Whitsunday Landslide Study

Landslide Susceptibility Investigation and Mapping

M30261

Prepared for
Whitsunday Regional Council

13 May 2019

Cardno

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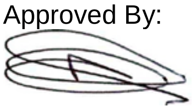

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1 Introduction

1.1 Background and Purpose of Study

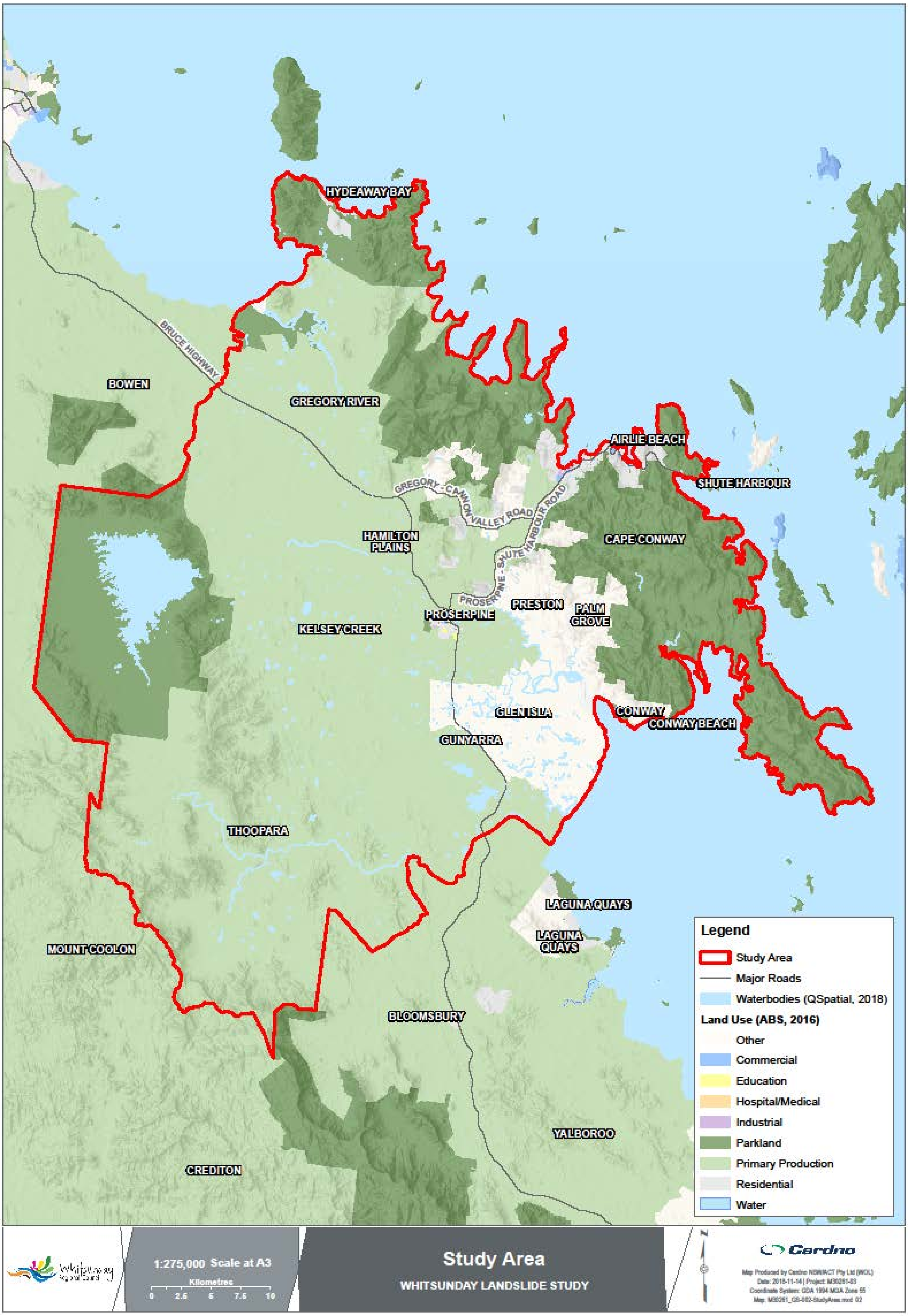
Under State Planning Policy 1/03 it is a requirement for local planning to map hazards, such as landslides, and ensure that development occurs in a manner that minimises the risk to people and property. Whitsunday Regional Council (WRC) have a planning scheme, which identifies landslide hazards in overlay mapping and moderates development within hazard areas via an associated overlay code and planning scheme policy that together meet the requirements of the State Planning Policy. This section of the planning scheme is now considered outdated, lacking in detail and does not consider all the elements that contribute to landslide risk, other than slope.

In July 2018 Cardno QLD Pty Ltd (Cardno) was commissioned by Whitsunday Regional Council to undertake a study to more accurately map landslide hazard areas at a higher resolution, identify varying levels of risk, set out mitigation strategies and ensure best practise in policy for development occurring within hazard areas.

This report details the results of the landslide susceptibility assessment for the Council area, which runs approximately from Hydeaway Bay to the north, to Shute Harbour and Conway area to the south.

The extent of the study area is outlined in Figure 1-1 on the next page

Figure 1-1 Map of the local area. Approximate extent of the study outlined in red.



1.2 GIS Data+

WRC supplied mapping metadata for a variety of elements that together have been considered in the development of mapping the landslide hazards. Data includes:

LIDAR contour data (10cm grid);

Soil type;

Geology;

Geomorphology;

Vegetation cover; and

Land use zoning.

1.3 Whitsunday Area

1.3.1 Geology and Geomorphology

The Whitsunday region is composed of six physiographic units with varying rock morphology and soil types that have characterised the region's morphology and varying disposition to landslide hazards.

The six physiographic units include:

The Clarke Range: mainly intrusive acid plutonic rocks from the Upper Carboniferous and Lower Permian, surrounded, sometimes unconformably, by the intermediate pyroclastics and flows of the Lower Permian Carmila Beds;

The Coastal Hills and Plains: the hills tend to be variably Lower Cretaceous volcanics of the Proserpine and Whitsunday Volcanic group, tending to be pyroclastics and extrusive volcanic rock, with minor volcanolithic sandstones. Plains are mainly Quaternary drift overlying the volcanics;

The Bowen-Proserpine lowland: mainly Quaternary drift with minor mangrove;

The Coastal Range and Continental Islands: the majority are acid volcanics and pyroclastics of the Lower Cretaceous Proserpine Volcanics and Whitsunday Volcanics, with minor granitic intrusions. The area is also characterised by the presence of numerous faults tending to strike NWN to N. The Hydeaway Bay area is almost entirely of Lower Permian granite and quartz diorite butting unconformably against the younger volcanics;

The Hillsborough Channel: some of the oldest rock in the region, primarily Upper Devonian to Lower Carboniferous intermediate flows and pyroclastics along with associated sandstones and siltstones. The area is penetrated by Lower Cretaceous granite and the Tertiary acid volcanics of the Cape Hillsborough beds;

The Coral Sea and Great Barrier Reef components are outside the scope of the investigation.

Select geology of the subject area is shown in Figure 1-2

1.3.2 Climate

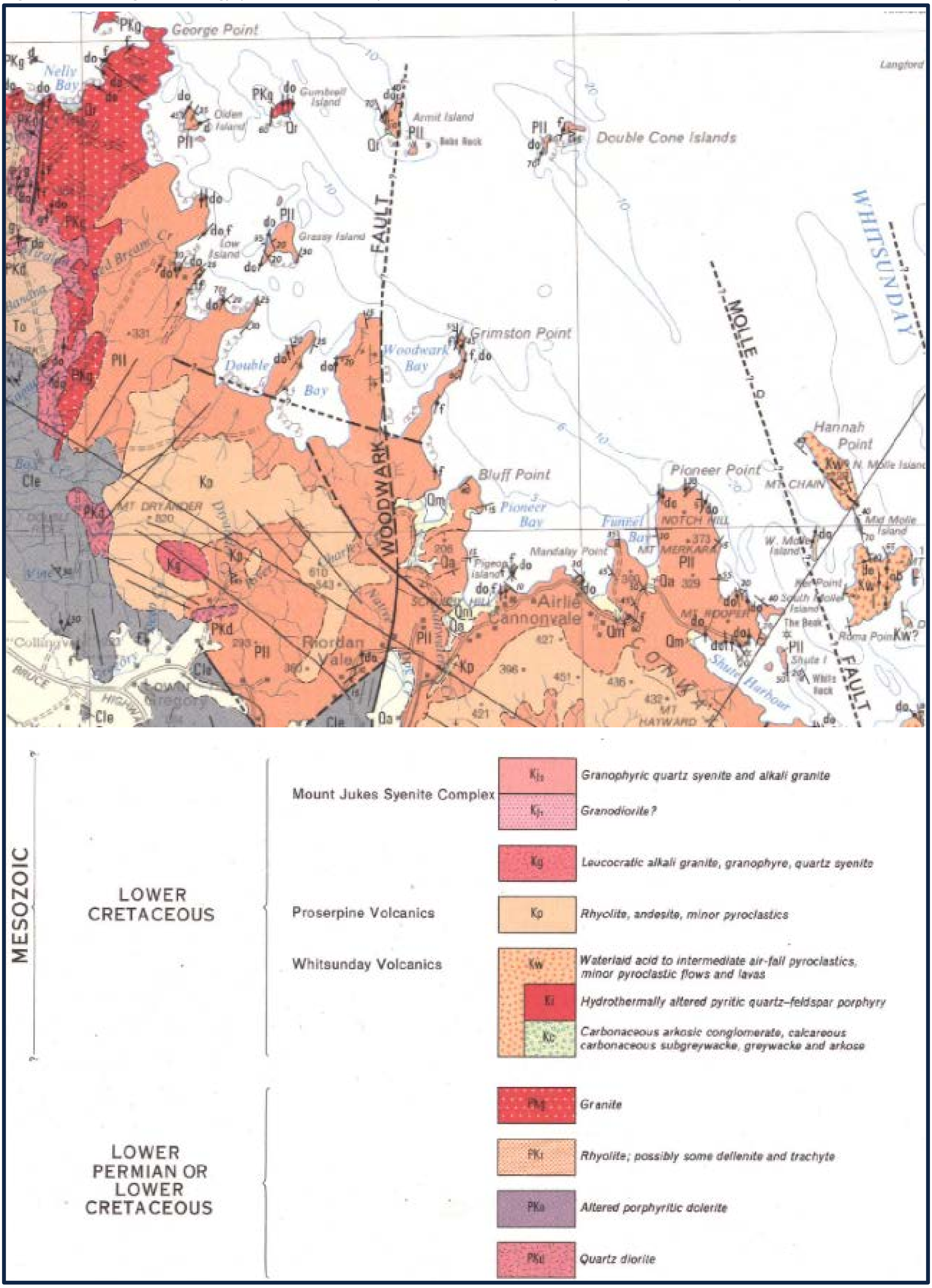
The region is comprised of two main climatic zones – the Tropical Areas of the Town of Whitsunday and Proserpine, and the Burdekin Dry Tropics around Bowen and Collinsville. The Tropical Areas are subject to large and intense rainfalls.

Mean average rainfall in Bowen in the period 1987-2015 was 892.7mm per annum. In the same period Proserpine received an average of 1429.2mm per annum. Rainfall patterns are similar for both localities, with peak rain falling between December and March, and relatively little in June to October.

1.3.3 Development

Historically the development of the urban areas has generally occurred in the low lying, flatter areas of the region, such as Bowen, Proserpine, Collinsville and the Town of Whitsunday. As population has increased, demand for new areas of development has resulted in urban areas sprawling beyond low lying spaces into areas of higher slope, particularly in the Town of Whitsunday.

Figure 1-2 Regional Geology (extract from Proserpine sheet SF55-4, Geological Survey of Queensland)



1.3.4 Previous Landslides

Within the Whitsunday region, there are areas that have a past history of significantly damaging landslides. The majority of the landslides within the region have been in the surrounds of Hydeaway Bay and Dingo Beach, with historical evidence also suggesting past landslides have occurred pre-development within Jubilee Pocket in the Town of Whitsunday.

The last major landslide event occurred in 2011 following abnormally heavy rainfall around Hydeaway Bay. Aerial photography also indicates that numerous smaller landslides have occurred within the Conway and Dryander slopes and are likely associated with rainfall and denudation following Cyclone Debbie in 2017. Within the populated areas, a large - though shallow - landslide occurred under Honeyeater Lookout, Cannonvale; as well as numerous minor slips around the Mandalay area and Coral Esplanade Hill at the same time.

2 Landslide Risk Overview

While landslides and associated erosive processes can occur in many different terrains and material types, a large proportion are triggered by anthropomorphic activity; particularly when the land is developed. Planners, developers and landowners need to be aware of the potential impact associated with development on sloping sites: impact is not limited to increasing slope through cut or fill, but any activity which alters the drainage, loads or undermines the slope or changes the materials through import or disturbance can also have the potential to cause landslides.

Landslide risk is not just confined to the particular block under development: altering the morphology upslope can also impact on blocks further down the slope, hence landslide hazard assessment and risk management needs to be considered holistically and cannot be limited to consideration of individual blocks only.

It is also important to note that there may be historic landslides which have not been identified, either due to small size, regrowth or modified topography. This report is not intended to replace thorough geotechnical investigations, which forms a crucial part of any development on sloping sites.

3 Methodology

3.1 GIS Methodology

3.1.1 Analysis Approach

A multi criteria analysis approach was used to assess landslide risk. Multi criteria analysis is a powerful spatial decision making tool to determine landslide susceptibility, allowing overlay of a range of criteria which influence the final output. This process uses a range of selection criteria, allocating rankings based on the importance or vulnerability of each search parameter. The flexibility of this analysis can incorporate many criteria and provides a neutral view on how the search parameters interact.

The GIS team worked alongside Cardno geotechnical staff and Whitsunday Regional Council staff to decide on factors contributing to landslide risk to be considered in the analysis (e.g. steepness of slope, vegetation cover) and to assign different risk ratings to those factors. The analysis was undertaken using Esri ArcMap 10.6 software. The final version of the risk analysis criteria, is shown in Table 3-1.

