sampling design, field methods and rationale

Field methods followed 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 CSIRO, 2016).

All fieldwork was vehicle-based, hence vehicle site access sometimes restricted sampling sites accessibility. Fieldwork was restricted to the dry season (i.e. outside the cyclone season) when rivers and creeks were passable, and roads and tracks were dry and traversable. Fieldwork towards the end of the dry season was avoided because soils were likely to be too hard to effectively sample, so the operational field season ran nominally between late April and late October. Field teams consisted of CSIRO and NT Government survey experts, and each fieldtrip comprised at least two remote area-ready vehicles working together.

Soil chemical and physical attributes for the newly collected samples were analysed using conventional laboratory methods (McKenzie et al., 2002; Rayment and Lyons, 2011; Thorburn and Shaw, 1987). All data were transferred to the NT Government's SALInfo digital 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 for DSM that firstly, covered the covariate space, and secondly, infilled geographic gaps in the useable pre-existing soil data discussed in Section 2.1. This sampling design technique produces 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, 2022). The soil–landscape variability was captured by selecting covariates representing soil forming factors (Fitzpatrick, 1980; Jenny, 1941). The seven covariates (Table 2-3) selected in the cLHS sampling design included:

- Prescott Index (soil leaching and formation index)
- DEM (relief patterns, patterns of through-landscape water movement and residence, etc.)
- slope % (mass wasting)
- Dynamic Land Cover, mean of 2000-2008 timeseries (seasonal vegetation dynamics)
- gamma radiometrics: including K-, Th-, U-, and total dose (soil history, age).

The cLHS sampling was constrained using the *cost* condition forcing sampling sites to be 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 pre-existing sampled sites within the study area using the *must.include* condition of the *clhs* package.

One hundred and fifty new 'primary' and 50 'secondary' sampling sites were generated. The primary were treated as priority sampling sites and distributed prior to each field survey. The secondary sites were available to be collected opportunistically after the primaries had been completed, e.g. if there was time left in the day. Furthermore, primary and secondary sites were accompanied by contingency sites available if these sites could not be accessed because of practical or safety reasons, e.g. fence lines, locked gates, flooding or high flows, etc. These were located within a radius of 250 m of the site. Ensuring similarity of soils was guaranteed using the similarity index methodology of Brungard and Johanson (2015). A similarity index of 0.8 was required to be an eligible contingency site so this meant that there were typically two to 5 contingency sites available for each primary or secondary site.

Twenty out of the primary 150 sites were selected for subsequent laboratory analysis. These samples were selected to capture the full covariate range of soils already sampled using the R program *clhs* package (Roudier et al., 2012) and involved using the 150 samples as covariates to constrain selections to the original population.

For reference and communication purposes, opportunistic sites along the way were sampled at non-planned locations deemed by the survey team to hold significant agricultural potential.

2.2.2 Soil sampling

All sampling site locations were recorded using a Garmin 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 1:5 soil/water ($EC_{1:5}$)
- 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† (Pachepsky and Rawls, 2003)	Affects rooting depth, permeability and drainage and soil workability
Sample analysis	Available water capacity (AWC)	Estimated by pedotransfer function from a range of data (Littleboy, 2002)	Capacity of soil to store moisture for plant use

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

2.2.3 Validation survey

A two-week field trip was undertaken in May 2022 to collect external validation sites. While the DSM model performance was principally checked through (quantitative) internal validation (Section 2.4.3 below), the field visits to mapped sites to test the quality of prediction from an expert point of view allowed the model quality to be tested and if necessary, influence model parametrisation for models that were re-run. A cLHS sampling design was employed to select 40 validation sites within a 100 m buffer of mapped roads and tracks[3]. Mapped reliability estimates from six DSM soil attribute maps (Section 2.4.4) listed below were used as covariates for the cLHS analysis:

- Drainage
- Permeability
- Rockiness
- Surface pH
- Surface texture

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

- Maximum clay content to 1.5 m depth.

Sites with comparative similarity indices (Section 2.2.1) to the primary cLHS validation sites that were no further than 250 m away and within the 100 m road buffer were identified as additional sites serving as contingencies in situations in which primary validation sites could not be practically reached.

Field validation was performed on DSM attributes that could be readily analysed in the field (e.g. pH) or could be expertly (qualitatively) assessed *in-situ*. Field evaluations were conducted on the following 15 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 data, all draft land suitability data (Section 2.5) 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 if 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 2 actual was acceptable but not class 3 modelled and class 4 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 for some attributes with 39 new observation points. This followed the sampling and description protocols described in Section 2.2.2 above.

2.2.4 Capturing soil and physiographic knowledge

As an essential complement to the DSM and land suitability analysis a study relying on traditional land resource assessment thinking and approach (Hewitt et al., 2008; McKenzie and Grundy, 2008) was undertaken. The new knowledge generated forms an underpinning of the knowledge-base and conceptual understanding of the soil-landscapes to allow aligned 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 methodology and paradigms (Hudson, 1992) by applying geomorphic principles to assess the distribution of soils and landscapes. From these, descriptions were 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 more suitable for agriculture (e.g., on Quaternary alluvium), or understanding soil-landscape processes such as erosion and deposition, leaching, flooding, waterlogging and salinity.

Understanding of the soils and landscapes were refined into knowledge frameworks describing soil types and physiographic units. Similar to previous Assessments (Bartley et al., 2013; Thomas et al., 2018a; Thomas et al., 2018b; Thomas et al., 2022), the soil units called 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 resources, to be relatable to agricultural potential, and to align, where practical, to ASC (Isbell and CSIRO, 2016). The physiographic understanding of the catchment draws strongly on prior mapping including lithology (Beier et al., 2002; Dunster et al., 2000; Sweet, 1973a; Sweet, 1973b; Sweet, 1977), land systems mapping (Stewart et al., 1970) and field observation, and aggregating this knowledge into so-called physiographic units comprising similar lithology, relief patterns, and weathering histories. Physiographic units serve as a framework to understand the potential agricultural lands and soils in terms of qualities and limitations, and given each unit is derived from a distinct group of lithologies and landforms, each gives rise to a distinct set of SGGs and geomorphic patterns – although noting some SGGs can span numerous physiographic units.

2.3 Laboratory methods

Soil physical and chemical analytical techniques were used on the newly collected soil samples that were discussed in Section 2.2. The analyses used on these newly collected samples 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 ($EC_{1:5}$), chloride, nitrate	1:5 soil to water ratio	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)	(Baker and Eldershaw, 1993)

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 covariate datasets (see Table 2-3), and consistent in terms of output specifications with the Assessment's regional scope.

DSM models can be expressed as statistically based rules representing the relationship between (i) the soil attribute at the sampling sites ("obs") and their (ii) geographic intersections of the covariates ("x, y"), as per Figure 2-3. 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, i.e. at every pixel covering the study area that does not contain a sampling site. This process of rule-to-covariate matching progresses through the whole study area to compile the complete final soil attribute data. In essence the environmental correlation approach is a digital analogue of the traditional soil surveyor's mapping approach, which relies on expertise of the soil surveyor to build models (rules) developed from time spent in the field and laboratory data from patterns of relief, drainage or vegetation (i.e. soil covariates) (Hudson, 1992; McKenzie et al., 2008). In the DSM analogue, the 'expert' knowledge equates to the statistical model that does the prediction.

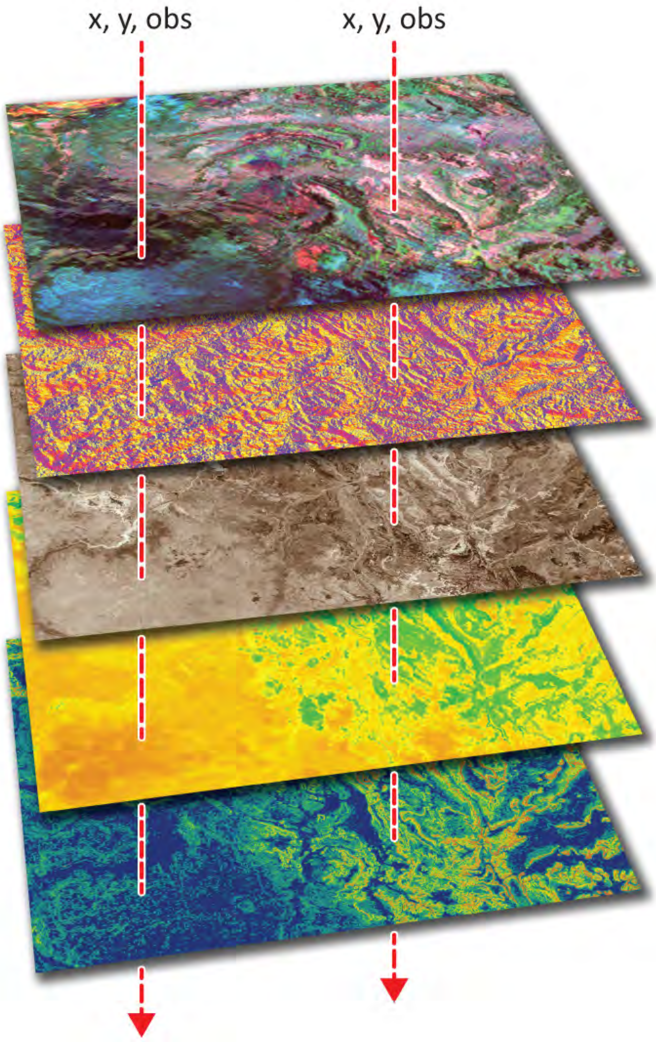

Figure 2-3 DSM models built from the spatial intersection of field and laboratory observations (drill arrows) and covariates

A major benefit of DSM compared to the traditional soil surveyor's approach 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 applied consistently so that there is no methodological or operator bias contained in the mapped outcome. Therefore, map users can be confident that all areas are systematically comparable. Furthermore, this makes updating maps a straightforward process once new soil observations or better covariates become available to re-run the modelling.

In addition to mapping soil attributes, DSM was used to map SGGs from site records. These maps predict soil classes, based on soil morphologies and soil–landscape relationships, and are used to communicate the area's soils. The SGG class for sodic clay subsoils is also used as direct input into the land suitability framework.

2.4.1 Identifying DSM soil attributes

The selection of DSM soil attributes to model and map is governed by the needs of the land suitability analysis (i.e. the limitations required) and SGG mapping. These selections in turn inform the selection of covariates used in the DSM process discussed in the next Section. The needs of the land suitability analysis are informed by the candidate crops and their growth needs and thresholds (i.e. limitations). The land suitability method and land suitability limitations are presented in full detail in Section 2.5. Table 2-6 identifies the limitations served directly by DSM outputs (see column 'Source'), and hence the environmental covariates used.

2.4.2 Environmental covariates

Covariates were selected as proxies for factors of soil formation (Jenny, 1941). The 38 covariates are presented in Table 2-3. All the covariates were in GIS raster file format (GeoTIFF) and co-registered to the WGS84 datum and re-sampled to a ground resolution of 1 arc-second, which equates to approximately 30 m × 30 m grid resolution at the latitudes of the Assessment. Covariates were used in two tasks covered in this report and shown in Table 2-3: (i) six covariates were used to select new sampling sites (Section 2.2.1), and (ii) 38 covariates were used to model new soil attributes (Section 2.4).

Table 2-3 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)	✓	
	Monthly 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)		✓
	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		✓

'scorpan' SOIL FORMATION FACTOR	COVARIATE	DESCRIPTION	CUSTODIAN/SOURCES	NEW SOIL SAMPLING DESIGN	DSM SOIL ATTRIBUTE MAPPING
	Rainfall seasonality	Maximum of mean monthly differences between successive months	CSIRO: (Harwood, 2019)		✓
	Land Surface Bowen Ratio	The ratio of energy fluxes from one state to another by sensible heat and latent heating respectively	CSIRO: https://portal.tern.org.au/actual-evapotranspiration-australia-cmrset-algorithm/21915		✓
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) https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/71069	✓	✓
	Mean FPAR	Fraction of Photosynthetically Active Radiation (FPAR) – Mean AVHRR time series	CSIRO: https://portal.tern.org.au/fractional-cover-modis-csiro-algorithm/21786		✓
	Mean bare ground fractional cover	Fractional cover Bare Soil-Mean MODIS time series	CSIRO: https://portal.tern.org.au/fractional-cover-modis-csiro-algorithm/21786		✓
	Max non photosynthetic vegetation fractional cover	Fractional cover MODIS CSIRO Land and Water algorithm Australia coverage	CSIRO: https://portal.tern.org.au/fractional-cover-modis-csiro-algorithm/21786		✓
	Green vegetation persistence	Landsat Thematic Mapper 2000–2010 Persistent Green-Vegetation Fraction	Terrestrial Ecosystems Research Network: https://portal.tern.org.au/seasonal-persistent-green-australia-coverage-23885/23885		✓
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;	CSIRO: Gallant and Austin (2015)		✓

'scorpan' SOIL FORMATION FACTOR	COVARIATE	DESCRIPTION	CUSTODIAN/SOURCES	NEW SOIL SAMPLING DESIGN	DSM SOIL ATTRIBUTE MAPPING
		longer range landform patterns			
	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)	✓	✓
	Gravity	Geologic Bouguer gravity anomaly	Geoscience Australia		✓
	Magnetics	Total magnetic intensity – TMI Geologic magnetism	Geoscience Australia		✓
	Silica	Total silica concentration	Geoscience Australia		✓
	Barest Earth – Blue Green Red SWIR1 SWIR2	30-yr time series of Landsat Thematic Mapper blue, green, red, 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 from Table 2-3, each representing important scorpan soil forming factors. The following puts these covariates into a scorpan framework with the discussions drawing on physiographic units presented in Figure 1-2 and Table 1-1.

Figure 2-4 (a) shows slope in the Victoria catchment Assessment area as an example of one of the *scorpan* relief soil forming factors. These patterns reflect to a large extent the parent material and landscape history of the area. The flatter, low relief areas coincide with the coastal marine plains units, the alluvial plains units and the Tertiary sedimentary plains units; the latter units dominate the far south of the study area and has remained sufficiently stable that the dominant soil forming action has come from deep weathering and minor redistribution on the plains, whereas the marine plains and alluvial plains units are fresher, juvenile, and reworked in the flooding environments during the Quaternary period. The low relief areas of the Assessment area are likely to have the deepest soils, hence the more agriculturally suitable soils. In contrast, the physiographic units with higher relief, mainly Basalt hills and Sandstone hills and some areas of Limestone hills are dominated by shallow soils, which combined with the steep slopes from the high relief will make lands unfavourable for agriculture – although pockets of more suitable soils will be found, especially where soils have formed on the Basalt geology. The moderate relief units of Basalt gentle plains and Limestone gentle plains will have soils with variable agricultural qualities in terms of depth, slope and composition. The variable soil compositions relating to agricultural potentials that result reflect the variable geologies comprising GPL units.

The gamma radiometrics (Figure 2-4 (b)) and weathering intensity index (WII) (Figure 2-4 (c)) together supply information on the landscape history of the Assessment area. Gamma radiometrics shows the geochemistry of the land surface in terms of abundances for potassium (K), thorium (Th) and uranium (U) (Minty, 1997), which relates to parent material composition and stage of weathering (*scorpan* parent material and age factors). The WII (Wilford, 2012; Wilford, 1995) indicates the age of landscape and the history of development (*scorpan* age factor). Signals showing fresher (less weathered) soils in high relief areas often coincide with Sandstone hills and Limestone hills units through the K and U dominated patterns (Figure 2-4b) and coincide with the weaker WII signals from Figure 2-4c. More strongly weathered soil patterns (i.e. patterns dominated by strong WII and Th signals) are consistent with the Tertiary sedimentary plains and the gently undulating Limestone gentle plains units (Figure 2-4b). The strong U signal from the southern Tertiary sedimentary plains units correspond to deeper, light textured soils (sands, loams) associated with the fringing Tanami dune fields. The extensive fresher Alluvial plains units of the West Bains and Angalarri Rivers (Figure 1-2) reflect the fresher upland parent materials (i.e. dominance of K and low WII) from which these sediments were sourced.

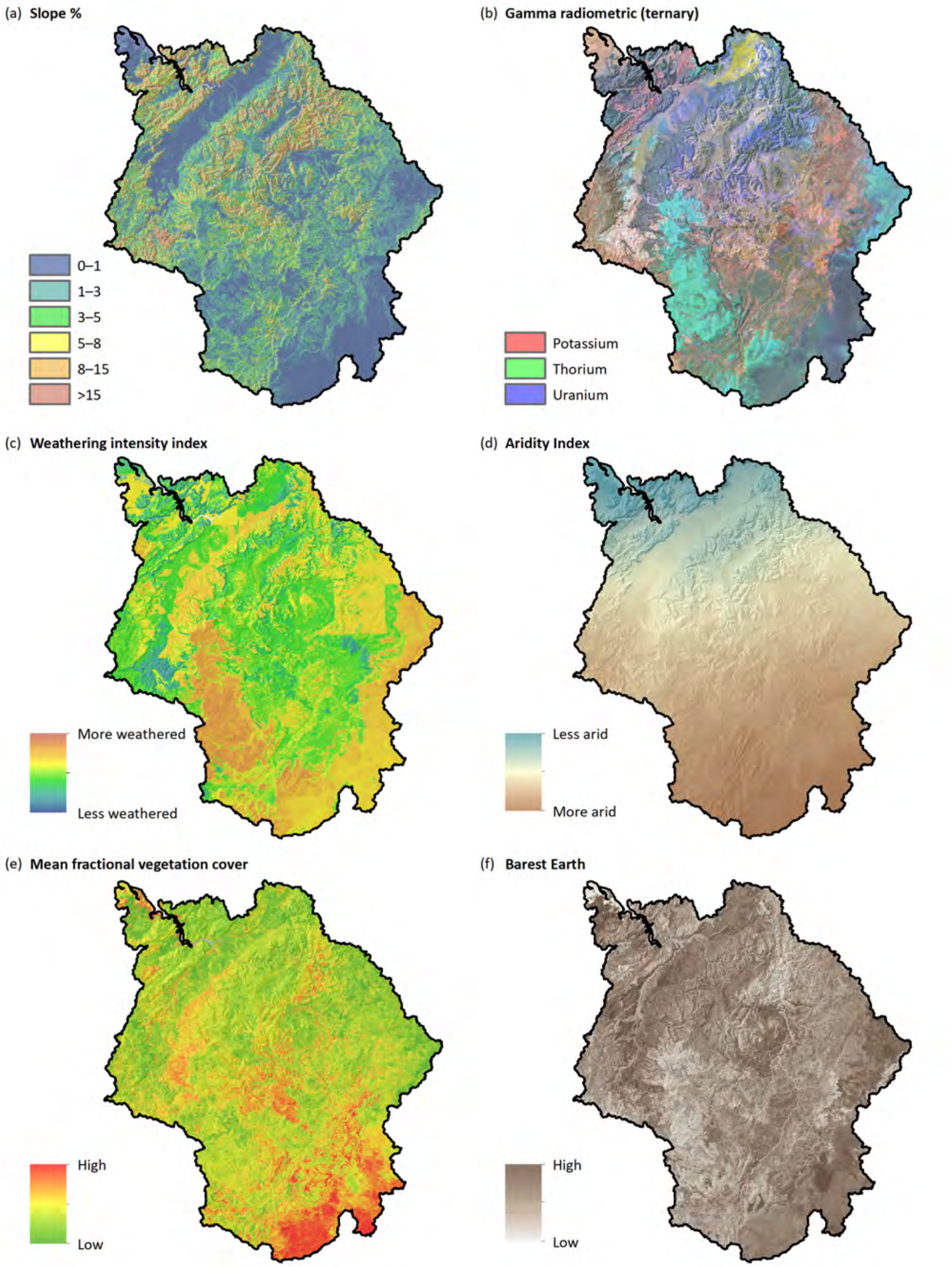

Figure 2-4 Selection of covariates used in DSM with underlying hillshade, including (a) slope %, (b) ternary gamma radiometrics, (c) Aridity Index, (d) Weathering Intensity Index, (e) mean fractional vegetation cover, and (f) bare earth – SWIR1 band.

The *scorpan* climate factor of aridity index in Figure 2-4 (d) 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 strong 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 episodic but significant influence 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 most strongly associated with the deeply weathered surfaces of the Tertiary sedimentary plains unit of the south of the Assessment area, as well as areas dominated by Sandstone hills units. The former unit is consistent with the higher aridity (Figure 2-4d) and lighter, more deeply weathered soils (Figure 2-4c), whereas the latter Sandstone hills units represent vegetation dynamics adaptations to the climate and shallow soils.

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 (marine plains units), the high relief and rocky areas (Basalt hills and Sandstone hills units), and the weathered lighter soils from the southern PT units.

The *scorpan* factors depicted in Figure 2-4 show how soil formation, soil types and agricultural land attributes interact and show how soils and their properties can be explained by such covariates, it can be seen how such soil and land properties can be predicted through these and other *scorpan* covariates.

2.4.3 Soil attribute mapping: continuous, binary, categorical 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 divides a dataset into more and more homogeneous subsets.

Random Forests are an ensemble learning method that employs ‘bagging’ (i.e. 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). 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 are continuous attributes, 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 point-based observations deemed to have a reliable source.

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
- Geoscience Australia bare rock data – locations captured from satellite imagery of bare rock
- TERN borehole data set – regolith depth extraction data set sourced from the National Groundwater Information System (NGIS) database
- vegetation sites where known species restricted to wet soil conditions exist
- microrelief 'yes' or 'no' sites sourced from satellite imagery data
- dataset of estimated AWC60, AWC100 and AWC150 – pedotransfer functions were run for all pre-existing point data where data to do so were available

- post validation sites for SGG, rockiness and drainage – the additional 45 sites collected on the validation trip were added to the SGG, rockiness and drainage model after validation to try to improve predictions in certain catchment areas.

All RF models that produced acceptable model statistics (R^2 >0.25, or Kappa >0.35[4]) were applied to map the soil attributes and their uncertainty over the full extent of the mapping area of the Victoria 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. In cases where the strongest comparable model statistics were achieved for more than modelled iteration of an attribute, the selection of the one to use in the land suitability analysis was made by the project soil surveyors familiar with the Assessment area through a structured expert elicitation approach.

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:

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

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 for every grid cell covering the study area was mapped and the resulting soil attribute map evaluated as above in Section 2.4.3 through a structured expert elicitation approach and against new validation observations made in the field (Section 2.2.3). The DSM models that generated strong reliabilities (CI and CV) and cross-checked through the structured expert elicitation approach to be deemed the best mapped result for the attribute were applied in the 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

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[4] 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.

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; FAO, 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 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 demands for each crop for each attribute/limitation is scored according to a 1 to 5 limitation class. As such, on a shallow soil the shallow rooted small crop may be assigned a 1-score whereas the horticultural deep-rooted crop may be assigned a 5-score. 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 depth 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; FAO, 1985), or defined by experts who are familiar with the selected crops and Assessment area.

The standard 5-class land suitability ranking used is based on guidelines developed by the Food and Agriculture Organization (FAO, 1976; FAO, 1985) and presented in Table 2-4. 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 2-4 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 the same level of 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 depth, 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[5] (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 River region agricultural land suitability framework (Andrews and Burgess, 2021). The framework used in this Assessment aggregates like-crops and cropping systems into crop groups; these are listed 1 to 21 in Table 2-5. The list is adapted from Andrews and Burgess (2021), while CSIRO has added new crops to this list, many of which have been harmonised into groups 1 to 16. New crops deemed prospective and

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

desirable but not fitting into NT's crop groupings have been added to Table 2-5 in this Assessment – these are the groups 17 to 21.

Table 2-5 Crop groups (1 to 21) and individual land uses evaluated for irrigation potential

Land uses are based on those used by Andrews and Burgess (2021) with amendment for the Victoria catchment with the addition of crop groups 18–21, based on CSIRO's previous work in northern Australia, including those used in the Northern Australia Water Resource Assessment (Thomas et al., 2018) which are in boldface.

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**
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 Victoria 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 22 crop groups were tested under dry season conditions, 20 under wet, and 16 as perennial systems of agriculture (see Appendix A). The limitations to management are reflected in the rules of the suitability framework and are presented in Appendix B.

2.5.3 Limitations applied

The 17 limitations and their sources used in the land suitability analysis are presented in Table 2-6. Of these four were from national climate data, 12 were derived from DSM land and soil attribute mapping (Section 2.4), and one (for ASS) derived directly from the DEM. Limitation rule thresholds are presented in the 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 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. The 8 m AHD threshold accommodates systematic errors noted (Gallant, pers coms) in the elevation data (Table 2-3) in tidal river systems across Northern Australia.

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 <500 to >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.

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 depth. 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. Soils with low cation exchange capacity, hence diminished buffering capacity because of mineral type and/or low organic carbon content, are at risk of acidification through rate of base removal (e.g. produce export) exceeding rate of base supply, e.g. through fertiliser addition or natural weathering product supply. Sandy soils are the most susceptible to nutrient imbalance acidification.

Soil depth

Adequate soil depth 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, hardsetting, 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 soil swelling and shrinking can undermine farm infrastructure. 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 subsoil intractable 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

Acid sulfate soils (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 exposed 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 oxidising sulfate layers posing serious risks to water quality, public health, and the health of 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 present the only land use potential. In those locations, 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.

These soils are restricted to coastal areas under marine influence, hence found within 8 m AHD.

Table 2-6 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 depth	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

2.5.4 Limitations not applied

As with the Flinders and Gilbert Agricultural Resource Assessment (Bartley et al., 2013), the Northern Australia Water Resource Assessment (Thomas et al., 2018b), and the Roper Water Resource Assessment (Thomas et al., 2022) 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 germination and 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 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 2-6). The land suitability assessment analysis follows the process as defined by the FAO (FAO, 1976; FAO, 1985). Using standard practice, 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 depth and water erosion) are then assessed to determine the most limiting factor and produce a single suitability class map for each crop group by season by 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 standard 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 like 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 by season by irrigation type i.e. 17 furrow/flood, 23 spray and 10 trickle and 8 rainfed, see Appendix A. The 58 unique grouped options reported here were derived by aggregating individual crops from the 126 unique land use options from the Northern Australia Water Resource Assessment (Thomas et al., 2018b).

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 there is a minimum size of contiguous area 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, extent or shape of individual parcels e.g. dissected by anabranching (Taylor, 2002) and incised stream channels. The effect is that, at a broad scale as reported here, the penalty of operational inefficiencies of farming the land outweighs the otherwise positive attributes of the soil. Two components of landscape complexity are considered here using methods from Thomas et al. (2022).

- 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 2-7 and Table 2-8). Readers will note that, although the analysis was made, it was never applied to land suitability maps in Section 3.5. This reason for not applying to the land suitability analysis was to ensure consistency of approach across the Assessments to date. It remains possible to retrofitting the approach to this Assessment land suitability analysis and to the preceding Assessments if required. The analysis described is an indicator of the utility of approach.

- The stream dissection component reflects elaborate patterns of incised (>1 m depth) anabranched channels in alluvial plains detected using Light Detection and Ranging (LiDAR). LiDAR coverage was incomplete for the catchment.

Contiguous suitable areas

The 5-class land suitability mapping data produce inherently 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 or fail the rule shown in Table 2-7.

Table 2-7 Rules to satisfy (✓) and or not satisfy (×) for minimum contiguous area and width for each crop group (Table 2-5)

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	✓	×	×	×

A two-step process was developed and applied across the catchment as a planning aid tactic. First the five FAO suitability classes presented in Table 2-4 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 one or two pixels of ‘not suitable’ contained in 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 2-7.

