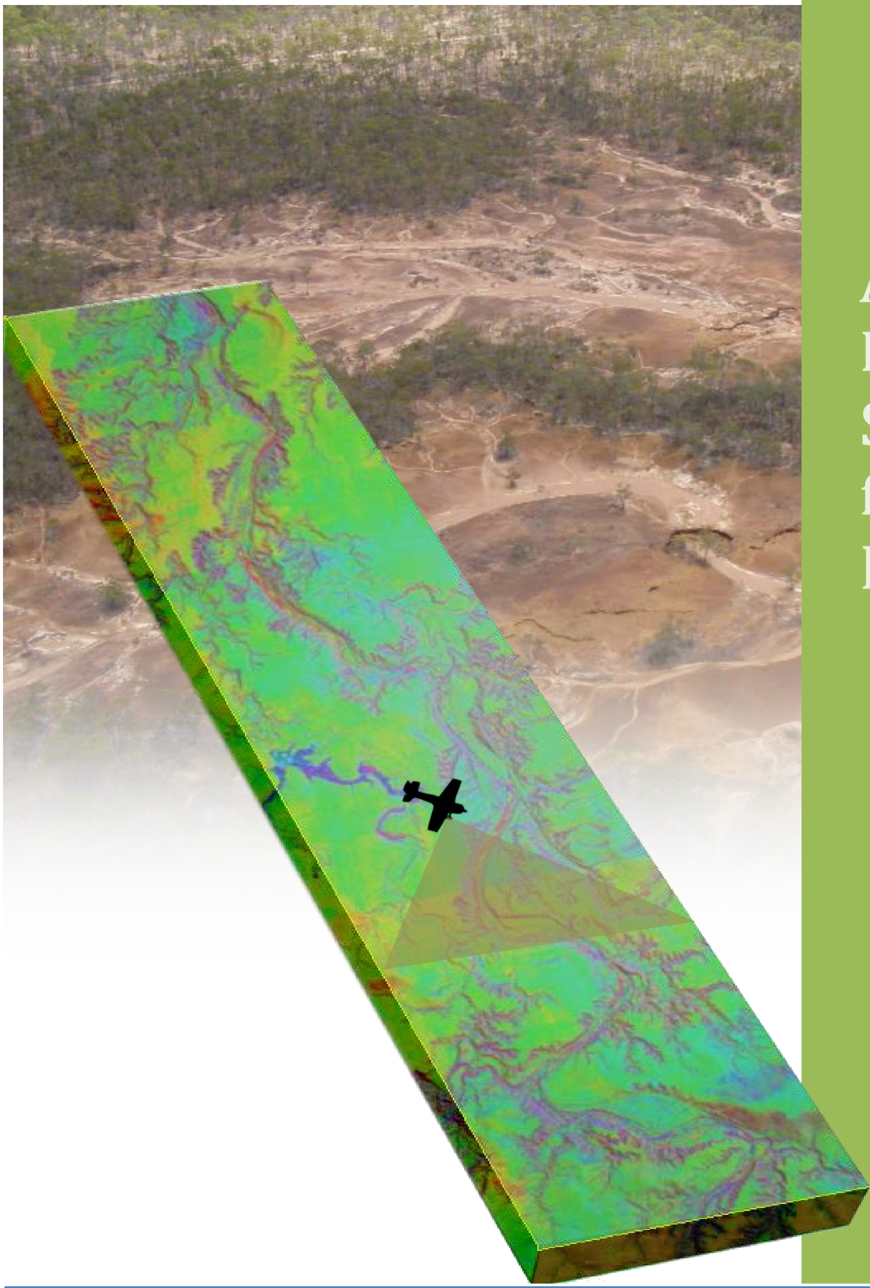

An Empirically-based Sediment Budget for the Normanby Basin

Andrew Brooks, John Spencer, Jon Olley, Tim Pietsch, Daniel Borombovits, Graeme Curwen, Jeff Shellberg, Christina Howley, Angela Gleeson, Andrew Simon, Natasha Bankhead, Danny Klimetz, Leila Eslami-Endargoli, Anne Bourgeault

Australian Rivers Institute

Griffith University

Appendix 13: LiDAR Block Summaries

Griffith UNIVERSITY

CARING FOR OUR COUNTRY

Appendix to the Final Report prepared for the Australian Government's Caring for our Country - **Reef Rescue initiative**

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http://www.capeyorkwaterquality.info

This Version: 3/03/2013

CAPE YORK WATER QUALITY

Appendix 13: LiDAR Block Summaries

Prepared by: Graeme Curwen, Andrew Brooks

1. Introduction

The empirical results from each LiDAR block is summarised here. Due to ground conditions, the format for each section follows roughly the same pattern, but significant details are drawn out where it will assist in building an accurate picture of the block.

2. Normanby LiDAR Block 2

Normanby LiDAR block 2 sits 20km inland, near the upper tidal limit, with the Bizant River being the main feature running through the middle of the 2009-2011 difference raster, see Fig 2.4. Elevation range within the area of the difference raster footprint is 0.5 to 10m. An active gully, known as "Bizant Gully" advanced approximately 40m between 2009 and 2011. This is an area that has been identified from sediment tracing as being a major contributor of sediment to PCB. An automated camera caught the progress of the gully.

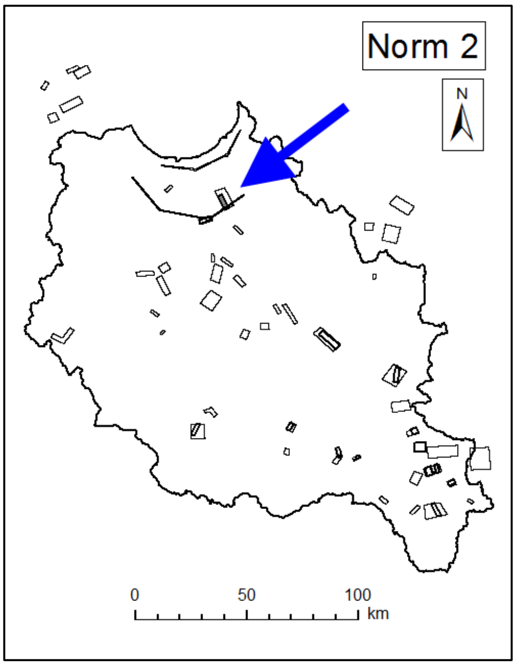


Fig 2.1: Block location

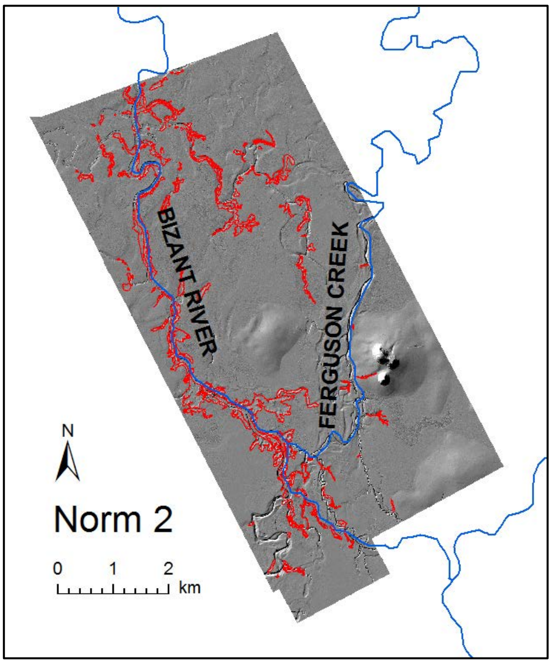


Fig 2.2: Digitising 2009 LiDAR

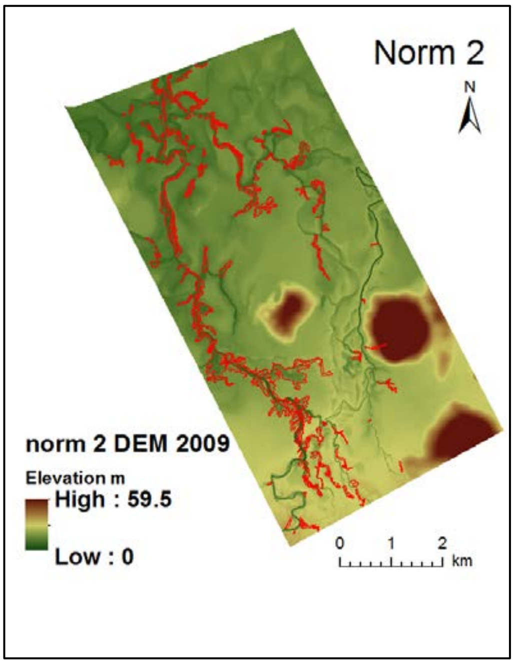


Fig 2.3: 2009 DEM

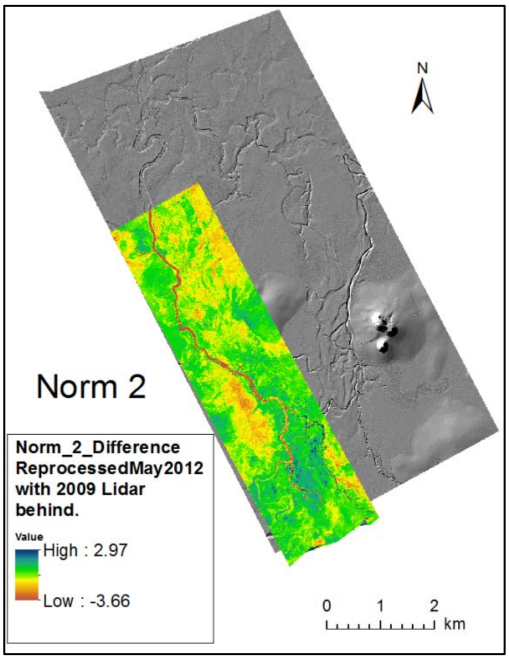


Fig 2.4: Difference raster footprint

Table 2.1: General statistics for Norm 2.

2009 LiDAR area	ha	4311
Reprocessed change raster area	ha	1260
Block elevation range	m	0.5 – 10.6
Number of LiDAR digitised features		136
Number of Google Earth mapped gullies		1

2.1 Alluvial and Colluvial geology

Most of the extent of repeat LiDAR for erosion detection sat on alluvial geology along the Bizant River, which was a distributary of the Normanby River. The split is in the south-eastern corner of Figure 2.5. The north-eastern corner of the block was colluvial geology, occupying approximately 15% of the area (Table 2.2).

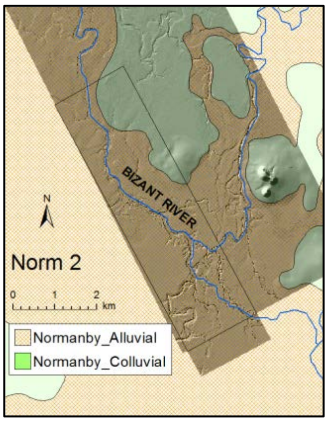


Figure 2.5: Alluvial and colluvial geology in Norm 2.