Table 3-1 Example landslide susceptibility criteria

Criteria	Criteria Breakdown	GIS Cell Value High Value = Greater Risk	Criteria Importance High Value = Greater Influence
Slope **Source:** Elevation data provided by WRC, with additional elevation data to fill the gaps sourced from http://elevation.fsdf.org.au/	0 - 5%	1	3
	5 - 10%	2	
	10 - 15%	3	
	15 - 20%	4	
	20 - 30%	5	
	30 - 50%	6	
	50 - 75%	7	
	> 75%	8	
Geology **Source:** Downloaded from QSpatial in the layer 'Regional geology 1970 - Burdekin River'	Dioritoid	1	1
	Granitoid	1	
	Mixed mafites and felsites (mainly volcanics)	2	
	Mixed volcanic and sedimentary rocks	3	
	Sedimentary rock	3	
	Granitoid behind Hideaway Bay	4	
	Alluvium	5	
	Colluvium	6	
	No data areas	3	
Soil Type **Source:** Provided by WRC in the layer	Friable non-cracking clay or clay loam soils - Dermosols, Ferrosols	3	2
	Red, yellow or grey loam or earth soils - Kandosols	3	

Criteria	Criteria Breakdown	GIS Cell Value High Value = Greater Risk	Criteria Importance High Value = Greater Influence
C_CS_GIS_SoilsAndLandSuitability	Seasonally wet soils requiring drainage or special management - Hydrosols	3	
	Cracking clay soils - Vertosols	4	
	Sand or loam over friable or earthy clay - Chromosols, Kurosols	4	
	Sand or loam over sodic clay - Sodosols, Kurosols	4	
	Deep sandy soils - Tenosols, Rudosols	5	
	Shallow stony soils - Rudosols, Tenosols	5	
Vegetation Cover **Source:** Provided by WRC in the layer C_CS_GIS_Remnant_DNRM_2013	Dense	1	1
	Mid-Dense	2	
	Sparse	3	
	Very Sparse	4	
	Grassland/Non-Remnant	5	
Profile Curvature **Source:** Elevation data provided by WRC, with additional elevation data to fill gaps sourced from http://elevation.fsdf.org.au/	Convex	1	2
	Moderately Convex	2	
	Linear	3	
	Moderately Concave	4	
	Concave	5	

The individual cell value scores assigned for the range of possible values within each criteria were standardised to values between 0 and 1 and the overall influence of each criteria (e.g. slope is a more important landslide risk factor than underlying geology) was also taken into account. The analysis was run using the Raster Calculator functionality within ArcMap 10.6. This resulted in a landslide risk GIS layer in raster format, with landslide risk ranging in values between 0 (lowest possible risk) and 1 (highest possible risk).

3.1.2 Analysis Results

After examining the initial results of the analysis and consulting with Cardno geotechnical staff regarding known landslide risk areas in the region, it was decided that values less than 0.55 would be considered low risk, values between 0.55 and 0.7 would be considered moderate risk, and values higher than 0.7 would be considered high risk.

Some locations within the study area were not covered or only partially covered by the geology dataset used in determining landslide risk. Rather than excluding these areas from the analysis, a risk score of 3 was assigned to these areas for the geology criteria, representing the value in the middle of the range of the possible geology scores as outline in Table 3-1.

The Raster layer was reclassified to values of 1, 2 and 3, corresponding to the low, moderate and high risk landslide categories respectively.

Following input from Cardno geotechnical staff and field-checking of the results, it was decided that some areas around Airlie Beach should be generally classified in the high landslide risk category to better reflect conditions in the area. It was also decided in collaboration with WRC that all areas with slopes of less than 5% should be classified as "Low Risk", regardless of the values assigned to the other criteria for these areas. The final landslide risk raster dataset provided by Cardno therefore combines the results of the GIS landslide risk analysis for the Whitsunday Regional Council area, enhanced by field observations of landslide risk areas around the Airlie Beach area.

3.2 Geotechnical Methodology

Recent landslides were assessed using various aerial photography sources. The size, morphology and runout distances were catalogued and compared to the GIS results. Ground truthing was then undertaken, which was done by a Principal and Senior Principal Engineering Geologist; this involved visiting the areas which are considered representative of the low, medium and high risks - as well as some marginal ones, and assessing landslide risk, both to the blocks and the immediate surrounds. Areas that we consider best practice for development of sloping blocks, as well as areas which we consider as marginally acceptable were also visited.

Following the ground truthing, the risk rating on the GIS maps relevant to local development were assessed and in some cases altered. Some areas, which had insufficient data to be given a risk rating from remote data were also assigned risk ratings.

Best practice for design and construction, and risk rating have been linked - three risk ratings have been assigned: Low, Medium and High. Further refinements were considered, however, as one of the criteria of the study is to identify mitigation strategies for Council and developers to reduce the risk of landslides and avoid damage to people and property, it was considered that additional risk ratings did not provide value and may prove confusing.

The risk ratings are defined as follows:

Low Risk: Little chance of landslide either on the property or being affected by instability on adjacent properties. Competently designed and executed earthworks on the property are unlikely to affect surrounding development and construction can be undertaken as per normal development guidelines. Slope stability assessment not required;

Medium Risk: The land is not at immediate danger of landslide, though this could occur if slopes are modified or drainage is altered. Earthworks carried out have the potential to impact adjacent properties. Depending on the morphology of the slope, conventional footings may be employed though design will need to be sympathetic to the slopes. Slope stability assessment required; and

High Risk: The land and immediate surrounds have a location and / or morphology that is conducive to the formation of landslides. Earthworks will have to be planned to not adversely affect the slope and modification of the drainage has a high potential to impact adjacent lots. In some cases earthworks may be required to improve the natural drainage or reduce the susceptibility to slope failure in other ways. Design of residences or other structures, including roads and other infrastructure items, needs to take into account the morphology of the land and unconventional footings or other design elements may need to be employed to minimise disturbance. Slope stability assessment required. In some cases development may not be appropriate.

The risk ratings are not based on quantitative values relating to single cause or trigger: for example, the slope angle or a given rainfall event; but are based on a number of factors, which together combine to affect the likelihood of slope failures occurring. These factors are presented in Section 5.2. Further information is contained within Section 8.2

4 Definitions and Terminology

The terminology adopted in this report has been designed to be consistent, as far as practicable, with national standards including the Australian New Zealand Standard AS/NZ 4360-1999 “Risk Management”, and “Guideline for Landslide Susceptibility, Susceptibility and Risk Zonation for Land Use Planning” Australian Geomechanics Society (AGS 2007a) and -“Practice Note Guidelines for Landslide Risk Management 2007” (AGS 2007c)

Acceptable Risk: level of human and / or material injury that is considered acceptable by society or authorities in view of the social, political and economic cost-benefit analysis.

Consequence: outcome or impact of an event.

Control: an existing process, policy, device, practice or other action that acts to minimize negative risk or enhance positive opportunities.

Event: occurrence of a particular set of circumstances.

Frequency: a measure of the number of occurrences per unit of time.

Geotechnical professional: a geotechnical engineer or geologist with specialisation in geotechnical and slope stability projects.

Hazard: a source of potential harm.

Landslide: the movement of a mass of rock, debris or soil down a slope.

Likelihood: used as a general description of probability or frequency.

Loss: any negative consequence or adverse effect, financial or otherwise.

Residual risk: risk remaining after implementation of risk treatment.

Risk: the chance of something happening that will have an impact on objectives. A risk is often specified in terms of an event or circumstance and the consequences that may flow from it. Risk is measured in terms of a combination of the consequences of an event and their likelihood.

Risk assessment: the overall process of risk identification, risk analysis and risk evaluation.

Risk evaluation: process of comparing the level of risk against risk criteria.

Risk identification: the process of determining what, where, when, why and how something could happen.

RPEQ: a person currently registered as a professional engineer of Queensland. In this context the main area of business is geotechnical engineering.

Slope: a surface with an appreciable gradient, whether of natural or artificial origin on which a landslide may form or which may be enveloped by a landslide.

5 Landslides and Landslide Characteristics

5.1 Introduction

Landslides are events that can occur in almost any terrain, but there are specific circumstances which lead to their formation. An appreciation of the triggers is required in order to mitigate against them.

5.2 Causes of Landslides

The causes of landslides are usually related to fundamental instability in the slope. For a landslide to form, there must be a cause and a trigger: the cause of the landslide is not necessarily the same as the trigger of the landslide.

Causes can be considered to be the factors that make the slope vulnerable to failure, and may include:

- Geological causes: weathering, shearing, jointing, adverse dips, differences in permeability;
- Morphological causes: slope angle; erosion, slope loading and denudation;
- Anthropogenic causes: deforestation, excavation, loading, over-steepening, quarrying and vibration, water loading of slopes by leaking pipes or effluent systems.

The trigger can be considered as an additional factor that turns a slope that is predisposed to failure, into an actual failure. In the majority of cases the main trigger for landslides is heavy or prolonged rainfall, however a combination of the causes listed above can also be triggers: for example, undercutting a heavily fractured slope, or a quarry with vibrations from blasting close to a jointed rockface.

The following section illustrates some of the commonly occurring landslides which may be expected in the local area.

5.3 Types of Landslide

The majority of landslides are defined as being the uncontrolled transport of materials downslope. Rare large rock avalanches have been observed to have long run-out distances over flat or even slightly uphill terrain, but are not common.

AGS 2007 recognises ten types of landslide which can be summarised into seven types of movement:

Falls: generally in rock, the natural downward motion of a detached block or series of blocks involving free falling, bouncing, rolling and sliding.

Figure 5-1 Small rock fall promoted by adverse dip and rootjacking by trees

Topple: failures involving the forward rotation and movement of a mass of rock, earth or debris out of a slope.

Figure 5-2 Adverse dip and jointing in a rock cutting promoting the formation of toppling failure

Rotational: a slide-type landslide along a distinctive curved surface. The slip surface of rotational slides tend to be deep, blocks of failed material can rotate as they fail and can sometimes be seen to tilt backwards into the slope.

Figure 5-3 Small rotational landslide in thick soils

Translational: a slide-type landslide that occurs along a distinct planar surface such as a fault, joint or bedding plane. This type is common where a layer of weak soils or weathered material overlies stronger bedrock.

Figure 5-4 Translational landslide removing weaker soils over stronger bedrock

Lateral spread: the extension of a cohesive soil or rock mass combined with a general subsidence of the fractured mass of cohesive material into softer underlying material.

Flows: Landslides that involve the movement of material down a slope in the form of a fluid, commonly occurs when material on a slope becomes saturated with water and develops into a debris flow or mud flow.

Complex: a combination of two or more types of movement.

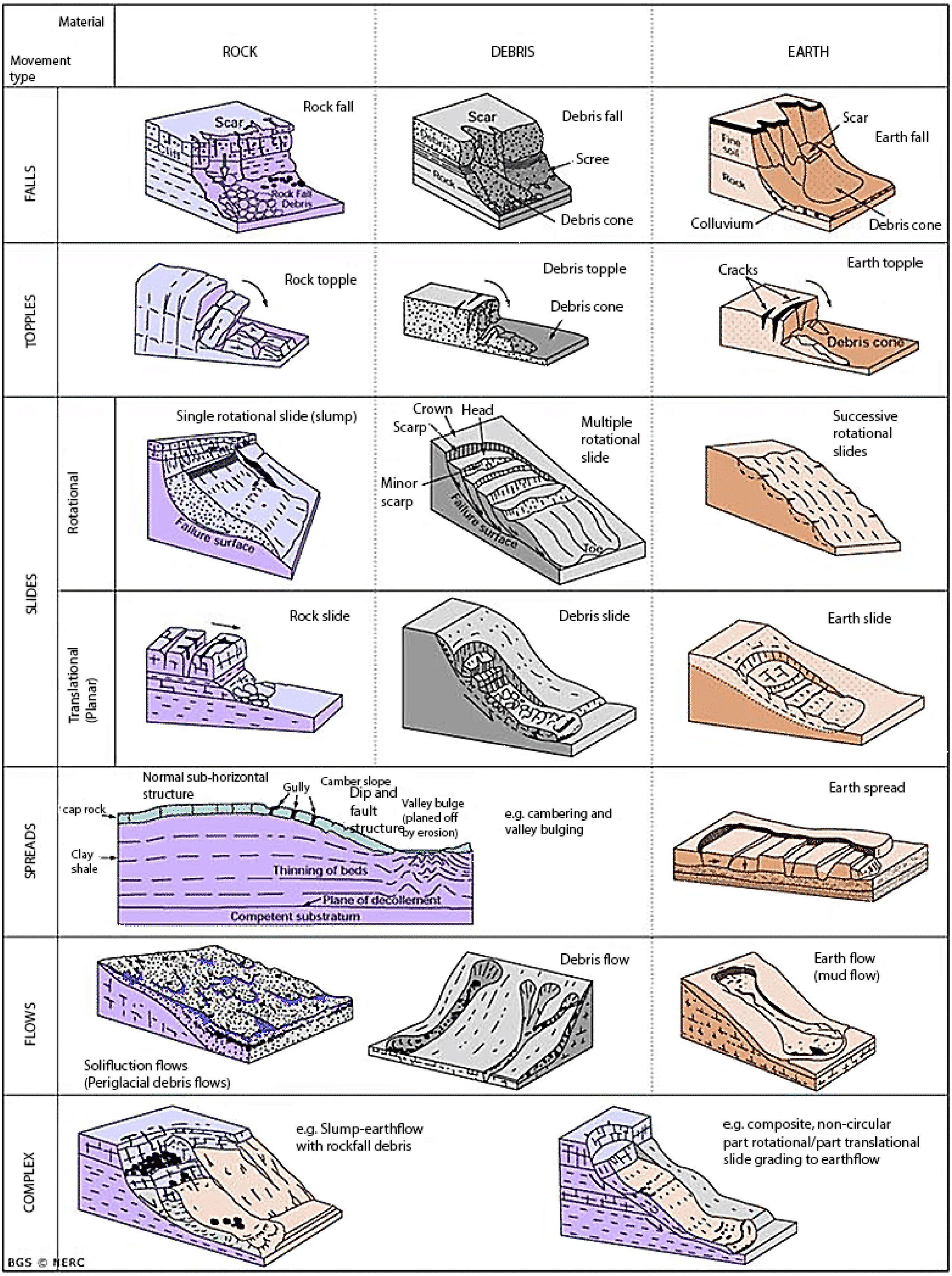
Additional landslide types occur such as lahar (fluidised volcanic debris) and sturzstrom (rock avalanche), however, they are not common occurrences in Australia and are not considered by AGS 2007.

An additional landslide type has been incorporated into this report: gully slides are considered to be a combination of translational and flow slides, caused by the concentration of water into defined drainage pathways.

Figure 5-5 Small gully landslide; fluidised material caused by concentration of water flow

A comprehensive landslide classification system is provided in Figure 5-6

Figure 5-6 Classification of landslides (Varnes, 1978, and Cruden and Varnes 1996), Image British Geological Survey



5.4 Surface Characteristics of Landslides

The ability to recognise the presence of a landslide is dependent on a number of factors: fresh landslides are generally easily recognisable providing they have distinct scarps and runouts, but some landslides are more subtle in morphology – such as creep and lateral spread. Recognition of these may be dependent on the experience of the geotechnical professional and the ability to recognise the morphological context.

In general terms, weathering processes will tend to form fairly uniform hill slopes; the presence of landslides will disrupt this uniformity and form (mainly) concave features, which may have hummocky ground or talus slopes at the foot of the hill where the failed material has accumulated.

The slope may also show benches, scars or scarps where the ground has been displaced, changes in vegetation may be present in historical landslide areas, and this may take the form of smaller trees in the form of regrowth, or a patch of different species through change in subsurface conditions and opportunistic recolonization.

Slow, creeping landslides and historic events may be recognisable by consistently bent trees; as the ground moves and tilts the trees will continue to grow near vertically, which can lead to a kink in the trunks – this will be exhibited by a number of trees and single specimens are not likely representative of slope movements. Creep and lateral spread in low-angle slopes may be seen by linear irregularities in the slope.