Table 2-8 List of crop groups (Table 2-5) for each minimum contiguous area rule from Table 2-7

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 anabranched (i.e. dissected) sections of a floodplain on the (a) West Baines River and (b) the Angalarri River. 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 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 2-4) because landscape complexity is not included in the standard land suitability rule set. The stream dissection data applies to all crop groups.

(a) (b)

Figure 2-5 Examples of heavily dissected sections of floodplains on (a) the West Baines River and (b) the Angalarri River

For the purpose of demonstration the application of this stream dissection component of landscape complexity followed these steps within the Assessment sub-area presented in Figure 2-5 (a):

- Using LiDAR 1.0 m ground resolution DEM, 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, a 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 was used to remove 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.

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 show cumulative scores of suitable (i.e. classes 1 to 3) classes at the geographic intersection of crop suitability maps. This analysis summarises the suitability of the selected 14 exemplar land management options (see Section 2.5.2 and Figure 3-34) 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 for each of irrigation type, including rainfed. As such, an index was calculated for furrow (17 instances), spray (22 instances) and trickle (10 instances) irrigation and rainfed (8 instances) (Appendix A).

2.5.8 Aquaculture land suitability

The suitability of soil and land characteristics for aquaculture development was also assessed using rules from Irvin et al. (2018) with adaptations made if necessary for Assessment area conditions and using the available DSM attribute dataset. The limitations considered included clay content, surface pH, soil depth and rockiness; these 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

3.1 Survey data

Soil records were collated from 6463 sites comprising pre-existing and new soil survey data. Table 3-1 summarises these data (see also Figure 2-1 for the geographic distribution). In terms of the pre-existing data, 6282 records were extracted from SALInfo and NATSoil, and all of these records were collected between the years of 1967 and 2021.

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

DATA TYPE	BOUNDARY	SITE NUMBERS	% OF ALL SITES
Victoria Assessment (new data)	Within catchment boundary	136	2
Victoria Assessment (validation data)	Within catchment boundary	45	< 1
Pre-existing DSM sites	Outside catchment boundary	5	< 1
Pre-existing data (pre-2022)	Within catchment boundary	3066	47
Pre-existing data (pre-2022)	Outside catchment boundary, within the model extent	3211	50
Total		6463	100

This activity sampled 136 new sites collected during the 2021 field season, and 45 more sites for validation purposes collected during the 2022 field season (totalling 181 new sites). The planned field program and data collection was for 150 primary DSM sites and subsidiary sites to be collected if time permitted during the 2021 field season. However, COVID-19 prevented permit access to some lands in the southern part of the catchment resulting in only 113 of these 150 primary DSM sites being captured. Table 3-2 describes the type and numbers of new site data collected by the activity. The region of the catchment that was impacted by a disrupted data collection campaign was well covered by pre-existing site data (Figure 2-1).

Table 3-2 Site data collected during the 2021 and 2022 field seasons by the activity

ACTIVITY SITES	SITE NUMBERS	% OF SITES
Primary DSM site (2021)	113	75% of primary DSM sites
Secondary DSM site (2021)	14	8% of total sites
Free survey (2021)	9	5% of total sites
Validation DSM site (2022)	39	98% of validation DSM sites
Validation free site (2022)	6	3% of total sites
Total	181	

In terms of proximity of new sampling sites to target sites (Section 2.2), 45% fell within 30 m (i.e. within 1 pixel) and 18% within 90 m. New and pre-existing sites were used in the DSM modelling – although not all pre-existing site records were used for all DSM attribute predictions as some records may have missed one of the soil attributes needed or were excluded because of criteria detailed in Section 2.1.

The distribution of sites used in the DSM (Figure 2-1) shows variable density across the catchment. Concentration of sites are apparent around the areas of special development interest (e.g. Kidman Springs and Keep River areas), and many fall outside the catchment, (e.g. the Katherine locality; as discussed in Section 2.1). Many of the sites beyond the catchment of the Victoria River were considered useful in the DSM process because they were likely to support modelling of soils inside the catchment boundary given similarities in formation factors and histories.

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 class)
- 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 depth)
- 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, % silt.

During the validation fieldwork a further 45 sites were collected (39 DSM plus the six free survey sites). The SGG, drainage and rockiness models were re-run after validation to improve the DSM products.

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. The distribution and source of soil data used to create the DSM attributes is presented in Appendix C.

3.2.1 Model evaluation

Overall, 105 models were generated for the activity and from these 105 digital soil attribute datasets were produced for the Victoria catchment 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, removing of covariate layers that negatively contributed to the model predictions, or adding an additional covariate to the stack to improve the model performance). For some soil attributes (drainage, permeability and SGG) a selective subset of all available observations was used based on expert knowledge following the first modelling round using all point observations available. In addition, for some soil attributes including drainage, rockiness and SGG, the observation data collected during the external validation were used to improve the model performance.

No model for any soil attribute stood out based on statistical measures alone. Final decisions for models to use followed a collaborative and iterative process involving assessment of outputs involving the field survey team, digital soil mappers and other experts with knowledge of soils and landscapes of the Assessment area. Creation of some models involved an iterative optimisation process that included testing expertly selected combinations of covariates and data points before the final model for each soil attribute was chosen bearing the best quantitative and qualitative test outcome. This was the case with drainage, permeability and SGG mapping.

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 3-3 for continuous soil variables and in Table 3-4 for categorical variables. 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 3-3 Random Forest model performances: continuous soil attribute maps products

ATTRIBUTE	SAMPLE SIZE	OOB PREDICTION ERROR	R^2	COMMENTS
A horizon depth	3527 observations	0.78	0.63	Only observations deemed to have a reliable source + Geoscience Australia bare rock data Log model
AWC 60	2441 observations	664	0.75	Only observations deemed to have a reliable source PTF estimated data + Victoria River Water Resource Assessment observations + Geoscience Australia bare rock data
AWC 100	1984 observations	301	0.96	Only observations deemed to have a reliable source PTF estimated data + Victoria River Water Resource Assessment observations + Geoscience Australia bare rock data AWC 60 map output used in the covariate stack
AWC 150	1743 observations	1203	0.93	Only observations deemed to have a reliable source PTF estimated data + Victoria River Water Resource Assessment observations + Geoscience Australia bare rock data AWC 60 map output used in the covariate stack
% Clay to 2m	4432 observations	165	0.70	All available observations
ESP	162 observations	1.64	0.55	All available observations Log model
K-factor	204 observations	0.00	0.58	All available observations
Surface pH	4561 observations	0.51	0.65	All available observations
Soil thickness	3856 observations	0.65	0.77	All available observations + Geoscience Australia bare rock data + TERN bore data Log model

Table 3-4 Random Forest model performances: categorical soil attribute maps products

ATTRIBUTE	SAMPLE SIZE	OOB PREDICTION ERROR	KAPPA	COMMENTS
Microrelief	662 observations	0.24	0.31	All available observations + Extra data from satellite imagery Modelled as discrete classes – 'Yes' or 'No'
Permeability	2250 observations	0.37	0.44	Selective subset of all available observations (4443) AWC 60 map output used in the covariate stack
Drainage	2376 observations	0.49	0.37	Selective subset of all available observations (5041) + vegetation sites + validation survey sites Weighted model on class 1
Rockiness	5843 observations	0.15	0.68	All available observations + Rockiness field observations + Lancewood data + Geoscience Australia bare rock data + validation survey sites + Rockiness field observations from validation survey Modelled as discrete classes – 'Yes' or 'No'
Surface salinity	666 observations	0.03	0.84	All available observations Modelled as discrete classes – 'Yes' or 'No'
SGG	3233 observations	0.35	0.57	Selective subset of all available observations (5034) + Rockiness field observations + Lancewood data + Geoscience Australia bare rock data + validation sites survey sites + Rockiness field observations from validation survey Weighted model on new Victoria catchment point sites (184) AWC 60 map output used in the covariate stack
Surface condition	4462 observations	0.28	0.49	Only observations deemed to have a reliable source
Surface structure	2150 observations	0.24	0.46	Selective subset of all available observations (4017) Weighted model on class 4
Surface texture	5189 observations	0.30	0.53	All available observations

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 fell within the suitability range for that attribute, 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 shown in Table 3-5 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.

Overall the validation results are typically less accurate compared to the experience of earlier Assessments (Bartley et al., 2013; Thomas et al., 2018a; Thomas et al., 2018b) and this outcome can be attributed to the collection of 75 % of the DSM sites with the remaining 25 % sites not accessed due to COVID travel restrictions. The results in Table 3-5 indicate that the strongest predictions (i.e. >75 % correctly predicted) included microrelief (100 % correctly predicted), surface salinity (98 %), soil surface condition (93 %) and rockiness (80 %). The weakest predictions (i.e. <50 % correctly predicted) were recorded for soil drainage (49 %), AWC100 (36 %), soil thickness (25 %) and AWC150 (18 %). AWC100 and AWC150 models had the least input data reflecting the low correct percentages. AWC60 predicts moderately well with 53 % correct. The weaker AWC predictions are likely to reflect fewer model input data points that were available for the deeper AWCs. SGG, depth of A horizon, soil permeability, surface pH, surface structure and surface texture are also moderately well predicted.

Drainage, SGG and rockiness models were rerun after completion of the field validation by including the validation results. The results below reflect the pre-validation models, and while not quantified because there was no follow-up field validation, it can be expected that the quality of models has been boosted by this incorporation.

It was noted during field validation that the drainage model results were variable and confused in the lower East and West Baines Rivers and the lower Victoria River areas. This observation is attributed to spatial and accuracy limitations of the DEM to accurately reflect the very low relief patterns present in these areas.

Table 3-5 Victoria catchment external validation results

DSM ATTRIBUTE	CORRECT	ACCEPT	FAIL	TOTAL	DSM ATTRIBUTE	CORRECT	ACCEPT	FAIL	TOTAL
Depth of A horizon	25	17	3	45	**Soil permeability**	26	7	12	45
%	56	38	6	100	**%**	58	16	26	100
Microrelief	45	0	0	45	**Soil thickness**	11	19	15	45
%	100	0	0	100	**%**	25	42	33	100
AWC60	24	10	11	45	**Soil surface condition**	42	2	1	45
%	53	23	24	100	**%**	93	5	2	100
AWC100	16	8	21	45	**Soil surface pH**	25	17	3	45
%	36	18	46	100	**%**	56	38	6	100
AWC150	8	12	25	45	**Soil surface structure**	30	1	14	45
%	18	27	55	100	**%**	67	2	31	100
Rockiness	36	6	3	45	**Soil surface texture**	32	7	6	45
%	80	13	7	100	**%**	71	16	13	100
Soil drainage	22	14	9	45	**Surface salinity**	44	0	1	45
%	49	31	20	100	**%**	98	0	2	100
SGG	30	9	6	45					
%	67	20	13	100					

3.3 Landscapes and Soil Generic Groups

As noted in Section 2.2.4, soil knowledge was captured in SGGs designed to simultaneously cover a number of purposes: to be descriptive so as to assist non-expert communication regarding soil and resources, to be relatable to agricultural potential, and to align, where practical, to ASC (Isbell and CSIRO, 2016). The SGG mapping from DSM was also used as input into the land suitability framework. SGGs). The SGGs are presented in Table 3-6.

Table 3-6 Soil Generic Groups, descriptions, management considerations, and correlations to the Australian Soil Classification (ASC)

SGG	SGG OVERVIEW	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS	ASC [6] 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)

[6] Isbell and the National Committee on Soil and Terrain (2016)

SGG	SGG OVERVIEW	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS	ASC [6] CORRELATION
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 freshwater	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 gradual increase in clay content at depth. Moderately deep to very deep red soils	Level to gently undulating plains and plateaux, and some unconsolidated sediments, usually alluvium	Moderate to high agricultural potential with spray or trickle irrigation due to their good drainage. Low to moderate water holding capacity, often hardsetting surfaces	Red Kandosols
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	Crests and slopes of hilly and dissected plateaux in a wide variety of landscapes	Negligible agricultural potential due to lack of soil depth, poor water holding capacity and presence of rock	Most soils <0.5 m, mainly very shallow to shallow Rudosols, Tenosols,

SGG	SGG OVERVIEW	GENERAL DESCRIPTION	LANDFORM	MAJOR MANAGEMENT CONSIDERATIONS	ASC [6] CORRELATION
		soils that may contain gravel			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 depth and presence of rock	Calcarosols

3.3.1 Landscape descriptions

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 3-6. 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, as well as their development history.

The following sections describe the major landscapes and distribution of SGGs across the Victoria 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 CSIRO, 2016), are also highlighted in the discussions to facilitate better interpretation of soils typically found in these SGGs.

The geology (Beier et al., 2002; Dunster et al., 2000; Sweet, 1973a; Sweet, 1973b; Sweet, 1977) and landforms (Stewart et al., 1970) of the Victoria catchment are dominated by the Proterozoic sediments in the northern and central parts of the catchment, Cambrian volcanics (and associated interbedded chert layers) throughout the eastern and far western parts of the catchment, the

Tertiary-Quaternary (Cenozoic) alluvium overlying a broad range of geologies, and the recent alluvial plains of the Victoria River and its tributaries draining north to the Joseph Bonaparte Gulf in the Timor Sea. Minor Cambrian limestones, Cretaceous labile sediments and deeply weathered sediments of the Sturt Plateau occur on the eastern catchment boundary. Other deeply weathered sediments occur as low plateaux in the south-western parts of the catchment (west of Kalkarindji) and in the south adjoining the Tanami Desert. The Proterozoic and Cretaceous geologies dip to the south-east under the Sturt Plateau, and most of these formations will once again re-emerge in eastern catchments of the Gulf of Carpentaria.

The older Proterozoic dolomites (and associated dolomitic siltstones/sandstones) form hills, ridges and gently undulating plains and pediments mainly in the central parts of the catchment (Figure 3-1). The hills are often benched due to alternating hard and relatively soft sediment layers.

Figure 3-1 Benched dolomitic hills and ridges

The overlying Proterozoic quartz sandstones, siltstones and shales (and some interbedded dolomites) have extensive faulting particularly in the north extending west into Western Australia. These very old rocks form plateaux, escarpments, steep hills and ridges with scree slopes, and minor gently undulating plains on shales. Figure 3-2 shows an example of the northern part of the Victoria catchment landscape featuring sandstone plateaux and escarpments that give way to alluvial plains formed by the river and its tributaries.

Figure 3-2 Sandstone plateaux and escarpments along the Victoria River in the northern part of the catchment

The exposed Cambrian basaltic volcanics with some interbedded chert layers overly the older Proterozoic geologies and occur extensively in the eastern to southern and far western parts of the catchment. Landform is mainly undulating to gently undulating rises and low hills, with relatively minor gently undulating plains. The hard chert layers form prominent low hills and ridges, and occasionally benches within the undulating rides and low hills.

Overlying the Cambrian volcanics are Cambrian limestones/dolomites that form mainly level and gently undulating plains with undulating rises and low hills. These rises and low hills are found adjacent to drainage lines in the east of the catchment.

Cretaceous labile sandstone, siltstone and mudstone sediments overlie the Cambrian limestones in the far eastern parts of the catchment adjacent to the Sturt Plateau to form plains to gently undulating rises. These sediments have been deeply weathered during the Tertiary and now form the Sturt Plateau with extensive plains, plateaux, low escarpments with gentle foot-slopes. These land surface features extend from a narrow strip on the eastern catchment boundary to a prominent landscape adjoining the Tanami Desert in the south. Other deeply weathered sediments in the south-western parts of the catchment form low plateaux and scarps.

The eroded material from various geologies and landforms have been deposited as alluvial plains of various ages. Relict Cenozoic alluvial clay deposits occur extensively as level to gently undulating plains over a range of geologies including quartz sandstones, limestones/dolomites, volcanics, labile sediments and deeply weathered geologies. These clay deposits represent the northern extremity of clay deposits of the Barkley Tableland. Erosion of the deeply weathered Cretaceous sediments on the Sturt Plateau has deposited sandy and loamy sediments locally as infill of lower landscape positions over the Sturt Plateau, and partially over the relict Cenozoic clay deposits on all deeply weathered landscapes. On the southern catchment boundary, the deeply weathered geologies have been reworked by wind to form sandplains with linear east-west sand dunes bordering the Tanami Desert.

Recent Quaternary alluvial plains are associated with all rivers and creeks. The main channels of the Victoria River and major tributaries are deeply incised into the alluvial plains, often with very narrow channel benches adjacent to the channels. In the lower Victoria catchment and Baines River sub-catchments, the seasonally wet, broad alluvial plains adjoin the marine plains. These broad alluvial landscapes generally contain a range of SGGs reflective of alluvium source, and landscape history and position.

3.3.2 Soils and Soil Generic Groups

The SGGs and soil attributes in the Victoria catchment are modelled by DSM from field observations, laboratory analysis data and covariates described in full in Section 2.4 while also drawing on previous surveys conducted in the area by the NT Government outlined in Section 2.1. Table 3-6 describes the SGGs, correlations to ASC (shown in parentheses in the section), and generalised management considerations, and the distribution of SGGs are shown in Figure 3-3. The corresponding areas for each SGG and their proportions as a percentage are presented in Table 3-7. Significant correlations between SGG distributions and physiographic units (Figure 1-2 and Table 1-1) are discussed.

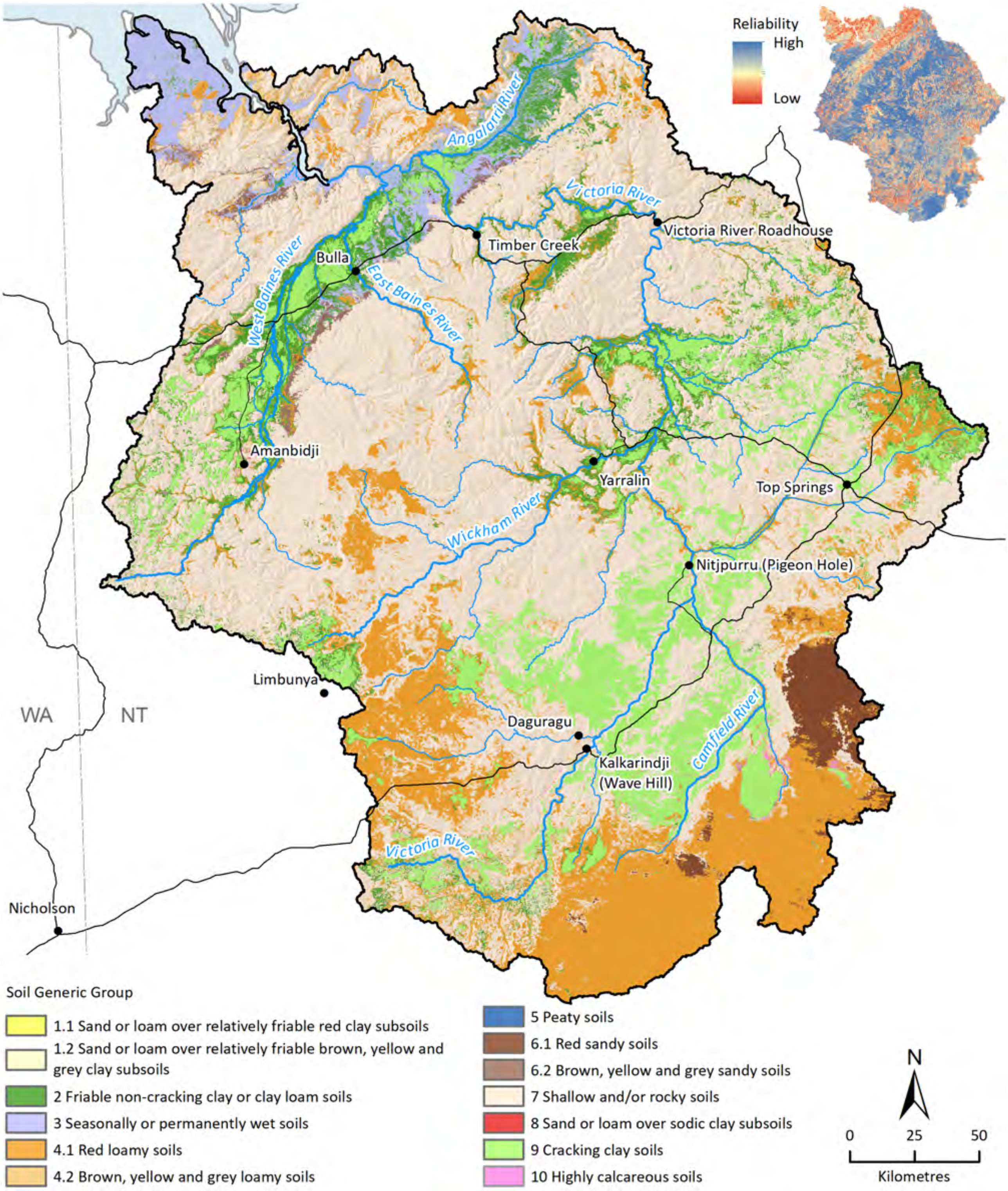

Figure 3-3 The Soil Generic Groups of the Victoria catchment produced by digital soil mapping. The inset map shows the data reliability, based on the confusion index as described in Section 2.4.4

Table 3-7 Area coverage and proportions for Soil Generic Groups in the Victoria catchment

SGG	DESCRIPTION	AREA (ha)	% OF STUDY AREA
1.1	Sand or loam over relatively friable red clay subsoils	780	0.01
1.2	Sand or loam over relatively friable brown, yellow and grey clay subsoils	2,010	0.02
2	Friable non-cracking clay or clay loam soils	536,580	6.5
3	Seasonally or permanently wet soils	295,660	3.6
4.1	Red loamy soils	1,439,840	17.5
4.2	Brown, yellow and grey loamy soils	80,440	0.9
5	Peaty soils	0	0
6.1	Red sandy soils	127,470	1.6
6.2	Brown, yellow and grey sandy soils	46,060	0.56
7	Shallow and/or rocky soils	4,730,850	57.4
8	Sand or loam over sodic clay subsoils	990	0.01
9	Cracking clay soils	962,440	11.7
10	Highly calcareous soils	16,880	0.2

SGG 1.1 and SGG 1.2

SGG 1.1 and SGG 1.2 soils (Chromosols, Kurosols) (Table 3-6) soils combined occupy minor areas (2,790 ha, 0.03 %) of the Victoria catchment (Table 3-7). The shallow (<0.15 m) sand or loam over friable clay variants of these soils are associated with gentle lower slopes of hills and rises on the less erosion resistant Proterozoic sandstones and dolomites in the mid catchment. Hence, when found, these soils are associated with the Limestone gentle plains and the sandstone hills physiographic units (Figure 1-2, Table 1-1). This group is split according to dominant subsoil colour reflecting landscape position. The soils are moderately suited to a range of grain and horticultural land uses, although being frequently found on sloping land with abundant surface rock from upper slopes means opportunities for agricultural development are often limited.

SGG 2

SGG 2 soils are friable non-cracking clays or clay loam soils (Ferrosols, Dermosols) (Table 3-6) and occur extensively throughout the catchment on Proterozoic dolomites, Cambrian basalts, Cambrian limestones, Cretaceous labile sediments, Cenozoic alluvium and Quaternary alluvium (536,580 ha, 6.5 %; Table 3-7). These soils include moderately deep to very deep (>0.5 – >1.5 m) variants with hardsetting sandy to loamy surfaces over friable red, brown and mottled brown clay subsoils (Dermosols).

The well drained, moderately permeable, very deep (>1.5 m) red and brown soils associated with the levees of the rivers and major tributaries are subject to severe sheet and gully erosion (Figure 3-4), and moderate wind erosion in the lower rainfall areas of the southern catchment. These non-sodic soils have very strong slaking properties (breakdown of dry soil aggregates to micro-particles in water) in the subsoils. McCloskey (2010) describes the erosion processes and erosion extent on the riparian zone of the Victoria River. The strong soil slaking, deeply incised river channel with steep slopes in the riparian zone, intensive rainfall events and past land management have all contributed to the severe erosion and very large sediment loads entering the waterways. Extensive areas of these soils also feature in the alluvial plains physiographic unit (Figure 1-2 and Table 1-1).

The well drained, moderately deep (0.5-1 m) red friable loams developed on the limestone/dolomite plains and pediments are subject to severe sheet erosion (shown in Figure 3-5) due to erosion of the thin (predominantly <0.1 m) sandy surface and exposure of the strongly slaking subsoil. The high silt and fine sand in the clay subsoil develops a strongly hardsetting scalded surface when eroded results in extensive runoff and rill erosion. In the lower rainfall southern parts of the catchment, these soils are also subject to wind erosion leaving exposed scalded subsoils. These sheet eroded soils are difficult to rehabilitate and have limited development potential. As they occur in association with extensive areas of shallow soils and rock outcrops, areas suitable for agricultural development are usually small and fragmented.

Moderately deep (0.5 – 1.0 m) red friable clays (Ferrosols) with scattered stone and boulders are restricted to the basalt geology in the undulating to steep rises and hills of the eastern catchment. Areas suitable for agricultural development are usually small.

Moderately large areas of seasonally wet, imperfectly drained mottled brown friable clay loam soils (Dermosols) on alluvial plains occur in the higher rainfall Baines River sub-catchment in the north.

Very deep (>1.5 m) moderately well drained clay loam soils with friable mottled brown and yellow subsoils occur to a minor extent on the Cretaceous labile sandstones, siltstones and mudstones in the east adjoining the Sturt Plateau and on the edge of the Cenozoic clay deposits scattered throughout the catchment. SGG2 soils comprise large areas of alluvium and so occurrence correlates strongly with the Alluvial plains physiographic unit (Figure 1-2 and Table 1-1).

All soils are suitable for irrigated agriculture and horticultural crops depending on soil wetness, slope and amount of rock. The soils on the alluvial plains and limestone/dolomite plains are usually highly fragmented limiting infrastructure layout and consequently agricultural opportunities.

Figure 3-4 Severe gully erosion on red and brown friable clay loam soils (Dermosols, SGG 2) on levees and alluvial plains in riparian areas of the Victoria River plains in the centre of the catchment (ND photo 370)

Figure 3-5 Severe sheet erosion on red friable clay loam soils (Dermosols, SGG 2) on pediments derived from dolomite (IMG P7316586)

SGG 3

SGG 3 soils (Table 3-6) includes seasonally wet or permanently wet soils (Hydrosols and aquic Vertosols). These soils comprise 295,660 ha (3.6 %) of the catchment (Table 3-7) and occur extensively on the level alluvial plains of the lower Baines and lower Victoria Rivers, the very gently undulating plains developed on Proterozoic shales in the north of the catchment (particularly in the lower Baines River sub-catchment), and low-lying alluvial coastal and marine plains. Soils typically have a mottled grey clay subsoil, often with debil-debil microrelief. The low-lying seasonally wet non-saline alluvial plains of the lower Victoria River are suited to a limited number of dry season irrigated crops. All other seasonally wet to permanently wet soils have limited potential for agricultural development. The coastal alluvial plains and very poorly drained saline marine plains subject to tidal inundation have very deep strongly mottled grey non-cracking and cracking clay soils subject to storm surge from cyclones. These near-coastal soils are potential acid sulfate soils. These soils are best represented in the marine plains physiographic unit (Figure 1-2 and Table 1-1).