2.2 Google Earth mapped Gullies

Only one Google Earth (GE) gully was mapped in the extent of repeat LiDAR, this lay on alluvial geology. Several other GE gullies were in the nearby area, with several being on colluvial geology to the north of the block. A validation exercise mapping gullies from orthophoto found 7.3ha of visible gullies in the repeat LiDAR extent, the area of GE gullies was 0.5% of this figure, highlighting the very conservative estimation of bare ground gully area given by GE mapping.

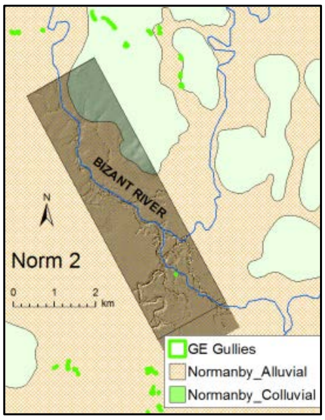


Figure 2.6: Location of Google Earth gullies

Table 2.2: Quantifying LiDAR and GE gullies in alluvial and colluvial geology.

Norm 2	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies ha	GE gullies as % of zone
Alluvial zone	1069	146.8	13.7	117.6	11.0	0.04	0.004
Colluvial zone	192	5.1	2.7	5.1	2.7	0	0

Approximately 14% of the alluvial area was digitised. Gullies were 11% of the alluvial area digitised, and channels were 3% of the area. Approximately 3% of the colluvial area was digitised, with all of this area being gullies.

2.3 LiDAR derived data

2.3.1 Horizontal adjustments

Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

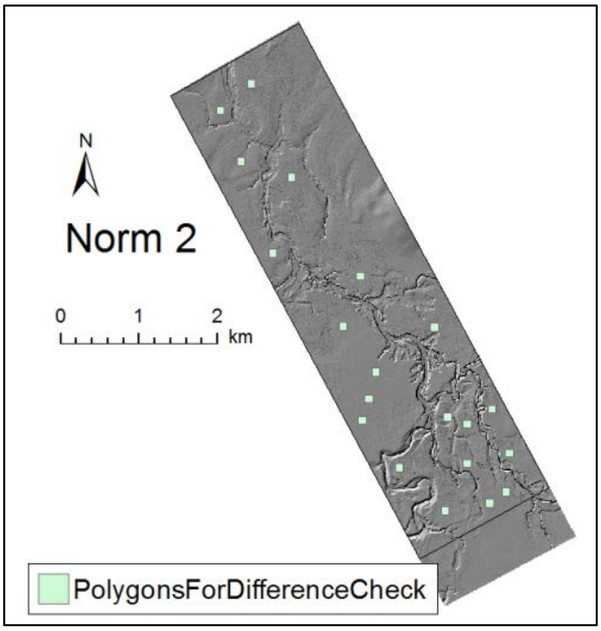
X,Y nudge (m)	1 , -1

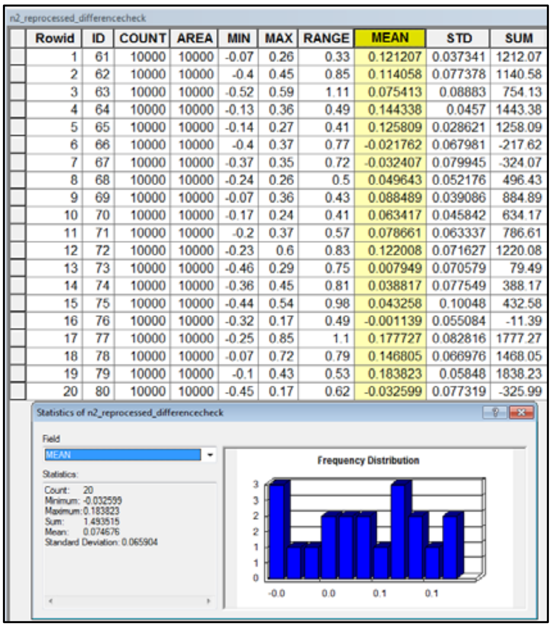
2.3.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.

Fig 2.7 and Table 2.3: Check for mean value of difference raster in flat areas.





n2_reprocessed_differencecheck

Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	61	10000	10000	-0.07	0.26	0.33	0.121207	0.037341	1212.07
2	62	10000	10000	-0.4	0.45	0.85	0.114058	0.077378	1140.58
3	63	10000	10000	-0.52	0.59	1.11	0.075413	0.08883	754.13
4	64	10000	10000	-0.13	0.36	0.49	0.144338	0.0457	1443.38
5	65	10000	10000	-0.14	0.27	0.41	0.125809	0.028621	1258.09
6	66	10000	10000	-0.4	0.37	0.77	-0.021762	0.067981	-217.62
7	67	10000	10000	-0.37	0.35	0.72	-0.032407	0.079945	-324.07
8	68	10000	10000	-0.24	0.26	0.5	0.049643	0.052176	496.43
9	69	10000	10000	-0.07	0.36	0.43	0.088489	0.039086	884.89
10	70	10000	10000	-0.17	0.24	0.41	0.063417	0.045842	634.17
11	71	10000	10000	-0.2	0.37	0.57	0.078661	0.063337	786.61
12	72	10000	10000	-0.23	0.6	0.83	0.122008	0.071627	1220.08
13	73	10000	10000	-0.46	0.29	0.75	0.007949	0.070579	79.49
14	74	10000	10000	-0.36	0.45	0.81	0.038817	0.077549	388.17
15	75	10000	10000	-0.44	0.54	0.98	0.043258	0.10048	432.58
16	76	10000	10000	-0.32	0.17	0.49	-0.001139	0.055084	-11.39
17	77	10000	10000	-0.25	0.85	1.1	0.177727	0.082816	1777.27
18	78	10000	10000	-0.07	0.72	0.79	0.146805	0.066976	1468.05
19	79	10000	10000	-0.1	0.43	0.53	0.183823	0.05848	1838.23
20	80	10000	10000	-0.45	0.17	0.62	-0.032599	0.077319	-325.99

2.4 Statistics

Table 2.4: Vertical adjustment of values in difference raster.

Layer	min	max	Mean	s.d.
Norm_2_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-3.66	2.97	-0.052	0.14
Norm_2 with edge effect removed	-3.66	2.97	-0.052	0.14
Areas of minimal change	-0.03	0.18	0.075	0.07
N2_Diff_adjusted	-3.61	2.89	-0.025	0.14

After adjusting for vertical offset between 2009 and 2011 DEMs, the mean value of difference raster cells on flat areas was 2.5 cm.

2.5 Values of change raster filtered to remove noise on floodplain.

Table 2.5: Values filtered to remove noise from floodplain.

raster	Values filtered
erosion	0 to -0.2
deposition	0 to 0.2

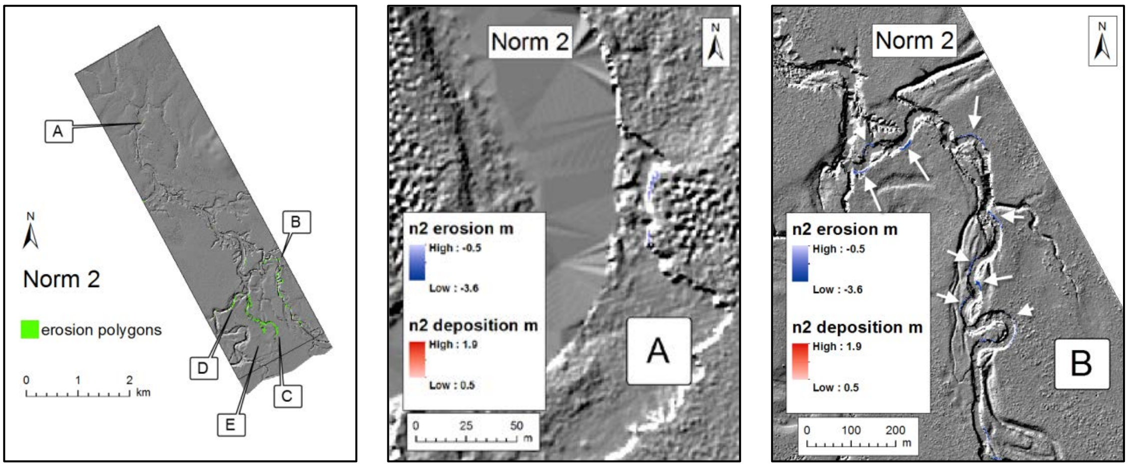
2.6 Aggressive filtering of erosion and deposition data

Table 2.6: Area of erroneous erosion and deposition removed by hand editing.

	Area erosion ha	Area deposition ha
Prior to hand thinning	6.80	0.61
After hand thinning	1.22	0.05

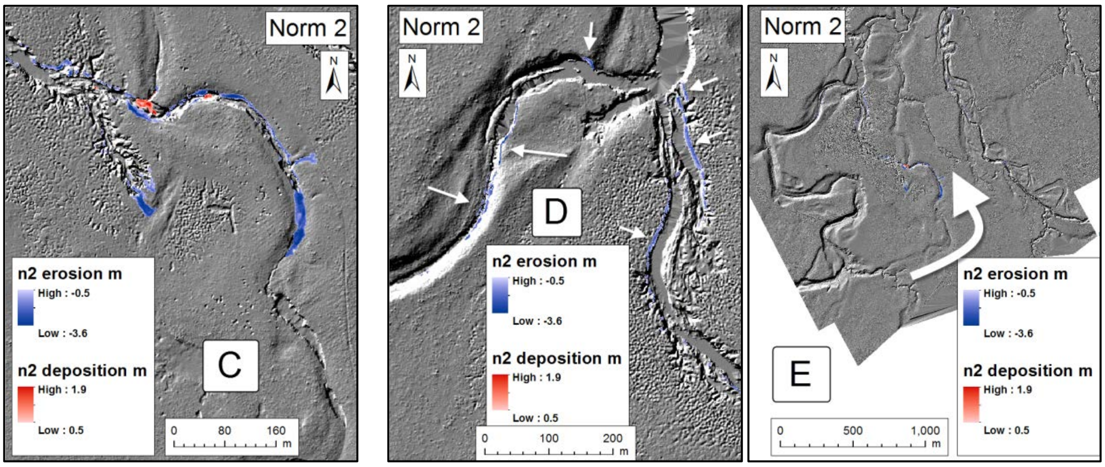
2.7 Observations

Figure 2.8: Location diagram and 5 observation diagrams of erosion in block 2.



Location A: Detectable erosion along the main channel in the tidal reach was minimal, restricted to a small headland.

Location B: The channel system between the Bizant River and Furguson Creek was eroding the outside bends of meandering loops, increasing the radius of curves. Deposition on the inside of bends was not detected.