Historic landslides may also be picked up in high-resolution topographic maps: downslope lobes and hummocks can often be seen, and when combined with irregularities in the slope and gullies, can identify areas which warrant further investigation.

Anthropogenic features may also be disturbed by landslides; powerlines may be tilted, retaining walls can bulge, roads and railway lines may show cracking and offset.

Sometimes, areas which are in danger of developing landslides can be picked up by the formation of tension cracks and the presence of springs and altered drainage, however, for the most part these areas need to be assessed by considering a combination of slope angles, material types and assessing the risk from historical records and context.

6 Contributing Factors Considered in Assessment

Multiple factors have been considered in the assessment of overall instability – refer to GIS methodology, but in the terms of the physical environment and land instability it can be stated that landslides are likely to occur in areas where they have historically occurred, and that they are likely to occur in areas with physical characteristics similar to where they have previously occurred.

To this end, the landslides currently visible in WRC's area have been analysed based on current aerial photographs, and the features which are common have been assessed.

It should be noted that historical landslides may not be visible in aerial photography due to vegetation growth and the effects of erosion over time. The majority of the landslides visible date from 2017 to 2018, and are likely the result of cyclonic rainfall associated with Cyclone Debbie; the exception appears to be the multiple landslides around Hydeaway Bay which date to early 2011 – exceptionally heavy rainfall was recorded in March 2011 which appears to have been the trigger.

7 Landslide Investigation

Table 7-1 Landslides within the WRC area.

Landslide reference	Map reference UTM)	Locality	Type	Runout distance (m)	Terrain / comments
LS1	677274.99 7755329.02	Cape Conway	Translational / gully	300	Concave basin, heavily gullied, slopes >30^0
LS2	678077.19 7753668.47	Cape Conway	Translational	130	Near crest of ridge, slopes >30º
LS3	654384.05 7779368.18	Hydeaway Bay	Translational	300	Slightly concave slope in excess of 30^0. Set of five narrow landslides which appear to be associated with runoff and are gully controlled
LS4	654386.00 777913.29	Hydeaway Bay	Translational	100	Mid-point of slope >30^0, relatively thick vegetation
LS5	654501.59 7779016.84	Hydeaway Bay	Shallow rotational head, translation / gully runout	210	Mid-point of slope >30^0, relatively thick vegetation
LS6	654672.33 7778888.15	Hydeaway Bay	Shallow rotational	40	Foot of slope >20^0
LS7	654439.69 7778895.08	Hydeaway Bay	Translational	280	Slightly concave slope >30^0, some gullying. Evidence that other translational landslides / tension cracks are forming at the head of the existing mass movement
LS8	654038.63 777919.80	Hydeaway Bay	Gully erosion	1100	Deep gully erosion in steep (>30^0), well vegetated area, runout distance is due to transport along gully
LS9	653800.07 7779359.75	Hydeaway Bay	Shallow rotational	20	Slope >30^0, heavily vegetated
LS10	653346.00 7779648.68	Hydeaway Bay	Translational / gully	1100	Series of gully landslides related to run-off processes, all originating near mid-point of steep slope, tending to be in more vegetated areas. Long runout due to transport along gully
LS11	653254.71 7778193.45	Hydeaway Bay	Translational	60	Foot of steep slope in heavily vegetated area

Landslide reference	Map reference UTM)	Locality	Type	Runout distance (m)	Terrain / comments
LS12	653153.54 7779373.12	Hydeaway Bay	Shallow rotational / gully	100	Steep, concave slope associated with drainage pathway. Heavily vegetated
LS13	653908.90 7778498.98	Hydeaway Bay	Translational / gully	1200	Steep, concave slope associated with drainage pathway. Heavily vegetated. Long runout due to transport along gully.
LS14	663872.55 7769311.17	Dryander	Translational	300	Heavily vegetated slope >20^0
LS15	659252.00 7768026.81	Dryander	Gully	200	Crest of slightly concave slope >30^0, moderately vegetated
LS16	659372.98 7768186.12	Dryander	Shallow rotational / translational	60	Mid-point of slightly concave slope >30^0, moderately vegetated
LS17	659407.91 7769571.80	Dryander	Translational	110	Mid-point of slightly concave slope >30^0, moderately to heavily vegetated, associated with gully run-off
LS18	659440.16 7769505.29	Dryander	Translational	30	Mid-point to crest of slightly concave slope >30^0, moderately to heavily vegetated, associated with gully run-off
LS19	662434.09 7768163.05	Dryander	Shallow rotational / gully	400	Two closely related landslides. Steep, slightly concave slope associated with drainage pathway. Heavily vegetated. Long runout due to transport along gully.
LS20	661919.85 7766987.19	Dryander	Shallow rotational / translational	30	Mid point of steep, heavily vegetated slope, appears to have moved but has not yet completely failed
LS21	662436.52 77648.10	Dryander	Shallow rotational / gully	800	Mid-point to crest of slightly concave slope >30^0, heavily vegetated, associated with gully run-off with long runout
LS22	662241.24 7763607.00	Dryander	Shallow rotational	60	Near crest of slightly concave slope >30^0, moderately to heavily vegetated, associated with gully run-off

Landslide reference	Map reference UTM)	Locality	Type	Runout distance (m)	Terrain / comments
LS23	663619.01 7758993.66	Dryander	Translational	50	Slide over rock near midpoint on concave slope >20⁰
LS24	680434.66 7754258.75	Conway	Translational	70	Mid point of steep slope >30⁰
LS25	679954.14 7754462.78	Conway	Translational	40	Mid point of steep slope >30⁰
LS26	683641.00 7753368.26	Conway	Translational / gully	500	Crest of steeply dipping, concave slope, associated with gully drainage lines
LS27	678656.35 7756574.02	Whitsunday Heights	Translational	50	Mid point of steeply dipping, slightly concave slope, heavily vegetated
LS28	679723.47 7756709.34	Near Jubilee Pocket	Gully	50	Mid point of steeply dipping >20⁰, concave slope, heavily vegetated. Associated with drainage lines
LS29	680559.90 7751267.86	Conway	Translational	120	Mid point of steeply dipping, slightly concave slope, drainage gully at toe
LS30	676758.92 7757509.11	Scrubby Hill	Translational	90	Foot of steep slope, heavily vegetated
LS31	676676.28 7757443.87	Scrubby Hill	Translational	35	Foot of steep slope, heavily vegetated
LS32	679150.01 7757146.84	Raintree Place	Rotational?	10	Appears to be associated with clearing or development on steep foothill, heavily vegetated
LS33	680094.09 7752675.12	Conway	Translational	30	Mid point of steeply dipping, slightly concave slope
LS34	680060.83 7752870.00	Conway	Translational	20	Mid point of steeply dipping, slightly concave slope
LS35	678722.05 7755628.33	Whitsunday Heights	Translational / gully	350	Near crest of slightly concave slope >30⁰, heavily vegetated, associated with gully run-off

7.1 Landslide Analysis

The local area was analysed for the presence of landslides using aerial imagery mainly dating from 2017-2018. 35 landslides or groups of multiple small landslides were identified, and the terrain, mode of failure and runout distances assessed. Accessible locations were checked during the ground truthing but the majority of the information has been gained from aerial imagery only.

7.1.1 Morphology of the Landslides

Three main failure mechanisms were observed: the most common are narrow translational landslides; the downslope movement of fairly superficial soils as a result of detachment along a change in geology. These movements commonly have a fairly small head, or source, and a longer runout area. These have the most widespread distribution.

Gully-related landslides are also common, often incorporating translational components. Gully landslides are often within unconsolidated debris that has accumulated within a drainage pathway and runout distances are often very long, however, they are restricted in occurrence.

The third landslide type observed is rotational. These are not particularly common as they need a deeper soil profile or highly fractured rock to form. Some appear to have a non-circular or compound morphology.

7.1.2 Terrain and Geology

The highest concentrations of landslides were found in the Hydeaway Bay area. Underlying geology is referred to in Section 1. Within the Hydeaway Bay area, the majority of landslides appear to be forming around the mid-point of the hill slope, and in association with more heavily vegetated areas. The landslides would appear to be forming in areas with a deeper regolith, manifested by the larger growth of vegetation.

The Conway area also contains a fairly large amount of recognisable landslides, though not concentrated as they are at Hydeaway Bay. In this area, there do not seem to be any strong correlation between the affected area and number of slope failures, though from aerial imagery it appears that many of the smaller slides are associated with slope denudation following Cyclone Debbie.

Within the Dryander area the observed landslides do not tend to show much correlation between location or vegetation cover.

The constant throughout all the observed landslides is the steepness of the slopes: all occurred on slopes steeper than 20^0, with the majority being on slopes in excess of approximately 30^0. The presence of morphological features that concentrate water, such as concave slopes or gullies, was also notable.

Geology is fairly consistent over the study area, with the majority of the area being situated on the Lower Permian Airlie Volcanics – predominantly acid to intermediate pyroclastics and flows; which sit unconformably against the Cretaceous Proserpine Volcanics – predominantly rhyolite, andesite and minor pyroclastics. Hydeaway Bay is a notable exception and comprises a granitic intrusion of uncertain date between the Lower Permian and Lower Cretaceous.

7.1.3 Runout Distance

There is a correlation between the length of the runout and the morphology of the terrain, in that gullies, and steeper landforms promote longer runout. The (generally) lesser vegetation found in gullies to impede the flow of the debris, and higher fluid content of the sliding material in a saturated area are the driving forces behind the long runouts. The highly fluidised debris associated with gully landslide events can have runout distances in excess of 1000m, however, these are very dependent and constrained by local ground morphology.

Areas which do not have these factors tend to have much smaller runout areas in the order of 10-50m.

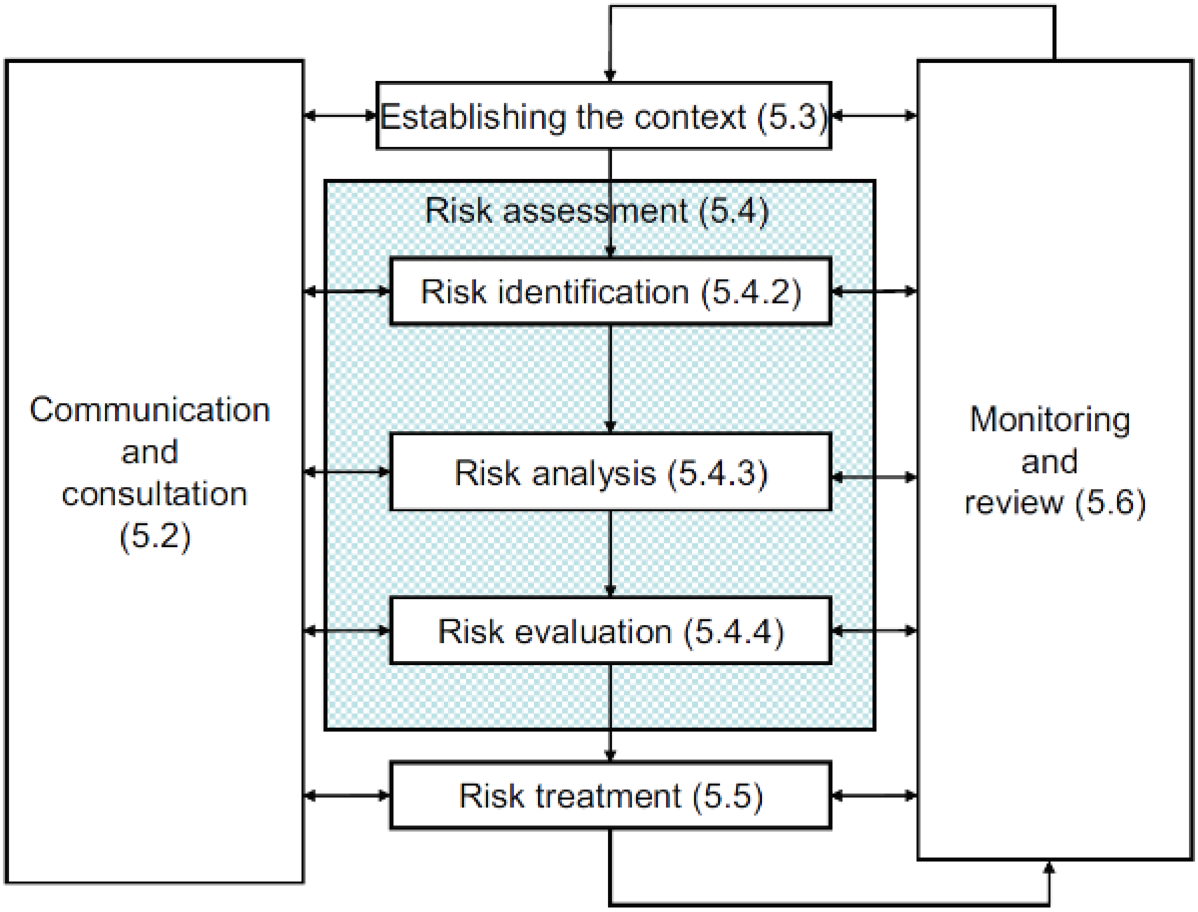
8 Landslide zoning and recommendations for development

8.1 Assessment under AGS 2007

The Queensland State Planning Policy (2017) states that landslide hazard risk assessment should be consistent with AS/NZS ISO 31000:2009 Risk Management.