SGG 4.1 and SGG 4.2

SGG 4.1 and 4.2 are the moderately deep to very deep (>0.5 - >1.5 m) loamy soils separated by colour reflecting their landscape position. The well drained red loamy variant SGG 4.1 (Kandosols) covering 1,439,840 ha (17.5 %) represent a significant area of the catchment. The moderately well drained brown and occasionally yellow loamy SGG 4.2 variant (Kandosols) covers a lesser proportion (80,440 ha; 0.9 %; Table 3-7). Combined these soils dominate the deeply weathered sediments of the Sturt Plateau in the east to south-east and other deeply weathered landscapes to the south and west of Kalkarindji. The deeply weathered character of these soils means that their distribution strongly correlates with the Tertiary sedimentary plains physiographic unit (Figure 1-2 and Table 1-1), and combined cover 18.4 % of the catchment.

Lateritised rock with ferricrete occurs on the deeply weathered geologies with exposed laterite (Stoops and Marcelino, 2010) common on the scarps. Generally, the intact deeply weathered surface has moderately deep to deep (0.5 - <1.5 m) red soils (SGG 4.1) with moderate amounts of iron nodules (Figure 3-6). The depth to iron pans and the amount of iron nodules in the profile relates to position in the landscape. For example shallow pans are associated with residual plateaux and concentrations of iron nodules on and/or in the soil profile in these positions (residual) or transported to places lower in the landscape.

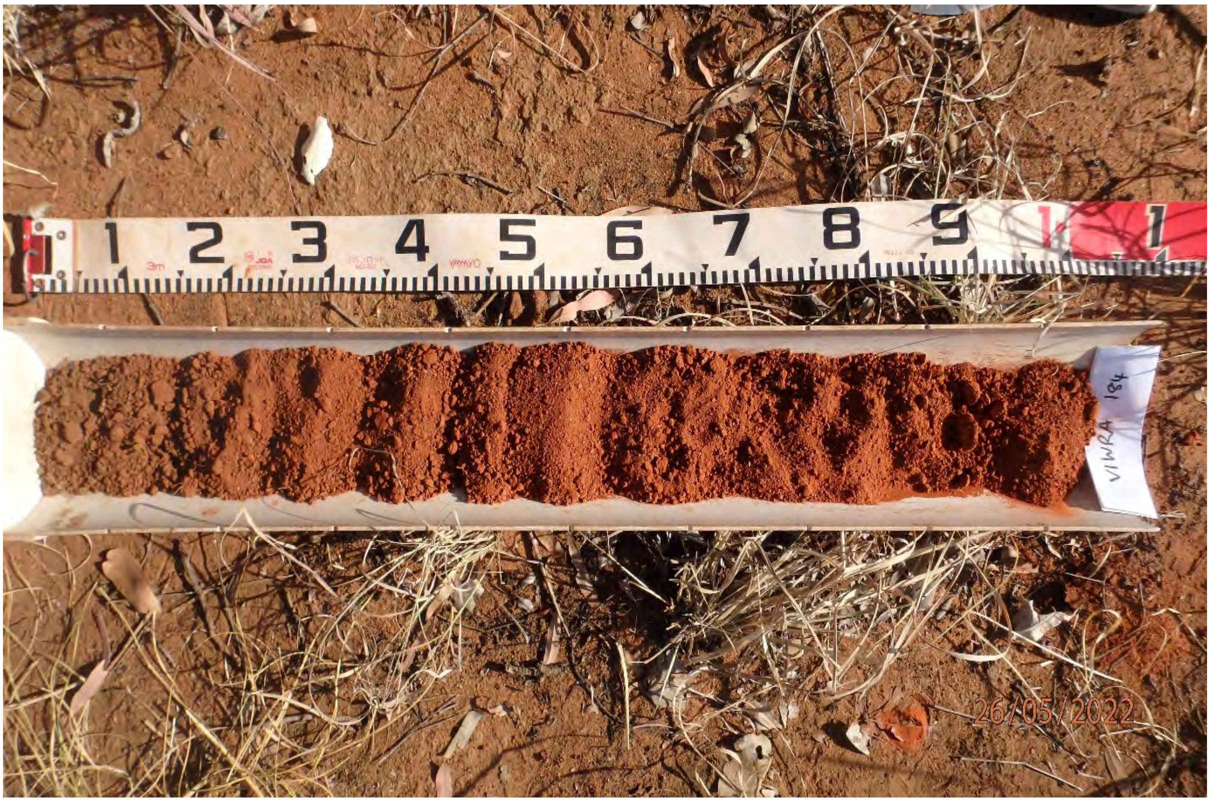

Figure 3-6 Well drained red loamy soils (SGG 4.1) with iron nodules on the Sturt Plateau (IMG P5267515)

SGG 4 soils (Table 3-6) on the deeply weathered landscapes are usually nutrient deficient with low to high soil profile water storage (70 - 140 mm). Irrigation potential is limited to spray and trickle irrigated crops on the moderately deep to deep soils with the low to high soil water storage. Water storage is reduced according as iron nodule content in these soils increases.

Kandosols (SGG 4) on other landscapes are uncommon and are restricted to areas of Quaternary alluvium (Figure 3-7), as well as on the Cretaceous labile sediments found in the east. 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 thin (mainly <0.15 m) sandy and loamy surfaces over red (SGG 4.1: shown in Figure 3-6 and Figure 3-7), brown and yellow (SGG 4.2) massive loam to clay subsoils. The landscape is frequently fragmented with narrow flat areas dissected by stream channels and deep gullies. Soils are highly suited to irrigated agriculture but characteristically narrow, ribbon-like distribution of these soils in the landscape may limit infrastructure layout and consequently agricultural opportunities. These moderately permeable soils have a moderate to high (100 – 140 mm) soil water storage capacity.

Figure 3-7 The very deep, well drained, sandy surfaced red massive loamy soils (Kandosol, SGG 4.1) on levees (IMG P8916642)

SGG 5

SGG 5, the peaty soils, although present in Northern Australia do not occur in the Victoria catchment.

SGG 6.1 and SGG 6.2

SGG 6.1 and SGG 6.2 are deep sandy soils (Table 3-6) and split by colour, which reflects their landscape position and resultant drainage and associated properties. Combined, these sandy soils (Rudosols, Tenosols) represent a minor combined area of 173,530 ha (2.7 %) (Table 3-7). Occurrence of red sands (SGG 6.1) on sandplains and sand dunes are concentrated on the northern extent of the Tanami Desert in the far south where wind has reworked the sandy red soil and tends to coincide with the Tertiary sedimentary plains physiographic unit (Figure 1-2, Table 1-1). The very deep (>1.5 m) brown and yellow sands (SGG 6.2) on alluvial fans associated with creeks fringing the quartz sandstone hills in the north of the catchment coincide with the alluvial plains physiographic unit (Figure 1-2, Table 1-1). soils tend to be highly permeable with very low soil water storage (<70 mm) with potential for irrigated horticulture utilising trickle or drip systems. In the absence of irrigation, agricultural potential of these soils is low.

SGG 7

SGG 7 soils (Table 3-6) cover a wide range of shallow (<0.5 m) and/or rocky soils, mainly Tenosols, Calcarosols, Ferrosols, Kandosols and Vertosols, but includes some Sodosols, Chromosols and Dermosols. The soil group is the most widespread contributing to 4,730,850 ha (57.4 %) (Table 3-7) of the catchment. They are widely found on Proterozoic to Cambrian geologies (sandstones, siltstones, basalts, dolomites/limestones) and exposed lateritic and duricrust surfaces of the deeply weathered plateaux. Their variable origins means that they correspond to multiple physiographic units, but especially upland units like Sandstone hills, Basalt hills, and Limestone hills (Figure 1-2, Table 1-1). The SGG may comprise many coarse fragment, rocky or shallow depth to bedrock conditions, including: >20% gravels (20-60 mm) or cobble (60-200 mm); common to abundant (>10%) stone (200-600 mm); >2% rocky outcrop; or soils with cumulative amounts of any >6 mm size fragments covering >50% on the surface and/or within the plough layer.

Soils like these tend to have very low to low soil water storage (<70 mm) and may sometimes be found on eroded slopes and where intense gully patterns have fragmented the land surface to make the land agriculturally unviable. Examples of SGG 7 soils include shallow (<0.5 m) Kandosols with abundant iron nodules, iron pans and exposed laterite on the rises and scarp areas of deeply weathered landscapes (as shown in Figure 3-8). Figure 3-9 shows an example of very shallow (<0.25 m) Tenosols and rock outcrop on the dissected quartz sandstone hills and dissected plateaux.

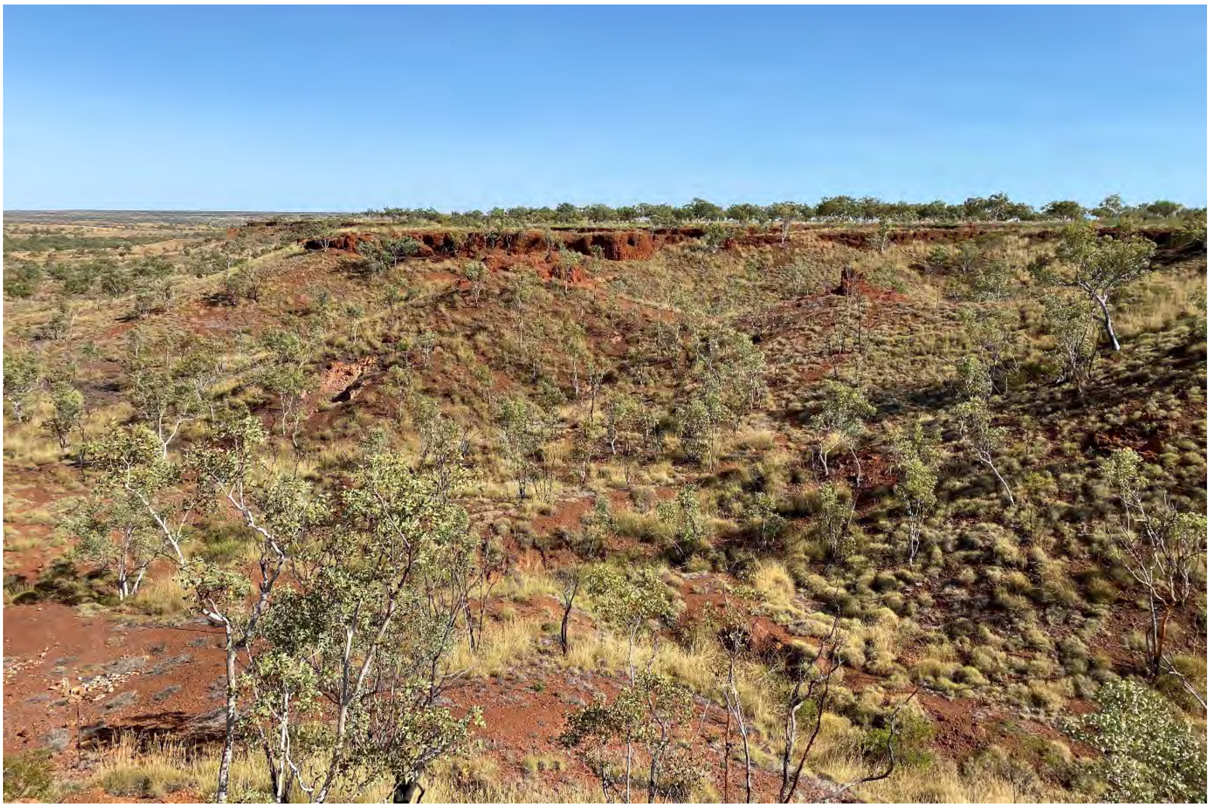

Figure 3-8 Shallow and rocky soils (SGG 7) on laterite outcrops and scarps of deeply weathered landscapes

Figure 3-9 Soil on rocky outcrops on dissected quartz sandstone hills and plateaux (SGG 7)

Figure 3-10 is an example of a shallow (<0.5 m) Calcarosol on limestone or dolomite, while Figure 3-11 shows an example of a rocky SGG 7 on Cambrian basalts. Surfaces of these soils are often gilgaied. The potential for irrigation development of these soils is low because of the shallowness and difficult workability due to surface stoniness and rockiness.

Figure 3-10 A shallow and rocky SGG 7 soil on dolomite

Figure 3-11 A rocky, cracking clay soil SGG 7 soil on Cambrian basalt

SGG 8

SGG 8 soils (Table 3-6) represent minor soils in the catchment covering 990 ha (0.01 %) (Table 3-7) and occur on Alluvial plains and Sandstone hills physiographic units (Figure 1-2, Table 1-1). These soils are characterised by sodic subsoils and are typically sands or loams over sodic, intractable clays (Sodosols, sodic Dermosols). Agricultural potential is low to moderate and soils would need to be carefully managed with respect to timing of irrigation, structural amelioration (addition of gypsum) and to minimise erosion susceptibility. Soils are dominated by gradational and texture contrast soils with hardsetting sandy loam, clay loam to silty clay loam surfaces over mottled brown or yellow (occasionally red) strongly sodic, dispersive, and structured clay subsoils usually at <0.3 m below the surface. All soils are slowly permeable and moderately well drained to imperfectly drained, and with low to high soil water storage (70 - 140 mm). Gradational soils with loam over mottled brown structured sodic clay subsoils frequently occur on alluvial plains, particularly in the Baines River sub-catchment. Sand and loam over mottled yellow or grey sodic clay are associated with Proterozoic shales on gently undulating plains and lower slopes (foot slopes and pediments) of rises to hills, mainly in the northern parts of the catchment. Soils often have abundant surface gravels and stone originated from steep sandstone escarpments and hillslopes upslope. SGG 8 soils frequently have very high salt levels in the profile and are subject to severe gully and sheet erosion due to dispersible subsoils and run-off from the adjacent steep slopes.

SGG 9

SGG 9 soils (Table 3-6) are slowly permeable cracking clays (Vertosols) and comprise 962,440 ha (11.7 %) of the catchment (Table 3-7). These occur on the alluvial plains associated with the Victoria River and major tributaries, as Tertiary/Quaternary relict alluvial plains throughout the catchment where they are associated with the alluvial plains physiographic unit (Figure 1-2, Table 1-1), and as level to gently undulating plains on Cambrian basalts where they have an association with the Basalt gentle plains and the Basalt hills physiographic units (Figure 1-2, Table 1-1).

These moderately deep to very deep (0.5 - >1.5 m), imperfectly to well drained, slowly permeable, brown, red or grey, and occasionally black, cracking clay soils are non-sodic to strongly sodic at depth and have soft self-mulching or hardsetting surfaces. Sodicity is inherited from the parent material. The 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 brown, red, black and grey cracking clay soils are suited to a variety of dry-season grain, forage and pulse crops, sugar cane and cotton.

The very deep (>1.5 m) clay plains of the Victoria River and West Baines River alluvial plains (Figure 3-12) are predominantly imperfectly drained to moderately well drained grey and brown hardsetting cracking clay soils, frequently with small (<0.3 m) normal gilgai depressions. These soils on the Baines River alluvial plains grade to seasonally wet soils (SGG 3), including aquic Vertosols.

Figure 3-12 A Brown Vertosols SGG 9 on alluvial plains along the West Baines River. Gilgai microrelief is evident

The Cenozoic clay plains as shown in Figure 3-13 are dominated by imperfectly drained self-mulching grey cracking clay soils grading to moderately well drained grey-brown clay soils in the lower rainfall southern parts of the catchment. This Tertiary/Quaternary relict alluvium deposited over a diverse range of geologies and frequently have shallow (0.1 - 0.2 m) normal to linear gilgai and surface gravels/stones of various lithology. These very deep (>1.5 m) grey to grey-brown Cenozoic clay soils are distinctly different to the SGG 9 Vertosols developed from basalt, which tend to be well structured and self-mulching, stonier and often shallower.

Figure 3-14 shows a landscape dominated by moderately deep to deep (0.5 - <1.5 m) gilgaied brown, black and red Vertosols on Cambrian basalts, which are predominantly gravelly/rocky (SGG 7) but occasionally less rocky versions are found – as shown in Figure 3-14. These soils occur on level to very gently undulating plains (slopes <1%). The moderately well drained self-mulching brown and black cracking clay soils occur mainly in the north-eastern and far western parts of the catchment, and grade to well drained brown and red clay soils in the lower rainfall southern part of the catchment. These areas tend to be small and fragmented.

Figure 3-13 A plain with Grey Vertosol SGG 9 soils on Cenozoic parent material near Top Springs. Linear gilgai surface microrelief is evident in the near left distance

Figure 3-14 A self-mulching Brown Vertosol SGG 9 on basalt with small amounts of stone on the surface. Gilgai microrelief is evident

SGG 10

SGG 10 soils in Table 3-6 are the highly calcareous soils covering 16,880 ha (0.2 %) of the catchment (Table 3-7). These soils occur in small areas on Proterozoic and Cambrian dolomites/limestones throughout the central and eastern parts of the catchment, and so are represented in the Limestone gentle plains physiographic units (Figure 1-2, Table 1-1). These red soils have abundant soft carbonate throughout the soil profile. The soils are generally suitable for spray or trickle irrigated cropping, particularly horticultural crops. However, nutrient availability can be compromised due to strong alkalinity. These soils tend to occur in small and fragmented patches, which may further reduce agricultural potential due to farm operation inefficiencies. SGG 10 soils often occur in association with the shallow and/or rocky soils of SGG7 and the red friable loams (Dermosols) of SGG 2.

3.3.3 General land suitability observations

In addition to the quantified land evaluation completed using statistical sampling, DSM and land suitability analysis (sections 2.4 and 2.5), a number of qualitative land evaluation observations and notes were taken during the land suitability team visits into the field (Section 2.2). This section summarises these observations with respect to the agricultural potential of the larger tracts of land showing regional agricultural potential. The locations of these tracts are identified in Figure 3-15 and there are explanations in Table 3-8 that discuss the agricultural potential of these areas. Readers will note that the discussions are restricted to larger tracts of land that have potential; this does not infer that smaller tracts of land with potential do not exist in the study area, which, under the right conditions, are capable of being farmed profitably.

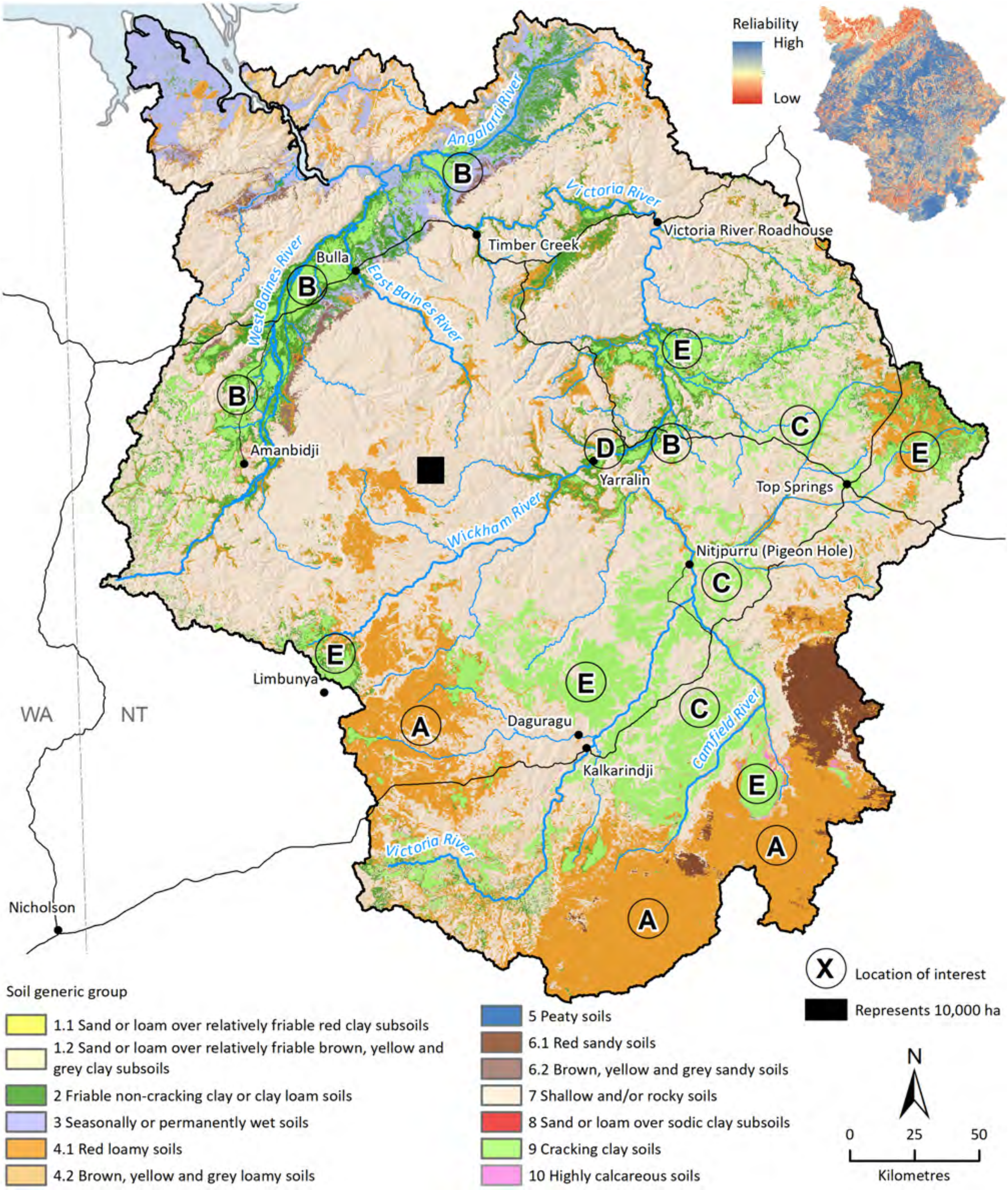

Figure 3-15 Soil Generic Group (SGG) map showing areas (A-E) referenced in Table 3-8. These locations identify the more extensive areas of potential agricultural development. Inset map shows the data reliability, based on the confusion index as described in Section 3.2.1

Table 3-8 Field (qualitative) land evaluation observations on Victoria catchment soils

AREA	LOCALITY/LOCATION NAME	COMMENT
A	Loamy soils of the Sturt Plateau, the plateau west of Kalkarindji and the southern part of the catchment	Moderately permeable red loamy soils (SGG 4.1) with varying amounts of iron nodules. Moderately deep to 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. 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 and cultivation operations. 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 Victoria and West Baines rivers	Comprises rarely flooded plains on the Victoria and West Baines rivers and regularly flooded plains on the Baines River, East Baines River and lower West Baines River. Soils are mainly moderately well drained to imperfectly drained brown or grey cracking clay soils (SGG 9) with self-mulching to hardsetting structured surfaces. The imperfectly drained clay soils of the alluvium grade to poorly drained grey clays (SGG 3) lower in the catchment. The cracking clay soils are suitable for furrow or spray irrigated sugarcane, dry-season cotton, grain and pulse crops, and forage crops. The main limitations are flooding on the flood plains during the wet season, workability, and landscape complexity due to the small and/or narrow areas limiting paddock size and irrigation infrastructure layout due to land dissection. Management of wet season cropping needs to consider crop tolerance to seasonal wetness and flood duration, depth, and frequency.
C	Brown, black and red cracking clay soils derived from basalt, mainly in the eastern and southern parts of the catchment	Moderately deep to deep, moderately well drained to well drained self-mulching cracking clay soils (SGG 9) on basalt plains, scattered throughout the eastern part of the catchment but mainly in the south. Surface gravels, cobble and stone present. Soils are suitable for a range of spray irrigated grain and pulse crops, mainly dry season cropping. Wet season cropping may be restricted by seasonal wetness and flooding. Extents are generally minor resulting in small and/or narrow areas limiting paddock size and irrigation infrastructure layout.
D	Red friable loamy soils on levees of the Victoria River and Wickham River	Predominantly very deep, well drained red and brown friable loams (SGG 2) on narrow levees. Soils subject to severe sheet and gully erosion throughout the catchment, and wind erosion in the lower rainfall areas in the south. 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 of land restrict irrigation layout and machinery use in most areas.
E	Grey cracking clay soils of the Cenozoic alluvium scattered through the eastern, southern and western parts of the catchment	Very deep, gilgaied, self-mulching, grey and occasionally grey-brown cracking clay soils (SGG 9) subject to seasonal wetness occur in the lower landscape positions of the deeply weathered plateaux and as level plains overlying a diverse range of other geologies. 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.

3.4 Soil attribute data and maps

In all, 18 DSM soil attribute maps were produced. A selection of these more influential in the land suitability analysis are presented below. These layers include soil thickness, available water capacity to 100 cm depth (AWC100), permeability, surface pH, rocky and/or shallow soils, and surface texture class. Interpretation of the soil patterns in the soil attribute layers is assisted by referencing the SGG mapping (Figure 3-15) and the soil landscape and SGG discussions (Section 3.3.2)). 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 physiographic units in the discussion below relate to those shown in Figure 1-2. The physiographic unit codes used in the discussion correlate to descriptions presented in Table 1-1.

3.4.1 Soil thickness

The predicted soil thickness and the reliability of the estimate for the study area is presented in Figure 3-16. The deeper soils are strongly associated with the marine plains, alluvial plains and Tertiary sedimentary plains physiographic units, e.g. SGGs 2, 3, 4.1, 4.2, 6.1 and 9. The shallower soils dominate the physiographic units with high relief including Sandstone hills, Limestone Hills and Basalt hills units, which coincide with SGG 7 in particular. Moderately deep soils dominate the landscape with moderate relief including the units Basalt gentle plains and Limestone gentle plains, especially SGGs 2 and 9. Shallower soils (e.g. SGG 7) are consistent with erosional landscapes where the rate of removal of weathering material exceeds the rate of accumulation. Figure 3-16 (b) shows that mapping reliability is strongest where soils are moderately deep to deep, and less reliable in the higher relief physiographic units.

