Technical Report to the Springvale Station Erosion Management Plan

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Acronyms used in this report

AGSO – Australian Geological Survey Organisation
AHGF – Australian Hydrologic Geospatial Fabric
BACI – Before After Control Impact
BMP – Best Management Practice
CHMP – Cultural Heritage Management Plan
CYMAG – Cape York Marine Advisory Group
DAF – Department of Agriculture and Fisheries
DEM – Digital Elevation Model
DERM – Department of Environment and Resource Management
DNRM – Department of Natural Resources and Mines
DRCM – Dynamic Reference Cover Method
DSITI – Department of Science Information Technology and Innovation
EHP –Department of Environment and Heritage Protection
EMP – Erosion Management Plan
ENSO – EL Nino Southern Oscillation
FPC – Foliage Projective Cover
GBR – Great Barrier Reef
GLM – Grazing Land Management
GPS – Global Positioning System
ILUA – Indigenous Land Use Agreement
LCA – Land Condition Assessment
LiDAR – Light Detection and Ranging
NESP – National Environmental Science Program
NCB – National Catchment Boundaries
NRM – Natural Resource Management
OSL – Optically-Stimulated Luminescence
PCB – Princess Charlotte Bay
RAFMAP – Road and Fence Maintenance and Abandonment Plan
RE – Regional Ecosystem
RG – Road Gullies
RUSLE – Revised Universal Soil Loss Equation
SCYC – South Cape York Catchments
SDR – Sediment Delivery Ratio
SSC – Suspended Sediment Concentration
TSS – Total Suspended Solids
YJV - Yalanji Joint Venture
WYAC –Western Yalanji Aboriginal Corporation

Note to the reader

The Technical Report to the Springvale Station Erosion Management Plan was produced as part of the Springvale Erosion Management Plan (EMP) Project.

The Springvale Erosion Management Plan Project was funded through the Queensland Department of Environment and Heritage Protection (EHP) and produced two final reports:

- Springvale Station Erosion Management Plan (EHP, 2017)
- Technical Report to the Springvale Station Erosion Management Plan (this report)

The Springvale Station Erosion Management Plan presents a summary of the recommended implementation approaches for reducing sediment loss from Springvale Station (www.qld.gov.au/environment/coasts-waterways/catchment-management/springvale-station).

The Technical Report to the Springvale Station Erosion Management Plan presents an introduction to the Springvale Erosion Management Plan Project as well as four technical reports that were produced by the multi organisational project team (Table 2, Figure 1) as part of the Springvale Erosion Management Plan Project:

- Desktop Cultural Heritage analysis
- Broad soil erosion assessment
- Desktop land condition analysis
- Erosion Management Plan to guide 2017 to 2022 actions.

These four reports represent the technical source material used in the production of the Springvale Station Erosion Management Plan.

Figure 1 The Springvale Erosion Management Plan Project Team inspecting a mature alluvial gully adjacent to Keetings Road on Springvale Station (5th June 2017) (Source: Lyndal Scobell).

Contents

1 Introduction to the Springvale Erosion Management Plan Project

In 2016 the Queensland Government purchased Springvale Station, a 56,295ha property in Far North Queensland (Figure 2), located just north of and connected to the Wet Tropics World Heritage Area. Springvale Station was purchased to add to the States' protected area estate for biodiversity conservation and to reduce accelerated soil erosion and sediment run-off entering the Normanby River basin, the largest basin that drains to the northern Great Barrier Reef (and the fourth largest river basin in the Great Barrier Reef catchment).

The acquisition of Springvale Station represents a whole-of-catchment approach to managing a State protected area. As well as protecting the property's important natural and cultural values, the ongoing management of Springvale Station will contribute to improving the water quality within the Normanby River catchment.

The objectives of the Springvale Station Erosion Management Plan are to:

- Identify priority erosion remediation areas and guide activities undertaken on the property to reduce sediment runoff to the Normanby River, Princess Charlotte Bay, and Great Barrier Reef lagoon according to best management practices and scientific and technical standards;
- Ensure that remediation works carried out under the Erosion Management Plan will not compromise the property's cultural and biophysical values, or cause collateral damage and increased erosion; and
- Identify monitoring and evaluation activities (in consultation with appropriate service providers) necessary to assess the efficacy and potential for replication of remediation techniques, and program adjustments through adaptive management.

The Springvale Erosion Management Plan Project has produced several reports across two phases of the project (Table 1). The reports in Phase One inform the development of the Erosion Management Plan to Guide 2017 Actions. All Phase One reports, inform the development of the Major Phase Two report - Erosion Management Plan to Guide 2017 to 2022 Actions.

Table 1 Description and timing of Springvale Erosion Management Plan Project reports.

Report Name	Description	Phase One (March, April 2017)	Phase Two (May, June 2017)
Desktop Cultural Heritage analysis	This report presents a draft Cultural Heritage protocol and desktop review of Cultural Heritage sites developed with Traditional Owners.	Draft	Updated
Broad soil erosion assessment	This report presents an analysis of soil and gully erosion within the geologic units found on Springvale Station as well as generic recommendations for soil erosion management across the property.	Draft	Updated
Desktop land condition analysis	This report presents a land condition assessment with relevant components that can be used for future non-grazing assessment of land condition.	Draft	Updated
Erosion Management Plan to guide 2017 actions	This report presents a costed no regrets action plan for 2017 to reduce sediment loss from priority gully complexes and sub catchments. It includes the identification and costs for data collection and the analysis required to support detailed site implementation plans.	Draft	Superseded
Erosion Management Plan to guide 2017 to 2022 actions	This report presents a costed five year action plan (2017-2022). It includes the identification and costs for data collection and the analysis required to increase the accuracy of the implementation plan for 2017-2022 through adaptive management processes.	N/A	Draft

The reports produced through the Springvale Erosion Management Plan Project will be complemented by a series of operational management plans to be developed by the Conservation and Biodiversity Operations section of the Queensland Department of Environment and Heritage Protection (EHP) throughout 2017 and 2018.

Cape York NRM was the project leader of the Springvale Erosion Management Plan Project. However, the Project Team consisted of professionals with experience in Traditional Owners knowledge, communication processes, catchment hydrology, geomorphology, soil erosion processes and rehabilitation strategies, grazing and native vegetation management, water quality monitoring and modelling, remote sensing and government processes. The team worked in collaboration across all aspects of the project. Major roles of the Project Team are defined in Table 2 .

Table 2 Major roles of Springvale Erosion Management Plan Project Team.

Name	Organisation	Major Role
Will Higham	Cape York NRM	Project manager. Oversight and facilitation of the project delivery process and project reports.
Lyndal Scobell	Cape York NRM	Communications / compiling project reports.
Andrew Brooks	Griffith University, Centre for Coastal Management	Lead erosion management plan (EMP) data and GIS analysis including costing of 5 year action plans.
John Spencer	Griffith University, Centre for Coastal Management	Support erosion management plan (EMP) data and GIS analysis including costing of 5 year action plan.
Jeff Shellberg	Private Consultant & Griffith University, Australian Rivers Institute	Lead the broad soil erosion assessment and support erosion management plan (EMP) data and GIS analysis including costing of 5 year action plan.
Joe Rolfe	DAF - Department of Agriculture and Fisheries	Lead the desktop land condition assessment. Support costing of the erosion management plan (EMP) 5 year action plans.
James Hill	Private Consultant	Support erosion management plan (EMP) data and GIS analysis including costing of 5 year action plan.
Jim Turnour	Yalanji Joint Venture	Develop a draft Cultural Heritage protocol for the desktop Cultural Heritage analysis to support project deliverables.
Brad Grogan	Yalanji Joint Venture	Desk top review of Cultural Heritage sites for the Cultural Heritage analysis to support project deliverables.
Dan Tindall / Rebecca Trevithick	DSITI – Department of Science Information Technology and Innovation	GIS analysis to inform the erosion management plan (EMP) as well as GIS analysis to inform the broad soil erosion assessment and the desktop land condition assessment.
Ryan Turner / Rowan Wallace	DSITI – Department of Science Information Technology and Innovation	Support the development of a conceptual monitoring and evaluation framework for erosion management plan (EMP) assessment.
Robbie Burns	EHP - Conservation Operations Unit, Conservation & Biodiversity Operations	Springvale Station property planning. Springvale Station property management and liaison, provision of EHP datasets/guidance; communications.
Matt Wallace	EHP - Conservation Operations Unit, Conservation & Biodiversity Operations	Springvale Station operations. Station management, site-visits, Cultural Heritage advice/protocols.
Jean Erbacher	EHP - Office of the Great Barrier Reef	Strategic advice. Sediment management, budget and investment, information and communications, issue resolution.
Lex Cogle	EHP - Office of the Great Barrier Reef	EHP Manager of the Springvale Erosion Management Plan Project. Key point of contact between Cape York NRM and EHP.

1.1 Springvale Station is a very important sediment source within the northern Great Barrier Reef

Catchment modelling, water quality monitoring and field assessments have identified Springvale Station as the single largest sediment producing property within the northern Great Barrier Reef (Brooks et al. 2013). Current modelling estimates suggest that the gullies on Springvale Station are responsible for ~ 40% of the gully erosion within the Normanby Basin (Figure 2). Springvale Station has been significantly degraded by erosion accelerated by historic land use activities (Brooks et al. 2013; Shellberg and Brooks 2013; Spencer et al. 2016; Brooks et al. 2016). Taking immediate action to significantly reduce sediment loss from Springvale Station is essential to improve both water quality and the resilience of the northern Great Barrier Reef to the impacts of climate change (Cape York NRM and SCYC, 2016).

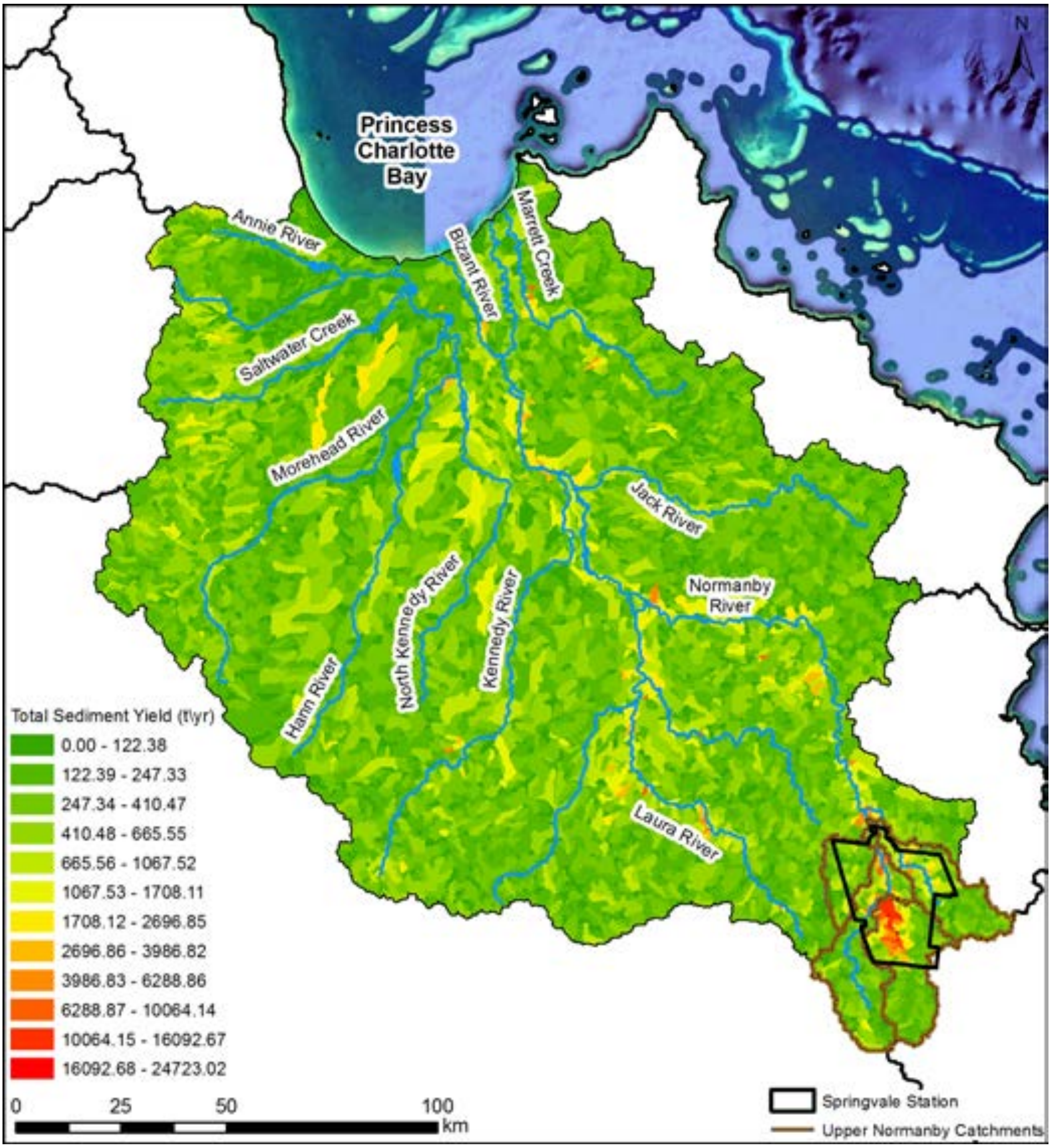

Figure 2 The location of Springvale Station within the Normanby Basin with modelled sediment yields at a sub-catchment scale (estimated from Brooks et al. 2013) (Source: Griffith University).

2 Desktop Cultural Heritage analysis

This report presents the desktop Cultural Heritage analysis component of the Springvale Erosion Management Plan Project. It details a draft protocol to manage Aboriginal Cultural Heritage on Springvale Station as part of the Erosion Management Plan (EMP). The protocol if followed should ensure the Department of Environment and Heritage Protection meets its duty of care to manage and protect Aboriginal Cultural Heritage on Springvale Station.

The report details that Springvale was an Aboriginal landscape part of a broader Kuku Yalanji nation of south eastern Cape York Peninsula. Most of the activities proposed as part of the EMP will cause soil disturbance and as such risk impacting Aboriginal Cultural Heritage. It is recommended therefore that a Cultural Heritage Management Plan is developed prior to implementing erosion management works to manage these risks.

The desktop Cultural Heritage analysis:

- was produced using a rapid assessment process that interpreted the best available information available to the project team
- presents a desktop review of Cultural Heritage sites and a draft Cultural Heritage protocol developed with Traditional Owners of Springvale Station
- does not present site specific information that is culturally sensitive
- does not provide Cultural Heritage clearance for any site specific on-ground works that are recommended in any of the reports produced through the Springvale Erosion Management Plan Project.

2.1 Introduction

Although Native Title has not been determined on Springvale Station it is widely acknowledged that it is part of the Kuku Yalanji Aboriginal estate of south eastern Cape York Peninsula (Buhrich, 2016; Anderson 1984). Prior to white settlement in the late 1880s Kuku Yalanji Bama (Aboriginal people) lived on what is now known as Springvale Station and there are story places and artifacts that need to be managed and protected as part of future planning for the property.

A Native Title claim was lodged in 2015 by the Cape York Land Council over Springvale Station as part of the Cape York United Number 1 Claim[1]. Yalanji Bama also have two Registered Native Title Body Corporates the Western Yalanji Aboriginal Corporation (WYAC) and Jabalbina Yalanji Aboriginal Corporation (Jabalbina) representing Traditional Owners who assert interests in Springvale Station. These organisations are both registered Cultural Heritage bodies under the Queensland Aboriginal Cultural Heritage Act 2003 and are points of contact for Cultural Heritage matters relating to Kuku Yalanji Bama.

These Cultural Heritage bodies have jointly undertaken this assessment and developed this protocol through their Yalanji Joint Venture (YJV). The desktop Cultural Heritage assessment was produced using a rapid assessment process that interpreted the best information readily available to the project team. This included a review of Aboriginal Cultural Heritage sites on the Queensland Government Register, a review of relevant reports, academic literature, legislation and a meeting of the project team representing the Cultural Heritage bodies and Department of Environment and Heritage Protection (EHP). Limited resources prevented a detailed field inspection of Springvale Station.

The desktop Cultural Heritage assessment established that Springvale Station is an Aboriginal Cultural Heritage landscape. It does not provide any site-specific information that is culturally sensitive or provide a Cultural Heritage clearance for any on-ground works that are recommended in reports produced through the Springvale Erosion Management Plan Project.

The Cultural Heritage protocol was developed to assist any person or organisations undertaking activities on Springvale Station under the guidance of the Erosion Management Plan to meet their duty of care to protect Aboriginal Cultural Heritage under Queensland and Australian Government legislation. It sets out a framework for the management and protection of Aboriginal Cultural Heritage and a procedure that must be followed to meet duty of care requirements under the Aboriginal Cultural Heritage Act 2003.

On-ground works where there is a risk of harm to Aboriginal Cultural Heritage will require a Cultural Heritage Management Plan to be developed or, at a minimum, Cultural Heritage site clearances to be undertaken by Traditional Owners. Ideally Cultural Heritage mapping would be undertaken to provide a broader understanding of the Cultural Heritage values across the entire property, reducing the risk of unknowingly damaging significant heritage values (Buhrich, 2016).

The protocol was developed following a review of the Aboriginal Cultural Heritage Act and Duty of Care Guidelines[2] and other protocols used by the Department of Environment and Heritage Protection for works in Cape York Peninsula and Jabalbina Yalanji Aboriginal Corporation's Policies and Procedures for Cultural Heritage clearances.

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[1] Cape York United Number 1 Claim was registered on the 6/2/2015 by the Federal Court of Australia. The contact for the Native Title Claim is the Cape York Land Council, Principal Legal Officer.

[2] The Aboriginal Cultural Heritage Guidelines are available online from the Queensland Government, Department of Aboriginal and Torres Strait Island Partnerships: http://www.datsip.qld.gov.au/people-communities/aboriginal-and-torres-strait-islander-cultural-heritage/the-cultural-heritage-duty-of-care

2.2 Desktop review of Springvale Station Aboriginal Cultural Heritage

The desktop review involved a rapid assessment including a review of the Department of Aboriginal and Torres Strait Island Partnerships Cultural Heritage Register, Cultural Heritage reports and academic and unpublished anthropological reports. Although limited resources prevented a detailed assessment of the property, it is clear from these reports and consultations with Cultural Heritage bodies that Springvale Station is part of a broader Kuku Yalanji clan estate and that there remains significant Aboriginal Cultural Heritage that needs to be managed and protected on the property.

2.2.1 Yalanji Bama Estate

Anthropology research records that Springvale Station is part of the broader Kuku Yalanji Aboriginal estate (Anderson 1984; Buhrich, 2016). Under Bama Lore (Aboriginal Law) the Kuku Yalanji estate is divided by mountain ranges and river catchments, each containing several to a dozen smaller clan estates. Yalanji people travelled extensively within and between these clan estates (Anderson, 1984; Wood, 2003).

From the late 1800s, Aboriginal people were forcibly removed from these clan estates but remain connected through their traditional lores and customs (Anderson, 1984). They are now re-asserting their rights and interest through Native Title and the Aboriginal Cultural Heritage Act 2003. Eastern Kuku Yalanji Traditional Owners achieved a Native Title consent determination in 2007 neighbouring Springvale Station and WYAC has an ILUA with small miners covering the western area of the station. Native Title has not been determined over Springvale Station and it forms part of the Cape York United 1 Claim. Yalanji Traditional Owners however, assert their Native Title interests through this registered claim and activities on Springvale Station may require future act notification if they affect Native Title rights (Native Title Act, 1993).

2.2.2 Cultural Heritage sites

The Queensland Government Aboriginal Cultural Heritage Act 2003 specifically protects Aboriginal Cultural Heritage. It defines Aboriginal Cultural Heritage as a significant Aboriginal area or object, or significant evidence of Aboriginal occupation of Queensland. It protects not only physical objects like scar trees and grave sites but areas where there may be no evidence of Aboriginal occupation. Story or ceremonial places important to Kuku Yalanji culture may for example include some mountains and water holes.

Springvale Station has been managed as a cattle property up until its purchase in May 2016 by the Queensland Government. There has therefore been limited work done to determine the extent of Cultural Heritage on the property. The Department of Aboriginal and Torres Strait Islander Partnerships Cultural Heritage Register has one recorded site on Springvale Station.

A short two-day survey on the West Normanby River however, undertaken in 2016 (because of planned mining activity) recorded eight sites including scar trees, artefacts and walking tracks (Buhrich, 2016). A half day field visit down Keetings Road completed as part of this project also identified signs of Aboriginal Cultural Heritage including scar trees.

These short field visits, anthropological reports and discussions with Traditional Owners confirm that Aboriginal people were actively living on what is now known as Springvale Station. Significant Aboriginal Cultural Heritage therefore remains on Springvale Station and it will be important to manage and protect. Particularly given the properties planned future as part of Queensland's protected area estate.

2.3 Draft Cultural Heritage protocol

This protocol will assist those undertaking erosion management activities on Springvale Station to meet the requirements of the Aboriginal Cultural Heritage Act 2003 (The Act). The Act establishes Aboriginal Cultural Heritage Guidelines which provide further information and definitions in relation to understanding Aboriginal Cultural Heritage duty of care[3]. If there is a risk of harming Cultural Heritage, this protocol should be read in conjunction with these guidelines.

2.3.1 Duty of care

The Aboriginal Cultural Heritage Act requires anyone who carries out a land-use activity to exercise a duty of care. Land users must take all reasonable and practicable measures to ensure their activity does not harm Aboriginal Cultural Heritage. The Act defines Aboriginal Cultural Heritage as anything that is:

- a significant Aboriginal area in Queensland; or
- a significant Aboriginal object; or
- evidence, of archaeological or historic significance, of Aboriginal occupation of an area of Queensland.

A significant Aboriginal area or object must be particularly significant to Aboriginal people because of either or both of the following:

- Aboriginal tradition;
- the history, including contemporary history, of any Aboriginal Party for the area.

In the same way, as non-Aboriginal heritage values are capable of protection, it is not necessary for an area to contain markings or other physical evidence indicating Aboriginal occupation or otherwise denoting the area's significance for the area to be protected as a significant Aboriginal area under the Act (DATSIP, 2004).

The Aboriginal Cultural Heritage Guidelines establish categories for assessing the risk of an activity harming Cultural Heritage. These include:

- activities involving no surface disturbance (Category 1)
- activities causing no additional surface disturbance (Category 2)
- developed areas (Category 3)
- areas previously subject to significant ground disturbance (Category 4)
- activities causing additional surface disturbance (Category 5).

The duty of care applies to any activity where Aboriginal Cultural Heritage is located. This includes Cultural Heritage located on freehold land and regardless of whether it has been identified or recorded in a database. The act requires engagement with Aboriginal parties if there is a risk that the activity may harm Aboriginal Cultural Heritage.

2.3.2 Springvale Station erosion management activities

The activities detailed in the Erosion Management Plan vary, from those which are likely to have little or no risk to Aboriginal Cultural Heritage (such as the destocking of pastures (Category 1) through to those that are likely to have a high risk of impacting Aboriginal Cultural Heritage (such as gully remediation (Category 5) or road repairs (Category 4)).

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[3] The Aboriginal Cultural Heritage Guidelines are available online from the Queensland Government, Department of Aboriginal and Torres Strait Island Partnerships: http://www.datsip.qld.gov.au/people-communities/aboriginal-and-torres-strait-islander-cultural-heritage/the-cultural-heritage-duty-of-care

Where there is a risk of harming Aboriginal Cultural Heritage, there is a need for either a Cultural Heritage Clearance or a Cultural Heritage Management Plan (CHMP) to be undertaken prior to an activity commencing.

2.3.3 Cultural Heritage Clearance or Cultural Heritage Management Plan (CHMP)

A Cultural Heritage Clearance is generally required for smaller scale works. Where a significant risk exists or a large amount of work is to be undertaken over an extended period, the development of a CHMP is a more practical and efficient way of managing Cultural Heritage risks. Aboriginal parties need to be consulted including Jabalbina, WYAC and the Cape York Land Council and Traditional Owners engaged to undertake planning and clearances.

2.3.3.1 Cultural Heritage Clearance

A Cultural Heritage Clearance involves a site inspection of the area where the activity is proposed with Traditional Owners to identify any Cultural Heritage likely to be impacted. A Cultural Heritage Clearance form will be completed during the inspection which identifies whether any objects or places of significance have been identified and how they should be managed (Appendix 1). Consultation is required with Aboriginal parties such as Cultural Heritage bodies including Jabalbina, WYAC and the Cape York Land Council to identify the appropriate Traditional Owners to be engaged to undertake the clearance.

2.3.3.2 Cultural Heritage Management Plan (CHMP)

Where a large amount of work is to be undertaken over an extended period a CHMP is a more effective way of managing risks of harming Aboriginal Cultural Heritage. The CHMP allows a survey to be undertake over the entire site and a plan developed to manage Aboriginal Cultural Heritage.

The desk top analysis has identified that Aboriginal Cultural Heritage does exist and is likely to be quite extensive on Springvale Station. Erosion management activities may involve earth works including gully remediation, road and track maintenance. These Category 4 and 5 activities within the Aboriginal Cultural Heritage Act Guidelines are likely to risk harming Aboriginal Cultural Heritage. A CHMP would ensure that the risks of damaging Cultural Heritage e.g. scar trees, walking trails or permanent water associated with old Aboriginal camps in the area can be managed effectively. It would also ensure that Aboriginal Cultural Heritage not obvious to non-Indigenous people is also protected as this would be identified during field surveys as part of the planning process.

A CHMP would therefore identify Aboriginal Cultural Heritage and any associated risks in undertaking the activity. It would then set out how the activity can be undertaken to effectively and efficiently manage these risks and protect Aboriginal Cultural Heritage.

Consulting with Aboriginal Parties such as Cultural Heritage bodies including Jabalbina, WYAC and the Cape York Land Council is important to identify the appropriate Traditional Owners to be involved in Cultural Heritage surveys and reaching agreements that ensure that activities can be undertaken. Provided activities are undertaken in line with the agreed CHMP then duty of care requirements under the Aboriginal Cultural Heritage Act 2003 would be achieved.

For further information in relation to this protocol contact:

The Yalanji Joint Venture
Phone: 07 4092 6712 or 07 4098 3552.
Email: admin@jabalbina.com.au or admin@westernyYalanjicorp.com

3 Broad soil erosion assessment

The Broad soil erosion assessment used the best available property-wide data sets to describe the spatial location of current erosion issues and provide general recommendations for property wide management of soil erosion to support future Springvale Station property management planning.

Surface geology was used as the base framework for identifying and describing current erosion issues. The geologic units are:

- Alluvium
- Colluvial Slopes
- Hodgkinson - Normanby Formation
- Basalt
- Granitic.

Current soil erosion issues within each geologic unit are described along with general recommendations for property wide management of soil erosion to be considered in future Springvale Station management planning.

The area of surface geologic units within the major sub- catchments is also described. The major sub-catchments within Springvale Station are:

- Granite Normanby
- West Normanby
- East Normanby
- Leichardt Creek.

Remote sensing analysis of ground cover and fire frequency and mapping of known roads, tracks and fencelines (linear disturbances), has been combined with previous property manager experience and expert analysis by the project team to describe three erosion management issues that should be addressed at a property wide scale through the future development of the Springvale Station operational plans:

- Cattle management
- Fire management
- Road and fence line management.

Key findings and general recommendations for property wide management are provided to support future Springvale Station management planning.

3.1 Major sub-catchments and geologic units of Springvale Station

Springvale Station is a 56,295 ha property located in the upper reaches of the Normanby River (Figure 3) where it is traversed by the three major upper tributaries of the Normanby system; the East, West and Granite Normanby Rivers. Respectively these three tributaries have catchment areas of 34,377, 46,456, and 40,996 hectares as measured at the downstream outlet of the property. A fourth and smaller tributary, Leichardt Creek (catchment area 16,925 ha) drains from the western edge of the property toward Lakeland, entering the lower reaches of the West Normanby River close to the downstream property boundary.

As a means of better understanding the key source areas of erosion on the property and to help the process of describing and prioritising the management of erosion sources on the property, the property has been broken up into a series of management units based on the major geologic units (Figure 4 and Table 3) coupled with the major sub-catchments (Figure 3).

The surface geology units were grouped into the following geologic units:

- Alluvium
- Colluvial Slopes
- Hodgkinson - Normanby Formation
- Basalt
- Granite.

While the property is currently divided into a series of paddocks, which have been used in the past to manage and describe the property, it is recommended that in future many of the fenced paddocks are decommissioned and these landscape/management units become the primary basis for both characterising and managing the property by land type (geology/soil/vegetation units). Management units henceforth will be described in terms of landscape unit identifiers, such as; the Granite Normanby alluvials, the West Normanby alluvials, the East Normanby colluvials, etc.

The following sequence of maps and graphs summarise the geo-landscape units that have been defined for this project. To enable the contributions from Springvale Station to be put in context with the contributions from the surrounding catchment, the data has been presented for:

- the whole upper catchment, as downstream as the northern boundary to the property (Figure 3; Figure 5)
- the area within the property boundaries (Figure 3; Figure 6)
- the area upstream of the property (Figure 7; Figure 8).

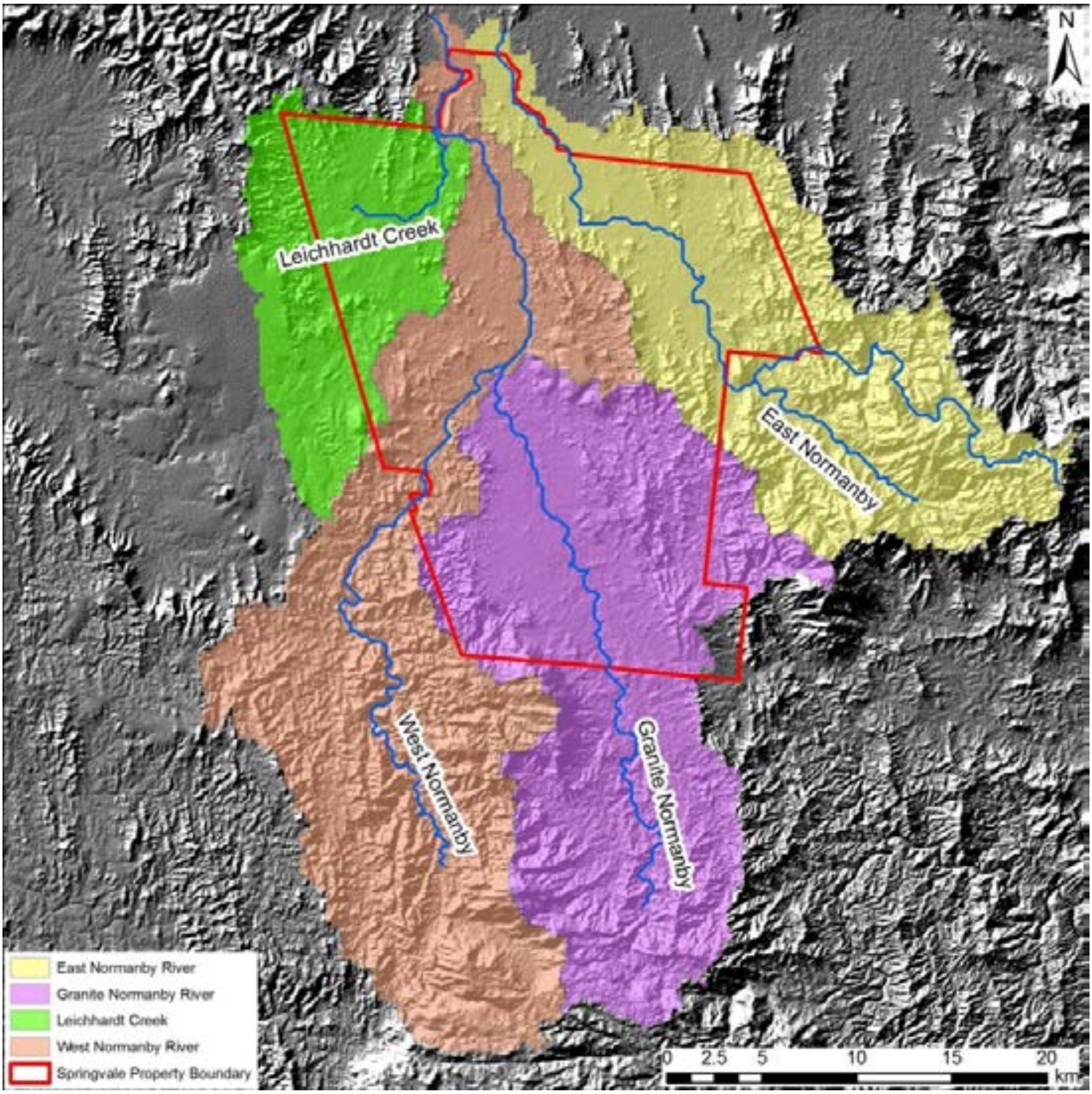


Figure 3 Springvale Station boundary showing the location of the property within the context of the major tributaries draining into the property (Source: Griffith University).

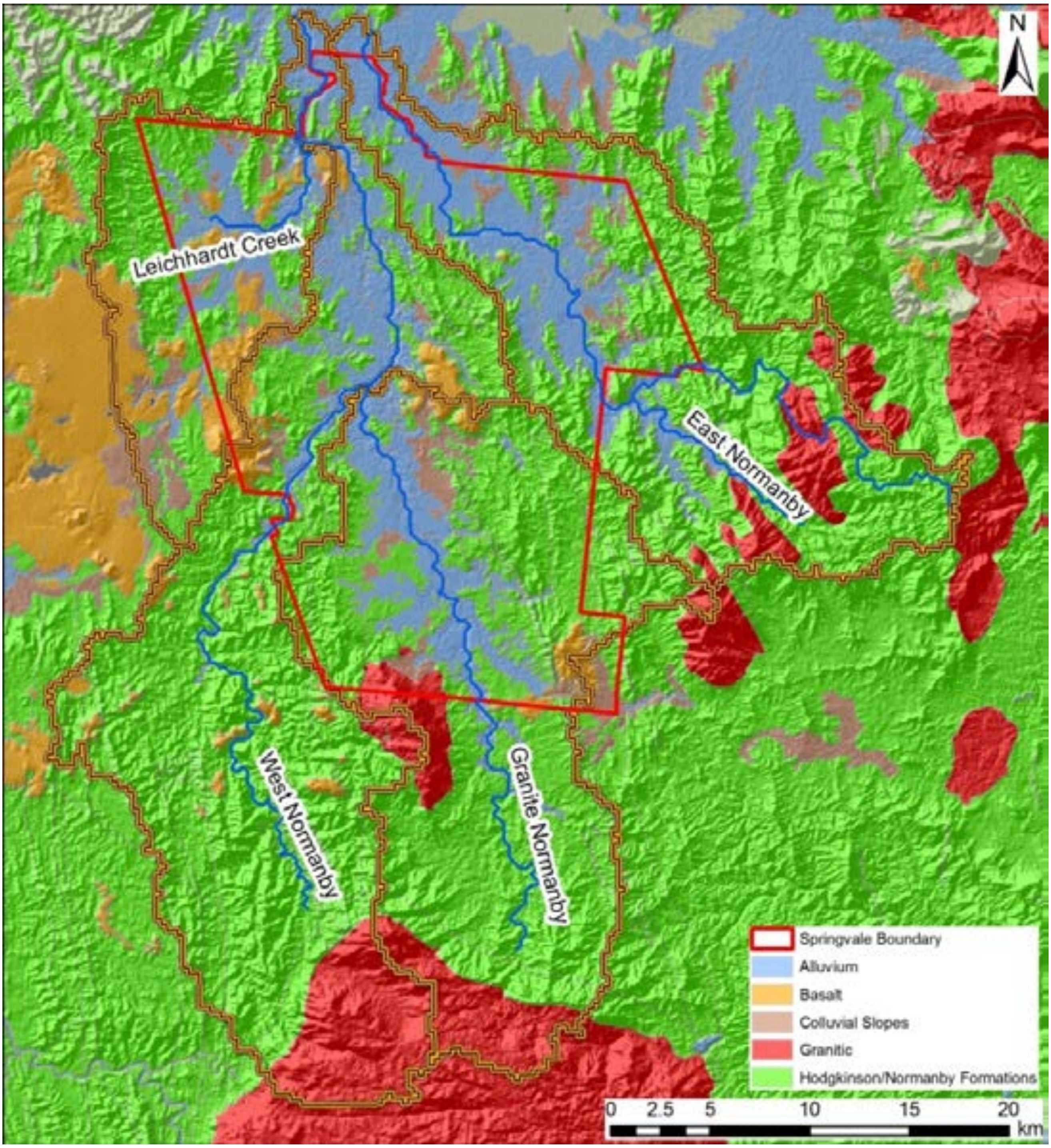


Figure 4 Major geological units that have been used for describing erosion management units within the upper Normanby catchment, showing the Springvale Station property boundary (Source: Griffith University).

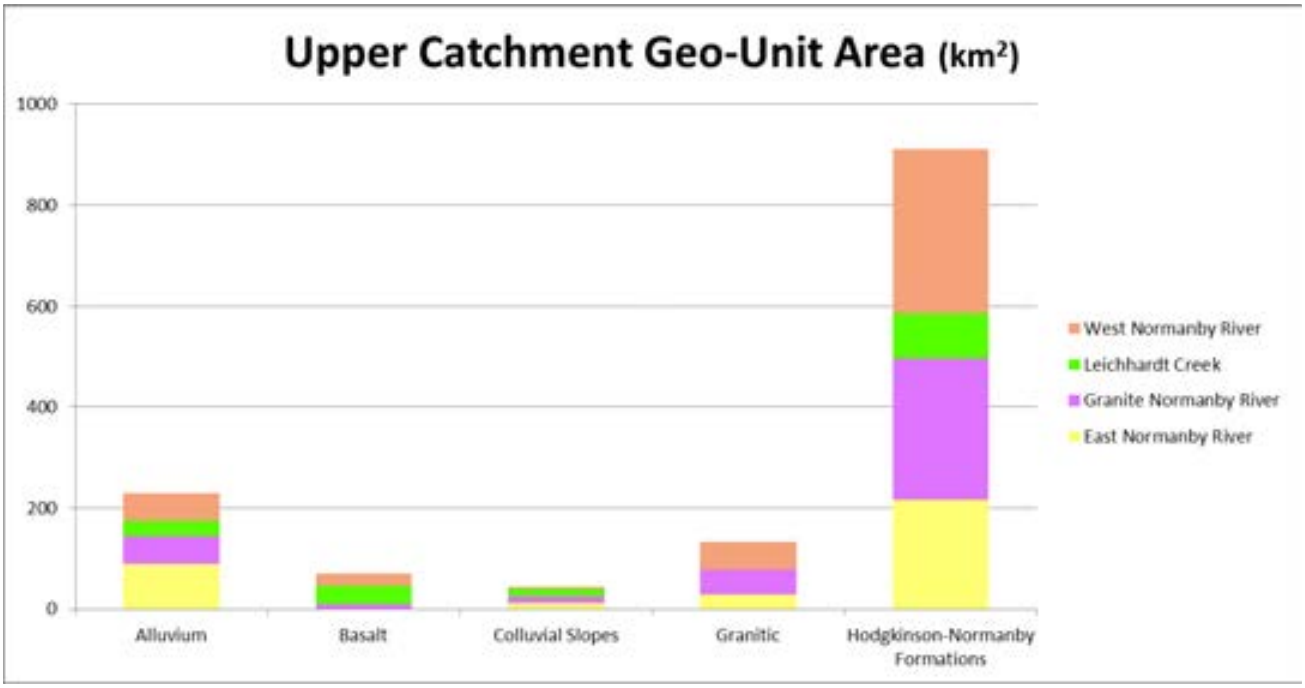


Figure 5 Graph for the total upper catchments that Springvale Station sits within showing the relative areas of the primary geological units used in this study derived from the 1:100K geological mapping (Source: Griffith University).

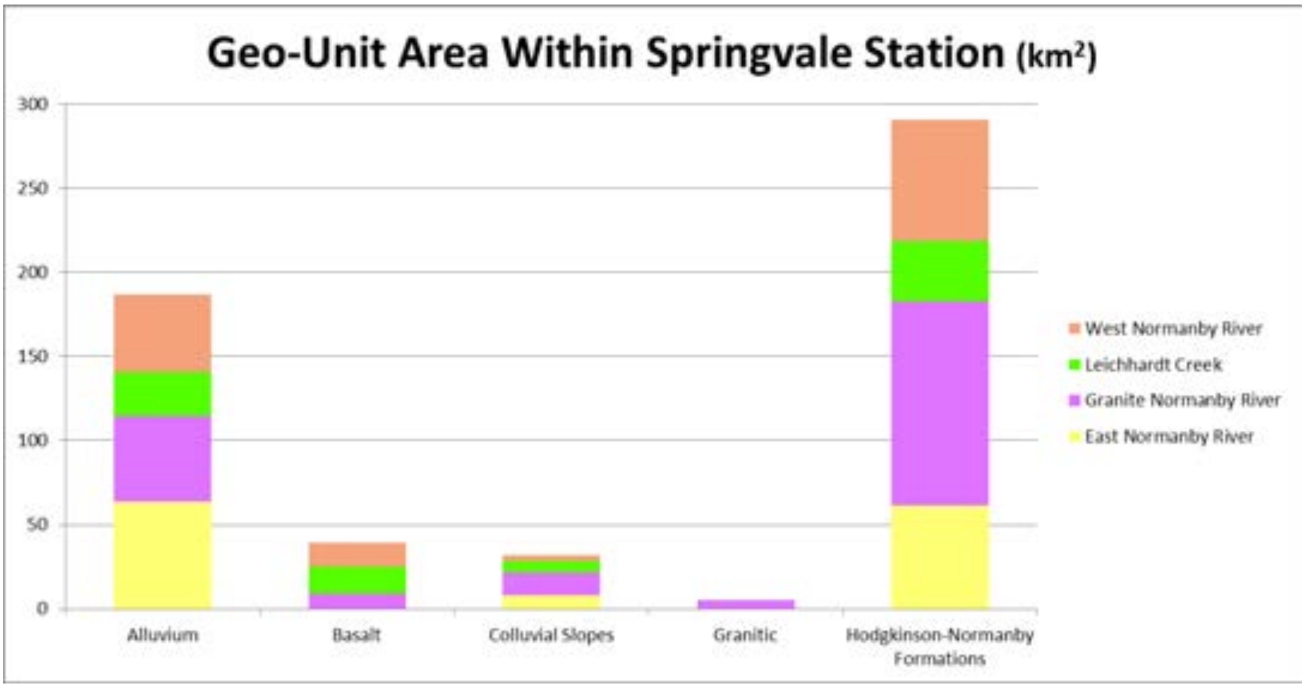


Figure 6 Total area of the major geological units on Springvale Station (i.e. sub-set of the plot above) showing their relative proportions in each of the 4 sub-catchments (Source: Griffith University).

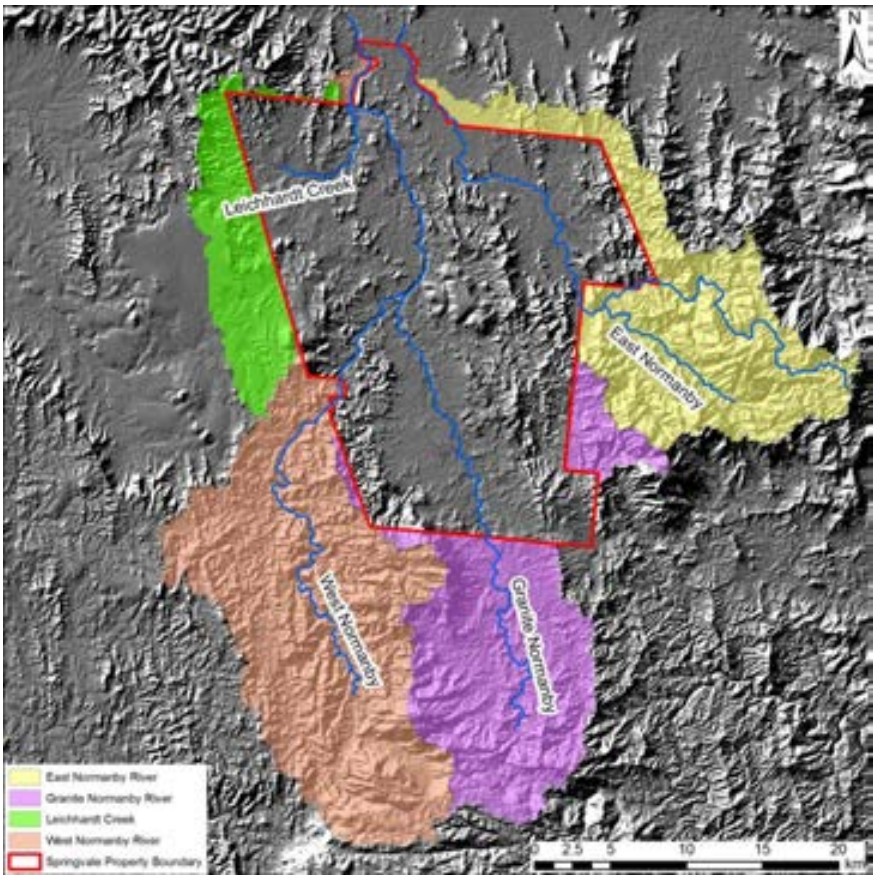


Figure 7 Portions of the 4 sub-catchments in the upper Normanby that are upstream of Springvale Station (Source: Griffith University).

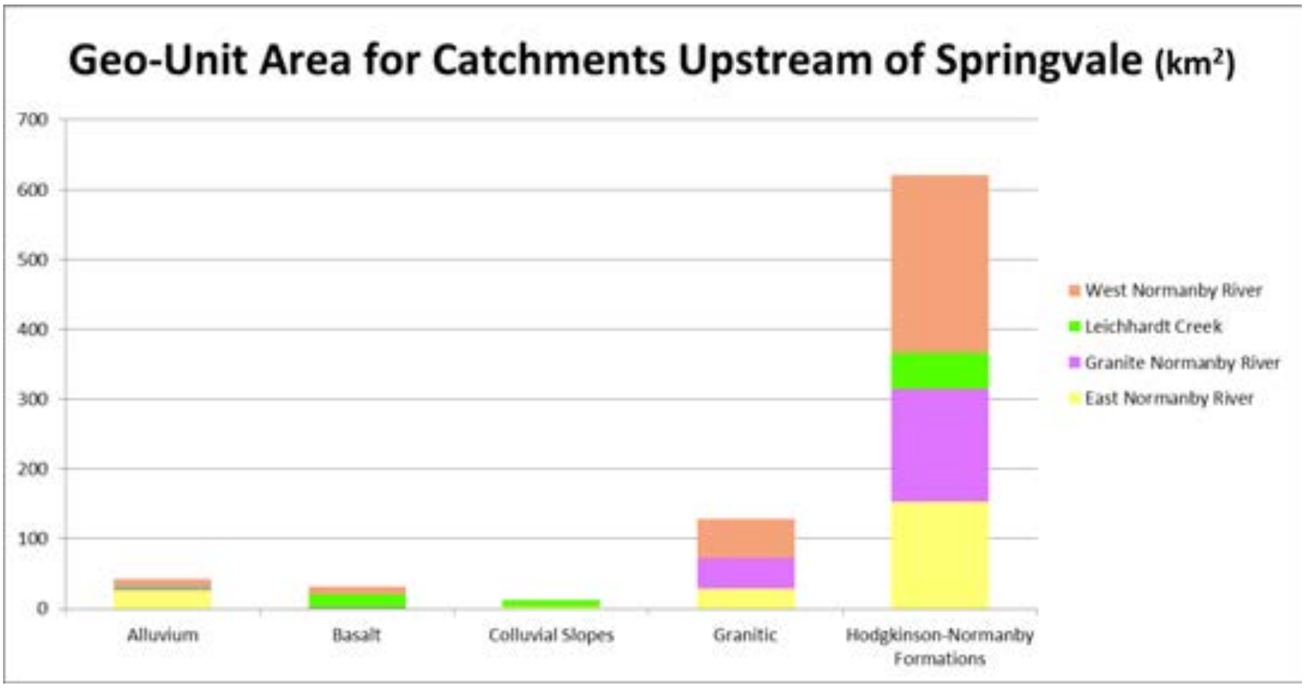


Figure 8 Areal extent of geological units in the sub-catchments upstream of Springvale Station (NB the relatively small areas of alluvium compared with inside the property boundary; highlighting the importance of the alluvial flats for grazing and erosion) (Source: Griffith University).

Table 3 Surface Geology of Springvale Station (State of Queensland 2017). Erosion hazard rating interpreted from Galloway et al. (1970), Biggs and Phillips (1995); AGSO (1995), Brooks et al. (2013); Shellberg and Brooks (2013) and State of Queensland (2017).

Geologic Unit	Geologic Formation	Unit Code	Description	Erosion Hazard
Alluvium	**Alluvium**	Qa	Floodplain Alluvium. Clay, silt, sand and gravel.	High
		Qat	Alluvial terrace above modern alluvium: partly dissected. Sand, silt, clay, minor gravel.	Very High
		Qpa	Flood-plain alluvium on high terraces. Clay, silt, sand and gravel.	Very High
		Qha	Active stream channels and low terraces. Sand, gravel, silt and clay.	High
		TQa	High-level alluvial deposits (generally related to present stream valleys but commonly dissected); Locally red-brown mottled, poorly consolidated sand, silt, clay, minor gravel.	High
Colluvial Slopes	**Colluvium**	Qr	Colluvial and residual deposits. Clay, silt, sand, gravel and soil.	Very High
		Qrt	Talus and steep colluvial slopes grading down to lower-gradient alluvial fans and outwash deposits. Gravel, sand and mud.	High
Hodgkinson-Normanby Formation	**Hodgkinson Formation**	Dh	Mainly pale to dark or greenish grey, fine to medium-grained, medium to thick-bedded, quartz-intermediate greywacke, rhythmically interbedded with siltstone and mudstone; minor conglomerate, conglomeratic greywacke.	Medium
		Dh/a	Pale to dark or greenish grey, fine to medium and locally coarse-grained, quartz intermediate greywacke, interbedded with minor siltstone and mudstone; minor conglomerate, conglomeratic greywacke.	Medium
		Dh/am	Rhythmically interbedded fine to medium-grained arenite and mudstone (locally phyllitic); minor conglomerate, minor chert and metabasalt; rare limestone.	Medium
		Dh/b	Dark greenish grey, fine-grained metabasalt; minor flow-margin breccia.	Low
		Dh/c	Pale grey to cream, thin-bedded to massive chert with minor interbedded mudstone.	Low
		Dh/cg	Dark grey, thick-bedded pebble to boulder conglomerate, conglomeratic greywacke.	Low
		Dh/l	Pale to dark grey, variably recrystallised, bioclastic limestone.	Low
		Dh/m	Mainly dark grey, thin bedded, mudstone, subordinate thin to thick bedded arenite beds, minor chert and basalt.	Medium
	Normanby Formation	Pno/a	Rhyolitic, andesitic, and basaltic lava flows, tuff, ignimbrite and other fragmental pyroclastic deposits.	Low
		Pno/b?	Andesitic and basaltic lava flows and tuffs; locally strongly foliated.	Low
		Pno/s	Thin to very thick bedded, fine to coarse-grained tuffaceous sediments.	Low
Basalt	**McLean Basalt**	Tm	Vesicular, amygdaloidal and massive analcite, nepheline and olivine-bearing basalt lava flows locally with lherzolite inclusions, minor coarse pyroclastic (vent and near-vent deposits).	Medium
		Tm/v	Fine to coarse pyroclastic deposits, some interbedded mafic lava.	Low
Granitic	**Mount Pike Granite**	Pgwp	White to pale grey, fine to coarse-grained biotite adamellite; enclaves common.	Low to Medium

Table 4 Land Systems of Springvale Station (Galloway et al. 1970). Erosion hazard rating interpreted from Galloway et al. (1970), Biggs and Phillips (1995); AGSO (1995), Brooks et al. (2013); Shellberg and Brooks (2013) and State of Queensland (2017).

Land System	Unit Code	Description	Erosion Hazard
Ninda (Alluvium and Colluvium)	**N**	Colluvial and alluvial aprons and fans; texture-contrast soils; mostly paperbark woodland but very variable.	High
		30% = Alluvial fans; slopes 0.5-3%; generally sand or fine-textured material; micro-relief of levees, channels, and back plains; partially subject to flooding.	
		30% = Colluvial aprons: slopes 1-5%: stony in upper parts; some gullying and sheet erosion.	
		20% = Dissected older colluvial aprons, slopes probably 2-10%; gullying and sheet erosion; probably fairly deeply weathered.	
		20% Colluvial aprons and plains slopes 0.5-5% mainly stony clay.	
Hodgkinson (Meta-sediments)	**H**	Undulating to hilly country on greywacke and other sediments; shallow gravelly soils; ironbark woodland.	Medium
		10% sporadic = Closely dissected hills and strike ridges; local relief 100--500 ft; slopes mostly 15-60%; much outcrop; active gullying and stream erosion.	
		45% throughout = Crests and upper slopes; local relief 40-100 ft; slopes mainly 3-10%; stony in places.	
		35% throughout = Lower slopes, local relief 0-50 ft; slopes 0-5%; rarely stony but some gullying and sheet erosion.	
		< 5% throughout = Narrow alluvial flats and terraces; possibly subject to flooding.	
Maytown (Meta-sediments)	**Ma**	Closely dissected low hills on volcanics, greywackes, and other sediments; shallow gravelly uniform medium to fine-textured soils; ironbark woodland, some box woodland.	Medium
		75% = Closely dissected hills: local relief 100-500 ft; slope mostly 15-60%; much outcrop; active gullying and stream erosion.	
		20% = Colluvial foot slopes; stony upper parts with slopes 10-20 %; sandy and loamy lower parts with slopes 1-15%; few outcrops; gullying and sheet erosion common.	
Starke (Granite and Meta-sediments)	**S**	Mountains on volcanics, granite, greywackes, and other sediments; deeply dissected plateaux on quartz sandstone; shallow rocky soils; ironbark or mixed eucalypt woodland.	Medium
		40% = Mountains on granite and volcanics; 2000--4000 ft above sea level; extremely rocky with extensive outcrops; narrow valleys with little or no alluvium.	
		25% = Dissected mountains on folded sediments and metamorphics; local relief 100-2000 ft; restricted colluvial foot slopes, stony in upper part, subject to gullying and sheet erosion.	
Lukin (Basalt)	**L**	Plains and low stony plateaux on basalt; structured red soils; box woodland, some bloodwood, ground cover of kangaroo grass and black spear grass.	Low to Medium
		50% = Gently undulating plains with few outcrops on weathered basalt.	
		35% = Stony undulating plains and plateau tops; bouldery outcrops common.	
		5% = Colluvial foot slopes; upper parts stony with slopes 25-50%; lower parts mainly clay with slopes 0-5 %; some gullying.	
		10% = Alluvial flats; probably mainly clay.	