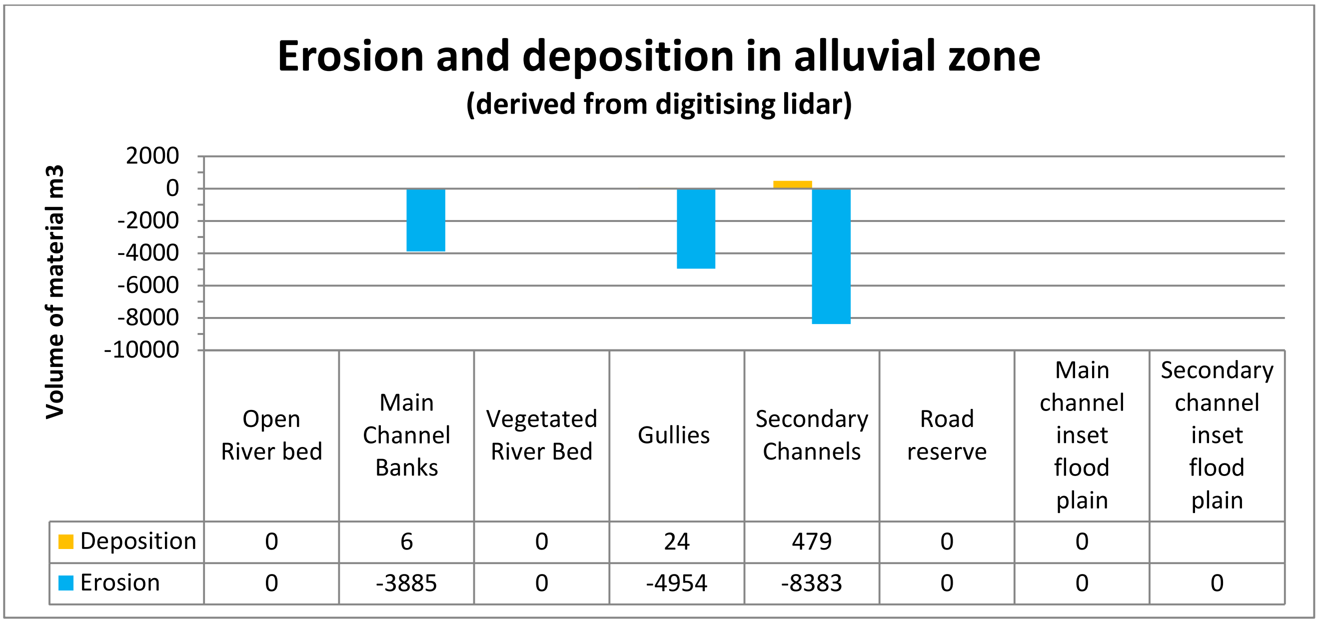
Location C: New gully formation into flood plain from overland flow in the gully on the left of the picture. On the right can be seen active channel widening and deepening following an existing water course. Material has been deposited on the inside of a bend 400m below the active head wall.

Location D: The upper limit of tidal flow occurs here. The main channel comes in from the left and is larger and more continuous than the channel with ponded water that goes to the bottom right of the picture. Bank erosion has occurred in both channels, but a larger amount has occurred in the right hand channel, which has the very active gully extension at its head (see picture C)

Location E: Overview of main channel and direction of overland flood flow that is driving gully erosion and channel widening in “Bizant Gully”.

2.8 Erosion and deposition

Table 2.7: Erosion and deposition in landscape units in block 2.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Deposition	0	6	0	24	479	0	0	
Erosion	0	-3885	0	-4954	-8383	0	0	0

- Gully extension between 2009 and 2011 resulted in nearly 5000m^3 of material being lost from block 2.
- Though gully extension was particularly active, up to 20m per year, the volume of material eroded from secondary channel widening and deepening was significantly more, at 8383m^3 over 2 years.
- Erosion from main channel banks near the upper tidal limit, 3885m^3, was of a similar magnitude to the loss from gullies.

2.9 Comparison of alluvial gullies to colluvial gullies

Table 2.8: Comparison of erosion and deposition in alluvial and colluvial geology.

Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
117.7	24	-4950	-21	5	0	0	0

All erosion detected in gullies by LiDAR difference in block 2 was in alluvial geology. The volume of material lost per year was approximately 2500m^3; measured deposition in gullies was extremely minor in comparison, being 12m^3 per year.

Though two gullies, each of approximately 2.5 hectares, were in colluvial geology, no erosion was measured here.

2.10 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

Table 2.9: Comparison of erosion activity in LiDAR and Google Earth gullies.

	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial gullies	117.6	-4953.5	-21
GE alluvial gullies	0.04	0	0

All measured erosion activity was in LiDAR gullies, no erosion was measured in the single Google Earth gully in the extent of the difference raster.

2.11 Gully Expansion 2009 – 2011

The largest patch of erosion was 0.15ha, which occurred not in a gully, but as widening and deepening of an existing, though very small, channel bed; see Figure 2.8 - location C, right hand channel. In the nearby vicinity was the rapidly advancing “Bizant Gully” which increased in area by 0.6ha in 2 years. Across the block, there were 110 locations that had measurable erosion of gully head walls, or erosion of channel banks into floodplain. The average area of expansion was 36 m^2, see table 2.10.

Table 2.10: Area of expansion of gullies between 2009 and 2011.

Gully Expansion 2009 - 2011	
Number of gully expansion locations	110
Sum area of gully expansions ha	0.4
Mean area of expansion m2	36

2.12 Landscape Classification

Though alluvial gullies were the dominant erosion feature in block 2, 117.6 ha, the volume of erosion from them was 40% less than the volume of erosion that came from 10.4 ha of secondary channel in the south of the block, (table 2.11).

Due to the flat topography in block 2, inset flood plains were not present. It has been seen that flood flows can wash over the area in the south of the block, characterised by a series of finger like extensions of gully and secondary channel migrating south eastward.

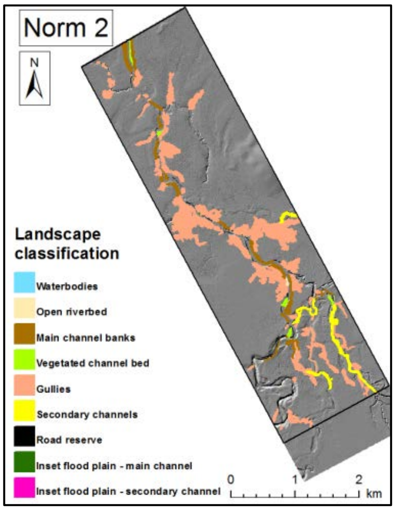
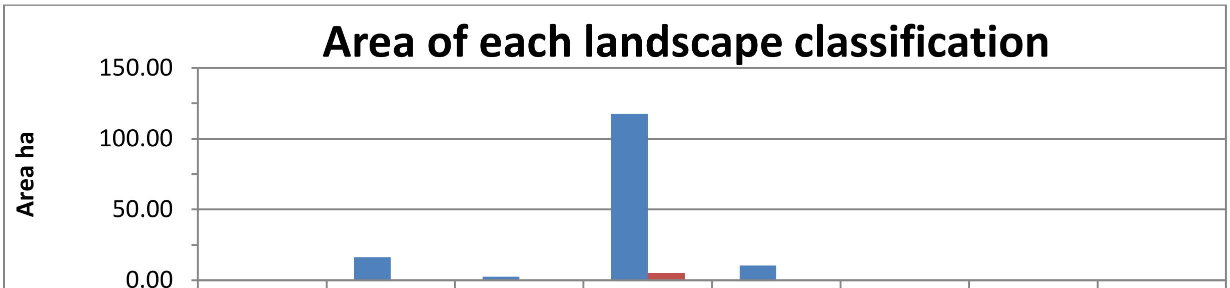


Figure 2.9: Landscape classification in block 2.

Table 1: Area of each landscape classification in block 2.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Alluvial ha	0.36	16.38	2.53	117.57	10.35	0.00	0.00	0.00
Colluvial ha	0	0	0	5	0	0	0	

2.13 Historical air photos

No historical air photos were available in Normanby block 2.

2.14 Timelapse Photography of Bizant Gully

3. Normanby LiDAR Block 4

Normanby LiDAR block (Norm 4) lies approximately 15km upstream of the junction of the East and West Normanby Rivers, with an elevation range of 118 to 264 m. LiDAR from 2009 was a rectangular footprint, but LiDAR flown in 2011 had an H shaped footprint to focus on alluvial areas. Features digitised on the original rectangular footprint have been clipped to the H shaped difference raster.

Active erosion was seen as linear gullies extending across alluvial surfaces towards colluvial slopes, incision of existing gully floors, and secondary channel widening. The 3rd highest source of measured erosion came from road drainage. Minimal erosion was detected in the East and West Normanby main channels.

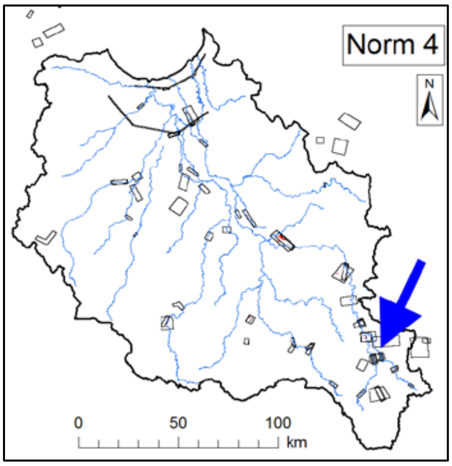


Fig 4.1: Norm 4 location.