The Risk Management process is displayed below (refer to the Standard for explanation of steps)

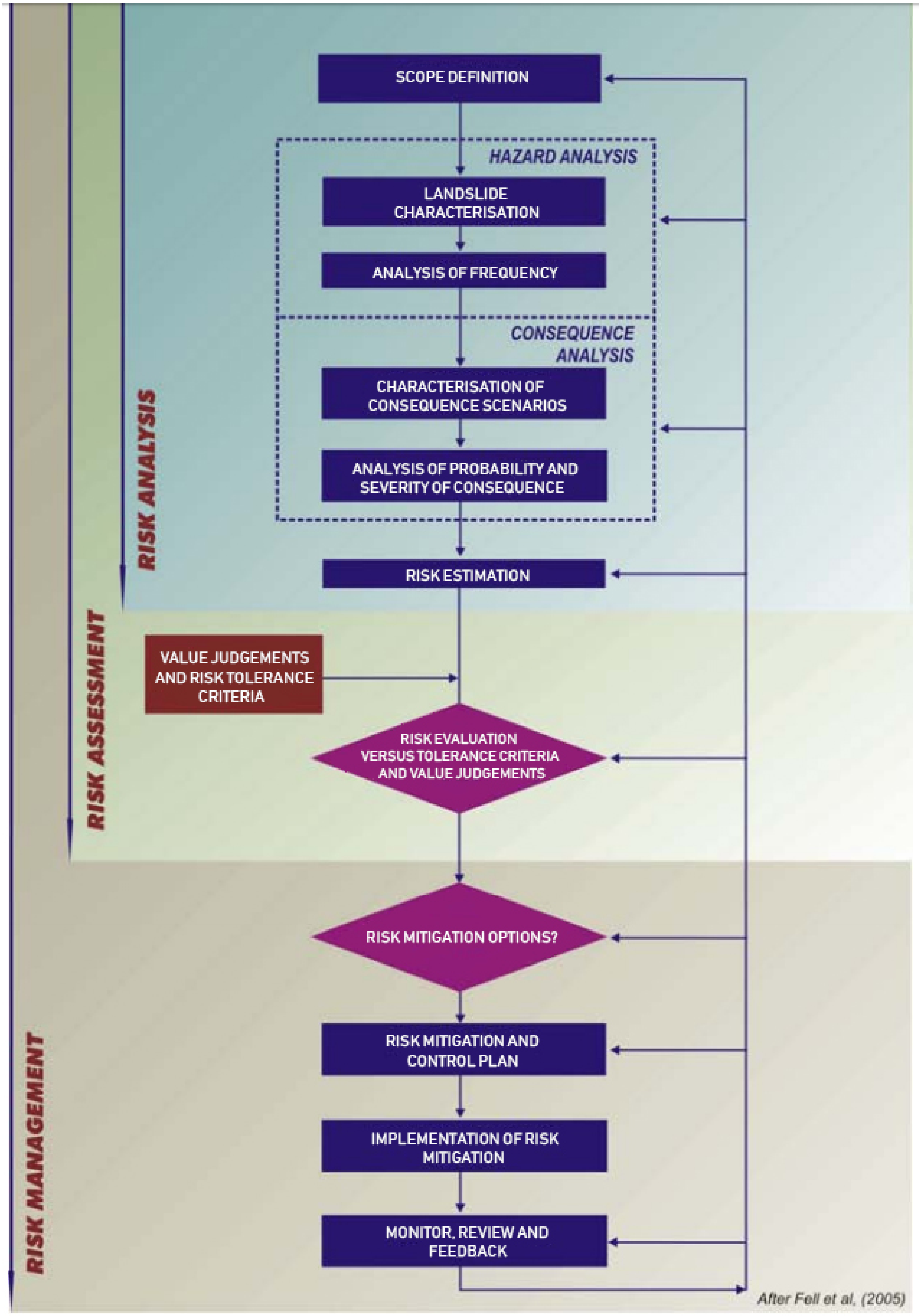
Figure 8-1 Risk Management process as per AS/NZS ISO31000



AGS (2007) presents a similar framework specific for the management of landslides as presented in Figure 8-2, (on the next page).

The technique employed by AGS is to identify the hazards, the elements at risk, the probability and the consequence, and from these calculate the risk rating. This report does not go into the intricacies of how the method is applied as it is expected that the slope practitioner is familiar with the method.

Figure 8-2 Framework for Landslide Risk Management



8.2 Hazard Categories

The previous criterion for whether slope stability analysis was undertaken is whether the slope was steeper than 15% or not. The aim of this report is to refine the risk rating based on a number of different criteria (see GIS section for details of those criteria). It is not, however, designed to replace the methodologies or aims of AGS 2007 or similar slope stability assessment methods.

The aim of the report is to define areas which require further assessment; this has been done by the creation of three hazard identification categories, which then define the requirement for further investigation.

The geomorphology and landslide data has been compiled and three hazard categories identified:

- Low;
- Medium; and
- High.

The categories are defined as:

Low Risk: Little chance of landslide either on the property, or being affected by instability on adjacent properties. Competently designed and executed earthworks on the property are unlikely to affect surrounding development and construction can be undertaken as per normal development guidelines. Slope stability assessment not required.

Medium Risk: The land is not at immediate danger of landslide, though this could occur if slopes are modified or drainage is altered. Earthworks carried out have the potential to impact adjacent properties. Depending on the morphology of the slope, conventional footings may be employed though design will need to be sympathetic to the slopes. Slope stability assessment required.

High Risk: The land and immediate surrounds have a location and / or morphology that is conducive to the formation of landslides. Earthworks will have to be planned to not adversely affect the slope and modification of the drainage has a high potential to impact adjacent lots. In some cases earthworks may be required to improve the natural drainage or reduce the susceptibility to slope failure in other ways. Design of residences or other structures, including roads and other infrastructure items, needs to take into account the morphology of the land and unconventional footings or other design elements may need to be employed to minimise disturbance. Slope stability assessment required.

9 Mitigation Strategies

Assessment of the landslide morphologies indicates that certain areas are more prone to landslide and the effects of runout than others:

9.1 Gullies

The largest number of landslides identified were associated with gullies; either directly as a result of erosion and failure of choked gullies, or as the result of gully erosion undermining material up the slope and causing failure. These gullies also show the longest runout distances, most likely due to fluidisation of the debris.

There are certain strategies that can be put in place to mitigate against gully erosion, these include: rock mattresses; devices to slow water flow and gabion reinforcement amongst them, however, the head of the failure is difficult to predict, and the easiest mitigation would be avoidance. Avoidance can be managed by positioning any structure away from a gully and careful mapping of the site to determine whether flow paths are present which may be prone to failure. The possibility of downslope transport is also of concern for lots further down the slope, though it does appear that these types of landslide are highly controlled by topography.

Cleaning and maintenance of gullies should also be undertaken; if fallen trees and boulders have choked the gully, the possibility of catastrophic failure of the created dam needs to be taken into account. Landholders should ensure that drainage pathways are free of obstruction prior to the onset of the wet season. Development should be avoided downslope of a gully, and infill to create flatter land should also be avoided as this alters the natural drainage pathways. Setback distance from gullies is best determined following site-specific assessment and will be based on a number of factors, including the extent of the upslope area drained by the gully and the potential velocity of the material being transported downslope.

9.2 Boulder Roll

Boulders are periodically found within the slopes. The risk relating to these is largely set by their ability to roll unimpeded, which in turn is dependent on the slope, set of the boulder within the slope and the amount of impedance such as trees and gullies. Smaller boulders are generally able to be removed or broken up. Large boulders are more problematic and may need to be assessed individually for stability; ongoing monitoring may need to be undertaken to ensure undermining is not occurring. Any modifications to the ground around them needs to take into account drainage patterns so that water erosion does not occur. Large boulder slopes above developments may be addressed with the use of catch fences or similar engineered constructions. Trees and dense vegetation may also prove useful in providing impedance to loose boulders, though trees near the boulder itself may promote instability by root-jacking.

9.3 Rotational Landslides

Rotational landslides are more likely to occur in areas of deeper regolith or fractured rock. Generally the Whitsunday area does not tend to show the required drift geology for this to naturally occur – only a very limited number were observed in the aerial photographs. These types of landslide are more likely where blocks have been modified and fill has been placed, and are most likely to occur along over-steepened faces where the base of the slip surface is at the interface between the fill and the natural ground.

Sites that have deep soils, or talus, at the base of slopes would be most prone to these failures. This would be determined during the stability investigation. Construction sympathetic to the slope would be necessary in this case, with the avoidance of effluents where water loading would affect the slope. Construction would also be best placed on flatter areas of ground, leaving a set-back distance from the crest of the slope roughly equivalent to the height of the slope. Alternatively, the site may be contoured with retaining walls, though in this circumstance it needs to be recognised that the retaining walls need to be placed below the base of the potential slip surface and into stable ground. A geotechnical assessment and appropriate design including local and global stability analysis will be required to determine design factors.

In the case of filled slopes, requirements under AS3798 need to be adhered to, with the fill tied into the natural slope ideally by means of keying the fill into the slope, scarification and removal of any deleterious materials. Retaining walls may be required depending on the depth and angle of the fill. Effluent systems and stormwater discharge will have to be located where water loading does not affect the slope.

Rotational landslides may also affect road embankments where fill has been built up. The risk can be minimised by adherence to the construction specification and reduction of the free batter slope at the side of the road to the lowest feasible angle. Drainage ditches that also hold water against the batter slope should also be avoided where possible.

9.4 Translational Landslides

The most common landslide type observed is the translational landslide: this type is common where a relatively thin layer of low strength material is found above a stronger layer, such as in soil overlying rock. Many of the landslides visible were associated with gully erosion and are likely triggered either by undercutting of the slope or concentration of water run-off. A smaller amount of translational landslides were seen on relatively consistent slopes though these slopes appear to have been denuded of trees during Cyclone Debbie; it appears that these have been triggered through a combination of disturbance of the soil cover and large amounts of rain.

Careful avoidance of areas which may be prone to translational landslides would be necessary: areas around gullies would be prone to undercutting, though this could be managed with rock mattresses or gabions if required. Building on steeply sloping lots would also require sympathetic construction methods: fill should be avoided, though engineered retaining walls properly keyed into the underlying rock may be an acceptable solution. Water should also be prevented from running over the site; catch drains from access roads and guttering diverting runoff away need to be installed and maintained. Effluent systems should be positioned away from the footings of the house and not downslope, and the disposal area appropriately terraced for the ground conditions. Setback distances from retaining walls as outlined in AS1547 need to be followed in order to avoid water loading.

9.5 Effectiveness and Cost of Remediation Methods

There are many typical engineering procedures that can be implimented to reduce landslide risk. The cost/benfit of these procedures need to be evaluated by the geotechnical practitioner and the designer in order to determine the most appropriate means of achieving an acceptable level of risk.

The following table summarises some of the procedures that may be implimented, along with commentary on limitations (modified from Gedney and Weber, 1978 *Special Report 176, Landslides: Analysis and Contro*l. National Research Council, Washington DC)

Guidelines for hillside construction (AGS 2007) are included in Table 9-1 and Table 9-2.

Table 9-1 Methods of slope stabilisation

Category	Procedure	Best Application	Limitations	Remarks
Avoidance	Relocate structure	Can be used as an alternative on any site providing adequate space is present to do so and clients are agreeable	May not be applicable to residential development on limited block size. On large blocks the aesthetic considerations of outlook have to be taken into account	Potentially lowest cost option but may only be applicable for a limited number of sites
	Completely or partially remove unstable materials	Where small volumes of excavation are involved and where poor soils are encountered at shallow depths only	May be costly to control excavations; may not be feasible for large landslides and may impinge on right-of-way and property boundaries. Removal of downslope mass may also destabilise uphill slopes	For isolated occurrence may be cost-effective, but may also require installation of retaining walls or other structures where there is a potential to affect other properties
Reduction of driving forces (conditions which induce landslide)	Reduce grade of slope	Best implemented during preliminary design phase; may also be applied to developments to reduce overall landslide risk on the site	Requires large geotechnical inputs and may need additional retaining structures and supervision of cut and fill. Where cut and fill is made, a comprehensive understanding of the potential behaviour of the site will be needed to ensure instability is not induced elsewhere	May be initially costly, but can reduce the need for earthworks following development. Will require input from planners and engineers to facilitate.
	Drain surface	Applicable in most circumstances, especially needed in slopes with roads at crests or where water runoff may be concentrated down slope. May also be used in the form of drainage channels in gullies to prevent erosion during heavy rainfall events.	Only applicable to correct surface infiltration and similar mechanisms.	May be a low-cost option if drainage measures are considered at design phase, will increase cost if retro-fitted. Stone pitching or lining of gullies may be costly and might not be feasible in steeper areas.
	Drain subsurface	On any slope with high groundwater levels	Not efficient where thin soils overlie rock	Drainage measues must be carefully designed so as not to induce failure. The deep soils with high groundwater that this method is intended for would be rare in the Whitsunday area.

Category	Procedure	Best Application	Limitations	Remarks
	Reduce weight	On any existing or potential slide	Requires lightweight materials that may be costly or limited in availability	Involves putting less pressure on the slope. Landowner may not be willing to compromise on building materials.
Increase resisting forces	Weight toe of landslide, install retaining walls or similar engineered structures at foot of landslide or potential landslide	Can be used on existing landslides and also as preventative measures	May not be effective on deep-seated landslides where the failure surface is below founding depth. Must be founded on firm foundation and adequately keyed into the underlying good strata	Preventative measures will be cheaper than remediation. Can be variable in cost depending on the amount of engineering and slope modification involved. A well-constructed wall will last many years with little maintenance. Cheaper solutions (gabion walls, brick interlink walls) built high may not provide adequate lateral resisting force to active landslides.
	Structural systems (reinforced soil walls and similar)	Where slopes are to be rebuilt following excavation, or at a steeper angle than soil type would commonly allow	Require good foundation soils and the base to be below the natural shear surface of the landslide	Can be expensive to build due to (normally) stringent fill requirements. If geofabrics are used as facing materials these may deteriorate over time
	Ground anchors	Where materials or access precludes any other option. May be part of remediation designes such as shotcreting	Requires ability of foundation soils to resist shear forces by anchor tension	Only really suitable for small areas due to cost of installation. May require ongoing maintenance.
Increase internal strength	Drain subsurface	On any slope with high groundwater levels	Not efficient where thin soils overlie rock	Drainage measures must be carefully designed so as not to induce failure. The deep soils with high groundwater that this method is intended for, would be rare in the Whitsunday area.
	Reinforced backfill (reinforced soil walls and similar)	Landslide remediation, embankments and steep fill slopes	Requires long-term durability of reinforcement system. May add load to head of potential landslide if not carefully designed	Can be expensive to build due to (normally) stringent fill requirements.
	Installation of insitu reinforcement	Best for temporary structures on stiff soils	Requires long-term durability of nails, anchors and micropiles, may not be considered a	Requires thorough soil investigation and properties testing. More limited to small