Table 5 Soils of Springvale Station (Biggs and Phillips 1995; AGSO 1995). Erosion hazard rating interpreted from Galloway et al. (1970), Biggs and Phillips (1995); AGSO (1995), Brooks et al. (2013); Shellberg and Brooks (2013) and State of Queensland (2017).

Soil Type	Unit Code	Description	Geology	Landform	Erosion Hazard	Erosion Type
Greenant	**Ga**	Deep duplex sodic acid to alkaline yellow soils formed on alluvial plains.	Alluvium	Alluvial plains	Very High; Unstable	Severe Gully, Rill, Sheet
Gibson	**Gs**	Deep Duplex sodic yellow or grey soils on colluvia and pediments from greywacke and slate.	Colluvium Alluvium	Footslopes	Very High, Unstable	Gully, Rill, Sheet
Kingjack	**Kj**	Moderately deep gradational non-sodic yellow soils on colluvia and pediments from greywacke and slate.	Colluvium Alluvium	Footslopes	High, Unstable	Rill, Sheet, Gully
Jeannie	**Jn**	Moderately deep gradational or uniform yellow soils formed on greywacke and slate.	Hodgkinson (Meta-sediments)	Hillslopes, Hillcrests	Medium, Semi-Stable	Rill, Sheet, Gully
Endeavour	**Ed**	Deep Gradational or occasionally Uniform red structured soil formed on basalt.	Basalt	Hillslopes, Footslopes	Low to Medium Stable	Sheet, Gully
Burn	**Br**	Deep Uniform red structured clay soils with nodules formed on basalt. Friable non-cracking clay or clay loam soils - Dermosols, Ferrosols.	Basalt	Hillslopes, Footslopes	Low to Medium Stable	Sheet, Gully
Quarantine	**Qt**	Moderately deep duplex sodic neutral to alkaline soils on lower slopes and fans derived from acid plutonic rocks.	Granite	Footslopes	Medium Semi-Stable	Rill, Sheet, Gully
Altanmouie	**Am**	Moderately deep Uniformly brown coarse sands formed on hillslopes of granite boulder formations. Deep sandy soils - Tenosols, Rudosols.	Granite	Hillslopes	Low to Medium Stable	Rill, Sheet

3.2 Erosion hazards by geologic unit

3.2.1 Erosion within basalt unit

The McLean Basalt geology on Springvale Station is dominated by basalt lava flows with local pyroclastic deposits (Table 3). This geology creates unique landforms typically dominated by low plateaus with undulating topography and stony soils, outcrops and colluvial footslopes at plateau and escarpment edges where rilling and gullying can be common, and undulating plains of colluvial/alluvial flats with soils derived from the plateaus and escarpments (Table 4; Galloway et al. 1970). The soils derived from the basalt typically have gradational or uniform profiles of red structured soils of non-cracking clay or clay loam, which are often friable with frequent stones and boulders (Dermosols or Ferrosols) (Table 5; Biggs and Phillips 1995; AGSO 1995).

Erosion into the basalt formation and soils can take several forms. While basalt rock and soil is very porous, overland sheet flows can still occur during heavy rainstorms (infiltration excess runoff) and lead to sheet erosion. Sheet erosion is most common toward the edges of basalt plateaus where the slope and rocky nature of the soil profile increases (Figure 9), or where soils are disturbed and compacted by machinery. The steep edges of basalt plateaus lead to the formation of rill, gully and creek channels (Figure 10). These slope inflection points are often where spring water emerges after infiltrating through the basalt plateau. Channel erosion can be enhanced at these spring areas where both surface and subsurface water meet (Figure 10).

Accelerated gullying into basalt soils can be found near plateau edges where human land use disturbance cuts into soil profiles and colluvium. Roads and fence-lines cut into the soil lead to concentrated erosion, and can cause rill and deep gully erosion (Figure 11; Figure 12; Figure 13). Cattle pads cut into basalt soils also can lead to concentrated flow and rill erosion (Figure 9; Figure 13). Soil erosion on alluvial flats with semi-structured clay or loam soils can be enhanced by tree clearing disturbance, soil tillage, and farming (Figure 14). Erosion on these flats is mostly concentrated along small ephemeral drainage lines, which can be incised from gully erosion enhanced by reduced vegetation cover and enhanced water runoff (Figure 14). Gullying can be especially pronounced at the edges of flats where slope increases (Figure 13; Figure 14; Figure 15). Springs are common within the basalt geology, and create many wetlands, boggy hollows and channel-less valleys, and perennial reaches of creek (hence 'Springvale'). Cattle are attracted to the wet spring areas, and can consume large amounts of grass and trample banks and spring heads. This disturbance can promote bank erosion and channel incision, leading to gullying of these wet areas (Figure 16). In time, spring water can be reduced as gullying drains local wetland areas.

The clay and organic rich soils derived from the McLean Basalt generally have high nutrient (Nitrogen, Phosphorus) concentrations and organic matter, compared to other soil types on Springvale Station. For example, bulk soil analysis of basalt soils at Lakeland have nitrate-N that range from 3 to 89 mg/kg, average 26 mg/kg, and Phosphate-P (Colwell) that range from 8 to 120 mg/kg, average 36 mg/kg (n= 7 samples; Lakeland farmers historic data). One sample on alluvial basalt soils (not in situ) at Springvale Station had nitrate-N of 3 mg/kg and Phosphate-P (Colwell) of 73 mg/kg. These data suggest that basalt soils can have 7x times more nitrate than sodic alluvial soils on average, and 6x times more phosphate than sodic alluvial soils on average at Springvale Station (Garzon-Garcia et al. 2016) (see section below on erosion within alluvium unit). However these data are very site dependent, and difference can range from 0 to >14 times. Overall soil and gully erosion rates in Basalt soils are much less than other soil types such as sodic duplex soils (AGSO 1995; Brooks et al. 2013), and basalt only covers ~7% (4022 ha) of Springvale Station. However, concentrated rilling and gullying into basalt soils can be significant sources of nutrient and sediment pollution. Therefore, gully erosion and resultant nutrient loss from basalt soils disturbed by human land use could be targeted with various measures to reduce these concentrated sources of pollution that affect downstream river and reef ecosystems.

Figure 9 Basalt plateaus on Springvale Station (Plum Creek headwaters) (Source: Jeff Shellberg).

Figure 10 Gully and creek channels draining basalt plateaus on Springvale Station (Plum Creek headwaters) (Source: Jeff Shellberg).

Figure 11 Colluvial gully erosion into basalt on the edge of a plateau, accelerated by road use, machine disturbance, and excess water runoff on Springvale Station (Source: Jeff Shellberg).

Figure 12 Road erosion into basalt on Springvale Station (Source: Jeff Shellberg).

Figure 13 Colluvial gully erosion into basalt, accelerated cattle pad, grazing and road disturbance on Springvale Station (Source: Jeff Shellberg).

Figure 14 Colluvial gully erosion into basalt soils cleared and tilled for improved pasture on Springvale Station (Source: Jeff Shellberg).

Figure 15 Colluvial gully erosion into basalt on Springvale Station, accelerated by land use disturbance (Source: Jeff Shellberg).

Figure 16 Gully erosion into a spring fed basalt tributary on Springvale Station, accelerated by land use disturbance (Source: Jeff Shellberg).

3.2.2 Erosion within Hodgkinson – Normanby Formation unit

3.2.2.1 Normanby Formation

There is a lack of site specific and field erosion information about the Normanby Formation on Springvale Station. These Permian igneous (volcanic) rocks are younger than the Devonian Hodgkinson Formation, but are embedded and folded within the Hodgkinson (Table 3). The area of Normanby Formation on Springvale Station is relatively small (1126 ha). Due to limited information on the erosion characteristics of Normanby Formation, we have grouped it with the Hodgkinson Formation landscape unit for mapping and calculation purposes. However, the igneous (volcanic) nature of the andesite, basalt, and tuff sediment within the Normanby Formation would make it generally less erodible than the Hodgkinson Formation (Table 3).

3.2.2.2 Hodgkinson Formation

The geology of the Hodgkinson Formation on Springvale Station is a complex suite of meta-sedimentary rock units altered by generally low grade metamorphism (heat and pressure). The Hodgkinson Formation covers 50% (28,103 ha) of Springvale Station (56,295 ha). Eight (8) separate units of the Hodgkinson Formation have been described on Springvale Station (Table 3). Sedimentary units include siltstone; mudstone; greywacke (marine clayey sandstone), arenite (quartz sandstone), conglomerate, chert, breccia, metabasalt, and limestone. Three units dominate on Springvale Station, with interbedded sandstones and mudstones to the west (Dh/am) and mudstone arenite, and greywacke to the east (Dh/m, Dh/a) (Table 3). This geology creates a distinct landscape of rolling hills and sharp ridge crests that are dissected by narrow deep valleys. The footslopes of these hills contains sedimentary outwash material deposited along colluvial footslopes, narrow alluvial flats and terraces, and wider colluvial and alluvial plains (Table 4; Galloway et al. 1970). The soils derived from the Hodgkinson Formation are mixed with shallow yellow rocky Kandosol and Dermosol soils on hillslopes (Jeannie), with yellow Dermosols (Kingjack) and yellow Sodosols (Gibson) on colluvial flootslopes and alluvial outwash plains respectively (Table 5; Biggs and Phillips 1995; AGSO 1995). Further downslope, the yellow Dermosols and Sodosols grade into deep duplex sodic soils formed on alluvial plains (Greenant).

The landscape of the Hodgkinson Formation is inherently unstable, with some soil units more unstable than others (AGSO 1995). Most of this instability is associated with the colluvial and alluvial deposits at the footslopes of steep hills that are dissected by a dense network of small streams that have cut into the bedrock landscape. Colluvium and Alluvium geologic units will be addressed separately and more specifically below. Improved mapping of bedrock/colluvial/alluvial boundaries will be essential to differentiate land zones for management purposes.

Erosion on the hillslopes of the Hodgkinson Formation is dominated by sheet erosion and some rilling (Figure 17). Hillslope erosion rates were measured at several adjacent sediment traps in the Hodgkinson Formation in greywacke units on neighboring Kings Plains Station and found to be very low under moderate grazing pressure (0.01 – 0.03 t/ha/yr; Brooks et al. 2014). Erosion rates in more erodible siltstone and mudstone units of the Hodgkinson Formation have not been measured, and could be higher than reported above, as could different slope positions and forms (planar, concave, convex). Overall, the rocky skeletal nature of soils on these Hodgkinson hillslopes and their tendency to form surface stone lags act as a semi-effective non-vegetative cover (Figure 17). Natural vegetation cover from kangaroo grass and Eucalyptus woodlands are still important mediators in enhancing slope and soil stability (Figure 17). Wildfires are common in the remote parts of the Hodgkinson Formation and can disrupt the balance of slope and vegetation cohesion, as can cattle grazing. While most slopes are semi-stable with pockets of colluvial erosion in hollows (Figure 18a), other slopes have been stripped of soil down to sub-soils, lags of gravel, and bedrock due to excessive grazing pressure (Figure 18b).

The Hodgkinson Formation is a very dissected landscape with many thousands of small stream channels of the dendritic drainage network, narrow bedrock valleys, and colluvial and alluvial hollows. Small channel bed and bank erosion rates have not been measured within the Hodgkinson

Formation for sediment budget modelling, except where detected in some places with repeat LiDAR surveys. Most of these small channels are not mapped in Australian Hydrologic Geospatial Fabric (AHGF) from the 9 second DEM used in the sediment budget model (Brooks et al. 2013), and many are still missing from 1:50,000 or 1:25,000 topographic maps. Some stream channels are semi-stable with coarse beds of slate and sandstone, while others are more vertically unstable on mud and siltstones with lags of mixed quartz and sandstone gravel (Figure 19). Much of the observed sediment output from the Hodgkinson Formation could come from the small channel and gully systems rather than the low erosion rates estimated from sheet erosion on hillslopes (Brooks et al. 2014).

Colluvial gully erosion within the thousands of narrow bedrock valleys within the Hodgkinson Formation is common, along with associated sheet and rill erosion (Figure 20; Figure 21). This incisional erosion into previously intact colluvial hollows can be both a natural process and once accelerated by land use (grazing, fire, loss of vegetation cover, excess water runoff, roads, fences). Roads and fence-lines cut by machinery and ongoing use has destabilized many soil profiles, delivered fine sediment (mudstone, siltstone products) to local creeks, and promoted channel incision, gullying, and local bank erosion in small creek channels (Figure 22; Figure 23; Figure 24). Cattle pads cut into hillslopes has also promoted rilling and gullying (Figure 21).

In remote areas of Springvale Station, the mudstones, siltstones, sandstones of the Hodgkinson Formation are the only bedrock around and available for use in erosion control projects on roads, fence-lines, and gullies. This material, especially mudstones and siltstones of the Granite Normanby, produce a large amount of fine sediment on excavation, working and use along a road. Washing of matrix fine sediment from framework gravels by rainfall and overland flow is often the result (Figure 25; Shellberg and Brooks 2013). The use of this Hodgkinson Formation material needs to be assessed on a case-by-case basis to avoid collateral damage and unintended consequences. Where clean rock is required for road base or gully stabilisation, the use of a screening plant at a suitable quarry site could provide a cleaner local resource. In other situations where wash of matrix fine sediment from framework gravels is tolerable, this material could be used for slope stabilization where the fine grained matrix can support plant growth below the residual stone lag. In areas where arenite (quartz sandstone) from the Hodgkinson Formation has been used to cap battered gully slopes, the slopes have stayed intact and modestly vegetated despite ongoing sheet erosion (Figure 26). Siltstone and mudstone may perform differently.

Figure 17 Dissected hillslopes and narrow valleys within the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 18 Semi-stable and unstable hillslopes in the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 19 Semi-stable and unstable headwater stream channels in the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 20 Colluvial gully erosion into hillslope hollows (colluvium) within the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 21 Sheet, rill, and colluvial gully erosion within the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 22 Road erosion (sheet, rill and gully) in the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 23 Fence-line, rill and gully erosion at road and cattle pad crossings of creeks in the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 24 Fence-line rill and gully erosion from tree clearing (chaining) on the fence in the Hodgkinson Formation on Springvale Station (Source: Jeff Shellberg).

Figure 25 Meta-sedimentary rock (mudstone, siltstone, sandstone) from the Hodgkinson Formation is the only rock source locally available in remote areas for road erosion control, but most often contains high levels of fine matrix material that rock fragments are embedded within (Source: Jeff Shellberg).

Figure 26 Example of a battered road cut (left, old West Normanby bridge approach) that was capped with arenite (quartz sandstone from the Hodgkinson Formation) around 10 years ago. The slope has modestly revegetated with weeds and clear water emerges from this slope compared with the sediment laden water derived from the untreated bank on the opposite side of the road (right) (Source: Jeff Shellberg (left) John Spencer (right)).

3.2.3 Erosion within granitic unit

The Mount Pike Granite geology on Springvale Station is dominated by grey biotite adamellite (quartz monzonite), which is an intrusive, felsic, igneous rock (Table 3). It makes up < 1% (460 ha) of the surface geology of Springvale Station, but contains the highest elevation areas of Springvale Station, from 400 up to 700 m above sea level. This geology creates unique landforms dominated by steep mountain peaks, large granite boulders field and outcrops, and extensive outwash plains of colluvium and alluvium (Figure 28; Figure 30; Table 4; Galloway et al. 1970). The soils derived from the granite are typically very shallow, sandy and rocky on immediate granite hillslopes. Colluvial and alluvial footslopes derived from granite can vary from deep duplex sodic neutral to alkaline soils to brown coarse sands (Table 5; Biggs and Phillips 1995; AGSO 1995). The plagioclase feldspars in the granite can be sodic in composition, and have contributed to the high levels of exchangeable sodium in colluvial and alluvial soils of the Granite Normandy River valley. Sodium from the marine sedimentary rocks of the Hodgkinson Formation also contribute to these sodic alluvial soils.

Erosion within the granite outcrops is difficult to detect as it is disguised within deep boulder crevasses and longer term weathering of saprolite. However, several examples exist on Springvale Station granite where shallow landslides and rapid debris flows have occurred on steep slopes in confined and unconfined locations during heavy rainfall events (Figure 29). It is presumed these are natural events where a geomorphic threshold was crossed.

Most erosion associated with the granite appears to be along the colluvial and alluvial footslopes and outwash plains of the granite mountains. On these footslopes, the sodic duplex soils derived from granite are highly prone to sheet, rill and especially gully erosion. Excess water runoff from the impervious granite can prove the energy for erosion, while reduced vegetation cover and cattle disturbance on granite derived soils can destabilise outwash material that has been building up at footslopes for tens of thousands of years. Most often the gully erosion is concentrated into linear colluvial deposits along drainage channels, but also can form into larger gully complexes of a mixture of colluvium and alluvium (Figure 30).

Colluvial soil and gully erosion will be addressed specifically below, and improved mapping of bedrock/colluvial/alluvial boundaries will be essential to differentiate land zones for management purposes.

Figure 27 Granite outcrops and boulders on Mt Pike Formation on Springvale Station (Source: Jeff Shellberg).

Figure 28 Granite outcrops and boulders on Mt Pike Formation on Springvale Station. Note outwash plain on footslope below (Source: Jeff Shellberg).

Figure 29 Landslide debris flows on steep slopes of Mt Pike Granite Formation on Springvale Station (left -15.966751; 144.987256; right -15.970356; 144.977313) (Source: Jeff Shellberg).

Figure 30 Colluvial footslope outwash plain below Granite outcrops on Springvale Station (Source: Jeff Shellberg).

3.2.4 Erosion within colluvial slopes unit

The colluvial slopes geologic unit on Springvale Station is poorly mapped due to scale issues, the size of individual pockets or hollows of colluvium, and the intermixing of colluvium and alluvium on outwash plains, narrow creek valleys, and river floodplains and terraces (Table 3). The surface geology layer suggests there is 3,428 ha of colluvium, but in reality this area could be >10,000 ha. Colluvium can be defined as poorly sorted and unconsolidated sediments deposited along footslopes and outwash plains by rainfall transport downslope, sheet flow erosion, downslope creep via gravity, or a combination. Gravity is an important component. Colluvium can be differentiated from alluvium from the size of coarser clasts, heterogeneous range of clasts from silt to gravel, cobble and boulder, angularity of fragments indicating minimal fluvial transport and reworking, lack of imbrication of gravels, and absence of distinct layering.

Colluvium on Springvale Station is most often found along the footslopes of bedrock hillslopes consisting of Basalt, Granite, and Meta-Sedimentary rock (Hodgkinson Formation). Colluvium often spreads onto steeper alluvial fans and outwash plains, where slopes are in the range of 0.5% on shallower plains to 10% at the base of flootslopes (Table 4; Galloway et al. 1970). Colluvial soils can be quite mixed in nature depending on their bedrock origin and distance from source areas. Colluvium pockets (hollows), on Hodgkinson Formation hillslopes, consist of shallow yellow rocky soils (Jeannie) (Kandosols and Dermosols), while colluvial flootslopes consist of yellow Dermosols (Kingjack), and alluvial outwash plains consist of yellow Sodosols (Gibson) (Table 5; Biggs and Phillips 1995; AGSO 1995). Further downslope, the yellow Dermosols and Sodosols of colluvium grade into deep duplex sodic soils formed on alluvial plains (Greenant). Colluvial soils derived from Granite can vary from deep duplex sodic neutral to alkaline soils to brown coarse sands (Table 5; Biggs and Phillips 1995; AGSO 1995). Colluvium, associated with Basalt soils on Springvale Station, has not been well described nor mapped.

Both the Granite and Meta-Sedimentary marine rock are sources of sodium ions during rock weathering. Both parent geologies have contributed to the high levels of exchangeable sodium ions in colluvial and alluvial soils of the Granite Normandy River valley, leading to duplex soils with highly dispersible and erodible sub-soils.

Sheet, rill, and gully erosion into colluvium geology and derived soils are common across Springvale Station. The thousands of narrow bedrock valleys within the Hodgkinson Formation often contains some form of sheet, rill, and gully erosion into colluvium, some of which is natural and some accelerated by land use (Figure 20; Figure 21). Gully erosion is most pronounced in colluvial hollows and narrow ephemeral creek valleys, within deposits derived from the meta-sediments (Figure 31), basalt (Figure 10; Figure 11; Figure 13 to Figure 16), and granite (Figure 30). However, the largest types of colluvial gully erosion is contained within the outwash plains (Figure 32; Figure 33). These colluvial footslopes and outwash plains often then blend into downstream alluvial plains, where gully erosion and incision has worked upstream from the channel network below.

Erosion on colluvium can be natural and accelerated by human land use. AGSO (1995) suggested "*footslopes erosion would under natural circumstances be balanced to an extent by aggradation with material derived from the above hillslopes*". However, this assumes the landscape is in equilibrium over long periods of time, when in reality the landscape has been in an incisional stage for thousands of years. Disturbance by land use (grazing, fire, loss of vegetation cover, excess water runoff, roads, fences) has accelerated this incisional potential on colluvial slopes and soils. Gully erosion into colluvium is the most common symptom. Roads and fence lines cut by machinery and ongoing use have destabilized many colluvial deposits (Figure 35; Figure 36), as have cattle pads. These impacts have been commonly seen by AGSO (1995) and Shellberg and Brooks (2013) across the Hodgkinson Landscape. While common, we know that road and fence line erosion is spatialy restricted and their locations can be readily identified, and as such are tractable erosion management issues.

Figure 31 Colluvial gully, rill and sheet erosion at footslopes of bedrock hillslopes on Springvale Station (Source: Jeff Shellberg).

Figure 32 Colluvial gully erosion into outwash plains near footslopes on Springvale Station (Source: Jeff Shellberg).

Figure 33 Colluvial gully, rill and sheet erosion on colluvial outwash plains near the footslopes of bedrock hillslopes on Springvale Station (Source: Jeff Shellberg).

Figure 34 Colluvial gully erosion at the interface of hillslope/colluvium/alluvium on Springvale Station (Source: Jeff Shellberg).

Figure 35 Colluvial gully erosion from road water diversion and a fence-line machine cut on Springvale Station (Source: Jeff Shellberg).

Figure 36 Road colluvial gully erosion on Springvale Station (Source: Jeff Shellberg).

3.2.5 Erosion within alluvium unit

The alluvium geologic unit covers 1/3 (18,617 ha) of the area of Springvale Station (56,295 ha). The alluvium is concentrated along the East Normanby, Granite Normanby, and West Normanby Rivers, as well as major creek tributaries and countless smaller tributaries. This alluvium consisting of unconsolidated or weakly cemented clay, silt, sand and gravel has been differentiated into 4 units including active stream channels and connected floodplains (Qha), general floodplain alluvium (Qa), alluvial terraces above modern alluvium and typical flood heights (Qat), and older high level alluvial deposits (TQa) (Table 3). These are in addition to often interfingered colluvial deposits (Qr, Qrt). Gravel, cobble, and sand dominate the active stream channels, while clay, silt and sand dominate the massive alluvial floodplain and terrace deposits.

The landscape forms of this alluvium consist of valley bottom deposits (typically < 0.5% slope) of intermixed floodplains, abandoned terraces, alluvial levees and back-plains, abandoned paleo-channels, alluvial aprons and fans, alluvial tributaries, and intermixed colluvial outwash plains and aprons (Table 4; Galloway et al. 1970). A majority of these alluvial soil units are inherently unstable as a result of deep incision of the river channels and tributaries into older massive alluvium deposited across these valleys ~ 30,000 years ago in the Pleistocene (AGSO 1995; Brooks et al. 2013; Shellberg and Brooks 2013). This has provided the relative relief for secondary incision into these deposits through rill, gully and channel erosion (e.g., Brooks et al. 2009; Shellberg et al. 2013a).

The soils of these alluvial deposits vary greatly depending on location and degree of weathering over time. These texture-contrast alluvial soils are generally described as "*deep duplex sodic acid to alkaline yellow soils formed on alluvial plains*" (Greenant) (Table 5; Biggs and Phillips 1995; AGSO 1995). In the field, they vary in colour from white to yellow to red, vary greatly in chemistry and degree of sodicity (exchangeable sodium percentage) with depth and spatially, and have a wide range of textures (clay to silt to sand to angular and rounded gravel) both vertically and horizontally over both small and large scales. Furthermore, they are not necessarily all texture contrast soils, with massive silt/clay soils dominating the full profile. The fine nature (clay and silt) and high sodicity of these massive soils limits their porosity and infiltration capacity, resulting in abundant surface water runoff. Soil conditions are most often dry centimetres to metres below the soil surface or banks in the wet season (e.g., Shellberg et al. 2013a), contrary to earlier hypotheses of groundwater basal sapping driving this erosion (Brooks et al. 2009). Towards footslopes, bedrock outcrops and tributary valleys, these alluvial deposits grade into colluvial deposits and soils consisting of other yellow Sodosols (Gibson), smaller areas of yellow Dermosols (Kingjack), as well as granite derived deep duplex sodic neutral to alkaline soils (Quarantine) and brown coarse sands (Altanmouie). The alluvial soils associated with basalt are poorly defined and lumped with Burn soils (Table 5; Biggs and Phillips 1995; AGSO 1995).

Overall the complexity and boundaries of these alluvial and colluvial deposits are poorly mapped, especially along the margins and interface with individual units. More detailed soil mapping of alluvium and colluvium using topographic LiDAR data as a base map will be essential to managing and understanding these units in more detail.

Both the Granite and Meta-Sedimentary marine rock are sources of sodium ions during rock weathering. Both parent geologies have contributed to the high levels of exchangeable sodium ions in colluvial and alluvial soils of the Granite Normandy River valley, leading to duplex soils with highly dispersible and erodible sub-soils.

The sodic, duplex, textural-contrast alluvium and colluvium soils associated with the Hodgkinson Landscape "*are amongst the most erodible soils on Cape York Peninsula*" (AGSO 1995). Specifically, this refers to sodic soils derived from both Granite and the Meta-Sedimentary marine rock of the Hodgkinson Formation. Sheet, rill, gully, and mass-wasting erosion are common in these alluvial deposits.

Sheet erosion is common on the undulating floodplains (Figure 37), as well as terrace and river banks, the heads of gullied terrain (Figure 38; Figure 39). The fine nature (clay and silt) and high sodicity of these massive soils limits their porosity and infiltration capacity, and enhances surface water runoff. Sheet flow erosion is also very important in rounded “pre-European” alluvial hollows and alluvial terrace slopes (i.e. prior slower phases of drainage network development), where earlier rounded sub-catchment forms and tributaries drain water from terraces toward incised rivers (Figure 40; Shellberg et al. 2016a; Brooks et al. 2013). These earlier drainage forms were dominated by *diffusive* sediment transport processes where rain and sheet erosion detached and moved soil particles and peds multiple short distances downslope (i.e., a form of soil creep) resulting in rounded convex slope forms developed over longer periods of geologic time (e.g., Fernandes and Dietrich 1997; Pelletier 2008). In contrast after gully channel incision into these incipiently unstable rounded landforms (Shellberg et al. 2016a), *advective* sediment transport processes began to dominate where dispersive sub-soil particles are rapidly exported (advected by fluvial transport) out of gully complexes following mass failure, scarp retreat, and side-wall failure as a result of deep rilling or gully channel incision (Pelletier 2008; Shellberg, unpublished data and manuscript) (Figure 41; Figure 42).

Disturbance of alluvial hillslope catchments – either through natural processes such as intense rainfall, fire, and river incision – or human land use such as grazing, loss of grass cover, cattle pads, roads and fences, and tree clearing – can increase water runoff, reduce vegetation and organic soil cohesion, concentrate water into rills, and promote downstream channel incision and gullying (AGSO 1995; Shellberg 2011; Shellberg and Brooks 2013; Shellberg et al. 2016a). Channel incision associated with lower river base levels and disturbance of adjacent alluvial soils, high banks and terrace slopes often promotes new rill and gully erosion into older rounded “pre-European” alluvial drainage forms (Figure 40; Figure 41). Over time with ongoing disturbance and growth of gully headcuts inset within older, rounded, alluvial slope catchments, these alluvial gully catchments erode *in situ* into the sharp gully forms seen today in the upper Normanby catchment (Figure 42; Shellberg, unpublished data and manuscript). Then over longer periods of time and gully evolution these gullies can erode further back into alluvial terrace slopes, and coalesce with neighboring gullies to form major scarp fronts of mature gully complexes (Figure 43).

In alluvial terrace situations with wider un-eroded alluvial hollows and paleo-channels, linear gully erosion headcuts can advance up valley and consume large areas that were virtually free of gully erosion pre-European settlement (Figure 45; Figure 46). These rapidly advancing gullies are more akin to alluvial gullies in the adjacent Mitchell River catchment (Brooks et al. 2009; Shellberg 2011; Shellberg et al. 2016a). Over time, these linear headcuts can lengthen and widen until the entire alluvial hollow or paleo-channel catchment is consumed by deep sharp gully faces. Multiple stages of gully evolution and erosion processes, forms and types often can be seen in areas of widespread and complex alluvial gully erosion (Figure 47).

Bank erosion into alluvial soils of incised rivers and tributary creeks is also common along East, Granite, and West Normanby Rivers (Figure 49). High banks eroding into Pleistocene alluvium (circa 30,000 years) look dramatic in the landscape, but are often somewhat protected at their toe by indurated (hardened) alluvium at depth. This type of bank erosion is largely natural along the incised rivers, where vegetation has only localized influence on erosion of these cut banks during major (such as casuarina trees at their toe). In contrast, alluvial terrace river banks between steep meander bends (e.g., Figure 48) are vulnerable to loss of vegetation cover from cattle grazing, and are prone to enhanced gully erosion and incision partially fueled by flood backwater and drawdown erosion into the lower ends of small tributary catchments (e.g., Shellberg et al. 2013a). Bank erosion in smaller tributaries can be accelerated by enhanced water runoff from catchment disturbance, reduced vegetation cohesion of banks due to grazing, and waves of bedload sediment (sand) released from upstream gully erosion (Figure 49).

“*The alluvial soils derived from the Hodgkinson Formation have significant potential to erode if managed incorrectly*” (AGSO 1995). This is definitely the case on Springvale Station, where historic overgrazing, fence-line construction, road cutting and use, weed invasion, and tree clearing increased alluvial gully erosion. As reviewed by Condon (1986), AGSO (1995); Shellberg (2011; et al. 2016a) and Shellberg and Brooks (2013) for sodic soils on floodplains in northern Australia, cattle pads (stock tracks) cut into alluvial terrace banks and hollows to access river water have concentrated water runoff and accelerated gully formation and incision. River frontage country historically received the greatest rates of grazing intensity reducing grass cover and promoting weed invasion (Condon 1986; Shellberg et al. 2016a), which is also the case for Springvale Station (Ted Lees, past Manager of Springvale Station, personal communication).

Fence-lines were historically installed on Springvale Station in attempts to control cattle grazing on river frontage country. However, the machine and cattle disturbance along these fence-lines led to deep gully erosion where fence-lines cross small or large tributary banks and channels (Figure 50; Shellberg and Brooks 2013).

Road and track erosion along alluvial floodplain soils is very severe on Springvale Station (Figure 51; Figure 52; Figure 53; Figure 54; Figure 55). Road cuts over steep banks with bulldozers or along alluvial flats with graders often lead to major sheet, rill and gully erosion. Road location, use and maintenance often did not take into account the highly unstable nature of these sodic soils (AGSO 1995; Shellberg and Brooks 2013). Initial sheet erosion concentrated along road scraps and cuts funnels water off alluvial flats during heavy rain with little infiltration. This water concentrates at steep road sections and cuts rills. Over time and years, these rills can form deep gullies that make the road impassible. Band-aid measures are often implemented each year to grader or doze out problem sections to maintain access, but over years to decades this makes the erosion much worse. Eventually road choke points develop where road caused erosion is so severe that vehicles cannot pass by the gullies that were created or accelerated by the road (Figure 53; Figure 54; Figure 55). Major intervention is often needed to regain access through these choke points (Shellberg and Brooks 2013) but extreme caution and careful design are needed as more bulldozer work and exposing more sodic subsoils can often make the matters much worse. The precautionary principle and proper design are paramount.

Tree clearing of sodic alluvial soils on Springvale Station has locally enhanced alluvial gully erosion along the margins and steep banks of cleared paddocks (Figure 56). Clearing disturbance can directly enhance gully erosion from machine tracks and disturbance of fragile soils (Figure 56; Shellberg and Brooks 2013). Disrupting the grass-tree balance of tropical woodlands can also change the water runoff and infiltration regimes (Figure 57). Mature trees and their deep roots promote deep water infiltration into sodic soils, as well as dry out the upper soil profile, aiding water storage during rainfall events. Whereas deep rooted native perennial grasses protect the upper soil surface and water balance. Disrupting this vegetation balance with too few trees and exotic shallow rooted annual grass, or too many trees seen with woodland thickening after initial tree clearance, can influence both water runoff and soil erosion on and off site (Figure 57; Shellberg and Brooks 2013).

Many off-stream dams have been constructed on sodic alluvium at Springvale Station and elsewhere in the Normanby. AGSO (1995) reports the "*failure of a number of dams (as a result of solution erosion) constructed on soils derived from Hodgkinson Formation indicates the…failure to acknowledge the nature of certain soils*". Several dam failures (partial or full) have occurred on Springvale Station, releasing trapped sediment to downstream waterways (Figure 58).

Bioavailable particulate nutrient (BPN) concentrations in sodic alluvial soils and gullies on Springvale Station have nitrate-N that range from 2 to 5 mg/kg, average 3.4 mg/kg, and Phosphate-P (Colwell) that range from 1 to 24 mg/kg, ave 5.46 mg/kg (Garzon-Garcia et al. 2016). These low nutrient concentrations are generally 6x times less than within basalt soils on the Station (see section above on erosion within basalt unit). However, gully erosion rates into sodic alluvial soils on Springvale Station are very high, with typical rates between 300 and 1000 t/ha/yr (Brooks et al. 2013; Shellberg and Brooks 2013). These erosion rates are the highest in the Normanby catchment and comparable to erosion hotspots around the globe (Shellberg et al. 2013b). Thus, seemingly low nutrient soils can yield the largest bioavailable particulate nutrient *loads* due to the very high bulk erosion rates. Unit area nutrient yields from alluvial gullies in Granite Normanby sodic soils were shown to be twice the yields from sugar cane paddocks or banana farms (Garzon-Garcia et al.

2016). Thus, both erosion magnitude and nutrient concentration need to be considered on a unit area, geologic unit, and property scale to assess nutrient yields. Further work is required to measure BPNs from all of the major soils and geological units on Springvale Station to enable appropriate comparisons to be made between loads derived from each unit.

Figure 37 Sheet flow erosion from alluvial flats on Springvale Station (Source: Jeff Shellberg).

Figure 38 Sheet flow erosion, soil scalding, and soil stripping above alluvial gully complexes on Springvale Station (Source: Jeff Shellberg).

Figure 39 Sheet flow erosion, cattle pad erosion, and shallow gully erosion at heads of alluvial gully complexes on Springvale Station (Source: Jeff Shellberg).

Figure 40 Pre-European alluvial drainage forms (rounded hollows and drainage networks on terrace banks) that are beginning to be stripped of soil, scarped, and incised by gullies ‘in situ’ to the pre-European landform (note intact trees growing on the original slope form dominated by diffusive erosion) (Source: Jeff Shellberg).

Figure 41 Pre-European alluvial gully hollow and slope forms that are being dissected and rejuvenated by gully incision (left) that more effectively advects (exports) sediment, in addition to slope degradation by rilling, sheet erosion, animal terracettes (cattle and wallaby), and slumping (Source: Jeff Shellberg).

Figure 42 Scarped and incised alluvial gully complexes in situ, with traces of the pre-European drainage forms (note trees on rounded convex slopes) on Springvale Station (Source: Jeff Shellberg).

Figure 43 Mature and fully scarped alluvial gully complexes destabilized from downstream gully channel incision and major scarp retreat on Springvale Station (Source: Jeff Shellberg).

Figure 44 Mature alluvial gully complexes where much of the pre-European drainage forms have been eroded by gullies on Springvale Station (Source: Jeff Shellberg).

Figure 45 Young linear gully headcuts advancing into uneroded alluvial hollows (channel-less valleys) on Springvale Station (Source: Jeff Shellberg).

Figure 46 Young linear gully headcuts advancing into uneroded alluvial terrace flats on Springvale Station (Source: Jeff Shellberg).

Figure 47 Widespread alluvial gully complexes on Springvale Station with mixed stages of gully evolution and vegetation cover (Source: Jeff Shellberg).

Figure 48 Alluvial gully complexes on both banks of the Granite Normanby River at Springvale Station (Source: Jeff Shellberg).


Figure 49 Bank erosion in large (left) and small (right) alluvial channels at Springvale Station (Source: Jeff Shellberg).


Figure 50 Fence-line erosion through alluvial soils at Springvale Station (Source: Jeff Shellberg).


Figure 51 Road cut erosion and resultant alluvial gully erosion at Springvale Station (Source: Jeff Shellberg).

Figure 52 Road cut erosion in alluvium at Springvale Station (Source: Jeff Shellberg).

Figure 53 Road passage choke points through alluvial gully complexes at Springvale Station. Note the topsoil that is often lost from soil surface disturbance, enhancing erosion into sodic sub-soils (Source: Jeff Shellberg).

Figure 54 Road passage choke points through alluvial gully complexes at Springvale Station (Source: Jeff Shellberg).

Figure 55 Road passage choke points through alluvial gully complexes at Springvale Station (note tyre on left) (Source: Jeff Shellberg).

Figure 56 Alluvial gully erosion accelerated by tree clearing disturbance and excess water runoff at Springvale Station (Source: Jeff Shellberg).

Figure 57 Tree clearing disturbance on sodic soils at Springvale Station affecting the fragile soil surface and ephemeral drainage channels on the floodplain prone to gullying, and disrupting the natural tree-grass balance in native woodlands (Source: Jeff Shellberg).

Figure 58 Potential for dam failure in areas where dams and bywash spillways are built on sodic soils and prone to alluvial gully erosion at Springvale Station (Source: Jeff Shellberg).

3.3 Broad soil erosion management issues

Please Note: This section is informed by the ‘Desktop land condition assessment’ that was written concurrently and is presented in the following section of this report.

While there are many localized soil erosion management issues on Springvale Station, (as discussed in the ‘hazard by geologic unit’ sections above) three broad soil erosion management issues have been identified that should be addressed strategically at a property-wide scale to reduce sediment loss:

- Cattle management
- Fire management
- Road and fence line management.

The ‘Erosion Management Plan to guide 2017 to 2022 actions’ presents more detail on specific actions related to these issues. Background to these issues is presented below:

3.3.1 Cattle management

The primary recommendation is - Develop a feral cattle management plan to maintain low cattle grazing pressure across the property.

3.3.1.1 Considerations for future cattle management

The following considerations for future cattle management have been informed by discussions with previous managers of Springvale Station (Elmes pers. comm., 2017; Quaid pers. comm., 2017; Marsh and Lees pers. comm., 2017). However, it is important to note that the considerations may not reflect the specific views of previous property managers.

General considerations

- Assuming that the current lessee does do a thorough job of removing the branded cattle from Springvale Station; any cattle that aren’t removed in 2017 will be sparse and not cost effective to muster in the first couple of years after it has been destocked.
- It is difficult to prevent cattle moving across the boundaries due to the channels of the East Normanby River, West Normanby River and Granite Normanby River as well as many smaller tributaries crossing the boundaries. While there are flood gates on the old boundary blocking fences, they require regular maintenance and replacement during and after the wet season to be effective for cattle management.
- It is important to note that, from an erosion minimisation perspective, it is not recommended to systematically restore all the old boundary blocking fences or construct a new fence around the entire Springvale Station boundary.

Cattle management option 1 based on a coordinated shooting program

- If the property is to be managed for nature conservation purposes then a coordinated shooting program rather than a mustering program would be the cheapest and most effective solution for the majority of the property. It is important to note that a shooting program will be more challenging in the western section of the property that bounds the Lakeland properties, because this area might continue to have branded cattle that need to be annually mustered and returned to the property of origin.
- Arrangements for coordinated shooting could be made with Kings Plains Station in the north and the other neighbouring properties on the eastern and southern sides that have nature conservation goals.
- The western boundary fence is considered to be the most important from a future cattle management perspective, because the neighbouring properties on the other boundaries were now generally being managed for conservation or Cultural Heritage purposes. This

western boundary fence would need to be significantly repaired and maintained annually to keep Lakeland cattle out of Springvale Station.
- Annual muster of the Farm area and Box Flats closest to the western boundary with Lakeland properties.
- Roll up and remediate all the internal fences that are not required for mustering.

Cattle management option 2 based on a bi-annual muster of feral cattle

- If a coordinated shooting program was not feasible, then every two or three years (depending on cattle numbers) muster the whole property during the dry season. Mustering effort should focus mainly on the Keetings area and Box Flats along the East, West and Granite Normanby Rivers and the areas around the dams. It will take about 8 weeks to muster the whole property and if it was done every second or third year, a contract musterer may do the job for the value of the unbranded cattle.
- The western boundary fence is considered to be the most important from a future cattle management perspective, because the neighbouring properties on the other boundaries were now generally being managed for conservation or Cultural Heritage purposes. This western boundary fence would need significant repairs and annual maintenance to keep Lakeland cattle out of Springvale Station.
- An annual muster of the Farm area and Box Flats closest to the western boundary with Lakeland properties.
- Consider repairing and maintaining the blocking fence and floodgates on the southern boundary between Keetings Paddock and Mt Amy.
- Consider repairing and maintaining the blocking fence and flood gates on the northern boundary with Kings Plain.
- Roll up and remediate all the internal fences that are not required for mustering.

3.3.2 Fire management

The primary recommendation is - Develop a fire management plan to encourage natural regeneration of perennial native grass species across the property.

3.3.2.1 Considerations for future fire management

The following considerations for future fire management have been informed by discussions with previous managers of Springvale Station (Elmes pers. comm., 2017; Quaid, pers. comm., 2017). However, it is important to note that the considerations may not reflect the specific views of previous property managers. Fire and fire break impacts on vegetation cover and soil disturbance need to be taken into account to minimise additional or accelerated erosion.

Fire management strategy:

- When you cross the Granite Normanby on the eastern side, it is a different climate to the rest of Springvale Station. The south east corner of the property is wetter and won't carry a burn until later in the year. This section of the property should be considered separately when planning early season fire breaks. Wildfires from the south east corner of the property have been a significant problem in the past. The continuous heavy grazing pressure has reduced the fuel load and supressed fire in the Box Flat areas for many years. However, as the property is destocked of cattle in late 2017 and fuel loads increase in subsequent years, consideration of fire management in the south east corner of the property will become important to prevent late season wildfires coming from the south east and spreading rapidly through the whole property.
- Due to consistently high cattle grazing pressure and invasion of weeds (such as annual grasses, sicklepod and hyptis) the Box Flats have not really had a decent fire for many years. 3-5m tall poplar gums have thickened considerably in the Box Flats in the last 20 years (such as in Dead Dog paddock and in the flats beside the East Normanby River). Consideration should be given to development of appropriate fire regimes in the Box Flat areas to supress weeds and encourage the regeneration of perennial native grasses and the

open grassy woodland vegetation community that was in these areas. This could be done as part of an overall property fire management plan that includes early season mosaic burning combined with storm burning and other planned burning strategies as part of the mix in strategic areas.

Fire breaks:

- Consider carefully timed aerial incendiary burns to create a 500m – 2km wide fire breaks on the western, southern and eastern boundaries using an aeroplane or helicopter. As soon as possible after the wet season, incendiaries could be dropped into the hilly areas at about lunch time, flying south from Isabella Creek inside the western boundary and then east along the southern boundary and then north just inside the eastern boundary to the Mulligan Highway.
- Consider a graded or slashed fire break along the western boundary fence to enable back burning against the Lakeland properties. This would require some work but could be done at the same time as repairing the western boundary fence.
- The north western corner of the property is probably the most difficult area to protect from fires coming from the north (through Kings Plains). Consider clearing a new fire break along the western boundary, starting at Boggy Creek and running adjacent to the western boundary fence for approximately 6km and then running in an easterly direction across the southern side of the Lakes clearing, then running north east to the West Normanby River. This would require some work but could be done at the same time as repairing the western boundary fence.
- The East Normanby, West Normanby and Granite Normanby Rivers act as fire breaks and can be used to back burn from to create fire breaks.
- The southern side of the Mulligan Highway acts as a fire break and can be back burnt from to create a fire break for fires coming from the south east.
- The northern side of the Mulligan Highway is a useful fire break for fires coming from the north. Could consider clearing a track from Boggy Creek to the homestead along the northern side of the highway to facilitate back burning.

3.3.3 Road and fence line management

The construction of roads and fence-lines through erodible soils at Springvale Station have invariably caused direct accelerated erosion through machine disturbance and ongoing vehicle use (Figure 59). This has occurred on all soil types including basalt (Figure 12), metasediments (Figure 22; Figure 23; Figure 24), colluvium (Figure 35; Figure 36) and alluvium (Figure 51; Figure 52; Figure 53; Figure 54; Figure 55). Improper placement, construction, and maintenance of dirt roads, tracks, and fences can concentrate water runoff and accelerate local and off-site gully erosion (AGSO 1995; Shellberg and Brooks 2013). Most often road and fence erosion is concentrated on the banks of hollows, small ephemeral creeks, and large creek and river crossings, where soil disturbance and/or grading (cutting) with machines (without water diversion structures or importing rock capping) has led to deep gully erosion and eventual road abandonment.

On Springvale Station (56,295 ha), preliminary mapping and ground truthing has identified 255.9 km of road or vehicle track, and 303.9 km of fence-line disturbance (Figure 60). This is a minimum total of 559.8 km of linear disturbance by machine. If an average width of road or fence disturbance is 6 metres (two passes of a machine), then 335.8 ha have been cleared by linear disturbance affecting 0.6% of the 56,295 ha property. This is compared to ~ 1700 ha of cleared pasture that represents 3% of the total property. However, linear disturbance by machine has a very concentrated influence on erosion and sediment production compared to pasture and weed covered paddocks, with some of the worst roads through sodic alluvial soils eroding at ~ 900 to 1600 tonnes/ha/year (Shellberg and Brooks 2013). However, average yields of the majority of the road network will be lower than these localized specific yields through the most highly eroded terrain.

Many of the mapped linear disturbance features in Figure 60 need more field verification of location and condition, especially fence-lines, as well as to update exact location paths. Thus, linear disturbance mapping and condition assessment is an ongoing work in progress as datasets improve over time from group efforts. Many of the known fence-lines are still intact, while many have fallen down from lack of maintenance from the 1990s, while yet other mapped linear disturbance were “aspirational fence lines” cut with bulldozers during the peak of property development, but never had posts and wire erected.

Figure 59 Examples of roads at Springvale Station graded repetitively on sodic soils that have concentrated water flow and caused deep gully erosion (Source: Jeff Shellberg).

There are other historic linear disturbances on the property that have been missed during mapping efforts. Improved field data and LiDAR topography across the whole property will highlight additional locations. Ground truthing and surveying these mapped features and associated erosion is a priority, along with a prioritized assessment of track maintenance, erosion control, and road abandonment / rehabilitation needs.

3.3.3.1 Location of roads

The best long-term solution to road and fence stability is to locate this infrastructure away from highly erosive soils or sensitive erosion features (i.e., avoidance). The preferred location of roads and tracks is on stable soils and bedrock geology, or subtle ridge and spur crests between drainage catchments, while not following the easiest or straightest path up a river valley or slope. Carefully planning road and fence routes will minimise the number of crossings of existing gullies, un-channelled hollows, small creeks, and rivers. This will reduce maintenance costs and minimise the potential for rill and gully erosion often created at steep banks at water crossings.

A full LiDAR topographic survey of Springvale Station will be needed to identify the most appropriate locations for roads, subtle but important catchment divides, and potential crossings of hollows, gullies, creeks, and rivers to avoid. These LiDAR data can be used to update more soil/geology units and boundaries and earlier gully mapping (AGSO 1995; Brooks et al. 2013) to more accurately locate erosion hazards. Once new preliminary routes are identified, field reconnaissance and route mapping using side-by-side utility vehicles, GPS, detailed topographic maps and air photos can be used to more precisely locate erosion hazards and adjust new road locations accordingly, or reroute existing roads.

3.3.3.2 Road abandonment and rehabilitation

Road and fence-line abandonment and rehabilitation will be needed in locations where infrastructure has been placed in sensitive locations and caused serious erosion from machine disturbance (e.g., Figure 24; Figure 51). Abandonment does not mean just walking away from an erosion hotspot created by man and machine - but entails active rehabilitation to reduce or stop ongoing erosion before abandonment. Road and fence abandonment and rehabilitation offer distinct opportunities to fix past mistakes at erosion hotspots (Shellberg and Brooks 2013).

For conservation success, a majority (> 50%) of the identified 255.9 km of road or vehicle track, and 303.9 km of fence-line disturbance on Springvale Station (Figure 60) will need to abandoned after specific rehabilitation actions are taken along each section of road or fence.

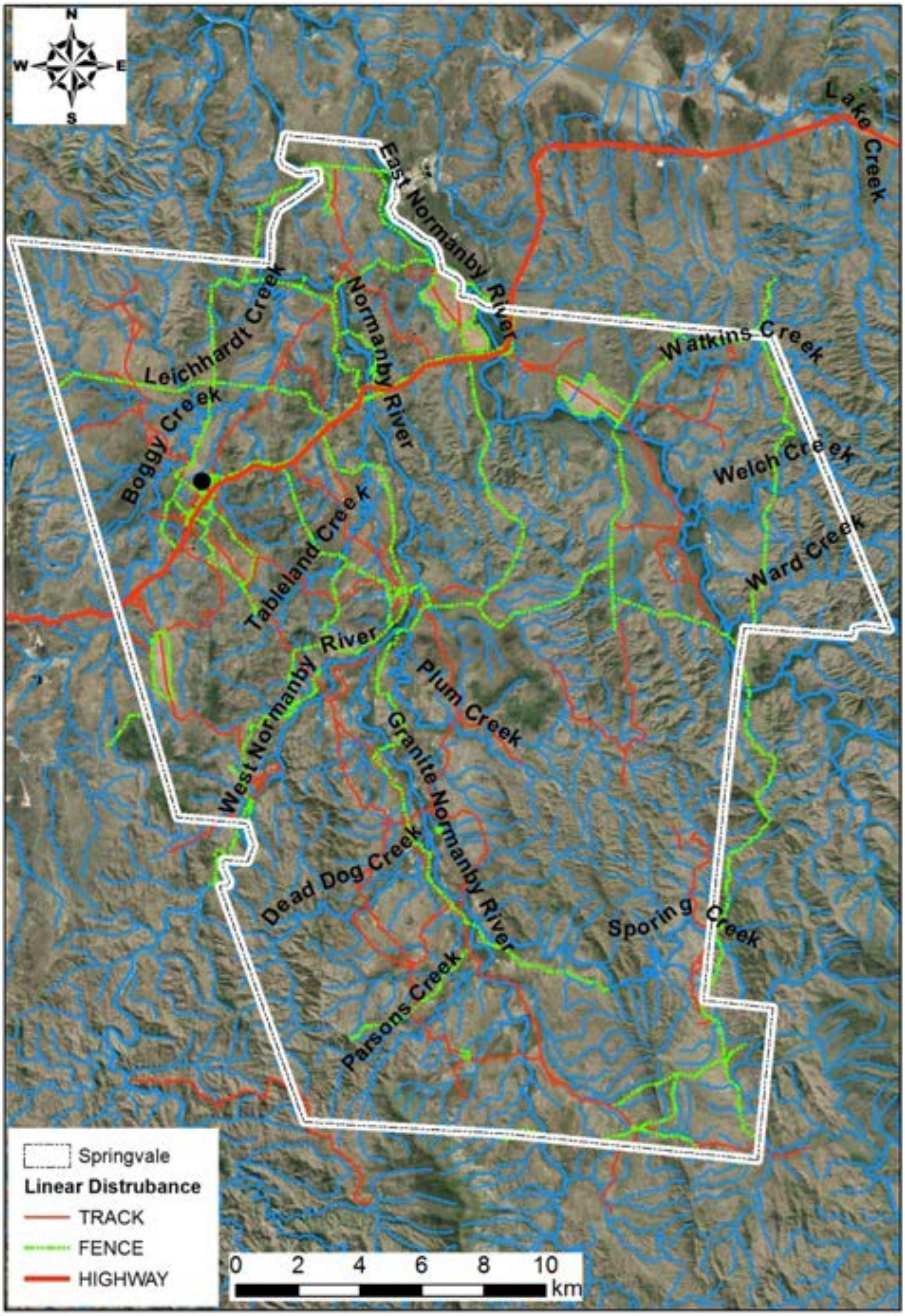


Figure 60 Known (minimal) locations of road, track, and fence line linear disturbances on Springvale Station (Source: Jeff Shellberg).