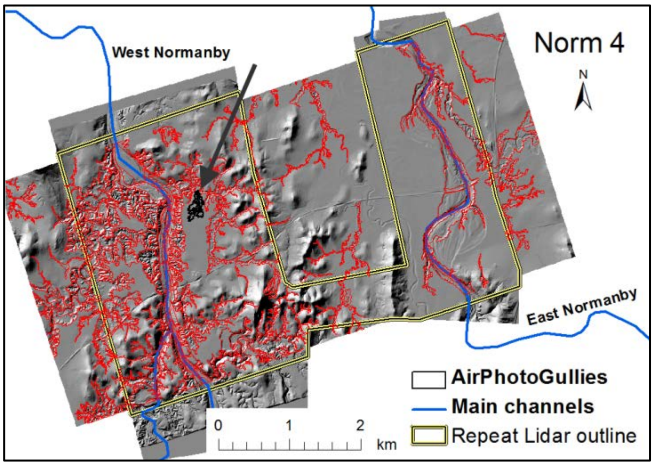


Fig 4.2: Digitising on 2009 LiDAR

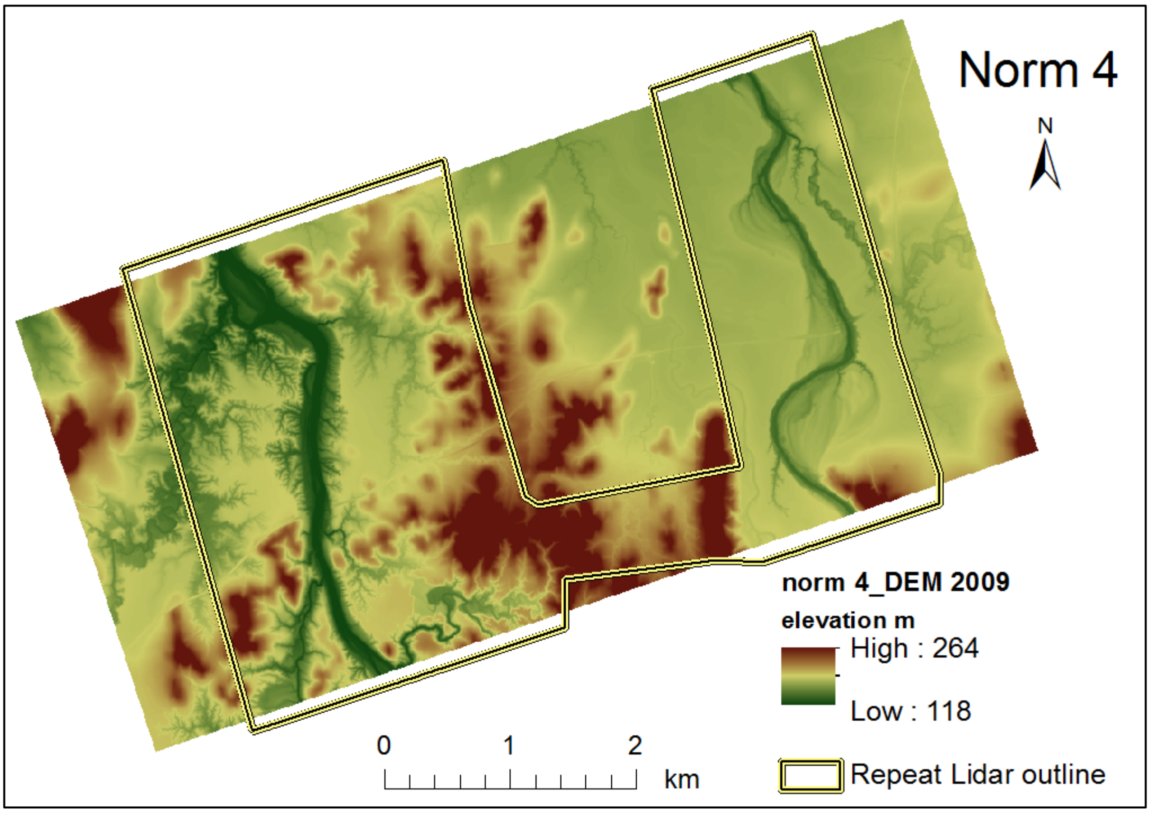


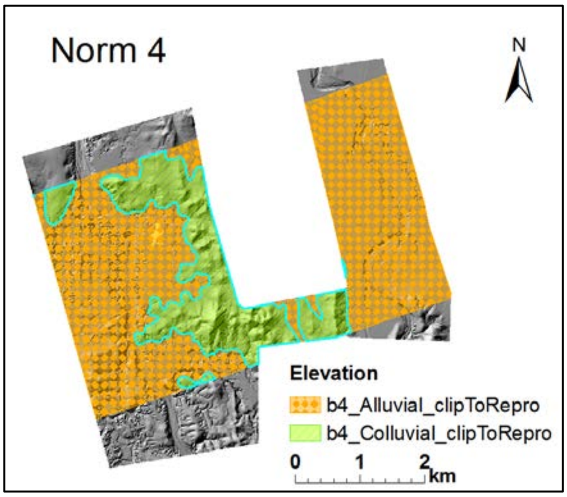
Fig 4.3: 2009 DEM.

Table 4.1: General statistics for Norm 4.

2009 LiDAR area	ha	4311
Reprocessed change raster area	ha	1662
Block elevation range	m	116 -263
Number of LiDAR digitised features		556
Number of Google Earth mapped gullies		114

3.1 Alluvial and Colluvial geology

Alluvial geology occupied 64% of Norm 4, with a range of hilly colluvial country rising to 120m above the valley floor separating the flood plains of the East and West Normanby rivers. The accuracy of the alluvial/colluvial boundary was checked against a 3° slope raster derived from the 30m DEM. It would appear the colluvial boundary should include additional land in the south western corner of the block, seen as elevated country in the DEM (Fig 4.3).



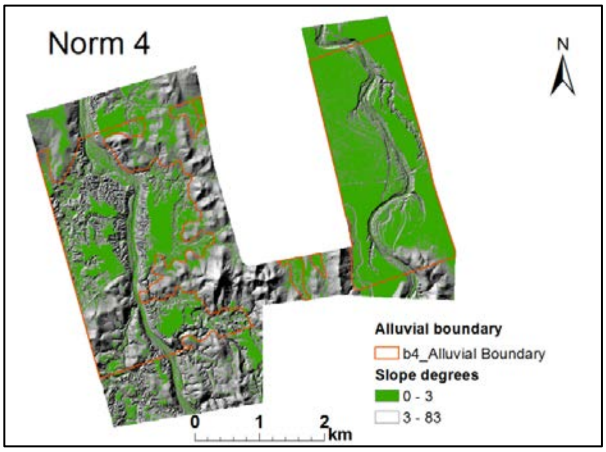


Figure 4.4: Alluvial and colluvial geology in Norm 4.

3.2 Google Earth gullies

Location of gullies mapped from Google Earth is shown in Fig 4.5. Density of GE gullies in NORM 4 was 0.019ha/km^2, which was the 10th ranked block of 13, with only 3 other blocks having a higher density of GE gullies. As can be seen in Fig 4.5, the location of GE gullies is mainly on alluvial geology, and predominantly in the West Normanby valley.

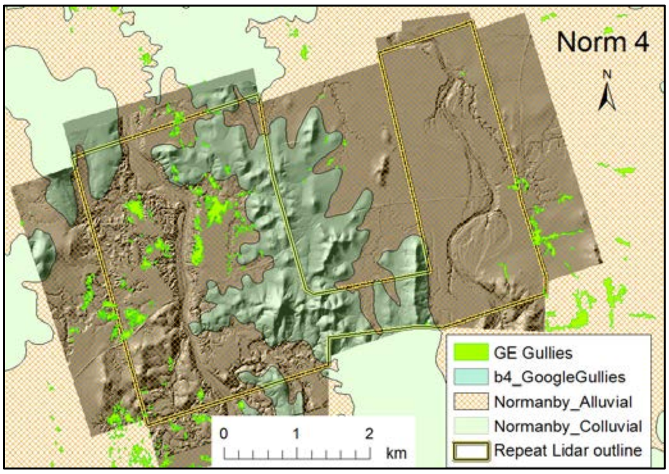


Figure 4.5: Location of Google Earth gullies in Norm 4 and surrounding area

Table 4.2: Quantifying LiDAR and GE gullies in alluvial and colluvial geology.

Norm 2	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies ha	GE gullies as % of zone
Alluvial zone	1169.3	475.0	40.6	239.0	20.4	27.5	2.4
Colluvial	392.8	37.3	9.5	35.5	9.0	1.9	0.5

zone							

It was found in Norm 4 that the area of gullies visible from vegetation penetrating LiDAR, 274ha, was approximately 10 times greater than that mapped from Google Earth, approximately 30ha. Not only was GE mapped gullies under representing the real area, but a problem highlighted in Norm 4 was that most erosion was occurring under vegetation, beyond the perimeter of GE mapped gullies.

It was found that 41% of the alluvial zone in Norm 4 was eroded by channels or gullies, and that alluvial gullies accounted for half of this area. Compared with this, the colluvial area had 9.5% of its area eroded, and the majority of this figure, 9%, was gully erosion.

3.3 LiDAR derived data

3.3.1 Horizontal adjustments

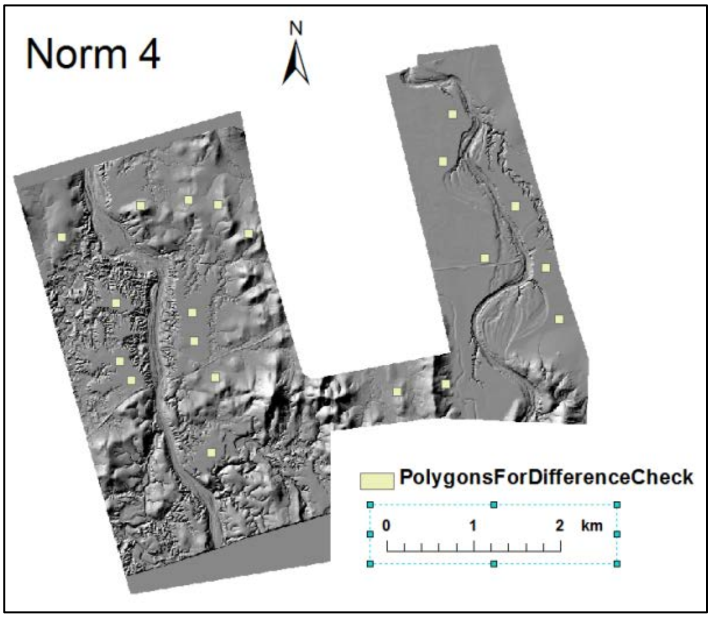
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

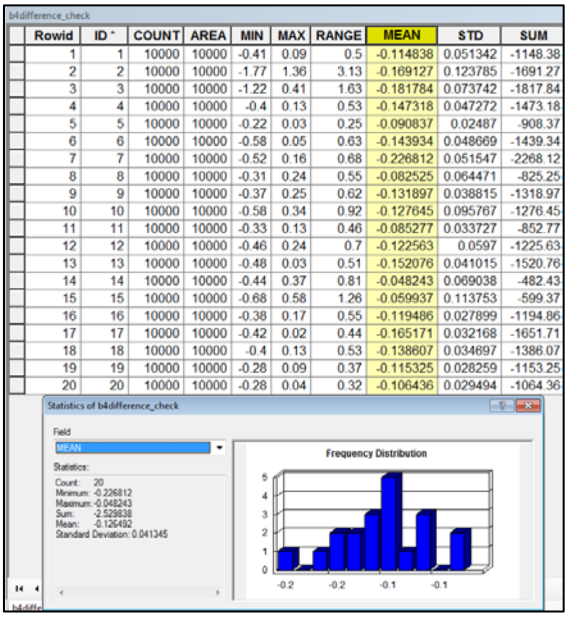
X,Y nudge (m)	1 , -1

3.3.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.




b4difference_check

Rowid	ID *	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	1	10000	10000	-0.41	0.09	0.5	-0.114838	0.051342	-1148.38
2	2	10000	10000	-1.77	1.36	3.13	-0.169127	0.123785	-1691.27
3	3	10000	10000	-1.22	0.41	1.63	-0.181784	0.073742	-1817.84
4	4	10000	10000	-0.4	0.13	0.53	-0.147318	0.047272	-1473.18
5	5	10000	10000	-0.22	0.03	0.25	-0.090837	0.02487	-908.37
6	6	10000	10000	-0.58	0.05	0.63	-0.143934	0.048669	-1439.34
7	7	10000	10000	-0.52	0.16	0.68	-0.226812	0.051547	-2268.12
8	8	10000	10000	-0.31	0.24	0.55	-0.082525	0.064471	-825.25
9	9	10000	10000	-0.37	0.25	0.62	-0.131897	0.038815	-1318.97
10	10	10000	10000	-0.58	0.34	0.92	-0.127645	0.095767	-1276.45
11	11	10000	10000	-0.33	0.13	0.46	-0.085277	0.033727	-852.77
12	12	10000	10000	-0.46	0.24	0.7	-0.122563	0.0597	-1225.63
13	13	10000	10000	-0.48	0.03	0.51	-0.152076	0.041015	-1520.76
14	14	10000	10000	-0.44	0.37	0.81	-0.048243	0.069038	-482.43
15	15	10000	10000	-0.68	0.58	1.26	-0.059937	0.113753	-599.37
16	16	10000	10000	-0.38	0.17	0.55	-0.119486	0.027899	-1194.86
17	17	10000	10000	-0.42	0.02	0.44	-0.165171	0.032168	-1651.71
18	18	10000	10000	-0.4	0.13	0.53	-0.138607	0.034697	-1386.07
19	19	10000	10000	-0.28	0.09	0.37	-0.115325	0.028259	-1153.25
20	20	10000	10000	-0.28	0.04	0.32	-0.106436	0.029494	-1064.36

Figure 4.6: location of polygons for check to difference raster, and statistics.