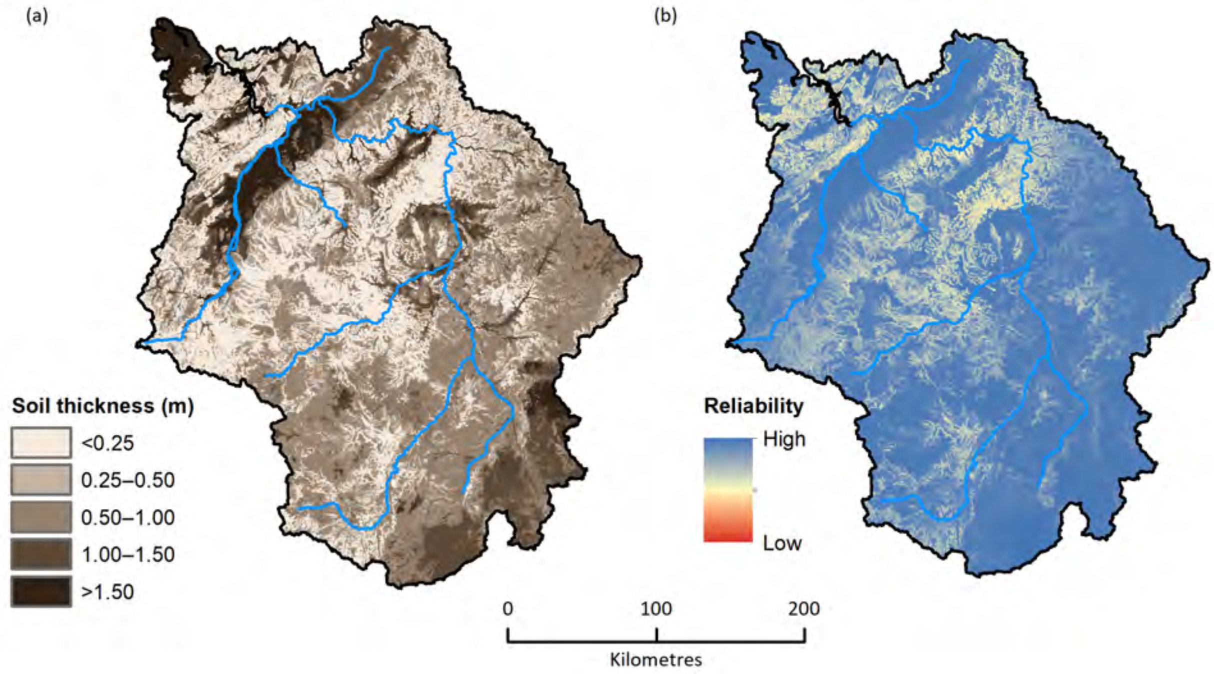

Figure 3-16 Distribution of (a) soil thickness and (b) the companion reliability mapping in the Victoria catchment

3.4.2 Surface texture

The surface texture classes mapped in the study area are presented in Figure 3-17 (a) and the mapping reliability in (b). The study area surface textures are dominated by sandy soils, which coincide with Tertiary sedimentary plains, Sandstone hills, Limestone hills and Limestone gentle plains physiographic units (Figure 1-2, Table 1-1). These areas are dominated by SGGs 2, 4.1, 4.2, 6.1 and 7. The presence of these light textures in the low relief plains of the Tertiary sedimentary plains unit is explained by sandstone geology and in some places the influence of the Tanami dunefields and sands blown in mantling the Tertiary landscapes. There are also extensive areas of clayey surface soils on Basalt parent material (i.e. physiographic units Basalt hills and Gentle basalt plains; SGGs 2, 7 and 9) as well as alluvial areas including the marine plains and alluvial plains units, which are generally composed of the SGGs 3 and 9. Areas of loamy soils are less common throughout the catchment and generally associated with some Tertiary sedimentary plains (SGG 4.1) and zones within the alluvial plains, Limestone gentle plains, Basalt hills and gentle Basalt plains (SGG 2) physiographic units. These units coincide with elements of SGG 2 and 4.1. Silty surface soils represent a very minor proportion of the Assessment area. Areas of highest prediction reliability are found around the physiographic units of the Tertiary sedimentary plains, areas of Basalt gentle plains and much of the Sandstone hills. Reliability tends to be lower around units of marine plains, Basalt hills and Limestone gentle plains.

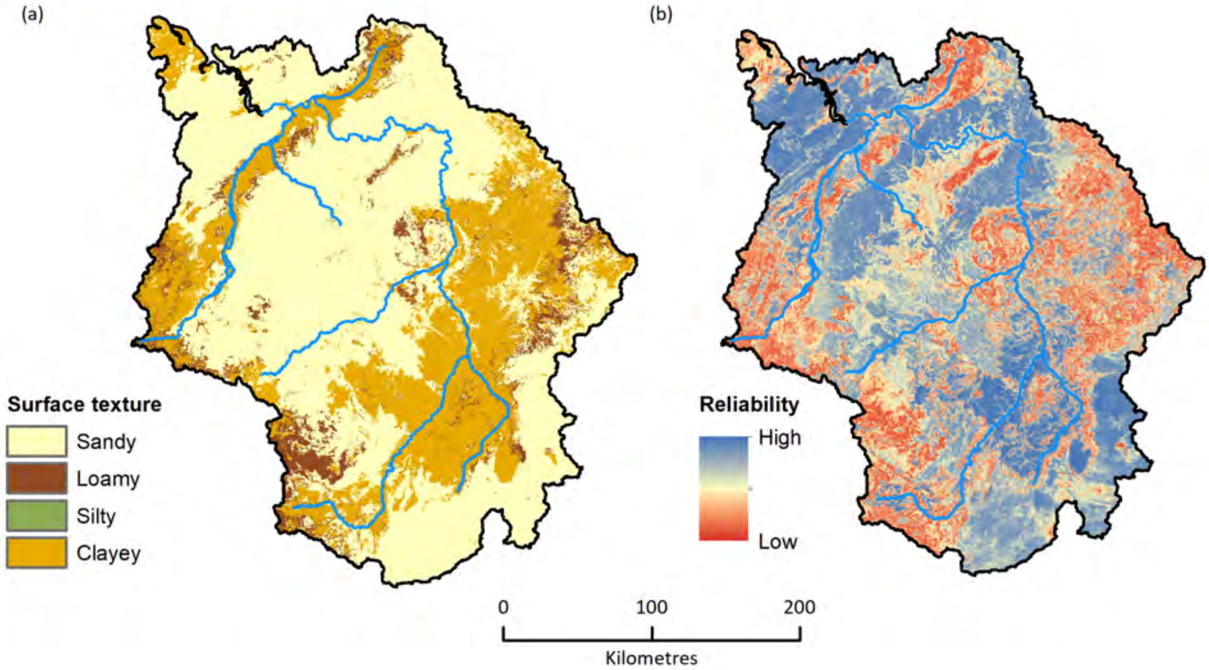

Figure 3-17 Distribution of (a) surface texture class and (b) the companion reliability mapping in the Victoria catchment

3.4.3 Available water capacity (AWC 100)

Figure 3-18 (a) shows AWC to 100 cm (1 m) depth. The amount of AWC is dominated by soil depth and soil texture class and reflected in Figure 3-16 and Figure 3-17, respectively; while surface texture class does not definitively indicate deep soil textures, the correlation is often positive. Figure 3-18 (a) shows the largest AWC values are found where soils are deep and are clay-rich, especially the physiographic units of marine plains, alluvial plains and Basalt gentle plains (SGGs 3 and 9). Moderately sized AWCs are noted in Tertiary sedimentary plains and Limestone gentle plains physiographic units. These moderately-sized AWC soils tend to coincide with SGGs 2, 4.1 and 7. The other units have low AWCs reflecting the combination of shallowness and coarser textures. For this attribute, the reliability of mapping from Figure 3-18 (b) is generally high although notably lower for Basalt gentle plains physiographic unit, and some areas of marine plains and alluvial plains.

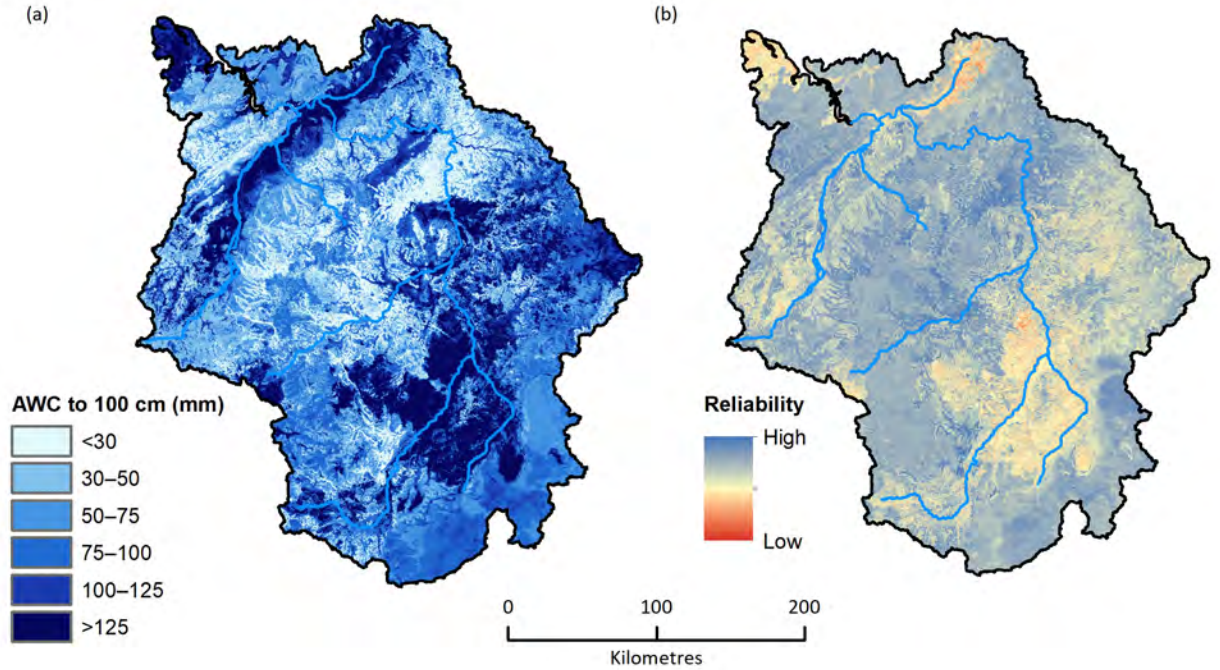

Figure 3-18 Distribution of (a) available water capacity in mm to 100 cm depth and (b) the companion reliability mapping in the Victoria catchment

3.4.4 Soil permeability

Soil permeability patterns are presented in Figure 3-19 (a) and the mapping reliability in (b). The lowest soil permeabilities are experienced in the clay-rich soils, especially those coinciding with marine plains, alluvial plains and Basalt gentle plains physiographic units, hence dominated by SGGs 3 and 9. The majority of the Assessment area is covered by moderate to high permeability, with highest permeabilities experienced in the sandier soils that dominate physiographic units including Sandstone hills and Tertiary sedimentary plains, where SGGs 6.1 and 7 predominate. Mapping reliability (b) is generally low to moderate throughout with little trend relating to physiographic units and SGGs.

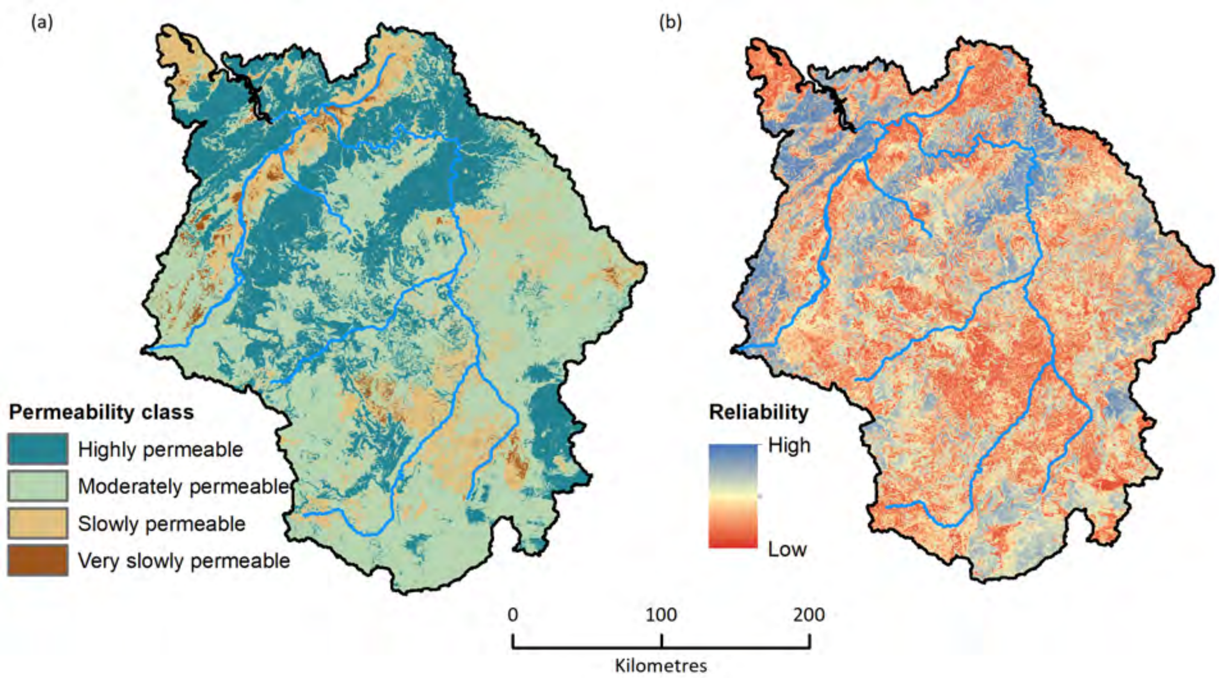

Figure 3-19 Distribution of (a) permeability class and (b) the companion reliability mapping in the Victoria catchment

3.4.5 Surface pH

The study area's pH patterns are displayed in Figure 3-20 (a). This shows the surface pH to be mostly in the range of pH 5.5 – 8.5, which is generally an acceptable range for agriculture, particularly when in ranges around the median. The physiographic units marine plains, Limestone hills, and Basalt gentle plains (i.e. clayier soils like SGG 2, 3, 7 and 9) typically show values in the range pH 7.0 – 8.5, i.e. neutral to alkaline. The remaining SGGs and physiographic units coincide with soils in the acid to neutral range (pH 5.5 – 7.0). These acidic soils tend to coincide with freer draining sandier soils with low buffering capacity and high permeability (e.g. SGGs 4.1 and 7) and/or soils derived from siliceous geologies like sandstone (e.g. Sandstone hills physiographic unit). The Calcarosols developed on dolomite/limestone have consistent high surface pH (>8). Mapping reliability (b) is highest in areas of physiographic unit of Tertiary sedimentary plains and some areas of Sandstone hills, and consistently lowest for the marine plains unit.

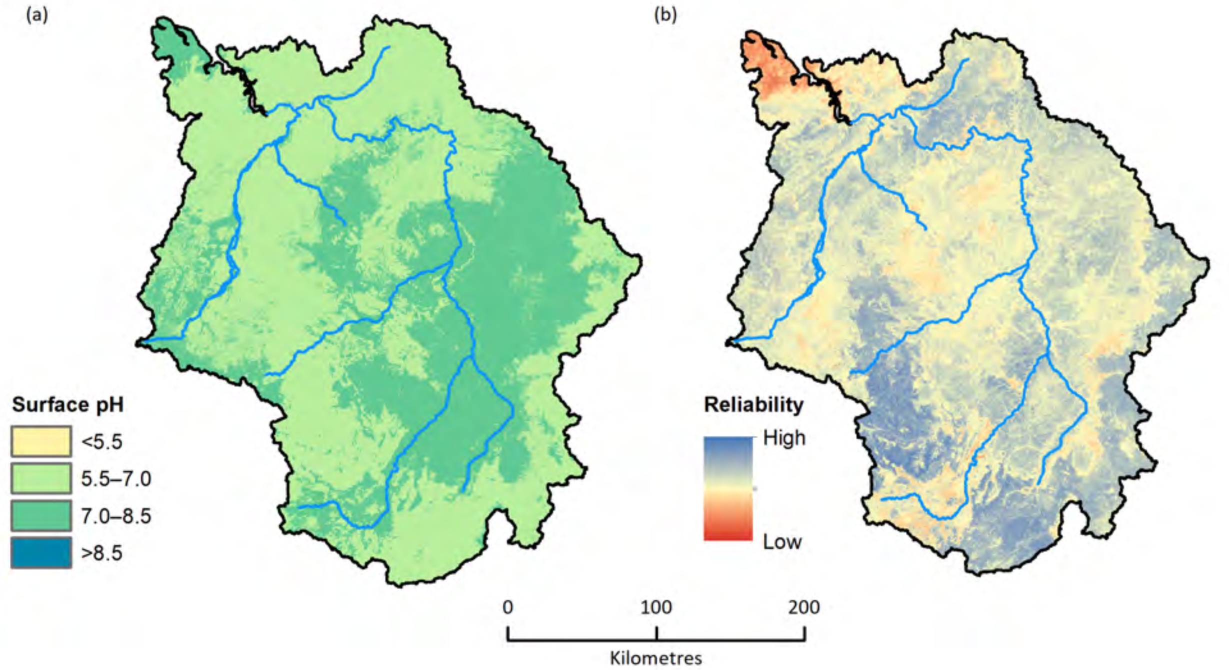

Figure 3-20 Distribution of (a) surface pH and (b) the companion reliability mapping in the Victoria catchment

3.4.6 Rockiness (shallow and/or rocky soils)

Figure 3-21 (a) shows the mapped prediction for surface rockiness. This shows that the alluvial physiographic units (marine plains and alluvial plains) and Tertiary sedimentary plains are generally free of surface rocks. These non-rocky soils are dominated by SGGs 2, 3 and 9 in the alluvial plains and 4.1 and 6.1 on Tertiary plains. All other units tend to be rocky at the surface consistent with their shallow status (e.g. SGG 7) or high relief conditions associated with hilly physiographic units, e.g. Sandstone hills, Basalt hills, and Limestone hills. The moderately deep to deep cracking clay soils on the Basalt gentle plains have surface rock due to the vertic (shrink/swell) properties of the soil pushing rocks to the surface. The reliability of mapping (b) is variable throughout, although generally most reliable in the alluvial plain unit, areas of Tertiary sedimentary plains, Sandstone hills and Limestone hills physiographic units.

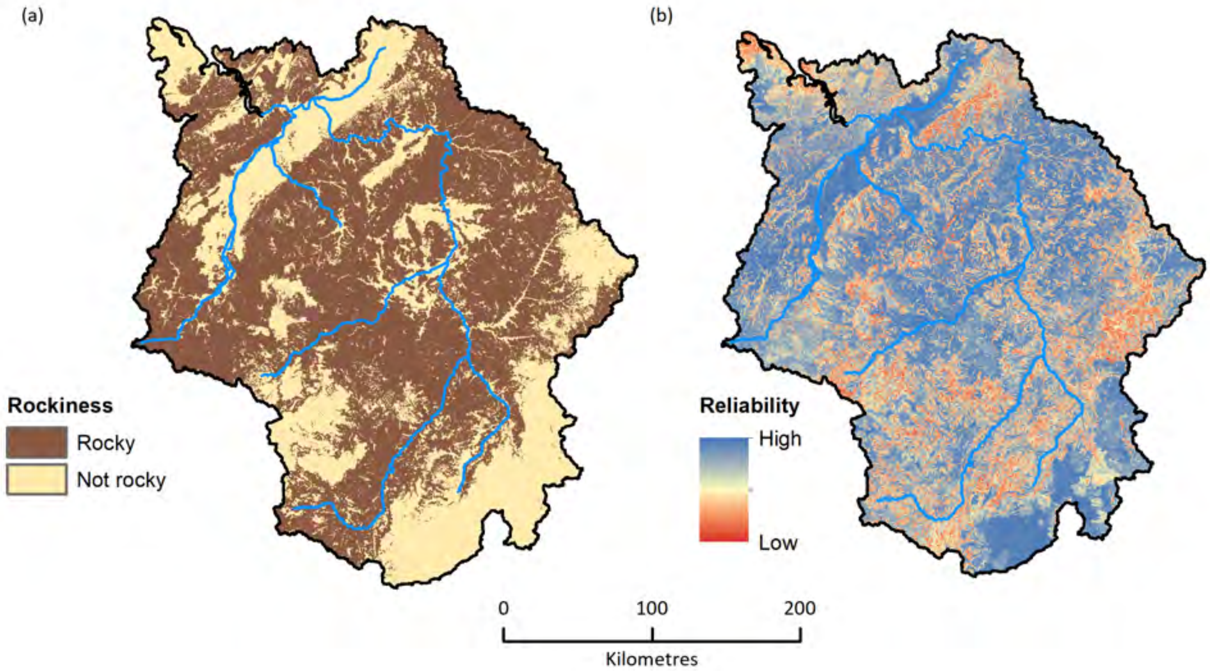

Figure 3-21 Distribution of (a) surface rockiness and (b) the companion reliability mapping in the Victoria catchment

3.4.7 Acid sulfate soils

The distribution of potential ASS in the Victoria catchment is shown in Figure 3-22 and indicates the soils are restricted to the Marine plains and upstream areas below 8 m AHD. The area of land affected by potential ASS is 166,720 ha, and these areas will significantly limit development opportunities for agriculture. ASS also affects built infrastructure due to seasonal or permanent wetness, natural salinity and the requirement to manage potential degradation from ASS. However, with correct site management of these soils, they can be suitably used for aquaculture (e.g. lined ponds).

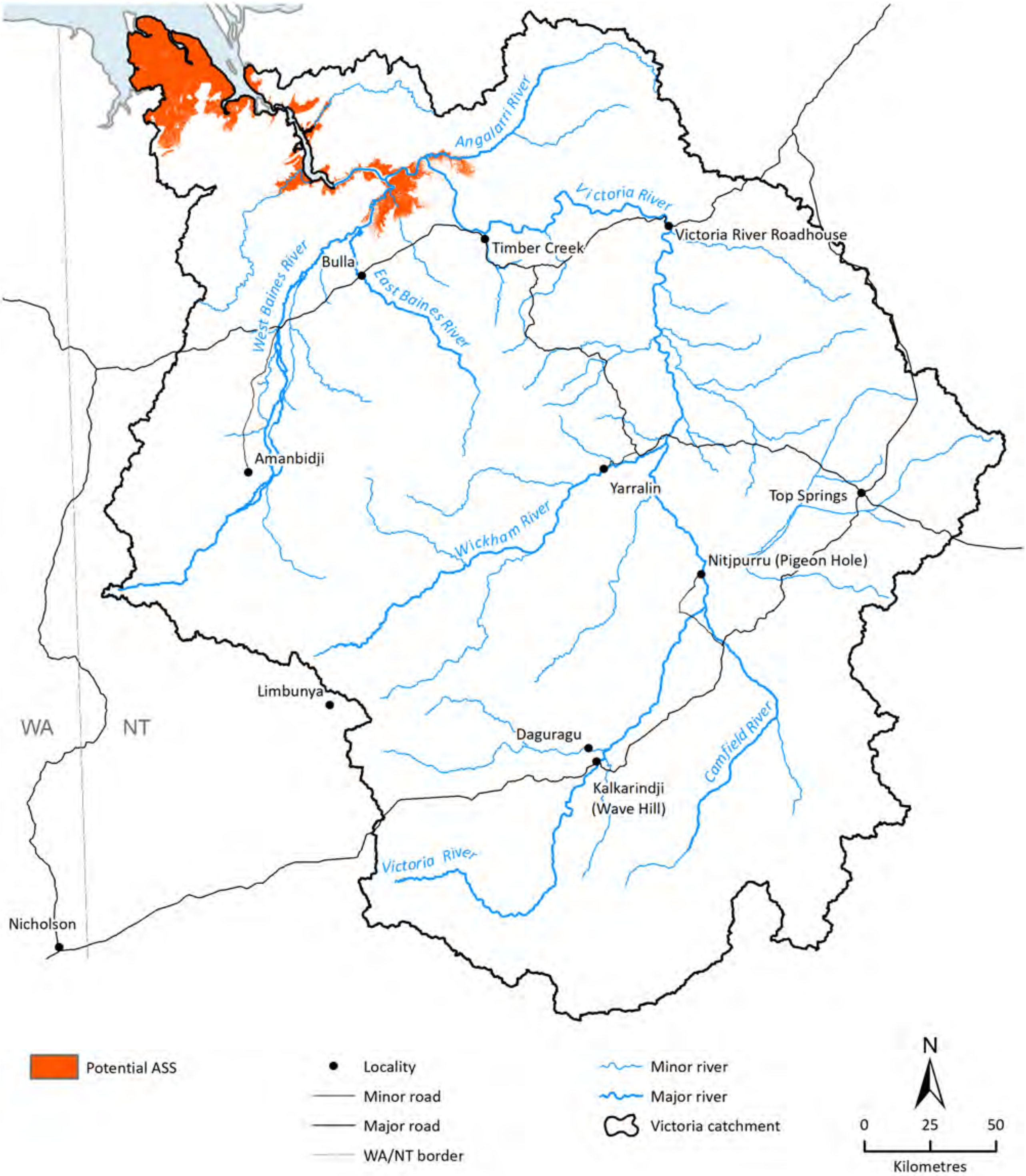

Figure 3-22 Distribution of potential acid sulfate soils in the Victoria catchment

3.5 Land Suitability

The following presents a selection of exemplar 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.

3.5.1 Land suitability distributions

The following section presents irrigated and rainfed crop group suitability (Section 2.5) distributions for 14 'exemplar' land uses, including two rainfed crop groups of interest. These selections have been chosen from the modelled 58 possibilities, which are shown in Appendix A. The exemplar land use options selected to represent a realistic set of options, i.e. the crop groups by season by irrigation type are expected to align to the catchment's growing conditions (land, soils and climate), market desirability and favourable growing experience from similar settings in Australia. Throughout the discussion readers are referred to the catchment physiographic units in Section 1.1 (Figure 1-2) and SGG mapping (Figure 3-15) and soil–landscape explanatories in Section 3.3 and where links to the inherent qualities of the soils and their generic agricultural opportunities are drawn. Comment is also made on the reliability of the land suitability mapping (sections 2.4.4 and 3.2.1) with presentation of companion mapping reliability maps. Area calculations for the land suitability classes for the various land uses are discussed in this section.

Figure 3-23 (a) shows the suitability distribution for crop group 7 (grain and fibre crops, including cotton and sorghum) under dry season furrow irrigation as well as the mapping reliability. This shows that most of the catchment is unsuitable for this land use as most is modelled as class 4 or 5. However, there are 625,400 ha (7.6 % of catchment) of class 3 clay soils (SGG 9; Figure 3-15) associated with areas of alluvial plains and Basalt gentle plains (Figure 1-2). The reliability of this mapping tends to be variable throughout the study area, although generally most reliable in areas coinciding with the Basalt hills and Basalt gentle plains in the eastern parts of the study area.

Figure 3-23 (b) shows the suitability distribution for crop group 7 under wet season rainfed management. Most of the study area is not suitable for this land use, although there are significant tracts of class 3 (797,200 ha; 9.7 %) mirroring the areas for the dry season furrow irrigation option above. However, there are significant areas that are class 2 in the higher rainfall northern half of the catchment, covering 86,200 ha (1 %) on friable loams (SGG 2). Most of the suitable areas are again associated with distribution of friable loams and clays (SGG 2 and 9; Figure 3-15) on the alluvial plains and gentle plains on basalt physiographic units (Figure 1-2). Mapping reliability is strongest in Tertiary sedimentary plains physiographic unit and variable elsewhere.