In the most simple cases, this might entail just rolling up fence wire on flats and allowing the area to revegetate without any ongoing disturbance. On simple roads on stable geology, this might entail installing water diversion banks (whoa boys) on steeper road sections, and above ephemeral creek crossings, as well as installing “tank traps” in strategic locations so that the road is not driven again. Active revegetation will also be appropriate.

In the more difficult and common situations on Springvale Station with bad road and fence erosion in sodic alluvial soil, more cautious and specific abandonment and rehabilitation designs will be needed to address past road and fence erosion (Shellberg and Brooks 2013). These local road/fence erosion “hotspots” offer opportunities to reduce erosion and rehabilitate areas that are known to be directly caused by man and machine. However, they also provide challenges and risks to even progressive machine operators, who often can fall into the trap of heavy-handed approach to bad erosion by choosing earth-reshaping and engineering approaches to the problem, when addressing the causes of erosion (concentrated water runoff) and carefully designed surgical treatments following principles of fluvial geomorphology and bioengineering are more appropriate along with proactive revegetation of native species.

Figure 61 Typical road and fence maintenance equipment and erosion control styles used on Cape York will NOT be appropriate for addressing much road and fence erosion at Springvale Station on sensitive sodic soils, while minimsing collateral damage and accelerated erosion (Source: Jeff Shellberg).

3.3.3.3 Major roads issues on alluvium and colluvial slopes

Most roads and fences in the alluvium and colluvial slopes geologic units (Priority Focus Sediment Management Areas outlined below) have been trapped in a vicious cycle of rapid annual clean-ups and machine re-grading to quickly get access to remote parts of the station for muster or delivering lick. Proper road maintenance budgets or plans have never been part of operations at Springvale Station. For example over the last 25 years, the road to ‘Keetings Paddock’ up the Granite Normanby Valley has been annually scraped with loaders or graders to rapidly get access for mustering (Figure 62). This occurred again in 2017. In easy cases, rills and gullies were smoothed over and filled with local borrow material of sodic soil, just to erode again the next wet season. In the larger more difficult cases, erosion problem areas were either battered via earthworks or just bypassed with a new road once a section of road became impassable. Relocating roads after serious erosion often just moves the problem from one location to another creating cycles of degradation (Figure 63; Figure 101). This style of management without any Best Management Practices (BMPs) (Shellberg and Brooks 2013) has led to a legacy of erosion damage and backlog beyond repair in many situations. These represent Worst Management Practices (WMPs).

Figure 62 Deep gullies formed annually during the wet season - down steep road cuts in sodic soils - can be difficult to regrade and fill in using heavy machinery, with very short-term access benefits at Springvale Station (Source: Jeff Shellberg).

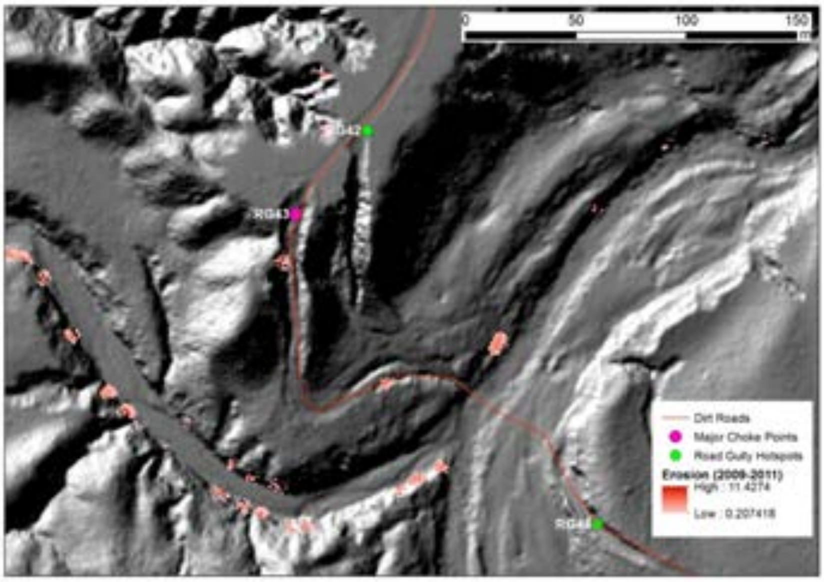


Figure 63 A road 'Choke Point' on the Granite Normanby road where deep gully erosion has restricted road access and forced machine operators to relocate the road nearby, creating the same situation again and perpetuating erosion cycles (Source: Jeff Shellberg).

The Granite Normanby Road (30 km long) from the Springvale Station homestead to the yards at the 'Keetings Paddock' on the southern boundary of the station has 71 gully erosion hotspots where the road has caused or accelerated gully erosion (Figure 64). These are called "Road Gullies" (RG), with often more than one gully in any one location. This includes 10 serious 'Choke Points' where deep gully erosion has restricted any reasonable road access. Another 30 of these road gullies make drivability difficult. In total, 85 km of dirt road have been surveyed by a geomorphologist in the Granite Normanby area, south of the Mulligan Highway. These surveys have documented and mapped 154 major road gully hotspots and 17 'Choke Points' across 85 km of road (Figure 64). This is an absolute minimum on these roads, as only major issues were documented. It also does not cover erosion on the rest of the 256 km of road and 304 km of fence-line on the property. These road gullies are most often associated with roads crossing of ephemeral creeks and rivers where the road drops over steep alluvial banks prone to gully erosion. In other locations gullies have migrated laterally into roads from both directions, fueled by concentrated road runoff that eventually threatens the road.

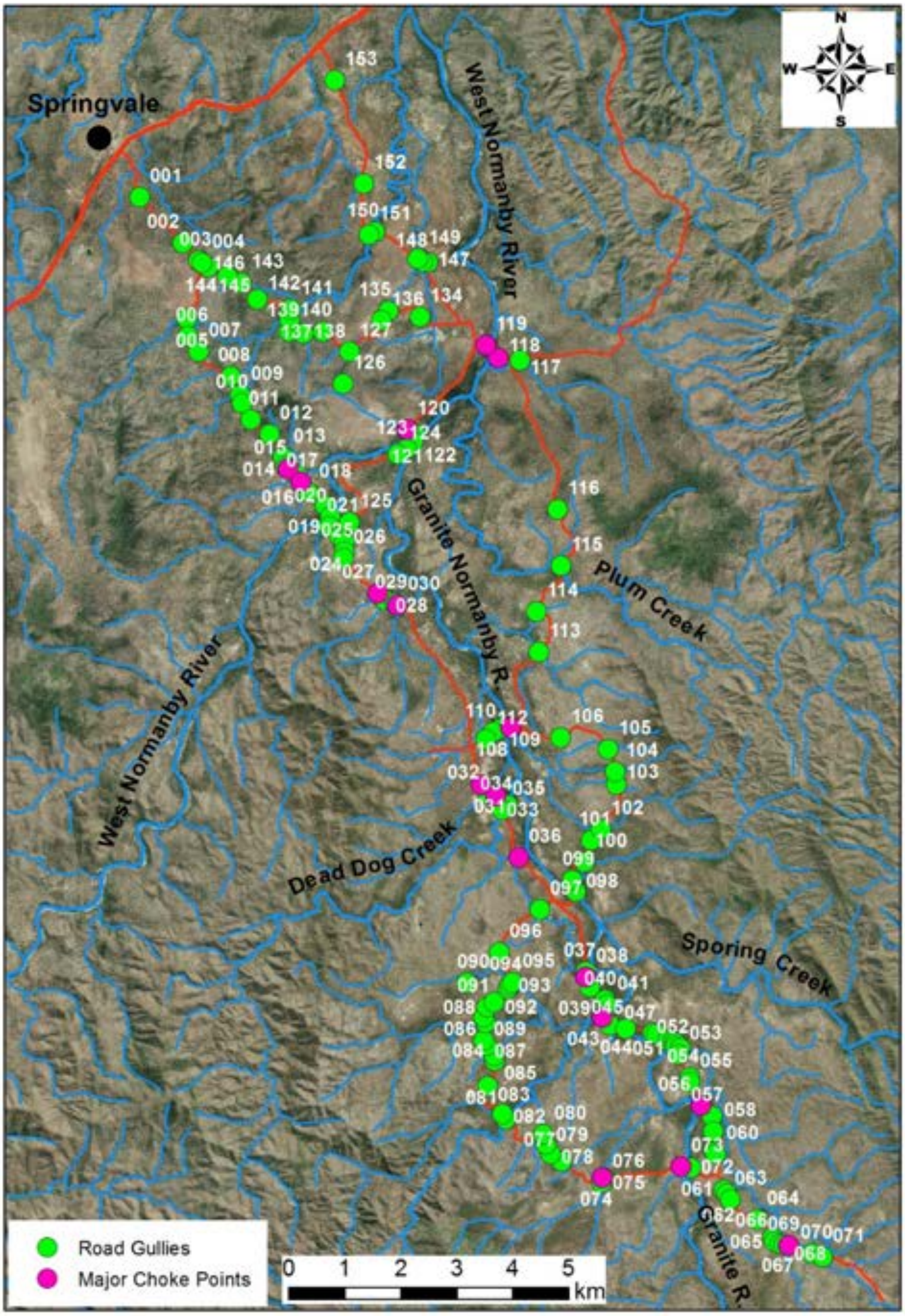


Figure 64 'Road Gullies' caused or accelerated by road construction and use along the southern half of Springvale Station between the Homestead and the 'Keetings Paddock'. Also included are road 'Choke Points' where gully erosion is so severe that it almost completely restricts vehicle access without heavy machinery intervention with appropriate bioengineering and precautionary principles of erosion control (Source: Jeff Shellberg).

The costs of maintaining this road network and accelerating erosion need to be weighed up against benefits of access and potential alternative routes less prone to erosion (Shellberg and Brooks 2013).

Future management at Springvale Station needs to be guided by a detailed Road and Fence Maintenance and Abandonment Plan (RAFMAP) as part of the overall Erosion Management Plan and Property Management Plan. Specifically, plans, guidelines, and designs are needed for road maintenance, road abandonment and rehabilitation, road use, and road re-construction where appropriate. A RAFMAP and resultant management need to be taken seriously if a reduction in human caused sediment pollutions is to be achieved at Springvale Station.

In 2012-2013, road stabilization trails were conducted at Springvale Station along the Granite Normanby Road (Shellberg and Brooks 2013). For general road stabilization sites, trials were conducted in 2.0 km of road length where thirty (30) water diversion banks (whoa boys) were installed in Dec 2012. The goal was to test their functionality in highly eroded terrain to safely divert excess road runoff from the road away from gully heads, to reduce overall erosion and increase road stability. Material for water diversion bank construction came from local silt/clay soils (variably sodic) excavated from small pits adjacent to the road that also served as water and sediment dissipation ponds. Where needed, additional non-sodic rock gravel material was also imported from local borrow pits (Hodgkinson Formation; Figure 25) to help construct diversion structures (Figure 65; Figure 66; Figure 67). Construction works were primarily conducted with a large backhoe with a 4-in-1 front bucket. A tip-truck supplemented rock material. Results were mixed after 5 years to 2017. In many places the whoaboys safely dissipated water off the road into stable location. In others, the diverted water caused additional adjacent erosion and still delivered polluted water to adjacent creeks. Whoaboys created and capped with rock gravel material (Hodgkinson Formation) were the most stable after 5 years, but experienced sheet erosion associated with the loss of fine silt matrix material, and in places the gravel also washed away.

a)

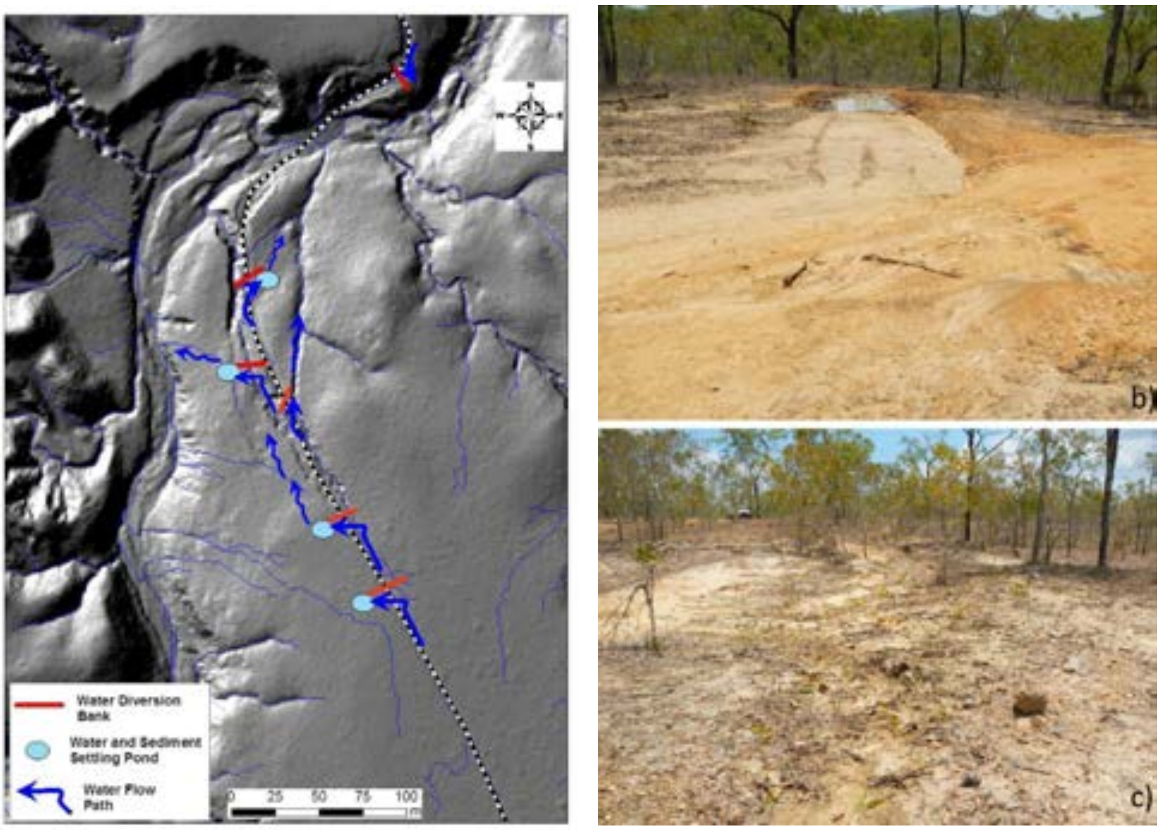


Figure 65 Improvements to road drainage at RG35 next to Dead Dog Creek a) mapped in plan view using a LiDAR hillshade with derived flow lines, with examples of b) a 'whoa boy' water diversion bank constructed from locally borrowed soil material excavated from a small settling pond, and c) an overland sheet flow path derived from the outlet of a settling pond eventually flowing into the creek (Source: Jeff Shellberg).

For major road ‘Choke Point’ sites (Figure 64), trials were conducted at 3 treatment and 1 control sites surveyed before and after with terrestrial LiDAR. These were the ‘easiest of the bunch’ of choke points. The control site had business as usual (annual grading end wet season), while the controls has combinations of water diversion banks, partial surface capping with rock, and full surface capping with rock. The results after one wet season indicated that using water diversion banks and rock armouring together on steep road cuts can reduce deep rill and gully scour and fill (from ± 1 m down to ± 0.2 m each year), but will not necessarily reduce short-term (1 year) erosion rates. In some instances without rock surfacing, erosion rates can increase from machine intervention. Using rock armouring of diversion banks and road surfaces can switch the erosion process from rilling and gullying into predominantly raindrop impact and sheet wash erosion. If a poor quality source of rock is used for armouring (Hodgkinson Formation; Figure 25), then short-term erosion rates over a few years can remain elevated until matrix fines are washed from the rock material. The degree that surface lags of coarse rock will provide longer-term protection against raindrop impact and sheet erosion in sodic soils is less clear. Results to 2017 indicated that rock gravel surface lags were holding on and providing soil protection, but needed some ongoing maintenance and touch-up with imported material.

Figure 66 Erosion at road choke points at steep river banks in sodic soils can be reduced by installing frequent water diversion banks (whoa boys) and capping them with imported coarse rock (Source: Jeff Shellberg).

Figure 67 Erosion at road choke points at steep river banks in sodic soils can be severe after whoaboys are installed but without any surface rock capping (Source: Jeff Shellberg).

3.4 Key findings of the broad soil erosion assessment

The key findings of the broad soil erosion assessment are:

- Significant soil erosion is evident within all surface geologic units within Springvale Station.
- Continuously high cattle grazing pressure, inappropriate fire regimes, road use and fence line clearings, broad scale tree clearing, dam construction, weed invasion and feral animals (pigs) have all contributed to accelerated soil erosion within Springvale Station.
- Alluvium and Colluvial Slopes geologic units have the highest concentration of gully erosion and the highest current soil erosion rates, and have been identified as the Priority Focus Sediment Management Areas and should be the focus of the Erosion Management Plan to guide 2017 to 2022 Actions.
- Roads and fence lines have the highest direct disturbance from human activities on soil and gully erosion, with erosion rates in sodic alluvial/colluvial soils equivalent to nearby non-road gully erosion.

3.4.1 General recommendations for property-wide soil erosion management

The following general recommendations are made to inform future Springvale Station property management planning:

- Develop a feral cattle management plan to maintain low cattle grazing pressure across the property.
- Develop a fire management plan to encourage natural regeneration of perennial native grass species.
- Develop a Road and Fence Maintenance and Abandonment Plan (RAFMAP) for all property roads and fences in order to assess existing condition, determine essential infrastructure and areas to abandon after rehabilitation, and design specific erosion control measures following Best Management Practices (e.g., Shellberg and Brooks 2013).

The ‘Erosion Management Plan to guide 2017 to 2022 actions’ presents more detail on specific actions to support these recommendations as well as detail on gully remediation priorities in specific areas.

4 Desktop land condition analysis

4.1 Background

Analysing land condition is an important component of the Erosion Management Plan (EMP) for Springvale Station, due to the relationship between land condition and the generation of sediment through erosion and land degradation processes, particularly gully formation.

In grazing production systems, land condition is simply defined as 'the ability of land to respond to rainfall to produce useful feed or fodder'. This definition is extended for this report to address 'the ability of land to maintain soil resources and reduce erosion'. Heavily grazed areas with low ground cover are more vulnerable to erosion than ungrazed areas with relatively high ground cover. This report documents a series of analyses of remotely sensed data products (e.g. ground cover) and field inspections for the Springvale Station to help inform the land condition component of the EMP. The key objectives of this work align with the objectives of the EMP and include:

- Describing and benchmarking the current land condition of land types across Springvale Station to help inform property management and remediation activities
- Identify the processes which have led to this land condition to ensure appropriate remediation activities are used
- Identify suitable actions to improve the land condition of targeted land types
- Develop a monitoring strategy to assess progress in improving land condition and reducing erosion from the station.

4.1.1 Defining management periods

Land condition is a function of climate, biophysical characteristics of the location of interest and the past and present land management regimes. For the purposes of the EMP, an understanding of the impacts and effect of the previous and current management regimes on land condition is therefore required in order to plan for future management, given a key objective is to improve land condition on the station.

Springvale Station has had a number of periods where the management regimes have differed over the last 30 years. These periods have corresponded to different owners of the property, as identified in discussion with local experts, and form the basis for the analyses in this report. The identified periods for the analysis are: 1990-1998; 1999-2003; and 2004 until 2016 after which the property was acquired by the State Government (Table 6; Appendix 5 - Brief History of Springvale Station).

Table 6 Management periods

Time period	Ownership	Grazing pressure
1990-1998	Private	Intensification - moderate to heavy
1999-2003	Private	Heavy
2004-2016	Private	Heavy
2016-2017	State Government	Transitional – heavy to light
2018-onwards	State Government	Light - none

Springvale Station has a long history of beef cattle grazing beginning in the late 1800's (Appendix 5). Post World War two there has been a steady increase in grazing pressure as property infrastructure (waters and boundary blocking fences) was developed (Elmes pers. comm., 2017). There was a period of rapid infrastructure development and intensification in the early 1990's that involved significant paddock subdivision fencing and clearing. There has been continuous heavy grazing of Springvale Station since 1998 (Marsh and Lees pers. comm., 2017; Quaid pers. comm., 2017). Following acquisition of the property by the State Government in 2016, it has been progressively destocked. Springvale Station is currently carrying 1500-2000 head of cattle, with plans to destock the property completely by late 2017. Given the size of the property and inherent mustering difficulties, it is expected that some cattle will remain on Springvale Station. However, these small stock numbers should have minimal impact on ground cover and land condition.

4.1.2 Stratification units for land condition assessment: land types and geologic units

Broad geologic units (described in detail in the ‘Broad soil erosion assessment’) were used as the basis for determining land types across the property. While FutureBeef Grazing Land Management (GLM) land types were initially considered for use as a stratification unit, the broader geologic units better represent the variation over the property, as described by local experts (Quaid pers. comm., 2017). In total, five geologic units (Figure 68 and Table 7) were identified, which describe the key land types based on soil, slope, vegetation and relative productivity. Paddocks were not used as units for spatial analysis as fencing was not consistently present through all management periods (Quaid pers. comm., 2017).

Table 7 Relative productivity of surface geologic units within Springvale Station (Source: Joe Rolfe).

Surface Geologic Units	Relative productivity
Alluvium	High
Basalt	High
Colluvial slopes	Moderate
Granitic	Not assessed
Hodgkinson/Normanby Formations	Low

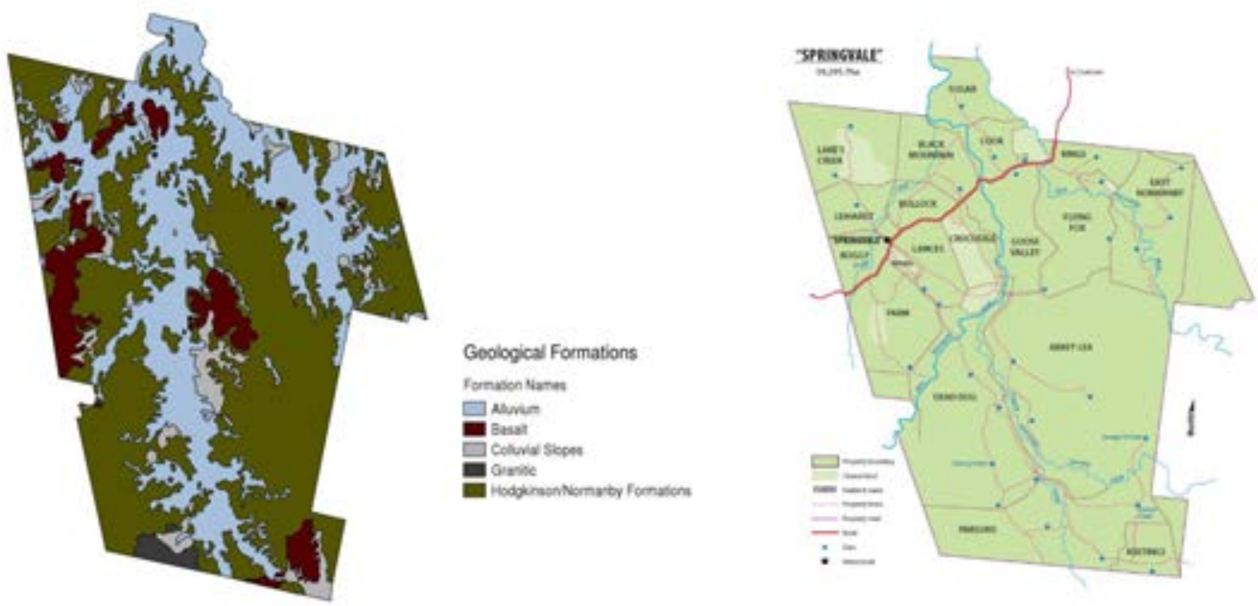


Figure 68 In the absence of accurate Grazing Land Management (GLM) land type mapping for Cape York, the surface geological formations (above left) were found to broadly represent the grazing land types on Springvale Station in relation to soil, slope, vegetation and productivity. Property development and infrastructure (fencing, waters and tracks) on Springvale Station is generally confined to the higher grazing value land types (basalts and alluvials).

4.2 Land condition analysis methods

The land condition analysis for Springvale Station consists of both on-ground assessments of land condition and a desktop assessment, based on various remote sensing products. It is important to note that while remote sensing can provide useful surrogates of factors which contribute to land condition state and change, it is not possible to adequately and directly assess land condition using remote sensing due to a range of data limitations. To obtain a complete understanding of the land condition at Springvale Station, on-ground assessment is required to help inform site-specific management activities, and to validate trends and indicators of land condition in the remote sensing data. These methods are discussed further below.

4.2.1 On-ground land condition assessment

On-ground assessment at Springvale Station was based on the ABCD framework, previously developed to describe grazing land condition (Chilcott et al., 2003). This method considers pasture composition, soil condition, weed infestation and woodland density to assign a land condition ranking or class to a land type. The ranking or land condition class is then used to identify the grazing land production potential, or carrying capacity, for a given location and land type. 'A' condition describes a land type at 100% of original carrying capacity; B condition has 75% of original carrying capacity; C condition has 45% of original carrying capacity; and, D condition has only 20% of original carrying capacity. It is important to note that different land types or geologic units have different original carrying capacity based on a range of factors related to climate, soil, tree density and pasture composition.

The ABCD framework is a simple and effective method of assessing land condition however it is potentially overly simplistic for the objectives of the EMP. It is therefore convenient to further subdivide the 4 standards to more accurately reflect the condition of particular sites. Thus, as well as condition scores A, B, C or D, we identified some sites as being in A minus (87% of original carrying capacity), B minus (60%), or C minus (33%) condition. Taking into account rainfall variability, it is considered that a sustainable management system would see grazing lands moving between A and B condition. The method relies on the observer having some experience in a region to understand what the original condition of a land type might have been. Due to limited project resources, the Springvale Station land condition assessment was based on a rapid on-ground inspection, with the rationale for each assessment recorded.

Pasture condition was assessed on the dominance of the original or preferred pasture species for that land type. For example, the original dominant pasture species was black spear (*Heteropogon contortus*) and kangaroo grass (*Themeda triandra*) on the more productive land types. If those species are still dominant, then pasture condition was considered good and thus not discounted.

Soil surface condition was considered on the basis of evidence of either gully or sheet erosion. While gullying is self-explanatory, the observers considered evidence of scalding, pedestaling or loss of fine particles for sheet erosion.

Weed infestation was assessed based on the extent of invasion of exotic weed species. Hyptis (*Hyptis sauveolens*), rubber vine (*Cryptostegia grandiflora*), Grader Grass (*Themeda quadrivalvis*), Sicklepod (*Senna obtusifolia*) and Snakeweed (*Stachytarpheta jamaicensis*) are examples of species included in the weed category.

The woodland density assessment was based on an estimate of the stability or increase in density of native or naturalised woody species. This included evaluating the distribution of age groups of woody species, or whether a generation of a certain species had escaped from within the grass canopy and grown to the extent that they were now unlikely to be controlled by fire or management.

4.2.2 Remote sensing

The desktop-based remote sensing component assessed woody extent and thickening; ground cover levels and dynamics; and historical fire frequency and extent. These assessments were made using Landsat-based products developed by the Queensland Department of Science, Information Technology and Innovation's Remote Sensing Centre.

The Landsat series of satellites are multispectral sensors with over 30 years of earth observation at a moderate spatial resolution (30 m). Landsat satellites acquire imagery every 16 days however the occurrence of cloud in imagery can result in gaps, sometimes up to months at a time.

4.2.2.1 Fractional cover and fractional ground cover products

The main products used for this assessment are seasonal fractional cover and its derivative seasonal ground cover (http://www.auscover.org.au/purl/landsat-seasonal-ground-cover). The fractional cover method measures land cover as percentages of green vegetation cover (tree and shrub foliage and living grass and forbs), non-green vegetation cover (leaf and other litter, dead vegetation, branches) and bare ground (soil and rock). Fractional cover images provide a measure of total vegetation cover – they do not distinguish between over-storey ‘green’ vegetation (i.e. trees and shrubs) and ground layer ‘green’ vegetation (i.e. grasses and forbs). The derivative product, seasonal ground cover, does make an adjustment to the fractional cover to exclude the over-storey (woody) vegetation to focus on the ground layer.

4.2.2.2 Seasonal composites

The remote sensing products used for this analysis are seasonal composites that provide a representative image of the property over a given season, rather than images from individual (i.e. every 16 day) dates (Flood, 2013). For simplicity, calendar seasons are used (i.e. summer, autumn, winter, spring). These seasonal products provide a clean product free of extreme outliers and with a greatly reduced area occluded by cloud; this is very useful for the Springvale Station property, as in the wet season, imagery over the property is badly affected by cloud.

4.2.2.3 Persistent bare

The persistent bare product is created from the seasonal ground cover images. For each pixel the value of bare ground for each season is compared and the 5th percentile selected. The 5th percentile is a robust estimate of the minimum level of bare ground over time. The higher this value the more persistently bare the pixel has remained. This layer can be thresholded to show the areas that are persistently bare above a certain level. For this analysis we selected 10% as this highlighted the gullied areas adequately.

4.2.2.4 Percentiles (ground cover ranking)

The percentiles analysis consists of looking at the property over a user-defined period and ranking the total ground cover for each pixel within the property for each season of the selected time period and then selecting the median of these ranking values for each pixel. This results in image that gives the typical ranking for each pixel, which highlights areas of relative degradation. The analysis of the percentile (ranking) was split into two management periods – 1990-1998 and 1999-2016, to align with the change in management from a moderate stocking rate pre-1999 to a heavy stocking rate post-1999.

4.2.2.5 Dynamic Reference Cover Method (DRCM)

The Dynamic Reference Cover Method (DRCM) is a method described by Bastin et al. (2013), which compares the cover at a given location with the best performing locations (in terms of cover) within the region around that location. By comparing locations within a localised region, it is assumed that the climate experienced is constant between location and the best performing locations, and any differences in cover are therefore due to land management. The DRCM is a relative measure which can provide an indication of more heavily grazed and degraded areas, or conversely, areas which have higher cover relative to the local region, possibly indicative of more sustainable grazing practices and/or more resilient parts of the landscape. For this analysis, only the best performing locations were used to indicate the potential levels of cover under ideal conditions.

4.2.2.6 Foliage Projective Cover (FPC) and persistent green vegetation and trend data

Foliage Projective Cover (FPC) is defined as the fraction of ground covered by the vertical projection of photosynthetic foliage of all strata (Specht, 1983). FPC is a metric that is used in remote sensing (i.e. satellite-based monitoring) as a direct estimate of the foliage (or leaves) of vegetation when viewed (vertically or near-vertically) from above, as is the perspective of the satellite. Herein, FPC refers to the foliage of woody plants only and is expressed as a percentage where: 0% FPC implies there is no woody plant foliage cover; and, 100% FPC implies total or complete woody plant foliage cover. The FPC data used for this report is the 2014 FPC product, produced using Landsat data from 1988-2014, calibrated by field measurements of FPC (Armston et al. 2008, Kitchen et al. 2010).

Persistent green vegetation is the green vegetation which generally persists in the long-term time series of the Landsat satellite imagery. The assumption with these data is that the less variable woody components of the vegetation (particularly the tree and shrub strata) will have a more persistent, less variable time-series signal than the more variable ground layers which are more affected by seasonal and grazing effects. It is derived by analysing the time-series of green cover fraction of the fractional cover data over time. Persistent green has been shown to be nominally similar to FPC in terms of estimating woody vegetation density or cover, but has the additional benefit of being able to be produced for any season due to being based on the seasonal fractional cover data.

Persistent green trend is derived from seasonal fractional cover using a weighted smooth spline fitting routine. This weights a smooth line to the minimum values of the seasonal green cover, representing the slower changing green component, ideally consisting of perennial vegetation including over-storey, mid-storey and persistent ground cover. The seasonal persistent green is then summarised using simple linear regression, and the slope of the fitted line is captured in this product. The original units are percentage points per year. For this report, the ~30 year time-series of seasonal persistent green data was analysed to determine subtle trends in the woody vegetation, with increases possibly indicative of changes in density due to vegetation succession processes, including thickening and encroachment.

4.2.2.7 Fire scar data

Characterising historic patterns of burning and changing fire regimes over time (spatial extent, timing, patchiness, frequency and intensity) is important for improving our understanding and management of fire, climate, land-use and vegetation interactions. The fire scar data used data derived following the methods developed by Goodwin and Collett (2014). Fire scars are automatically detected and mapped using dense time series of Landsat imagery acquired over the period 1987 - present. In addition the products from 2013 onwards have undergone significant quality assessment and manual editing. From these base products the extent, burn frequency and time since last burn were calculated.

4.2.2.8 Limitations of remote sensing data

Due to its large area coverage and long-time series of systematic data acquisition, remote sensing, particularly from Landsat, can provide valuable information on historical land condition and monitor areas that are not accessible for with on-ground assessments. However, there are limitations of spatial and temporal scale which need to be considered in the use of remote sensing techniques, particularly for localised land degradation issues, such as those on Springvale Station. A brief discussion of these limitations follows.

4.2.2.9 Image spatial resolution

The 30 m spatial resolution of the Landsat satellites sensors is not sufficiently high to accurately ‘map’ erosion features such as gullies. In general, mapping gullies, and other narrow, linear features, requires the features be around six times the size of the image spatial resolution. Data from multispectral satellites with finer spatial resolution but similar spectral characteristics to Landsat, such as the European Space Agency’s Sentinel-2A satellite has recently become available, allowing for the production of fractional cover imagery at 10 m spatial resolution. As more of these data become available over time, the mapping and monitoring of smaller features, including bare patches associated with scalds and gullies, can be improved for the property.

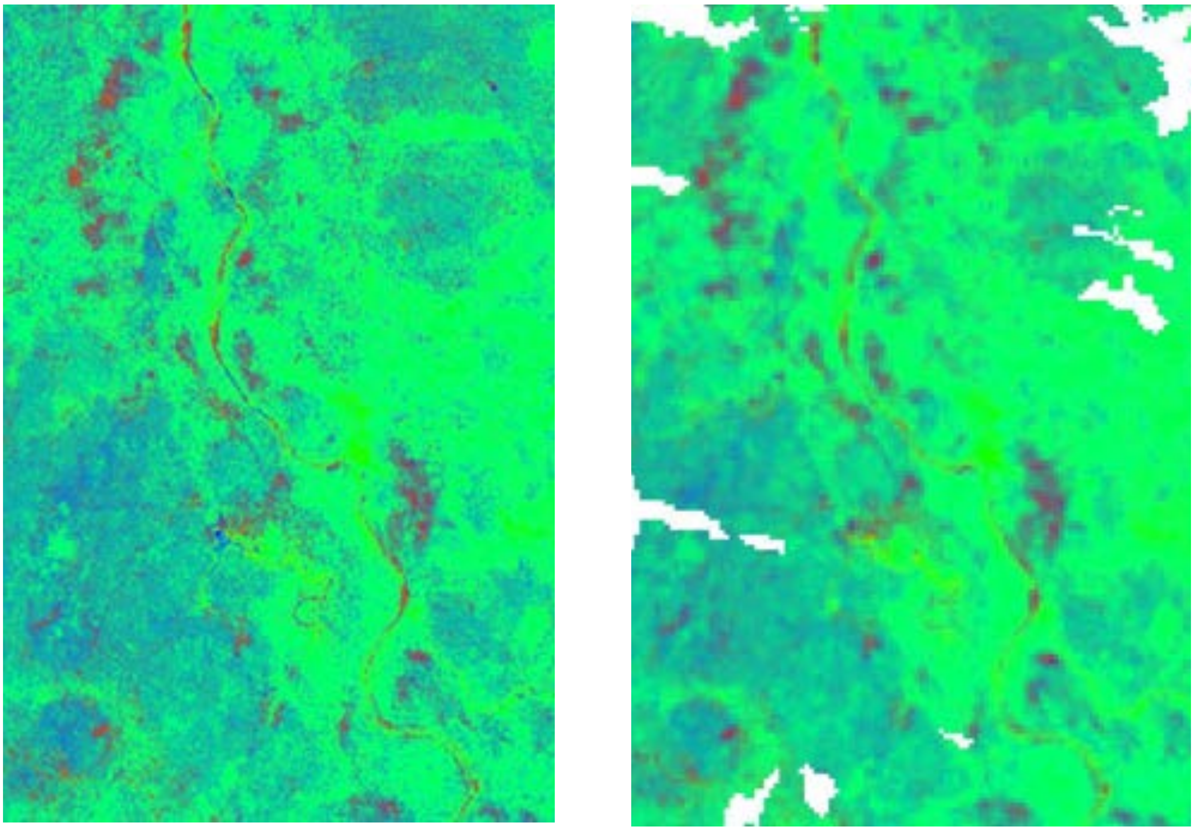
Figure 69 (a) and (b) shows the Sentinel-2 fractional cover over Springvale Station for spring 2016 and the corresponding Landsat Fractional Cover for the spring 2016 for comparison. There are presently some limitations to the Sentinel-2 product. It is only available as a fractional cover product, without woody vegetation removed to create a ground cover product. The imagery is also only available since the beginning of 2016, making it unsuitable for historical analysis. However, ongoing monitoring should include both Landsat and Sentinel 2 to take advantage of the finer spatial resolution of Sentinel-2 and the long historical record of Landsat. In addition, the combination of the two satellites will help to improve the frequency of monitoring at Springvale Station, potentially further improving seasonal compositing and providing greater ability to monitor in cloudy periods. A Sentinel-2 based seasonal ground cover product is planned for production in the next 12 months.

4.2.2.10 Cloud cover

The Landsat and Sentinel 2 satellites are both passive, optical sensing systems, meaning that they detect reflected solar radiation in visible to short-wave infra-red parts of the electromagnetic spectrum. Similar to a standard digital camera or the hum eye, these sensors are unable to penetrate or view the earth’s surface through cloud. Springvale Station is subject to high levels of rainfall and associated clouds, particularly in the wet season. As a result, there are considerable periods of time when the Springvale Station property is almost entirely occluded by persistent cloud cover. This includes the wet periods immediately following the dry season, when ground cover may be at its lowest, and runoff and erosion risk is greatest. Therefore, there may be periods where a valid observation by the satellite is not possible. The seasonal compositing of the data does help overcome some of these limitations, as will the combination of the Landsat and Sentinel-2 satellite imagery. However, there are still likely to be periods where valid observations are not possible, potentially limiting a continuous and systematic monitoring of the land surface on the station.

4.2.2.11 Temporal resolution of median composite product

Seasonal fractional cover and seasonal ground cover are seasonal products created using a medoid approach (Flood, 2013). This approach is a robust and reliable method of reducing noise or outliers in the data, but may mask extreme events that are of importance to the land condition on the station (e.g. localised rapid declines in ground cover, fire, periodic inundation). There are limited alternatives for monitoring however, due to the high levels of cloud cover experienced over Springvale Station. Individual date imagery may be more suitable for detailed monitoring of ground cover condition at the end of the dry season, depending on cloud cover.



(a). Sentinel-2 Fractional Cover for spring 2016.

(10 m resolution)

(b). Landsat Fractional Cover for spring 2016.

(30 m resolution)

Figure 69 (a) left, shows the Sentinel-2 fractional cover over Springvale Station for spring 2016 and (b) right, shows the corresponding Landsat Fractional Cover for the spring 2016 for comparison (Source: DSITI).

4.3 On-ground land condition assessment results

Overall, the land condition of Springvale Station is poor in the high productivity land types (Table 8).

Table 8 Land condition of Springvale Station geologic units (Source: Joe Rolfe).

Geologic units	Condition
Alluvium - general	C-
Alluvium - gullies	D
Basalt	C
Colluvial slopes - general	C
Colluvial slopes – gullies	D
Granitic	Not assessed
Hodgkinson - Normanby Formations - general	A/A-
Hodgkinson - Normanby Formations - areas of cattle concentration	C

4.3.1 Condition of land types with high grazing value (alluvium, basalt, colluvial slopes)

The basalt and alluvial units were assigned a high grazing value based on producer and DAF assessment of land type productive capacity. Historically, these land types have been preferentially grazed due to the low sloping topography (in most cases), inherent productivity (e.g. these areas typically have desirable pasture species, higher fertility soils and greater soil moisture holding capacity) and property infrastructure (fencing and waters). Paddock assessments indicate sustained overgrazing and set stocking over a long period of time. Overstocking, in the absence of wet season spelling, has impacted dramatically on pasture composition and ultimately land condition on these land types.

Land condition was decided after a rapid assessment of pasture composition, soil surface condition, weed invasion and woodland density parameters. The basalt and alluvial formations (active gullies and scalded areas excluded) are in C and C- condition indicating original carrying capacity has been reduced by more than 60%. Loss of 3P (palatable, productive and perennial) pastures and exotic weed invasion are impacting on carrying capacity (Figure 70). Key 3P grasses such as Themeda, Chrysopogon and Heteropogon species have dramatically declined across the alluvial and basalt land types while weeds such as Grader Grass (Themeda quadrivalvis), Sicklepod (Senna sp.), Hyptis (Hyptis sp.), Sensitive weed (Mimosa sp.) now dominate these once productive land types.

In general, the colluvial soils occur in close association with the alluvial or frontage soils and therefore have as similar history of overgrazing. In good condition, the colluvial soils are not as productive as the frontage soils in terms of water holding capacity and 3P pasture composition. The colluvial soils are generally in C condition and have lost half their original carrying capacity, in most part due to soil surface condition (sheet and gully erosion) and pasture species decline. Exotic weed infestations on the colluvial soils are moderate in comparison to the dense and diverse infestations found on the frontages.

The scalded areas and active gullies across the alluvial and colluvial soils are substantial and the primary focus of the Springvale Station Erosion Management Plan. Where cattle grazing access is possible these areas have lost in excess of 80% of the original carrying capacity (D condition). The steep and active gully systems (Figure 71) have been completely taken out of production.

Figure 70 Overgrazing on the frontages (alluvial soils) has taken place over several decades on Springvale Station. In good condition these areas support productive, palatable and perennial grasses (3P). Loss of 3P pastures, weed invasion and some woodland thickening have reduced original carrying capacity by more than 60% (Source: Joe Rolfe).

Figure 71 Active gully systems occur throughout the alluvial or frontage land types. Road infrastructure and sustained overgrazing have accelerated the erosion rates of dispersible soils on Springvale Station (Source: Joe Rolfe).

4.3.2 Condition of the range country (Hodgkinson - Normanby Formations)

The Hodgkinson - Normanby Formations, or range country, dominate Springvale Station and are generally considered to be a low grazing productivity land type. The ranges consist of hilly and steep country on skeletal soils and in good condition supports a mix of annual and some 3P grasses (Schizachrium, Eragrostis, Aristida, Heteropogon and Themeda spp.). Due to time constraints and the focus on the higher productivity land types, the granitic soils were not inspected during this assessment.

Overgrazing and land condition decline across the range country is generally limited to areas where cattle were concentrated due to fencing and water infrastructure. Although in C condition these areas are not widespread. The majority of the range country (Figure 72) has not been preferentially grazed and is in good condition (A or A-). Fire frequency, in the form of hot late season burns, has been high across the ranges due to low grazing pressures and accumulated fuel loads. Where late season fires have been reduced due to stocking pressure, there is evidence of some woodland thickening on Springvale Station. The observed woodland thickening was also investigated using the persistent green trend data from the remote sensing.


Figure 72 The range country (Hodgkinson-Normanby Formation) covers a significant area of Springvale Station. Cattle access, and therefore overgrazing, has been limited across these skeletal soils due to the steep topography and lack of property infrastructure (Source: Joe Rolfe).

4.3.3 Ground cover

In a grazing situation, good ground cover (≥ 50%) at the break of the wet season indicates that stocking decisions made earlier have provided the best opportunity to maximise moisture infiltration while minimising runoff and soil loss. Ground inspections of paddocks and key land types on Springvale Station in May and June 2017 indicated the Springvale Station destocking program is increasing ground cover significantly (Figure 73). Although herbaceous weeds dominate the more productive land types, the break of season ground cover, in the absence of grazing, is predicted to remain very high (active gully systems excluded).


Figure 73 The increase in ground cover since the reduction in stock numbers on Springvale Station is very encouraging (left). Some actively eroding areas continue to be impacted by cattle on Springvale (right) (Source: Joe Rolfe).

4.4 Remote sensing desktop analysis results

4.4.1 Persistent green / Foliage Projective Cover and woody thickening

Springvale Station is dominated by open woodlands and woodland vegetation formations; more than 85% of the station has a foliage projective cover of less than 30% (Figure 74). This assessment was based on the 2014 Foliage Projective Cover product (Armston et al., 2008) are typical of the rangeland and savannah environments of the Cape York region.

Figure 75 shows the extent of woody thickening that has occurred on the property over the last 30 years of the Landsat record, as estimated by analysing the persistent green trend data. A previous property manager anecdotally noted that there appears to have been considerable woody thickening over portions of the property (Quaid, pers. comm.). Areas where the remote sensing analysis indicates woodland thickening appears to correlate with the heavily grazed areas of Springvale Station. This evidence was supported by the on-ground drive-by assessment.

4.4.2 Persistent bare

The persistent bare image (Figure 76) demonstrates the areas of the property where the greatest levels of bare ground have consistently occurred for the past 30 years. These are displayed as the white areas on the green background. These white areas have maintained at least 10% bare ground within each pixel at all times in the past 30 years, and are indicative of potential gullies and scalds. While 10% bare ground may not be considered excessive, this figure represents the minimum level bare ground falls to, even in periods of high rainfall. At other times, such as in drought, these areas would be considerably barer. The persistence of a minimum level of bare ground is indicative of severe local degradation, naturally bare features and infrastructure such as roads. These bare areas are heavily concentrated in the high production value land types such as the basalt and alluvial geologic units. This corresponds with the on-ground assessment that identified degraded areas in the alluvial and basalt geologic units.

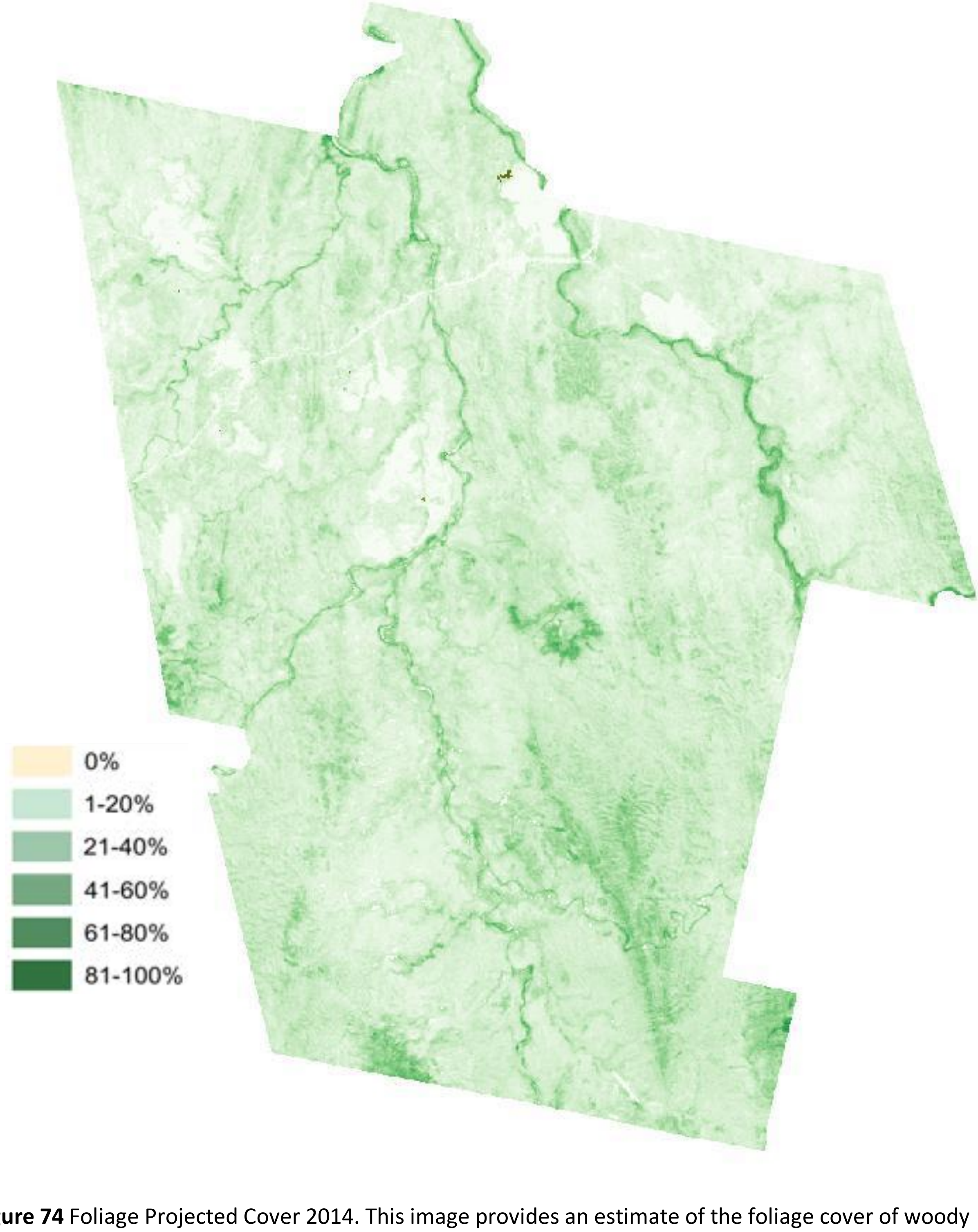


Figure 74 Foliage Projected Cover 2014. This image provides an estimate of the foliage cover of woody vegetation and is generated by a time-series analysis of Landsat imagery from 1988-2014. Darker shades of green represent higher woody vegetation cover (Source: DSITI).

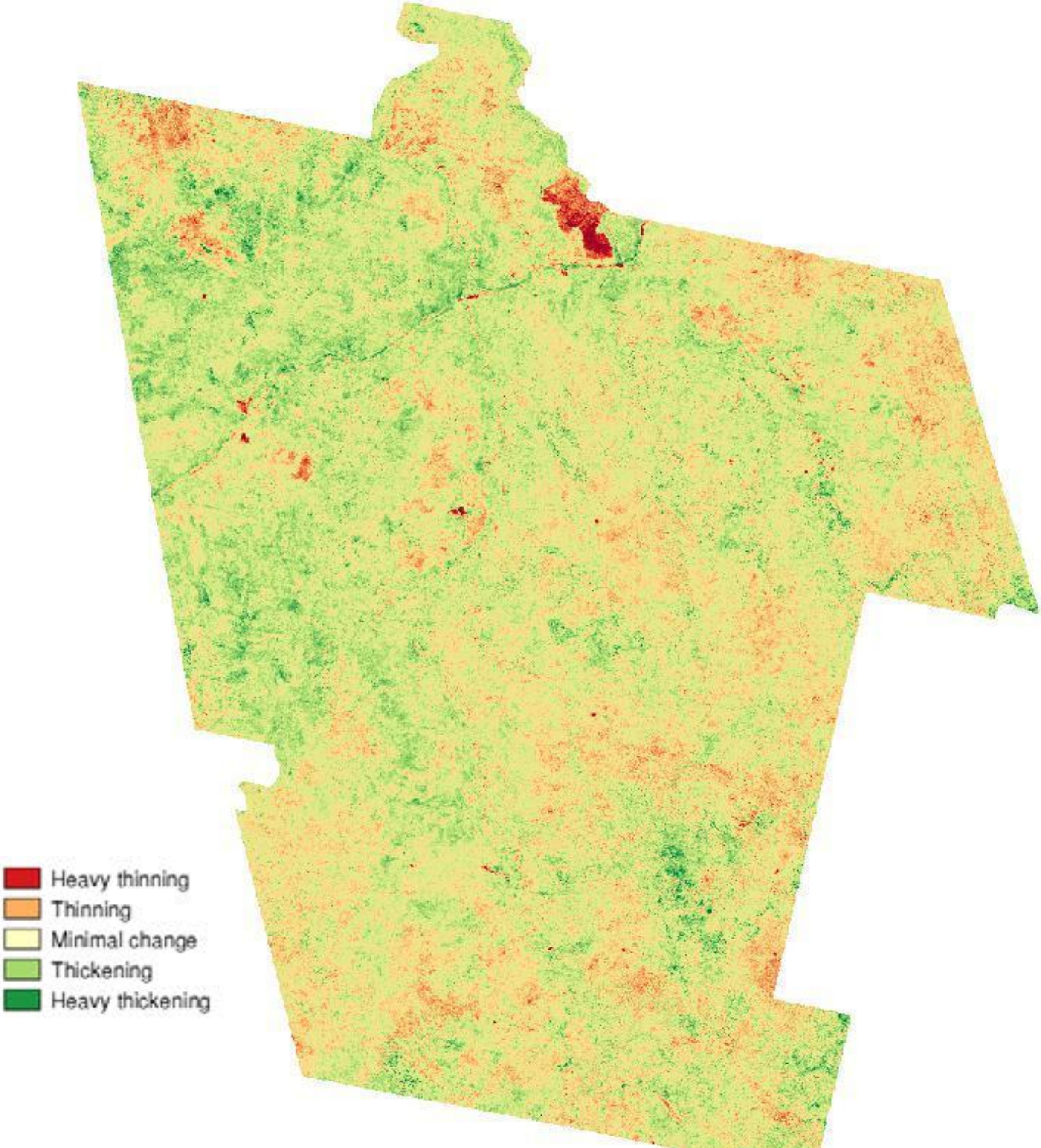


Figure 75 Vegetation thickening between 1986 and 2015. This image provides an indication of areas on the property which have shown a long-term (1988-2012) increase (darker green areas), decrease (red areas), or no change (yellow areas) in the density of persistently green vegetation. Persistent green vegetation is assumed to be woody vegetation but may be confused with persistently green pasture or other herbaceous vegetation. Where an increase is indicated, these areas may represent possible woodland thickening or densification, or possible long-term encroachment of woody vegetation. Where a decrease is indicated, this may represent possible thinning, clearing, repeated fire exposure or other vegetation density reduction over time (Source: DSITI).