Table 2: Statistics from adjusting difference raster for bias.

Layer	min	max	Mean	s.d.

Norm_4_Difference_2009-2001_Reprocessed.tif (as supplied by Terranean)	-15.59	38.29	-0.21	0.41
Extract_tif1 (edges trimmed)	11.83	8.01	-0.17	0.15
Extract_tif1 (sampled area of minimal change)	-0.23	-0.05	-0. 126	0.04
NORM 4_Diff_adjusted	-11.70	8.14	-0.045	0.15

The mean cell value of the adjusted difference raster was - 4.5 cm.

Table 3: Values of change raster filtered to remove noise

raster	Values filtered
erosion	-0.2 to 0
deposition	0 to 0.2

3.4 Observations

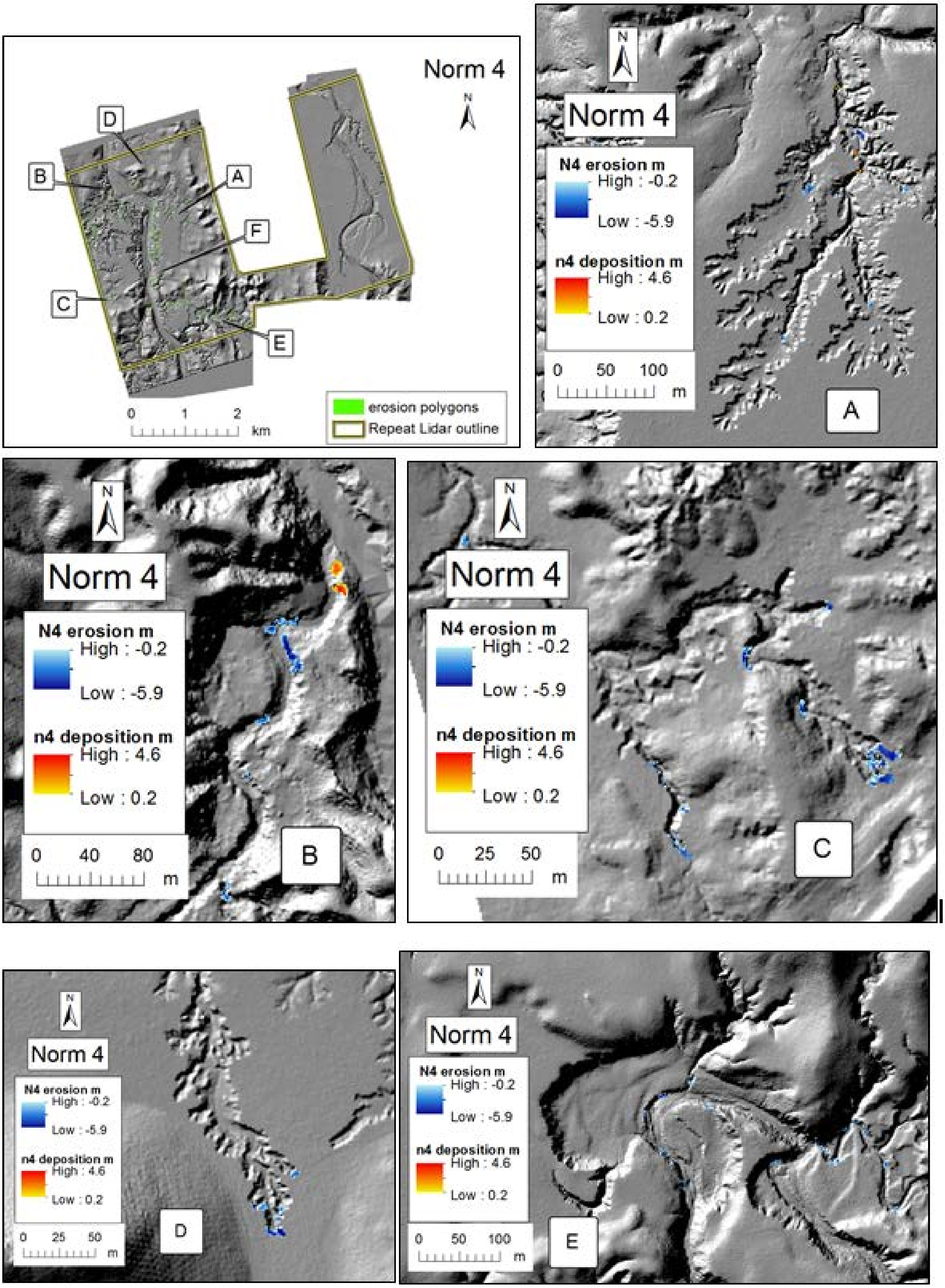


Figure 4.7 Observation of erosion patterns in Norm 4.

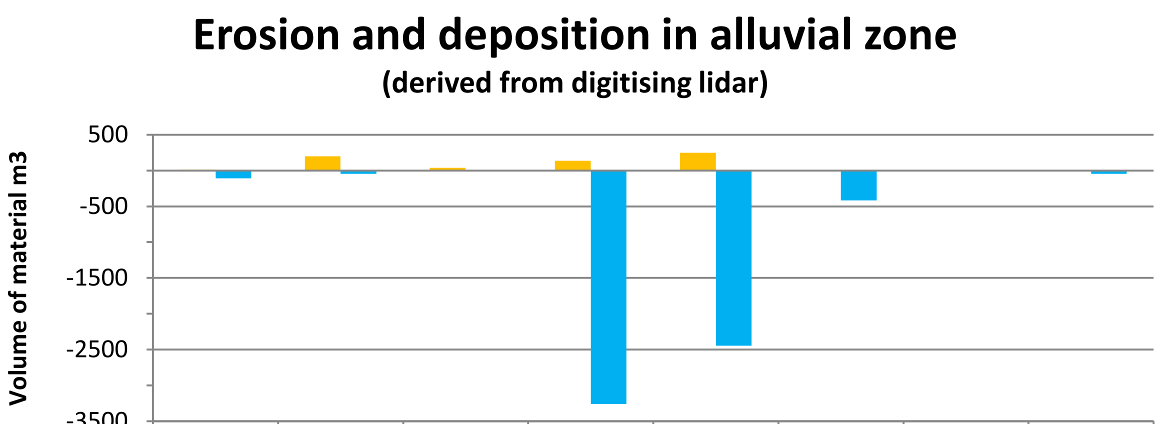
Location A: A large gully had minimal erosion activity at perimiter head walls, but incision channels advancing in at least 5 locations were carving through the gully floor, advancing between 6 and 13 m between 2009 and 2011.

Location B: Erosion in a secondary channel, with deposition of material near the confluence with the West Normanby main channel.

Location C: Gully advance through hummocks, and erosion of the sides of the exit channel.

Location D: A gully advancing through alluvial material between two colluvial slopes.

Location E: Inset flood plains can be seen at different levels in this secondary channel. Outsides of bends are eroding and actively cutting new levels into inset flood plains.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Deposition	12	199	39	139	249	0	0	0
Erosion	-107	-45	-1	-3258	-2445	-415	0	-45

Figure 4.8: Large volumes of erosion came from gullies and secondary channels. The contribution from road drainage, 415 m^3 was on a par with the second largest producing unit in Norm 4, a 700m section of secondary channel with active bank erosion, see figure 4.7 location E.

3.5 Comparison of alluvial gullies to colluvial gullies

Table 4 Alluvial and colluvial gullies had a similar rate of erosion when expressed as yield per hectare per year, but colluvial gullies were an order of magnitude less in area and volume of erosion than alluvial gullies.

Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
223.2	138	−3257	−14	31.3	0	−427	−14

3.6 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

Table 2.9: The area of bare ground gullies captured from GE mapping was approximately 10% of the gully area seen in LiDAR, but the volume of erosion from bare ground (GE) gullies was 20% of the volume measured from alluvial gullies from LiDAR imagery. This supports field observations of erosion advancing under vegetation.

	Area ha	Erosion m^3	Yield m^3/ha/yr
LiDAR alluvial gullies	223.20	-3257.54	-13.97
GE alluvial gullies	27.98	-680.49	-11.61

3.7 Gully Expansion 2009 – 2011

Table 2.10: Area of expansion of gullies between 2009 and 2011.

Gully Expansion 2009 - 2011	
Number of gully expansion locations	69
Sum area of gully expansions ha	113.6
Mean area of expansion m2	1.7