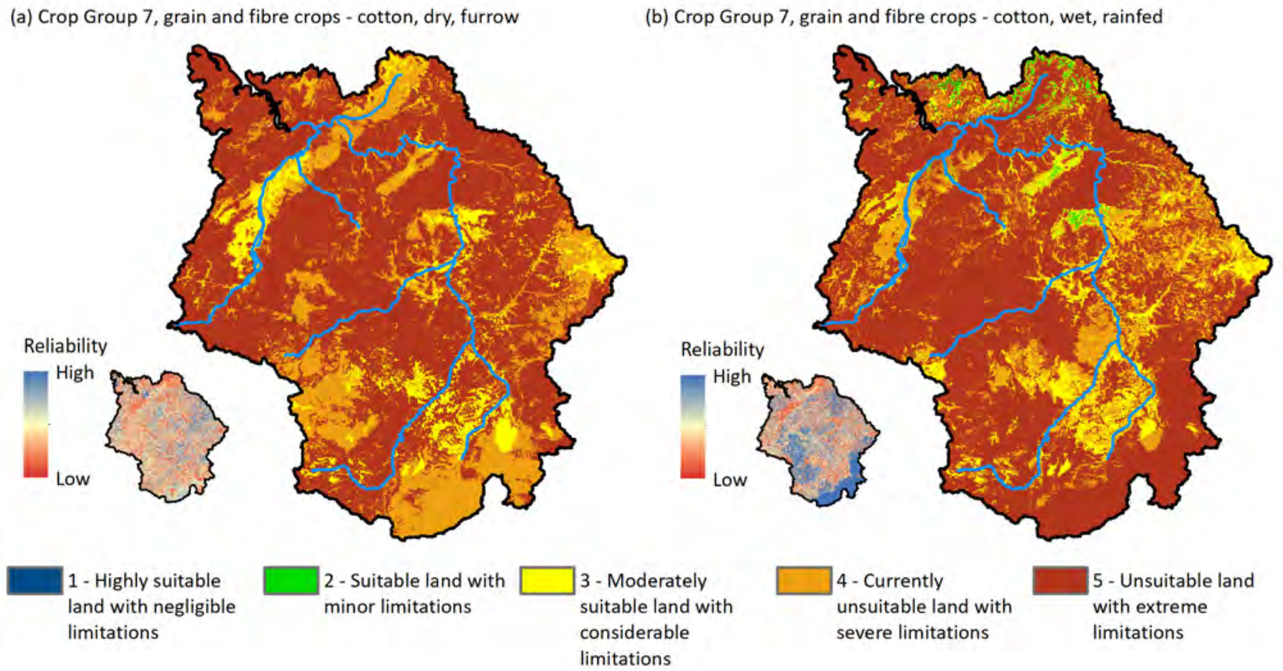

Figure 3-23 Modelled land suitability for crop group 7, 'grain & fibre crops' such as cotton or sorghum (grain), grown using (a) furrow irrigation in the dry season and (b) rainfed over the wet season

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 2-5

The land use suitability distribution for crop group 12 (hay and forage, including annual grass and sorghum) under wet season rainfed management is shown in Figure 3-24 (a). Much of the catchment is unsuitable for this land use although areas of class 3 (751,500 ha; 9.1 %) and to a lesser extent class 2 exist (102,000 ha; 1.2 %). The class 3 areas are mostly associated with friable loams and clays (SGG 2 and 9) on alluvial plains and gentle plains on Basalt physiographic units, and class 2 areas can be found within these on friable loams (SGG 2) on the alluvial plains physiographic units (Figure 1-2).

Figure 3-24 (b) shows the modelled land use suitability distributions for crop group 14, perennial hay and forage, which includes Rhodes grass under spray irrigation. The maps shows that significant areas of the catchment are suitable (class 3 or class 2). Class 2 areas, which cover 1,928,200 ha (23.3 %), are strongly associated with the freely draining red loamy soils (SGG 4.1), red sandy soils (SGG 6.1) in Tertiary sedimentary plains and the red friable loams of the alluvial plains and Limestone gentle plains physiographic units. Class 3 areas (991,300 ha; 12 %) include the clay soils (SGG 9) of the alluvial plains and Basalt gentle plains physiographic units. The reliability of the land suitability mapping is variable throughout the catchment.

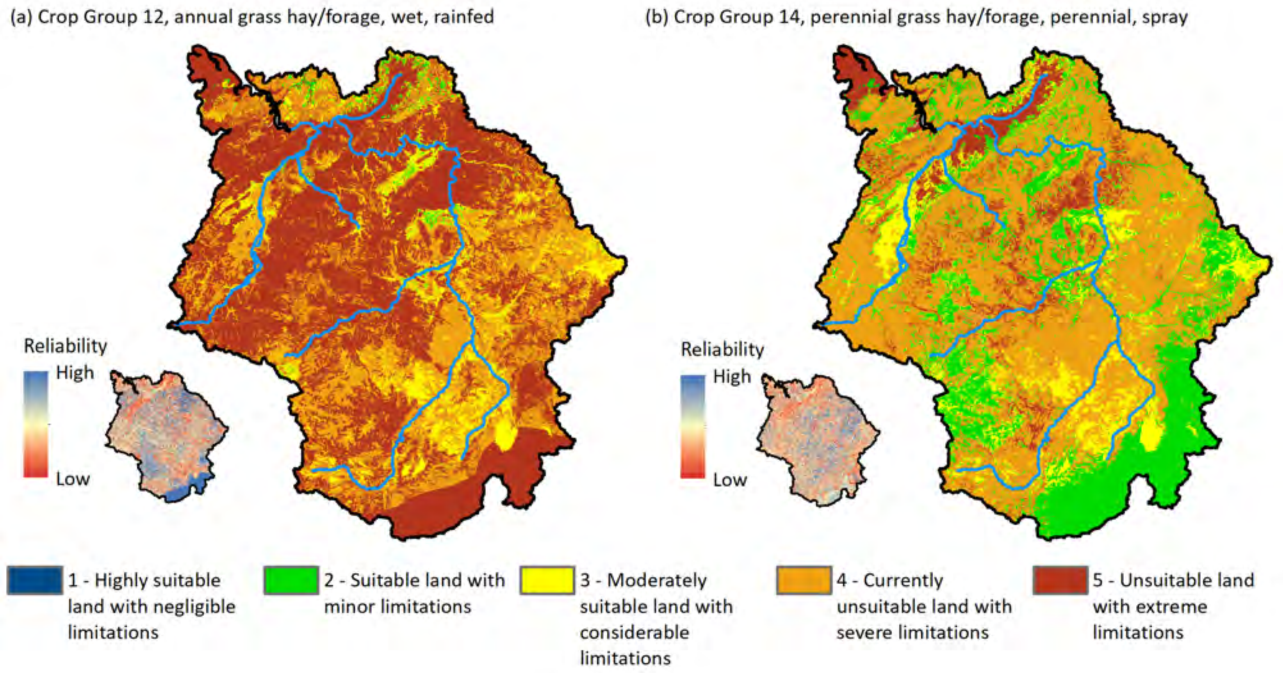

Figure 3-24 Modelled land suitability for (a) crop group 12, 'hay and forage (annual)' such as sorghum (forage), maize (silage), rainfed grown in wet season, and (b) crop group 14, 'hay and forage (perennial)' such as Rhodes grass, spray irrigated

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 2-5

The suitability for crop group 10, pulse crops (includes Mungbean, soybean and chickpea), grown under dry season spray irrigation is shown in Figure 3-25 (a). Significant parts of the catchment are suited to this land use with patterns quite similar to those of crop group 14 under spray irrigation (Figure 3-24 (b)) above. Class 2 areas, covering 1,768,300 ha (21.4 %), occur on the feely draining red loamy soils (SGG 4.1) and red sandy soils (SGG 6.1) in Tertiary sedimentary plains and friable loams (SGG 2) of the alluvial plains and Limestone gentle plains physiographic units. The class 3 (875,000 ha; 10.6 %) on the clay soils (SGG 2 and 9) of the alluvial plains physiographic units. The reliability of the land suitability mapping is variable throughout the catchment.

Figure 3-25 (b) presents the land use suitability distributions for crop group 13, legume hay/forage (e.g. lablab) under dry season furrow irrigation. Minor areas are suitable as class 3 (620,00 ha; 7.5 %). These areas are restricted to alluvial plains and Basalt plains physiographic units that have clayey soils (SGG 9). The modelling reliability is variable throughout the catchment.

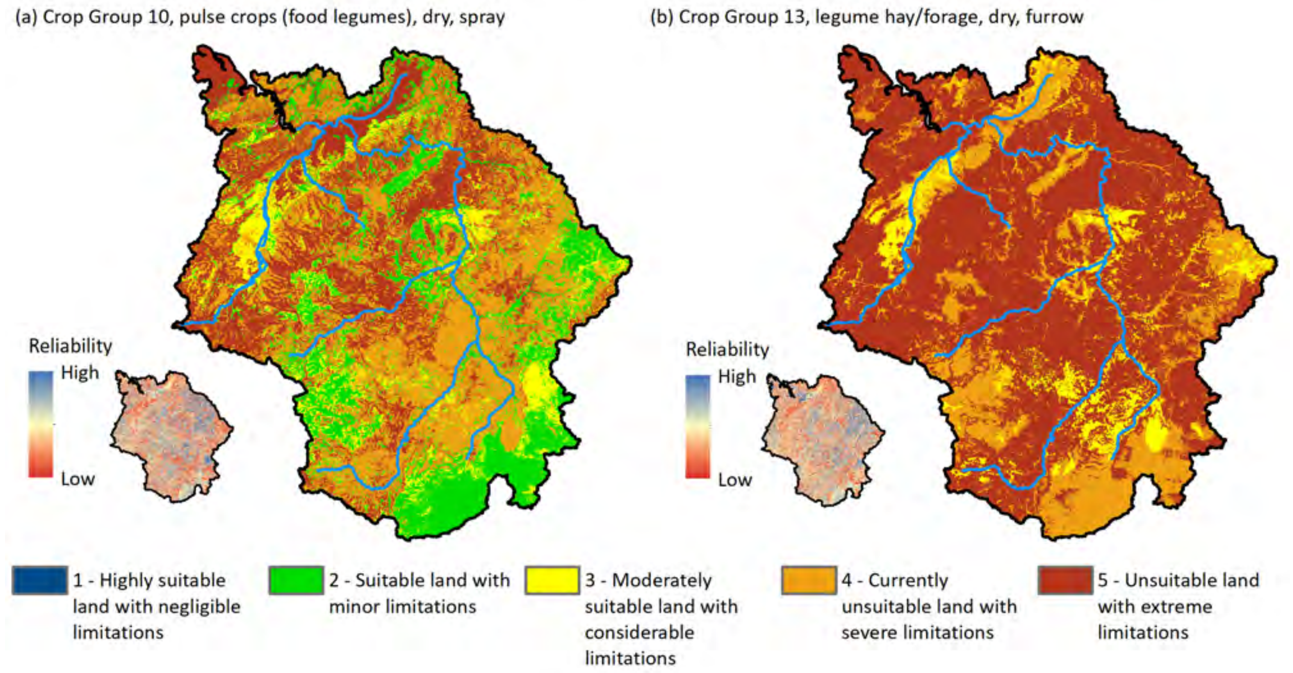

Figure 3-25 Modelled land suitability for (a) crop group 10, 'pulse crops' such as Mungbean, soybean and chickpea, grown using dry season spray irrigation, and (b) crop group 13 'hay and forage (annual)' such as lablab, dry season furrow irrigation

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 2-5

The suitability distributions for crop group 1, tropical tree crops, which includes mango and lychee, grown under trickle irrigation is shown in Figure 3-26 (a). This shows a significant proportion of the catchment to be suitable, including class 1, 2 and 3. The class 1 instances (72,000 ha; 0.9 %) are found in localised areas generally on the edge of alluvial plains at the interface with Sandstone hills physiographic units. The areas of class 2, covering 857,700 ha (10.4 %) coincide with red loamy soils (SGG 4.1) of the Tertiary sedimentary plains physiographic units as well as the friable loams (SGG 2) of the Limestone gentle plains and alluvial plains units. Notably, the alluvial plains of the West Baines and Angalarri Rivers show little prospectively for the land use. There is a significant area of class 3 (1,631,200 ha; 19.7 %) coinciding with the Tertiary sedimentary plains in the southern parts of the catchment where red loamy soils (SGG 4.1) are dominant, and lesser areas associated with the well-drained clay soils (SGG 9) on alluvial plains and gentle plains on Basalt in the centre of the catchment as well as the friable loams (SGG 2) found in the Limestone gentle plains of the east. The reliability of mapping is high in the red loamy soils (SGG 4.1) of the southern Tertiary sedimentary plains and in the centre of the catchment.

Figure 3-26 (b) shows the modelling for crop group 2, tropical citrus under trickle irrigation. It shows that most of the catchment is not prospective for this land use, although small areas of class 2 (84,000 ha; 1 %) are to be found associated with SGG 4.1, the red loamy soils in the north of the study area. There is more class 3 land covering 854,200 ha (10.3 %) available associated with SGG 4.1 of the Tertiary sedimentary plains, the friable loams (SGG 2) of central alluvial plains, and the eastern Limestone gentle plains physiographic units. The modelling reliability is strong for most examples of the Tertiary sedimentary plains in the catchment with reliability variable elsewhere.

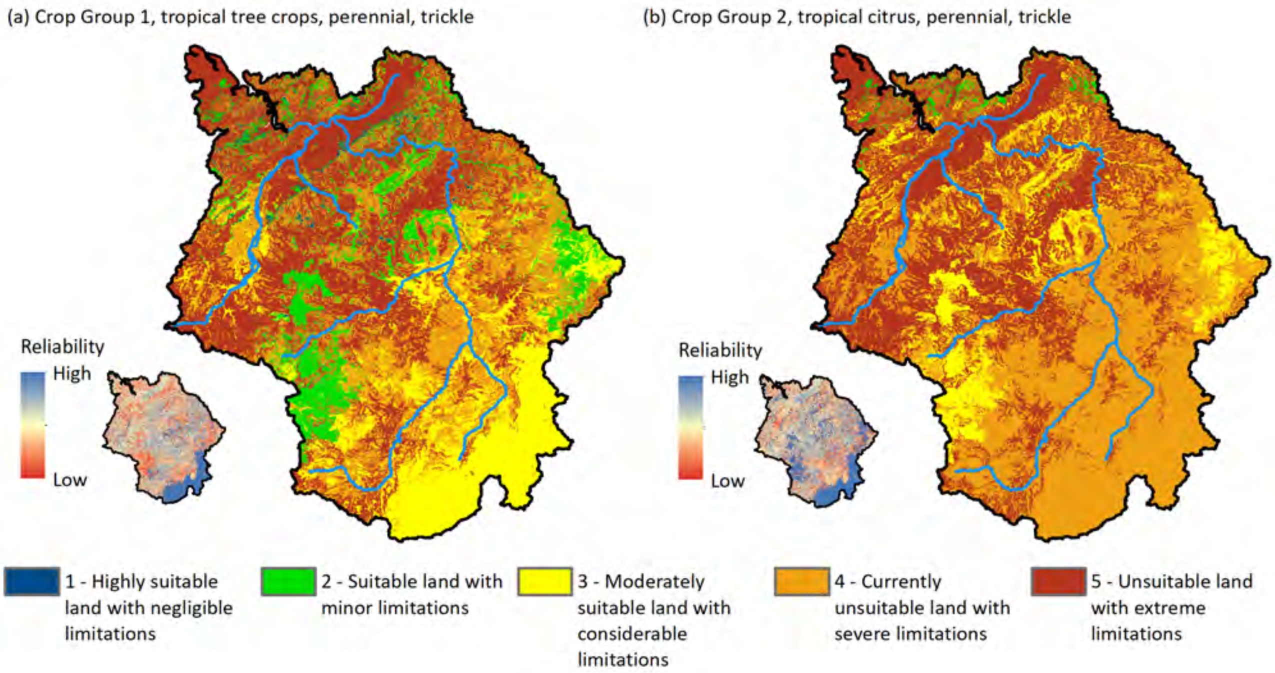

Figure 3-26 Modelled land suitability for (a) crop group 1, 'tree crops/horticulture (fruit)' such as perennial mango and lychee, grown using trickle irrigation, and (b) Crop group 2, 'tree crops/horticulture (fruit)' such as citrus grown using trickle irrigation

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 2-5

Figure 3-27 (a) shows that there are minor areas suited in the catchment to crop group 19, oilseeds (e.g. sunflower, sesame) under wet season furrow irrigation. The prospective areas are class 3 comprising 423,000 ha (5.1 %) areas coincide with cracking clay soils (SGG 9) of alluvial plains units and Basalt gentle plains. The mapping reliability follows no discernible soil or physiographic patterns.

Figure 3-27 (b) represents the suitability distributions for crop group 9, small seed crops, which include chia and quinoa, grown under dry season spray irrigation. It shows that significant areas are suitable with large tracts of class 2 and lesser areas of class 3. Class 2, covering 2,046,600 ha (24.8 %) areas are strongly represented by red and brown sandy soils (SGGs 6.1 and 6.2), the friable loam soils (SGG 2) of alluvial plains and Limestone gentle plains, and the loams (SGG 4.1) of Tertiary sedimentary plains physiographic units. Areas of class 3 (829,700 ha; 10 %) are notable in the clay soils (SGG 9) on alluvial plans and gentle plains on Basalt. The reliability of mapping is variable throughout the catchment.

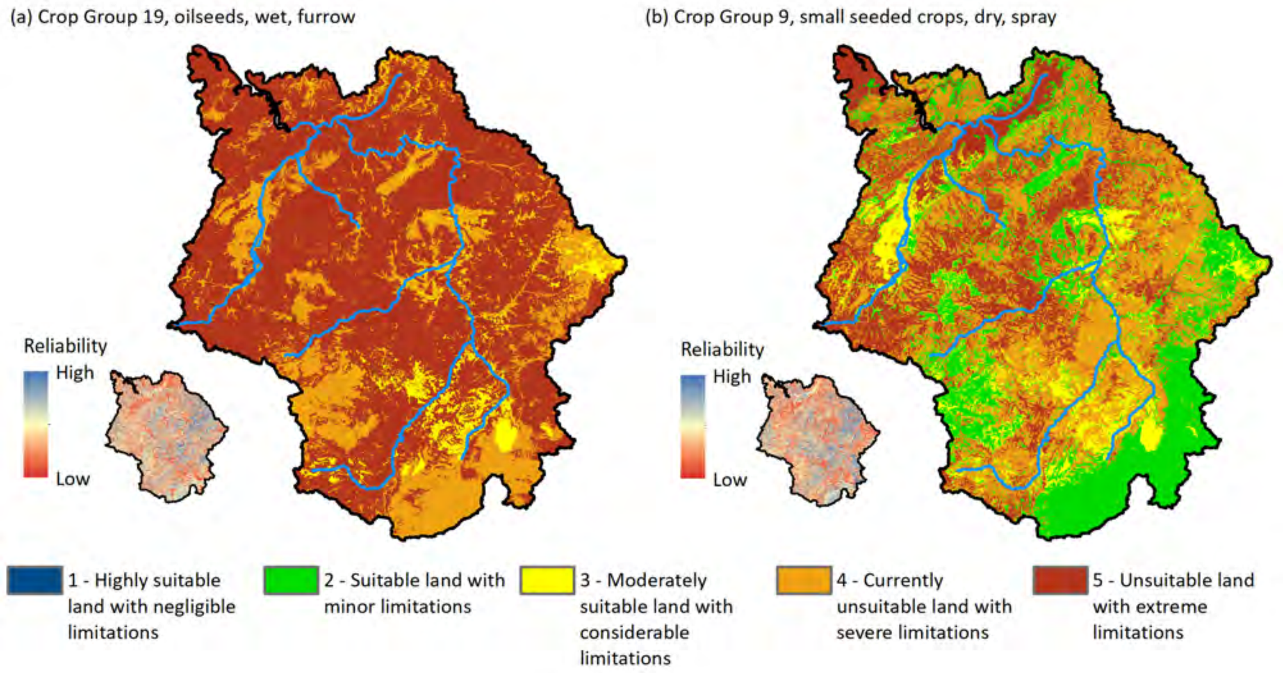

Figure 3-27 Modelled land suitability for (a) crop group 19, 'oilseeds' such as sunflower and sesame, grown by wet season furrow irrigation, and (b) crop group 9, 'small-seeded crops' such as chia, quinoa and medical poppy, grown by dry season spray irrigation

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 2-5

Figure 3-28 (a) shows how suitability is distributed around the catchment for crop group 3, intensive horticulture with examples including cucurbits under dry season trickle irrigation. The suitability patterns mirror aspects of those in Figure 3-27 (b) above for crop group 9 grown under dry season spray irrigation. Crop group 3 under dry season trickle irrigation has class 1 suitability examples in the Tertiary sedimentary plains red loamy soils (SGG 4.1) in the south of the catchment. These cover an area 56,700 ha, or 0.7 % of the catchment. There are extensive areas of class 2 (2,080,100 ha; 25.2 %) associated with red loamy soils (SGG 4.1) on Tertiary sedimentary plains and friable loams (SGG 2) on alluvial plains and Limestone gentle plains units, and class 3 (927,600 ha; 11.2 %) areas on clay soils (SGG 9) in alluvial plains and gentle plains on Basalt units, as well as clays associated with Limestone gentle plains and Basalt gentle plains. Mapping reliability is variable throughout.

Figure 3-28 (b) shows the land suitability distributions for crop group 6, root crops that includes sweet potato and peanuts under dry season spray management. The map shows there is a large component of land suitable as class 2 (2,026,800 ha; 24.5 %), which coincide with the friable loams (SGG 2) of the alluvial plains and the Limestone gentle plains and much of the red loamy soils and sands (SGG 4.1 and 6.1) that occur in the Tertiary sedimentary plains. There are minor areas of class 3 (303,144 ha; 3.7 %). Mapping reliability is variable throughout the catchment.

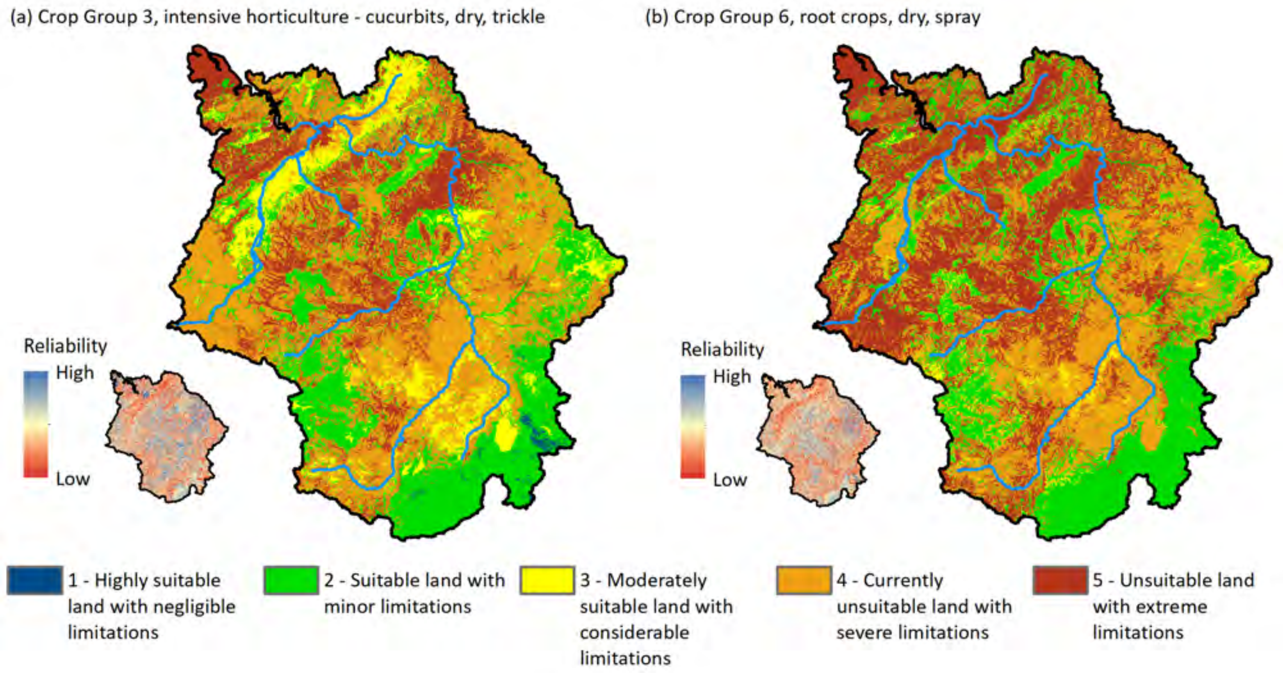

Figure 3-28 Modelled land suitability for (a) crop group 3, 'intensive horticulture (vegetables, row crops)' such as cucurbits, grown by dry season trickle irrigation, and (b) crop group 6, 'root crops' such as sweet potato, peanut and cassava, grown by dry season spray irrigation

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 2-5

Figure 3-29 (a) shows the suitability class distributions for crop group 15, silviculture and forestry including Indian Sandalwood, managed through trickle irrigation. There are significant areas (1,273,200 ha; 15.4 %) of class 2 soils coinciding with the well-drained red loamy soils and red sands (SGG 4.1 and 6.1) found on the Tertiary sedimentary plains as well as on the friable loams (SGG 2) associated with the Limestone gentle plains and some areas of alluvial plains. Around these areas are also examples of class 1 soils covering 72,840 ha (0.9 %). There are examples of class 3 soils combining to make 973,600 ha (11.8 %) also associated with the red loamy soils (SGG 4.1) on the Tertiary sedimentary plains, and the friable loams (SGG 2) on the Limestone gentle plains and some areas of alluvial plains. Mapping reliability tends to be highest in areas of the Tertiary sedimentary plains, otherwise the distribution is variable across the study area.

The suitability distributions for crop group 8, grain and fibre corps (e.g. rice) under dry season flood irrigation are shown in Figure 3-29 (b). There are very localised examples of class 2 (8,500 ha; 0.1 %) to be found in some alluvial plains associated with clay soils (SGG 9). of the most suitable soils in the catchment for this land use are class 3 clayey soils (SGGs 9) associated with the alluvial plains and lesser areas located on level plains in the Basalt gentle plains unit. These class 3 soils represent 788,400 ha (9.5 %) of the catchment. Mapping reliability is variable throughout.

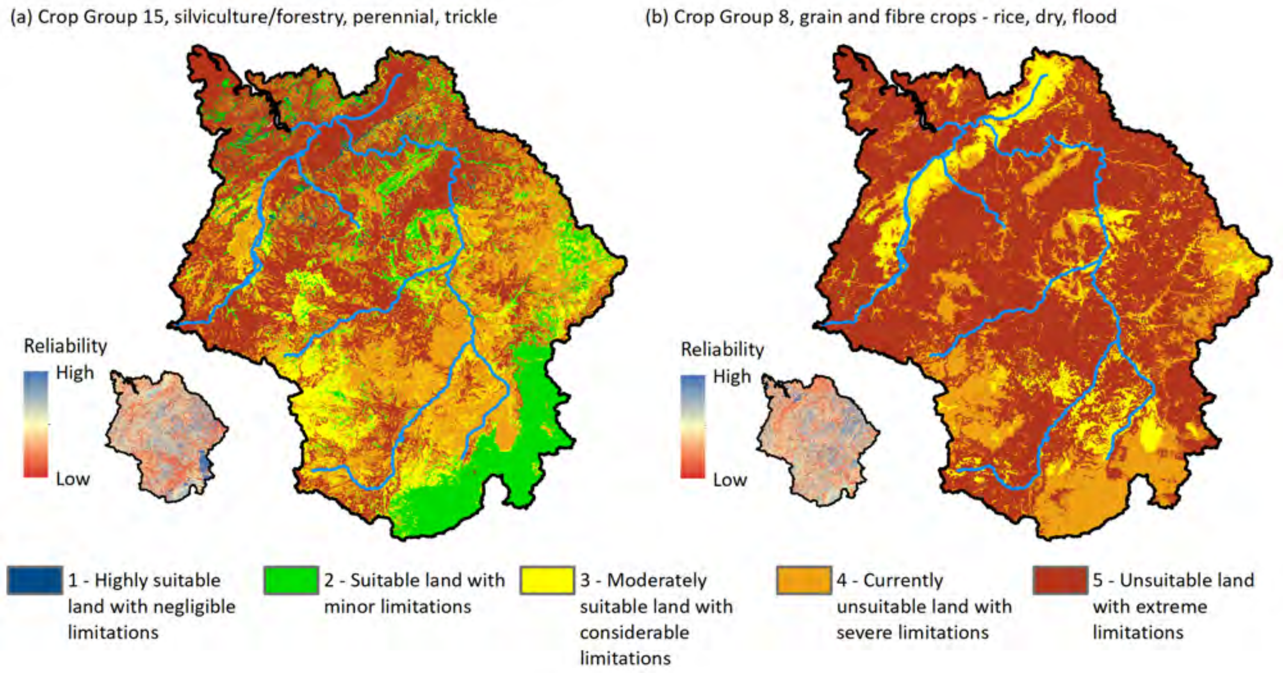

Figure 3-29 Modelled land suitability for crop group 15, 'silviculture/forestry (plantation)' such as Indian sandalwood, grown using trickle irrigation, and (b) for crop group 8, 'grain and fibre crops' such as rice, grown using dry season flood irrigation

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 2-5

The suitability class distributions for the Victoria catchment for each of the 14 land uses discussed above are summarised in Figure 3-30. This shows that in all cases there are no land uses that combined suitable classes (class 1, 2 and 3) represent more than 50 % of the catchment area. Crop group 3, intensive horticulture under dry season trickle irrigation (Figure 3-28 (a)), is the most extensive of the exemplar land uses covering 37.1 % (3,066,400 ha) of the catchment with suitability class 3 or better. Other land uses with class 3 or better include crop group 14, hay and forage under spray irrigation (Figure 3-24 (b)) that covers 2,920,800 ha (35.4 %) and crop group 9, oilseeds, grown under wet season furrow irrigation covering 2,876,300 ha (34.8 %) (Figure 3-27 (b)). The least extensive land uses in terms of their land coverage of class 3 or better include crop group 7, grain and fibre grown with dry season furrow irrigation (Figure 3-23 (a)) covering 624,500 ha (7.6 %), crop group 13, hay and forage grown under dry season furrow irrigation (Figure 3-25 (b)) that covers 622,800 ha (7.5 %). Finally, crop group 19, oilseeds grown under wet season furrow irrigation (Figure 3-27 (a)) is the least extensive with 423,100 ha (5.1 %).