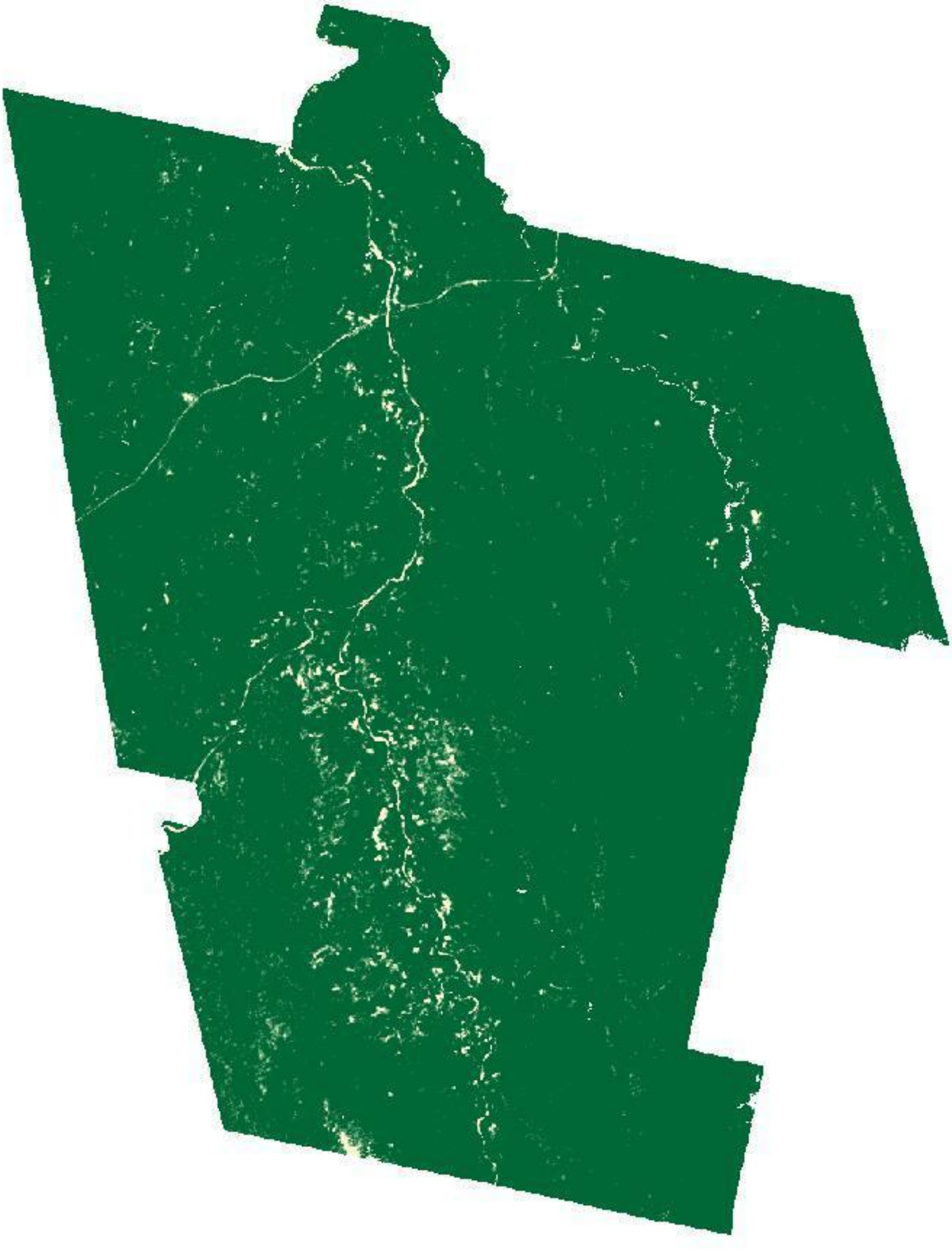


Figure 76 The persistent bare image identifies the areas where ground cover is always very low (white areas). This appears to align with the developed and most heavily grazed areas on Springvale Station (Source: DSITI).

4.4.3 Ground cover dynamics

Remotely-sensed ground cover is often used as a proxy for land condition as it can be indicative of areas of the landscape which are degraded or areas which have sustained high levels of ground cover over a prolonged period and in dry times, potentially indicating better land condition. It is important to note that while ground cover data from remote sensing is a useful proxy for land condition, at present, it is not possible to determine species composition from these data. Therefore, high levels of ground cover may be due to herbaceous weeds which may not be good for productivity, but may still have some benefit over bare ground or low cover for minimising erosion and runoff. It is therefore important to exercise caution when interpreting the remote sensing data, depending on the purpose for which it is being used and assessed.

The greatest driver of ground cover levels is rainfall, followed by grazing management. Figure 77 shows the levels of ground cover on Springvale Station in relation to the rainfall since 1990. The relationship between rainfall and ground cover levels is evident, with higher rainfall leading to higher ground cover. Green cover immediately increases following rainfall, replacing bare ground and non-green cover and then over time ‘hays’ off (i.e. dries out to become non-green cover) and bare areas also increase. Bare ground over the property is consistently low, which is typical of the region; at no time since 1990 has bare ground levels over the entire property exceeded 20%.

The driest and barest season on the ground at Springvale Station is typically spring (i.e. the late dry season), which is followed by wet season rainfall in summer and autumn and subsequent greening up across the property. The greenest period is typically in autumn, with haying off occurring in winter. While 2015 had summer rains occurring considerably later than usual and persisting through autumn, the broad seasonal pattern can still be seen in the four images in Figure 78.

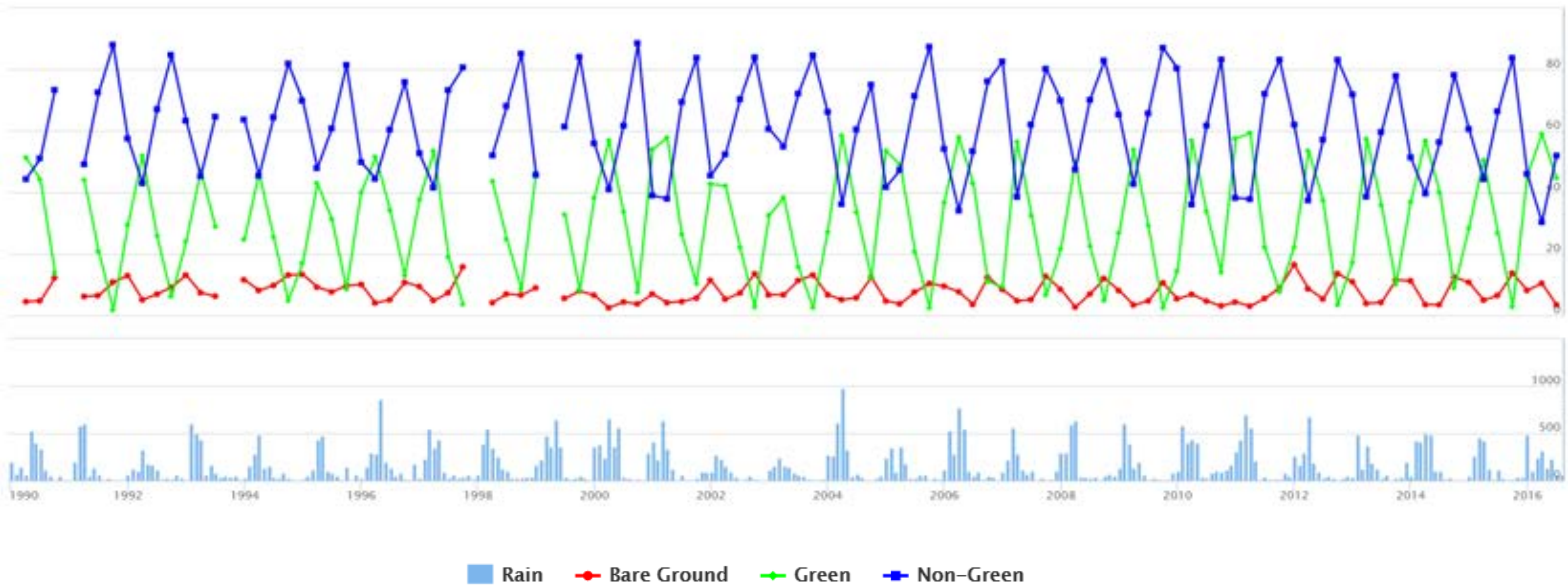


Figure 77 Ground cover and rainfall relationship for 26 years (1990 - 2016) on Springvale Station (Source: DSITI).

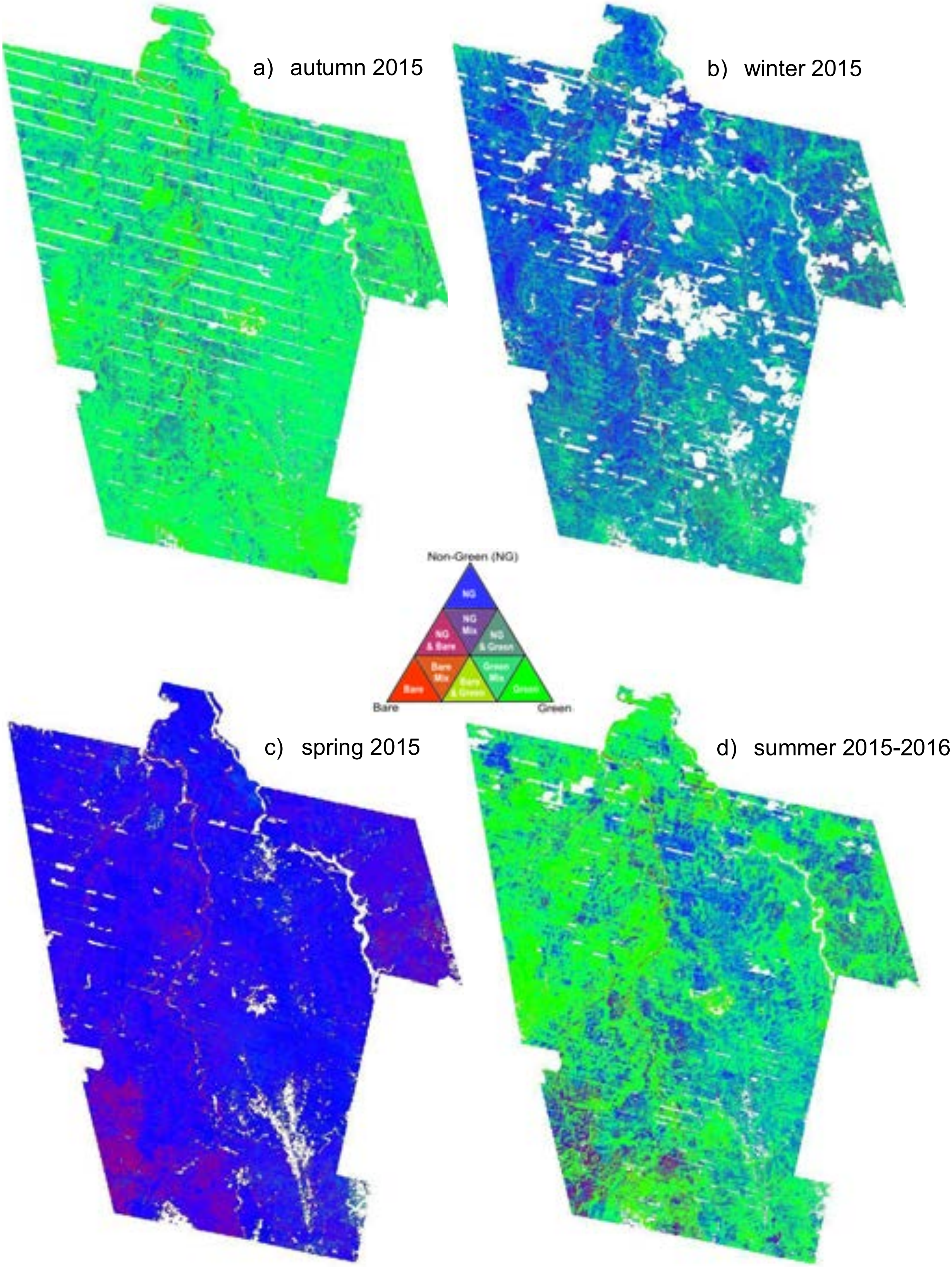


Figure 78 Seasonal ground cover images over Springvale Station for 2015. a) autumn, b) winter, c) spring and d) summer. Red = bare ground, blue = non-green ground cover and green = green ground

cover. Composite colours represent mixtures of these classes. The seasonal ground cover pattern can be clearly seen (Source: DSITI).

Visual inspection of the seasonal ground cover imagery over time shows that the bare areas identified in the persistent bare image quickly ‘green up’ after the commencement of the summer rains and become significantly more vegetated (Figure 78). Prior to this increase in ground cover, however, these bare areas may act as a potentially significant sediment source.

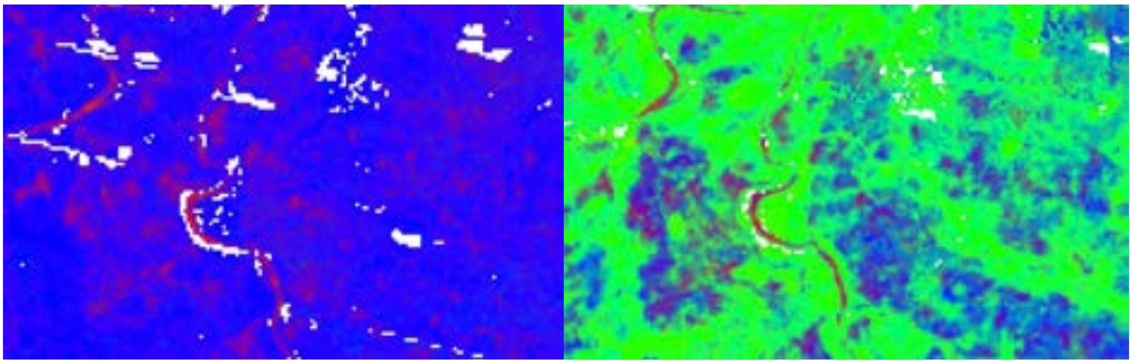


Figure 79 Ground cover over heavily degraded alluvial soils in spring 2016 (left) and summer 2016 (right). Red areas = bare ground, green areas = green ground cover and blue areas = non-green ground cover (Source: DSITI).

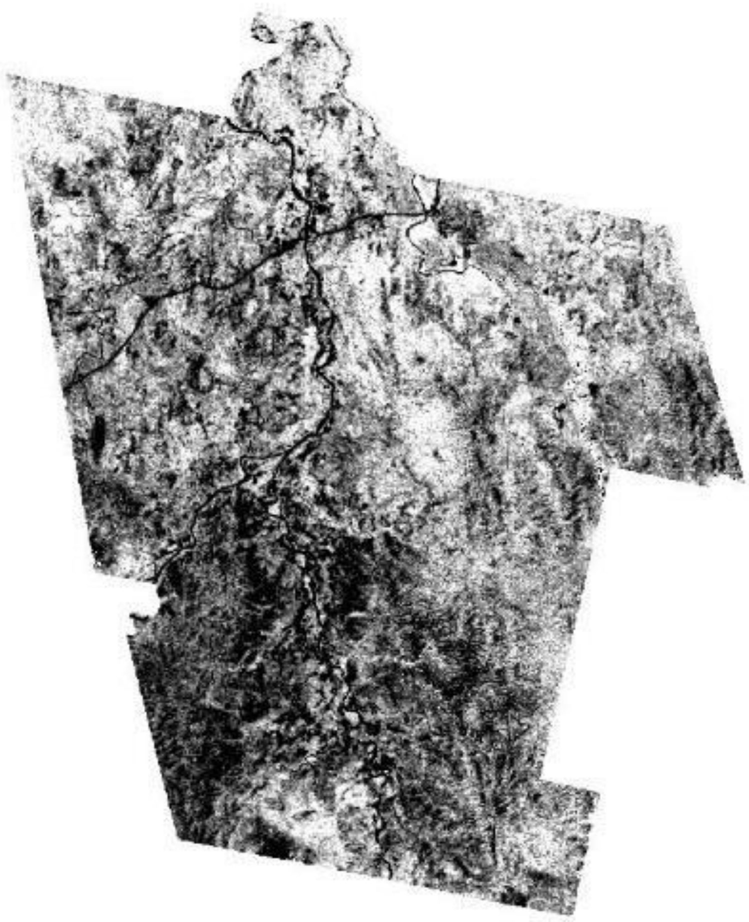
Based on a comparative analysis of the station with the regional levels of remotely sensed ground cover using the DRCM, is generally maintained at a high level across the property, but lower than the best performing areas in the region, which are consistently above 90% ground cover at all times. An assessment of the time-series of the seasonal ground cover data also highlights regions of persistently bare ground, particularly evident in the alluvial paddocks of Springvale Station. These regions do increase in cover significantly after the summer rains but return to bare in the drier months. More detailed monitoring at the end of the dry season may be appropriate to assess cover at this sensitive time.

4.4.4 Percentiles

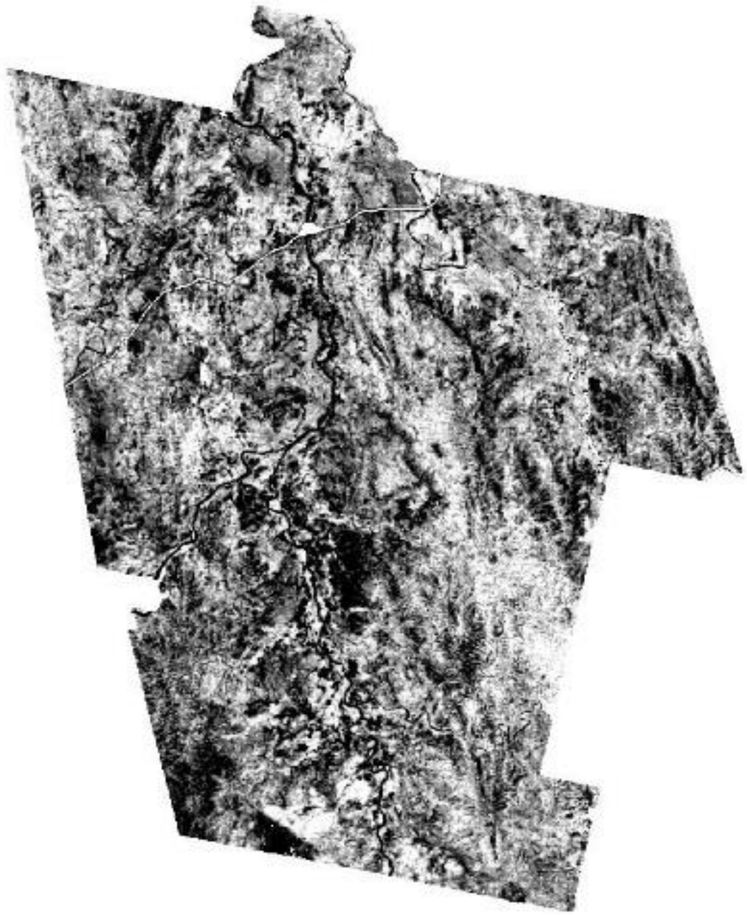
Figure 80 shows the poorest performing areas in relation to ground cover over each period. Darker areas represent areas of lower cover with lighter areas being more vegetated. Figure 80 illustrates a shift in the degraded areas over the property post 1998, a period when continuously high stocking rates have been identified. Between 1990 and 1998, cattle production intensified and the most degraded areas of the property, in relation to ground cover, were largely restricted to southern section of the property (on the south side of where the West Normanby River branches from the Normanby River) and diffuse. With continuous heavy grazing, post 1998, the pattern of ground cover across the property has shifted to reduced cover in other areas of the property and highly concentrated in certain areas.

4.4.5 Fire regime

Based on the Landsat fire history, the majority of the Springvale Station property has not experienced fire for many years (Figure 81), with the exception of the Hodgkinson - Normanby Formation which still experiences regular fires. This lack of fire across the property is not typical of this region, which normally has a bi-annual fire regime (Lisa Collet, Remote Sensing Fire expert, pers comm). This alteration of the fire regime is most likely due to high grazing pressure reducing fuel loads. It is expected that with reduced grazing pressure as destocking proceeds, fire frequency and extent will increase and should be monitored.



90-98 management period – intensification moderate to heavy grazing



99-16 management period – heavy continuous grazing

Figure 80 Ground cover ranking within the Springvale Station property for two identified management periods, intensification prior to heavy grazing and after continuous heavy grazing. Darker areas represent areas of lower cover with lighter areas being more vegetated (Source: DSITI).

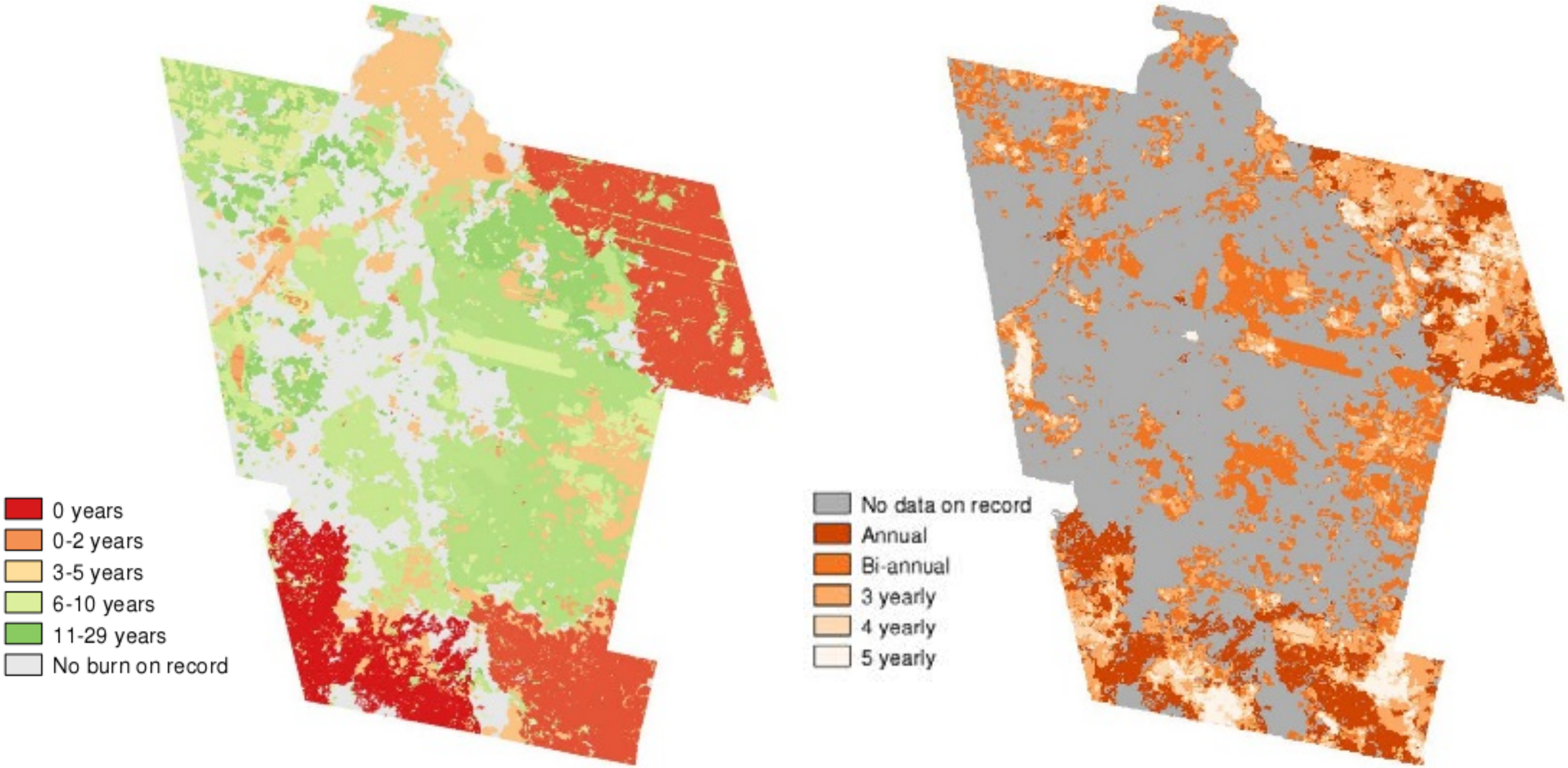


Figure 81 (a) on Left is Time since burn, current as of 2015. Recent fires will not have been captured in the image. (b) on right is Fire frequency (Source: DSITI).

4.5 Conclusions and recommendations

Heavy continuous grazing has caused a decline in land condition and ground cover levels and an increase in erosion. Destocking will likely benefit the high grazing value land types in terms of perennial grass recovery and increasing ground cover (see the case study on pasture condition monitoring that follows), although there will be a lag effect before this recovery is realised. This will in turn reduce runoff into the substantial gully systems on Springvale Station. However, destocking alone will not stabilise the active alluvial and colluvial gully networks on Springvale Station. The 'Erosion Management Plan to guide 2017 to 2022 actions' identifies and costs pilot project areas and 'best bet' gully stabilisation techniques.

General recommendations of the Desktop Land Condition Analysis include:

1) Undertake regular (seasonal or annual) land condition monitoring
    a) Install fixed photo points (landscape and ground) on the alluvials and basalts to monitor weeds, perennial pasture recovery and ground cover. Some land condition recordings could be included in relation to species frequency and contribution to yield. Tree basal area can also be easily recorded at these sites.
2) Undertake regular (seasonal) remote sensing monitoring
    a) This monitoring should include ground cover levels (particularly in gullied areas); woody extent/thickening; and fire frequency and aim to detect altered patterns since destocking.
    b) Conduct quantitative ground cover fieldwork at the end of the dry season to continue to calibrate and validate remote sensing products used for monitoring.
    c) Investigate analysis of individual date imagery over the end of the dry season, to monitor changes in bare ground.
    d) Establish timelapse cameras ('phenocams'), co-located with selected land condition monitoring sites to provide additional detail on the greening response and ground cover levels following the start of the wet season, where satellite imagery is often affected by cloud cover.
    e) Continue to compare Springvale Station to the local region to benchmark and monitor recovery and also to help quantify and understand the effects of different grazing strategies on landscape recovery.
3) Develop and implement weed management plan
    a) Control woody weeds and native woodland thickening using fire, when there is adequate fuel (storm burns following 50mm or rainfall).
    b) Control non-woody weeds such as grader grass, Hyptis, Noogoora burr and sicklepod using fire in conjunction with chemical control and other methods. Fire alone does not control grader grass and can cause mass emergence of Sicklepod seedlings following rain.
4) Develop and implement revegetation plan for gullies
    a) Rapidly establishing grass cover is a key element of any scald or gully remediation program. Soil disturbance and shallow planting depths are required for successful grass establishment, but may also cause additional erosion.
    b) Assess potential of native grass species suitable for scald and gully rehabilitation, given issues with seed harvesting, procurement and germination rates.
    c) Assess risks and potential of exotic grass species for scald and gully rehabilitation, given potential invasiveness of these species.

CASE STUDY: Pasture condition monitoring at Springvale and Kings Plains 2012-2016

Monitoring the changes from destocking cattle from large areas of properties can be difficult on a limited budget and few field sites. Remote sensing can assist in detecting major changes over large areas over longer periods of time (see sections above). However, field data are important to validate any remote sensing. More importantly, empirically field data are essential to quantify actual conditions on the ground, as remote sensing can have inherent errors and limitations, as well as scale issues.

A small amount of empirically field data on pasture condition exist at Springvale Station, and neighbouring stations at Kings Plains and Crocodile (Shellberg and Brooks 2013; Shellberg, Segboer, Hughes, unpublished data). These data can be used to help set the baseline pasture conditions and any changes over time. It is recommended to expand on these limited datasets to a much larger number of sites across Springvale Station following a Before After Control Impact (BACI) design.

Methods

'Before' destocking conditions of Vegetation Cover and Land Condition Assessments (LCAs) at river frontage pasture locations (terraces above gullies) were conducted in November 2012 at Springvale and Kings Plains Stations before any cattle destocking (Shellberg and Segboer, unpublished data). Methods for assessment are outlined in Shellberg and Brooks (2013) and in Table 9. At Springvale, 10 grazed plots ($4m^2$ each) were monitored on high alluvial terrace surfaces above gully heads at sites distributed across Abby Lea and Dead Dog Paddocks along the Granite Normanby River. At Kings Plains, 15 plots were monitored at comparable alluvial terrace sites above gullies in November 2012 (Dingo; 12-Mile; Ranch Paddocks).

Kings Plains Station under new ownership began destocking Dingo and 12-Mile in late 2013. By 2016, few cattle remained in these paddocks. These Kings Plains paddocks became treatment (impacts) sites to detect changes in pasture condition from historic grazing, while the Springvale sites continued to be grazed as normal until the grazing lease expires in late 2017. In Nov-2016, these monitoring plots on Springvale and Kings Plains were resurveyed for comparison and assessment. They will be revisited again in Nov-2017 and Nov-2018 as part of the Reef Trust project on Kings Plains.

Additional BACI plots data also exist within and around alluvial gullies with and without cattle exclusion fences at Springvale and Kings Plains (over 100 plots total), but these data target gully vegetation changes rather than general property pasture changes (Shellberg and Brooks 2013). However, they could be used for more detailed assessment of local pasture changes from destocking.

Preliminary results to 2016

Preliminary results of pasture condition at Springvale and Kings Plains plots indicated that increases in perennial grass cover and pasture yield occurred at Kings Plains following destocking, with minimal changes to tussock counts and weed cover (Figure 83). In contrast at continuously grazed sites on Springvale Station, pasture conditions either declined or stayed stagnant (Figure 83). From these vegetation plot data at Kings Plains, it is evident that changes to moderate grazing pressure and stocking rates had moderate influences on ground cover over the period studied (2012-2016). Under these moderate grazing situations, rainfall variability is also as important as grazing pressure on influencing cover. Rainfall totals (annual) were similar in 2012 and 2016, but additional years of data are needed. Additional data exist at Springvale plots from July 2014, but Kings Plains data are limited to 2012 and 2016.

Improvements to vegetation cover take time (Shellberg and Brook 2013; Shellberg et al. 2016b). Between 2012 and 2016 some significant improvements in perennial cover were being observed at Kings Plains paddocks. Additional pre-2011 before data during periods of higher stocking rates at Kings Plains would have been needed to document the full changes from spelling and destocking, as indicated by anecdotal observations and photos from 2009-2010. Longer term datasets (10-20 years) on pasture condition will be needed to track any additional improvements on Springvale Station. Grazing exclusion areas on Springvale are beginning to show some improvement over time at paddocks above gully heads (Figure 82). However, vegetation cover internally within gully complexes is much slower to respond and recover following cattle exclusion (Shellberg and Brook 2013; Shellberg et al. 2016b). Overall these data suggest that any strategy for reducing sediment yields, as a function of reduced grazing pressure and passive increases in grass cover, will likely occur fairly quickly (5-10 years) on pasture hillslopes and very slowly over several decades internally within gully complexes. Increases grass cover on pasture hillslopes across large areas could reduce hillslope sediment production in the short-term, and thus influence the < 10% of the total sediment budget. Whereas, the slow passive recovery of vegetation within gullies will have minimal influence in the short-term on sediment yields from > 50% of the total sediment budget.

Figure 82 Various examples of grazing pressure influences on pasture grass biomass and ground cover at Springvale Station inside and outside cattle exclusion areas (Source: Shellberg and Brooks, 2013).

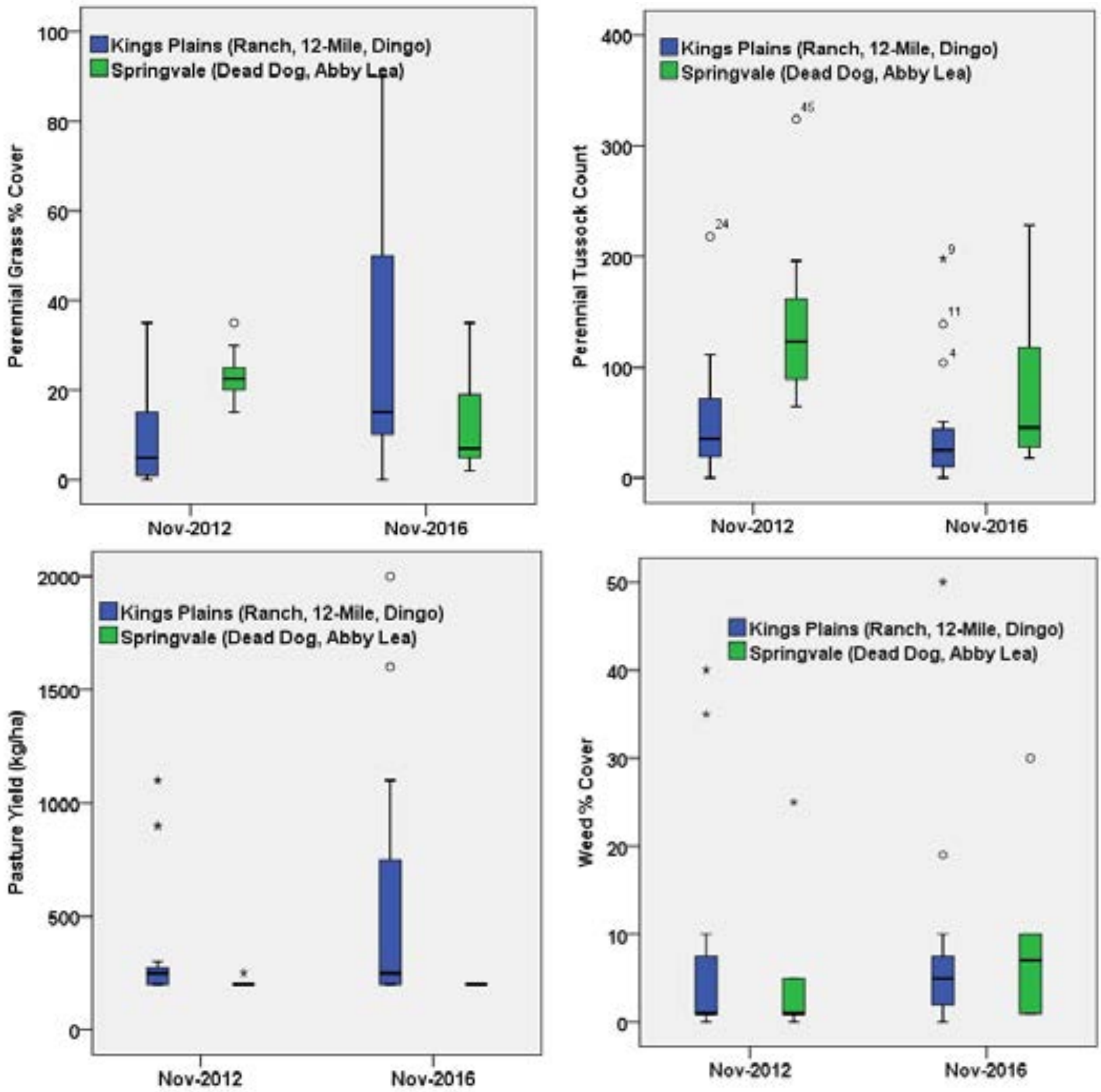


Figure 83 Changes in pasture vegetation conditions between Nov-2012 and Nov-2016 at Kings Plains (n=15) and Springvale Stations (n=10) on high terrace surfaces above gully heads (Source: Shellberg and Segboer, unpublished data).

Table 9 Monitoring report template for vegetation cover and pasture condition (Source: Shellberg and Brooks, 2013).

Pasture Monitoring Template

Site Name______________________ Plot ID______________________
Date__________ Time__________ Plot Area (m^2)__________________

GPS Tracklog Running? **Yes** ☐ **No** ☐
Photo of GPS Time Stamp? **Yes** ☐ **No** ☐
GPS Position Waypoint of Marker Stake? (*Time Averaged*) **Yes** ☐ **No** ☐
Plot edge oriented North-South? (*Use compass*) **Yes** ☐ **No** ☐

Plot Photos
2.5 m from Stake, Centered on Stake, (North Looking South) Photo # __________
6.0 m from Stake, Centered on Stake, (North Looking South) Photo # __________
2.5 m from Stake, Centered on Stake, (South Looking North) Photo # __________
6.0 m from Stake, Centered on Stake, (South Looking North) Photo # __________
Vertical Plot Photo (NE Quad) Photo # __________
Vertical Plot Photo (NW Quad) Photo # __________
Vertical Plot Photo (SW Quad) Photo # __________
Vertical Plot Photo (SE Quad) Photo # __________
Canopy Vertical Photo, Looking Up at Sky # __________
Additional Site Area Photos (with Stake Ref.) Photo #s __________________
Additional Plant Part Close-up Photos #s __________________________

Ground Cover (*aerial projection downward*)
Total % Organic Ground Cover ______________________________
(Nearest 5 %, standing grass/weeds, dead matted grass, roots, leaves, sticks, wood)
% of total area (oblique) = leaves/sticks ____________
% of total area (oblique) = dead matted grass ____________
% of total area (projection downward) = standing vegetation (all)__________
% of total area (projection downward) = standing weeds____________
% of total area (projection downward) = perennial pasture grass cover________

Perennial Pasture Grass Cover (*rooted, standing, not herbaceous weeds, %*)________
(Aerial Projection downward, not just basal area)(Same as value above)
# of Species__________
Total Count (#) of Perennial Tussocks ______________________
NE Quad______, NW Quad______, SW Quad______, SE Quad______
Species Names (if Known) ______________________________

____

Pasture Yield Estimate (*kg/ha*) (*use plot area and immediate surroundings*)
Yield Guide Used (*Frontage, Yellow Earth, Granite*) ____________________
Pasture Grass Yield Only (kg/ha)________________________
(exotic or native grass *w/out* herbaceous weeds, shrubs, trees)
250 ☐, 300 ☐, 400 ☐, 500 ☐, 600 ☐, 800 ☐, 900 ☐,1100 ☐,
1300 ☐1600 ☐, 1700 ☐, 2000 ☐, 2200 ☐, 2400 ☐

Pasture Yield With Herbaceous Weeds and Exotic/Native Grass (*kg/ha*)________
250 ☐, 300 ☐, 400 ☐, 500 ☐, 600 ☐, 800 ☐, 900 ☐,1100 ☐,
1300 ☐1600 ☐, 1700 ☐, 2000 ☐, 2200 ☐, 2400 ☐

Land Condition

Total % Organic Ground Cover (*see above*)____________________________

Perennial Pasture Grass Cover (*see above*)____________________________

Dominant Pasture Plants (*list top 4 and total #*)__________________________

____

Dominant Weed Plants (*list top 4 and total #*)____________________________

____

Weed Dominance (*% of individual plants*)
Abundant > 50% ☐, Mod 20-50% ☐, Low 5-20% ☐, Slight <5% ☐, None ☐

Soil Crust Condition (*broken-ness*)
Intact < 5% ☐, Slight 5-20% ☐, Moderate 21-50% ☐, Extensive >50% ☐

Erosion Features (*gullies, rills, tracks/pads, sheeting, scalds, hummocks, terracettes*)
Insignificant < 5% ☐, Slight 5-20% ☐, Moderate 21-50% ☐, Extensive >50% ☐

Deposited Material (*silt, sand, gravel, rock, not organic*)
Insignificant < 5% ☐, Slight 5-20% ☐, Moderate 21-50% ☐, Extensive >50% ☐

Vertical Distance from Stake Top to Soil Surface (*use tape measure*)
- Upslope (mm)____________________
- Downslope (mm)__________________

Overall Land Condition Class
- A☐ Good (*dense perennial grass, no signif. weeds, no signif. erosion*)
- B☐ Fair (*mod. perennial grass, a few weeds, minor erosion*)
- C☐ Poor (*low perennial grass, weeds common, obvious erosion/scalds*)
- D☐ Very Poor (*few perennial grass, weeds infestation, severe erosion/scalds*)

COMMENTS

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5 Erosion Management Plan to guide 2017 to 2022 actions

The ‘Erosion Management Plan to guide 2017 actions’ used the best available high resolution within-property data sets combined with the property-wide data sets to define a Priority Focus Sediment Management Area within Springvale Station and outline appropriate land management actions and locations to reduce soil and gully erosion. Specifically, the Erosion Management Plan covers how to:

- Reduce the risk of new soil and gully erosion occurring,
- Reduce the areas currently affected by soil and gully erosion, and
- Prevent the growth of established gullies.

5.1 Priority Focus Sediment Management Area

A Priority Focus Sediment Management Area within Springvale Station has been identified using the team’s field knowledge of geologic units and their erosion issues, coupled with the Normanby Empirical Sediment Budget (Brooks et al. 2013) and updated data included in Brooks et al. (2016) and Spencer et al. (2016). The Normanby sediment budget (Brooks et al, 2013) was based on an extensive 4 year field and remote sensing study which used multiple lines of evidence analysis to identify the sources and fate of sediment from source to sink in the Reef lagoon. The study incorporated satellite remote sensing, repeat aerial LiDAR surveys, historical air photo analysis, measured in-stream sediment concentrations and hillslope erosion rates, radionuclide and geochemical sediment tracing, along with road, track and fence line mapping. Whilst this work undoubtedly has limitations and did not measure all budget components or sediment sources and sinks at the same level of detail (Table 10), to date this is the most detailed sediment budget to have been conducted in the any GBR catchment. Future improvements will be made to progress the data sets and scientific knowledge.

The Normanby empirical sediment budget (Brooks et al., 2013) has been used to analyse the sediment contribution from each geologic unit from the major sub-catchments within Springvale Station. Updated data from Brooks et al. (2016) and Spencer et al. (2016) was also included.

The surface geologic units analysed are:

- Alluvium
- Colluvial Slopes
- Hodgkinson - Normanby Formation
- Basalt
- Granitic.

The major sub-catchments analysed are:

- Granite Normanby
- West Normanby
- East Normanby
- Leichardt Creek.

The Alluvium and Colluvial Slopes geologic units within the four major sub-catchments have been identified as areas sensitive to accelerated soil erosion. They are ranked in the following priority order based on field knowledge and the analysis of modelled sediment loss:

1 Granite Normanby Alluvium and Colluvial Slopes

2 West Normanby Alluvium and Colluvial Slopes

3 East Normanby Alluvium and Colluvial Slopes

4 Leichardt Creek Alluvium and Colluvial Slopes

All future property management activities within all these areas should consider soil erosion mitigation strategies supported by expert advice and site planning.

The modelled top 25 soil erosion producing sub-catchments within Springvale Station have been identified to support prioritisation of gully remediation and road remediation actions. The analysis of the full set of 252 sub-catchments on Springvale Station, estimates that around 60% of the modelled sediment yield is derived from the top 25 of these sub-catchments (or 7.2% of the land area), and all of these fall within the alluvial and colluvial geological units in the Granite Normanby and West Normanby. This model analysis has a degree of uncertainly (all models are inherently wrong and contain residual error; Kondolf and Matthews 1991). However, this analysis has been interpreted in conjunction with repeat LiDAR analysis, local empirical data, and expert field knowledge to define focus areas for gully remediation actions in known high erosion areas.

It is recognized that the relative order of these top 25 and other sub-catchments will likely change once LiDAR data is available for the entire property and higher resolution analysis of the gully distribution and typology throughout the entire property to document the full distribution of erosion and gully types in much higher resolution, along with improved estimates of the sediment budget. However, it is unlikely that new very large gully hotspots will be found, and the alluvial/colluvial soils will remain the Priority Focus Sediment Management Area, dominated by the Granite Normanby.

The mapping of gully density in heavily wooded terrain will become more apparent with new LiDAR, as well as gully type and stage of gully evolution. Property wide LiDAR data will be essential for developing a processed-based prioritisation scheme for erosion control at Springvale Station not exclusively based on estimated sediment yield. It is recommended that future prioritization be based on mapping all erosion features (sheet, scald, rill, gully, bank, mass failure, road/fence disturbance, infrastructure), the full range of soil types and erodibility, gully type and stage of evolution, future erosion risk, degree of human caused erosion acceleration, sediment yield, accessibility, material availability, potential for collateral damage, and practicality of intervention. Detailed designs and intervention strategies will be required for any erosion control works, which also is when further higher resolution analysis can be undertaken at the scale of individual gully complexes.

Road and fence line erosion hotspots and ‘choke points’ limiting access have been identified separately from field surveys for the Granite Normanby and West Normanby sub-catchments (Figure 102). These data help define known erosion and access problem areas that are recommended for no regrets road stabilisation actions in the 2017/18 calendar years. Some of these areas are within the modelled top 25 soil erosion producing sub-catchments, and some are not, due to the scale of air photo gully mapping compared to field mapping of road and fence erosion issues and associated gullies of various size. Systematic LiDAR data and comprehensive road/fence erosion surveys will improve these two datasets. However, prioritisation of road and fence erosion hotspots for intervention and major gully erosion hotspots (top 25 sub-catchments) can occur separately but simultaneously. Both roads and gullies are known to be problems needing to be addressed to reduce sediment yields.

5.1.1 Empirically-modelled sediment budget and yield estimates for Springvale Station

Sediment source data in the Normanby catchment and Springvale Station is summarized below. This data is derived from extensive field and remote sensing work acquired through a 4 year Australian Government Reef Rescue Project carried out between 2009 and 2013 (Brooks et al., 2013), with additional follow up work acquired through NESP project 1.7 in 2015/16 (Brooks et al., 2016). An overview of the data inputs to the initial version of the Normanby empirical sediment budget, from which much of the data presented here is drawn for Springvale Station, is summarised below. Readers should also refer to the original source reports and appendices for a detailed description of the input data sources. Additional data derived from further LiDAR change detection carried out as part of the NESP project in 2015/2016 across 2532 hectares of land with common LiDAR in 2009, 11 & 2015 shows how erosion rates at the site scale vary considerably over the short term.

The model data presented here are the best available across the whole catchment. They represent the state of knowledge at the conclusion of the 2013 Reef Trust/MTSRF Project, with some updates. This work undoubtedly has limitations with dataset uncertainty, and did not measure all budgets components or sediment sources and sinks at the same level of detail. All models are inherently wrong and contain residual error (Kondolf and Matthews 1991), but over time they can be improved to support a deeper understanding of erosion and deposition processes. A list of some of the key known sources of error and uncertainty are provided below (Table 10).

However to date, this model is the most detailed sediment budget to have been conducted in any GBR catchment with supporting empirical data. It provides a strong basis for first order management prioritization at the geologic unit scale, and identifies some known hotspots of gully erosion at the sub-catchment scale. Future improvements will be made to progress the data sets and scientific knowledge, and improve our understanding of various sediment sources and inter-annual variability of erosion. Ideally the catchment model would be updated as the new empirical data becomes available (e.g. new LiDAR change detection across all of Springvale Station), however sufficient resources have not been available to complete this task to date.

5.1.1.1 Natural vs accelerated erosion

The sediment yield data derived from this empirical modelling approach represents a snapshot in time of the contributions from as many of the erosion and deposition processes that could be adequately measured and hence parameterized in a model. The model does not, however, distinguish whether a process is natural or accelerated by land use. Some processes, such as hillslope mass movement (shallow rapid landslides), were not parameterized in the model, partly because they are natural, less frequent events in this landscape that are hard to predict and measure. Some mass failures would be difficult to manage beyond basic land use BMPs (grazing, fire, roads), even if we could adequately parameterize them. However, of the major processes that are parameterized, it is sometimes very difficult to determine the precise extent to which the process has been accelerated by human land use.

Sheet, rill and gully erosion associated with roads, cattle tracks, fence lines, can clearly be defined as accelerated processes. However, not all gullies are initiated and accelerated by land use on Springvale Station. For other processes such as hillslope erosion or streambank erosion, both of which are natural processes which occur in the absence of “European land use” pressures, it is very difficult to determine the precise extent of recently observed erosion that is accelerated. We don’t have direct evidence for the pre-European rates of erosion associated with these processes, hence we can only infer rates of acceleration from indirect sources of evidence (such as sedimentological evidence of increased sediment accumulation rates; or major grazing disturbance of hillslopes).

Stream bank erosion rates are particularly difficult to attribute acceleration factors to, given that there are multiple factors driving the process, with interactions between many of the variables. There are indirect drivers, such as catchment hydrology, which can be modified by reduction in vegetation cover, increased water runoff rates, climate change and variability, changes in catchment soil permeability, drainage network extension (through gully or channel erosion), and changes to in-channel vegetation and large woody debris loadings (influencing channel network roughness). More direct disturbance factors include grazing pressure on banks, which directly disturbs bank sediments and reduces vegetation cover that is stabilizing the banks through root cohesion. Increased bed material loads (sand and gravel), and in-channel sedimentation associated with increased gully erosion upstream, can also drive more bank erosion in some places, or lead to less in others. Hence, the multi-factorial nature of bank erosion drivers makes it extremely difficult to assign any sort of acceleration factor.

Gully erosion presents a slightly more tractable problem, because it is fairly obvious when a gully is eroding into a previously uneroded surface that this is a “young process”, the origin of which can often be determined using a combination of historical air photographs and field-based geomorphic evidence. OSL dating of deposited gully sediments at Springvale Station indicate that erosion rates have increased 5x to 10x since European settlement compared to background rates pre-European settlement (Brooks et al. 2013). The situation is slightly more complicated when the gully erosion is occurring within the bounds of an earlier drainage form (floodplain hollow) or a "prior gully", which was stable at the time of first European settlement, but has been reactivated and accelerated since grazing or other disturbance pressures were initiated (Brooks et al. 2013; Shellberg et al. 2016a). The very existence of these earlier drainage forms is a function of a longer landscape evolution process that has been evolving over at least the last 10,000 + years, forming the landscape template onto which the modern day erosion processes are superimposed. As outlined in this report, most of the alluvial gullies on Springvale Station are located on old floodplains (terraces) which typically have basal sediment ages of at least 30,000 years old (Brooks et al., 2013, Pietsch et al., 2015). The earlier drainage forms and prior gullies that have eroded into these surfaces have occurred over the last 10,000 years as the main channels incised in response to declining long term sediment supply rates driven in part by changing climate and hydrology. This left these old floodplains abandoned well above the contemporary levels of even the largest floods, and allowed these alluvial sediments to sit and weather for thousands of years, weathering to highly unstable sodic soils. The sodic nature of these soils, coupled with the fact that they are now perched high above this massively entrenched macro channel, has left a landscape that is now inherently unstable. It was then into this naturally unstable template that cattle and other disturbances were introduced, setting off a highly predictable (in hindsight) chain of events that reactivated prior gullies and initiating new gullies, causing them to erode to extents not seen at least for the last 30,000 years (e.g., Shellberg et al. 2016a).

In summary, there is good evidence that much (but not all) of the active gullying that can be observed today within Springvale Station, is an accelerated process. While the precise loads delivered from these gullies will vary from year to year – the general areas where the most active gullies are found will not. Equally the erosion associated with roads, tracks and fence lines is clearly a purely anthropogenic process, and should be minimised and stabilised where possible, while still maintaining the minimum amount of access required around the property to manage it. It is difficult to say to what extent the other processes such as channel erosion are accelerated (it is likely they are to some extent), and so these processes need to be monitored, but will probably not require direct management. Rather, bank erosion and hillslope erosion are best addressed through broad scale management measures such as reducing grazing pressure, weed and fire management.

5.1.1.2 Basis for erosion source identification

The Normanby sediment budget was designed at the scale of the whole Normanby Catchment, which pinpointed Springvale Station as the highest concentrated erosion source, particularly for gully erosion. Errors and uncertainties with interpretation increase as the data are used at finer scales, such as understanding the detailed erosion and complexity within Springvale Station itself. Therefore, caution should be taken when using this catchment wide model for detailed planning work within Springvale Station.

The catchment scale sediment budget modelled is built from the following data inputs:

- **LiDAR data.** Airborne Light Detection and Ranging (LiDAR) data was collected in a series of sample blocks covering around 3% of the catchment, and included samples of channels at all scales and gullies in all parts of the catchment. The initial acquisition was undertaken in June 2009.
- **Repeat LiDAR** was flown two years after the original LiDAR dataset, to enable geomorphic change to be determined, and hence sediment production from different parts of the landscape to be measured. The repeat LiDAR was acquired in September/October 2011 and encompassed 0.5% of the total catchment area. Additional LiDAR was acquired and analysed in 2015 as part of NESP project 1.7.
- **Gully mapping** was conducted at two different spatial scales using two datasets. First, bare ground gullies were manually digitised from Google Earth to provide a minimum gully

distribution of the largest bare earth gullies across the entire catchment. Second, gullies were also digitised at high resolution from within the LiDAR bare ground DEM. The LiDAR change detection (2009-2011) undertaken within these delineated gullies in the LiDAR blocks then formed the basis for deriving rates across the catchment within the Google Earth derived gully mapping. LiDAR was only able to detect major change in gully scarp retreat (> 1m horizontal and 0.5 m vertical). The reason that the Google Earth mapped gully extent is regarded as a minimum is that the bare ground LiDAR data has highlighted the fact that there is up to an order of magnitude more (in terms of area) gullies hidden below vegetation than are clearly visible as bare ground gullies. Furthermore, the LiDAR change detection shows that in many instances these vegetated gullies are sometimes more active than the bare ground gullies.