3.8 Landscape Classification

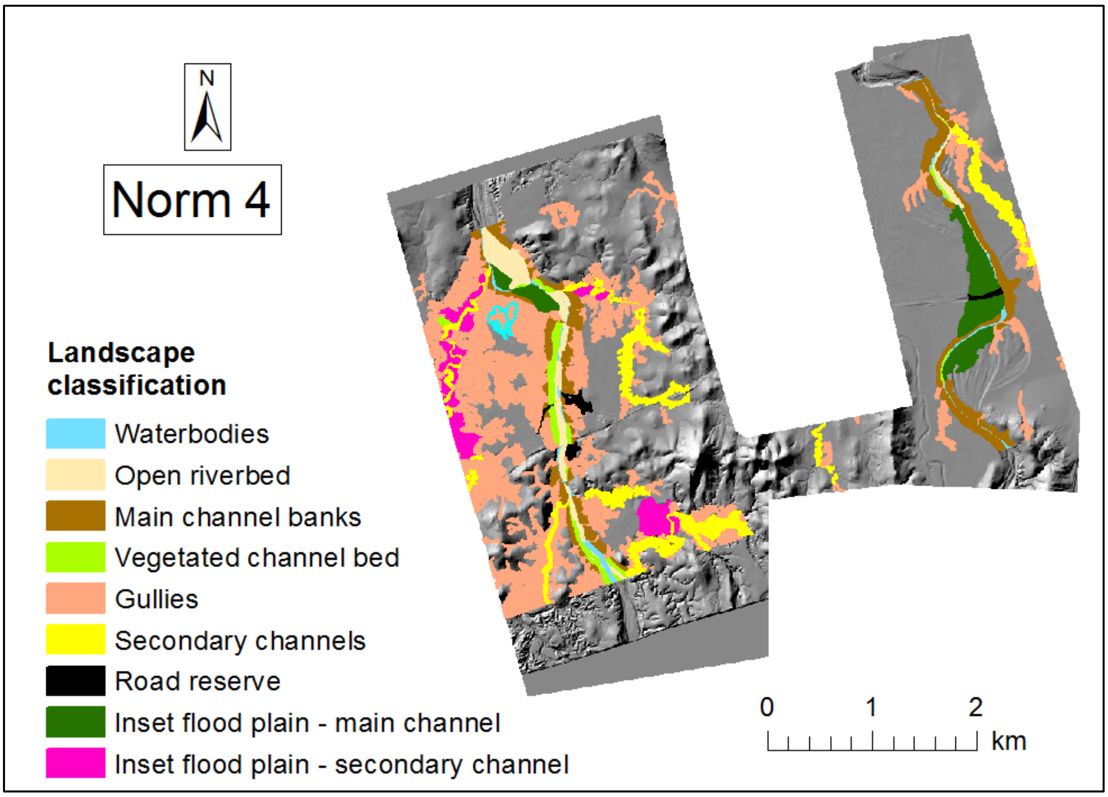
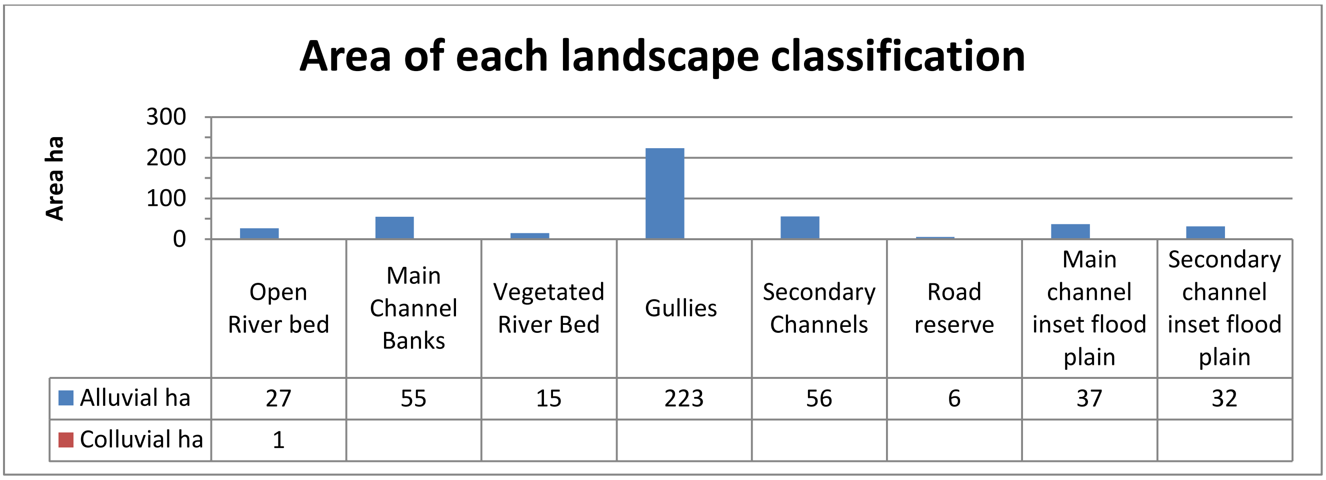


Figure 4.9: All 9 landscape classes are represented in Norm 4. Approximately half of the block was alluvial gullies. Main channel banks and secondary channels had similar areas of 12 to 13% of total area. Inset flood plains along main channels and secondary channels also had a similar area, being 7 to 8% of total area.



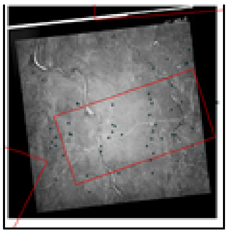
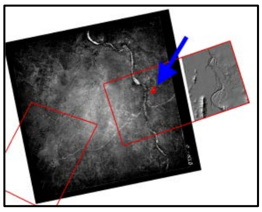
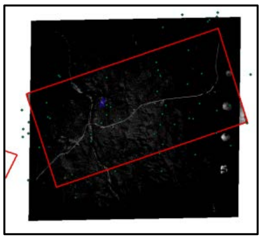
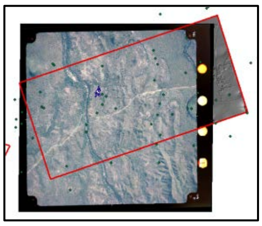
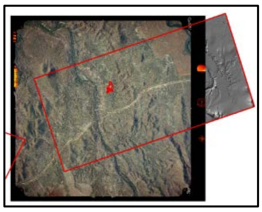
	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Alluvial ha	27	55	15	223	56	6	37	32
Colluvial ha	1							

Figure 4.10: Area of each landscape classification in block 4.

3.9 Historical air photos

One gully on Norm 4 was readily identified in air photos from 1952, 1957, 1982, 1987 and 1994; which was a record for time slices for this section of the Normanby project.

Table 2.11: Meta data for historical air photos covering Norm 4.

Image date	Photo ID	Scale	Flying height	RMS error	Air photo relative to 2009 LiDAR block
1/01/1952	QAP0150_146.tif	23900	12750ft	5.25352	
1/01/1957	QAP0730_015.tif	39600	20000ft	0.000	
1/01/1982	QAP4071_105.tif	24900	4600m	2.45737	
1/01/1987	qap_4111_182.tif	25000	4310m	0.00002	
19/10/1994	QAP5321_196.tif	25000	4630m	6.44978	

The gully to the east of the West Normanby was approximately 450m in length and 230m at its widest. The head scarp was 1.5- 2m below the surrounding flood plain, with a multi lobed incision about 2m deep advancing along several drainage lines.

Minimal erosion was measures at head walls, but the incisions advanced at up to 12m between 2009 and 2012.

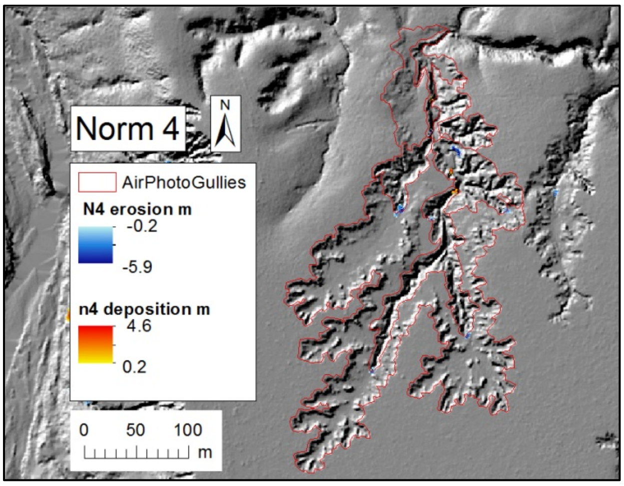


Figure 4.11: Incision of gully floor is the main erosion activity in the gully identified from air photos.

3.10 Historical gully extent

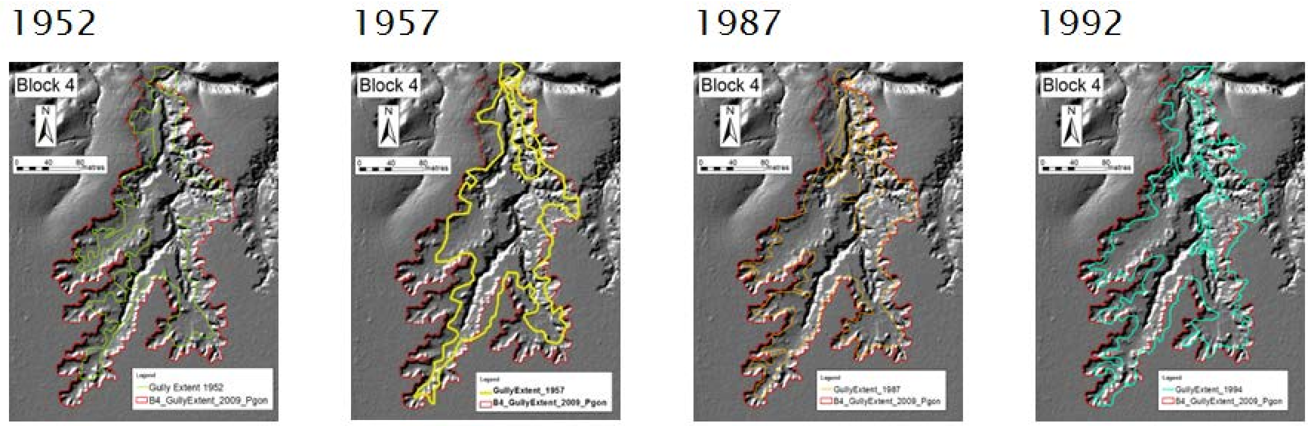


Figure 4.12: Incision of gully floor was not seen in the 1952 image, but between 1957 and 2009 the advance of the longest incision was 218 m, an average of 4 m per year. In comparison, head wall advance at different locations was between 20 and 40 m, an average annual advance of less than 1 m.

Table 2.12: A remarkably consistent rate of erosion was calculated over 5 decade and 2 decade intervals from air photos, with a small spike in rate over the shortest interval, from 1994 to 2009. The gully did not expand in area between 2009 and 2011, but erosion from incisions along drainage lines produced 19 m^3/ha/yr, approximately one fifth of the historical rate. It is possible the forces driving gully expansion have reduced, but the gully floor has not yet reached a stable equilibrium.

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

4. Norm LiDAR Block 5

Normanby LiDAR block 5 (Norm 5) covered the junction of the East and West Normanby rivers, which was approximately 250 km inland. The alluvial plains were at 80m elevation, surrounding hills rose to 305 m. Surprisingly few really active erosion sites were found in this block despite there being massive gully complexes visible in the orthophoto. Seven gullies were able to be tracked through time with historical air photos.

A very extensive and broad secondary channel occupied the western part of the block. This appeared to have significant amounts of bank erosion.

Fig 5.1: N5 location

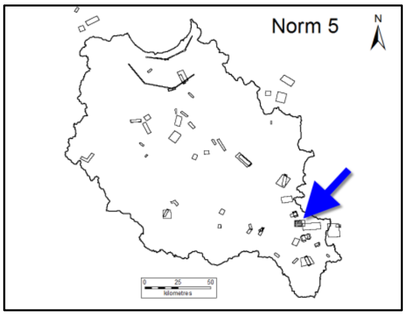


Fig 5.2: Digitising on 2009 LiDAR.

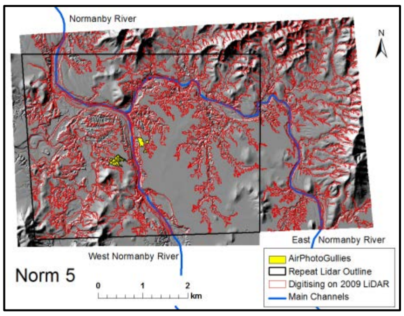


Fig 5.3: 2009 DEM.

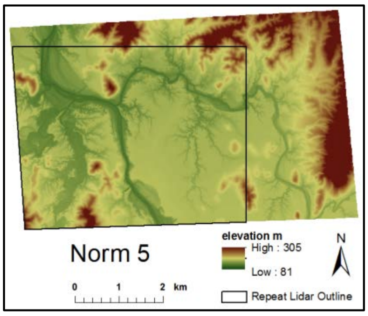


Table 5.1 General statistics for Norm 5.