All 58 land suitability maps, including the majority that are not exemplar land uses, are presented in Appendix E.

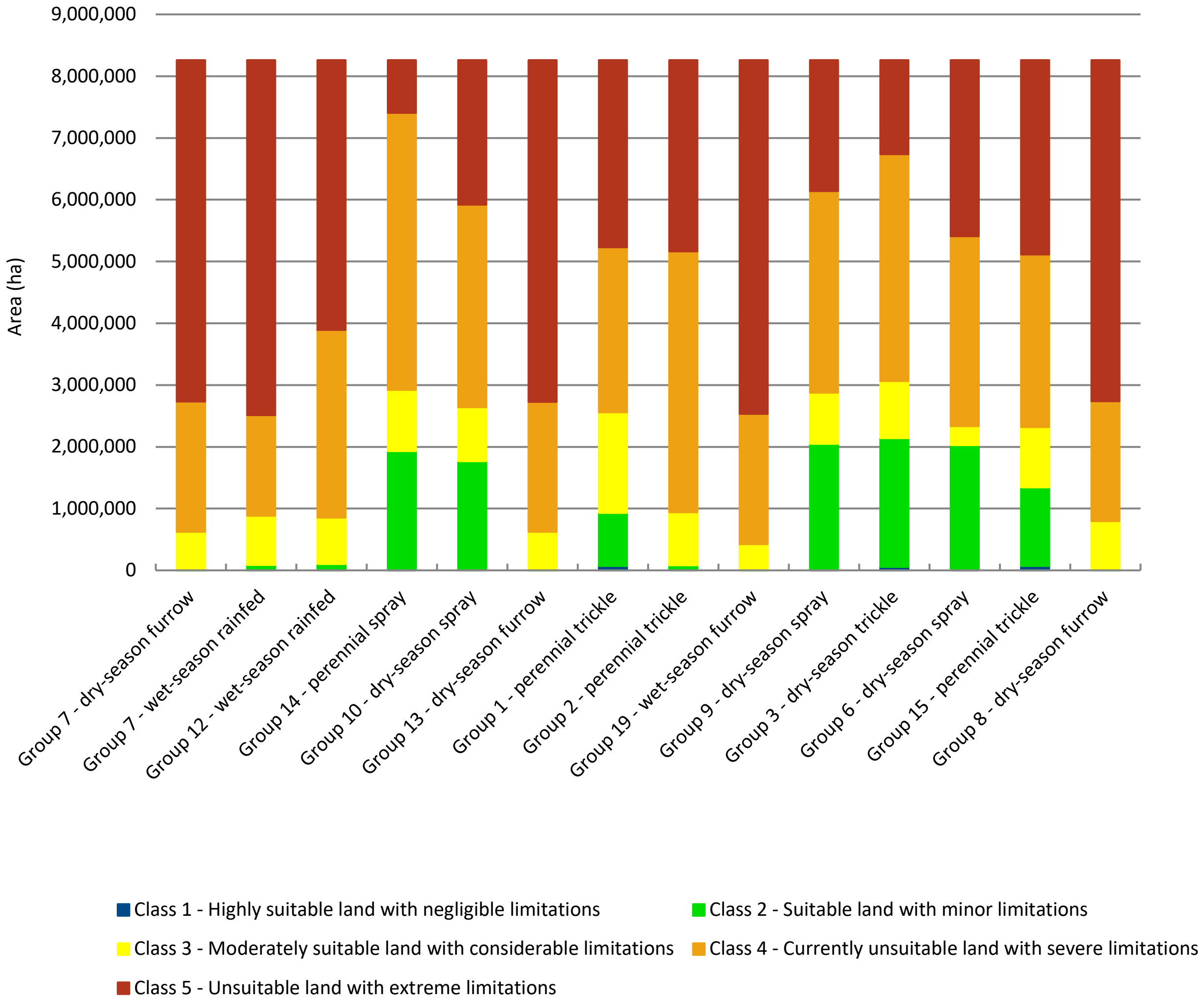

Figure 3-30 Area (ha) of the Victoria catchment mapped in each of the land suitability classes for the 14 selected land use options

A description of the five land suitability classes is provided in Table 2-4. More detail on the 21 crop groups, and example crops, is found in Table 2-5 and Section 2.5.1.

3.5.2 Landscape complexity

Methods were tested (Section 2.5.6) to assess the contiguousness of parcels of suitable cropping lands. The methods were based on natural distributions of soil and land variability to address operational farming constraints imposed by parcels of suitable land being too small according to natural variability of land, or physical limits on suitable farming land parcel sizes caused by land dissection through anabranching. 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 3-31 (c), and the plates (a) to (d) illustrate the workflow to address contiguous areas in situations where spatial variability of suitability class distributions is high, shown in plate (a). The following illustrated discussion focusses on changes occurring in the fixed position ellipsoid in the illustration plates. Plate (b) presents an aggradation of classes 1 to 3 (i.e. suitable classes) as green, and classes 4 and 5 (non-suitable) as white. Next, plate (c) shows the result of GIS filtering to aggregate units into minimum areas of 25 ha. In cases this causes non-suitable land to be included in suitable lands (compare plates (c) and (a)), and conversely, suitable lands included in non-suitable areas (plate (d)). While the strategy means localised losses of suitable land, plus incorporation of non-suitable areas into the larger suitable land units, the overall benefit is likely to be positive from a farm practice perspective.

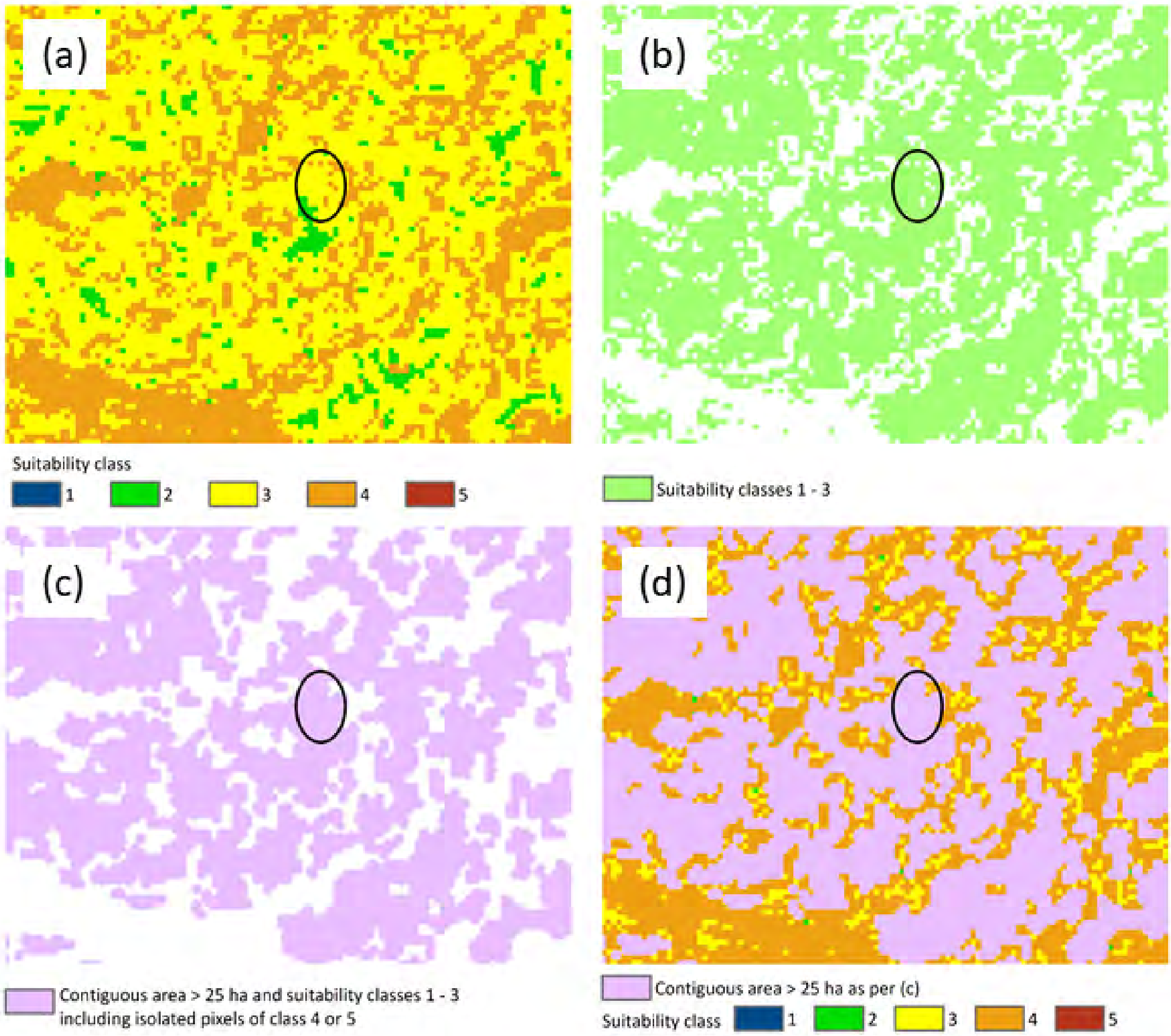

Figure 3-31 Example of the application of the contiguous areas processing, the black ellipse is used to highlight agriculturally unsuitable single and double pixels that get included into the suitable contiguous area data reflecting on-ground management

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

The results of the floodplain stream dissection analysis demonstrates that while there are widespread areas of stream dissection beyond the main river channels in much of the alluvial areas in the catchment, most channels are <1m deep thus do not make the land unsuitable from a land dissection perspective. The example shown in Figure 3-32 shows the LiDAR analysis of a section of dissected West Baines River floodplain showing channels >1 m deep. This shows that the majority of channels are <1 m deep, so according to the dissected land criteria, most of the land is not dissected despite much of it appearing so.

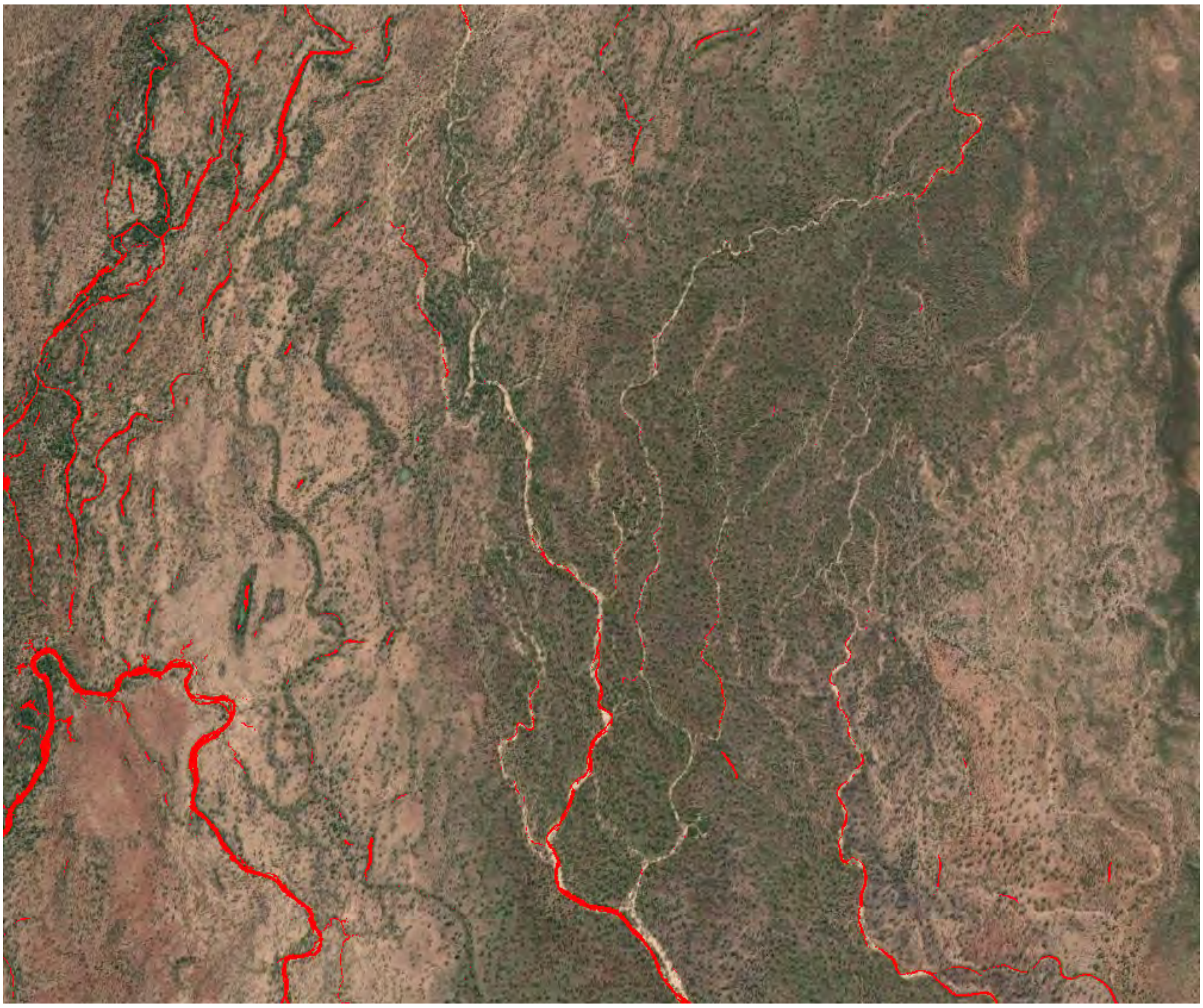

Figure 3-32 A section of the West Baines River floodplain alluvium showing the mapped extent (red) of the stream meeting the > 1m criteria. The majority of streams running through the floodplain have not been identified because the channels were less than 1 m deep

The landscape complexity methods are presented to illustrate possible tactical approaches to address physical constraints to farming caused by soil and land variability. While it was possible to employ these outputs as additional ‘farm practice’ limitations to the land suitability analyses, they have not been applied in this study for two reasons. Firstly, as these constraints relate mainly to the economics of farm set up and operation, each investor decision will be influenced by a set of considerations governed by their own financial circumstances and tolerances. For this reason, these farm practice limitations are appropriately applied on a case-by-case basis when planning the farm and can even be modified in terms of threshold settings according to investor needs and instincts. Secondly, applying these limitations to this land suitability analysis when the same has not been applied in prior Assessments affects comparability of agricultural opportunity reporting across all Assessments. It is possible to retrospectively apply these approaches to all if desired.

3.5.3 Versatile agricultural land

Figure 3-33 shows the versatility of agriculture under four management systems namely, spray (a), trickle (b), furrow (c) irrigation methods and (d) rainfed agricultural versatility. In terms of irrigation-type versatility, a significant proportion of the study area shows high to moderate versatility for spray irrigation (Figure 3-33 (a)); the most versatile areas area associated with the red loam soils (SGG 4.1) of the Tertiary sedimentary plains physiographic units. Here the well-drained and moderately permeable (Figure 3-19) character of these soils is what makes them the most suitable for spray irrigation. Areas on the alluvial plains coinciding with clay soils are less versatile for spray irrigation, and this is likely to reflect the lower permeability of these clay-rich soils like SGG 9.

The versatility of lands for trickle irrigation are shown in Figure 3-33 (b). Patterns are similar to those of spray irrigation, although versatility is notably lower in the southern tracts of the Tertiary sedimentary plains (generally SGG 4.1). This may be a climatic factor where evaporation rates are higher in these southern areas of the catchment.

Figure 3-33 (c) shows how land versatility under furrow irrigation is distributed across the study area. The catchment is generally less versatile compared to spray and trickle irrigation, with the most versatile areas corresponding with clay soils (SGG 9) of gentle plains on Basalt and alluvial plains. Desirable attributes for this land use combine level sloping land gradients, low permeability (Figure 3-19) and low levels of surface rockiness (Figure 3-21). Areas of high to moderate versatility comprise a minor proportion of the whole catchment.

The versatility of rainfed lands is shown in Figure 3-33 (d). This shows the most versatile areas to be linked to alluvial plains and gentle plains on Basalt where clay soils (SGG 9) with larger AWC values (Figure 3-18) and deep soil (Figure 3-16) combine. Like furrow irrigation, versatility of land is generally low throughout the catchment.

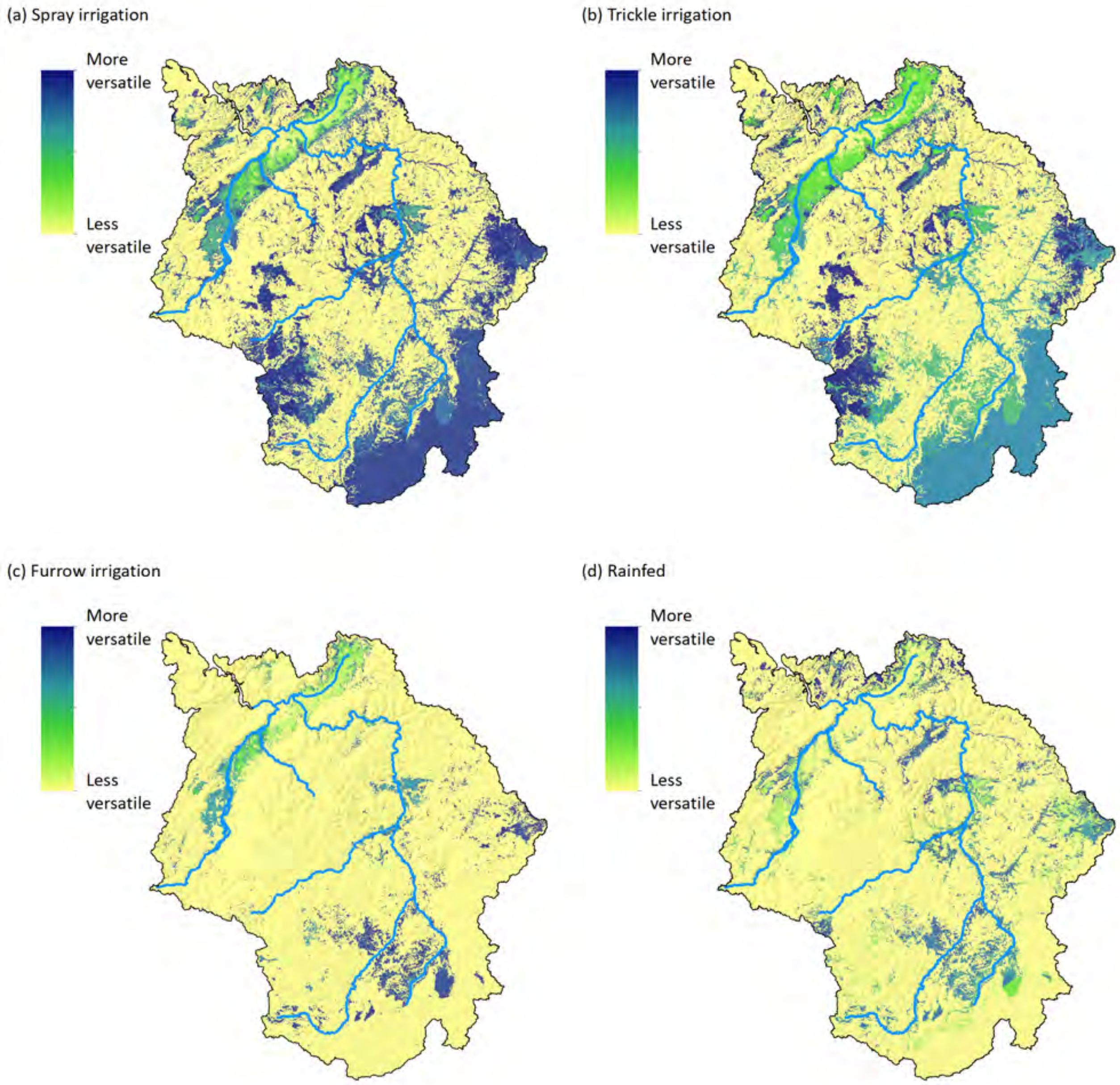

Figure 3-33 Agricultural versatility for (a) spray, (b) trickle and (c) furrow irrigation types, and (d) rainfed
Higher index values indicate greater versatility for each irrigation option. Displays are not suited to inter-irrigation type comparisons

Figure 3-34 shows the versatility index map of agriculture lands derived from the 14 exemplar land uses presented in Section 3.5.1. The most versatile land occurs on areas of the alluvial plains and the gentle plains on Basalt. These are areas where clay soils (SGG 9) are dominant and where there is greatest opportunity for all three irrigated and rainfed land uses overlap (Figure 3-33). The areas of Tertiary sedimentary plains also have a higher degree of versatility, and this is where spray and trickle irrigation are most prospective because of well-drained, permeable soils like SGG 4.1. Large areas of higher versatility are also associated with the alluvial plain clays (SGG 2 and 9), particularly in upper reaches of the West Baines River where opportunity for furrow irrigation (Figure 3-33 (c)) combine with the other options. However, most of the catchment has low (zero) versatility where no forms of land use are suited. These areas coincide with high relief, hilly country i.e. in the Basalt hills, Sandstone hills and Limestone hills physiographic units and where shallow and/or rocky soils with low AWC dominate (SGG 7) (Figure 3-21).

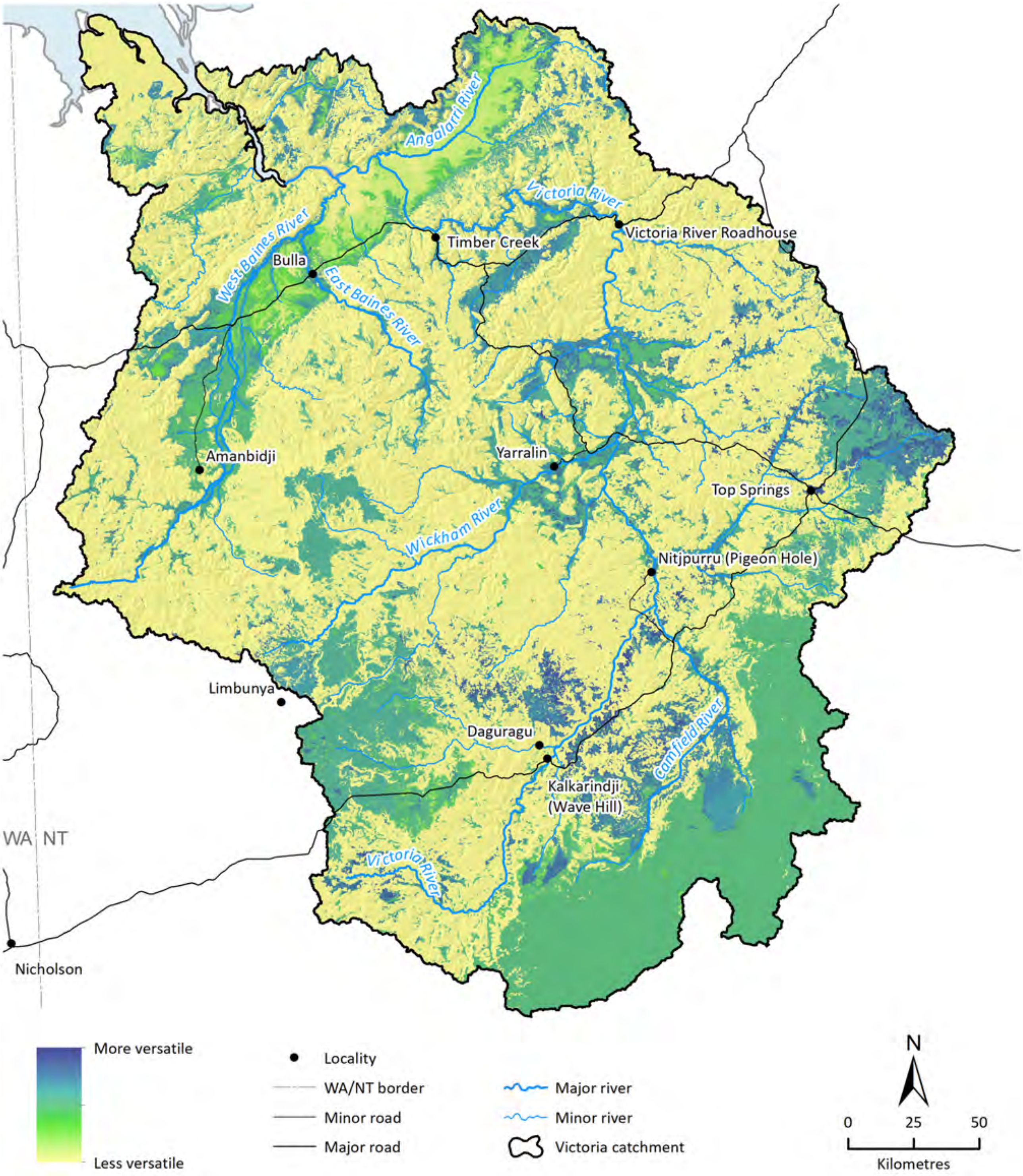

Figure 3-34 Agricultural versatility index map combining 14 unique land use options
Higher index values denote land that is likely to be suitable for more of the 14 selected land use options

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.

3.5.4 Aquaculture land suitability

The land suitability for aquaculture considers proximity to seawater for marine species and 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 longevity, 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. In the discussions that follow, reference is made to physiographic units (see Figure 1-2 and Table 1-1) and the SGGs (see Section 3.3, and Figure 3-15).

Figure 3-35 (a) presents the land suitability mapping for freshwater lined aquaculture. This shows that there are significant tracts of lands with soil attributes suitable for this land use. The large tracts of suitability class 2 areas coincide with level plains with deep soils (Figure 3-16) and no rock (Figure 3-21) associated with the marine plains, the alluvial plains and the Tertiary sedimentary plains physiographic units. The class 3 suitability areas coincide with Limestone gentle plains and some gentle plains on Basalt.