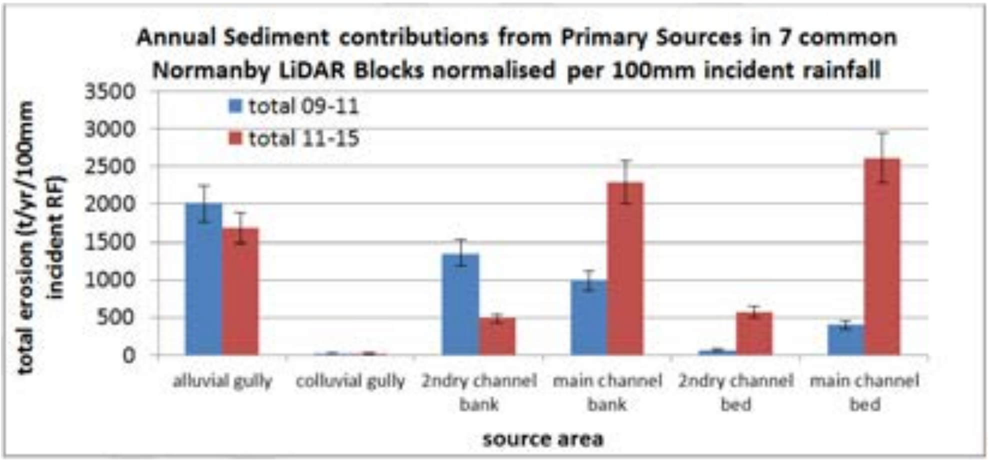
- The short-term sediment production rate data was then coupled with **longer term gully change data derived from historical aerial photography** at 21 sites across the catchment (primarily located within the LiDAR blocks so that the short term rate data could be compared with the multi-decadal data derived from the aerial photography time series data.
- The same LiDAR change detection data used to derive the short term (2 yr) gully sediment production data were also used to determine **sediment production from channel bank erosion in small alluvial tributaries as well as from main channel banks**.
- These same LiDAR data also highlighted erosion from other parts of the channel zone – particularly open channel bed and bars, which predominantly produce bed material load - but do produce some (<63µm) suspended sediment. In addition, these data also highlight where in-channel deposition is occurring (where deposition exceeds the minimum threshold for detection - which was generally 0.5m in vegetated channels or 0.25m in more open channels).
- **Bank erosion rates** were also derived from a geotechnical analysis of 4 sites in the catchment - as a pilot for a subsequent, more detailed, analysis of bank erosion in the catchment. These data, coupled with aerial videography of a 110km survey of the channel network in the upper reaches of the East and West Normanby Rivers, provide an independent check of the rates derived from the repeat LiDAR data. A subsequent study (Brooks et al., 2015; with excerpts reproduced in Appendix 6) undertake detailed assessment of channel erosion rates and drivers in selected channel reaches on Normanby Station and elsewhere.
- **Hillslope erosion rates** have been quantified using a new low-cost sediment trap (see Brooks et al., 2014a & b). Total wet season hillslope sediment production was measured at sites from representative soils on the four major geological units within the upper parts of the Normanby catchment. These data were then used to test the predicted hillslope erosion rates at the same sites using the various iterations of the RUSLE model that have been used to derive the catchment scale sediment budget in previous model runs.
- **Sediment concentration and load data.** At the commencement of the project the existing data on total suspended solid (TSS) concentrations at the active gauges in the catchment were insufficient in quantity and quality across a range of discharges to derive reasonable estimates of the sediment load at any of the gauges except Kalpowar. Hence additional suspended sediment concentration (SSC) data was collected, particularly at high stage, given that much of the existing data was for low to moderate stage conditions. Consequently a series of rising stage samplers (*sensu* Colby 1961)) were deployed at three operating gauges (Laura @ Coalseam, East Normanby, Normanby at Battle Camp) and one discontinued gauge (West Normanby). Continuous stage recorders were also deployed to correlate to current and past stage and discharge data. In addition to this a relationship between TSS and turbidity data was derived from the combination of the existing DERM ambient water quality monitoring data and additional data collected as part of the project (Howley 2010; Howley et al. 2013; 2016). When combined, these data enabled us to convert a considerable amount of existing turbidity data (e.g., the CYMAG ambient water quality monitoring data) into sediment concentration data. When coupled

with the existing DERM TSS data at 5 gauge sites and the new flood SSC data, sediment rating curves were then derived for these gauges to estimate sediment load time series data.

- **Sediment tracing data**. Given the scale of the catchment, no amount of load and source monitoring data is sufficient in its own to construct a sediment budget. Hence an extensive geochemical sediment tracing program was conducted across two wet season (2009/10 and 2010/11) to test the claimed dominance of hillslope surface erosion over sub-surface gully and bank erosion sources. Data were collected on hillslope source materials - using a new method developed for the Normanby project – in which the mobilised material is used as the source sample rather than the soil grab sample method that has typically been used in the past. In-stream samples were collected using the integrated sampling method (Phillips, Russell et al. 2000) as well as the drape sampling method (Caitcheon, Olley et al. 2012) and tracing was continued right through the catchment to sediment cores within PCB.
- **Sediment coring in PCB.** 45 sediment cores were collected from PCB and a source tracing analysis carried out to identify the relative proportions of terrestrial sediments comprising the bay sediments accumulated over decadal to century timescales (500 to 5000 years). Recent flood event sampling of geochemistry provided additional details about the fate of fine suspended sediment. The contemporary flood sediment sampling provided a different story to the time integrated benthic accumulation rates in PCB. The flood samples highlighted the significance of Springvale Station as a dominant source of fine sediment to Princess Charlotte Bay (Howley and Olley, unpublished data).
- **Geochronology data** was collected at a range of sites to determine: 1) incisional histories within alluvial gullies; 2) depositional rates within in-channel bench deposits; 3) floodplain aggradations rates. At total of 85 dates were calculated using Optically Stimulated Luminescence (OSL) dating. The gully incisional history data enabled us to confirm the hypothesis that “gully erosion was accelerated by post-European land use”; whereas the bench dating enabled us (in combination with sediment particle size analysis data) to determine the importance of these features as sinks or temporary storages of a proportion of the suspended sediment load. Long term floodplain aggradation data, enabled us to firstly test whether there was any evidence for a recent increase in sediment supply (as predicted by the previous SedNet modeling); and secondly to derive some typical long-term sediment aggradation rates (which represents internal losses within the catchment, reducing the sediment throughput from the catchment).
- **Road erosion.** The data collected over the 2011-12 wet season (Gleeson 2012) suggested that road erosion was locally significant. Data from this was study was used as a first approximation of erosion rates from roads and associated road gullies within the sediment budget model.
- **All of these data were used to parameterize a new sediment budget model.** The model uses the latest DNRM hydrologic modelling (Source Catchments) data for ~300 sub-catchments in the basin. These we have interpolated to the ~9600 Normanby basin stream segments in the Australian Hydrologic Geospatial Fabric (AHGF) (Bureau of Meterology 2012) stream network (derived from the 9 sec DEM of Australia) as the basis for the catchment model. In each of these segments we have estimated the contribution from upstream, hillslope, gully and channel erosion, and the storage of sediment in the segment and the downstream transport. The model we have used is a modified version of the SedNet Model (sensu Prosser et al., 2001) using empirically derived input datasets on gully, hillslope and channel erosion. A full description of the model can be found in Brooks et al. (2013).

Table 10 Known errors and uncertainties within Normanby sediment budget data.

Erosion Process	Nature of Uncertainty and Error
Gully erosion rate from LiDAR	Airborne LiDAR has a limit of detection (LoD) of between 0.2 – 0.5m depending on the site. Hence erosion detected by this method over the relatively short periods of time between the surveys used in this study (2 & 4 yrs) will be absolute minimum values, biased towards detecting rapid headscarp retreat and secondary incision of the largest gully features. This method does not detect gully sidewall or gully floor lowering at rates of a few cm to a few tens of cm over these short periods. Such contributions are significant as they are occurring over the whole gully surface area. With sufficient time between surveys (i.e. compared to the baseline), such processes will eventually be detected, once the annual erosion increments cumulatively exceed the LoD. However, the short-term rates represented by the data acquired to date are likely to significantly underestimate the sediment yields from gullies (by up to 75%, Shellberg et al. 2013b). For similar reasons, broadscale deposition will also be underestimated (i.e. within catchment storage). However, in our sediment budget model, in-channel sediment deposition has been accounted for based on empirically derived in-channel bar and bench aggradation rates determined from sedimentological analysis and OSL dating.
Hillslope rilling and shallow gullying	For the same reasons outlined above, the repeat airborne LiDAR method will not detect shallow near-surface erosion features on the landscape such as sheet erosion, hillslope rilling, or small but widespread gullies on all geology types. Erosion from highly disturbed areas (e.g. roads, cultivated paddocks) will also not be detected. Classic rilling in the Hodgkinson Formation is dependent on the lithology of geological sub-units, with sandstone (greywacke) at hillslope plots less erodible by rilling than mudstone and siltstone units and beds common in western Springvale Station. Where present, LiDAR will miss rilling and sheet erosion on a variety of hillslopes. Therefore, sediment from these sources is likely to be under-represented, and will likely to have been attributed to other sub-surface processes (i.e., large channel and gully erosion), potentially over-estimating them.
Hillslope channel erosion	The Normanby catchment sediment budget used 9621 sub-catchments, and 9635 stream segment links mapped in Australian Hydrologic Geospatial Fabric (AHGF) derived from the 9 second DEM. Thus major and some minor tributaries are included, but many thousands of small stream channels of the dendritic drainage network are not included. Many real channels are still missing from the 1:250,00, 1:50,000 and even 1:25,000 topographic maps (e.g., Rustomji et al. 2010). For example, locations and sediment yield data do not exist for the dense dendric drainage network of the Hodgkinson Formation, which are also below the LoD of LiDAR change detection. Headwater stream channels in all geologies make up a large proportion of the channel network and are known to be important sources and storage areas for both fine and coarse sediment (e.g., Benda et al. 2005; Bartley et al. 2007). For example, much of the observed sediment output from the Hodgkinson Formation (50% of the area of Springvale Station) could come from bed and bank erosion from small channel and gully systems (e.g., Figure 19), rather than the low erosion rates estimated from sheet erosion on hillslopes (Brooks et al. 2014). This sub-surface channel erosion will have been attributed in the model to other sub-surface processes (i.e., larger channel and gully erosion), potentially over-estimating them.
Hillslope surface erosion	Estimates of hillslope erosion have been derived using two independent approaches: 1) measurements of hillslope erosion on soil mantled bedrock slopes determined from sediment traps to provide locally relevant K & C factors, which have then be used to run a locally specific RUSLE model with K values extrapolated according to geology (sensu Brooks et al., 2014a,b), 2) radionuclide tracing studies (Olley et al., 2013). The results from the two approaches provided estimates of hillslope surface erosion in the range of 1 – 10%, which is well within the experimental errors of both approaches and were considered to be consistent. Sheet and rill erosion from scalded parts of alluvial/colluvial gully complexes, and other stripped hillslopes, have a sub-surface radionuclide signature - and this might otherwise be considered surface erosion. Thus, widespread surface erosion from scalded and rilled alluvial/colluvial areas may be underestimated, and would be lumped with the overall sub-surface gully erosion process Surface erosion from alluvial terrace slopes above gullies were not well parametrized in the hillslope erosion model (due to lack of field calibration data and topographic resolution). However, these slopes would have surface radionuclide signatures that were detected in the tracing studies of (Olley et al., 2013).

	Roads and tracks will also be contributing surface erosion, which more than likely will have a "sub-surface" radionuclide signature, leading to confounding between sources. Regardless of the signature from these linear disturbance sources, these have been separately accounted for in the model based on empirical extrapolation of estimates derived from Gleeson (2012) for main roads like the PDR. However, these road erosion estimates are a very absolute minimum due to a lack of full mapping and measurement of all road and fence line disturbances in the catchment (later updated by Spencer et al. 2016), and more importantly lack of measurement of thousands of road and fence erosion hotspots such as those documented on Springvale Station (Shellberg and Brooks 2013) but not included in the sediment budget.
In stream sediment load measurements	All sediment loads derived from in-stream sampling have large uncertainties, potentially >±30%, due to river discharge errors ±20% and average cross-section sediment concentration of ±30%, as well as limited sediment concentration data. This is especially the case on the West Normanby River with discharge errors up to >30% due to rating curve limitations. These measurement errors of sediment load output would influence the magnitude of sediment needing to be apportioned in the model to upstream sources and sinks. It is also known that there is considerable bypass of flows from the Normanby River at the Kalpowar gauge (the most downstream gauge on the Normanby) during high flow, through distributary channels that breakout from the Normanby channel upstream of the gauge. Hence the measured sediment loads at this gauge are a significant underestimate of the loads from the upper catchment.
Channel and Gully erosion rate extrapolations	Only a small proportion of the landscape is covered by repeat LiDAR (~1% - albeit in the most active areas) which necessitates rate extrapolations to be made from limited sites where rates have been calculated to the rest of the catchment using proxy metrics. This is in addition to the issues outlined above with LoD errors associated with aerial LiDAR data, which apply equally to channel erosion as they do to gully erosion. In the case of the gullies, estimated rates from LiDAR are applied to the mapped gully extent outside the LiDAR blocks (stratified by sub-catchment). The measured channel erosion rates are extrapolated to a classified stream network (i.e. applying locally derived rates at the sub-catchment scale). Obviously, these interpolated rates are subject to error (both over and under-estimating rates – given that the average measured rates were then extrapolated).
Short term rates	The initial sediment budget relied primarily on repeat LiDAR collected two years apart and hence is a function of the conditions during those two years. As the subsequent analysis 4 years later indicates, minimum erosion rates at some locations went up and others went down in the second period, most likely due to variations in local rainfall intensity and duration, and in the case of channel erosion, major differences in the nature of flood hydrographs (Figure 84). To mitigate this effect, multi-decadal air photo time-series were also analysed to compare the short term rates with the longer term rates, and in most cases there was reasonable agreement between the two. However, it should be remembered that short term erosion rates do vary spatially within the catchment depending on where the rain falls, and temporally as a function of inter-annual rainfall variability. A more detailed discussion is given in Brooks et al. (2016).  **Figure 84** Annual Sediment contributions from different sources normalised per 100mm of incident rainfall showing the variation between the two LiDAR time intervals (Source: Griffith University).

5.1.2 Results of the empirically-modelled sediment yield estimates for Springvale Station

The following sequence of maps and graphs summarise the model estimated total sediment yield from each geologic unit from the empirically-modelled sediment budget for the Normanby Catchment (Brooks et al. 2013). To enable the contributions from Springvale Station to be put in context with the contributions from the surrounding catchment, the estimated sediment yield data have been presented for:

1) the whole upper catchment, as downstream as the northern boundary to the property (Figure 85);

2) the area within the property boundaries (Figure 86); and

3) the area upstream of the property (Figure 87).

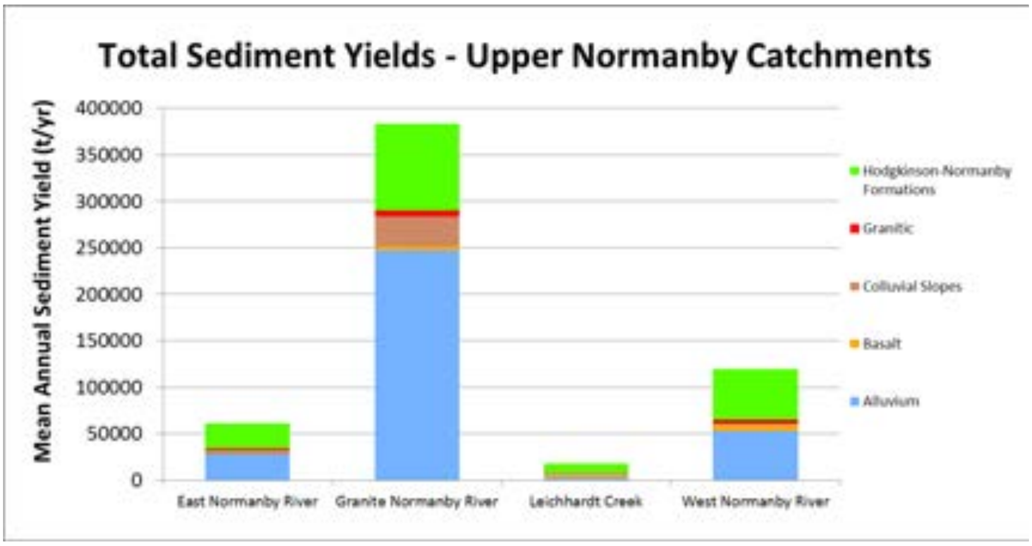


Figure 85 Model estimated total sediment contributions from each sub-catchment broken down by sources from each geological unit for the whole of the upper Normanby catchment down to the stream outlets at the northern property boundary (Source: Griffith University).

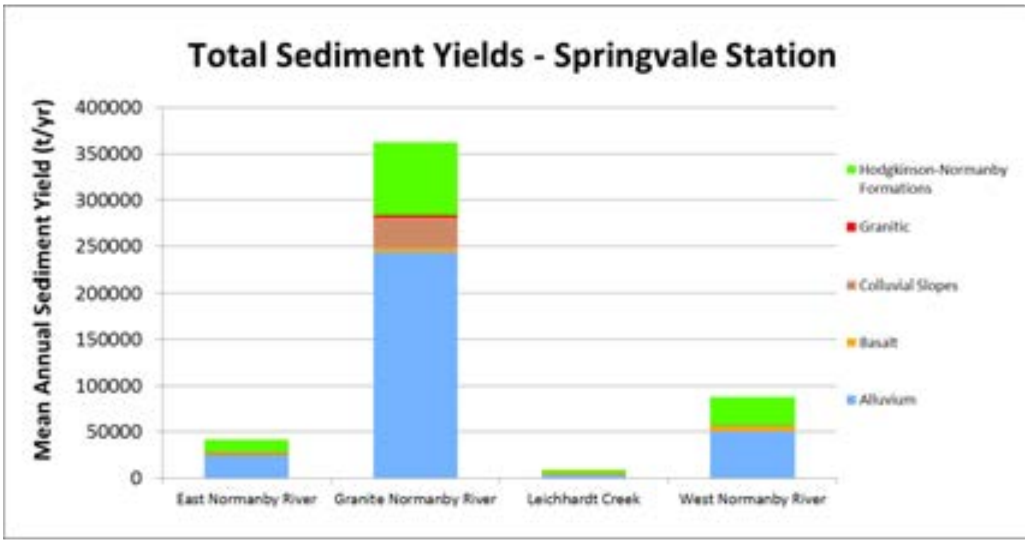


Figure 86 Model estimated sediment yield for the portions of the four major tributaries on Springvale Station broken down by geologic unit (Source: Griffith University).

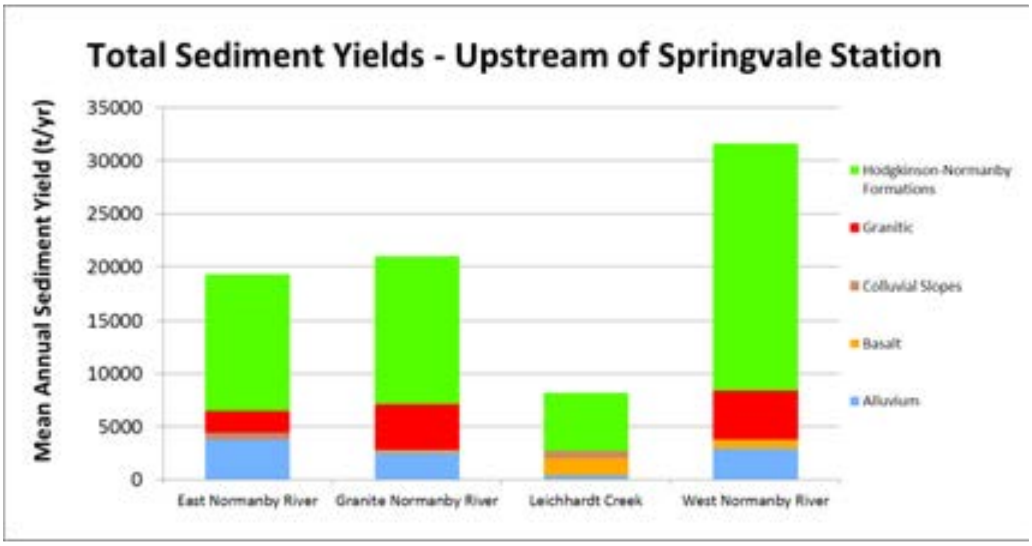


Figure 87 Model estimated sediment yields for contributing sub-catchments upstream of Springvale Station (note the y axis scale is an order of magnitude less than that in Figure 85 and Figure 86 (Source: Griffith University).

5.1.3 Priority soil erosion areas

The distribution of very large gully erosion areas mapped with Google Earth on Springvale Station is highly concentrated within the Granite Normanby alluvium geologic unit (Figure 88). However, other areas of alluvium and other geology (colluvium, basalt, Hodgkinson, and granite) on the property are also riddled with gully erosion of various sizes, and are poorly mapped in some areas due to tree cover, size and width of the gully compared to image resolution, and lack of LiDAR data. Only full LiDAR coverage for the property will identify the true nature of soil and gully erosion distribution.

The estimated modeled sediment yield from the property is dominated by the contribution from this Granite Normanby area, as demonstrated by the estimated yield difference in Figure 86 compared with Figure 87. This relative magnitude estimate of the Granite Normanby compared to other areas is likely correct base on field experience on the ground, but is also influenced and biased to some extent toward large gullies that can be seen from Google Earth and derived erosion rates from repeat LiDAR above the limit of detection. See sediment budget limitations in Table 10.

As estimated in Figure 6 and Figure 8 the modelled total sediment yields are not proportional to the area of the geological units, rather they are disproportionately derived from the alluvial and colluvial geo-units. The concentration of large mapped gullies on the Granite Normanby alluvium is further demonstrated in Figure 89, which shows that greatest aerial extent of mapped gullies is based on the alluvial and associated colluvial geo-units in this area.

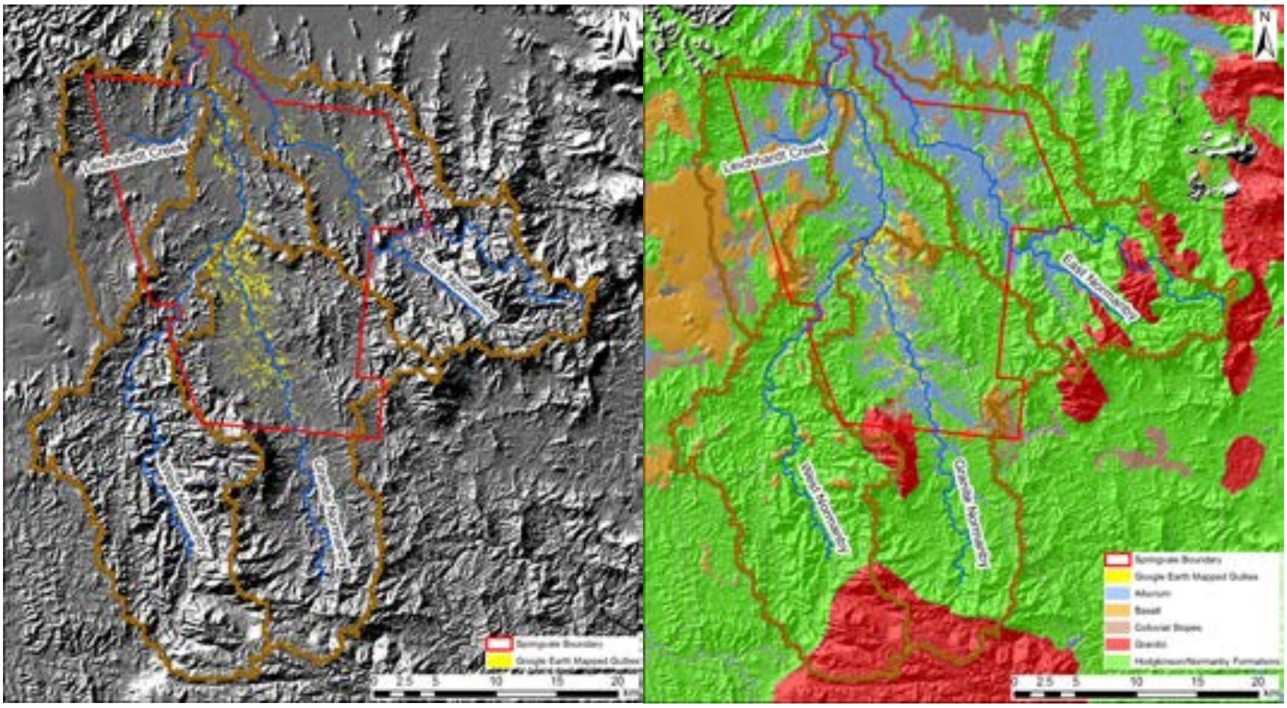


Figure 88 Map showing the distribution of all GE mapped gullies (i.e. alluvial and colluvial) in the upper Normanby catchment, showing the relationship between the alluvial areas and the gullying (Source: Griffith University).

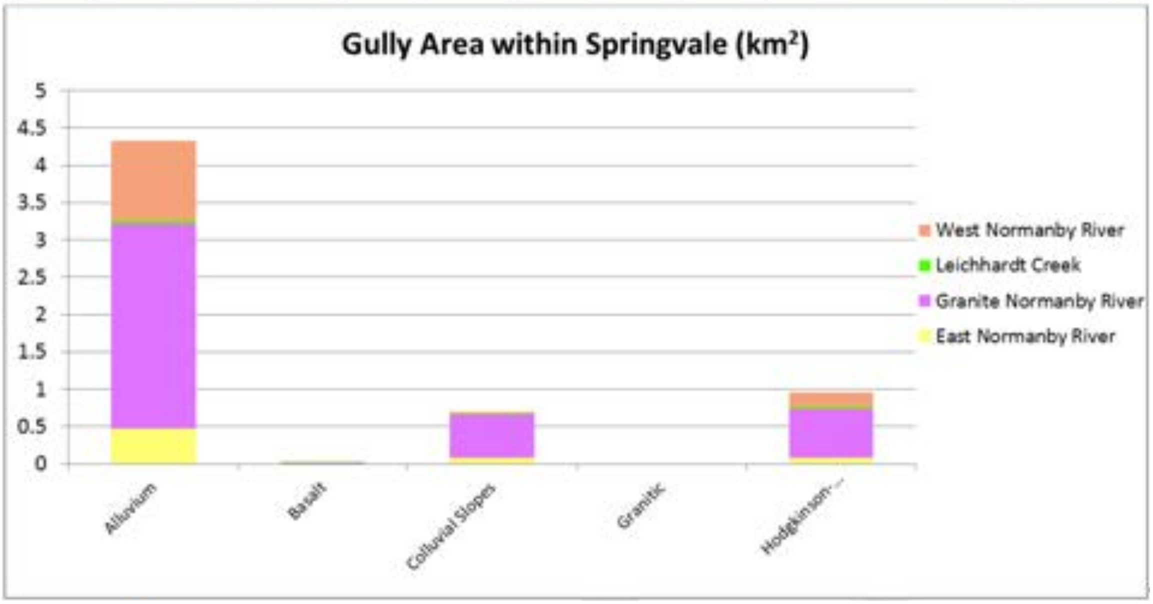


Figure 89 Areal extent of GE mapped gullies according to the geo-unit and major sub-catchment (Source: Griffith University).

5.1.4 Priority soil erosion management issues

Two primary erosion management issues have been identified on Springvale Station, which to varying degrees are functionally related:

- gully erosion
- linear disturbance features (i.e. roads, tracks and fencelines).

5.1.5 Gully erosion

The estimated total modelled annual average sediment yield from the whole of Springvale Station is approximately 500,000 t/yr. Of this total, the current model iteration estimates that ~ 90% is sourced from sub-surface erosion sources from scalding and stripped soil profiles, rilling, shallow gullying, deep gullying, bank and channel erosion in small and large channels. The bulk of this is driven by gully erosion and incision into the alluvial/colluvial landscape, but small secondary channel erosion is also a major sediment source along with others above (Brooks et al. 2013). Sub-surface erosion into other geology units (Hodgkinson, Basalt, Granite) via gully and channel erosion also contribute to this yield. The current model iteration attributes much of this sub-surface erosion to the largest bare earth alluvial/colluvial gullies mapped with Google Earth. However in reality, this sediment yield is spread across a larger range of sub-surface erosion features mentioned above. Determining the true mix of sub-surface sediment sources on Springvale Station will require more research, as indicated in model uncertainties outlined in Table 10.

Estimates of the sediment delivery ratio (SDR) between Springvale Station and Princess Charlotte Bay (PCB), in isolation of all other downstream sediment inputs, are unknown. However it is clear that there is significant sediment storage within the system downstream of Springvale Station (Brooks et al., 2013; Pietsch et al., 2015). Given that the Kalpowar gauge is known to underestimate water discharge (and associated sediment loads) by as much as 43% due to discharge bypassing the gauge (Wallace et al., 2012), estimating sediment delivery ratios using this gauge is extremely fraught. However, best estimates of the sediment delivery ratio between the East and West Normanby gauges and Kalpowar are likely to be in the range of 30% - 60%, although this will vary significantly as a function of sediment particle size. SDR changes between Kalpowar and the river mouth are extremely difficult to estimate due to the absence of load data at the river mouth(s). Longer-term (decades to centuries) estimates of SDRs based on geochemical tracing, suggest that additional sediment sources from the coastal plain come into play downstream of Kalpowar that may significantly increase the sediment loads delivered to PCB above those reflected by the Kalpowar gauage (Brooks et al., 2013). Recent flood plume tracing from two flood events suggests that 50% of the less than 10 µm fraction of the sediment in the plumes is sourced from the upper Normanby catchment above the Battle Camp gauge, which is largely Springvale, Kings Plains, and Normanby Stations (Howley and Olley, unpublished data).

If significant inroads are to be made towards reducing sediment yields from Springvale Station, then it is imperative that major efforts are directed towards stabilising sub-surface erosion sources. Addressing gully initiation and growth and reducing sediment yields from incision processes is a key issue, especially since this is a key process accelerated by land use (Brooks et al. 2013; Shellberg and Brooks 2013; Shellberg et al. 2016a). It is not clear what proportion of the overall sediment load at Springvale Station is coming from the > 550 km of road and fence linear disturbance by machines (Figure 60), and road interactions and initiation with gullies. However, field evidence indicates that road and fence erosion is an important issue that does warrants immediate attention (see section above; Shellberg and Brooks 2013). In addition, stable roads through this landscape will be important for providing access to gully areas for various management interventions. For these reasons, we have presented two separate assessments of the road and gully distribution within the property to help prioritise management effort.

Higher resolution information is, however, required for designing any management works on the property for both roads and gullies, so this prioritisation process should only be regarded as a “first cut”. A more focused assessment at a finer resolution (using LiDAR analysis and ground survey) in the prioritised sub-catchments will be needed in the future.

Sediment yield heat maps (Figure 90) visually represent the spatial location of the highest priority sub-catchments within Springvale Station in terms of modelled sediment yield from gullies, as well as gully area. The map in Figure 92 shows a heat map of the 542 sub-catchments in the upper Normanby based on modelled total sediment yield from the sub-catchments. Figure 93 shows the top 25 sub-catchments (of 542 in the upper Normanby) ranked according to modelled total sediment yield, which can be seen to closely mirror the general pattern within the gully heat maps. Also shown in Figure 91 and Table 11 are the ranked modelled sediment yields for the NCB sub-catchments, indicating that ~ 60% of the modelled total sediment yield from Springvale Station is currently estimated to come from the top 25 sub-catchments (of 254) or 7.1% of the property area (Appendix 2 summarises the model data for all 254 subcatchments). The top 18 sub-catchments (4.8% of the property area) are estimated to contribute ~50% of the sediment load. These data should be interpreted with an understanding of model uncertainly outlined in Table 10.

It should be pointed out that the gully area represented in Figure 90 is the bare ground areas of the gullies that are visible within air photo imagery in Google Earth. These data have largely driven the results of the modelled sediment budget. However, from detailed mapping using LiDAR data (Figure 94), which enable the vegetated portions of gully complexes to be mapped as well as the bare ground areas, it is apparent that the extent of gullies in these three LiDAR blocks is on average nine times greater than the bare ground mapping has indicated (Table 12). This will be an important consideration when planning, designing and budgeting rehabilitation strategies for the gullies on Springvale Station. Many more gullies exist than we are currently estimating across all geological units at Springvale Station. Improved mapping, classification, and prioritization of these gullies will be important for long-term management decisions.

It is likely that the non-bare ground parts of the gullies will typically require less intensive management than the bare ground portions. However, this largely depends on the stage of gully evolution. Actively retreating gully fronts can be obscured by the trees that they are eroding into, and hence the most active parts of the gully that could warrant management are not always reflected in the bare ground portions of the gully complex. Management intervention into bare and treed gully areas will needed to be assessed on a case by case basis taking multiple factors into account.

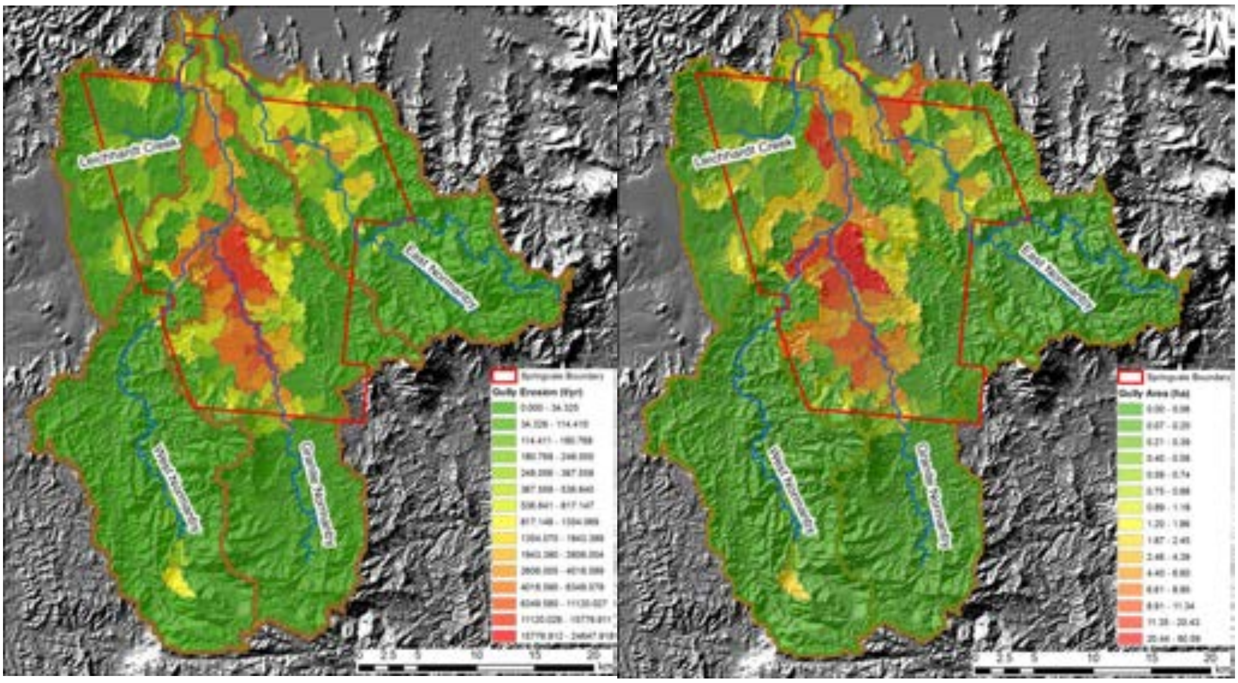


Figure 90 Modeled sediment yields from alluvial and colluvial gully erosion (combined) on Springvale Station and the upper Normanby catchment (Left); and gully area on Springvale Station (Right) (Source: Griffith University).

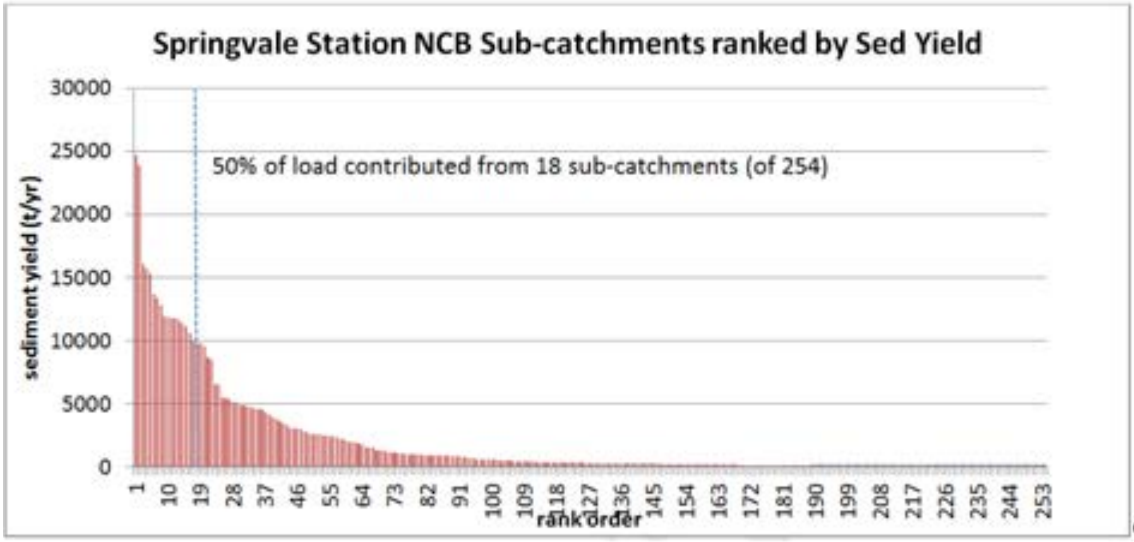


Figure 91 Modelled sediment yield of the 254 sub-catchments within Springvale Station arranged in rank order of estimated yields. Note that 50% of the total sediment yield is modelled from just 18 sub-catchments (Source: Griffith University).

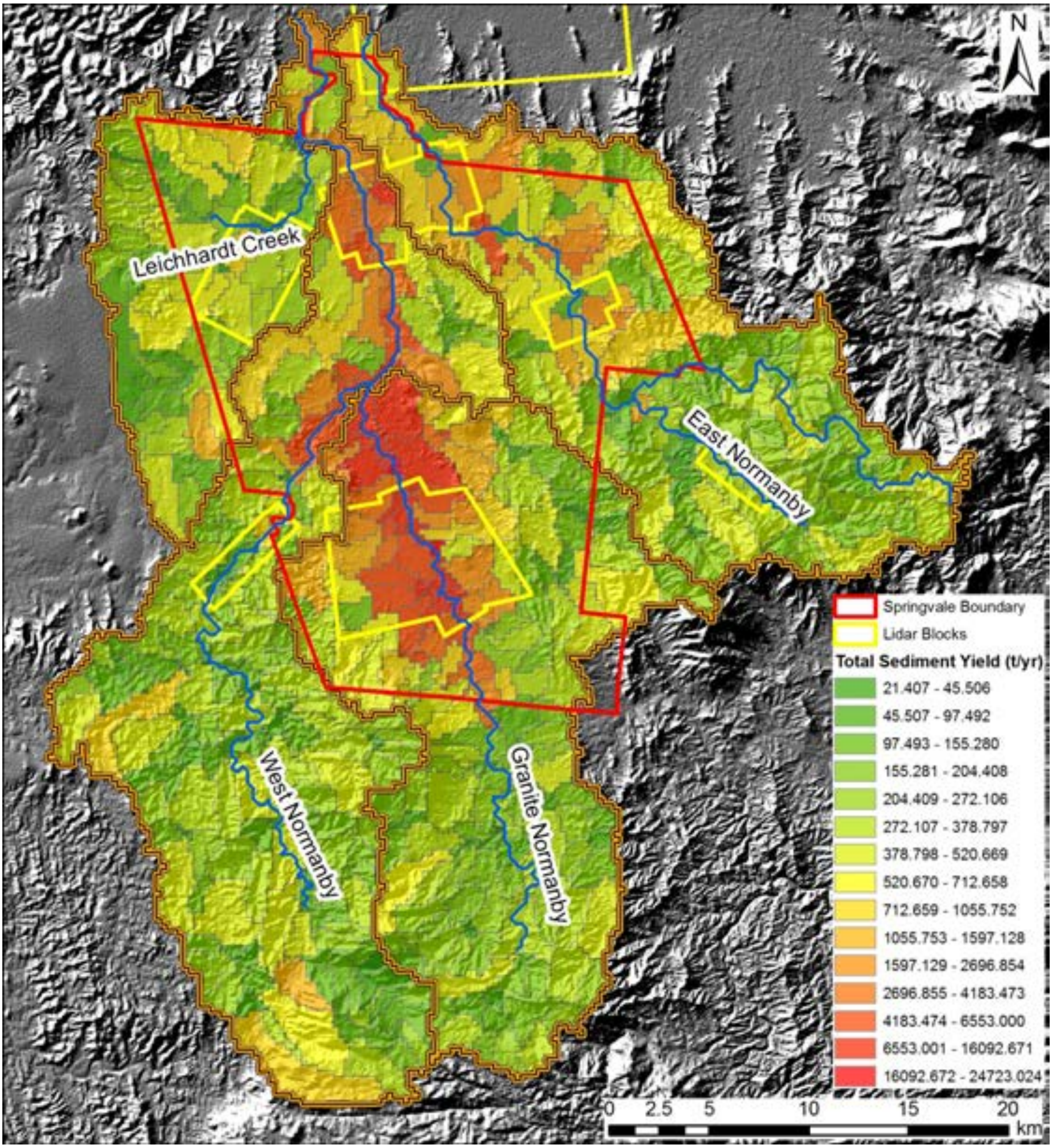


Figure 92 Heat map showing modelled total sediment yield for the entire upper Normanby catchment, showing the location of existing LiDAR data (Source: Griffith University).

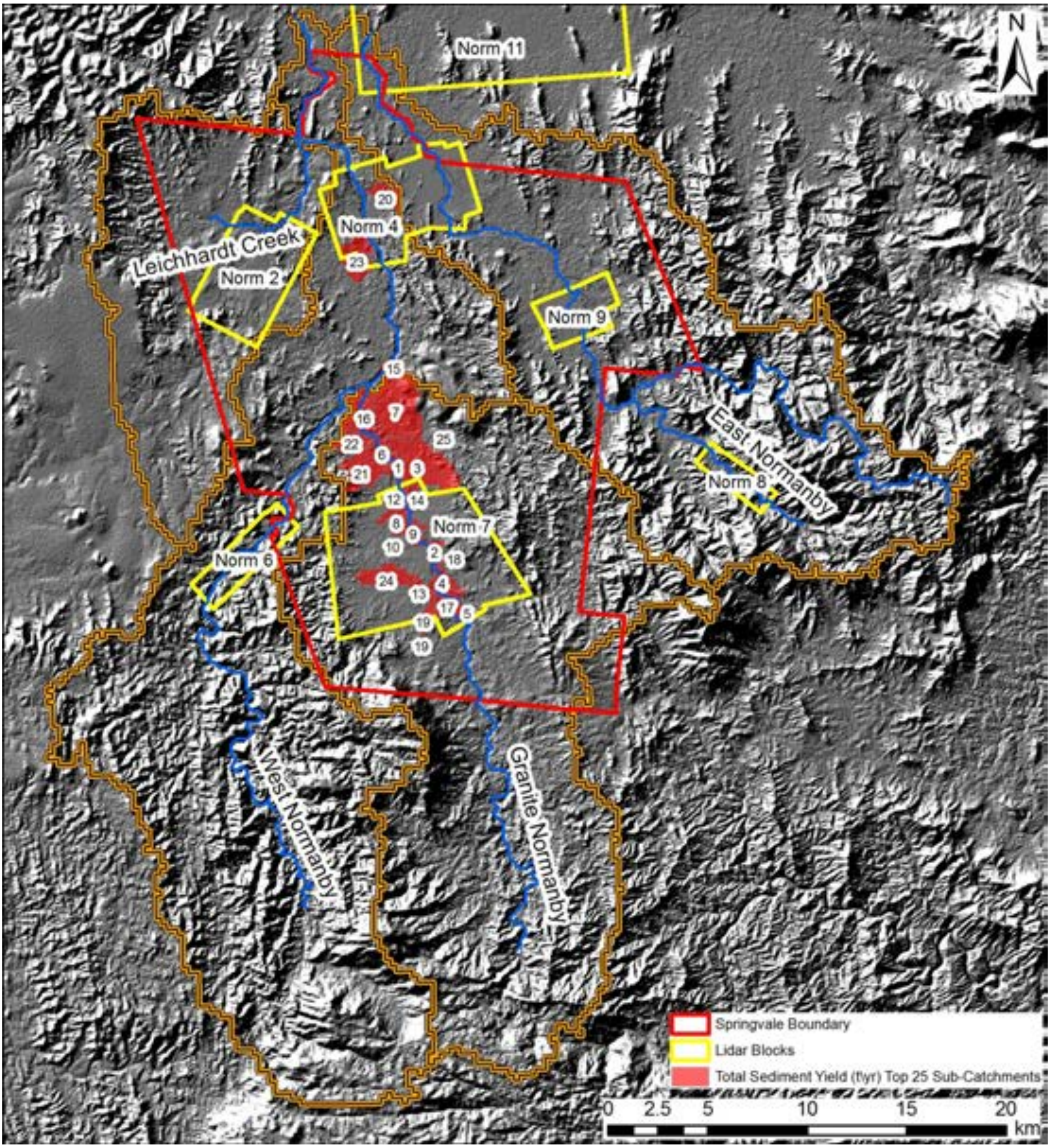


Figure 93 Top 25 sub-catchments on Springvale Station based on estimated (modelled) total sediment yield (of 542 sub-catchments in the upper Normanby). Also shown are the boundaries of the existing LiDAR blocks (Source: Griffith University).

Table 11 Top 25 NCB sub-catchments (of 254 on Springvale Station) ranked according to modelled total sediment yield (Source: Griffith University).

rank	IDNum	River	NCB_Area (ha)	Tot Sed Yield (t/yr)	Cm'ltve % sed cntrib'tn	Gully Sed Yield (t/yr)	Gully Area (ha)	Road Length (m)	Road Area (ha)
1	9225	Granite Normanby R	66.7	24723	4.9%	24648	11.04	73	0.029
2	9346	Granite Normanby R	51.9	23918	9.7%	23856	9.56	0	0.000
3	9237	Granite Normanby R	629.8	16093	12.9%	15777	59.53	3789	1.137
4	9397	Granite Normanby R	133.3	15727	16.1%	15559	14.67	2247	0.770
5	9419	Granite Normanby R	74.1	15325	19.1%	15219	7.23	1157	0.347
6	9181	Granite Normanby R	103.7	13718	21.8%	13590	11.34	712	0.214
7	9133	Granite Normanby R	666.9	13396	24.5%	12965	60.59	3206	0.956
8	9313	Granite Normanby R	74.1	12793	27.1%	12695	7.25	2385	0.845
9	9333	Granite Normanby R	111.1	11938	29.5%	11736	7.91	945	0.347
10	9321	Granite Normanby R	22.2	11906	31.8%	11884	2.17	232	0.093
11	9259	Granite Normanby R	44.5	11827	34.2%	11752	2.84	839	0.280
12	9284	Granite Normanby R	96.3	11816	36.5%	11741	8.71	1426	0.543
13	9390	Granite Normanby R	51.9	11667	38.9%	11615	4.92	809	0.809
14	9272	Granite Normanby R	44.5	11410	41.2%	11327	3.45	1005	0.301
15	8974	West Normanby River	66.7	11173	43.4%	11120	3.98	1587	0.857
16	9141	Granite Normanby R	289.0	10584	45.5%	10319	20.43	2610	0.799
17	9403	Granite Normanby R	118.5	10064	47.5%	9969	7.24	1200	0.360
18	9355	Granite Normanby R	14.8	9824	49.5%	9802	0.81	326	0.098
19	9396	Granite Normanby R	118.5	9781	51.4%	9738	7.78	0	0.000
20	8546	West Normanby R	140.9	9541	53.3%	9414	9.97	1273	2.114
21	9258	Granite Normanby R	326.0	8682	55.0%	8434	19.52	4191	1.419
22	9160	Granite Normanby R	111.2	8514	56.7%	8409	5.79	2160	0.779
23	8733	West Normanby R	296.5	6553	58.1%	6350	14.84	2921	2.472
24	9378	Granite Normanby R	259.3	6534	59.4%	6239	11.06	3945	1.225
25	9142	Granite Normanby R	22.2	5549	60.5%	5518	0.65	514	0.154

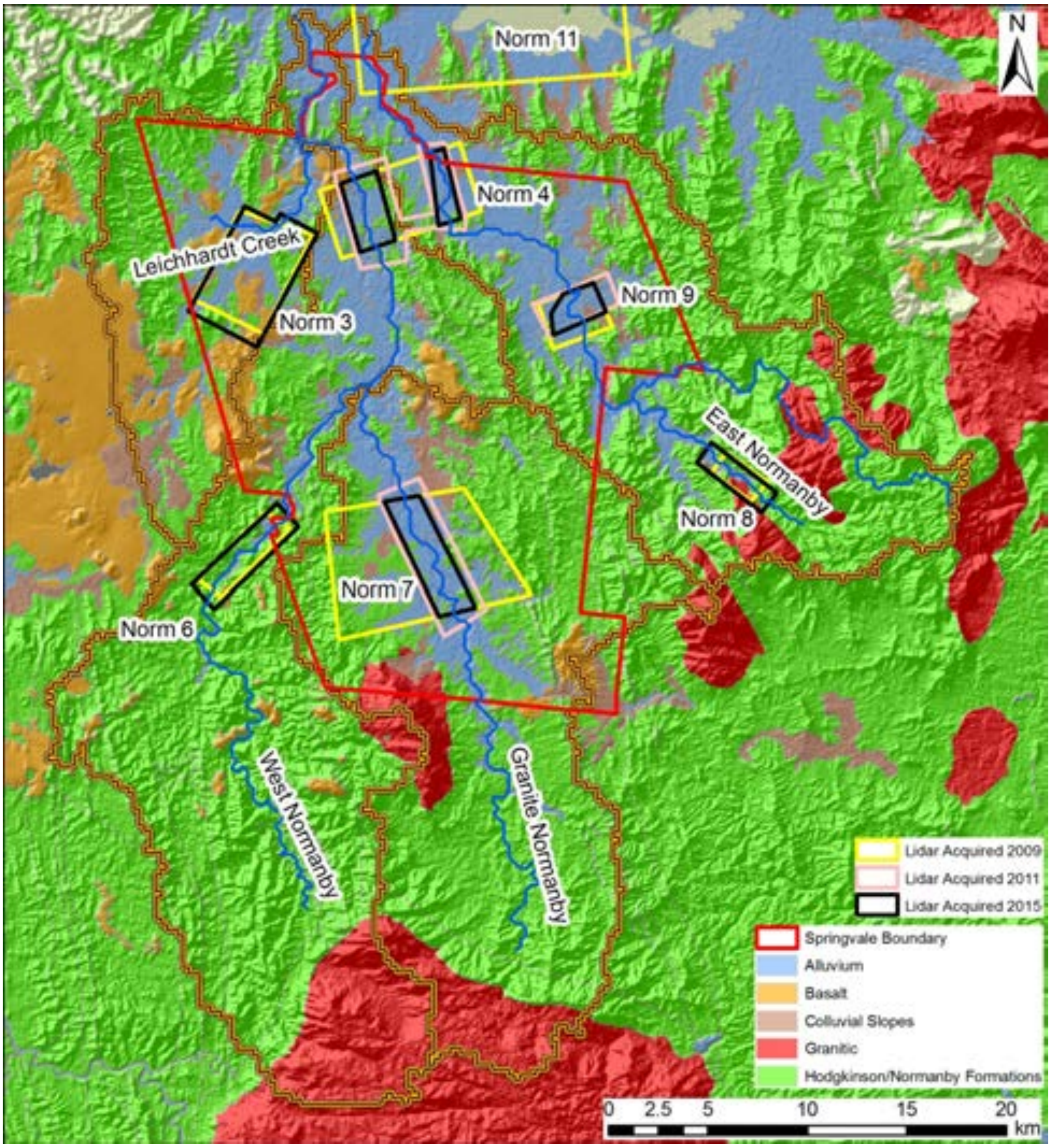


Figure 94 Map of Springvale Station showing the location of the LiDAR blocks acquired in 2009, with sub-sets repeated in 2011 and 2015 (Source: Griffith University).

Table 12 Mapped gully area using Google Earth (visible- bare ground) and LiDAR (whole gully complex – including vegetated portions) (Source: Griffith University).

Springvale Station Mapped Gullies			
LiDAR Block #	**Total Area of Alluvium/Colluvium mapped (ha)**	**Gully Area Mapped in GE (ha)**	**Gully Area mapped in LiDAR (ha)**
4	1562	29.4	274.5
7	1114	72.1	496.1
9	502	6.1	212.8
Total	**3178**	**107.6**	**983.4**
	Average ratio of under estimation in GE =		**9.1**

5.1.6 Linear disturbance features (roads, tracks and fence lines)

The road and fence line linear disturbance network is important for three reasons as part of the erosion management planning process:

1. Roads / fences represent direct sediment sources created by human land use
2. Roads / fences are often initiation points for gully erosion, or are adding additional drainage into established gullies and thereby increasing their effective catchment area and increasing their rates of erosion
3. Roads provide necessary access routes to other gully sites, enabling them to be managed.