2009 LiDAR area (ha)	3485
Reprocessed change raster area (ha)	2097
Reprocessed extent elevation range (m)	280 – 270
Number of LiDAR digitised features	703
Number of Google Earth mapped gullies	104

Alluvial and Colluvial geology

The alluvial geology within the repeat LiDAR footprint was 75% of the block area. East of the repeat LiDAR footprint, colluvial slopes rose to 170m above the main channel elevation. Accuracy of boundary of alluvial/colluvial zone seemed reasonable in this block.

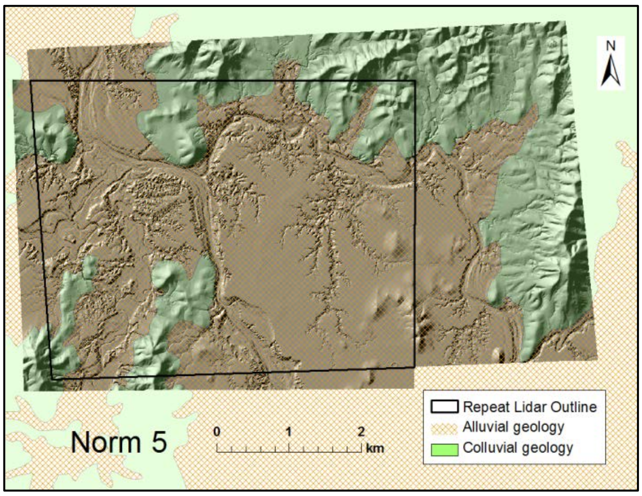


Figure 5.4: Alluvial and colluvial geology in Norm 5. Note that some low hills near the south east corner of the repeat LiDAR footprint are not mapped as colluvial, but possible should be, but overall the mapped boundary nicely delineates flat alluvial surfaces from slopes of colluvial surfaces.

4.1 Google Earth mapped gullies

Gullies mapped from Google earth were numerous on alluvial plains, with a total area of 39.6 ha. The area of GE gullies mapped on colluvial geology was 0.4ha.

The area of GE gullies was 11% of that mapped from LiDAR in the alluvial zone.

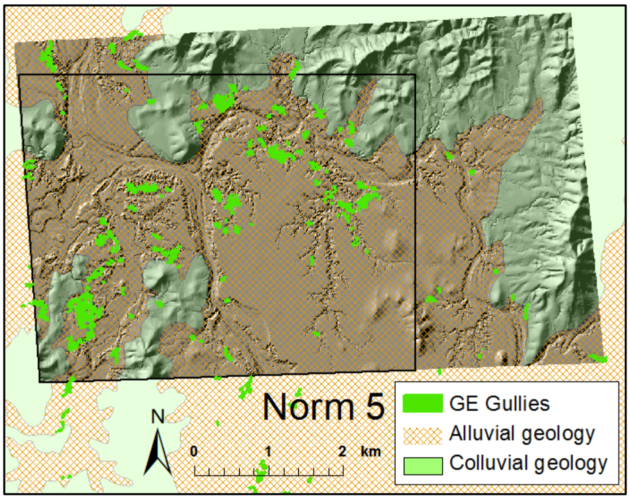


Figure 5.5: Location of Google Earth gullies in Norm 5.

Table 5.2: Quantifying LiDAR and GE gullies in alluvial and colluvial geology.

Normanby 5	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	1684	881.4	52.3	344.8	20.5	39.6	2.4
Colluvial zone	412.7	49.6	12.0	40.1	9.7	1.7	0.4

Of the alluvial geology in Norm 5, 20% of the area had been affected by gully erosion, and 30% by main or secondary channels. On colluvial slopes gully activity affected approximately 10% of the area.

4.2 LiDAR derived data

4.2.1 Horizontal adjustments

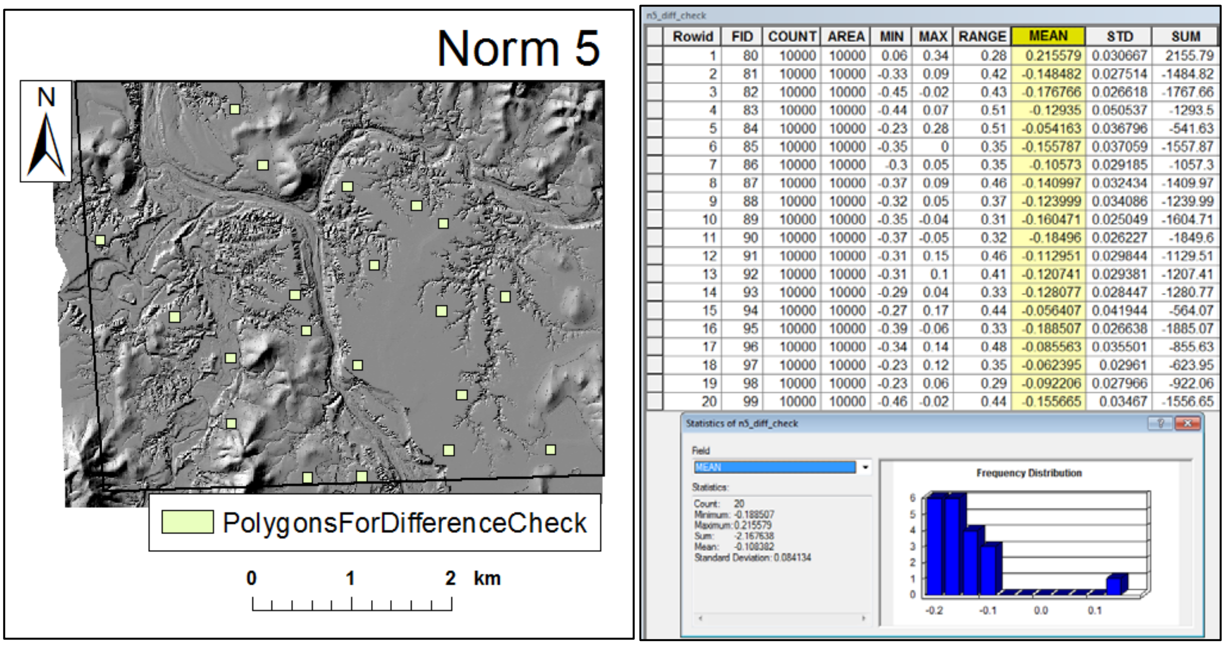
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

X,Y nudge (m)	1 , -1

4.2.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.



Rowid	FID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	80	10000	10000	0.06	0.34	0.28	0.215579	0.030667	2155.79
2	81	10000	10000	-0.33	0.09	0.42	-0.148482	0.027514	-1484.82
3	82	10000	10000	-0.45	-0.02	0.43	-0.176766	0.026618	-1767.66
4	83	10000	10000	-0.44	0.07	0.51	-0.12935	0.050537	-1293.5
5	84	10000	10000	-0.23	0.28	0.51	-0.054163	0.036796	-541.63
6	85	10000	10000	-0.35	0	0.35	-0.155787	0.037059	-1557.87
7	86	10000	10000	-0.3	0.05	0.35	-0.10573	0.029185	-1057.3
8	87	10000	10000	-0.37	0.09	0.46	-0.140997	0.032434	-1409.97
9	88	10000	10000	-0.32	0.05	0.37	-0.123999	0.034086	-1239.99
10	89	10000	10000	-0.35	-0.04	0.31	-0.160471	0.025049	-1604.71
11	90	10000	10000	-0.37	-0.05	0.32	-0.18496	0.026227	-1849.6
12	91	10000	10000	-0.31	0.15	0.46	-0.112951	0.029844	-1129.51
13	92	10000	10000	-0.31	0.1	0.41	-0.120741	0.029381	-1207.41
14	93	10000	10000	-0.29	0.04	0.33	-0.128077	0.028447	-1280.77
15	94	10000	10000	-0.27	0.17	0.44	-0.056407	0.041944	-564.07
16	95	10000	10000	-0.39	-0.06	0.33	-0.188507	0.026638	-1885.07
17	96	10000	10000	-0.34	0.14	0.48	-0.085563	0.035501	-855.63
18	97	10000	10000	-0.23	0.12	0.35	-0.062395	0.02961	-623.95
19	98	10000	10000	-0.23	0.06	0.29	-0.092206	0.027966	-922.06
20	99	10000	10000	-0.46	-0.02	0.44	-0.155665	0.03467	-1556.65

Figure 5.6 Location of polygons to check bias in LiDAR difference raster, and values from sampled areas.

Table 5.3: Statistics of raw difference raster, and corrections applied to reduce bias on non-eroding surfaces.

Layer	min	max	Mean	s.d.
Norm_5_Difference_2009-2001_Reprocessed.tif (as supplied by Terranean)	-37.23	31.47	-0.27	0.46
Extract_tif1 (edges trimmed)	-37.23	8.66	-0.22	0.19
Extract_tif1 (sampled area of minimal change)	-0.19	-0.05	-0.13	0.04

N5_Diff_adjusted	−37.1046	8.79	−0.095	0.19

Table 5.4: Values of change raster filtered to remove noise

raster	Values filtered
erosion	−0.2 to 0
deposition	0 to 0.4

Two layers were created from the modified difference data, one for erosion, one for deposition.

Aggressive hand editing to remove erroneous data from LiDAR interactions with trees and steep slopes removed 12,000 patches of false erosion and deposition across the block.