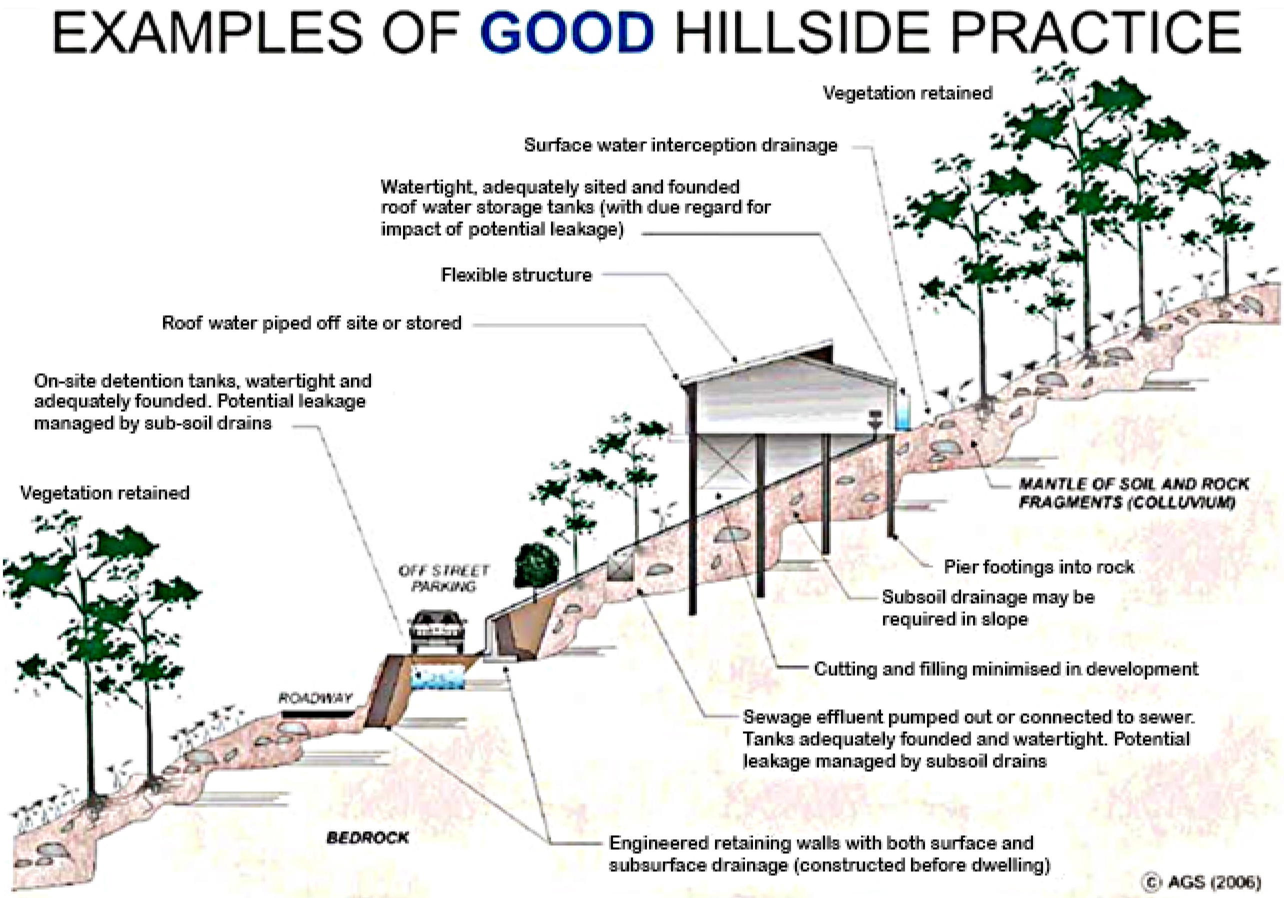
Category	Procedure	Best Application	Limitations	Remarks
			permanent solution depending on gound conditions	areas that need intense treatment.
	Biological stabilisation (vegetation)	On soil slopes of modest height	May require irrigation and ongoing maintenance. Plants may not have adequate longevity. May not suit where shallow soils overlie rock	Requires local experience to ascertain what plants work best.
	Chemical stabilisation	Where sliding surface is well defined and soil reacts positively to treatment	Long term effectiveness has not been evaluated; environmental stability unknown	Likely to be difficult to utilise on steeply sloping terrain, may be expensive for potentially little return.

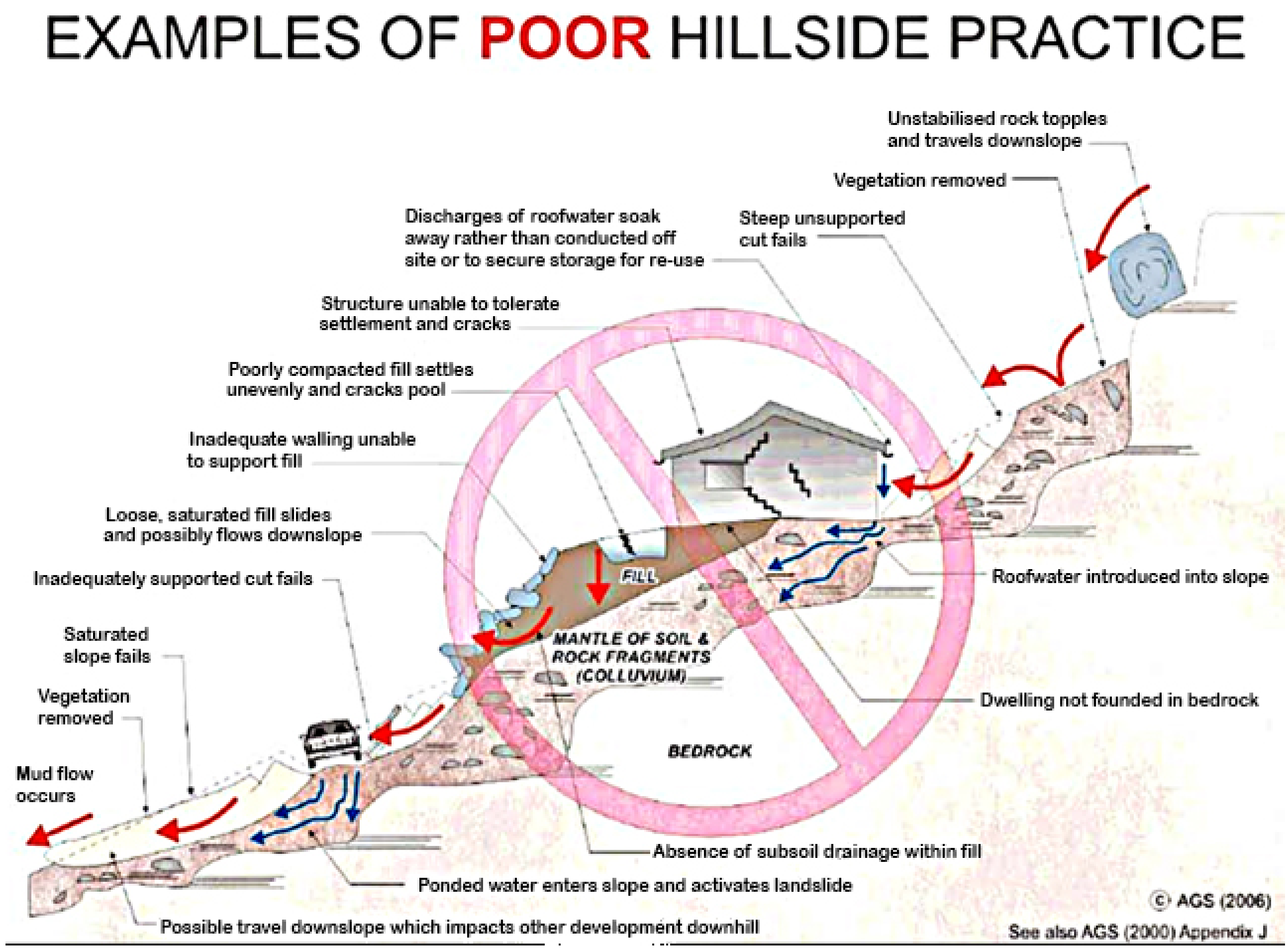
Table 9-2 Some guidelines for hillside constructon (AGS 2007)

	GOOD ENGINEERING PRACTICE	POOR ENGINEERING PRACTICE
ADVICE		
GEOTECHNICAL ASSESSMENT	Obtain advice from a qualified, experienced geotechnical consultant at early stage of planning and before site works	Prepare detailed plan and start site works before geotechnical advice.
PLANNING		
SITE PLANNING	Having obtained geotechnical advice, plan the development with the risk arising from the identified hazards and consequences in mind.	Plan development without regard for the Risk.
DESIGN AND CONSTRUCTION		
HOUSE DESIGN	Use flexible structures, which incorporate properly designed brickwork, timber or steel frames, timber or panel cladding. Consider use of split levels. Use decks for recreational areas where appropriate.	Floor plans, which require extensive cutting and filling. Movement intolerant structures.
SITE CLEARING	Retain natural vegetation wherever practicable.	Indiscriminately clear the site
ACCESS & DRIVEWAYS	Satisfy requirements below for cuts, fills, retaining walls and drainage. Council specifications for grades may need to be modified. Driveways and parking areas may need to be fully supported on piers.	Excavate and fill for site access before geotechnical advice.
EARTHWORKS	Retain natural contours wherever possible.	Indiscriminate bulk earthworks.
Cuts	Minimise depth. Support with engineered retaining walls or batter to appropriate slope. Provide drainage measures and erosion control.	Large-scale cuts and benching. Unsupported cuts. Ignore drainage requirements.
Fills	Minimise height. Strip vegetation and topsoil, and key into natural slopes prior to filling. Use clean fill materials and compact to engineering standards. Batter to appropriate slope or support with engineered retaining wall. Provide surface drainage and appropriate subsurface drainage.	Loose or poorly compacted fill, which if it fails, may flow a considerable distance including onto property below. Block natural drainage lines. Fill over existing vegetation and topsoil. Include stumps, trees, vegetation, topsoil, boulders, building rubble etc. in fill.
Rock Outcrops and Boulders	Remove or stabilise boulders, which may have unacceptable risk. Support rock faces where necessary.	Disturb or undercut detached blocks or boulders.
RETAINING WALLS	Engineer design to resist applied soil and water forces. Found on rock where practicable. Provide subsurface drainage within wall backfill and surface drainage on slope above. Construct wall as soon as possible after cut/fill operation.	Construct a structurally inadequate wall such as sandstone flagging, brick or unreinforced blockwork. Lack of subsurface drains and weepholes.
FOOTINGS	Found within rock where practicable. Use rows of piers or strip footings oriented up and down slope. Design for lateral creep pressures if necessary.	Found on topsoil, loose fill, detached boulders or undercut cliffs.

	Backfill footing excavations to exclude ingress of surface water.	
SWIMMING POOLS	Engineer designed. Support on piers to rock where practicable. Provide with under-drainage and gravity drain outlet where practicable. Design for high soil pressures, which may develop on uphill side whilst there may be little or no lateral support on downhill side.	
DRAINAGE		
Surface	Provide at tops of cut and fill slopes. Discharge to street drainage or natural watercourses. Provide general falls to prevent blockage by siltation and incorporate silt traps. Line to minimise infiltration and make flexible where possible. Special structures to dissipate energy at changes of slope and/or direction.	Discharge at top of fills and cuts. Allow water to pond on benched areas.
Subsurface	Provide filter around subsurface drain. Provide drain behind retaining walls. Use flexible pipelines with access for maintenance. Prevent inflow of surface water.	Discharge roof runoff into absorption trenches.
Septic and Sullage	Usually requires pump-out or mains sewer systems; absorption trenches may be possible in some areas if risk is acceptable. Storage tanks should be watertight and adequately founded.	Discharge sullage directly onto and into slopes. Use absorption trenches without consideration of landslide risk.
EROSION CONTROL & LANDSCAPING	Control erosion as this may lead to instability. Revegetate cleared area.	Failure to observe earthworks and drainage recommendations when landscaping.
DRAWINGS AND SITE VISITS DURING CONSTRUCTION		
DRAWINGS	Building application drawings should be viewed by geotechnical consultant.	
SITE VISITS	Site visits by consultant may be appropriate during construction.	
INSPECTION AND MAINTENANCE BY OWNER		
OWNER'S RESPONSIBILITY	Clean drainage systems; repair broken joints in drains and leaks in supply pipes. Where structural distress is evident see advice. If seepage observed, determine causes or seek advice on consequences.	

Figure 9-1 Examples of good and bad hillside practise (AGS2007)





10 Guidelines for Reducing Landslide Hazard

10.1 Application of Landslide Risk Assessment

A stringent geotechnical investigation which meets the criteria specified by Whitsunday Regional Council Planning Scheme SC6.5.7 is to be carried out where there is a risk of landslides. For these areas, a site classification alone does not provide sufficient information to allow the design of appropriate control measures.

Whitsunday Regional Council Planning Scheme SC6.5.7 provides a guide to the contents and depth of detail required in the landslide risk assessment. The following sections describe the level of detail which may be required for various sites.

10.2 New Subdivisions

For subdivisional works where the entire subdivision is contained within land assessed as Low Risk on the attached risk maps, development can be undertaken without further assessment subject to Operational Works permissions and / or buildings certification.

For subdivisional works where the risk rating is assessed as Medium or High Risk on the attached risk maps, and following development of the land, the risk is of the development reduced to “very low” in accordance with ‘Landslide Risk Management’ (Australian Geomechanics Journal Vol 43, No. 1. March 2007 – AGS 2007) by means of earthworks, an overall slope stability certification can be assigned if the following occurs:

- Where the slope has been reduced by means of cut and fill, the fill has been laid under Level 1 supervision in accordance with AS3798.
- All fill is to be retained by means of appropriately designed and certified retaining walls. All retaining walls shall be certified by an RPEQ engineer competent in geotechnical design.
- Cuts shall be assessed for stability. It is recommended that prior to subdivisional development a comprehensive geotechnical investigation is undertaken to identify the material present and the cut angles which can be employed to promote long-term stability.
- Prior to the signing of the Plan of Subdivision, the developer must provide geotechnical certification written by an experienced and appropriately qualified geotechnical professional, that the subdivision has been constructed in accordance with the approved plans and that the landslide risk level is “very low” in accordance with AGS 2007.

Building lots have a number of different criteria assigned to determine risk level and this is based on more than slope. Where the lot has been assigned or reduced to a very low risk, the developer must include in the sales contract a condition that any building or associated works (such as, but not limited to earthworks, installation of a pool or effluent, creation of raised garden bed or contouring the land) must be designed and certified by a geotechnical professional to maintain landslide risk as Low.

A development that meets the above criteria does not require landslide risk assessments for individual lots.

Where the lot/s are rated as Medium or High Risk on the attached risk maps and are not reduced to “very low” in accordance with AGS2007 following development, the lot/s will require individual certification, and a condition inserted to the effect that any building and associated development works must be designed and certified by a geotechnical professional to reduce and maintain the landslide risk as “very low” with reference to AGS 2007

10.3 Existing Subdivisions

Existing subdivisions in areas contained within land assessed as Low Risk on the attached risk maps, site works can be undertaken without further assessment subject to Operational Works permissions and / or buildings certification.

For existing subdivisions where the risk rating is assessed as Medium or High Risk on the attached risk maps, and following development of the land, the risk is of the development reduced to “low” in accordance with AGS 2007, a slope stability may not be required providing the proposed works do not trigger operational works or buildings certification. If these are triggered, slope stability assessment may be required should there be the possibility of financial loss or injury if the earthworks fail. The volume and position of the earthworks relative to adjacent properties should be taken into account as there are likely to be higher consequences for slope failure in denser developed areas than would occur in rural residential blocks.

Within existing subdivisions, generally the opportunity for reducing the consequences of landslide has passed. Reduction in risk is therefore best directed at reducing the probability of a trigger affecting the slope.

There is a correlation between water in slopes and the triggering of failures, therefore regular maintenance and care with the placement of new structures can ameliorate some of the risk.

Drains should be regularly inspected and maintained so that water runoff does not pond or overflow. Catch drains and gutters at the top of slopes in particular need attention to minimise run-off onto slopes during heavy rain. Erosion around drains and cracking of the drain itself presents pathways for water to enter a slope.

Adequate drainage behind retaining walls and through shotcrete are essential for their performance. Weepholes should be inspected to ensure that they are functioning, and gravel pack behind retaining walls periodically checked for silting up. Geotextiles used as filter blankets are particularly susceptible to clogging if the soils are silty or dispersive, but this may be avoided with the correct graduated filter system.

Effluents and sewage systems should be designed to be the right size to avoid water loading on the site. Where possible the trenches should be positioned so that they are not directly downslope of the property, or else the site appropriately terraced so that stability is not compromised.