A Road and Fence Maintenance and Abandonment Plan (RAFMAP) will be needed as part of the overall Erosion Management Plan and Property Management Plan at Springvale Station (see recommendations in the staged and targeted implementation strategy below). This will require detailed assessment and characterisation from field data and high resolution (LiDAR) to plan and prioritise road and fence management work, beyond that recommended as actions in the establishment phase of implementation (2017 - 2018).

The map in Figure 96 shows an initial simplistic (unclassified) representation of the linear disturbance network on the property, within an underlying "heat map" to represent the total length of these linear features within the associated NCB sub-catchment. Further detailed work is required to more adequately characterise and prioritise the linear disturbance network (i.e. appropriately weighting the importance of different roads and fences) according to:

1. the geological unit that it traverses
2. slope
3. proximity to active gullies and road choke points
4. stream network intersections points, and road contributing catchment area
5. road/fence size
6. road/fence condition
7. road/fence erosion rates
8. future road and fence use for management needs.

Completing this process will be much more accurate and achievable should LiDAR data become available across the entire property, coupled with detailed field survey data.

Data presented in Figure 95 shows that there are extensive lengths of linear disturbances in the most sensitive alluvial/colluvial areas. Where possible a management objective should be to reduce and rehabilitate the lengths of these features in these sensitive areas. Some of these road areas are within the modelled top 25 soil erosion producing sub-catchments, and many others are not, due to the scale of air photo gully mapping compared to field mapping of road and fence erosion issues and associated gullies of various size. Property wide LiDAR data and comprehensive road/fence erosion surveys will improve these two datasets. See Appendix 3 for an example of a multi criteria metric that could be further developed to support implementation as more detailed datasets become available.

Prioritisation of road and fence erosion hotspots for intervention (e.g., Figure 102) and major gully erosion hotspots (top 25 sub-catchments, Figure 93) can occur separately but simultaneously. Both roads and gullies are known to be problems needing to be addressed to reduce sediment yields.

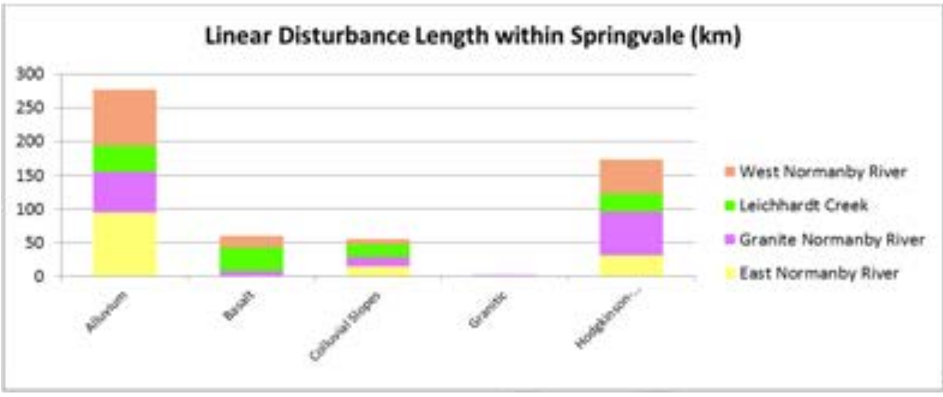


Figure 95 Linear Disturbance length broken down by geo-unit and tributary sub-catchment (Source: Griffith University).

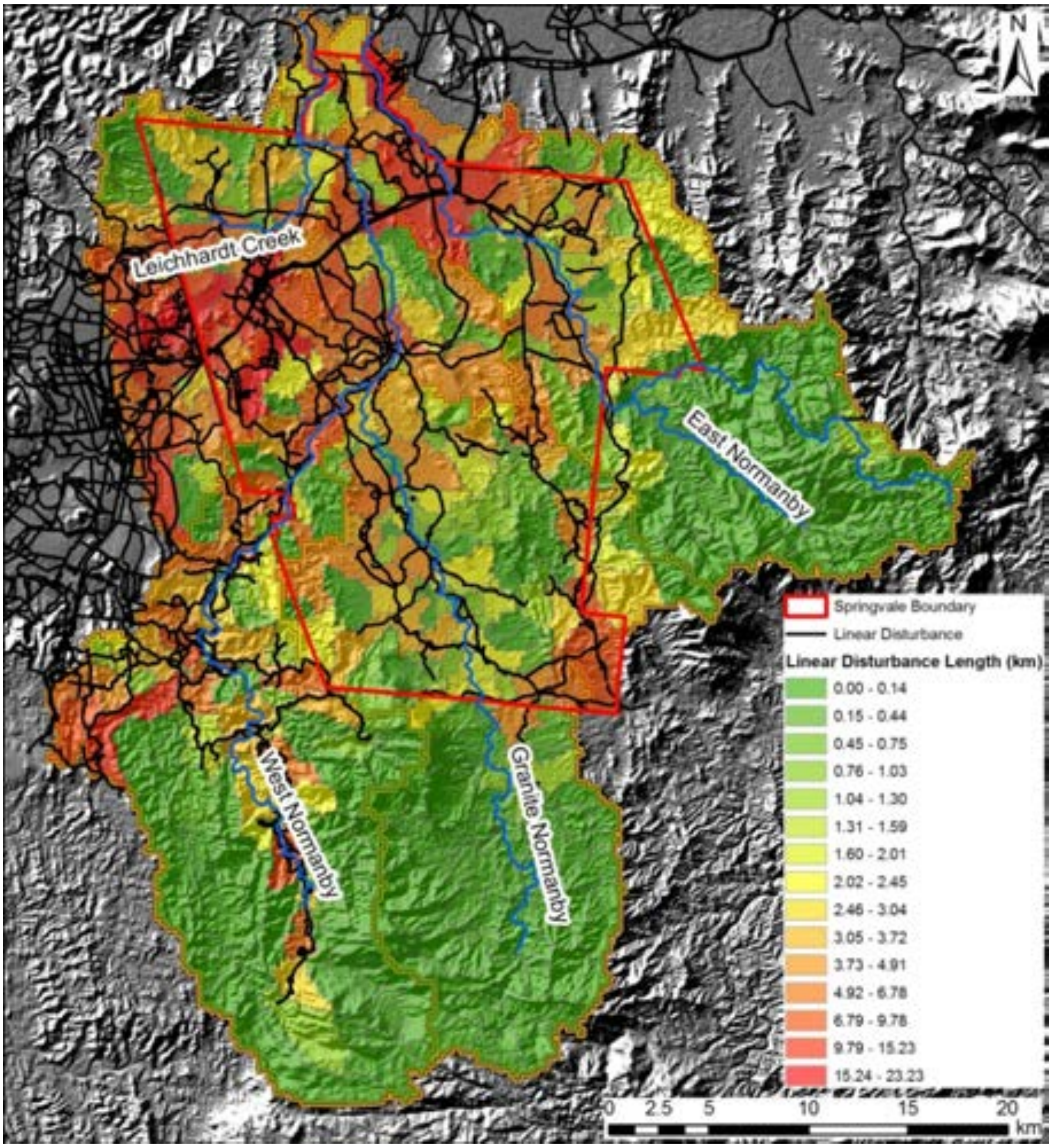


Figure 96 Map of Springvale Station showing the road, track and fence lines (linear disturbances) with associated heat map which represents the total length of linear disturbance within each sub-catchment. The source of the data is a combination of the network mapped by Spencer et al. (2016) as part of the Cape York

WQIP, coupled with recent tracklogs from Jeff Shellberg and Dean Faulks et al (EHP) (Source: Griffith University).

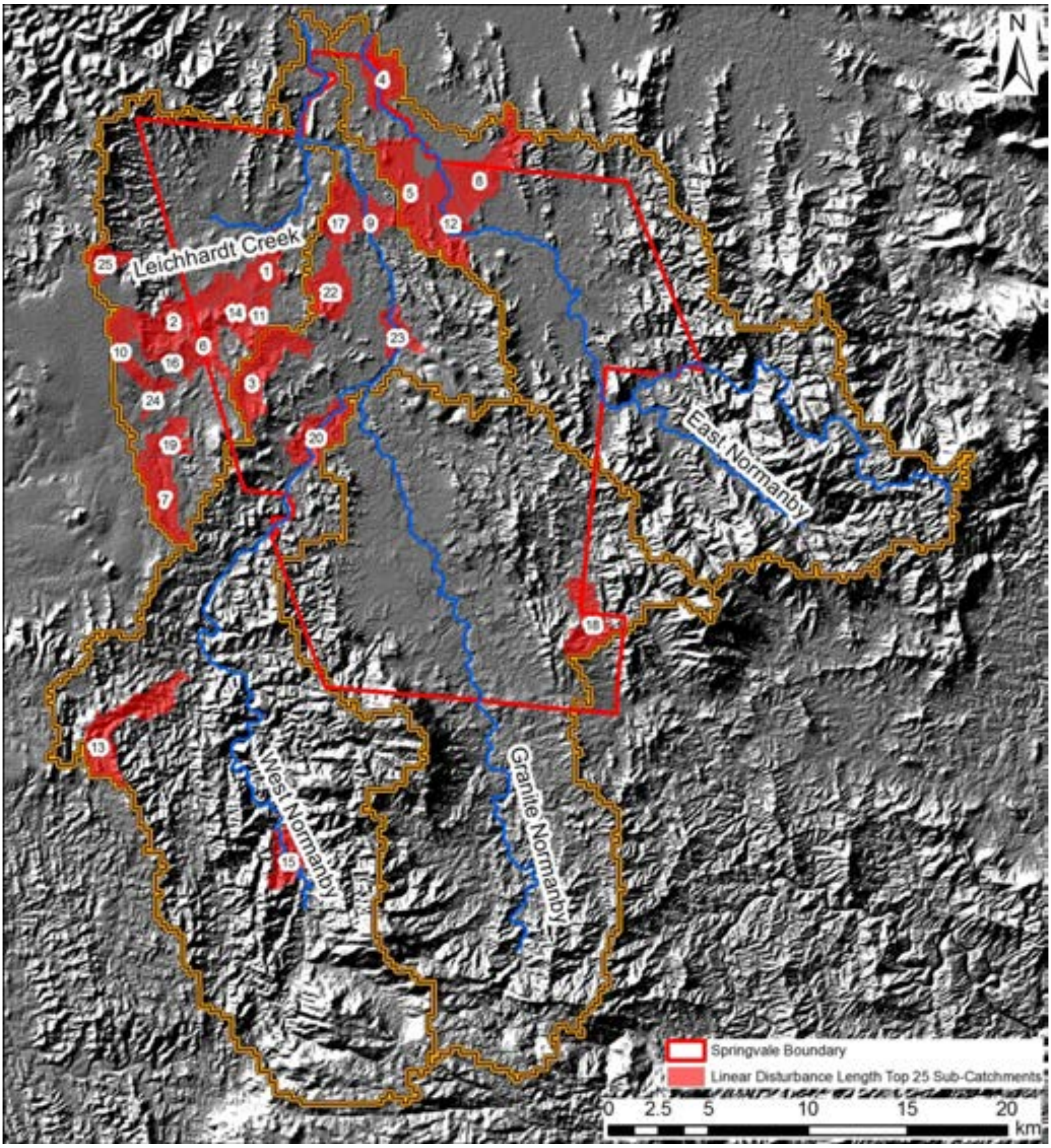


Figure 97 Top 25 sub-catchments by linear disturbance length (Source: Griffith University).

5.2 A staged and targeted implementation strategy to guide 2017 to 2022 actions

The analysis of available information combined with the on-ground experience of the project team has been used to describe a staged and targeted implementation strategy to guide 2017 to 2022 actions that is logical, practical and achievable (given that adequate funding is secured).

The recommended implementation strategy for the Springvale Station Erosion Management Plan involves three logical sediment responses for the period 2017 to 2022:

- Sediment maintenance / prevention response 2017-2022 - property-wide activities.
- Establish sediment reduction response 2017-2018 - strategic demonstration sites.
- Targeted sediment reduction response 2018-2022 – within 500m of the road network.

5.2.1 Assumptions of the Springvale Station Erosion Management Plan implementation strategy

- Cultural Heritage mapping and clearance surveys will be included in all action plans. The proximity of gully erosion to Cultural Heritage, and the level of threat of gully erosion to Cultural Heritage, should be considered in prioritising where to intervene.
- The degree that land use has accelerated soil and gully erosion varies across the land - not all gullies are initiated and accelerated by land use.
- The causes and drivers of erosion should be assessed, and addressed, where possible, in conjunction with treating the erosion sites.
- Treatments will be tailored to individual sites using expert advice and detailed designs, in order to avoid collateral damage that increases erosion due to disturbance of highly dispersive soils with machinery or carelessness.
- As part of the design and implementation for each site, consideration will be given to whether the outcome leads towards:

    Rehabilitation – broadly defined as - to slow down erosion through intensive and / or passive means and attempting to recreate semi-natural habitat that is self-perpetuating towards the state that would exist naturally in the area (e.g. in landscapes that retain high ecological and / or cultural values)

  or / and

    Remediation - broadly defined as - to slow down erosion through any means possible, with less concern for the habitat outcome and a return to the natural state (e.g. in landscapes that have crossed a threshold to a highly disturbed state)
- Not all options must be taken at any given site; but combinations are recommended.
- Not all gullies or gully types are suitable or practical for erosion control intervention.
- Some rehabilitation/remediation options are experimental and inherently riskier, such as reshaping entire mature alluvial gully complexes, and will need to be proven to be effective and practical at scale before repeating across large areas.
- Not all treatment options will achieve sediment reductions over similar timescales, so consideration should be given to using combinations of treatments that will produce the greatest sediment reductions over the shortest timescale.
- Priority should be given to erosion sites and rehabilitation/remediation options that are logistically practical, cost effective and can achieve measureable improvements in sediment loss within reasonable timescales.

5.2.2 Soil and gully erosion types, rehabilitation, remediation and monitoring options

For cost-effective sediment reduction to be achieved at Springvale Station, it is critical to target specific remediation / rehabilitation actions to specific soil and gully erosion types. A synthesis of all available gully management information (including project team workshop minutes) was used to produce management guidelines for the soil and gully erosion types present on Springvale Station (Figure 98 and Appendix 4), and is largely based on work in Shellberg and Brooks (2013) and Shellberg et al. (2016b).

Table 13 presents a matrix of potential rehabilitation / remediation options for soil and gully erosion as a quick reference guide. More detail on rehabilitation, remediation and monitoring options is presented for each soil erosion or gully types in Appendix 4.

The following cost effectiveness considerations have been defined to support a site by site implementation approach that encourages targeting of specific rehabilitation or remediation options to the specific soil and gully erosion types present at the site:

- Annual sediment loss from gullies and associated soil erosion processes within Springvale Station range from 25t/ha/year to 2500t/ha/year from site to site.
- Road gullies have been measured at 800 to 1600t/ha/year.
- Many gullies on Springvale Station are producing in excess of 300t/ha/year.
- A typical minimum cost effectiveness target per tonne of sediment erosion avoided is $300/t/year.
- Site assessments to support soil and gully erosion remediation designs should identify the erosion or gully type and its evolutionary stage, degree that the erosion has been increased by land use, and include an estimate of the current erosion rate (t/ha/year).
- Soil and gully remediation designs should describe specific actions tailored to specific erosion and gully types to achieve a minimum cost effectiveness of $300/tonne/year reduction.
- The calculation of cost effectiveness should include a sediment reduction efficiency factor that represents the % reduction in sediment loss that will be achieved by the specific actions (including the risk of failure or collateral damage).
- For example – for a specific gully, site assessments estimate that it is producing 400t/ha/year. The proposed gully remediation actions are estimated to reduce sediment loss by 50% (i.e. 200t/ha/year). The maximum cost of the proposed remediation actions (including site design, implementation supervision and monitoring) would be calculated as 400t/ha/year x 0.5 x $300/t = $60,000/ha.
- The approach described above is consistent with the Technical Guide for the Reef Trust Phase IV Gully and Stream Bank Erosion Control Program (Wilkinson et al., 2016). However, the “Gully Toolbox” also uses a delivery ratio to represent the proportion of the sediment loss (from the treatment site) that is delivered to the Great Barrier Reef Lagoon. This is used to compare the cost effectiveness of gully remediation in different locations within a catchment. For Springvale Station, it is considered that the same delivery ratio (WQIP used 40% (Cape York NRM and SCYC, 2016)) can be applied to all soil or gully remediation sites.
- An estimate of the sediment delivery ratios between the recommended treatment sites and the West Normanby Bridge and East Normanby Bridge water quality gauge sites would be beneficial for the conceptual understanding of the impact of improved soil and gully management on water quality monitoring results.
- Addressing soil and gully erosion across the Great Barrier Reef catchment is a priority action for achieving sediment reduction targets. As implementation progresses there is likely be a range of new/innovative/repurposed technologies that emerge. Applying new technologies at a large/commercial scale could reduce the total cost of achieving sediment reduction targets.

Table 13 Matrix of potential rehabilitation / remediation options for soil and gully erosion. YES means the option is appropriate, MAYBE means the option might be appropriate. Not all options must be taken at any given site, depending on geomorphic condition and other contingencies.

Potential Rehabilitation/ Remediation Option	Alluvial/ Colluvial Slopes Above Gullies	Scalded Soils & Shallow Gullies	Colluvial Gullies	Young (Linear) Alluvial Gullies	Mature (Amphitheatre) Alluvial Gullies	Old (Deep/ Revegetating) Alluvial Gullies	Roads & Fences	Cleared Paddocks
Cattle destocking	YES	YES	YES	YES	YES	YES	YES	YES
Fire management	YES						YES	YES
Fire exclusion		YES	YES	YES	YES	YES		
Weed control	YES	YES					YES	YES
Water / soil retention structures	YES	YES		YES				
Water diversion structures	YES		YES	YES	YES	YES	YES	YES
General revegetation (grass, shrub, trees)	YES	YES	YES	YES	YES	YES	YES	YES
Intensive grass planting (plug/seed)		YES	YES	YES	YES	YES		
Soil amendments (mulch/compost/gypsum)	MAYBE	YES	MAYBE	MAYBE	MAYBE	MAYBE		
Head cut chute drop structures			YES	YES	MAYBE (locally)			
Mechanical reshaping / battering		MAYBE	MAYBE	MAYBE	MAYBE			
Avoid machine disturbance	YES	MAYBE			MAYBE	YES	MAYBE	YES
Rock capping			MAYBE	MAYBE	MAYBE		YES	
Geopolymer and hydromulch			YES	YES	YES			
Gully channel grade control structures (brush, wood, rock)		YES	YES	YES	YES	YES		
Promote natural recovery and geomorphic evolution	YES	MAYBE			MAYBE	YES		YES
Basic monitoring	YES	YES	YES	YES	YES	YES	YES	YES
Intensive monitoring				YES	YES		YES	

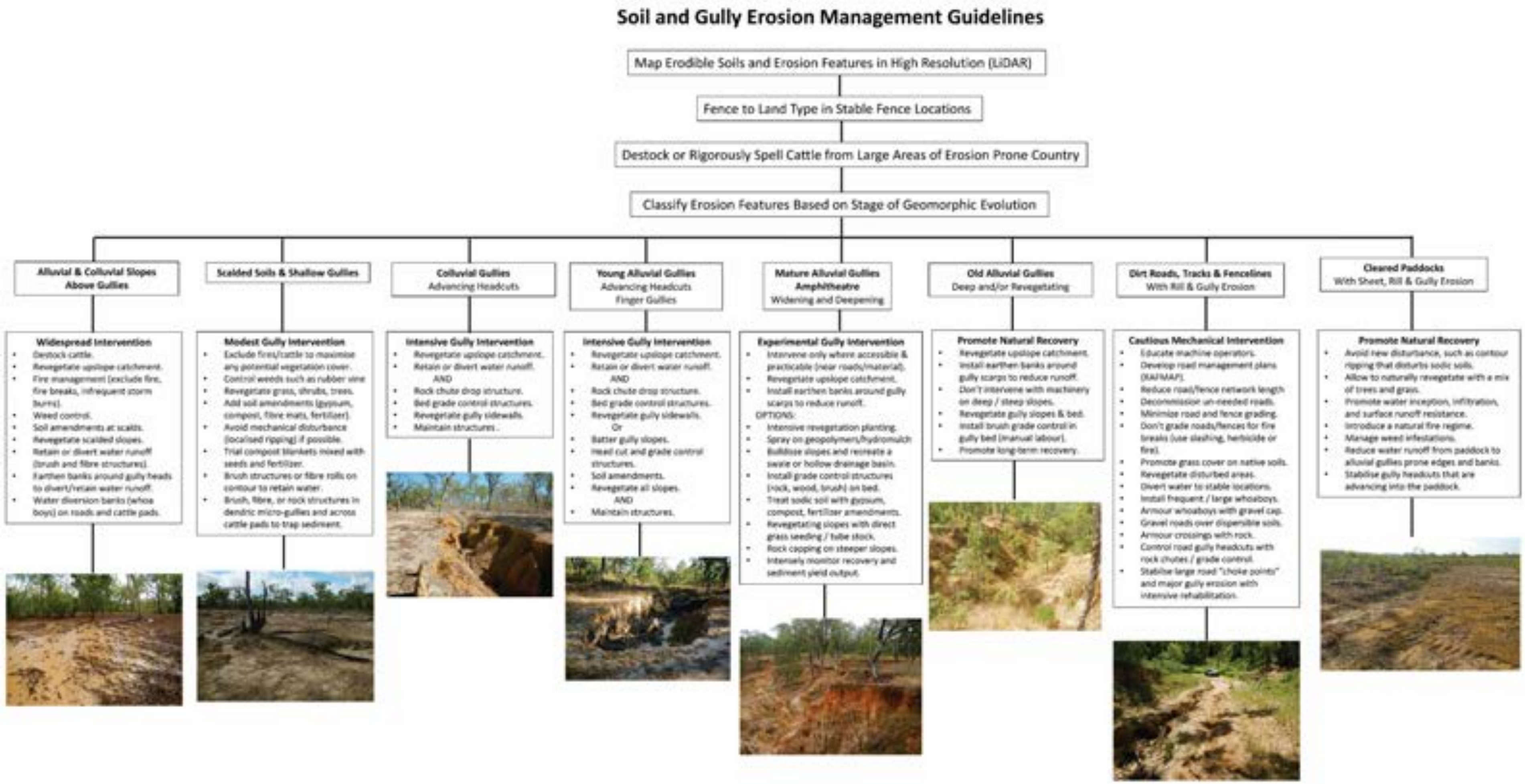


Figure 98 Management guidelines for the soil and gully erosion types on alluvial and colluvial soils present on Springvale Station (Source: updated from Shelberg et al. 2016b) (Refer to Appendix 4 for more detail on rehabilitation, remediation and monitoring options for each erosion type).

5.3 Sediment maintenance / prevention response 2017-2022 - property wide activities

A ‘Desktop land condition analysis’ was carried out using available remote sensing data sets to interpret ground cover, woody thickening and other indicators of land condition for the period 1990 to 2016 For this period ground cover was consistently high at the property scale (not individual gully catchments), but varied with season and the amount of rainfall. A rapid field assessment conducted in 2017 identified that, while cover is high in many places, the main vegetation types are not desirable (i.e., many exotic annual weeds). As a result, the overall current land condition of Springvale Station is considered to be poor (D to C condition) in the basalt, alluvium and colluvial slopes surface geologic units (Table 8).

The long-term ground cover pattern (LandSat) has been analysed for persistently bare areas. The persistently bare areas (white) appear to align with the areas of the property that have been more developed for grazing landuse and have been heavily grazed. The pattern of persistently bare areas is also consistent with the pattern of roads, gullies and stream channels as shown in Figure 76.

Three property wide activities are recommended preventative / maintenance measures to improve the overall land condition (particularly native vegetation cover) of the property (EMP Appendix). These activities are considered an essential foundation for the successful implementation of any sediment reduction response because they address the underlying causes of accelerated soil and gully erosion and aim to improve overall land condition.

5.3.1 Feral cattle management

Development and implementation of a feral cattle management plan is required to maintain very low to zero cattle grazing pressure across the property. The plan should include:

- Strategic boundary fencing in appropriate stable locations such as the western boundary with Lakeland properties (please note: it is **not** recommended from a sediment erosion perspective to fence the entire property along the boundaries through rugged and intact terrain prone to erosion).
- Coordinated shooting and/or mustering program for feral cattle.

Approximate total annual cost to develop and implement feral cattle management = ~ $100,000

5.3.2 Fire management

Development and implementation of a fire management plan is required to encourage an improvement in land condition. The plan should include:

- Boundary (aerial incendiary) and Highway fire breaks (early dry season burning mosaic) to stop wildfires and ensure proactive control of fire regime from arsonists.
- Experimental fire regimes designed to encourage perennial native grass communities and reduce woodland thickening and weed invasion, where appropriate.

Approximate Total Annual Cost to develop and implement fire management = ~ $100,000

5.3.3 Road and fence line management (outside Priority Focus Sediment Management Areas)

Development and implementation of a Road and Fence Maintenance and Abandonment Plan (RAFMAP) for all property roads and fences outside the alluvium/colluvium priority focus sediment management area is required to:

- Assess existing condition
- Determine essential infrastructure and areas to abandon after rehabilitation, and

- Design specific erosion control measures following Best Management Practices (e.g., Shellberg and Brooks 2013).

There are many road and fence line management issues on Springvale Station outside the alluvium/colluvium priority focus sediment management area that can be addressed with standard Best Management Practices (BMPs) for erosion control on primitive road systems (Hadden 1993; Jolley 2009; QDERM 2010abc; NSWOEH 2012). Many of these areas could be addressed immediately with well-training erosion control personnel and some basic geomorphic guidance.

Difficult road erosion hot-spots can still be encountered outside the outside the alluvium/colluvium priority focus management area, and must be treated with caution (see 'Broad soil erosion assessment'). Extra advice and enhanced BMPs will be appropriate for these sensitive areas (e.g., Shellberg and Brooks 2013). This is especially the case at creek crossings where roads and fence lines have cut into narrow pockets of alluvium/colluvium. Attempts at fixing these road cuts with standard equipment and approach could accelerate sediment pollution into local waterways, rather than reduce it. Therefore, it is recommended that work at many of these difficult areas wait for the completion of a Road and Fence Maintenance and Abandonment Plan (RAFMAP) after year 1 (2017), so that the extent and magnitude of erosion at these road/fence hotspots is surveyed and design recommendations are developed (see below for RAFMAP)

Approximate total annual cost to implement road and fence line management (***outside the alluvium/colluvium priority focus sediment management area)*** = ~ $100,000

5.3.4 Cost effectiveness of the sediment maintenance / prevention response 2017-2022

The total cost over five years (2017 to 2022) including basic site monitoring of on ground works is estimated to be $1.5M.

The total annual sediment yield reduced after 5 years of implementation is estimated to be 10,000t/year.

Estimated Cost Effectiveness (2017-2022) = $1,500,000/10,000t/year = $150/t/year

The cost of the recommended property-wide activities is estimated to be $300,000 per year for five years including the development and updating of site specific plans to support implementation. It is considered pragmatic to combine the annual budget for these activities to enable flexibility for the on-property managers to define costed annual action plans across cattle, fire and road preventative / maintenance action. More detail is presented in the 'Broad soil erosion assessment' and the 'Desktop land condition analysis'.

An improvement in land condition will result in reduced sediment loss from hillslopes across all geologies, and may also increase water infiltration and reduce runoff from the catchment above active gullies, reducing their cumulative erosion rates over time. Sediment tracing has estimated that 10 percent of the total sediment load is from surface soils on various hillslopes (i.e., not channel, bank, or gully erosion). It is estimated that cattle, fire and road preventative / maintenance actions could reduce the sediment loss from hillslopes by ~20% percent (~2 percent reduction in total sediment loss of ~ 500,000 t/year from Springvale Station). This could equate to 10,000 tonne/year of sediment reduction from surface erosion after a 5 to 10 year period of implementation (2017-2022+). It is unclear how effective these activities will be in further reducing sediment loss from active gullies of various sizes on Springvale Station, but additional indirect benefits are likely at the decade scale (2017 to 2027). Water quality monitoring should be undertaken to quantify the actual reduction in sediment loss from both hillslope and gully sediment sources as these activities are implemented.

5.3.5 Monitoring to support the sediment maintenance / prevention response 2017-2022

- Remote sensing of ground cover and fire frequency.
- Keep records of grazing, fire and RAFMAP on ground works (using standard site record sheets – grazing = land condition photo point record sheets, fire = ignition points and controlled burn record sheets, road = Gully Toolbox site record sheets or new road erosion record sheet).
- Water quality monitoring should be undertaken to quantify the actual reduction in sediment loss from both hillslope and gully sediment sources as property wide activities are implemented.

5.4 Establish sediment reduction response 2017-2018 - strategic demonstration sites

In 2017, the cost-effective and practical remediation or rehabilitation of extensive areas of gully erosion in the Great Barrier Reef catchment should be considered experimental. The recommended demonstration sites described below will help quantify sustainable sediment reduction benefits, between 2017 to 2022, without major risks, collateral damage, and impacts to biodiversity, aesthetic, or cultural resources of Springvale Station.

The four activities described below are recommended for the establishment phase (2017-2018) of a sediment reduction response.

5.4.1 Road erosion and associated mature alluvial gully demonstration sites

- Focus on active road gullies, road choke points restricting road access (Figure 102), complemented by a small number of experimental treatments for mature alluvial gully scarps associated with or near road choke points (Figure 101) along the Keetings Road area between the homestead and Keetings Yard.
- Develop detailed site designs that tailor specific remediation/rehabilitation actions to the specific sites using a range of different treatment options (including monitored control sites with no treatment) (Figure 98; Appendix 4).
- Integrate monitoring to enable the sediment reduction and cost effectiveness of different remediation/rehabilitation options to be quantified to inform future implementation.
- Maintain and adapt treatments over time to improve effectiveness (these are demonstration sites to inform implementation, not pure research sites).
- Produce case study communication products to enable the learnings to be shared.

5.4.2 Young (linear) rapidly advancing alluvial gully demonstration sites

- Focus on the linear rapidly advancing West Normanby Distal Gully (Figure 105; Figure 106; Figure 107)
- Develop detailed site designs that tailor specific remediation/rehabilitation actions to the specific sites using a range of different treatment options (including monitored control sites with no treatment).
- Integrate monitoring as part of the detailed site design to enable the sediment reduction and cost effectiveness of different remediation/rehabilitation options to be quantified to inform future implementation.
- Maintain and adapt treatments over time to improve effectiveness (these are demonstration sites to inform implementation, not pure research sites).
- Produce case study communication products to enable the learnings to be shared.

5.4.3 Native seed collection program to support implementation

- Focus on recommended native grass species required for demonstration sites (Table 16; Table 17).
- Build capacity of local seed collectors in identification of grass species and their stage of reproduction (could include a field guide).
- Define local areas (GPS locate) where sufficient grass seed can be sourced.
- Provide support to seed collectors on efficient seed collection techniques.
- Establish clear procedures and local facilities for seed drying and storage.

5.4.4 Improving gully prioritisation and site planning

- Collection of topographic LiDAR data across all of Springvale Station to support future planning and prioritisation of erosion control sites.
- Field surveys to support a Road and Fence Maintenance and Abandonment Plan (RAFMAP).

- Analyse complete LiDAR dataset and field surveys to improve prioritisation of locations and actions for the Targeted Sediment Reduction Response using process-based geomorphic classification and stage of erosion evolution.
- Detailed site design and cost effectiveness estimates of remediation/rehabilitation options to fast track the Targeted Sediment Reduction Response.
- Updated Sediment Budget for Springvale Station to support improved estimation of sediment reductions achieved through 2017 to 2022 implementation actions (funding could be sought from separate research and development funding streams).

The establishment of the demonstration sites and the native seed collection program should be undertaken in a way that fosters capacity building and practical experience for stakeholders that are likely to be involved in the Targeted Sediment Reduction Response 2018 – 2022 phase of implementation.

5.4.5 Cost of the establish sediment reduction response 2017-2018

The estimated cost for each of the four recommended activities is:

1 Road erosion and associated mature alluvial gully demonstration sites - Estimated Cost is $450,000 for design, implementation (including native seed) and monitoring to a standard that can detect the difference in sediment concentrations between experimental control and treatments at both road gullies and associated mature alluvial gullies.

2 Young (linear) rapidly advancing alluvial gully demonstration sites - Estimated Cost is $310,000 for design, implementation (including native seed) and monitoring to a standard that can detect the difference in sediment concentrations between experimental control and treatments at the West Normanby Distal Gully.

3 Native seed collection program to support implementation - Estimated Cost is $40,000 (not including the cost of seed collection which should be borne by the remediation site).

4 Improving gully prioritisation and site planning - Estimated Cost is $730,000.

An estimate of cost effectiveness of these establishment phase activities is not presented. These establishment phase activities involve extra planning, design, monitoring and capacity building expenses that should be considered a strategic investment towards high quality, cost effective outcomes during the Targeted Sediment Reduction Response 2018 – 2022 phase of implementation.

For the demonstration sites, the individual treatments should be representative of treatments that could achieve a minimum cost effectiveness of $300/t if applied at scale during the Targeted Sediment Reduction Response 2018 – 2022 phase of implementation.

5.4.6 Monitoring to support the establish sediment reduction response 2017-2018

- Repeat aerial LiDAR (ideally before and after)
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR (before and after) suitable for smaller sample areas (DEM)
- Ground cover photo points and record sheets
- Gully Toolbox monitoring of on ground works before and after
- Sediment concentration and water runoff yield from treated/control gullies
- Native seed germination and colonisation success.

5.5 Targeted sediment reduction response 2018 - 2022 – within 500m of the road network

This phase of implementation builds from the experience gained through implementation of the Targeted Demonstration Sites. It utilises the Springvale Station LiDAR dataset (to be acquired in 2017) and site assessments to design and implement site specific soil and gully erosion remediation activities to significantly reduce sediment production from erosion within 500m of the major road network. It represents larger-scale experimentation to up-scale lessons learned from the strategic demonstration sites to large areas of erosion. It will involve sustainable sediment reduction benefits without major risks, collateral damage, and impacts to biodiversity, aesthetic, or cultural resources of Springvale Station.

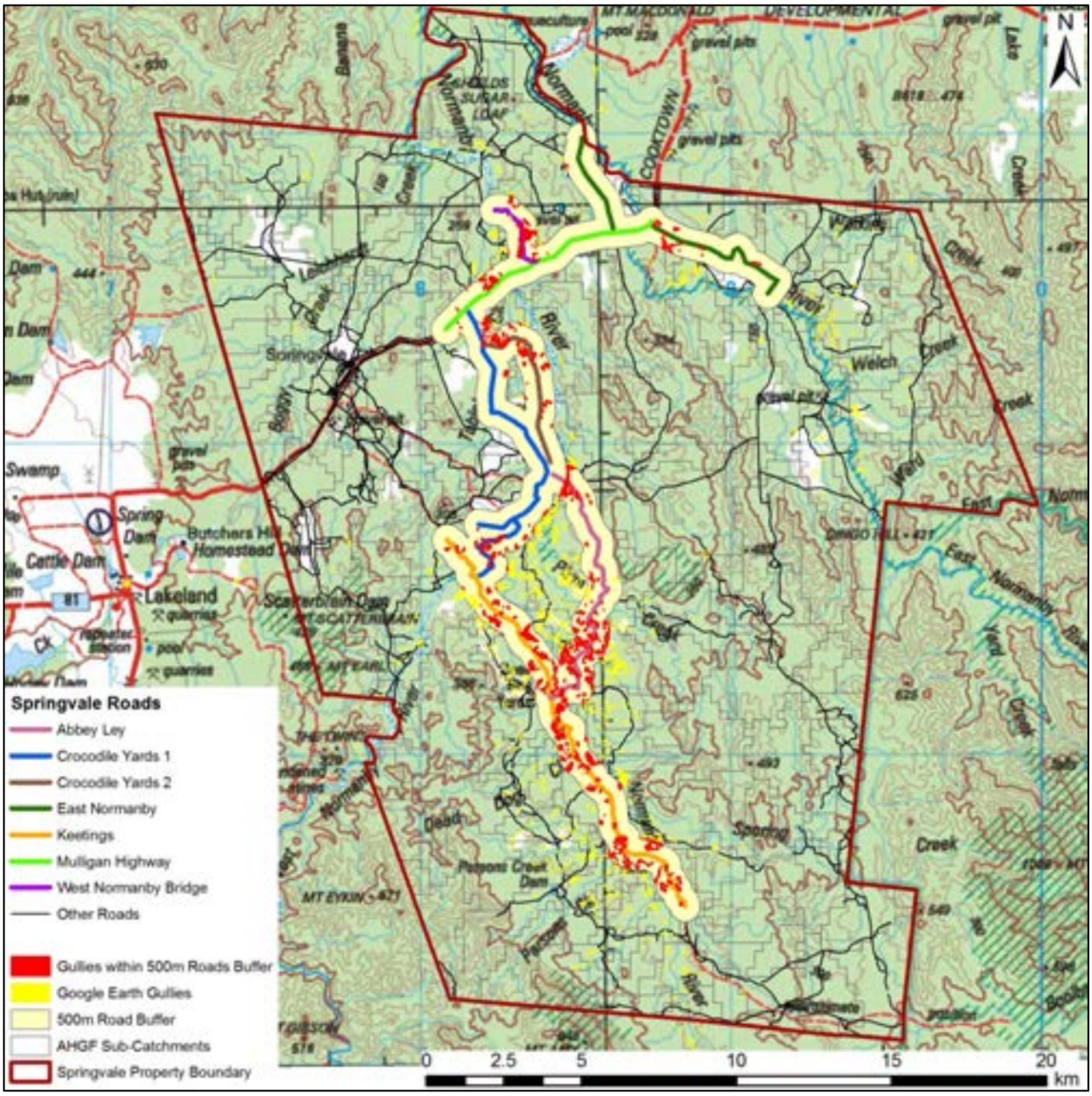


Figure 99 Selected major roads Springvale Station with gullies (red) that are within a 500m buffer of these main roads and are within the Alluvial / Colluvial Slopes geologic units (Source: Griffith University).

Actively eroding soil and gully erosion within 500m of the existing property road network is the logical location for a targeted investment to significantly reduce sediment loss from concentrated corridors of human land use disturbance, while also minimising collateral damage through the construction of new roads to isolated gully complexes.

Specific sections of road have been identified for this targeted phase of implementation and a 500m mask on each side of the road has been applied to define the area that should be investigated further (Figure 99). Some sections of road have been identified because they support property wide operational activities (East Normanby, Cook Paddock). However most have been identified because they are located adjacent to or within the modelled estimates of the top 25 sediment producing sub-catchments (the black shaded areas shown in Figure 100).

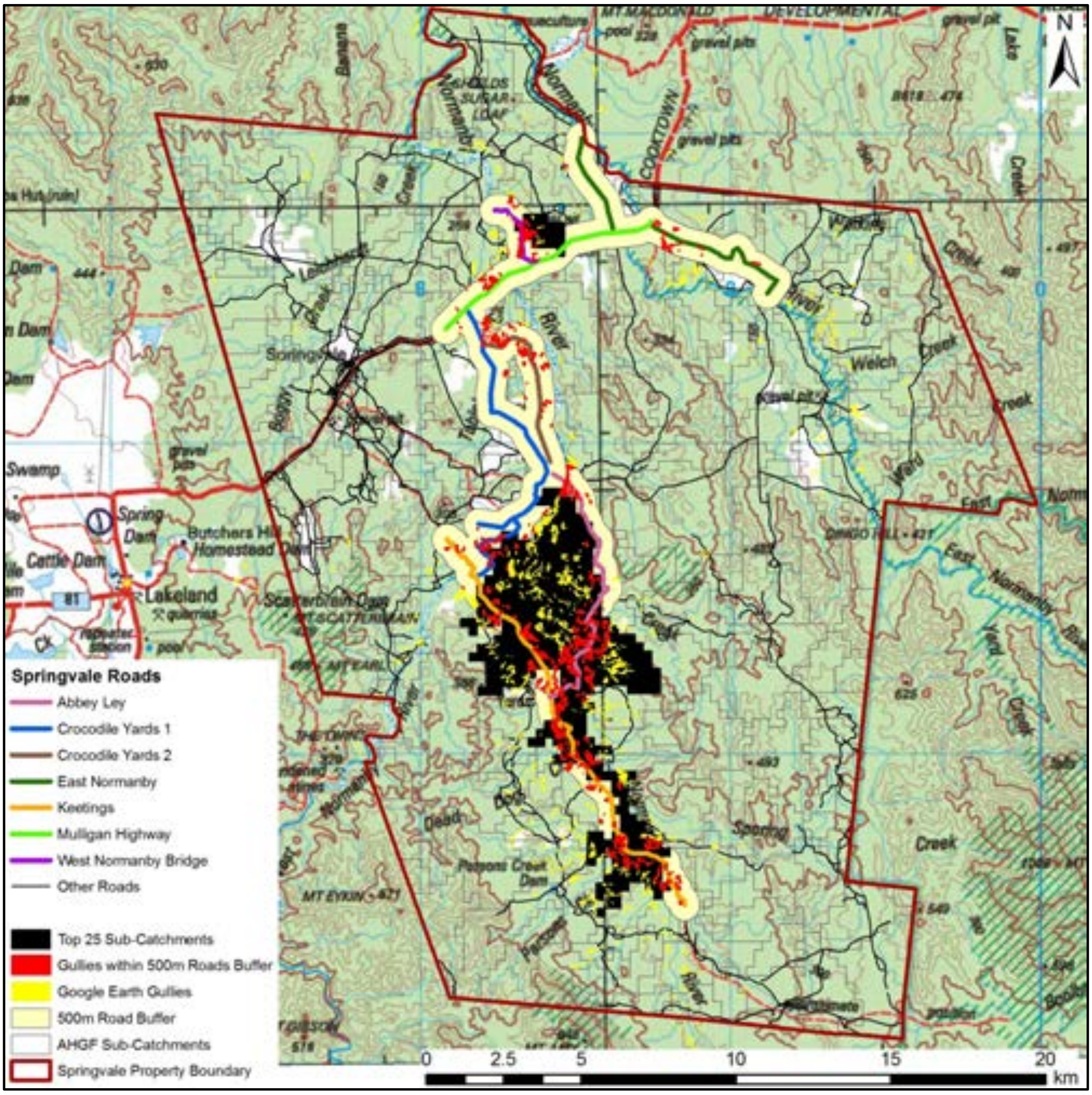


Figure 100 Alluvial / Colluvial Slopes gullies within a 500m road buffer are presented as red. The top 25 sediment producing sub-catchments are presented as the black background. Gullies that are within the top 25 gully sediment producing sub-catchments but are more than 500m from the road network are presented as yellow on black background (Source: Griffith University).

The modelled top 25 sediment producing sub-catchments should be considered as the logical location for future expansion of the targeted sediment reduction response, starting with the soil and gully erosion within 500m of the road network and expanding carefully to more isolated gully areas (within these sub-catchments) as successful gully remediation outcomes and avoidance of risks and collateral damage are achieved. The modelled top 25 sediment producing sub-catchments are currently estimated to produce approximately 60% of the current total sediment load from Springvale Station (Figure 91). These estimates and priority locations should be updated and confirmed as more LiDAR and field data become available over time across all of Springvale Station.

There are ~195ha of Google Earth mapped gullies (bare earth) within the identified 500m road mask that should be investigated in 2017/18 for active soil and gully erosion remediation in the 2018 to 2022 period (Figure 99; Table 14). Once a complete LiDAR dataset is available for Springvale Station, the total area of gullies within the identified 500m road mask is likely to be between five and ten times larger than the area of gullies visible on Google Earth.

The recommended approach is to use available LiDAR datasets and site assessments to identify and develop costed remediation designs for the following highly active soil and gully erosion types based on their stage of channel evolution and degree of human disturbance:

- Young (linear) rapidly advancing alluvial and colluvial gullies
- Road gullies (including road choke points)

It is also recommended to identify and develop costed remediation designs for a relatively small number of the following soil and gully erosion types to demonstrate and quantify cost effective treatments:

- Mature alluvial gullies
- Scalded soils and shallow gullies
- Disturbed alluvial slopes

LiDAR mapping plus on ground sites assessments are recommended to develop detailed soil and gully erosion remediation designs and to confirm that the recommended approach, spatial location and costing estimate is sound. It is important to note that analysis of full-LiDAR coverage of Springvale Station may reveal other high priority areas to target within the current modelled top 25 sediment producing sub-catchments. Targeting high priority areas using LiDAR and ground-truthing in the future will be based on stage of gully evolution, erosion rates, and practicality of intervention.

Table 14 Area of Google Earth mapped gullies within 500m of specific road sections (Source: Griffith University).

Road Name	Area of Google Earth mapped gullies within the 500m road buffer (Hectares)
Abbey Ley	45.60
Crocodile Yards 1	16.11
Crocodile Yards 2	16.36
East Normanby	7.98
Keetings	86.52
Mulligan Highway	9.60
West Normanby Bridge	13.09
Total	**195.26**

5.5.1 Cost effectiveness of the targeted sediment reduction response 2018-2022

Estimate of cost and sediment saved:

- It is estimated that there is at least 50ha of active soil and gully erosion (average sediment loss 400t/ha/year) that are of the type, evolutionary stage and current erosion rate that could be cost effective and practical to treat within the identified 500m road mask (Figure 99).
- The proposed remediation actions should be tailored to the specific site and aim to achieve a 50% sediment reduction across the 50ha of active erosion area (average sediment loss 400t/ha/year).
- The estimated cost to treat 50ha of eroded area producing on average 400t/ha/year to achieve a 50% reduction in sediment loss based on a minimum cost effectiveness of $300/t is $3M (average of $60,000 per hectare).
- The estimated sediment reduction is 10000 t/year (which is 2% of ~500,000 t/year coming from Springvale Station).

5.5.2 Monitoring to support the targeted sediment reduction response 2018-2022

- Repeat aerial LiDAR (ideally before and after)
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR (before and after) suitable for smaller sample areas (DEM)
- Ground cover photo points and record sheets
- Gully toolbox monitoring of on ground works before and after
- Native seed germination and colonisation success.
- Sediment concentration and water runoff yield from treated/control gullies
- East and West Normanby Bridge Water Quality monitoring sites. If the top 25 sediment producing sub-catchments are targeted then the East Normanby monitoring site could represent a control, with the West Normanby monitoring site representing a treatment. It is important to note that these gauges would have difficultly detecting a 2% change in sediment loads (within measurement error) in a short time period unless they were gauged to full international standards of super gauges with robust fluvial measurement and calibration techniques (Shellberg et al. 2016a).

5.6 More detail on the establish sediment reduction response 2017-2018 - strategic demonstration sites

More detail on each component of the establish sediment reduction response 2017 – 2018 phase is provided here to clarify the purpose of the activity and to support the fast tracking of these activities through standard government procurement processes. The rough costs presented here are designed to support budgeting and procurement processes and should be considered a minimum working budget to achieve a good quality outcome.

It is recommended that several immediate gully erosion control projects begin in 2017 -18 at several known hotspots of road and gully erosion. These locations will serve as monitored demonstration sites with different remediation/rehabilitation treatments to demonstrate the practical realities of road and gully erosion control, access and infrastructure needs, materials and personnel involved, the success of on-site rehabilitation and remediation, and the benefit to reductions in sediment yield off-site.

For the demonstration sites, the individual treatments should be representative of treatments that could achieve a minimum cost effectiveness of $300/t if applied at scale during the Targeted Sediment Reduction Response 2018 – 2022 phase of implementation.

The recommended strategic demonstration sites are all located within the alluvial/colluvial geology units of the Priority Focus Sediment Management Area (Figure 4). The following criteria were used to select initial sites:

1. Located within the alluvial/colluvial units of the Priority Focus Sediment Management Area.
2. Where data, field knowledge, and experts agree that there is an immediate need (high erosion or infrastructure impact).
3. Where intervention is reasonable in regards to the stage of geomorphic evolution of the erosion area, gully, or channel.
4. Where the consequences of failure and collateral damage are minimal using the knowledge and design tools presently at hand.
5. Are highly connected to the stream network.
6. Preferably within an area that has repeat LiDAR analysis (2009, 2011, 2015).
7. Have an existing property road nearby for access (or be a short distance from the Mulligan Highway).
8. Be an erosion area or gully complex of a scale that can be treated with available financial resources (Lower financial resources = smaller treatment area).
9. Have adjacent comparable erosion location that can be used as a control for treatment sites to quantify erosion reduction benefit.
10. Ideally be close to suitable sources of material that could be used in a design (rock, wood).

These focused investments would be complemented by the longer-term feral cattle management and fire management activities that apply to the entire property.

5.6.1 More detail on road erosion and associated mature alluvial gully demonstration sites

Estimated Cost is $450,000 for design, implementation (including native seed) and monitoring to a standard that can detect the difference in sediment concentrations between experimental control and treatments at both road gullies and associated mature alluvial gullies.

The ‘Broad soil erosion management issues’ section of the ‘Broad soil erosion assessment’ reviews in detail the major road erosion problems on Springvale Station, and especially associated with alluvium/colluvium soils in the Priority Focus Sediment Management Area. For example, the Granite Normanby Road (30 km long) from the Springvale Station homestead to the yards at the ‘Keetings Paddock’ on the southern boundary of the station has at least 71 gully erosion hotspots where the road has caused or accelerated gully erosion (Figure 68; Figure 102). This includes 10 serious

‘Choke Points’ where deep gully erosion has restricted any reasonable road access. Another 30 of these road gullies make drivability difficult.

Management of these major road and fence erosion issues needs to be guided by a detailed Road and Fence Maintenance and Abandonment Plan (RAFMAP). Specifically, plans, guidelines, and designs are needed for road maintenance, road abandonment and rehabilitation, road use, and road re-construction where appropriate.

Focusing initial erosion control activities at Springvale Station along these highly degraded road and fence networks represents the most basic ‘No Regrets’ activities and ‘low hanging fruit’ for positive results for sediment reduction in the short-term (1-5 years). Erosion rates at some of the gullies ‘Choke Points’ have been measured with terrestrial LiDAR to be ~ 900 to 1600 tonnes/ha/year, which are very high on a world scale for both roads and gullies (Shellberg and Brooks 2013; Shellberg et al. 2013b).

It is assumed that maintaining access along Granite Normanby Road to Keetings will be a priority for future management access. Alternative routes are difficult -- but possible and should be discussed. It is logical to address the major erosion along the road to Keetings, and other very difficult road sections, to 1) provide property access to other areas of major erosion and management needs (weeds, fire), and 2) to address road erosion caused directly by man and machine. Additional experimental gully rehabilitation works could also be focused at gullied terrain around the ‘Choke Points’, as machine access by default will be available (Figure 101).

However, the total costs of maintaining this road network and accelerating erosion need to be weighed up against benefits of access, sediment reduction, and potential alternative routes less prone to erosion (Shellberg and Brooks 2013).

Road stabilization designs, lessons learned, and Best Management Practices (BMPs) for Springvale Station roads can be gleaned from data and experiences in Shellberg and Brooks (2013), reviewed in the ‘Broad soil erosion management issues’ section of the ‘Broad soil erosion assessment’.

Figure 101 An example of a three-way “road intersection” and “Choke Point” through a large alluvial gully complex accelerated by historical road and fence use, which could be the site of “No Regrets” activities to both provide stable road access and rehabilitate the surrounding gully complex for sediment reduction goals (Source: Jeff Shellberg).