The land suitability patterns for freshwater earthen aquaculture are presented in Figure 3-35 (b). This shows most of the land to be unsuitable, although there are areas of class 2 and 3 restricted to level plains with deep (Figure 3-16), impermeable (Figure 3-19), rock free (Figure 3-21) clay soils (SGG 9) in the marine plains and alluvial plains physiographic units.

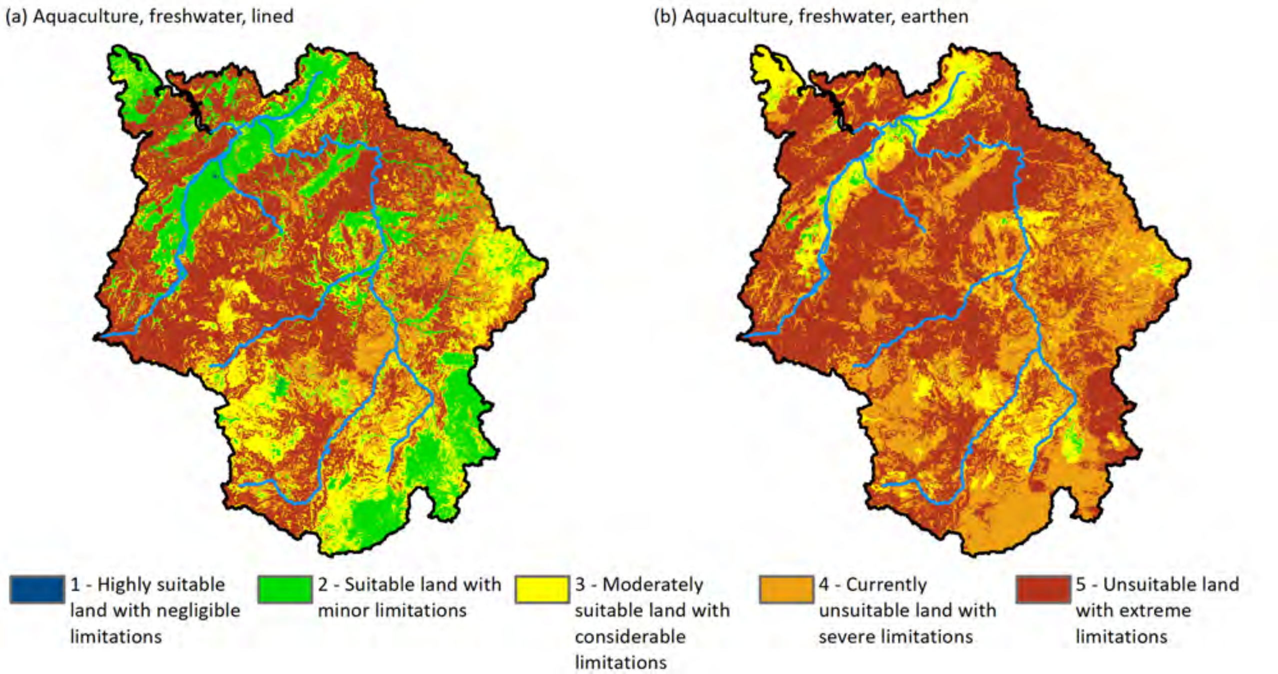

Figure 3-35 Land suitability for freshwater aquaculture in (a) lined ponds and (b) earthen ponds

The land use suitability for marine aquaculture is presented in Figure 3-36. This land use is restricted to areas with marine tidal influence; the lower reaches of the catchment. There are minor areas of class 2 and 3 suitability for marine lined aquaculture shown in Figure 3-36 (a) restricted to seasonally or permanently wet soils (SGG 3) and clay soils fringing the river (SGG 2 and 9). Figure 3-36 (b) shows the distributions of marine earthen aquaculture. The land suitability patterns are similar to Figure 3-36 (a) for lined aquaculture, albeit with less class 2 soils. Prospective areas are associated with marine plains and alluvial plains physiographic units.

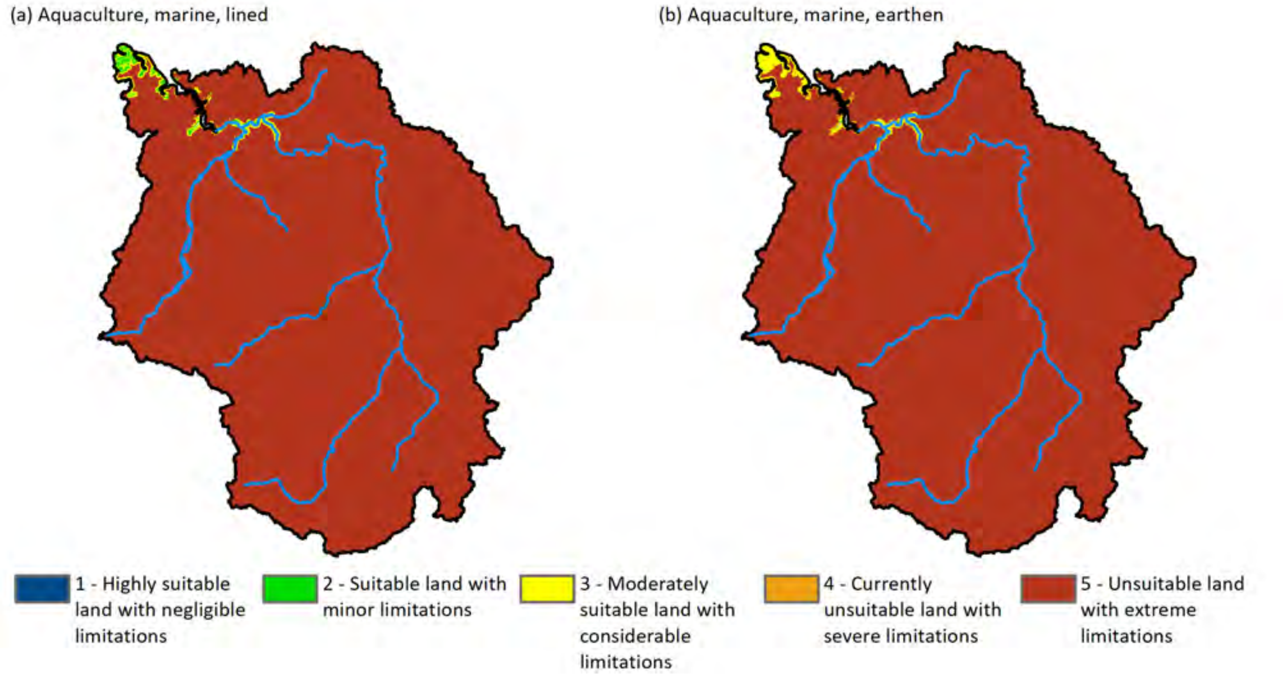

Figure 3-36 Land suitability for marine aquaculture in (a) lined ponds and (b) earthen ponds

Figure 3-37 is an enlargement taken from Figure 3-36 showing areas of class 1, 2 and 3 land suitability in more detail.

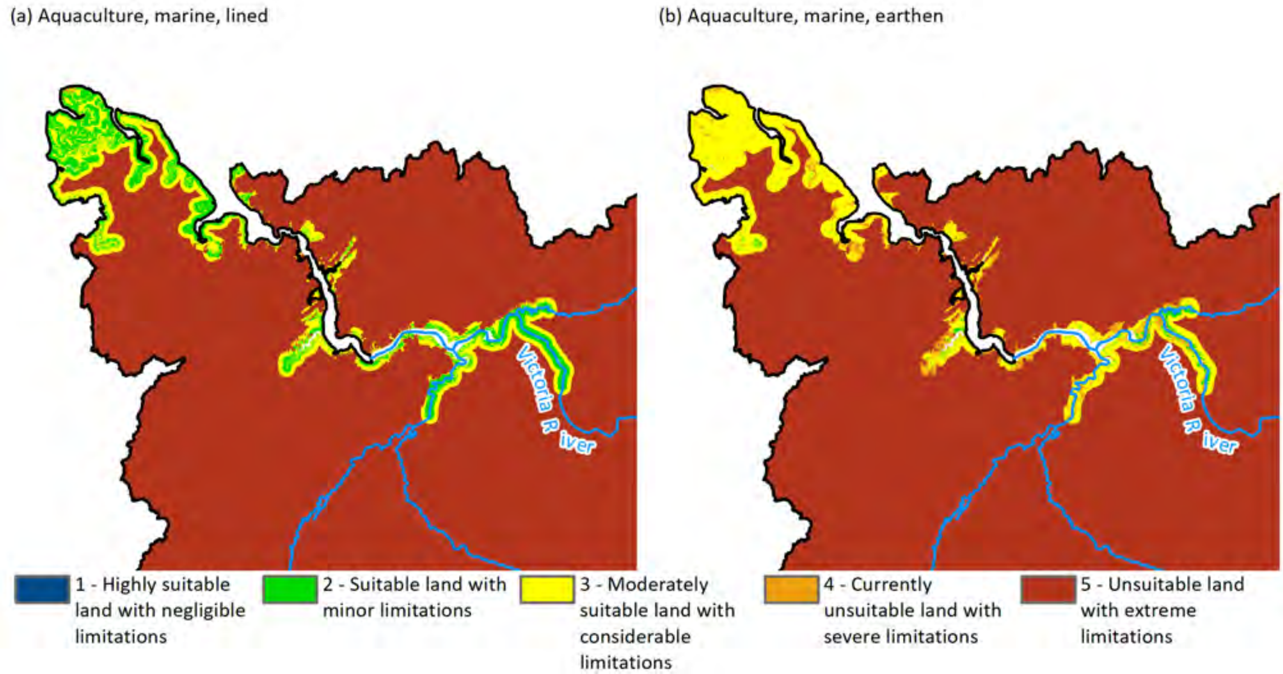

Figure 3-37 Enlarged class 1, 2 and 3 land suitability areas for marine aquaculture in (a) lined ponds and (b) earthen ponds

3.5.5 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 attribute and suitability data. Artefacts are observed as unnaturally crisp edges in maps with no clear physiographic rationale and can be inherited from DSM covariates (Section 2.4.4). In this study, there are likely to be three sources of artefacts from:

- binary covariates (e.g. vector-based geological mapping)
- the decision tree algorithm reflecting data decision points for threshold splits in continuous covariates (Section 2.4.4).
- raster-based covariates reflecting cultural land patterns, for example remote sensing showing the overprint of land use at boundaries like roads, urban/rural interfaces, or paddock boundaries with different crops on each side.

These types of artefacts are generally minor across the range of data and the catchment.

While mapped artefacts may 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 3.5.2 – involving on-ground assessments prior to decision making can either identify or put context to mapped artefacts.

An example of DSM artefact propagation from input covariates is shown in the SGG mapping in Figure 3-38 (a), (b), and (c). One source of artefact is demonstrated in the Thematic Mapper Bare Earth satellite remote sensing image in Figure 3-38 (a). Figure 3-38 (c) another source is Smectite covariate, which exhibits a crisp boundary inherited from the original vector GIS file format. The resulting SGG DSM attribute shown in Figure 3-38 (b) shows the combined overprint of both input covariates. Figure 3-38 (d) demonstrates the effect propagated in land suitability analysis caused by limitation value thresholds. In this case this shows the influence of the cut-off at a certain number of days >40 degrees Celsius and how this limitation threshold impacts the suitability class mapping for wet season rainfed annual feed grasses.

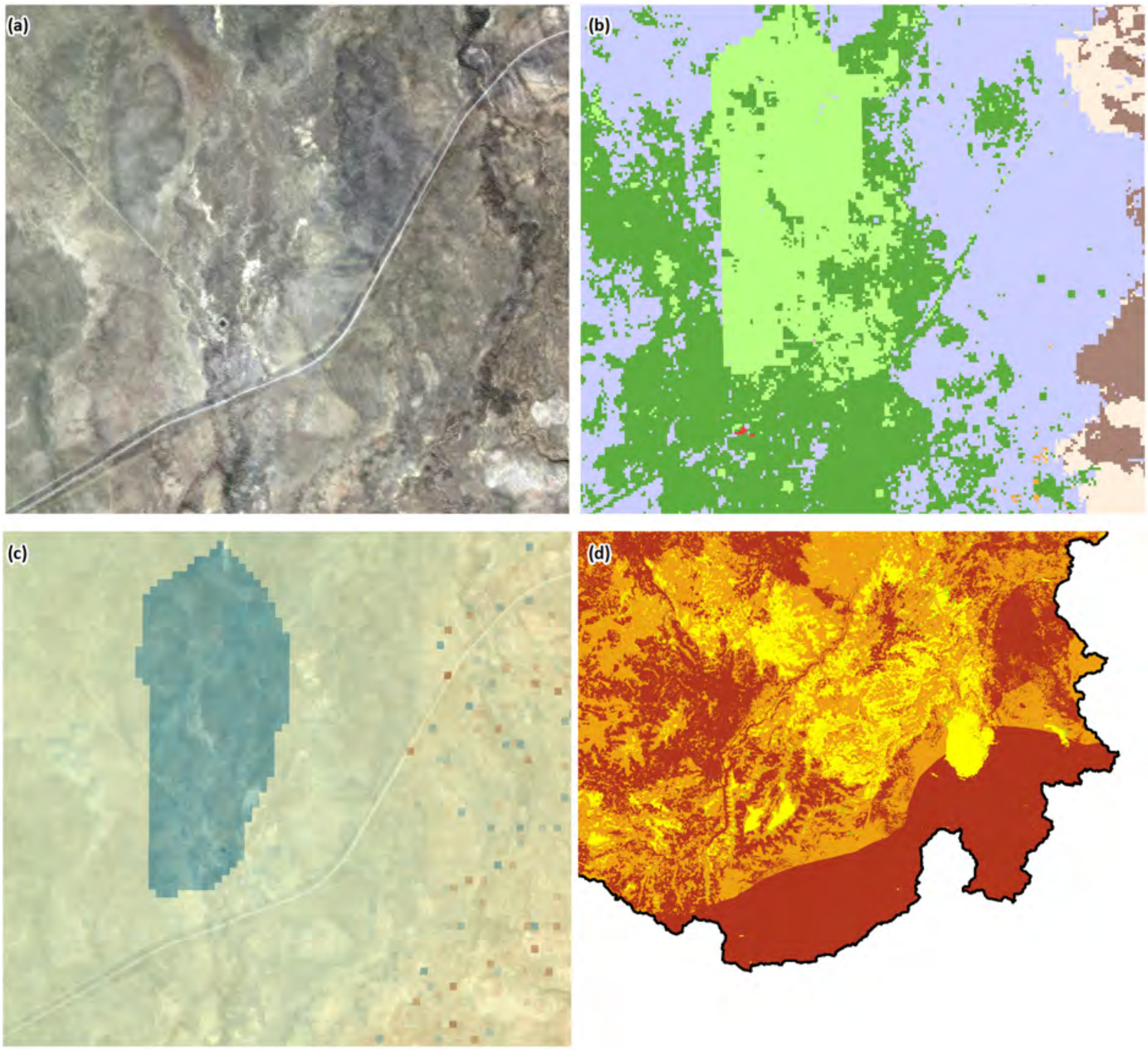

Figure 3-38 Example propagation of apparent artefacts

For the panels above (a) satellite image showing National Highway 1 traversing the landscape west of Timber Creek; (c) the Smectite covariate exhibiting the effect of a vector-based input dataset for the same area; (b) SGG mapping with the artefacts from the input covariate data as distinct features and (d) a distinct line feature in the wet-season rainfed annual feed grasses suitability data an artefact from decision points for threshold splits in continuous covariates exist in this case heat stress climate data (number of days over 40 degrees Celsius)

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 Victoria River Water Resource Assessment. The Assessment area incorporates the catchment of the Victoria River in the Northern Territory, an area of 82,400 km^2. The activity's main objective was to produce crop and aquaculture suitability data and maps to assist the Australian community, developer interests, land use policy, and to offer a broad appraisal of land intensification opportunity in the catchment.

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 data from 136 new sampling sites collected during this study, and soil data from 6282 pre-existing soil sampling sites. 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; FAO, 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 Section 2.5 and summarised in Appendix A. A land suitability analysis was also conducted for aquaculture with freshwater and marine options.

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) and the Roper Water Resource Assessment. Despite evolving modifications in methodologies the output of all Assessments remain consistent and comparable.

The land suitability assessment is framed around crop 'limitations' relating to land, soil and climate attributes. While the climate datasets were supplied by public sources, an important component of this activity was the generation of new land and soil attribute maps for the Victoria catchment through DSM. These DSM attributes included soil thickness, surface pH, surface texture class and surface rockiness, and their generation was enabled by national covariate datasets, pre-existing soil data and new soil data collected during the activity.

The land suitability framework matches instances of crop group by season by irrigation type (plus rainfed). Individual crops were not assessed in the suitability assessment, rather we used 21 groups of crops (crop groups) selected according to similarity of growing needs and limitation thresholds. Accordingly, 58 land use scenarios, comprising the 21 crop groups by season (wet, dry and perennial) by irrigation type (17 furrow/flood, 23 spray, 10 trickle, and 8 rainfed) options were modelled in the land suitability assessment shown in Appendix A. 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 through to 3 are marked as suitable. Appendix E presents the results of the 58 land suitability options.

The reliability of the DSM attribute and the land suitability mapping was also estimated using statistical methods. These estimates were mapped and accompany the DSM and land suitability mapping so that users may gauge the quality of outputs for their needs.

A further expansion of the land suitability data was used in a methodology to create indices capturing the versatility of cropping lands. These indices combine the crop land suitability mapping to discriminate areas coinciding with a high degree of land suitability for multiple crops (high versatility lands) versus lands where few or none were suitable (low to no versatility rated lands). Two types of agricultural versatility maps were generated: the first showing crop versatility for 14 'exemplar' cropping combinations, and the second showing irrigation versatility for each irrigation type (spray, trickle and furrow) as well as rainfed agriculture. These indices were developed to guide land use policy and potential development and to prioritise areas that are potentially the most prospective for agricultural intensification in the Victoria catchment. Places of high versatility are candidate areas for further more intensive investigation.

To summarise the outputs of the agricultural versatility maps in Section 3.5, overall, i.e. simultaneously considering the 14 exemplar land uses (Figure 3-34), the most versatile lands in the Victoria catchment were associated with the Alluvial plains, the Limestone gentle plains in the east, and the gentle plains on Basalt (Figure 1-2). Here, friable loams and clay soils (SGG 2 and 9; Figure 3-15) are dominant with favourable characteristics for spray and trickle irrigation (as shown in Figure 3-33) including a high water holding (AWC) (see Figure 3-18). Areas of high to moderate versatility are associated with the Tertiary sedimentary plains where red loamy soils dominate (SGG 4.1), which are often well suited to spray and trickle irrigation because of the drainage qualities of these soils. Low to zero versatility areas have attributes that are not amenable to irrigated land preparation e.g. due to surface rockiness (Figure 3-21), shallow and/or rocky soils (SGG 7) or because of high relief and sloping land typical of the hilly physiographic units including Basalt hills, Sandstone hills and Limestone hills.

The outputs of the aquaculture land suitability show opportunity for freshwater species (Figure 3-35) in lined ponds to be widespread throughout the catchment due to the extensive distribution of favourable soil and land characteristics evident in the level lands of Marine plains, Alluvial plains and Tertiary sedimentary plains physiographic units in particular. Here soils are also amenable being absent of rocks (Figure 3-21) and of sufficient depth to be workable (Figure 3-16). Aquaculture with fresh water in earthen ponds has limited suitable areas that are restricted to plains physiographic units where low permeability (Figure 3-19) is an important characteristic associated with clays (SGG 9). Marine aquaculture's (Figure 3-36) range is restricted to the tidal zones of the catchment on the marine plains and alluvial plains where tidal conditions apply.

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, thus reflecting a low intensity or reconnaissance-type land evaluation. It is therefore important for users to be aware that the information provided characterises land suitability over a broad area and thus is best suited as a regional-scale overview and appreciation of opportunity. 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 ASS).

Limitations not considered in this assessment may have a bearing on the viability of an enterprise. These include:

- Economics and finance, including subsidies and grants, produce market prices, fertiliser and fuel price, etc,
- proximity to produce processing (e.g. cotton gins and abattoirs), transport networks and service hubs, and markets,
- flood risk,
- land management-induced secondary salinity,
- presence of areas excluded conservation, and
- proximity to available 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. Some of these factors 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.

Finally, the land suitability frameworks (crops and aquaculture) offer a systematic, quantitative framework to analyse land and water development opportunities in the Assessment area. These outputs inform the other activities undertaken in the Assessment, including Surface water hydrology, Agriculture and socio-economics, Surface water storage, Indigenous water values, rights, interests and development goals and Ecology. The outputs from this activity allow for realistic trade-offs to be made between the types and size of development opportunities (and limitations) before development should continue.

Should conditions change 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 to reflect new crop varieties, policy shifts, changing climate of other environmental conditions, or availability of new or updated datasets. For example, access to finer scale covariates or soil sampling for DSM will allow finer scale resource assessments to be made delivering outputs attributable with greater reliability.

All data 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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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 2-5.

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
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

LAND USE CODE	CROP	SEASON	IRRIGATION TYPE
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 CropGrp19_W_R	CropGrp7_W_R CropGrp8_W_R CropGrp9_W_R CropGrp10_W_R CropGrp13_W_R	CropGrp11_P_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	CropGrp8_W_S	CropGrp14_P_S
CropGrp1_P_T	CropGrp8_W_R	CropGrp15_P_T
CropGrp2_P_T	CropGrp9_D_S	CropGrp16_P_T
CropGrp3_D_S	CropGrp9_W_R	CropGrp17_P_T
CropGrp3_D_T	CropGrp10_D_S	CropGrp18_D_S
CropGrp4_D_S	CropGrp10_W_R	CropGrp18_W_S
CropGrp4_D_T	CropGrp11_P_S	CropGrp19_D_S
CropGrp5_D_T	CropGrp11_P_R	CropGrp19_W_S
CropGrp6_D_S	CropGrp12_D_S	CropGrp19_W_R
CropGrp6_W_S	CropGrp12_W_S	CropGrp20_P_S
CropGrp7_D_S	CropGrp12_W_R	CropGrp20_P_T
CropGrp7_W_S	CropGrp13_D_S	CropGrp21_P_S
CropGrp7_W_R	CropGrp13_W_S	CropGrp21_P_T
CropGrp8_D_S	CropGrp13_W_R	

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 CropGrp1_P_T CropGrp2_P_T CropGrp15_P_F CropGrp15_P_T CropGrp20_P_S CropGrp20_P_T CropGrp21_P_S CropGrp21_P_T	CropGrp3_D_T CropGrp4_D_T CropGrp5_D_T CropGrp16_P_T CropGrp17_P_T CropGrp18_D_F CropGrp18_W_F	CropGrp3_D_S CropGrp4_D_S CropGrp8_D_F CropGrp8_D_S CropGrp8_W_F CropGrp8_W_S CropGrp8_W_R CropGrp9_D_F CropGrp9_D_S CropGrp9_W_R CropGrp19_D_F CropGrp19_D_S CropGrp19_W_F CropGrp19_W_S CropGrp19_W_R	CropGrp10_W_R	CropGrp7_D_F CropGrp7_D_S CropGrp7_W_F CropGrp7_W_S CropGrp7_W_R CropGrp12_D_F CropGrp12_D_S CropGrp12_W_F CropGrp12_W_S CropGrp12_W_R	CropGrp10_D_F CropGrp10_D_S	CropGrp6_W_S CropGrp6_D_S

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	CropGrp7_D_S	CropGrp11_P_S	CropGrp17_P_T	CropGrp7_D_F	CropGrp13_D_F
		CropGrp1_P_T	CropGrp7_W_S	CropGrp11_P_R	CropGrp18_D_S	CropGrp7_W_F	CropGrp13_W_F
		CropGrp2_P_T	CropGrp7_W_R	CropGrp12_D_S	CropGrp18_W_S	CropGrp8_D_F	CropGrp13_W_R
		CropGrp3_D_S	CropGrp8_D_S	CropGrp12_W_S	CropGrp19_D_S	CropGrp8_W_F	CropGrp14_P_F
		CropGrp3_D_T	CropGrp8_W_S	CropGrp12_W_R	CropGrp19_W_S	CropGrp9_D_F	CropGrp15_P_F
		CropGrp4_D_S	CropGrp8_W_R	CropGrp13_D_S	CropGrp19_W_R	CropGrp10_D_F	CropGrp18_D_F
		CropGrp4_D_T	CropGrp9_D_S	CropGrp13_W_S	CropGrp20_P_S	CropGrp11_P_F	CropGrp18_W_F
		CropGrp5_D_T	CropGrp9_W_R	CropGrp14_P_S	CropGrp20_P_T	CropGrp12_D_F	CropGrp19_D_F
		CropGrp6_D_S	CropGrp10_D_S	CropGrp15_P_T	CropGrp21_P_S	CropGrp12_W_F	CropGrp19_W_F
		CropGrp6_W_S	CropGrp10_W_R	CropGrp16_P_T	CropGrp21_P_T		

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

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES								
		A	B	C	D	E	F	G	H	I
W14	Poorly drained and highly or moderately permeable	3	4	3	5	4	4	3	4	5
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_W_R	CropGrp3_D_S	CropGrp20_P_S	CropGrp16_P_T	CropGrp13_W_R	CropGrp18_D_S	CropGrp7_D_S	CropGrp1_P_S
		CropGrp8_D_S	CropGrp8_W_S	CropGrp3_D_T	CropGrp20_P_T		CropGrp13_W_S		CropGrp12_D_S	CropGrp1_P_T
		CropGrp8_W_F		CropGrp4_D_S					CropGrp19_D_S	
				CropGrp4_D_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

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES								
		J	K	L	M	N	O	P	Q	R
W11	Imperfectly drained and moderately permeable	3	4	2	3	2	2	4	2	3
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

CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES						
		S	T	U	V	W	X	Y
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
			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 Victoria 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 CropGrp10_W_R CropGrp12_W_R CropGrp19_W_R	CropGrp7_W_R CropGrp8_W_R CropGrp13_W_R