Pools and water tanks should be suitably founded. The pool position needs to be placed with consideration to adjacent structures as it can potentially load the top of retaining walls, or unload the base unless engineering principles are considered. Water loss needs to be immediately investigated to avoid leakages adding water load to the slopes.

Landscaping should be sympathetic to the slope and not cause concentration or ponding in water. Erosion should be noted and the source repaired, and associated silt cleaned from drainage systems.

Any indications of movement on the site such as subsidence, tension cracking and distress in the building and associated infrastructure needs to be referred to a professional engineer for assessment.

10.4 Roads and Other Infrastructure

Roads are usually formed by a combination of cut and fill. On particularly steep slopes extensive soil reinforcement or other retaining measures may also be applied.

The level of geotechnical investigation should be appropriate for the scale and risk of the road; back country roads may not be as critical when failed as major highways. All design and construction must be based on sound engineering and investigation.

In general, cut batters must be appropriate to ensure the long term stability of the slope, these typically range from 2H:1V in soils to near vertical in rock. Where this is not possible due to concerns about room appropriate soil reinforcement may be used.

Cuttings in rock should be inspected and any method to reinforce the slope (where necessary) installed. Where possible, adequate set-back distance between the toe of the slope and the fog line should be present to minimise risk of boulder fall onto the road. Other engineered solutions such as catch fences and ditches or shotcrete and rock bolts may be warranted but it should be recognised that these will require ongoing maintenance.

Inspections of the slopes in accordance with NSW Transport Roads and Maritime Services Guide to Slope Risk Analysis (version 4 as of September 2018), or the Queensland Transport and Main Roads equivalent should be undertaken at regular intervals: the time between inspections can be varied based on assessed risk to users of the road.

10.5 Minor Works

Where minor works are to be undertaken following the development of a site classed as Medium or High Risk, the adoption of all the recommendations within the slope stability report may not be appropriate or reasonable. The basic principles of the report will need to be considered.

Minor works should be evaluated on a site by site basis but are likely to comprise proposed works of relatively low monetary value. Where these works do not change the existing risk (providing the existing risk has been assessed to be within the tolerable range) a supplementary landslide risk assessment may not be needed.

Proposed works that may not require further investigation include earthworks that cannot affect existing structures or adjacent properties; for example, small shed platforms away from the residence and adjacent infrastructure and site boundaries may be permissible, but the placement of unretained fill above a property boundary may not be.

In general terms, if the proposed works on site could potentially cause a monetary loss or injury to the people on the site or adjacent land during the course of normal use, then they would require formal assessment through supplementary slope stability assessment.

11 Stability Practitioners

Assessment of stability, the recognition of existing landslides and the potential for slope mobilisation is a specialised skill. It is to be considered separately from the site classification and it is not considered acceptable for a technician, driller or site classifier to undertake slope stability assessment.

The investigator should be qualified in an appropriate discipline; geotechnical engineering or geology with a geological engineering speciality. Ideally the practitioner should have a formal slope stability qualification (such as RMS Slope Stability ver 4), though experience under the guidance of a qualified practitioner is also acceptable.

It is also not considered acceptable for reports to be undertaken by unqualified personnel and a signature added by a qualified person who is not familiar with the locality.

12 References

Australian Geomechanics Society Practise notes for Landslide Risk Management, 2007. Journal and News of the Australian Geomechanics Society, Vol 42, No. 1

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Varnes, D.J. (1978) Slope Movement Types and Processes. In: Schuster, R.L. and Krizek, R.J., Eds., Landslides, Analysis and Control, Transportation Research Board, Special Report No. 176, National Academy of Sciences, 11-33.

13 Limitations

Geotechnical services are provided by Cardno (Qld) Pty Ltd in accordance with generally accepted professional engineering and geological practice in the area where these services are rendered. The client acknowledges that the present standard in the engineering, geological and environmental profession does not include a guarantee of perfection, and no other warranty, expressed or implied, is extended by Cardno (Qld) Pty Ltd.

It is the reader's responsibility to verify the correct interpretation and intention of the results presented herein. Cardno (Qld) Pty Ltd assumes no responsibility for misunderstandings or improper interpretations that result in unsatisfactory or unsafe work products. It is the reader's further responsibility to acquire copies of any supplemental reports, addenda or responses to public agency reviews that may supersede recommendations in this report.

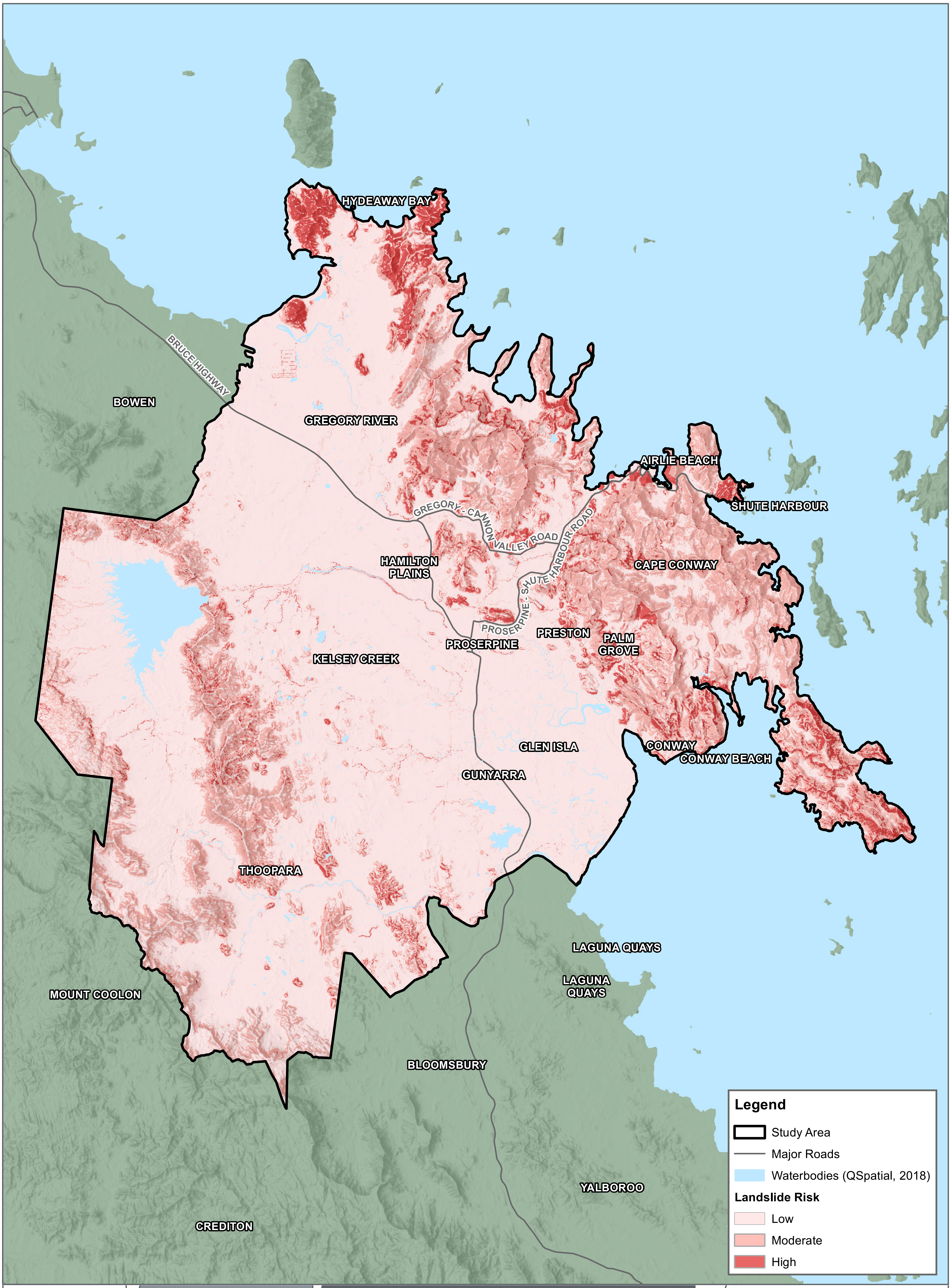
The findings presented in this report have been based on the investigation described herein. There are always some variations in subsurface conditions across a site, which cannot be fully defined by investigation. It is unlikely that the measurements and values obtained from sampling and testing during the investigation will represent the extremes of conditions that may exist within the site. Hence, it is recommended that if any ground conditions significantly different to those described in this report are encountered during construction, further advice should be immediately sought from Cardno (Qld) Pty Ltd.

This report has been prepared specifically for Whitsunday Regional Council and the project designers. Information contained in this report should not be construed as appropriate for other purposes or other users.

APPENDIX

A

RISK MAPS



Whitsunday Regional Council

1:275,000 Scale at A3

Kilometres

0 2.5 5 7.5 10

Regional Landslide Risk

WHITSUNDAY LANDSLIDE STUDY

N

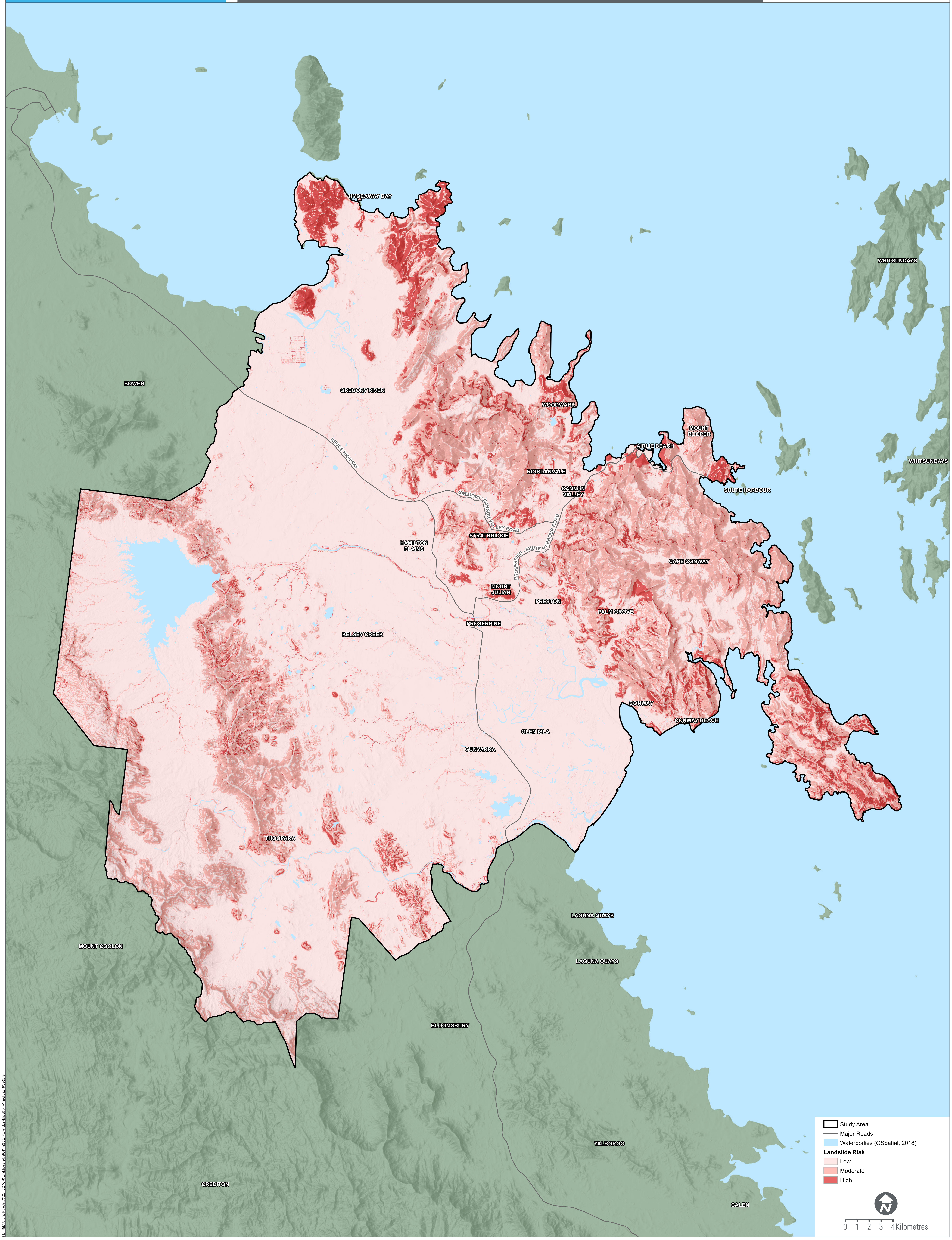
Cardno

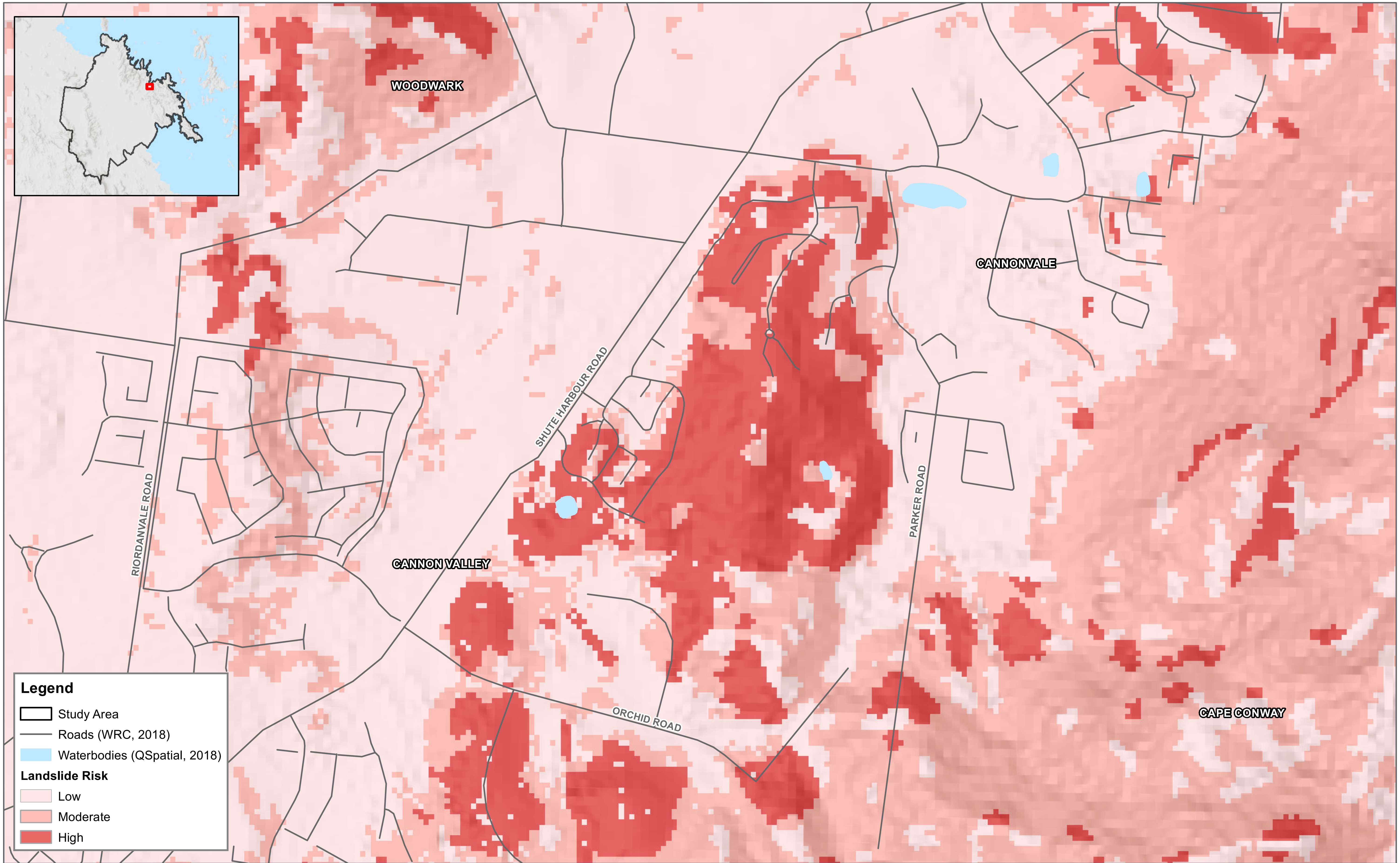
Map Produced by Cardno NSW/ACT Pty Ltd (WOL)
Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-006-RegionalLandslideRisk.mxd 04