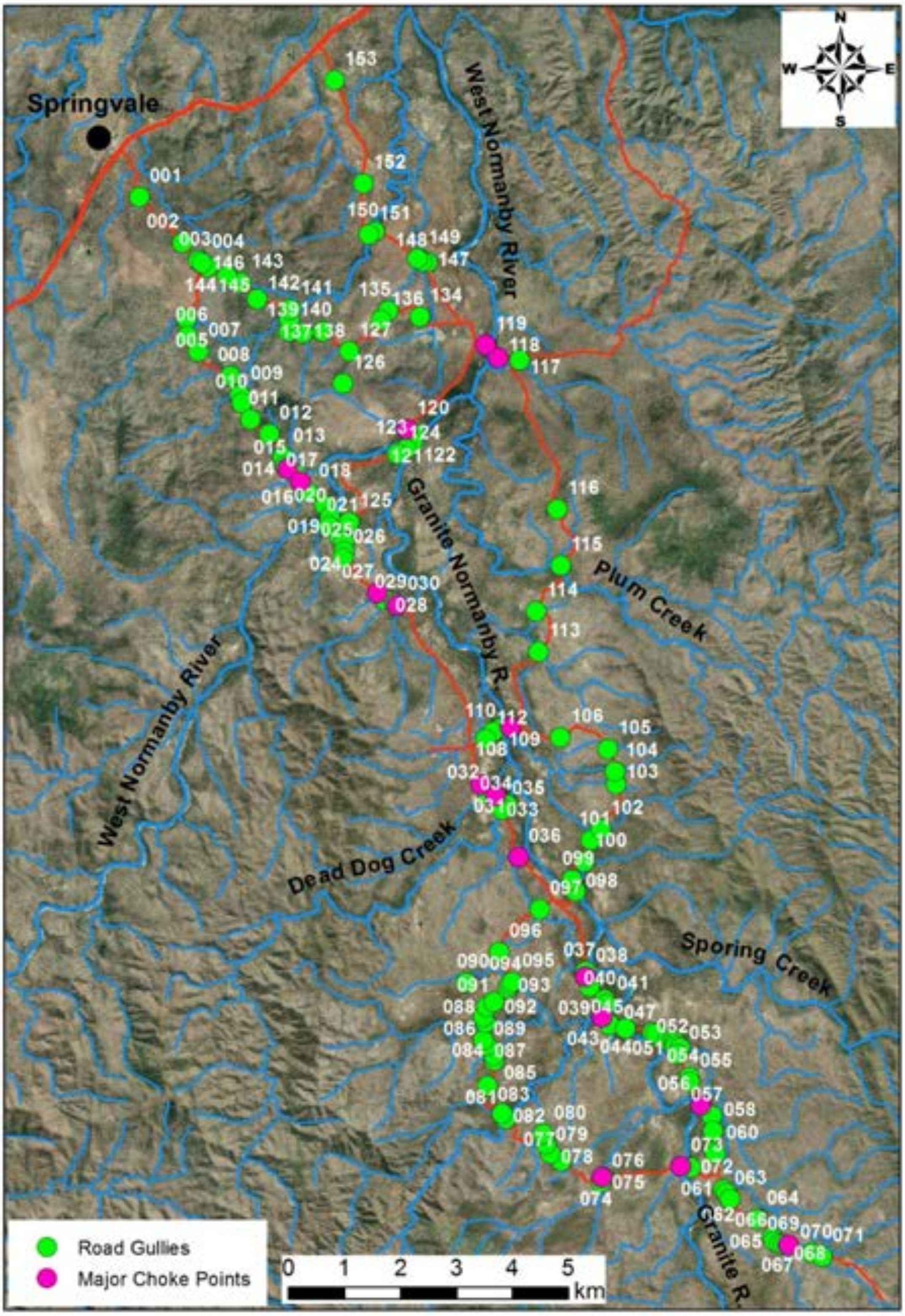


Figure 102 ‘Road Gullies’ caused or accelerated by road construction and use along the southern half of Springvale Station between the Homestead and the ‘Keetings Paddock’. Also included are road ‘Choke Points’ where gully erosion is so severe that it almost completely restricts vehicle access without heavy machinery intervention with appropriate bioengineering and precautionary principles of erosion control (Source: Jeff Shellberg).

Costs for erosion control at degraded road sections on sodic soils can vary greatly depending on the severity of the problem, the distance to any potential sources of rock, rock quality, the experience and skill of machine operators, and the degree of supervision often needed to avoid collateral damage and 'project drift'. These are reviewed in the road stabilization examples in Shellberg and Brooks (2013), as well as the 'Broad soil erosion assessment'. With an efficient operator and close supervision and design, installing one simple water diversion bank (whoa boy) constructed with local native (sodic) material cost ~ $200, while a complex structure using locally imported rock (borrow pit) cost ~ $400. One gully hotspot with 4 whoaboys and rock capping cost ~$2000 in total (Shellberg and Brooks 2013). These costs would likely double for less efficient operations or quadruple if rock was imported from far away (Lakeland).

For the most complex 'Choke Points', it would likely cost $10,000 up to $20,000 per hotspot to provide longer term road access, and even more to stabilize the associated larger gullies complexes adjacent to the road. For 71 road gully hot spots including 10 'Choke Points', it is estimated that $122,000 + $100,000 = $222,000 would be needed to stabilize 30 km of road network access, or ~ $7400 per km. This excludes design costs. This could occur over one or more years in stages, and would address the worst 30 km (12%) of the road network on Springvale Station (255.9 km), not including fence-lines.

These costs are similar to works done on nearby Kings Plains Station that installed 200 rock whoaboys across 50 km of road, sheeted 6.5 km of road with rock, and stabilized 12 major eroded road sections (not as big as on Springvale Station) for $182,000 at ~ $254 per tonne of sediment reduced estimated from reduced vertical sheet and rill erosion on the road prism (Hughes and Shellberg, unpublished data).

During Year 1 (2017) no regret actions, we are recommending focusing on at least two road 'Choke Points' and associated gully scarps that block access to the Granite Normanby Keetings Road (Figure 102). These are the first major choke points in sodic soils encountered when travelling up the Keetings Road. There are more problems further along the Keetings road, and eight (8) additional 'Choke Points' could be addressed in Year 1 (2017) if funding was available.

- Road Gully 17/18 on the West Normanby Keetings Road (Figure 103)
- Road Gully 28/29 on the Granite Normanby Keetings Road (Figure 104)

Figure 103 Choke Point erosion and gulling at road gully 18 (Source: Jeff Shellberg).

Figure 104 Choke Point erosion and gulling at road gully 29 before (top, 2016) and after (bottom, 2017) regrading to maintain immediate access for cattle management. Stabilizing this sediment will be critical before the 2017/18 wet season (Source: Jeff Shellberg).

Specific design ideas for these road “Choke Points” can follow and build upon experiences in Shellberg and Brooks (2013). Stabilizing these points for improved access would entail rock grade control structure within advancing headcuts on either side of the road, battering scarped road edges to a stable slope, and capping the road surface and batters with imported or local rock gravel. Additional revegetation would also be needed, and treatment of exposed sodic soil with gypsum where not capped with rock.

Cost consideration ~ $20,000 for 2 major choke points for access, or $100,000 for 10 major choke points for access plus $122,000 for 61 road gully hot spots for access along Keetings Road.

5.6.1.1 Mature alluvial gully experimental treatments associated with or nearby road ‘choke points’

Due to readily available road access to Road Gully 17/18 and 28/29 and need for machinery at these sites, mature alluvial gully scarps in gullied areas adjacent to the suggested road could be used as additional demonstration sites for erosion control. Adjacent gully scarps of mature alluvial gullies at or nearby these road choke points could be used to test major earthwork, battering and revegetation options on big gully walls and scarps (Figure 101). Testing these more intrusive and higher risk techniques are more appropriate near roads and key access points, rather than deeper into more remote parts of Springvale Station with additional values and risks.

Adding these mature alluvial gully experimental treatments to the 2017- 2018 establishment phase of implementation could be considered a bonus and beyond actions needed to immediately address the road choke points and access along Keetings road. However it is considered a logical, low risk strategy to start with some carefully designed and monitored mature alluvial gully demonstration sites before including these mature alluvial gully types in the Targeted Sediment Reduction Response phase of implementation.

5.6.2 More detail on young (linear) rapidly advancing alluvial gully demonstration sites

Estimated Cost is $310,000 for design, implementation (including native seed) and monitoring to a standard that can detect the difference in sediment concentrations between experimental control and treatments at the West Normanby Distal Gully.

Young rapidly advancing alluvial gullies (along with Road Gullies) are a priority gully type to address in the Targeted Sediment Reduction Response 2018- 2022 phase of implementation. It is recommended to develop a high quality monitored demonstration site with various treatment options at the West Normanby Distal Gully (Figure 105; Figure 106) described in more detail below.

5.6.2.1 West Normanby Distal Gully

This gully complex (Figure 105) was chosen as an erosion control demonstration for multiple reasons. It is an active area of erosion with multiple headcuts migrating upstream into an earlier (pre-European) hollow or gully network. If these headcuts are allowed to advance, then the entire gully network could be rejuvenated with channel incision, creating much larger gully scarps and increasing the future sediment yield many times. The area has multiple gully complexes at multiple stages of channel evolution into pre-European landforms, which can be used as control sites as well as space-for-time control. The site has repeat LiDAR over three years (2009, 2011, 2015) as well as historic air photo imagery (Figure 106) and gully scarp (not surface or sidewall) erosion rates are well known for the site (Table 15).

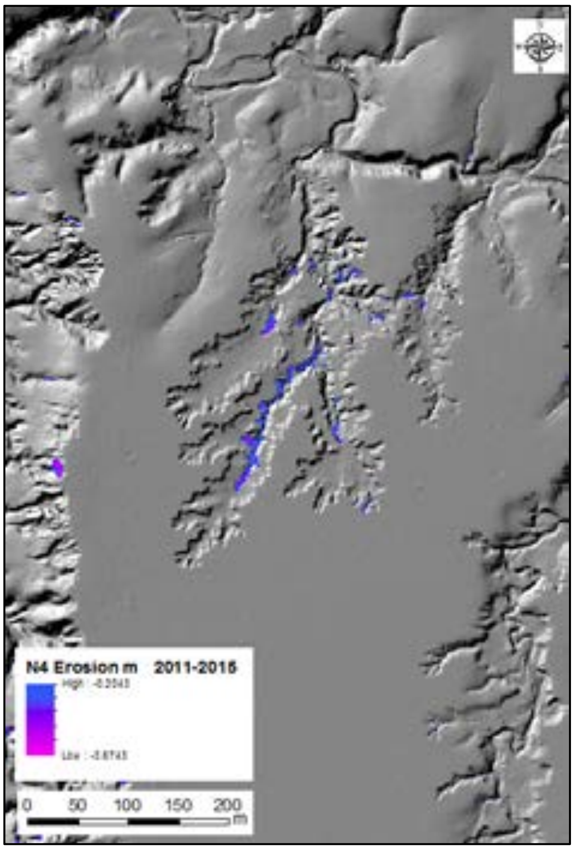


Figure 105 A large distal gully complex near the West Normanby Bridge which shows total erosion between 2011 and 2015 of 989m^3 of which, 924m^3 was from secondary incision (Source: Griffith University).

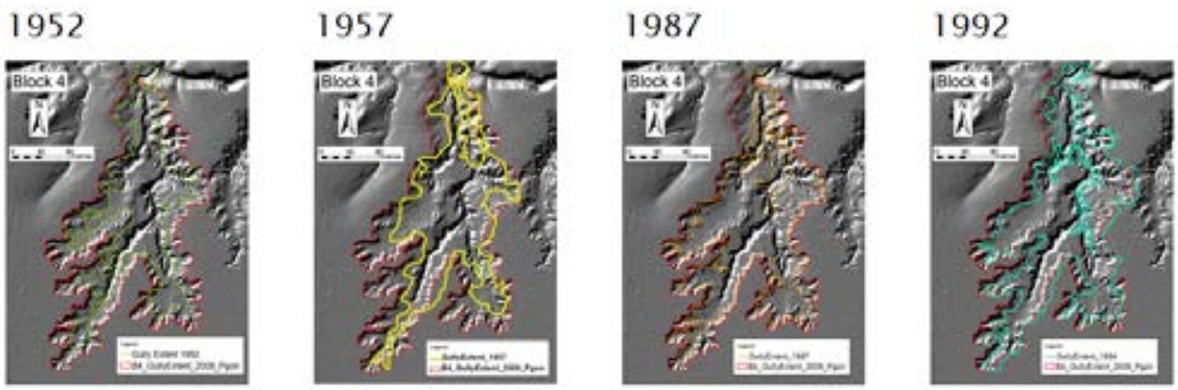


Figure 106 Growth of the distal gully in Figure 105 derived from air photo analysis back to 1952. Incision of gully floor was not seen in the 1952 image, but between 1957 and 2009 the advance of the longest incision was 218 m, an average of 4 m per year. In comparison, head wall advance at different locations was between 20 and 40 m, an average annual advance of less than 1m (Source: Griffith University).

Table 15 Erosion rates determined over 5 decades from air photos, and recent erosion from LiDAR analysis (Source: Griffith University).

Interval	Gully area at start of period ha	Rate of loss m^3/yr	Yield m3/ha/yr Based on 2009 gully area
1952 - 2009	2.18	615	131
1957 - 2009	2.63	445	95
1987 - 2009	3.19	634	135
1994 - 2009	3.50	787	168
2009	4.70		
2009 - 2011	4.70	2205	470

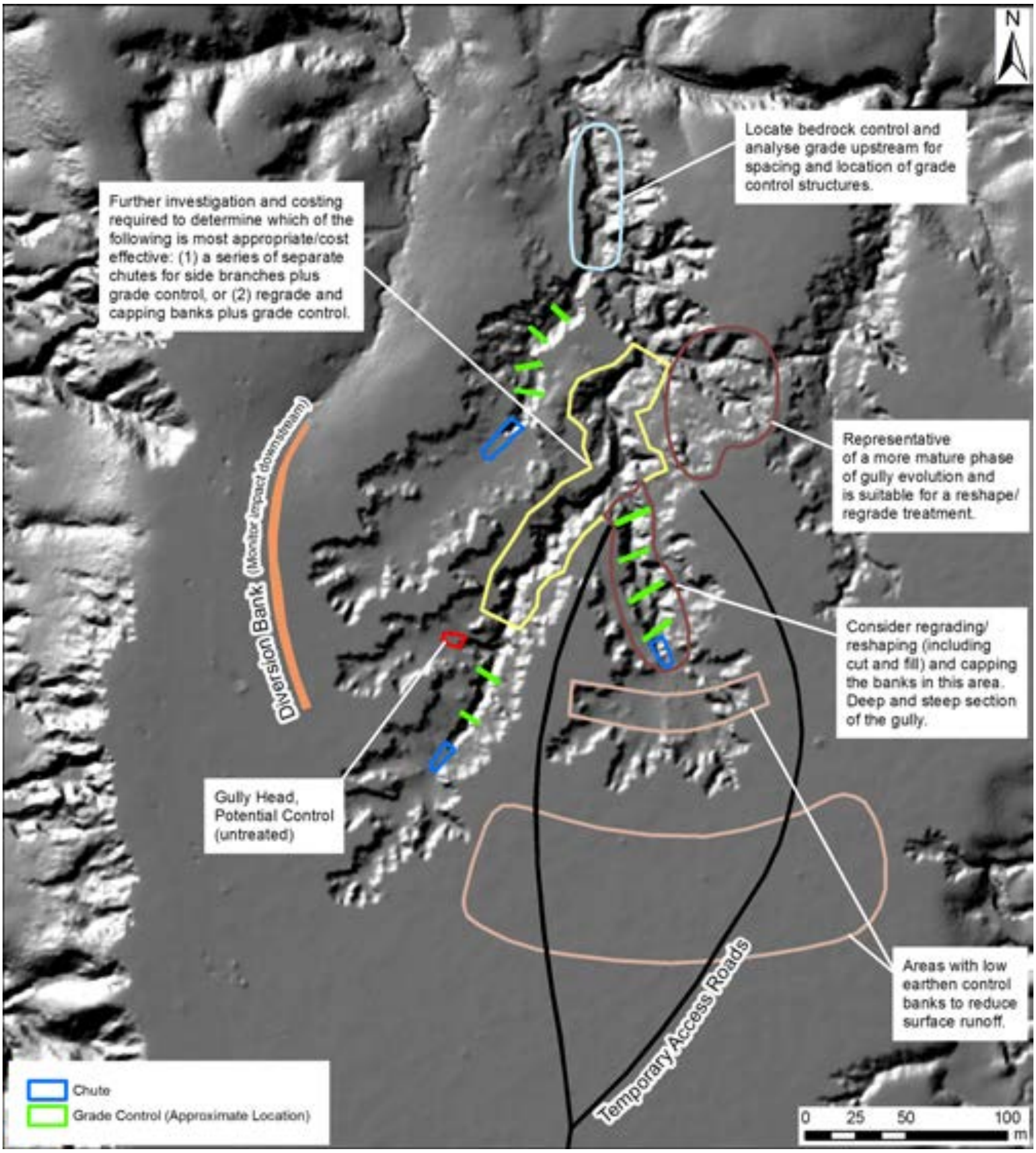
The site is close to the Mulligan Highway, and has reasonable access across vegetated flats for personal and machinery. However, the existing fence line track toward the site will need to be updated and realignment, as the existing fence line (track) is part of another existing experimental gully site and cattle exclusion area on the proximal bank of the West Normanby, with vegetation monitoring plots inside and outside the cattle exclusion fence that cannot be disturbed by road development (Shellberg and Brooks 2013). However, having an additional remediation investment in this general area would result in a good demonstration site of different approaches.

The proposed treatment at this site could involve the following:

- Staggered porous rock grade control structures embedded well into the bed and banks of the gully, as well as a rock chute at the upstream most headcut(s).
- Rock will be used at strategic locations using surgical placement with machinery, and not blanket the site.
- In some sections of the gully complex, consideration should be given to full regrading of gullies and capping with rock and/or stabilized and augmented new “soil”. This would be accompanied by rock graded control structures within the gully floor.
- Revegetation with locally sourced native grasses and trees will occur in disturbed soils around the rocks structures and other bare areas. Direct seeding of bare ground will occur twice during the first wet season, with follow-up in areas with poor germination success.
- The catchment area within and around the gully complex is currently dominated by exotic grader grass (*Themeda quadrivalvis*) and thickened tree and shrub cover. Altering fire and grazing regimes in this area might be able to open up the canopy and shift the dominance of annual grass to perennial (which will be a major weed vegetation experiment). Improving the catchment vegetation condition might help reduce water runoff into the gully system.
- Installing water diversion or retention bunds around the gully heads, where water can be safely redirected to mitigate water runoff issues, while minimizing off-site water delivery impacts and disturbance to existing tree and shrub vegetation.

- Surface stabilization of sodic scalded surfaces using gypsum, compost and mulch with minor regrading where appropriate.

Figure 107 below presents a conceptual gully remediation design for the West Normanby Distal Gully (Top is LiDAR, Bottom is aerial photograph) that was developed by the Springvale Erosion Management Plan Project Team during site assessments on the 6th June 2017.



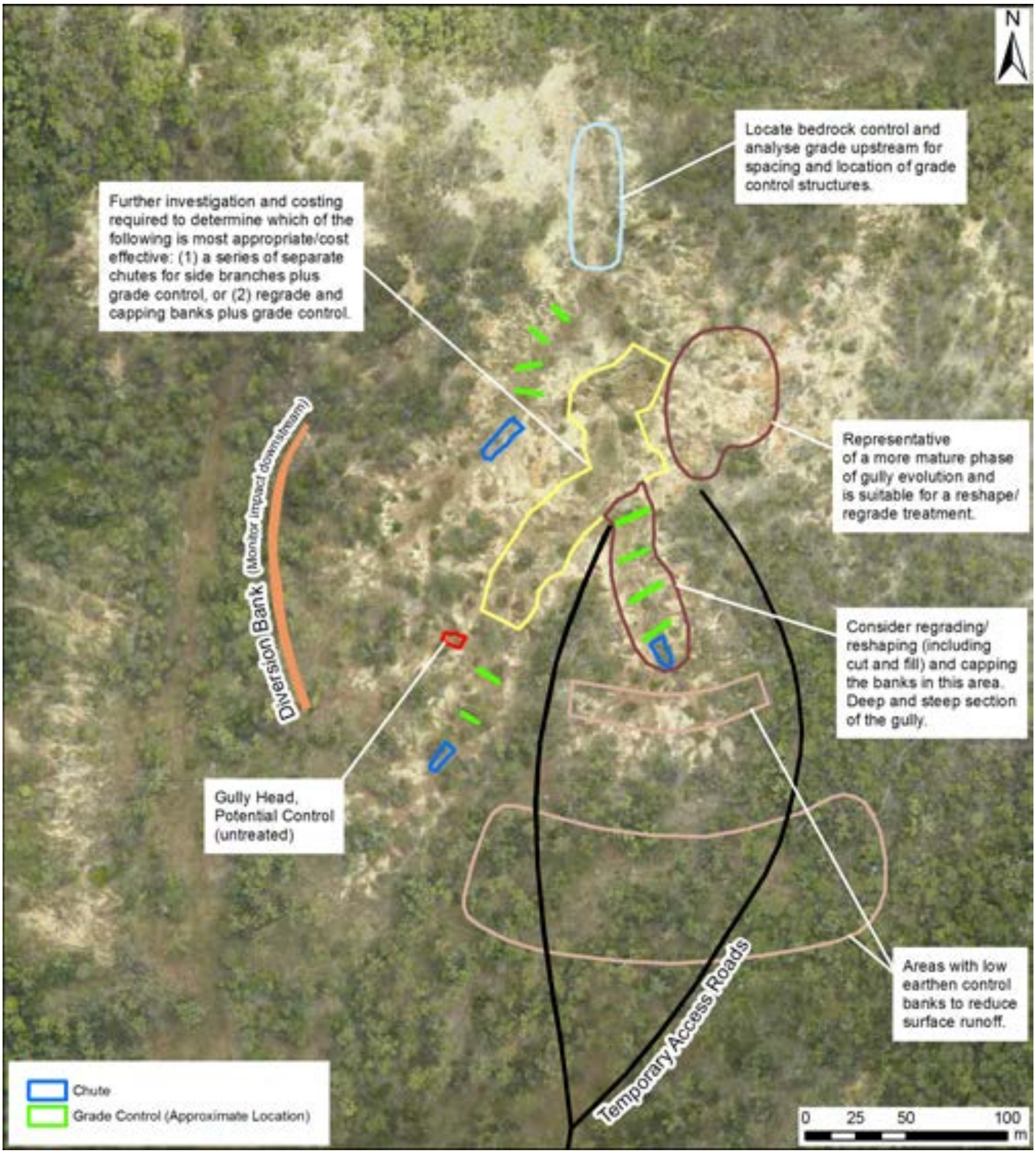


Figure 107 Conceptual gully remediation design for the West Normanby Distal Gully (previous page is LiDAR base layer, this page is aerial photograph base layer). LiDAR is a very useful planning tool for developing gully remediation plans, where LiDAR is unavailable more detailed site surveys will be required (Source: Griffith University).

5.6.3 More detail on grass seed collection in 2017/2018 for future gully remediation

Estimated Cost is $40,000 (not including the cost of seed collection which should be borne by the remediation site).

There are two rehabilitation options for remediation of the Springvale Station gully complexes;

1) Non-Assisted
2) Assisted.

Non-assisted rehabilitation relies on natural processes to remediate areas of erosion over time (Shellberg and Brooks 2013; Shellberg et al. 2016b). In areas where gully complexes are regarded as minor and adjacent to intact stands of native vegetation no rehabilitation may be required. In these areas vegetation may colonise the gully complexes and naturally stabilise the eroded areas.

Assisted rehabilitation will be required for some gully complexes at Springvale Station. This will involve several rehabilitation techniques ranging from direct seedling to the strategic planting of specific species. Irrespective of the techniques chosen, a large quantity of seed will be required. It is understood that works may not commence in earnest until 2018 however acquiring seed for rehabilitation will need to have been completed beforehand. This proposal focuses primarily on the acquisition of grass seed. Tree and shrub species will be determined after site assessment have been performed in May/June.

In general assisted remediation for direct seeding requires 20kg^{+}/ha of grass seed. Acquiring large amounts of seed from suppliers is problematic for two reasons;

1) Seed suppliers do not have an extensive range of species. Whilst some seed could be sourced by commercial suppliers most will need to be collected.
2) Maintaining genetic diversity within natural populations is essential for the existence of many grass species. Within dry tropical environments there is a high variation in the genetic diversity between populations of grass species (for example see Fitzgerald et al., 2011 - "Genome diversity in wild grasses under environmental stress"). These variations can be attributed to each population being exposed to different environmental stresses. Differences in genetic structure are believed to assist in adapting to area specific conditions.

Sourcing grass seed from interstate or southern Queensland threatens the genetic integrity of naturally occurring grass populations within the Cape York region. There is a high potential for genetic diversity becoming diluted which threatens the ability of species adapting to local environmental conditions.

To overcome these problems it is proposed that grass seed is collected at Springvale Station and surrounding properties.

5.6.3.1 Species selection

In determining the grass species to be used for remediation the following criteria was used;

- Species should be found or at least recorded at Springvale Station.
- Grass species should be perennial
- Grass species selected should include a range of phenological emergence times (i.e. some species will emerge from root stock immediately after the first rains of the wet season whilst others will emerge later).

To determine the grass species currently recorded at Springvale Station, electronic searches of the EHP REDD (ver. 10) and Wildnet (Wildlife Online) were conducted.

5.6.3.2 Regional Ecosystems

A search of the most common Regional Ecosystems occurring on Springvale Station include a grass layer consisting of a mixture of the following;

- *Themeda triandra*
- *Sarga plumosum*
- *Heteropogon contortus*
- *Heteropogon triticeus*
- *Mnesithea rottboelloides*

The species listed above will be included in the proposed grass seed mixture.

Over 150 grass species have been located at Springvale Station (Data from the Wildnet database - EHP – Wildlife Online). Of those several exhibit characteristics that enable them to persist in areas of seasonal inundation and others germinate/re-sprout at the beginning of the wet season. All selected species show potential to assist in stabilising areas effected by erosion. These include;

- *Alloteropsis semialata*
- *Arundinella nepalensis*
- *Chrysopogon filipes*
- *Chrysopogon pallidus*
- *Imperata cylindrica*

5.6.3.3 Recommended seed mixtures

Two seed mixtures are proposed for the gully complexes at Springvale Station. The first mixture (Table 16) is to be applied above gullies to stabilise existing top soil and reduce the velocity of surface run-off. These species are perennial grasses that are common within the RE descriptions found at Springvale Station. The second mixture (Table 17) is to be applied within gully complexes. These species were chosen as they can endure seasonal inundation, act as sediment barriers and develop root systems that stabilise gully floors and banks.

Table 16 Recommended seed mixture for direct seeding above gully complexes. Prices per Kg are standard industry rates (Source: James Hill).

Species	Seed placement	Cost $/kg	Mixture (Kg/ha)	$/ha
Themeda triandra	Above	$400	2kg/ha	$800
Sarga plumosum	Above	$150	4kg/ha	$600
Heteropogon contortus	Within/Above	$150	5kg/ha	$750
Heteropogon triticeus	Above	$400	4kg/ha	$1600
Mnesithea rottboelloides	Within/above	$450	2.5kg/ha	$1125
Alloteropsis semialata	Within/above	$550	2.5kg/ha	$1375
Total			**20kg/ha**	**$6250/ha**

Table 17 Recommended seed mixture for direct seeding within gully complexes. Prices per Kg are standard industry rates (Source: James Hill).

Species	Seed placement	Cost $/kg	Mixture Kg/ha	$/ha
Heteropogon contortus	Within/Above	$150	5kg/ha	$750
Mnesithea rottboelloides	Within/above	$450	2.5kg/ha	$1125
Chrysopogon filipes	Within	$400	2.5kg/ha	$1000
Chrysopogon pallidus	Within	$400	2.5kg/ha	$1000
Imperata cylindrica	Within	$1000	3kg/ha	$3000
Arundinella nepalensis	Within	$450	2kg/ha	$900
Alloteropsis semialata	Within/above	$550	2.5kg/ha	$1375
Total			**20kg/ha**	**$9150/ha**

5.6.3.4 Seed collection program

Most species of grass occurring in the Cape York bioregion produce seeds within the first six months of the year (Table 18). In doing so they avoid seasonal fires and enable seeds to enter the soil seed bank. It is proposed that seed collection begin December 2017 and extend through to May/June 2018. The overall amount of seed required will determine the number of staff that will necessary to reach seed quotas. Flexibility in reaching seed quotas will also be needed to consider poor seasonal seed production due to climatic variations (i.e. ENSO) and/ or logistical issues experienced when collecting.

Table 18 Seeding times of grass species recommended for use for gully complexes on Springvale Station (Source: James Hill).

Species	Seeding times
Themeda triandra	Summer
Sarga plumosum	March - April
Heteropogon contortus	April - May
Heteropogon triticeus	March - May
Mnesithea rottboelloides	January - March
Chrysopogon filipes	Wet season
Chrysopogon pallidus	Wet season
Imperata cylindrica	November onwards – This species appears to seed in burnt areas immediately after the first rain of the wet season.
Arundinella nepalensis	Late wet season
Alloteropsis semialata	December - January

5.6.3.5 Seed specialist visit

A seed specialist will be required to assist and direct seed collections. The primary role will be to;

- Identify grass species and their stage of reproduction
- Locate areas where sufficient grass seed can be sourced
- Provide support by educating collectors on efficient seed collection techniques
- Provide support in drying and storage procedures.

The specialist will be required to make 5 visits that will co-occur with the onset of reproduction in selected grass species. The estimated cost of specialist advice to establish a local seed collection program is presented in Table 19.

Table 19 Estimated cost of seed specialist advice required to establish a local seed collection program (Source: James Hill).

Rates	Daily	Weekly	Total cost of 5 visits
Daily surveys	$1,200	$6,000	$30,000
Accomodation and meals	$150	$750	$3,750
Travel & car hire		$650	$3,250
Production of seed collection guide and printing			**$2,500**
Total			**$39,500 (excluding GST)**

5.6.4 More detail on improving gully prioritisation and site planning

Estimated Cost is $730,000 for all five activities described below (Please note that the updated sediment budget for Springvale Station could come from a separate research budget).

5.6.4.1 Collection of topographic LiDAR data across all of Springvale Station to support future planning and prioritisation of erosion control sites

A full topographic LiDAR survey across Springvale Station is a prerequisite and priority for the development of a full balanced erosion management plan. Topographic, erosion, and sediment budget datasets collected and distributed across the Normanby Catchment scale (Brooks et al. 2013) are fairly coarse for detailed planning at the property scale. Initial erosion control activities can start within the first year without full LiDAR data at ‘no regret’ problem areas and activities (see below), but proper planning and prioritization must be based on a full coherent baseline dataset across the whole property. The full range of erosion features and types (sheet, rill, gully, bank, mass failure, road/fence disturbance, infrastructure like dams) must be known and assessed for proper prioritization and relative ranking. This prioritization should be based on improved mapping of soil and slope types (especially the boundary of colluvium and alluvium to bedrock), process-based geomorphology, stages of channel and gully evolution (young vs old gullies), more accurate knowledge of erosion magnitudes where possible, and improved mapping of human land use disturbance areas. Full LiDAR cover will be key to this understanding for prioritization.

For example, existing survey data of erosion distribution and magnitude across Springvale Station are incomplete (Table 10). Boundaries of different soil types and thus erosion processes are poorly mapped across Springvale Station. Mapping gullies from Google Earth is biased towards large bare visible gullies, and misses thousands of gullies, rills and scalds under the tree canopy or not detectable due to their size in bedrock colluvial hollows, colluvial footslopes, or alluvial valleys. Bank erosion is currently only detected in existing LiDAR blocks, and even then bank erosion in small channels can be missed by repeat LiDAR, as can much gully, rill and sheet erosion. Roads and fencelines are poorly mapped without full LiDAR coverage, and erosion at creek crossings associated with these features is not mapped or quantified well. Furthermore, features such as scalded terrain and rilling and shallow gully erosion of colluvial/alluvial soils are un-mapped and missed in existing sediment budgets, although it is acknowledged that the highest concentrations of these processes tend to occur in close proximity to partially mapped gullies and are thus represented indirectly in these areas. Mapping of rilling, shallow gully and channel erosion is more incomplete in the Hodgekinson and basalt geologic units due to scale issues. The drainage density of creeks cut into hillslopes of all types are greatly underestimated to properly estimate small channel erosion, acknowledging that the degree that this type of erosion is accelerated by land use is unknown. Current sediment budget estimates are based on extrapolation from these strategically located sample data, but it is recognized that they are not sufficient for detailed planning across the entire property.

LiDAR across the property at the minimum will provide a baseline template for mapping land units and erosion types for specific prioritization, and at best will serve as the data template for greatly improved sediment budget calculations needed to support property management for the next decade or two (if separate research funding becomes available).

Cost consideration of LiDAR survey = $70,800 (590 km^2 at ~ $120 per km^2)

Cost consideration of LiDAR geomorphic analysis of land units and erosion types = ~ $60,000 (includes ground truthing)

Approximate Total Cost of LiDAR survey and analysis = ~ $130,000

5.6.4.2 Field surveys to support a Road and Fence Maintenance and Abandonment Plan (RAFMAP)

Future management at Springvale Station needs to be guided by a detailed Road and Fence Maintenance and Abandonment Plan (RAFMAP) as part of the overall Erosion Management Plan and Property Management Plan. Specifically, plans, guidelines, and designs are needed for road maintenance, road abandonment and rehabilitation, road use, and road re-construction where appropriate. A RAFMAP and resultant management need to be taken seriously if a reduction in human caused sediment pollutions is to be achieved at Springvale Station.

Erosion along roads and fence lines is a 100% direct source of anthropogenic sediment from land use that is typically directly delivered to local creeks (for at least a portion of the disturbance area upstream of the drainage line). It is a source of sediment that can be directly addressed through improved management, but can also made worse by improper actions. Road erosion is often considered “low hanging fruit” and a prerequisite to all other activities to ensure reasonable, safe, and pollution free access to the property, as well as rehabilitating and abandoning un-needed roads and fences.

Existing knowledge of road and fence locations at Springvale Station has improved, with 255.9 km of road or vehicle track, and 303.9 km of fence line disturbance mapped (Figure 60). However, erosion associated with each km of these roads and fences is poorly documented. To date, 85 km of dirt road have been partially surveyed by a geomorphologist in the Granite Normanby for erosion hazards, and mapped 154 major road gully hotspots and 17 ‘Choke Points’ as an absolute minimum (Figure 64; Figure 102). These types of surveys need to be improved upon in detail and expanded to the whole property. These field data can be coupled with LiDAR surveys across the property to accurately assess erosion hazards, especially concentrated where roads and fences cross creek and gully channels.

The foundation of a Road and Fence Maintenance and Abandonment Plan (RAFMAP) at Springvale Station is comprehensive surveys of erosion issues along roads and fences, coupled with improved mapping and geomorphic interpretation with property wide LiDAR data. Prioritization can occur once these data are gathered, collated and interpreted. Logistical issues such as road/fence need and use will also come into play on where, if and how to intervene with road erosion. Erosion magnitude and risk to future access or sediment yields will also be factors to consider.

Similar surveys could occur for dam stability and erosion hazards, and erosion hazards associated with disturbance and infrastructure such as cleared paddocks, yards, and waste dumps.

Field surveys are the foundation data needed for a RAFMAP. The field surveys could be designed and implemented in a way that also captures Cultural Heritage information. However additional Cultural Heritage mapping and clearance surveys and site designs for erosion control will be needed to transform field data and interpretation into design actions.

In the meantime during the 1st year (2017/18), road/fence erosion issues can be addressed at known problem areas where both access and erosion magnitude issues are present. For example, at the road choke points mapped in Figure 102.

Approximate Total Costs of Road/Fence Surveys, LiDAR Interpretation, and Road and Fence Maintenance and Abandonment Plan = ~ $50,000

5.6.4.3 Analyse complete LiDAR dataset and field surveys to improve prioritisation of locations and actions for the targeted sediment reduction response using process-based geomorphic classification and stage of erosion evolution

Updated prioitisation of erosion control locations and actions can occur once full datasets are available on property-wide LiDAR, road/fence inventories, and sediment budget (if conducted). While it is assumed that this will be finalised in Year 2 (2018) of the project, it should be planned and fast tracked in the second half of 2017. Updated prioritisation will be based on:

- Cultural Heritage constraints to intervention
- Biodiversity and landscape integrity (aesthetics) constraints to intervention
- The proximity of gully erosion to Cultural Heritage, and the level of threat of gully erosion to Cultural Heritage
- Total number or area of erosion types
- Geomorphic assessment of erosion risk and relative magnitude in sum
- Sediment yields per erosion type summed cumulatively across all features of that type as well as unit specific sediment yield (if available from updated sediment budget)
- Stage of channel evolution of gully types (based on area or volume remaining to erode, or erosion risk)
- Degree that erosion has been directly or indirectly influenced by land use
- Proximity of erosion features to infrastructure, road access, and material access
- Practicality of intervention, risks of intervention and potential collateral damage (increased sediment yields or damage to other values)
- Cost of intervention per unit benefit sediment reduction or other property value

Approximate Total Cost of updated prioritisation to incorporate new datasets = ~ $100,000

5.6.4.4 Detailed site design and costing to refine 5-year implementation plan: detailed site design and cost effectiveness estimates of remediation / rehabilitation options to fast track the targeted sediment reduction response

Detailed site design will be required to support implementation of the 2018 – 2022 actions. While it is assumed that this will be finalised in Year 2 (2018) of implementation, it should be planned and fast tracked in the second half of 2017.

- Site design for gully erosion control within the 500m road mask (catchment, scarp, channel)
- Site design for road and fence erosion control within the 500m road mask
- Site design for disturbed area erosion control (cleared paddocks, dams, dumps) (notes that this does not include Cook Dam issues).

The field surveys, required to complete these site designs, could be designed and implemented in a way that also captures Cultural Heritage information. However Cultural Heritage mapping and clearance surveys may be required independently from the erosion control site design surveys to ensure that Cultural Heritage is identified and protected.

Approximate Total Cost of detailed site design to support 5 year actions = ~ $150,000

5.6.4.5 Updated sediment budget for Springvale Station (including bioavailable particulate nutrient budgeting) to support improved estimation of sediment reductions achieved through 2017 to 2022 implementation actions

An updated sediment and nutrient budget and associated calculations are not absolutely essential for improved prioritization based on the requisite property-wide LiDAR and road/fence surveys. Geomorphic interpretation of these property wide LiDAR data-sets could be the basis of detailed prioritization without new budgeting. However, updated sediment budget calculations (estimates) on all landforms could add more detailed weight to decisions on specific features to concentrate on based on sediment yield, geomorphic evolution, land use disturbance intensity, and practicality of intervention.

LiDAR data and road/fence data at the property scale will greatly enhance an updated sediment budget. However, additional field data would need to be collected from past missing components to the sediment budget to supplement existing available data (Table 10). These specifically are:

- Updated LiDAR change detection time series (i.e. including data from the 2015 refly along with the new LiDAR resurvey covering the full extent of the original LiDAR surveys flown in 2009.
- Higher resolution sediment tracing
- Soil sheet, rill and scald erosion from a variety of land types (alluvium, colluvium, hillslope varieties (siltstone, mudstone, vs. greywacke dominated) under various disturbance intensities (grazing, fire, road) that are poorly quantified in existing models.
- Gully erosion in areas with erosion change under the vertical detection limit of repeat LiDAR (0.2 to 0.5 m).
- Channel, rill and shallow gully erosion in bedrock and colluvial valleys that dominate the drainage density of Springvale Station, as well as alluvial channel erosion.
- Road and fence erosion magnitudes.
- Accurately gauged sediment yields at smaller sub-catchments (~ 1 km^2) and main river gauges (East and West Normanby) (i.e., super gauge approach, Shellberg et al. 2016c) to better quantify actual yields to compared to budget calculations and assess accuracy and potential missing budget components or magnitudes.

Approximate Total Cost of improved sediment budget with field validation = ~ $300,000

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Appendix 1 – DRAFT Springvale Station Cultural Heritage Clearance Form

Appendix 2 – Springvale Sub-catchments Modelled Sediment Yield Ranking Data Set

Appendix 3 - DRAFT Prioritisation Based on a Combined Gully & Linear Disturbance Metric

Appendix 4 - Gully Types, Remediation, Rehabilitation and Monitoring Options

Appendix 5 – Brief History of Springvale Station

APPENDIX 1 - DRAFT SPRINGVALE STATION CULTURAL HERITAGE CLEARANCE FORM

PROJECT LOCATION:		**PROJECT NUMBER:**	
PROJECT NAME:		**Date:**	

RECITALS:

1. This Agreement is a Field Inspection Agreement between the Aboriginal Parties and the Department of Environment and Heritage Protection (EHP) the Managers of Springvale Station.
2. EHP proposes to XXXX ("the Project") on land described as (insert property details) ("the Project Area").
3. EHP and the Aboriginal Party have assessed Aboriginal Cultural Heritage implications for the Proposed Activity in the Project Area and reached an agreement to manage these.

THE PARTIES AGREE:

1. Unless otherwise specified terms used in this agreement have the same meaning as given in the *Aboriginal Cultural Heritage Act 2003 (Qld)*
2. A field inspection of the project area shown on the plan in Attachment A was completed on < insert date> and surrounding area as required by the Traditional Owners and/or:

On/site inspection information	

3. The parties agree that XXXX may proceed with the Proposed Activity in the project area in accordance with the management arrangements described in the following paragraphs.

4. The parties agree that the following table records the agreed outcomes arising from the Field Inspection:-

Activity	**Access**
Has a Find been identified? *If Yes, describe in the Finds record in paragraph 5 below.*	Yes ☐ No ☐

Are there any Cultural Heritage constraints requiring management arrangements? *If Yes, describe in the Finds record in paragraph 5 below.*	Yes ☐ No ☐

5. The Parties agree that < there is no additional information to include in the Finds Record in this paragraph > OR < the following table is the Find Record referred to in the preceding paragraph and particularises how XXXX will manage Cultural Heritage in the Project Area and every find identified during the field inspection.

FINDS RECORD						
Find Number	**Lot on Plan**	**Find Type (i.e scar tree, artefact)**	**Easting**	**Northing**	**Cultural Heritage Site Record and Management Arrangements**	**Attach Ref.**
1						
2						
3						
Comments or restrictions						

SIGNED for and on behalf of YYYY Aboriginal Corporation by the following Traditional Owners:

Signature:	**Signature:**
Name:	**Name:**
Date:	**Date:**

SIGNED for and on behalf of XXXX

______________________________________Dated:

Signature above.

____

Print name above.

____

T**itle/Authority**

APPENDIX 2 – SPRINGVALE SUB-CATCHMENTS MODELLED SEDIMENT YIELD RANKING DATA SET

rank	Count	IDNum	River	NCB_Area (ha)	Total Sed Yield (t/yr)	cummulative % sed contribution	Gully Sed Yield (t/yr)	Gully Area (ha)	Road Length m	Road Area (ha)
1	165	9225	Granite Normanby River	66.7	24723	4.9%	24648	11.04	73	0.029
2	201	9346	Granite Normanby River	51.9	23918	9.7%	23856	9.56	0	0.000
3	170	9237	Granite Normanby River	629.8	16093	12.9%	15777	59.53	3789	1.137
4	217	9397	Granite Normanby River	133.3	15727	16.1%	15559	14.67	2247	0.770
5	224	9419	Granite Normanby River	74.1	15325	19.1%	15219	7.23	1157	0.347
6	160	9181	Granite Normanby River	103.7	13718	21.8%	13590	11.34	712	0.214
7	148	9133	Granite Normanby River	666.9	13396	24.5%	12965	60.59	3206	0.956
8	192	9313	Granite Normanby River	74.1	12793	27.1%	12695	7.25	2385	0.845
9	198	9333	Granite Normanby River	111.1	11938	29.5%	11736	7.91	945	0.347
10	194	9321	Granite Normanby River	22.2	11906	31.8%	11884	2.17	232	0.093
11	174	9259	Granite Normanby River	44.5	11827	34.2%	11752	2.84	839	0.280
12	184	9284	Granite Normanby River	96.3	11816	36.5%	11741	8.71	1426	0.543
13	211	9390	Granite Normanby River	51.9	11667	38.9%	11615	4.92	809	0.809
14	180	9272	Granite Normanby River	44.5	11410	41.2%	11327	3.45	1005	0.301
15	125	8974	West Normanby River	66.7	11173	43.4%	11120	3.98	1587	0.857
16	150	9141	Granite Normanby River	289.0	10584	45.5%	10319	20.43	2610	0.799
17	219	9403	Granite Normanby River	118.5	10064	47.5%	9969	7.24	1200	0.360
18	204	9355	Granite Normanby River	14.8	9824	49.5%	9802	0.81	326	0.098
19	216	9396	Granite Normanby River	118.5	9781	51.4%	9738	7.78	0	0.000
20	47	8546	West Normanby River	140.9	9541	53.3%	9414	9.97	1273	2.114
21	173	9258	Granite Normanby River	326.0	8682	55.0%	8434	19.52	4191	1.419
22	155	9160	Granite Normanby River	111.2	8514	56.7%	8409	5.79	2160	0.779
23	86	8733	West Normanby River	296.5	6553	58.1%	6350	14.84	2921	2.472
24	208	9378	Granite Normanby River	259.3	6534	59.4%	6239	11.06	3945	1.225
25	151	9142	Granite Normanby River	22.2	5549	60.5%	5518	0.65	514	0.154
26	235	9441	Granite Normanby River	66.7	5476	61.6%	5402	2.45	978	0.293

27	63	8616	East Normanby River	303.9	5371	62.6%	5275	10.61	157	0.219
28	215	9395	Granite Normanby River	281.5	5163	63.7%	4961	8.86	2735	1.493
29	136	9049	West Normanby River	126.0	5162	64.7%	5014	3.72	2604	1.201
30	191	9312	Granite Normanby River	51.9	4875	65.7%	4811	2.05	0	0.000
31	226	9422	Granite Normanby River	296.3	4863	66.6%	4674	10.36	3076	1.181
32	177	9264	Granite Normanby River	266.7	4855	67.6%	4595	8.90	2311	0.693
33	163	9196	West Normanby River	629.9	4714	68.5%	4347	15.75	8813	2.779
34	209	9379	Granite Normanby River	311.1	4647	69.5%	4401	9.95	4842	2.072
35	232	9434	Granite Normanby River	170.4	4589	70.4%	4439	4.85	2613	0.784
36	120	8941	West Normanby River	333.5	4556	71.3%	4299	7.93	8341	5.067
37	130	9011	West Normanby River	207.5	4375	72.2%	4282	6.06	5230	2.264
38	62	8615	West Normanby River	333.6	4183	73.0%	4019	8.45	11486	20.124
39	176	9263	Granite Normanby River	385.3	3974	73.8%	3666	9.57	6340	2.328
40	69	8644	West Normanby River	467.1	3886	74.6%	3630	13.91	9231	11.292
41	241	9455	Granite Normanby River	274.0	3667	75.3%	3507	5.65	1788	0.872
42	77	8673	East Normanby River	140.8	3492	76.0%	3286	3.81	1429	0.331
43	152	9149	Granite Normanby River	96.3	3342	76.7%	3237	1.66	993	0.298
44	234	9438	Granite Normanby River	259.2	3112	77.3%	2923	5.63	3315	0.995
45	205	9362	Granite Normanby River	133.3	3056	77.9%	2885	3.10	1272	0.331
46	23	8397	West Normanby River	155.7	3042	78.5%	2894	3.21	1358	0.407
47	83	8709	East Normanby River	44.5	3032	79.1%	2957	1.08	560	0.784
48	96	8802	West Normanby River	400.3	2855	79.7%	2606	7.17	1112	1.112
49	227	9423	Granite Normanby River	163.0	2697	80.2%	2538	2.88	1029	0.309
50	73	8657	West Normanby River	44.5	2621	80.7%	2546	0.60	0	0.000
51	190	9311	Granite Normanby River	207.4	2614	81.3%	2425	2.83	3192	0.983
52	171	9245	Granite Normanby River	214.9	2589	81.8%	2345	3.44	638	0.191
53	28	8452	West Normanby River	393.0	2545	82.3%	2234	5.20	6033	3.703
54	115	8915	West Normanby River	370.6	2500	82.8%	2165	6.60	7618	5.740
55	138	9061	West Normanby River	474.3	2483	83.3%	2110	5.84	4681	3.277
56	210	9380	Granite Normanby River	385.2	2454	83.8%	2190	5.70	2243	0.673
57	76	8672	East Normanby River	118.6	2343	84.2%	2238	1.79	1190	0.357
58	42	8524	West Normanby River	74.1	2218	84.7%	2112	0.84	1496	1.816
59	105	8838	East Normanby River	281.6	2191	85.1%	1911	4.39	1572	1.387

60	169	9236	West Normanby River	59.3	2036	85.5%	1943	0.79	997	0.299
61	182	9274	Granite Normanby River	303.8	1967	85.9%	1585	3.86	1114	0.334
62	64	8617	East Normanby River	259.4	1966	86.3%	1735	3.67	3285	0.982
63	221	9408	Granite Normanby River	244.4	1922	86.7%	1666	3.13	1712	0.514
64	145	9107	West Normanby River	340.9	1841	87.1%	1627	3.34	6238	2.805
65	246	9466	Granite Normanby River	141.7	1605	87.4%	1531	1.01	2044	2.044
66	98	8816	East Normanby River	148.2	1597	87.7%	1470	1.56	1529	2.141
67	158	9172	West Normanby River	170.4	1588	88.0%	1354	1.67	3100	0.930
68	60	8603	East Normanby River	185.3	1371	88.3%	1159	1.77	3907	1.172
69	134	9033	East Normanby River	377.9	1351	88.6%	1001	2.89	4113	2.774
70	181	9273	Granite Normanby River	407.5	1334	88.8%	998	2.17	1913	0.725
71	43	8525	West Normanby River	22.2	1208	89.1%	1187	0.18	184	0.257
72	220	9407	Granite Normanby River	971.0	1185	89.3%	608	4.52	3850	1.151
73	149	9134	Granite Normanby River	340.8	1173	89.5%	949	1.73	3373	1.176
74	65	8630	East Normanby River	733.9	1117	89.8%	697	3.75	10628	16.704
75	133	9032	Granite Normanby River	200.1	1114	90.0%	917	0.98	1949	0.585
76	7	8279	East Normanby River	483.2	1057	90.2%	722	9.24	11562	15.366
77	75	8671	East Normanby River	96.4	1056	90.4%	972	0.50	346	0.484
78	59	8602	East Normanby River	96.4	1023	90.6%	909	0.72	2138	0.642
79	143	9105	West Normanby River	852.3	1019	90.8%	473	2.15	20584	11.526
80	240	9453	Granite Normanby River	162.9	1002	91.0%	801	1.07	887	0.266
81	247	9467	Granite Normanby River	133.3	975	91.2%	817	0.61	1132	0.451
82	238	9451	Granite Normanby River	239.9	956	91.4%	777	1.03	0	0.000
83	72	8647	East Normanby River	326.1	949	91.6%	601	1.61	2615	0.683
84	92	8775	East Normanby River	170.5	938	91.8%	746	1.05	0	0.000
85	81	8707	Leichhardt Creek	296.5	938	92.0%	687	1.51	4238	2.709
86	35	8487	East Normanby River	159.3	933	92.1%	852	1.64	2368	1.339
87	175	9260	Granite Normanby River	592.7	910	92.3%	430	1.94	896	0.269
88	29	8453	East Normanby River	320.4	909	92.5%	623	1.70	4758	3.234
89	74	8670	East Normanby River	889.7	894	92.7%	350	2.34	15234	18.254
90	12	8327	East Normanby River	326.3	866	92.9%	655	1.43	4009	2.531
91	114	8914	West Normanby River	563.3	864	93.0%	440	2.04	6023	3.976
92	141	9092	Granite Normanby River	177.8	821	93.2%	712	0.68	2172	0.992

93	126	8986	East Normanby River	444.6	780	93.3%	488	1.70	4068	2.012
94	67	8632	East Normanby River	215.0	688	93.5%	507	0.88	702	0.211
95	113	8897	East Normanby River	615.2	684	93.6%	238	1.19	5447	4.422
96	9	8296	Leichhardt Creek	386.4	654	93.8%	360	1.84	160	0.032
97	243	9460	Granite Normanby River	536.2	628	93.9%	180	0.74	3224	1.853
98	70	8645	East Normanby River	155.7	617	94.0%	520	0.67	3224	2.649
99	139	9062	Granite Normanby River	192.7	608	94.1%	422	0.43	544	0.163
100	137	9050	West Normanby River	815.2	605	94.2%	222	0.97	3801	3.249
101	206	9371	Granite Normanby River	266.7	589	94.4%	357	0.51	0	0.000
102	8	8295	Leichhardt Creek	381.2	572	94.5%	198	0.58	2684	0.750
103	104	8837	East Normanby River	281.6	546	94.6%	289	0.65	2102	2.625
104	102	8835	West Normanby River	578.2	521	94.7%	148	0.70	8540	9.765
105	108	8866	Leichhardt Creek	489.2	506	94.8%	210	0.55	10119	12.240
106	110	8878	East Normanby River	913.7	503	94.9%	21	0.30	2343	3.208
107	90	8761	East Normanby River	192.7	481	95.0%	248	0.39	0	0.000
108	153	9150	East Normanby River	578.0	469	95.1%	13	0.04	867	1.214
109	93	8776	East Normanby River	155.7	454	95.2%	221	0.28	1459	0.421
110	11	8310	East Normanby River	308.4	443	95.3%	171	0.42	2763	1.395
111	4	8239	Leichhardt Creek	494.0	436	95.3%	0	0.00	3038	0.882
112	97	8815	West Normanby River	689.3	429	95.4%	0	0.00	3841	3.841
113	41	8523	Leichhardt Creek	570.9	410	95.5%	114	0.52	3503	3.312
114	202	9347	Granite Normanby River	170.4	410	95.6%	230	0.32	0	0.000
115	178	9265	Granite Normanby River	548.2	405	95.7%	0	0.00	0	0.000
116	212	9391	Granite Normanby River	311.1	402	95.8%	242	0.62	0	0.000
117	197	9326	West Normanby River	600.1	397	95.8%	0	0.00	0	0.000
118	87	8741	West Normanby River	489.2	390	95.9%	0	0.00	0	0.000
119	15	8358	East Normanby River	124.9	383	96.0%	306	0.17	5406	3.282
120	10	8309	West Normanby River	303.7	378	96.1%	197	0.32	1121	0.336
121	229	9427	Granite Normanby River	274.0	371	96.1%	0	0.00	0	0.000
122	244	9461	Granite Normanby River	222.2	368	96.2%	211	0.38	4480	2.113
123	49	8548	East Normanby River	227.8	361	96.3%	204	0.68	3926	1.934
124	34	8486	Leichhardt Creek	296.6	348	96.4%	145	0.23	2249	1.799
125	154	9159	Leichhardt Creek	258.8	347	96.4%	147	0.54	2939	2.957