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

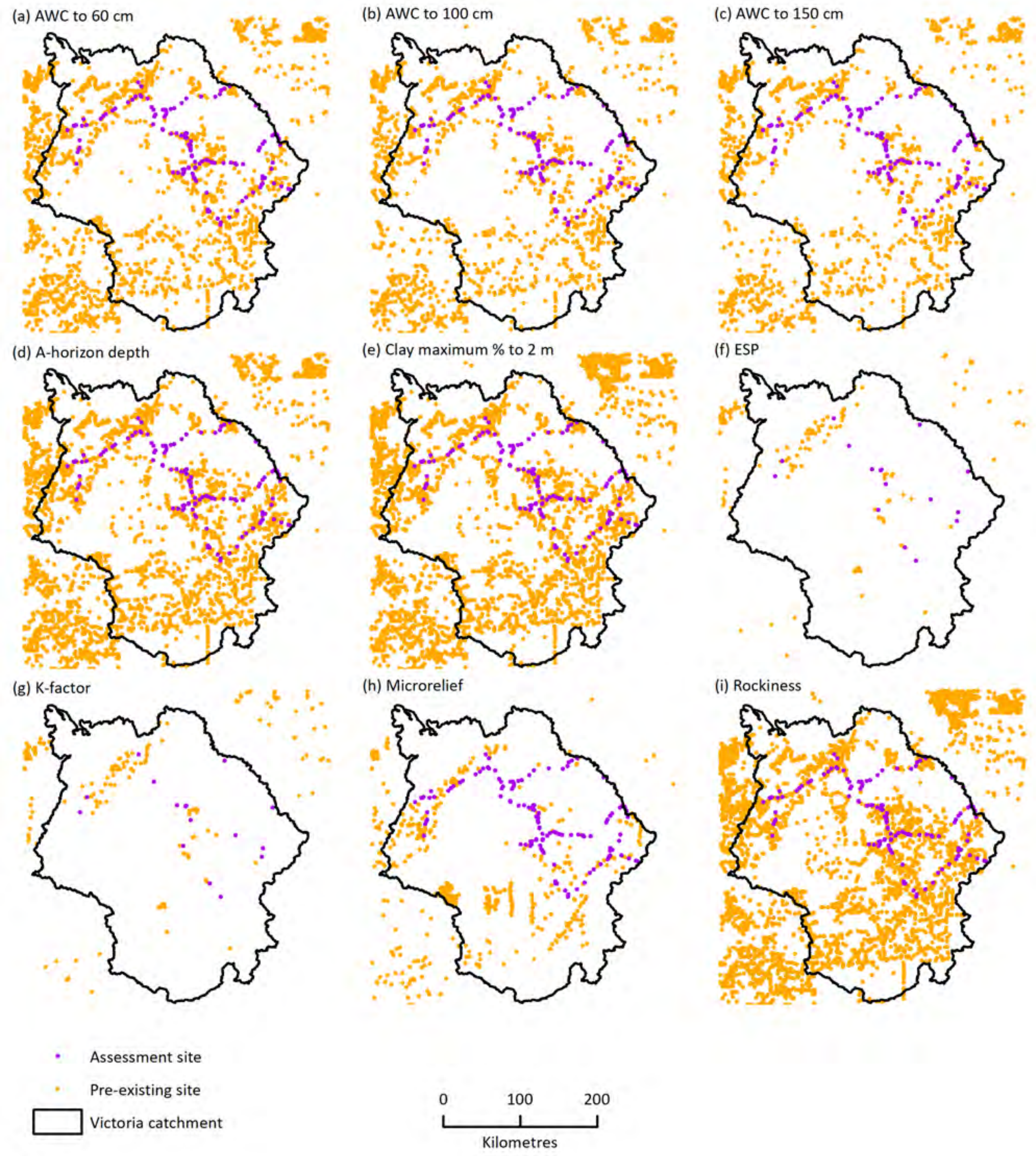
CODE	DESCRIPTION	SUITABILITY SUBCLASSES FOR LAND USES			
		A	B	C	D
MR2-1	Rainfall 800–1000 mm, AWC to 1.0 m >215 mm	1	1	1	1
MR2-2	Rainfall 800–1000 mm, AWC to 1 m 180–215 mm	1	1	2	2
MR2-3	Rainfall 800–1000 mm, AWC to 1 m 140–180 mm	2	2	2	2
MR2-4	Rainfall 800–1000 mm, AWC to 1 m 110–140 mm	3	3	3	3
MR2-5	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

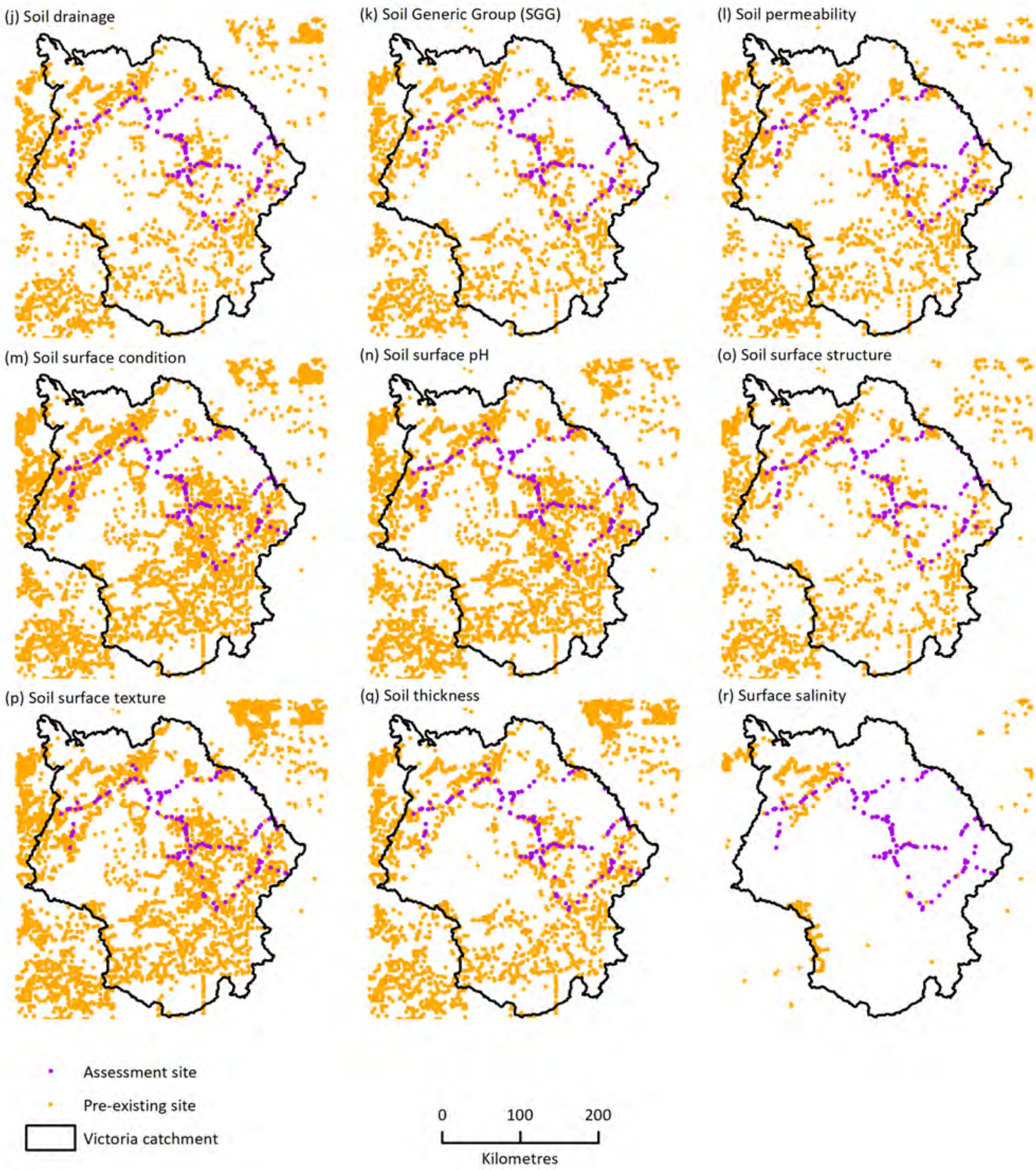
Apx Table B-26 Soil water availability – rainfed land uses, table 3 of 3

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 CropGrp8_W_R CropGrp9_W_R CropGrp10_W_R CropGrp12_W_R CropGrp13_W_R	CropGrp19_W_R	CropGrp11_P_R

Appendix C Soil data sites used in DSM

Plates show the contribution and location of site soil data collected in the activity (Assessment site) and pre-existing site soil data for modelling each attribute.





(j) Soil drainage
(k) Soil Generic Group (SGG)
(l) Soil permeability
(m) Soil surface condition
(n) Soil surface pH
(o) Soil surface structure
(p) Soil surface texture
(q) Soil thickness
(r) Surface salinity
Assessment site
Pre-existing site
Victoria catchment
0
100
200
Kilometres

Appendix D Land suitability rules for aquaculture

Apx Table D-1 Land suitability rules for aquaculture

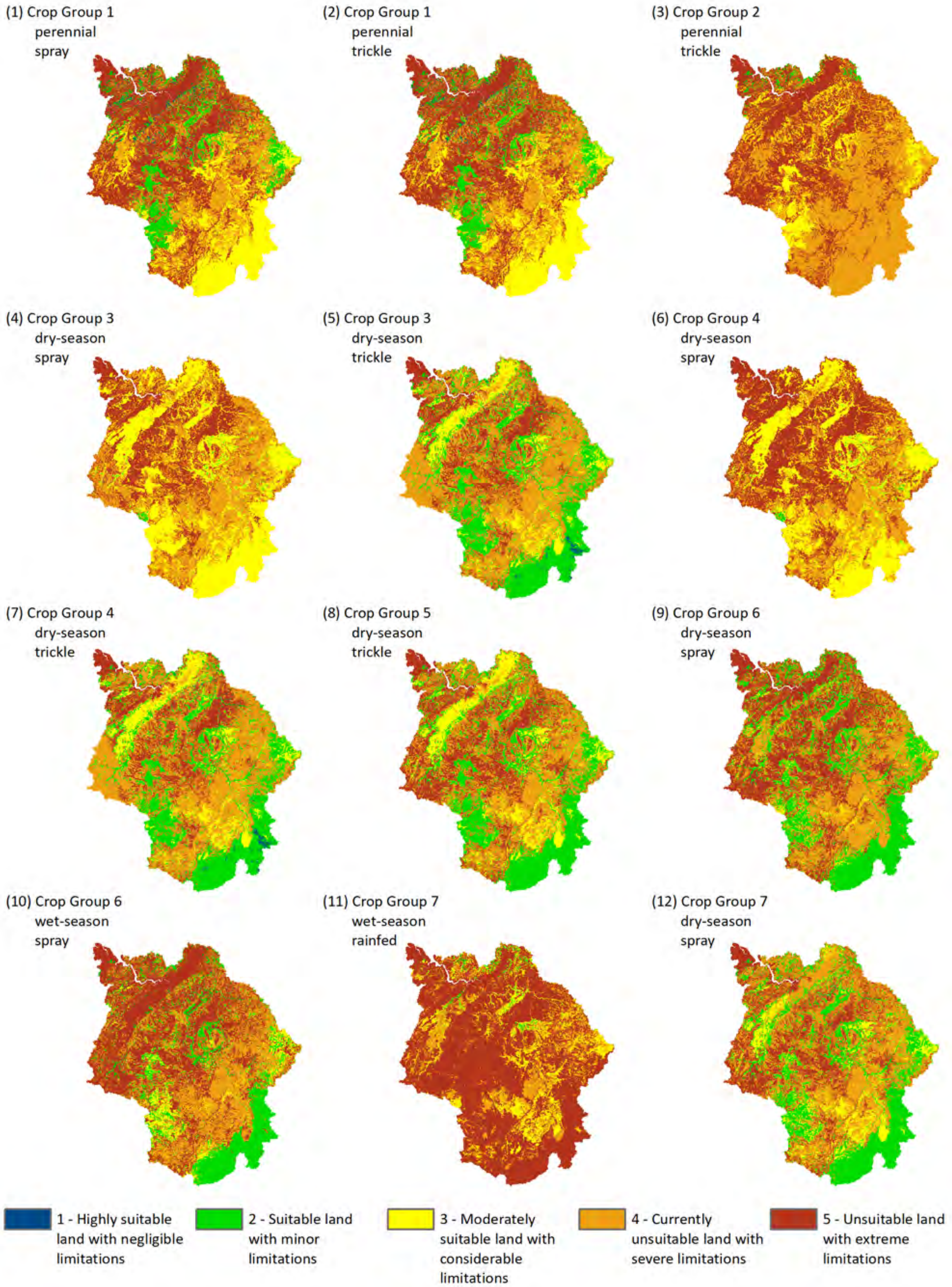
ATTRIBUTE	RULE	MARINE EARTHEN	MARINE LINED	FRESH WATER EARTHEN	FRESH WATER LINED
Distance to marine water	<500m	1	1		
	500–1000m	2	2		
	1000–2000m	3	3		
	>2000m	5	5		
Elevation	0–5m	3	3		
	5–15m	1	1		
	15–20m	2	2		
	20–25m	4	4		
	>25m	5	5		
Slope % (STRM)	Slope <2%	1	1	1	1
	>2% and <4% slope	2	2	2	2
	>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 E Maps of land suitability options

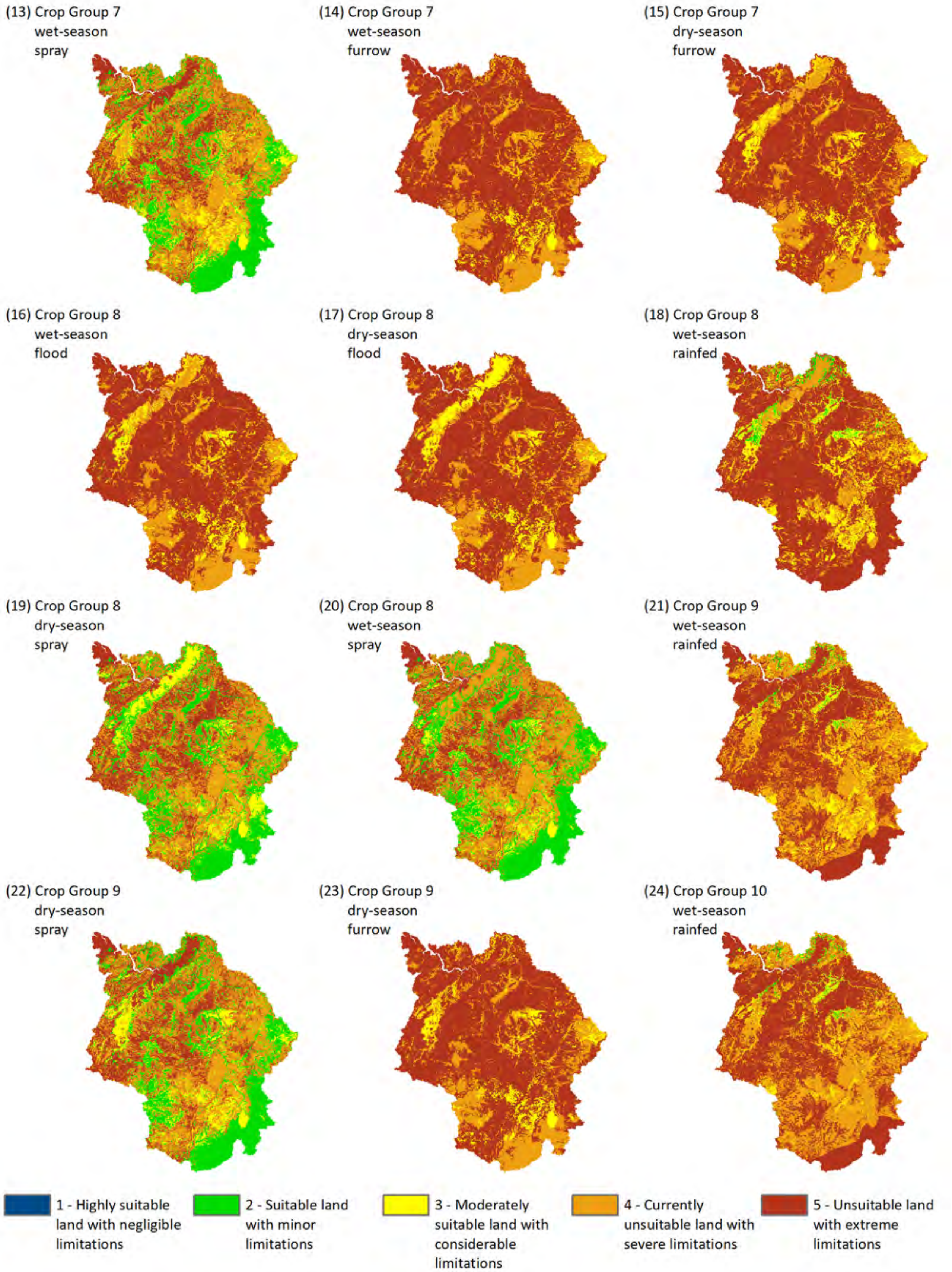
Full suite of land suitability maps for crop groups by season by irrigation type, as presented in Appendix A.

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.

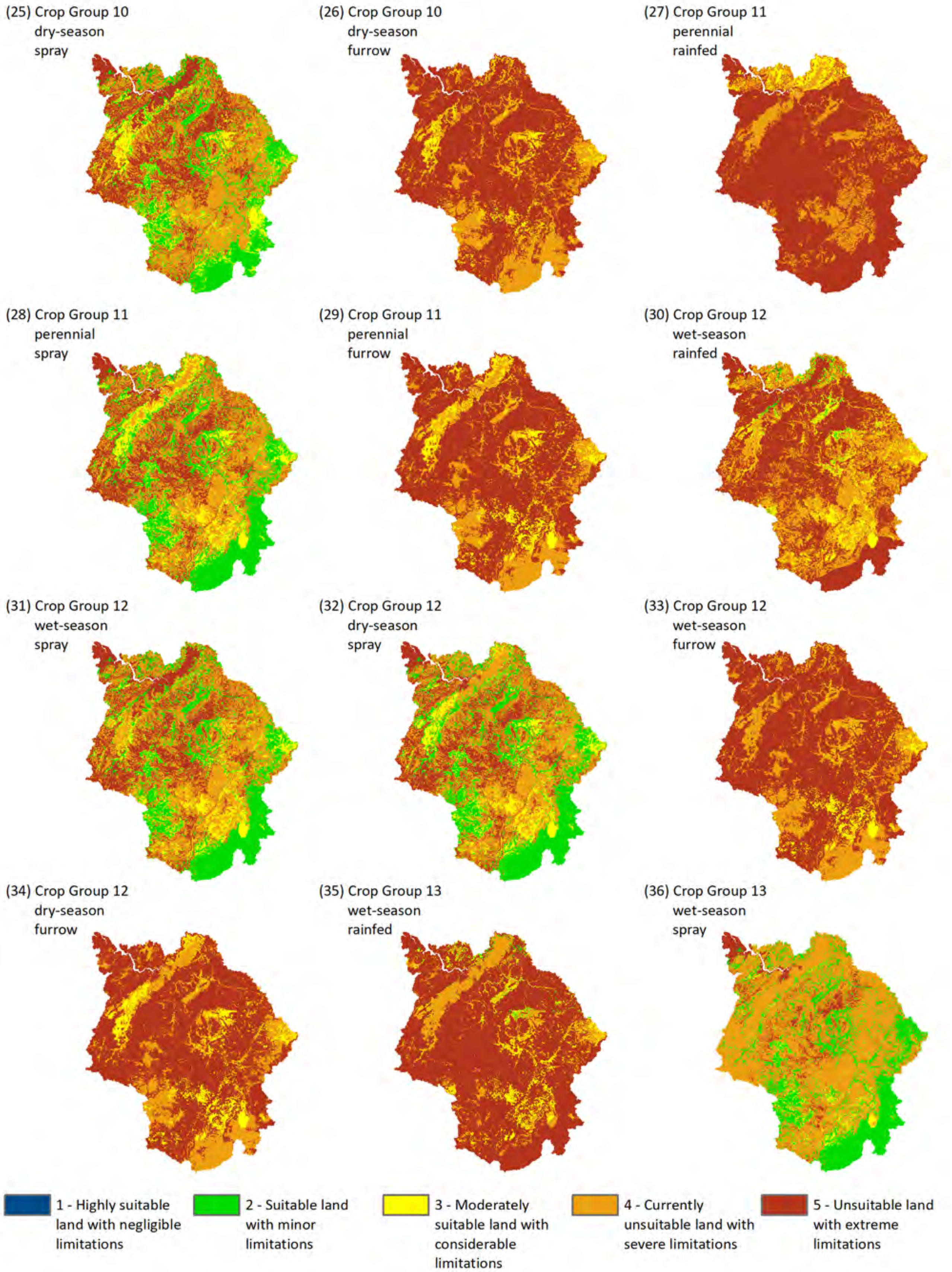
All data including land suitability and the companion reliability maps are publicly available from the CSIRO Data Access Portal (https://data.csiro.au/).



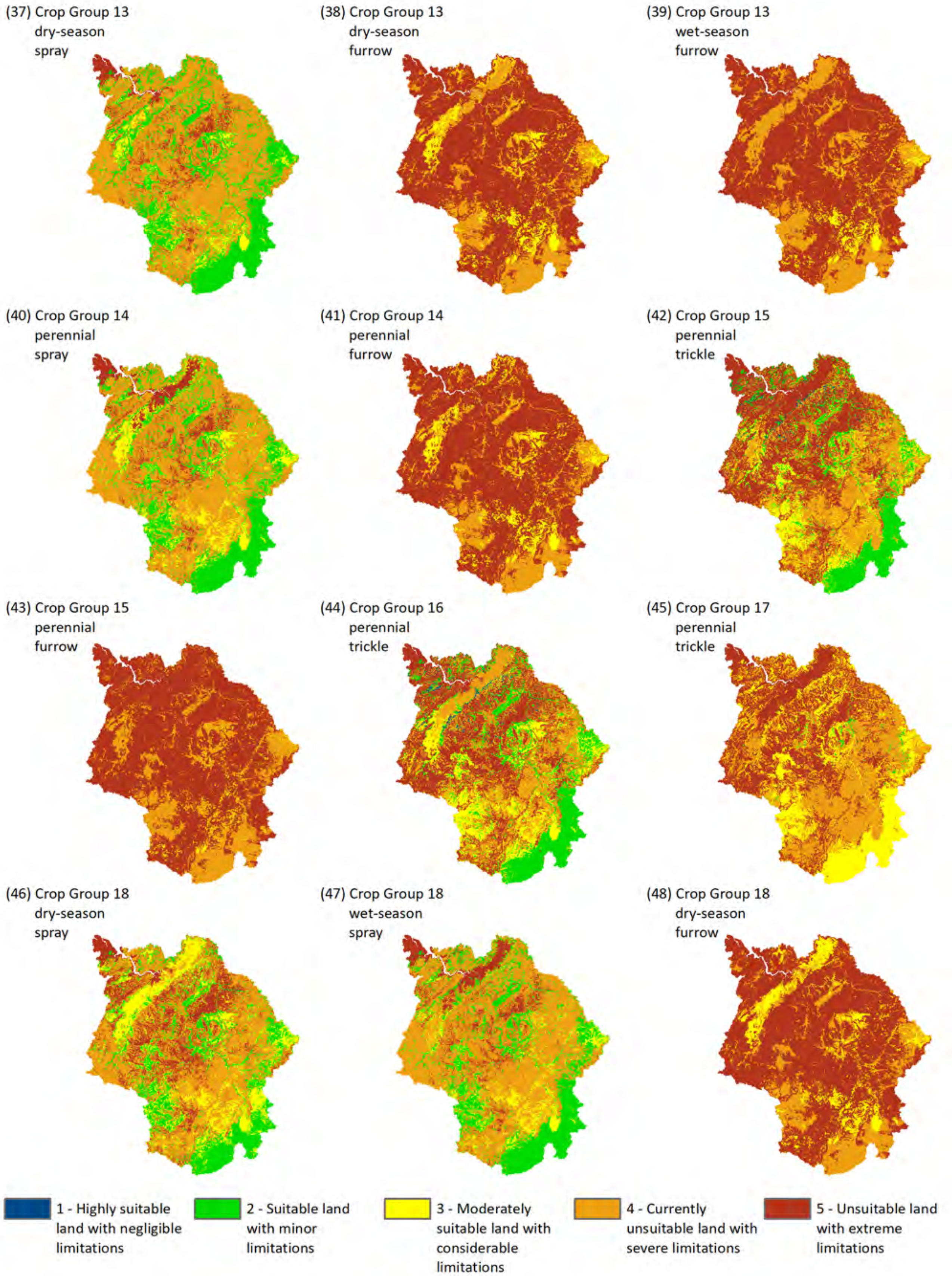
Apx Figure E-1 Suitability for land use options 1 to 12 from Appendix A



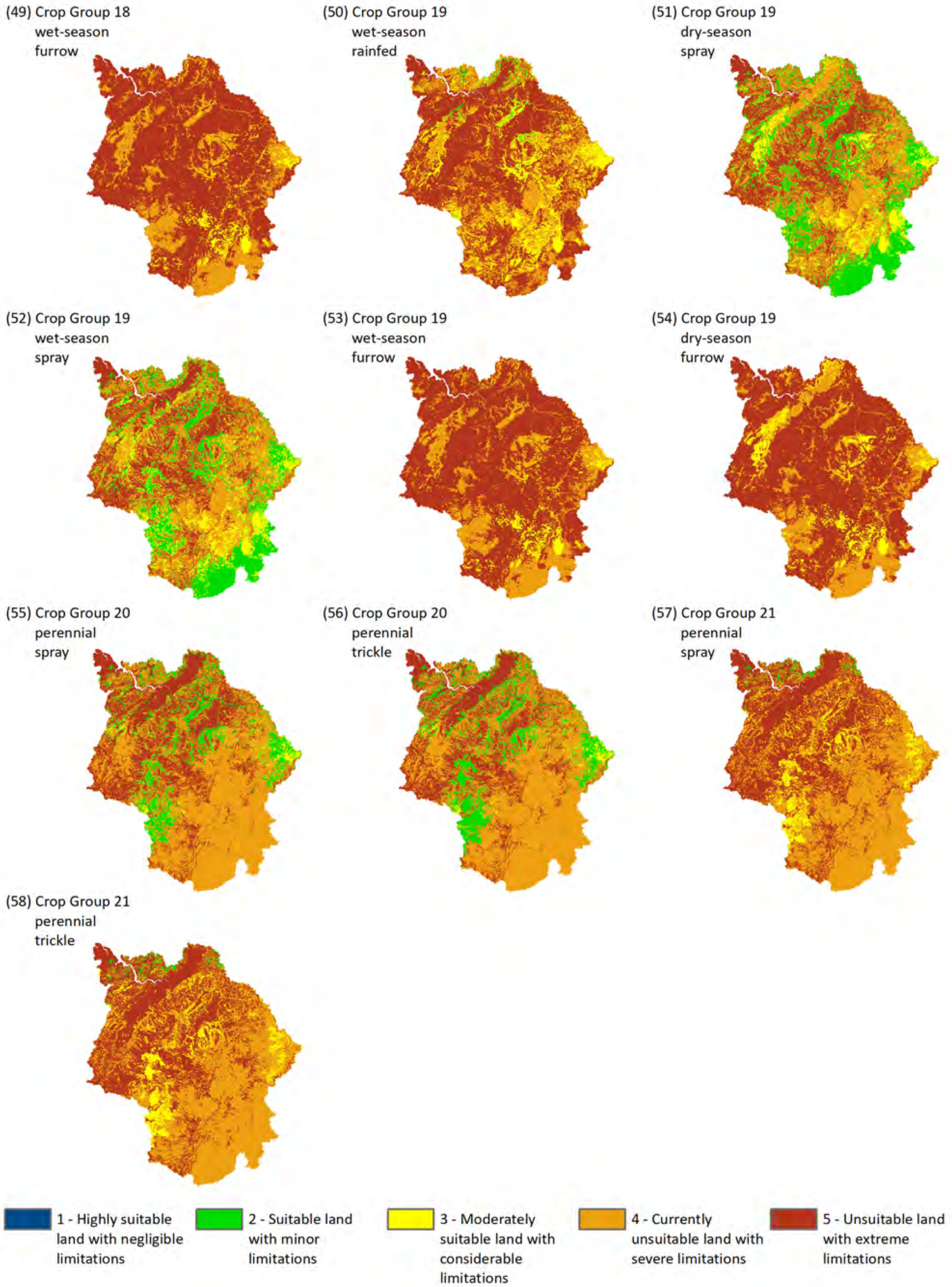
Apx Figure E-2 Suitability for land use options 13 to 24 from Appendix A



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



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



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

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