Cardno

Regional Landslide Risk
Whitsunday Landslide Study

Whitsunday Regional Council





Whitsunday Regional Council

1:10,000 Scale at A3

Metres

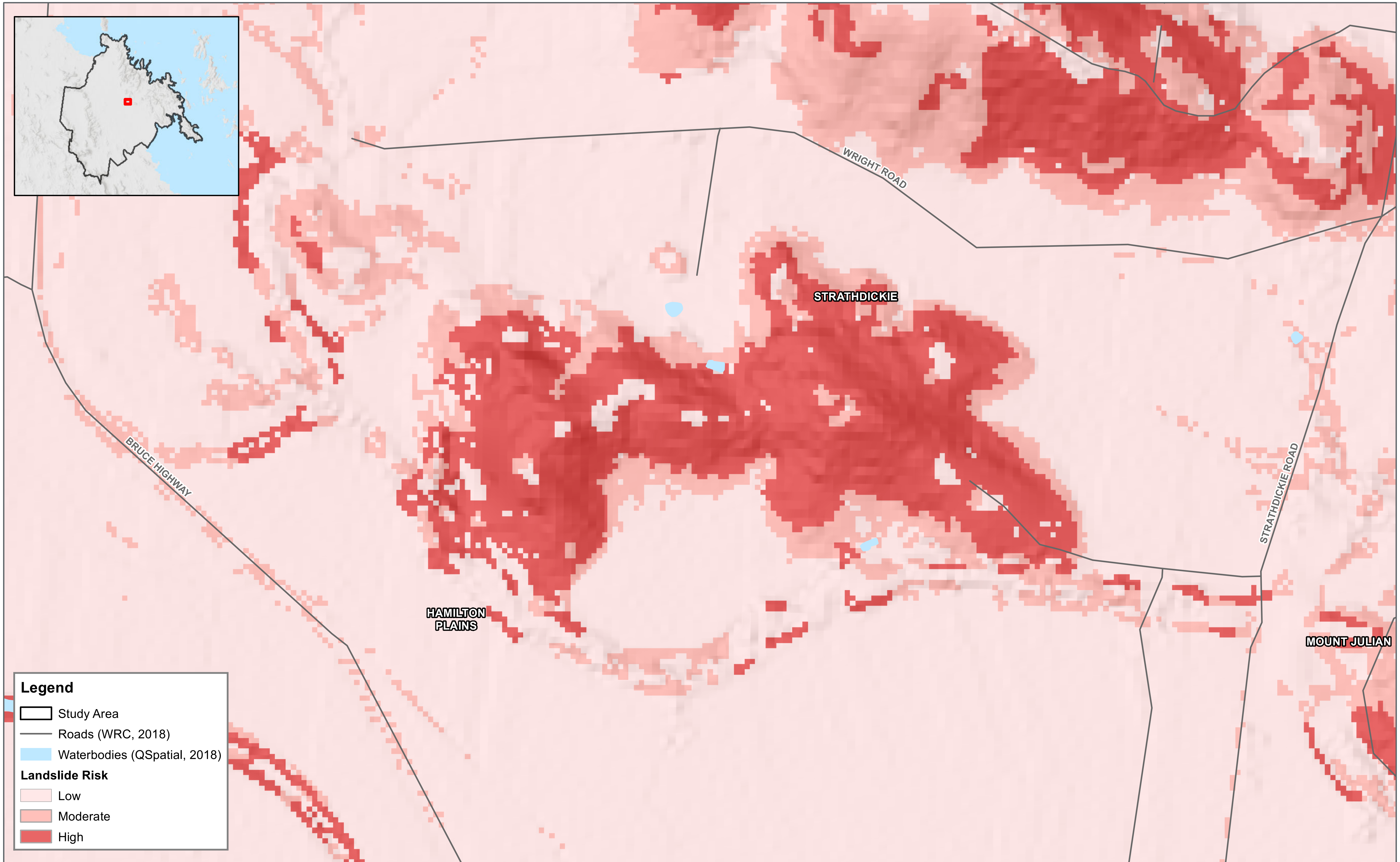
0 100 200 300 400

Landslide Risk - Cannonvale

WHITSUNDAY LANDSLIDE STUDY

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd (WOL)
Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04



1:10,000 Scale at A3

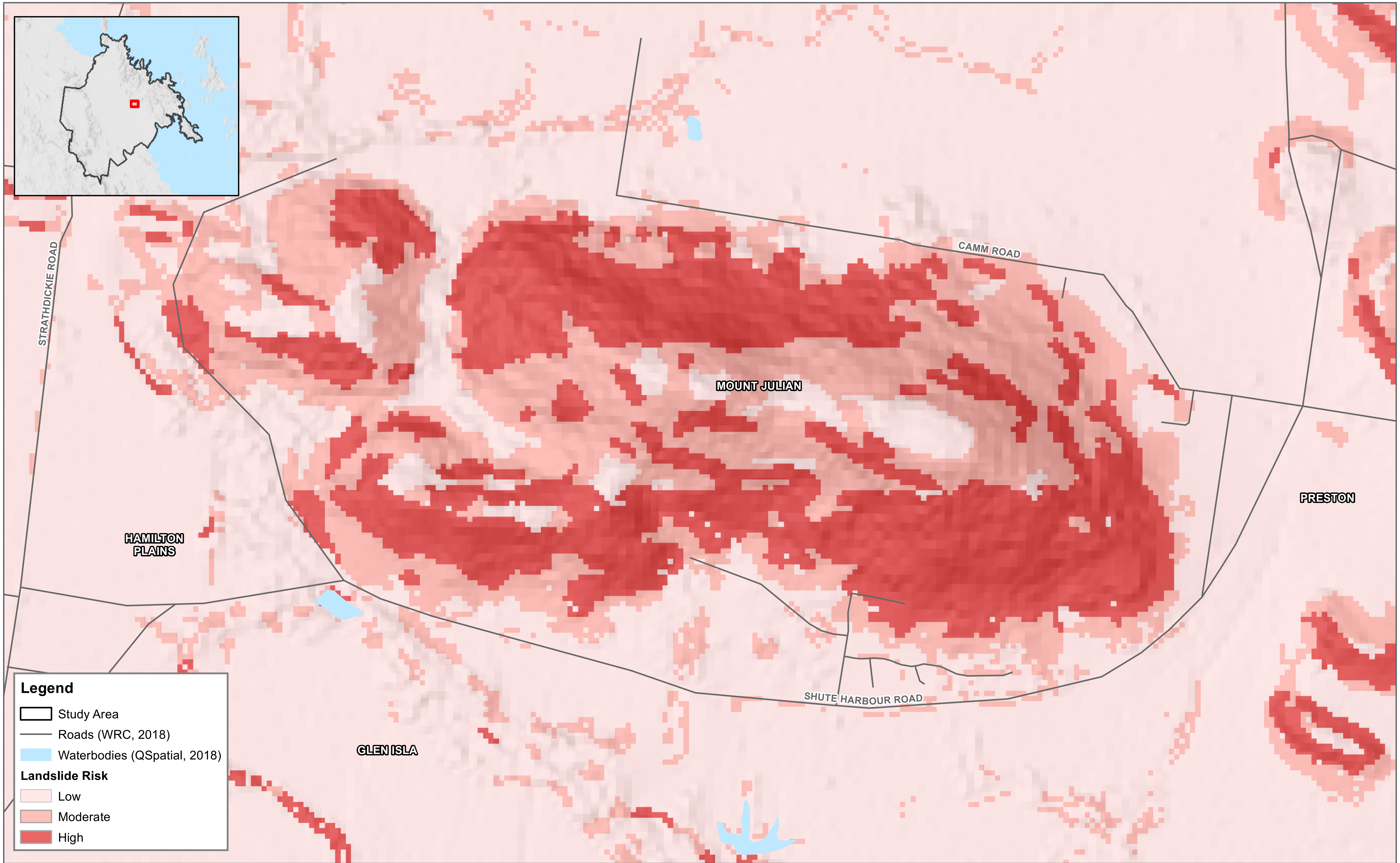
Metres

0 100 200 300 400

Landslide Risk - Foxdale

WHITSUNDAY LANDSLIDE STUDY

Map Produced by Cardno NSW/ACT Pty Ltd (WOL)
Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04



Whitsunday Regional Council

1:10,000 Scale at A3

Metres

0 100 200 300 400

Landslide Risk - Mount Julian

WHITSUNDAY LANDSLIDE STUDY

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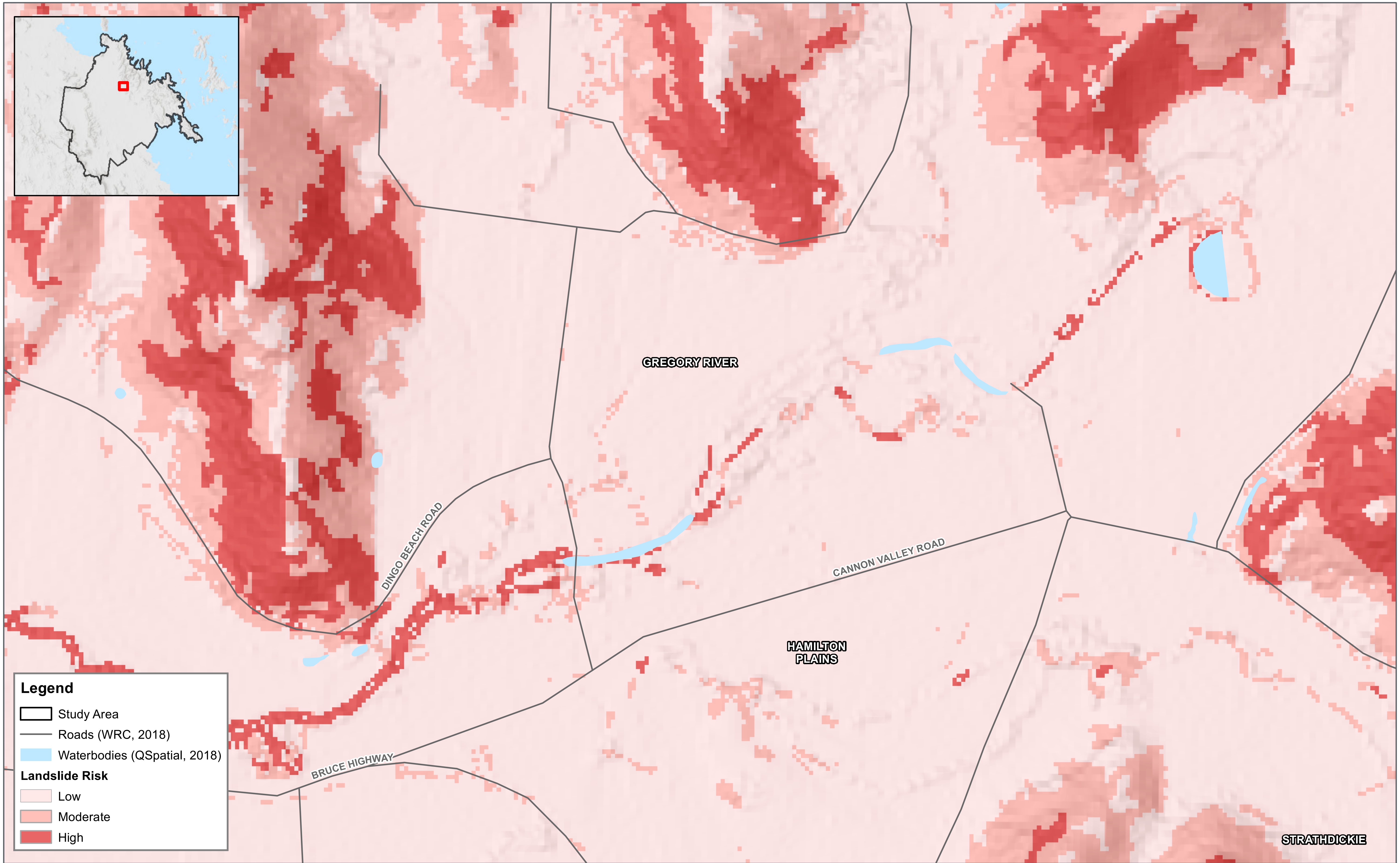
Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04