126	68	8643	Leichhardt Creek	316.4	337	96.5%	133	0.55	2864	0.859
127	18	8371	East Normanby River	359.1	330	96.6%	0	0.00	3267	1.313
128	146	9108	Granite Normanby River	437.2	330	96.6%	0	0.00	6267	1.994
129	233	9435	Granite Normanby River	474.8	321	96.7%	0	0.00	7514	3.794
130	52	8569	Leichhardt Creek	133.5	316	96.7%	135	0.14	1956	0.672
131	132	9031	West Normanby River	437.3	316	96.8%	0	0.00	2214	0.820
132	89	8760	Leichhardt Creek	437.4	316	96.9%	28	0.10	23230	24.633
133	94	8777	East Normanby River	155.6	314	96.9%	167	0.20	60	0.012
134	82	8708	Leichhardt Creek	281.7	313	97.0%	69	0.13	4870	9.048
135	116	8916	West Normanby River	429.9	305	97.1%	0	0.00	2558	1.033
136	249	9471	Granite Normanby River	420.5	299	97.1%	0	0.00	0	0.000
137	231	9431	Granite Normanby River	318.5	297	97.2%	0	0.00	2587	0.988
138	245	9465	Granite Normanby River	109.0	293	97.2%	139	0.16	0	0.000
139	111	8887	Leichhardt Creek	200.1	287	97.3%	61	0.08	10795	13.122
140	140	9077	East Normanby River	422.4	285	97.4%	0	0.00	3888	2.038
141	185	9285	Granite Normanby River	192.6	279	97.4%	0	0.00	791	0.316
142	236	9447	Granite Normanby River	464.0	278	97.5%	0	0.00	6267	3.689
143	186	9288	Granite Normanby River	400.1	276	97.5%	0	0.00	711	0.213
144	1	8163	West Normanby River	48.4	275	97.6%	243	0.28	709	0.709
145	14	8343	West Normanby River	76.3	274	97.6%	225	1.15	79	0.111
146	144	9106	West Normanby River	274.2	272	97.7%	0	0.00	4085	1.225
147	112	8896	West Normanby River	185.3	244	97.7%	0	0.00	516	0.349
148	101	8834	Leichhardt Creek	496.6	244	97.8%	20	0.08	7901	6.441
149	85	8732	West Normanby River	177.9	243	97.8%	62	0.09	3876	7.212
150	239	9452	Granite Normanby River	229.6	242	97.9%	0	0.00	2453	0.918
151	54	8585	Leichhardt Creek	289.2	228	97.9%	29	0.07	5575	1.673
152	225	9420	Granite Normanby River	162.9	224	98.0%	0	0.00	0	0.000
153	157	9171	West Normanby River	272.6	220	98.0%	0	0.00	0	0.000
154	237	9450	Granite Normanby River	385.4	219	98.1%	0	0.00	1137	0.568
155	188	9303	West Normanby River	186.9	217	98.1%	84	0.17	1893	0.877
156	78	8699	Leichhardt Creek	59.3	212	98.1%	181	0.06	0	0.000
157	119	8940	West Normanby River	163.1	211	98.2%	0	0.00	3991	2.443
158	131	9012	East Normanby River	30.6	205	98.2%	183	0.27	661	0.446

159	88	8742	East Normanby River	392.8	204	98.3%	0	0.00	2294	1.553
160	99	8832	Leichhardt Creek	244.9	203	98.3%	46	0.67	150	0.045
161	223	9418	Granite Normanby River	229.6	200	98.3%	0	0.00	0	0.000
162	230	9430	Granite Normanby River	185.1	198	98.4%	0	0.00	472	0.472
163	218	9398	Granite Normanby River	303.7	194	98.4%	0	0.00	1149	0.357
164	199	9339	Granite Normanby River	170.4	191	98.5%	0	0.00	0	0.000
165	84	8731	Leichhardt Creek	151.8	190	98.5%	0	0.00	0	0.000
166	38	8506	Leichhardt Creek	244.7	190	98.5%	0	0.00	855	0.257
167	33	8485	Leichhardt Creek	170.5	190	98.6%	0	0.00	3262	0.979
168	135	9048	West Normanby River	148.2	189	98.6%	0	0.00	0	0.000
169	27	8451	Leichhardt Creek	185.4	188	98.6%	0	0.00	0	0.000
170	189	9304	West Normanby River	142.8	187	98.7%	0	0.00	1402	0.493
171	124	8973	Leichhardt Creek	237.2	186	98.7%	0	0.00	4833	9.110
172	147	9122	East Normanby River	209.5	186	98.8%	0	0.00	0	0.000
173	248	9468	Granite Normanby River	123.0	184	98.8%	0	0.00	568	0.170
174	55	8586	Leichhardt Creek	355.9	181	98.8%	0	0.00	5010	4.378
175	250	9476	Granite Normanby River	129.8	177	98.9%	66	0.03	2111	2.111
176	162	9183	Granite Normanby River	214.9	174	98.9%	0	0.00	410	0.123
177	56	8599	Leichhardt Creek	53.4	169	98.9%	85	0.23	1058	0.317
178	123	8956	West Normanby River	133.4	168	99.0%	0	0.00	3989	2.359
179	6	8278	East Normanby River	240.2	163	99.0%	13	0.12	7025	4.564
180	164	9197	Granite Normanby River	244.5	161	99.0%	0	0.00	3283	0.985
181	103	8836	West Normanby River	148.2	160	99.1%	0	0.00	437	0.437
182	121	8942	East Normanby River	163.0	159	99.1%	0	0.00	1267	1.599
183	106	8839	East Normanby River	149.1	155	99.1%	0	0.00	0	0.000
184	100	8833	Leichhardt Creek	148.1	152	99.2%	38	0.00	0	0.000
185	193	9314	Granite Normanby River	257.3	146	99.2%	0	0.00	4003	1.287
186	200	9345	West Normanby River	160.4	145	99.2%	0	0.00	0	0.000
187	213	9392	Granite Normanby River	125.9	138	99.2%	0	0.00	747	0.247
188	109	8877	West Normanby River	140.8	137	99.3%	0	0.00	1024	1.024
189	122	8955	Leichhardt Creek	287.4	136	99.3%	0	0.00	4989	9.886
190	44	8533	Leichhardt Creek	155.7	126	99.3%	0	0.00	554	0.554
191	166	9226	East Normanby River	187.3	125	99.4%	0	0.00	0	0.000

192	51	8568	Leichhardt Creek	81.6	114	99.4%	0	0.00	272	0.082
193	167	9234	West Normanby River	184.3	112	99.4%	0	0.00	64	0.032
194	172	9246	Granite Normanby River	119.6	111	99.4%	0	0.00	0	0.000
195	2	8228	West Normanby River	196.1	110	99.4%	0	0.00	4448	2.257
196	48	8547	East Normanby River	126.0	106	99.5%	0	0.00	1435	0.485
197	107	8850	East Normanby River	118.6	106	99.5%	0	0.00	3793	1.138
198	5	8254	Leichhardt Creek	95.1	99	99.5%	0	0.00	960	1.039
199	79	8700	East Normanby River	150.9	99	99.5%	3	0.15	2229	0.669
200	66	8631	East Normanby River	118.6	95	99.5%	0	0.00	2255	2.230
201	156	9161	Granite Normanby River	51.9	94	99.6%	0	0.00	0	0.000
202	129	9010	Leichhardt Creek	62.3	92	99.6%	67	0.00	1721	1.861
203	179	9266	Granite Normanby River	177.9	84	99.6%	0	0.00	3307	0.992
204	207	9372	Granite Normanby River	66.7	84	99.6%	0	0.00	0	0.000
205	203	9348	Granite Normanby River	66.7	84	99.6%	0	0.00	893	0.357
206	26	8432	East Normanby River	56.3	83	99.6%	56	0.00	2754	3.034
207	214	9393	Granite Normanby River	130.2	82	99.7%	0	0.00	1072	0.322
208	3	8238	Leichhardt Creek	72.0	82	99.7%	0	0.00	0	0.000
209	91	8762	East Normanby River	165.0	81	99.7%	0	0.00	136	0.041
210	222	9413	Granite Normanby River	78.4	77	99.7%	0	0.00	0	0.000
211	128	8996	East Normanby River	141.5	75	99.7%	0	0.00	0	0.000
212	61	8614	Leichhardt Creek	89.0	74	99.7%	0	0.00	2122	0.971
213	127	8987	East Normanby River	160.6	68	99.8%	0	0.00	0	0.000
214	251	9477	Granite Normanby River	53.0	63	99.8%	0	0.00	577	0.173
215	40	8522	Leichhardt Creek	14.8	62	99.8%	0	0.00	0	0.000
216	118	8923	East Normanby River	81.5	54	99.8%	0	0.00	1152	1.613
217	46	8545	Leichhardt Creek	29.7	53	99.8%	0	0.00	574	0.172
218	17	8370	Leichhardt Creek	31.6	53	99.8%	0	0.00	896	1.038
219	161	9182	Granite Normanby River	51.9	52	99.8%	0	0.00	317	0.095
220	57	8600	Leichhardt Creek	37.1	52	99.8%	0	0.00	290	0.087
221	22	8396	Leichhardt Creek	78.3	50	99.8%	0	0.00	58	0.058
222	196	9325	West Normanby River	10.0	48	99.8%	42	0.00	0	0.000
223	24	8398	East Normanby River	100.0	47	99.9%	0	0.00	3059	2.090
224	253	9483	Granite Normanby River	24.5	45	99.9%	25	0.00	289	0.289

225	32	8466	Leichhardt Creek	44.5	44	99.9%	0	0.00	552	0.139
226	168	9235	West Normanby River	22.2	43	99.9%	0	0.00	489	0.147
227	80	8706	Leichhardt Creek	22.2	43	99.9%	0	0.00	0	0.000
228	187	9296	Granite Normanby River	60.0	40	99.9%	0	0.00	1490	0.447
229	36	8488	East Normanby River	35.5	33	99.9%	0	0.00	812	0.299
230	50	8558	Leichhardt Creek	33.8	33	99.9%	0	0.00	417	0.409
231	39	8507	Leichhardt Creek	37.1	31	99.9%	0	0.00	232	0.070
232	20	8384	Leichhardt Creek	22.2	31	99.9%	0	0.00	563	0.672
233	159	9173	Granite Normanby River	14.8	31	99.9%	0	0.00	0	0.000
234	58	8601	Leichhardt Creek	22.2	31	99.9%	0	0.00	0	0.000
235	37	8505	Leichhardt Creek	29.7	31	99.9%	0	0.00	372	0.372
236	228	9425	Granite Normanby River	14.8	31	100.0%	0	0.00	0	0.000
237	142	9093	East Normanby River	17.2	25	100.0%	0	0.00	0	0.000
238	45	8534	East Normanby River	14.8	22	100.0%	0	0.00	0	0.000
239	95	8791	East Normanby River	14.8	22	100.0%	0	0.00	0	0.000
240	117	8917	West Normanby River	22.2	22	100.0%	0	0.00	953	0.636
241	53	8584	Leichhardt Creek	14.8	21	100.0%	0	0.00	70	0.021
242	71	8646	East Normanby River	14.8	21	100.0%	0	0.00	426	0.128
243	254	9488	Granite Normanby River	54.0	21	100.0%	0	0.00	1840	1.276
244	31	8465	Leichhardt Creek	13.1	19	100.0%	0	0.00	584	0.584
245	21	8395	Leichhardt Creek	10.6	18	100.0%	0	0.00	278	0.278
246	242	9459	West Normanby River	18.1	15	100.0%	0	0.00	441	0.220
247	19	8383	Leichhardt Creek	13.3	12	100.0%	0	0.00	0	0.000
248	16	8360	East Normanby River	6.1	7	100.0%	2	0.00	0	0.000
249	13	8342	Leichhardt Creek	6.4	6	100.0%	0	0.00	0	0.000
250	30	8464	Leichhardt Creek	5.2	6	100.0%	0	0.00	220	0.220
251	183	9275	Granite Normanby River	1.6	2	100.0%	0	0.00	0	0.000
252	25	8414	East Normanby River	0.9	1	100.0%	0	0.00	0	0.000
253	252	9479	Granite Normanby River	0.0	1	100.0%	0	0.00	0	0.000
254	195	9322	Granite Normanby River	0.0	0	100.0%	0	0.00	0	0.000
			totals	**55351**	**501191**		**457408**	**598**	**569293**	**414**

APPENDIX 3 - DRAFT PRIORITISATION BASED ON A COMBINED GULLY & LINEAR DISTURBANCE METRIC

As a means of developing a prioritisation schema that combines sediment source hotspots and gully area with the linear disturbance network, a prioritisation map has been produced which combines three metrics in a standardised fashion into a single metric (Figure 108). Three key metrics derived for the NCB sub-catchments; modelled total sediment yield, gully area, and linear disturbance length, have been ranked and then the rankings have been scaled to a range between 0 – 1 across the whole population of 542 sub-catchments across the Upper Normanby catchment. Then the scaled rankings have been summed (without weighting) into a single metric for each sub-catchment. The derived metric was then ranked and is presented (Figure 108) categorically to highlight the top 25 sub-catchments, then the next 75 sub-catchments, with the remainder grouped in 100s of sub-catchments. The derived prioritisation schema provides a simple but rational basis for combining the gully and linear disturbance issues into a single metric.

This first draft multi-variate prioritisation metric is **not recommended** for immediate use; however, it could be further developed to support future prioritisation of sediment management activities, as implementation of the Erosion Management Plan to Guide 2017 to 2022 Actions progresses.

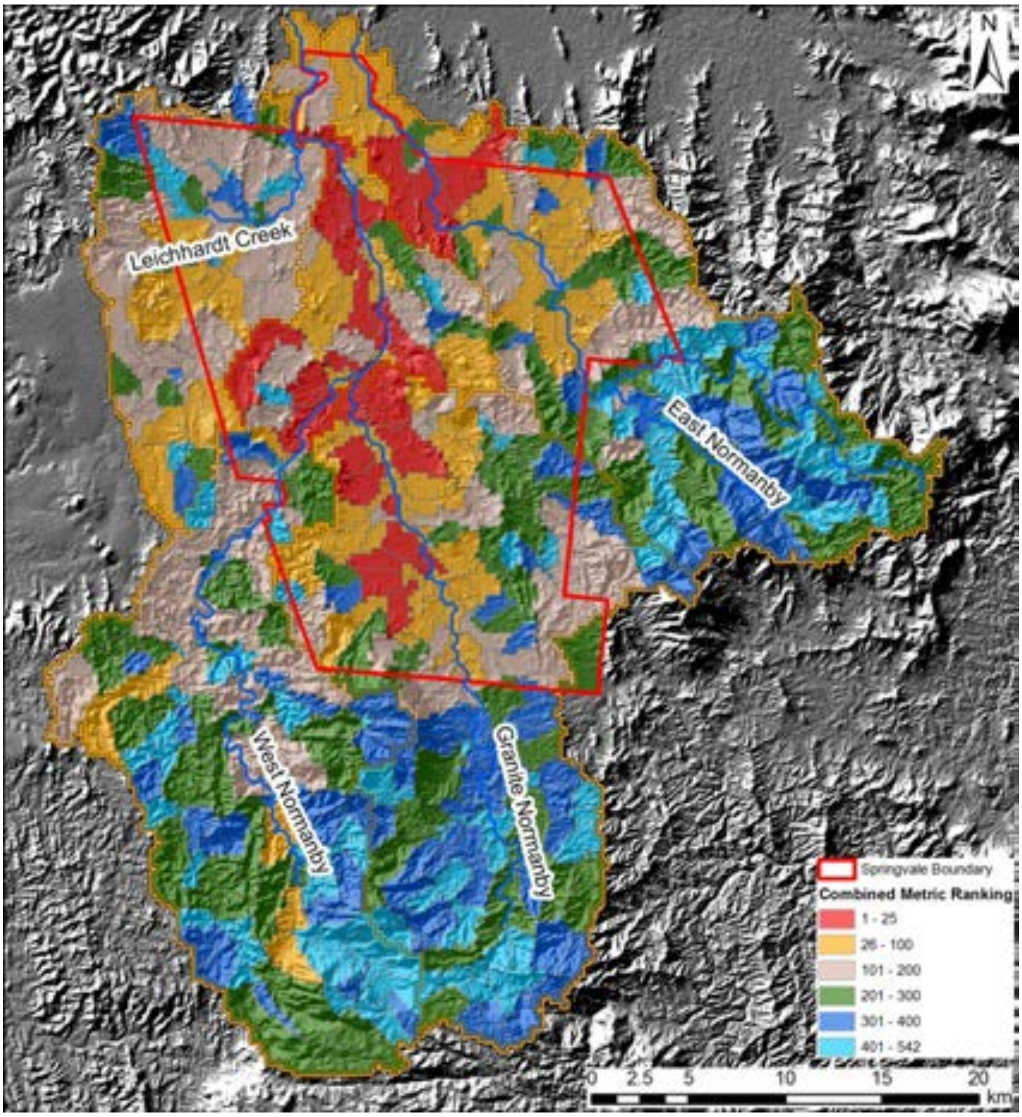


Figure 108 Prioritisation map based on a single metric combining sediment yield, gully area, and the length of linear disturbance features within each sub-catchment (Source: Griffith University).

APPENDIX 4 – GULLY TYPES, REMEDIATION, REHABILITATION AND MONITORING OPTIONS

For cost-effective sediment reduction to be achieved at Springvale Station, it is critical to target specific remediation/rehabilitation actions to specific soil and gully erosion types. A synthesis of all available gully management information (including project team workshop minutes) was used to produce management guidelines (Table 13) for the soil and gully erosion types present on Springvale Station (Figure 98), and is largely based on work in Shellberg and Brooks (2013) and Shellberg et al. (2016b).

<u>Alluvial and Colluvial Slopes Above Gullies</u>

Photo Examples (Source: Jeff Shellberg)


Rehabilitation or Remediation Options

- Increase perennial grass cover
  - Cattle destocking
  - Active revegetation of grass – direct seeding or tubestock.
- Fire management
  - Locally tailor fire regimes to soil type and vegetation community for specific objectives (i.e. increase perennial grass cover, weed control).
  - In highly erodible locations, fire could be excluded altogether to maximise any potential vegetation cover.
  - Prescribed aerial and/or ground burning in the early-dry season to install fire breaks without soil disturbance (i.e., no grading).
  - Early-wet season 'storm-burns' (1-3 days after first >25mm rain) could be used infrequently (> 5 years) and cautiously in highly-erodible river frontage to control weed and woodland thickening and promote increased grass cover, if it can be demonstrated that storms burns don't increase water runoff and gully erosion in the early wet season.
- Weed management
- Soil amendments treatment of scalded areas (gypsum, compost, fibre mats, fertilizer) with associated revegetation
  - Preferably without mechanical disturbance (localised ripping) to avoid the risk of collateral damage.
  - Soil response to amendment (fertility, organic matter).
- Reduce water runoff and sheet flow velocity to promote infiltration
  - Brush structures or fibre rolls on contour to retain and spread water
  - Contour banks are <u>not</u> advised on intact woodland terrain or sodic soil.
  - Earthen banks (bunds) around gully heads to retain water runoff and/or divert into safe disposal points, using locally imported material.
  - Water diversion banks (whoa boys) on roads and large cattle pads to retain and divert water runoff.

Monitoring Options to Document Success

- Photo Points (GPS located + star pickets)
- Ground vegetation cover (%), grass basal area, native species diversity, weeds.
- Sediment retention behind micro- and macro-roughness elements.
- Surface erosion depth compared to reference points (erosion pins)
- Water and sediment runoff yield from slopes (traps or flumes)
- Gully scarp retreat at the bottom or base of hillslopes (shallow or steep)

Scalded Soils and Shallow Gullies (alluvium or colluvium)

Photo Examples (Source: Jeff Shellberg)


Rehabilitation or Remediation Options

- Increase perennial grass cover
    - Cattle destocking
    - Active revegetation of grass, shrubs, trees – direct seeding / tubestock.
    - Treat scalded areas with soil amendments (gypsum, compost, fibre mats, fertilizer) without (preferred) or with mechanical disturbance (localised ripping), which has the risk of collateral damage.
    - Trial innovative surface treatments such as sprayed compost blankets mixed with seeds and fertilizer.
- Fire management
    - Exclude fires to maximise any potential vegetation cover.
- Weed management
    - Control weeds such as rubber vine.
- Reduce water runoff and sheet flow velocity to promote infiltration
    - Brush structures or fibre rolls on contour to retain and spread water.
    - Brush, fibre, or rock structures in dendric micro-gullies and across cattle pads to trap sediment output and aggrade the channels for revegetation.
    - Grade control structures in linear gullies eroding into scald areas

Monitoring Options to Document Success

- Photo Points (GPS located + star pickets)
- Ground vegetation cover (%), grass basal area, native species diversity, weeds.
- Sediment retention behind micro- and macro-roughness elements.
- Surface erosion depth compared to reference points (erosion pins)
- Water and Sediment runoff yield from slopes (flumes)
- Gully scarp retreat at the bottom or base of hillslopes (shallow or steep)
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR – small sample areas

Colluvial Hillslope Gullies (typically linear)

Photo Examples (Source: Jeff Shellberg)


Rehabilitation or Remediation Options (in combination above/at/below scarps)

- Reduce water runoff from slopes above gully head (see sections on Alluvial and Colluvial Hillslopes, or Road and Fence Gullies).
- Earthen banks (bunds) around gully heads to retain water runoff and/or divert into safe disposal points, using locally imported material.
- Rock chute (or other drop structure) at gully head to reduce head cut retreat.
- Grade control structures (brush, wood, rock) sequentially placed in the gully bottom, carefully embedded into the bed and banks to prevent outflanking.
- Stabilise gully side-walls with vegetation (grass, shrub) and grade control.
- Active revegetation of grass, shrubs, trees – direct seeding / tubestock.
- In extreme cases (not generally recommended), reshape the entire gully with machinery, install head cut and grade control structures, add soil amendments (gypsum, compost, fibre mats, fertilizer), and revegetate.
- Gully plug dams are not recommended on Springvale Station due to the need for long-term maintenance, risk of failure in sodic soils and intense rainfall events, and the biocultural conservation goals of the property.

Monitoring Options to Document Success

- Photo Points (GPS located + star pickets)
- Gully scarp and sidewall retreat rates (GPS, DEM etc).
- Erosion depth compared to reference points (erosion pins)
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR – small sample areas (DEM)
- Ground vegetation cover (%), grass basal area, native species diversity, weeds.
- Sediment retention (bed elevation) behind grade control structures.
- Sediment and water runoff yield from treated/control gullies (flumes)

Linear Rapidly Advancing Alluvial Gullies (Finger Gullies)

Photo Examples (Source: Jeff Shellberg)

Rehabilitation or Remediation Options (in combination above/at/below scarps)

Slopes Above Headcut

- Reduce water runoff from slopes above gully head (see sections on Alluvial and Colluvial Hillslopes, or Road and Fence Gullies).
- Earthen banks (bunds) around gully heads to retain water runoff and/or divert into safe disposal points, where available, using locally imported material.

Headcut

- Rock chute (or other drop structure) at gully head scarp to reduce head cut retreat (typically with ~10% slope with cut-off trench, geofabric, dissipater).
- Rock waterway (or grass) at gully head scarp to reduce grade (<2%) by removing larger volumes of earth, reshaping, geofabric, rock or grass capping, and grade control.
- Side slopes and aprons of chutes could be stabilised with cement/soil mixtures (pugging) or a variety of geopolymers, with caution to key into soil to prevent undermining.

Channel

- Grade control structures (brush, wood, rock) sequentially placed in the gully bottom, carefully embedded into the bed and banks to prevent outflanking.
- In-channel chutes for large drops in bed level.
- Stabilise gully side-walls with vegetation (grass, shrub, trees) (direct seeding / tubestock) and grade control.
- In extreme cases (not generally recommended), reshape the entire gully with machinery, install head cut and grade control structures, add soil amendments (gypsum, compost, fibre mats, fertilizer), and revegetate all slopes.
- Gully plug dams are not recommended on Springvale Station due to the need for long-term maintenance, risk of failure in sodic soils and intense rainfall events, and the biocultural conservation goals of the property.

Monitoring Options to Document Success

- Photo Points (GPS located + star pickets)
- Gully scarp and sidewall retreat rates (GPS, DEM etc).
- Erosion depth compared to reference points (erosion pins)
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR – small sample areas (DEM)
- Ground vegetation cover (%), grass basal area, native species diversity, weeds.
- Sediment retention (bed elevation) behind grade control structures.
- Sediment and water runoff yield from treated/control gullies (flumes)

Mature Alluvial Gullies (Amphitheatre)

Photo Examples (Source: Jeff Shellberg)


Considerations Whether to Intervene

- Ratio of gully area / to total catchment area (LiDAR derived) to assess contributing catchment area, potential for overland flow input, potential future erosion, and stage of channel evolution.
- Rate of head scarp retreat *vs.* rate of incision *in situ* into pre-European hollows
- Depth of head scarp and gully depth, and practicality of sending machines into deep gullies while minimising collateral damage and costs.
- Slope of head scarp, compared to slope of outlet channel, and potential to erode back into the landscape in the future.
- Degree of natural re-vegetation and any slope feedbacks toward stability.
- The extent that the gully complex has been initiated and accelerated by land use *vs.* naturally responding to base level changes over the last 10,000 years - not all gullies are man-made or accelerated by land use.
- Volume of earth material that would need to be excavated to lay the slope back to an angle that feasibly could be stabilised (~10-20%) via bioengineering.
- Proximity to well-established & stable roads to gain machinery access.
- Proximity to borrow material (rock, soil, wood) that will not produce collateral damage or other cultural, environmental, aesthetic, or conservation impact.
- None of these methods below have been tried at very large scales (whole alluvial gully complexes), and thus are experimental with risk and uncertainty.
- Maximum sediment reduction success for any treatment would be ~ 50%. That is, the gully will still continue to erode to some degree after treatment.

Rehabilitation or Remediation Options (in combination above/at/below scarps)

Slopes Above Gully Scarps

- Reduce water runoff from slopes above gully head (see sections on Alluvial and Colluvial Hillslopes, or Road and Fence Gullies).
- Earthen banks (bunds) around gully heads to retain water runoff and/or divert into safe disposal points, using locally imported material on original surface.

Gully Scarps

Option 1: Active Revegetation ONLY (without regrading):

A knowledge gap exists to what extent *intensive* active re-vegetation of grass species in large alluvial gullies can be a) successful, and b) reduce surface or scarp gully erosion and trap sediment in the gully bed (cost/benefit). With up to $100,000 per hectare being utilised for more intensive gully retreatments, the question remains whether a fraction (say 1/3rd $33,000/ha) could be used for intensive re-vegetation efforts to assist and speed up natural recovery. Re-vegetation would entail hand planting grass plugs, seeds, or other innovative techniques using hardy native grass (e.g., *Mnesithea rottboelloides*) planted in the wet season when soils are loose. Experimentation to this effect could support the viability of larger proposals to aerially distribute pelletised grass seeds at dense rates into thousands of hectares of gullies during the wet.

Option 2: Full Re-grading of Mature Amphitheatre Gullies

- Bulldozing slopes into a more uniform shape.
- Re-creating a swale or hollow catchment shape to promote natural flow paths and mimic pre-European hollow shapes.
- Laying the scarp slope grade back to a lower slope (from > 100% (45°) to less than < 20% (11.3°) = large volumes of earth.
- Installing grade control structures (rock, wood, brush) frequently along the wide hollow bed.
- Treating sodic soil with gypsum, compost, fertilizer amendments.
- Revegetating slopes with direct grass seeding / tube stock / hydromulch.
- Rock capping on steeper slope surfaces.
- Alternatively rock blanket all slopes.
- Alternatively use plastic lattice on soil surface and revegetate.

Option 3: Spraying Geopolymers or Shotcrete on Slopes

Numerous market products exist to spray on various polymers, glue binding agents, concrete, and/or hydromulch across steep unstable slopes. The advantage is that slopes would not necessarily need to be battered and material could be sprayed on *in situ.* However, thick blankets would be needed to ensure good fabric binding, as well as attention to detail around gully micro-features to prevent collapse or undermining. Any geopolymer blanket would need to be "keyed" into the soil at depth at the gully head (upslope) to prevent undermining from overland flow. Polymers could be used with hydromulch if grass vegetation is desirable (rehabilitation vs. remediation). Some degree of battering could assist geopolymers success, especially at the immediate gully scarp.

Channel

- Grade control structures (brush, wood, rock) sequentially placed in the gully bottom and outlet channel (in situ or battered) carefully embedded into the bed and banks to prevent outflanking.
- Stabilise gully outlet side-walls with vegetation (grass, shrub, trees) (direct seeding / tube stock) and grade control.

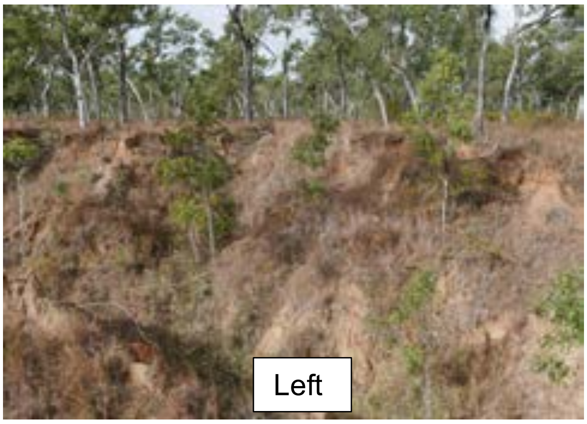
Monitoring Options to Document Success

Due to the experimental nature of the treatment of large unstable gully complexes, significant monitoring would be needed to accurately demonstrate sediment reduction success and different erosion processes influenced by intervention.

- Sediment and water runoff yield from treated/control gullies, using fully automatic continuous gauging stations with surrogate technologies.
- Airborne LiDAR, before/after, treatment/control.
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR – suitable for smaller sample areas (DEM)
- Ground vegetation cover (%), grass basal area, native species diversity, weeds.
- Photo Points (GPS located + star pickets).

Old Alluvial Gullies (Deep and/or Re-vegetating)

Photo Examples (Source: Jeff Shellberg)



Considerations Whether to Intervene

- Some older alluvial gullies have been eroding for 100 years or more, and are still active in places. However, as they incise toward their ultimate base-level, their slopes begin to revegetate with trees and grass. This is especially the case toward the middle and lower reaches of the gully catchment where erosion started first and slopes are stabilising in their evolutionary cycle. Cattle access is often difficult in this very steep terrain.
- Assess the erosion rate
- Head scarps of older gullies that have reached their maximum limit at the divide with other gully catchments can have very steep and very deep scarps, 8 to 16 m deep in places.
- While still raw and eroding, the practicality for mechanical intervention into very deep/steep slopes needs to be cautioned against, due to the large volumes of earth that would be required to be moved to lay the slope back to an angle that feasibly could be stabilised (~10-20%), and the potential for collateral damage on nearby healing gully slopes and adjacent intact terrain.
- The extent that the gully complex has been initiated and accelerated by land use *vs.* naturally responding to base level changes over the last 10,000 years - not all gullies are man-made or accelerated by land use.
- Many old and deep gullies are more remote on Springvale Station, due to roads and fencing actively avoiding these areas. Access practically needs to be considered and potential for collateral damage associated with intervention.

Rehabilitation or Remediation Options

Slopes Above Gully Scarps

- Reduce water runoff from slopes above gully head (see sections on Alluvial and Colluvial Hillslopes, or Road and Fence Gullies).
- If a terrace catchment area still exists above the headscarp, and is contributing accelerated water runoff onto the scarp (road, fence, cattle pad), earthen banks (bunds) around gully scarp could be used to retain water runoff and/or divert into safe disposal points, using locally imported material on original surface.

Gully Scarps

- Older gullies with active revegetation and feedback cycles toward stabilisation should *not* be disturbed with machinery or mechanical intervention.
- Vegetation established on slopes could be enhanced with proactive vegetation planting (grass, shrub, trees) via direct seeding or tubestock.
- Soil amendments could also be considered to encourage revegetation.

Channel

- Brush and timber grade control structures could be sequentially placed in the gully bottom and outlet channel using hand crews (manual labour) with wood material harvested by hand from local terrace slopes or densely forested riparians zones at the gully outlet.
- Vegetation established on gully bottom and channel outlet could be enhanced with proactive vegetation planting (grass, shrub, trees) via direct seeding or tubestock, in order to promote sediment trapping from upslope scarps.

Monitoring Options to Document Success

- Sediment and water runoff yield from treated/control gullies, using fully automatic continuous gauging stations with surrogate technologies.
- Airborne LiDAR, before/after, treatment/control.
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR – suitable for smaller sample areas (DEM)
- Ground vegetation cover (%), grass basal area, native species diversity, weeds.
- Photo Points (GPS located + star pickets).

Previously Cleared Paddocks

Photo Examples (Source: Jeff Shellberg)


Rehabilitation or Remediation Options

- Avoid any ongoing disturbance, such as contour ripping, which will further disturb sodic dispersible soils.
- Allow to naturally revegetate with both tree and grass mixes to promote water inception, infiltration, and surface runoff resistance.
- Introduce a natural fire regime that promotes a heathy mix of grass and trees in open woodlands.
- Manage weed infestations in disturbed paddocks.
- Reduce water runoff from paddock edges into alluvial gullies or riparian zones of ephemeral creeks and rivers.
- Install earthen banks (bunds) around gully heads to retain water runoff and/or divert into safe disposal points.
- Stabilise gully headcuts that are advancing into the paddock from the terrace and paddock edge (see Linear Rapidly Advancing Alluvial Gullies above).

Monitoring Options to Document Success

- Photo points (GPS located + star pickets).
- Vegetation cover (%), basal area, native species diversity, weeds.
- Water runoff velocity and volumes per rainfall input.
- Gully scarp retreat at the edge of paddock.

Road and Fence Gullies

Photo Examples (Source: Jeff Shellberg)

Rehabilitation or Remediation Options

- Educate machine operators on Best Management Practices (BMPS)
- Develop Road and Fence Maintenance and Abandonment Plans (RAFMAP)
- Reduce road and fence network length through decommissioning and rehabilitation.
- Minimize road and fence grading.
- Promote grass cover on native soil roads, tracks and fences to provide cohesion (minimise grading).
- Revegetate disturbed areas of roads and fence (grass, trees, shrubs)
- Don't grade roads and fences for fire breaks (use slashing or chemical breaks to burn off).
- Gravel roads over dispersible soils with imported material.
- Divert water to stable locations.
- Install frequent / large whoaboys to divert water and maintain height and drivability.
- Armour whoaboys with gravel cap.
- Armour crossings and approaches to creeks and rivers with rock and gravel.
- Control road gully headcuts with rock chutes and grade control (see Young Alluvial and Colluvial Gully sections above).
- Stabilse large road "choke points" and major gully erosion through intensive rehabilitation (see Mature Alluvial Gullies and Young Alluvial Gullies sections above)

Monitoring Options to Document Success

- Photo Points (GPS located + star pickets)
- Road / Fence Condition Surveys (condition, surface cover, grass cover, % eroded, rill depth, gully frequency, BMP function)
- Drone photogrammetry to generate digital elevation models (DEM)
- Terrestrial LiDAR – small sample areas (DEM)

APPENDIX 5 - BRIEF HISTORY OF SPRINGVALE STATION

This brief history of Springvale Station is focused on documenting changes to land management, landuse and land development over time.

- The country of the upper East, Granite, and West Normanby Rivers in northern Australia has been inhabited by Aboriginal People for tens of thousands of years.
- Anthropological records and clan interviews indicate that there were several tribes, estates, and/or clans that lived around the East and West Normanby Rivers near present day Springvale Station, notably the *"Djugunwarra in the region of East and West Normanby Rivers, Springvale and Boggy Creek, and Dandiwarra at King Plains station*" (David Thompson, personal communication).
- Dr Walter Edmund Roth was the First Protector of Aboriginals in north Queensland, including the Boggy Creek Aboriginal Reserve (16,000 acres, 1894-1908). In 1898, Roth wrote that the country around the Reserve was called *Birbira* by the local Aboriginal people, and that "*they used to travel to the head of the Daintree River, the Bloomfield River, Mt Windsor (Kalmbar), and sometimes the Laura River and Maytown (Wulburjurbur). However, according to Roth, in 1899* [after 30 years of European settlement] *there was bad feeling between some groups and travel was limited.*" (Roth 1898 cited in Khan 1993).
- Roth called the local people at Butcher's Hill Koko-yerla(n)-tchi (Koko-yellanji) known today as Gugu-Yalanji (Roth 1898; Khan 1993).
- McConnel (1939) described and mapped (to unknown accuracy) the tribes of the Normanby headwaters including the Koko-Wallandja (Granite/West Normanby headwaters), Koko Yelandji (Normanby River, Banana Creek), Koko Wara (Laura River), Koko Bididji (Kings Plains) and Koko Nyungal (Upper East Normanby and Annan River). She also mapped place or clan names of the West Normanby (Koko Jiling), Granite Normanby (Kangawara) and Butcher's Hill (Kangar).
- The Kuku-Nyungkul occupation and usage patterns of the upper Annan River and very upper East Normanby Rivers (east of Springvale) prior to 1885 was described by Anderson (1983), where the country was divided into nine patrilineal clan estates.
- Wood (2016) outlines the difficulty in using and interpreting tribal names across the larger language group of *Kuku Yalanji* and associated dialects. "Warra" names often described small patrilineal clans, camps, or riverine clan clusters rather than large ethnos. "Kuku" names "*overlaid and bracketed a collection of toponymic -warra names of up to ten patricians occupying a segment of river drainage*" reflecting that "*these drainages were the loci of dialect divergence*" (Wood 2016). He describes the problem with "shifter" names that "*shifts depending on the social, linguistic, or directional subjectivity of the speaker*". Most often Yalanji is used with a built-in lack of level specificity to denote the greater "Yalanji people" and language group. Historical versus contemporary interpretation of tribe, clan estate, or clan names "*does not indicate that the 'right tribe' for the area has 'died out' or been displaced*", but rather groups names cannot always be "*taken at face value or made to speak in a direct and simple way to the determination of native title-holders*" (Wood 2016).

European Colonisation and Settlement (1873-1945)

- European explorers first traversed inland Cape York Peninsula in the mid-1800s (Leichhardt 1844-45; Kennedy 1848; Jardine 1864-65; Hann 1872; Mulligan 1873) (see Jack 1922 for detail and Fensham 1997 for maps).
- Hann (1872) was one of the first European explorers to travel near the present-day Springvale Station. He crossed the East/West Normanby Rivers on 17-18 October 1872.

Hann encountered Aboriginal People, who entered his camp at night and who he shot at to disperse out of the camp (Hann 1872; Jack 1922).

- Hann (1872) described the East or Granite Normanby River as having a "*clean sandy bed of 30 yards in width with shallow pools of water*" (17/10/1872). He also describes the country between the Normanby and Lakeland and "*broken and rangy*" between "*slate and quartz ranges*" but does not mention erosion (18/10/1872). The basalt country at Lakeland was described as "*very fine grazing basalt country*" with a "*fine running creek with very deep water holes in it with plenty of reeds and grass on its banks*" with "*spotted trout which are very good but small*" (20/10/1872).
- Gold was discovered by Hann (1872) on the Palmer River (Mitchell catchment) in August 1872. By 1873, the Palmer Gold Rush was on, and tens of thousands of miners travelled to Cooktown in route to Maytown and the Palmer gold fields (Holthouse 1967; Jack 1922; Ryle 2000).
- Tin was discovered on the Annan River in 1885, after which 800 miners flocked to the area including the very upper East Normanby River east of Springvale (Saint-Smith 1916; Anderson 1983; Ryle 2000). Peak mining activity occurred between 1885-1900.
- The Aboriginal contact history with tin miners on Kuku-Nyungkul country of the Annan River is described in Anderson (1983), which dramatically changed land rights and social structure.
- Alluvial gold was discovered in the East Normanby River by Mulligan in 1874 (Jack 1922), and the West Normanby produced alluvial gold in 1874 as reported in the Queenslander (Wallace 2012). Payable gold was found at Dead Dog Creek by early miners (note two creeks by this name on Springvale). By 1876, miners spilled over into the Normanby from gold rushes on the Hodgkinson (1876) and Palmer (1873) Rivers (Jack 1922; Lack 1962; Wallace 2012).
- Anecdotal information suggests "*evidence of old workings has been found over extensive areas of alluvial wash and perched terraces along West Normanby and Granite Normanby rivers"* (GMSA35, Endeavour Gold Project-West Normanby River FNQ, http://goldminesales.com.au/index.php/component/osproperty/endeavour-gold-project-west-normanby-river-fnq).
- In 1883-1884, J.T. Embley conducts the first official Queensland State surveys of the upper Normanby River (Jack 1922).
- Cattle graziers followed miners in the late 1880s to take up grazing leases from the State of Queensland and feed meat to the miners.
- Butcher's Hill Station was taken up by James Earl of Townsville on 14 March 1877 on basalt country near present day Lakeland (Lack 1962).
- Springvale Station was originally taken up by Thomas Morris on 15 March 1881, and transferred to John Cook in 1886 (Lack 1962).
- The family history of European settlement and grazing at Butcher's Hill Station is described by Wallace (2012).
- In the 1880s, Butchers Hill Station became a shelter for Aboriginal People escaping "dispersals" from Native Police, with help of Aboriginal people working on the cattle station. "Dispersals" occurred after miners on the West Normanby River were attacked by Aboriginal people (Wallace 2012).
- The Boggy Creek Aboriginal Reserve (16,000 acres) was gazetted by the Queensland Government in 1894 at Butcher's Hill and was rescinded in January 1908 (Brisbane Courier 18-Sep-1901; Queensland Government Gazette, 11-Jan-1908).
- An Upper Laura Native Mounted Police camp existed at Butcher's Hill.
- Dr Walter Edmund Roth was the First Protector of Aboriginals in north Queensland, including the Boggy Creek Aboriginal Reserve. In 1898 Roth stated that there were 50

Aboriginal people (Koko-yerla(n)-tchi or Koko-yellanji) at the reserve that were not being well fed by subsidised protectors (Khan 1993).

- Roth collected numerous Aboriginal artefacts from the Boggy Creek Aboriginal Reserve, which are now stored at The Australian Museum, and include: wooden charms, woven bags and baskets, shell ornaments, fishing nets, and womeras (Khan 1993).
- The Boggy Creek Aboriginal Reserve (16,000 acres) was rescinded in January 1908 (Queensland Government Gazette, 11-Jan-1908). The inhabitants were moved to other reserves and areas.
- Springvale Station, and neighbouring Kings Plains and Butcher's Hill Stations were well stocked with cattle from the 1880s onward (Wallace 2012; Lewis 2015).
- The Queensland State Archives (in Runcorn) could have official state "pastoral run" files from the late 1800s to 1960 for Butchers Hill, Springvale, and Kings Plains Stations that could contain lease conditions, ownerships, cattle numbers, infrastructure improvements, land condition, weed invasion, and other official correspondence. Quick online searches displayed minimal information (http://www.archivessearch.qld.gov.au.). However, a Boggy Creek "pastoral run file" (28205, Cook District: Run No. 174) is present with information covering the period 1908-1936, after the closure of the Boggy Creek Aboriginal Reserve in 1908.
- Cattle numbers of the Cook District (corrected for boundary changes over time) increased dramatically after 1873 and European settlement, peaking at ~98,500 head in 1890, declining to ~27,500 head in 1906 following the Federation Drought, increasing to >100,000 head by 1915, fluctuating between 80,000 to 120,000 from 1915-1974, and peaking at 146,400 head in 2011 (Lewis 2015).
- The family history of European settlement and grazing at Butcher's Hill Station is described by Wallace (2012).

Elmes Family Lease (1945-1991)

- Edward (Sid) and Ivy Elmes took over Springvale in approximately 1945. The property at that time had relatively little infrastructure other than a hand cut wooden slab house. The property had been abandoned from the previous owners, and the Elmes family paid the outstanding rates to purchase the property. The new cattle business was re-started with 50 new head of cattle. A second wooden homestead was built in 1965 (Graham Elmes, personal communication).
- Rather than fencing infrastructure, Sid Elmes focussed on putting in dams to encourage the cattle to move away from the Box Flats along the rivers, where cattle naturally congregated and continuously grazed near permanent river water and springs. As a result, in the wet season the cattle would move out of the Box Flats into the hilly country, then graze around the dams in the early dry season, before moving back to the rivers and Box Flats in the dry
- The road to Keetings was partially based on the original stockroute to the Daintree. The current alignment was used as a logging road to get timber for constructing the old East/West Normanby Bridges, harvested from Callaghan's Creek after World War II. The road was then improved by pastoralists with loader and trucks to put gravel on bulldust patches and river crossings. Annual maintenance to open the road took 3 days to fill in washouts on steep sections, clear sand from river crossings, and patching sections with gravel (Graham Elmes, personal communication).
- In the 1970s and 80s, the Keetings paddock was the only major fenced paddock (approximately 6-8 square miles) on red soils. The area grew good grass, was near 2 permanent and 6 semi-permanent springs and permanent water in Callaghan Creek, and had a yard and loading ramp. The road to Keetings paddock was maintained in a good condition to enable a semi-trailer (single axle truck with 40 foot trailer) to access the yard

and haul cattle. A block fence and fire break was maintained at the southern Springvale boundary near Keetings. There was a mining camp (and old bore hole) at the junction of Callaghan and Bulbin Creek (Graham Elmes, personal communication).

- In the 1980s, Graham Elmes cleared and developed 250 acres of basalt red soil in the Farm area of Springvale for cultivation of corn. The corn was stored and used to fatten steers at both Springvale and Butcher's Hill, 130 steers at a time, with 2000 steers fed corn from the Farm area (Graham Elmes, personal communication).
- The paddocks around the Springvale homestead, and the Farm Paddock, were cleared sometime before 1986 (NASA/USGS Landsat satellite archive).
- Weed management focused on lantana, rubbervine, and sicklepod in December-January. Sicklepod was first noticed at the West Normanby Bridge, where people would camp (Graham Elmes, personal communication).

United Cattle Stations (Great Pacific Company Ltd) Lease (1991-1998)

- Springvale was sold in 1991 to United Cattle Stations owned by Great Pacific Company Ltd (its key shareholder Ted Raymond from Boston, USA, a.k.a. Boston Cattle Company). Over 4000 head were included in the sale, of which 3800 head were mustered to demonstrate cattle numbers (Graham Elmes, personal communication).
- As soon as they purchased the property, Great Pacific started subdividing the property into 5000 acre paddocks, with the plans for development and subdivision of pastoral lease into freehold land. Blocks were fenced with two strand electric fences with no earth, that became ineffective in the dry season. Alignment of the new fence clearings was not well planned (straight lines) and many were unable to be maintained, except on horseback, due to erosion (Sue Marsh personal communication).
- NASA Landsat satellite images indicate that major vegetation clearing on the property initiated in 1991 around the Springvale homestead basalt, with the Cook paddock cleared by 1992, and the Crocodile paddocks cleared by 1993.
- The Keating's Paddock on basalt soils of the upper Granite Normanby was cleared of tree vegetation in 1994 for a landing strip for aerial seeding purposes.
- The initial vegetation clearing was not completed properly, with knocked down trees only windrowed in places, but with very quick tree regrowth (Sue Marsh and Ted Lees personal communication).
- Approximately 12,000 ha (30,000 ac) of pasture was seeded to varies types of legumes in the early 90s, which is now well established and spread throughout the property, such as wynn cassia and stylo (Slaney and Co, 2014).
- The Farm paddock was used to grow a corn crop in 1992 but farming was not continued by Great Pacific (Sue Marsh personal communication).
- Ted Lees (and Sue Marsh) were hired in 1993 as head stockmen under a 5-year contract to manage the property for Great Pacific. Their orders were to prepare the property for sale after significant loss of investment with development, clearing, and lack of returns (Sue Marsh and Ted Lees personal communication).
- Fencing infrastructure was improved over time (removing electric fences), blocking fences in the north and south were improved, and weaners, steers, dry cows, bulls and horses were separated paddocks where possible. However, 30% of mustered cattle would be unbranded cleanskins, with cattle from other properties in the mix (10 Mile, Diggers Ck and Mt Gibson). Fencing changed the property from a "Serengeti" style of free movement across the landscape, toward concentrated grazing in paddocks. Cattle moved towards the coast (Keetings) during the dry season and inland (Leichardt) during the dry. Cattle tended to build up on the new fences eventually breaching them. (Sue Marsh personal communication).

- Weeds in the 1990s were concentrated in disturbance areas. Grader grass was present along roads, yards and holding paddocks, but not at Keetings or Abby Lea paddocks which were still native grass. Rubbervine was present in a few areas, and rubbervine fungal rust was introduced. There was lantana and some hiptus in the East Normanby, but was not widespread across the property. There was no sign of sicklepod in flats or paddocks, which became a problem in the Lakeland area and Springvale after 1998 (Sue Marsh personal communication).
- Great Pacific maintained a breeding herd of approximately 3500 to 4000 head (Luke Quaid personal communication).

Alan Quaid Lease (1998-2004)

- Alan Quaid purchased Springvale in 1998.
- Luke Quaid worked as the property manager of Springvale from 1998-2004, and also from the Elmes family on Springvale in the 1980s.
- Alan Quaid bought the property with about 1000 head, typically had a breeding herd of about 3000 to 3500 head, and branded about 1200 to 1400 calves per year (Luke Quaid personal communication).
- Fence lines that had been constructed across hills dissected with creeks were impossible to maintain and fell into disrepair in a couple of years due to a lack of cattle using these areas (Luke Quaid personal communication).
- The Quaid's rationalised the fences and paddocks, abandoned un-needed fences, installed new fences on the West Normanby, repaired ¾ of the Keetings Paddock fence, build extra dams, re-cleared some past cleared paddocks, and kept internal fences in good repair for strategic stocking (Luke Quaid personal communication).

Damien Curr Lease (2004-2015)

- Damien Curr purchased Springvale in 2004.
- Luke Quaid continued to work as the property manager of Springvale from 2004-2015.
- A breeding herd of about 3000 to 3500 head was targeted, branding about 1200 to 1400 calves per year. However, market price and selling strategy resulted in steers being held for longer, which meant that the herd would be up to 5500 head or more in some years (Luke Quaid personal communication).
- Many internal fences were abandoned during this time. New strategic fences were installed, such as south from Crocodile yards to separate the Dead Dog and Abbey Lee paddocks. However, these internal fences were not always consistently maintained (Luke Quaid personal communication).
- Internal property roads were used to distribute lick to the cattle. Loop roads through paddocks were formalised to facilitate the distribution of lick (Luke Quaid personal communication).
- *Leucaena leucocephala* was planted in the East Normanby paddock after 2004's as a legume fodder crop for cattle. It is a fast-growing mimosoid tree native to southern Mexico. Leucaena is a noxious weed of high concern for spreading to natural environments. Leucaena trails at the East Normanby paddock were successful for a number of years, but eventually was abandoned due to cost and maintenance requirements. It is unknown if it is still present or escaped.
- Since 1990, the breeding herd on Springvale has been consistently maintained at or above 3000 breeders, with actual stocking rate consistently between 4000 and 5500 head (Luke Quaid personal communication).

- The long term carrying capacity for Springvale was likely between 1500 to 2000 head. If it had have been stocked with approximately 2000 head since 1990, then the native pastures would probably still be ok. Only the Box Flats along the Granite Normanby, East Normanby and West Normanby and the red soil areas (like Keetings) can carry cattle (Luke Quaid personal communication).
- Erosion is widespread on Springvale today, with gullies expanding anywhere there was a fence line or road clearing or disturbed soil. Some gullies have moved long distances in 20 years, and are dangerous to ride a horse beside due to the ground collapsing underfoot (Luke Quaid personal communication).
- Weeds are widespread on Springvale today, such as grader grass, sicklepod, rubbervine, snakeweed, and lantana in the East Normanby. Sicklepod is all through the best grazing country and there are only small patches of kangaroo grass left in some places like Keetings and the top of Gorge Creek in the south-eastern corner (Luke Quaid personal communication).
- Between 2009-2014, Springvale was the training facility of Outstation North, which trained more than 300 young Indigenous men and women in Certificate II in Agriculture (Beef Production) (Slaney and Company, 2014).
- Between 2012 and 2014, Springvale was prepared for sale to a potential developer (Slaney and Company, 2014).
- Past cleared paddocks were re-chained and cleared of regrowth in 2012 in preparation for sale, specifically Crocodile, Cook, Spring, and House paddocks (NASA/USGS Landsat satellite archive). Some of these paddocks were seeded with exotic pasture grass (floren bluegrass) to promote development and compete with weeds (grader grass) (Isha Segboer personal communication, Reef Rescue program).
- In 2013, water licenses were obtained from Queensland State for multiple irrigation proposals at Springvale, with an annual minimum of 15,000 ML, with an unquantified top limit (Slaney and Company, 2014).
- Optimistic proposals were pitched to irrigate approximately 1700 ha of cleared and pulled land (low-fertility sodosols or modest fertility ferrosols) with water from 5+ proposed dams (Slaney and Company, 2014).
- In Oct-Nov 2013, the construction Cook Dam (700 to 1200 ML) was completed, but without fish passage or an engineered spillway to mitigate risks. A proposal was pitched to irrigate 200 ha of Bananas in Cook Paddock on low-fertility dispersible yellow sodosols (Slaney and Company, 2014).

Queensland Government Lease Purchase (2015-present)

- In 2015 the Queensland Government purchased Springvale Station with the major goals of 1) improving the biodiversity and conservation values of this part of the Wet Tropics and Cape York bioregions, and 2) reducing erosion and sediment yields from this highly-degraded property that was disproportionately contributing very high sediment loads to the downstream river and Great Barrier Reef (GBR) ecosystems.
- Sediment and water quality research on Springvale Station and the Normanby catchment highlighted the extreme erosion occurring on the property, best management practices (BMPs) needed, and potential outcomes for the Great Barrier Reef (Brooks et al. 2013; Shellberg and Brooks 2013; Howley et al. 2013).

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