Whitsunday Regional Council

1:12,500 Scale at A3

Metres 0 100 200 300 400

Landslide Risk - Gregory River

WHITSUNDAY LANDSLIDE STUDY

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd (WOL)
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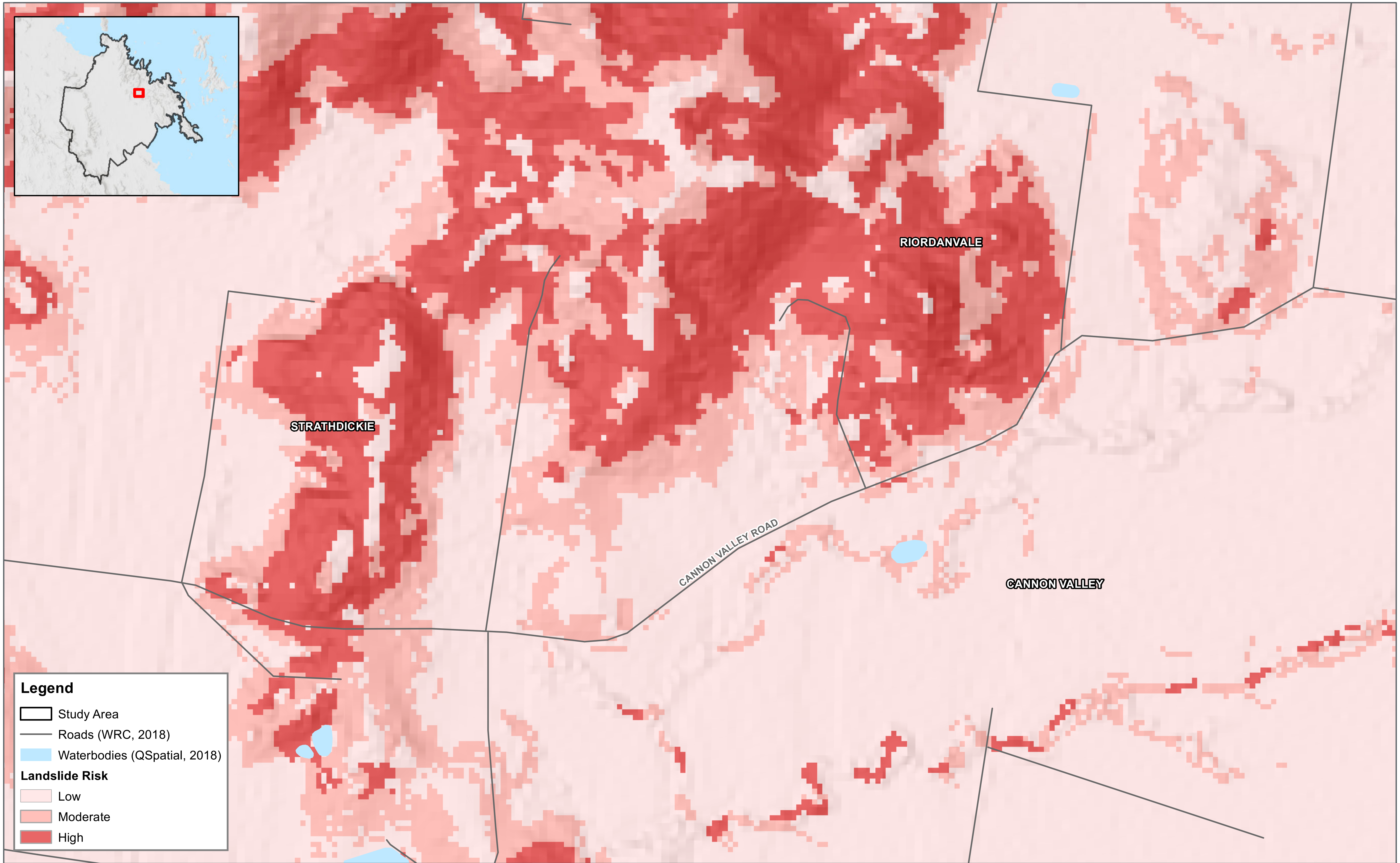
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04

Landslide Risk - Cannon Valley Road

WHITSUNDAY LANDSLIDE STUDY



1:10,000 Scale at A3

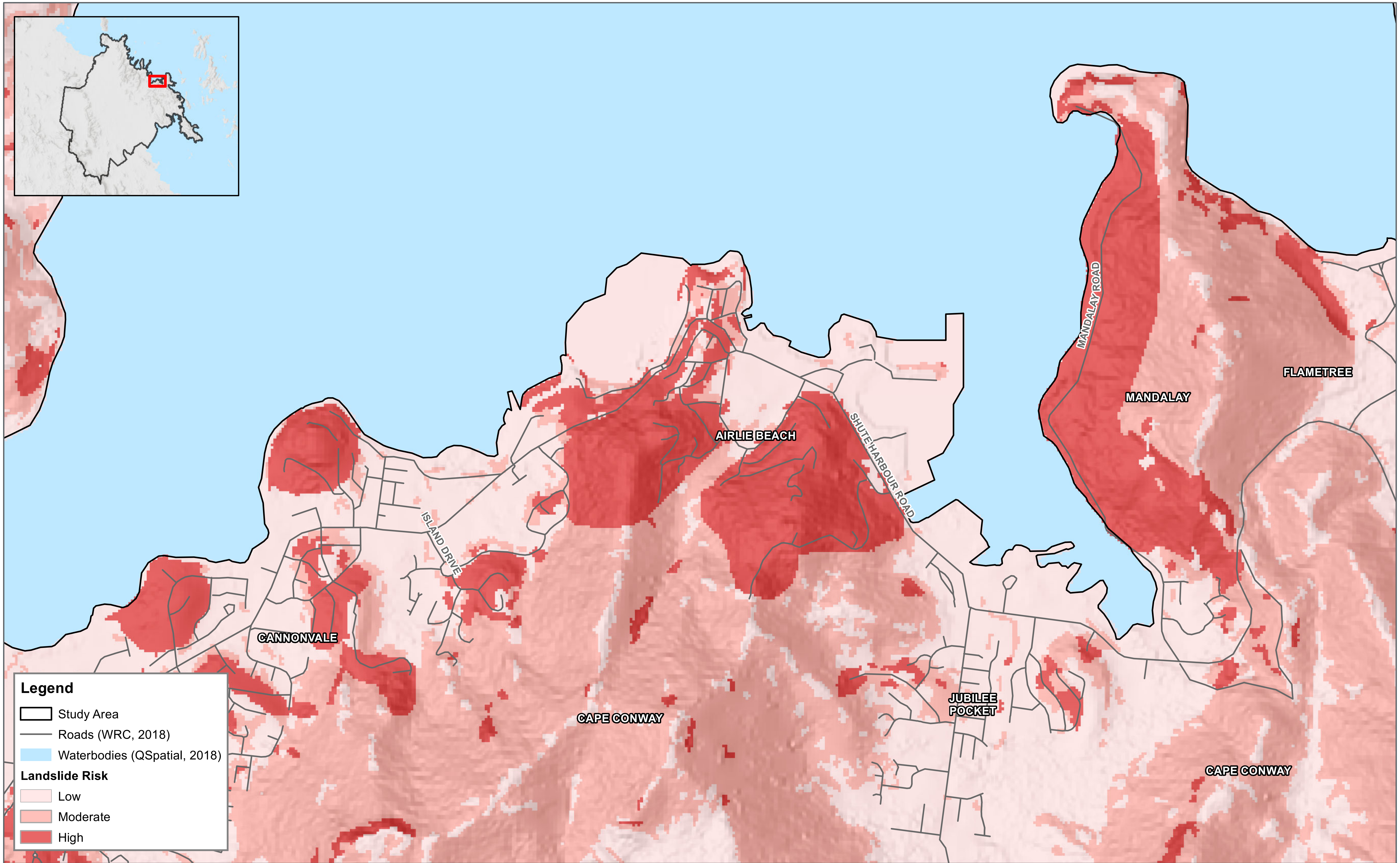
Metres

0 100 200 300 400

Whitsunday Regional Council

Cardno

Map Produced by Cardno NSW/ACT Pty Ltd (WOL)
Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04



Whitsunday Regional Council

1:20,000 Scale at A3

Landslide Risk - Airlie Beach

WHITSUNDAY LANDSLIDE STUDY

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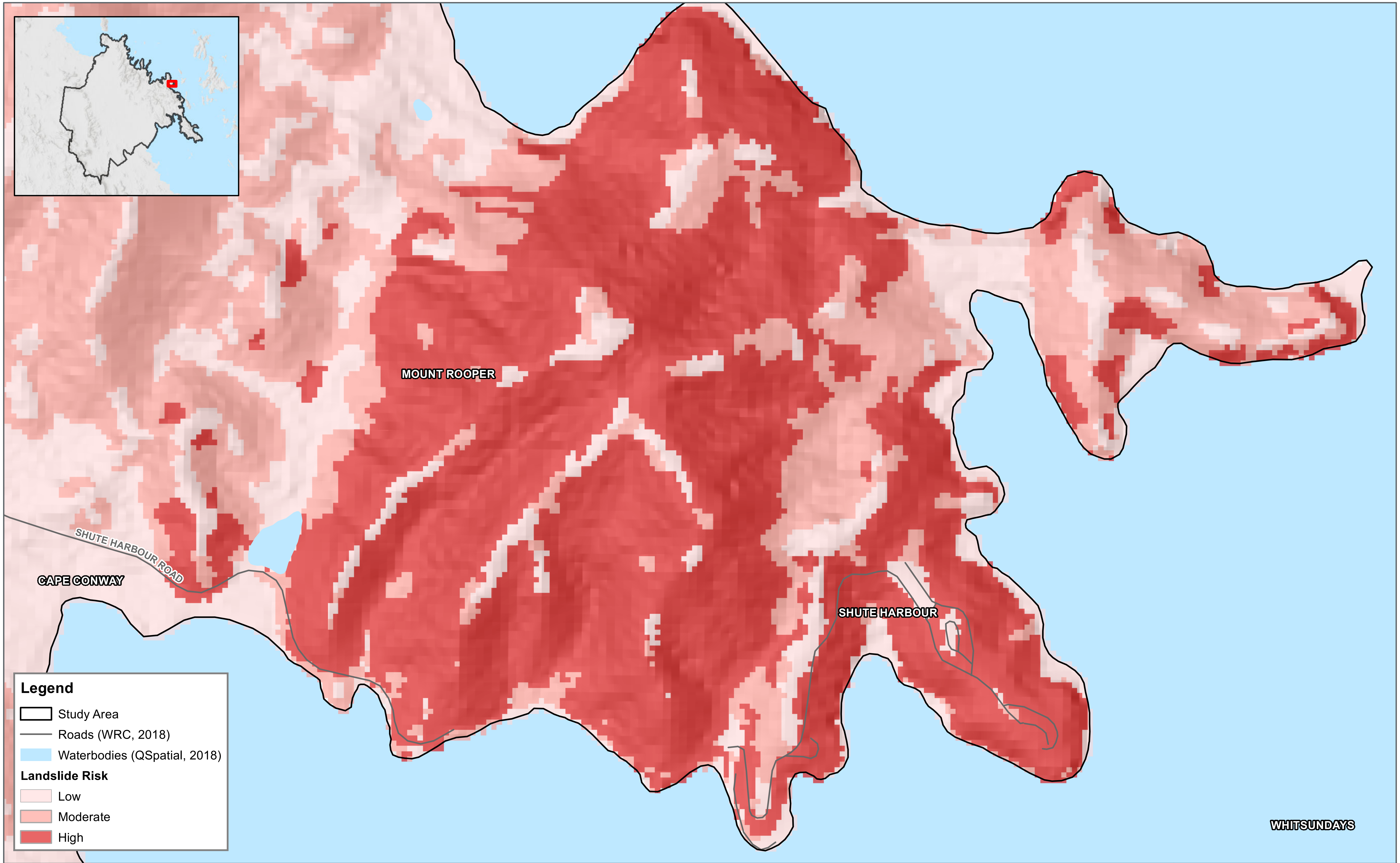
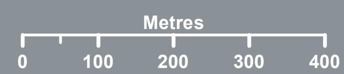
Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04



Whitsunday Regional Council

1:10,000 Scale at A3



Landslide Risk - Shute Harbour

WHITSUNDAY LANDSLIDE STUDY

N

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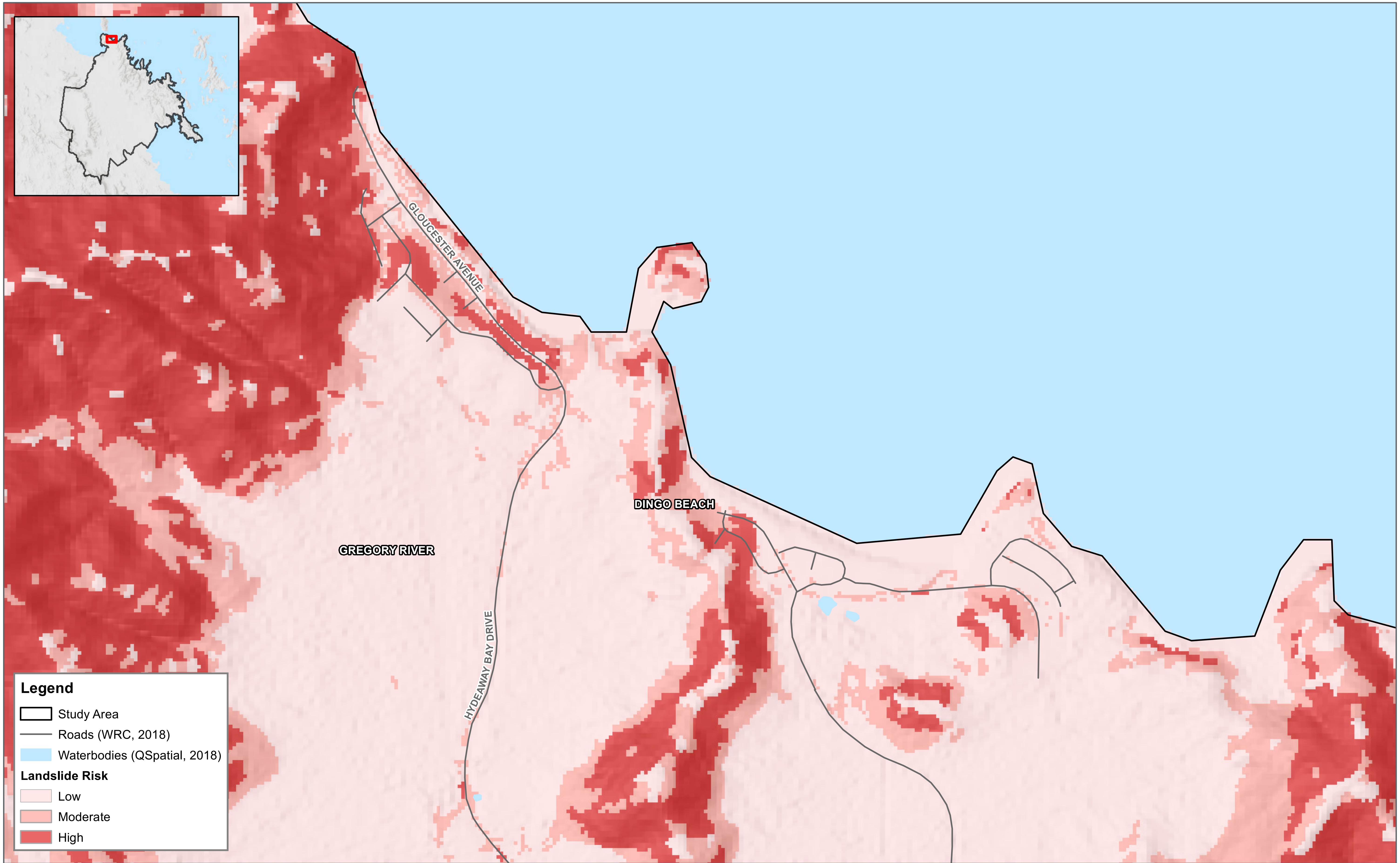
Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04



Whitsunday Regional Council

1:15,000 Scale at A3

Metres

0 100 200 300 400

Landslide Risk - Dingo Beach

WHITSUNDAY LANDSLIDE STUDY

N

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Date: 2019-05-09 | Project: M30261-03
Coordinate System: GDA 1994 MGA Zone 55
Map: M30261_GS-013-LandslideRisk3CatDDP.mxd 04