4.3 Observations from erosion and deposition analysis.

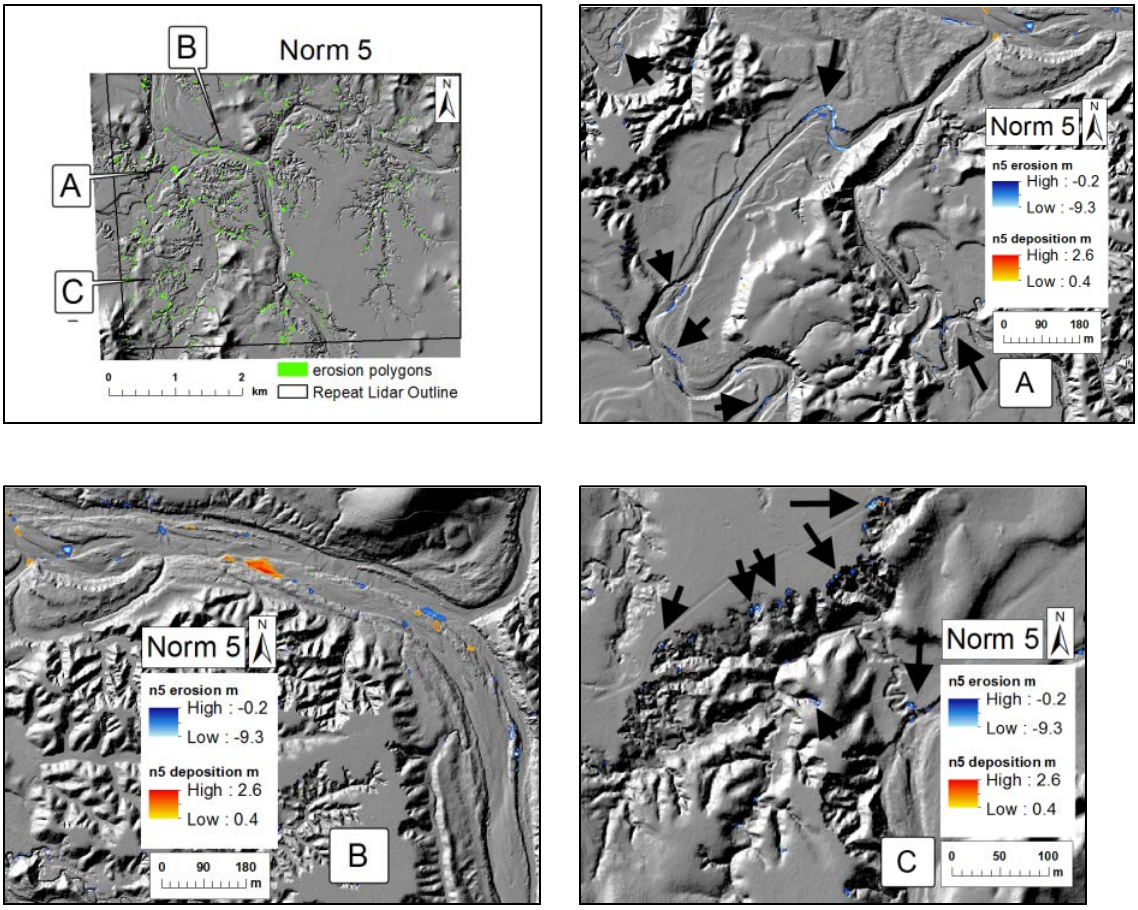


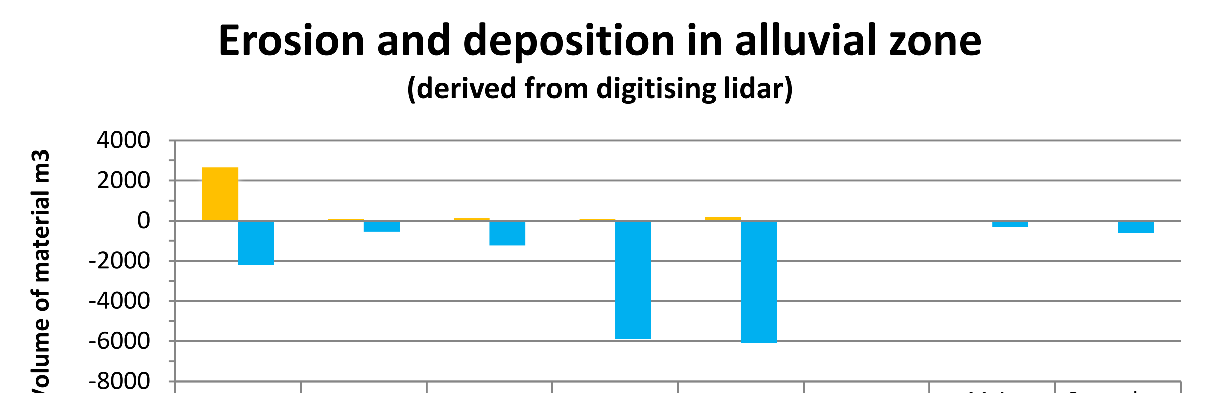
Figure 1.7: Location diagram and detailed

Location A: Active channel migration as the outsides of bends are eroded in two secondary channels.

Location B: The mainly open river bed had patches of erosion nearer the main channel , but away from the main channel, the large patch of deposition occurred between two clumps of vegetation on the open riverbed.

Location C: A 10m high bank with continuous scarp front along the 400m length of bank

Table 5.5: Values for erosion and deposition on land units in Norm 5.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Deposition	2658	81	115	73	192	0	11	
Erosion	-2209	-549	-1234	-5910	-6085	0	-305	-610

- The volume of erosion measured from alluvial gullies, 5910m3, was similar to the volume from secondary channels, 6085.
- The area of alluvial gullies was 345ha, whereas secondary channels were 141 ha.
- Yield from alluvial gullies was 8m3/ha/yr, but yield from secondary channels was significantly higher at 21m3/ha/yr.
- Open riverbed had a nett gain of 9m3/ha/yr, though vegetated channel bed, bank and inset flood plains had nett losses to erosion of 22, 4 and 1 m3/ha/yr respectively.

4.4 Comparison of alluvial gullies to colluvial gullies

Table 5.6: Comparison of erosion and deposition between alluvial and colluvial geology.

Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
344.79	73	−5910	−8	40	15	−448	−5

Total erosion from alluvial gullies was an order of magnitude larger than erosion from colluvial gullies in Norm 5; 5910 m^3 compared to 448 m^3. Yield per hectare per year was similar for the two classes of geology; alluvial 8 m^3/ha/yr, colluvial 5 m^3/ha/yr; but the colluvial zone was 12% of the alluvial area.

4.5 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

Table 5.7: Comparison of erosion activity in LiDAR and Google Earth gullies.

	Area ha	Erosion m^3	Yield $m^3/ha/yr$
LiDAR alluvial gullies	344.8	-5910.3	-8.5
GE alluvial gullies	40	-904	-11

The area of Google Earth gullies was 11% of the area of LiDAR mapped gullies in the alluvial zone, but the volume of erosion coming from the area mapped as GE gullies was 15% of the total volume of erosion from LiDAR mapped gullies. This pattern is consistent with that found in other LiDAR blocks. The similar value of yield per hectare per year is a product of the differences in area of the two data sets.

4.6 Gully Expansion 2009 – 2011

Mean area of expansion per site of erosion was reasonable low, at 2.4m2 per location. Overall, 111 m2 of alluvial land was overtaken by gully erosion between 2009 and 2011.

Table 5.8: Area of expansion of gullies between 2009 and 2011.

Gully Expansion 2009 - 2011	
number of gully expansion locations	47
sum area of gully expansions ha	111
mean area of expansion m2	2.4

4.7 Landscape Classification

Inset flood plains are present beside main and secondary channels. The 127 ha area of inset flood plain adjacent to secondary channels was approximately the same as the area mapped as secondary channel, 141 ha. The secondary heading to the south east corner of figure 5.8 has progressed approximately 3 km from the main channel. It has 8 or more separate gullies radiating from it like octopus arms, dividing the flood plain into smaller units.

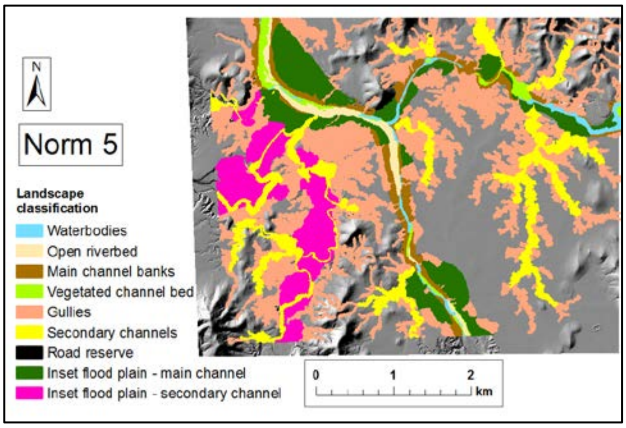
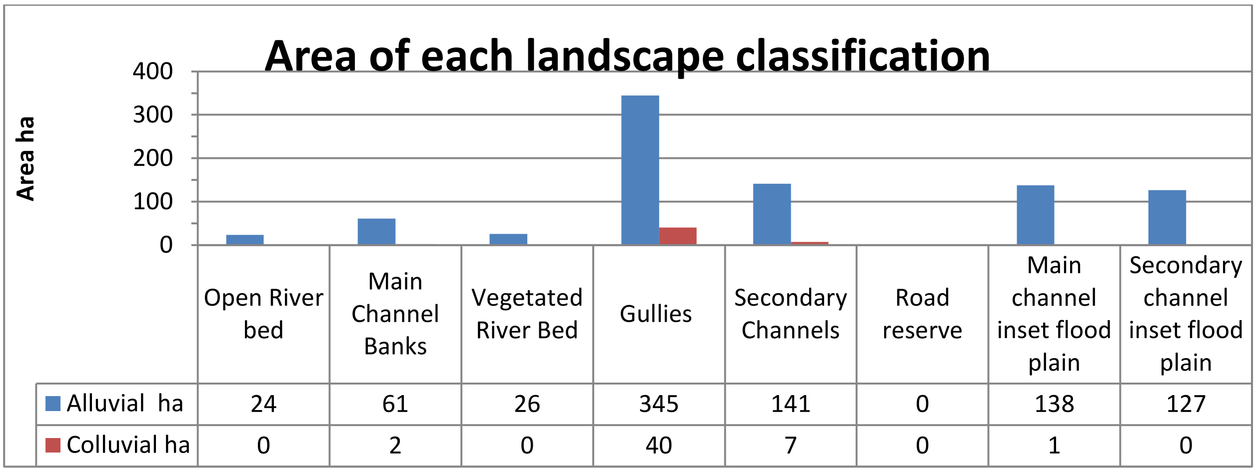


Figure 5.8: Distribution of landscape classes in Norm 5.

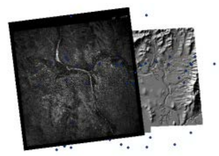
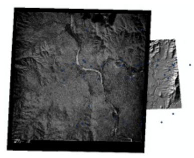
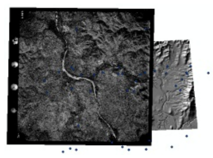
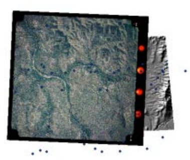
Table 5.9: Area of each landscape classification in block 5.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Alluvial ha	24	61	26	345	141	0	138	127
Colluvial ha	0	2	0	40	7	0	1	0

4.8 Historical air photos

Table 5.10: Meta data of air photos used to identify gullies in Norm 5.

Image date	Photo ID	Scale	Flying height	RMS error	Air photo relative to 2009 LiDAR block
1/01/1952	QAP0310_030	23900	12750ft	0.86617	
1/01/1957	QAP0711_018	40000	20000ft	1.30106	
1/01/1982	QAP3977_162	25000	4600m	2.96476	
1/01/1987	QAP4112_159_1987	25000	4310m	1.85934	

Three gullies to the east of the main channel and one to the west of the main channel were identified from air photos with sufficient clarity to allow delineation of features in successive air photos. Erosion rates over five decades (1950s to 2009) and two decades (1980s to 2009) were 320% and 430% respectively higher than the rate over the 2 year period from

2009 to 2011 calculated from repeat LiDAR (See table 5.11). This was different to the average erosion rates over the same time frames for all LiDAR blocks, which showed a 2 year rate of 115 m3/ha/yr, compared to 91 m3/ha/yr (5 decades) and 112 m3/ha/yr (2 decades).

Table 5.11: Erosion rates for 4 gullies over 5 decades, 2 decades (from air photos) and 2 years (from LiDAR).

		Yield: volume material lost divided by area of 2009 gully divided by interval m3/ha/yr		
		Air photo data		LiDAR data
	2009 area ha	1950s to 2009	1980s to 2009	2009 to 2011
N05 eg1	0.33	no data	22	28.00
N05 eg2	0.30	51	91	0.00
N05 eg3	1.81	47	161	46.00
N05 wg1	4.08	111	97	13.00
Mean	1.63	70	93	22

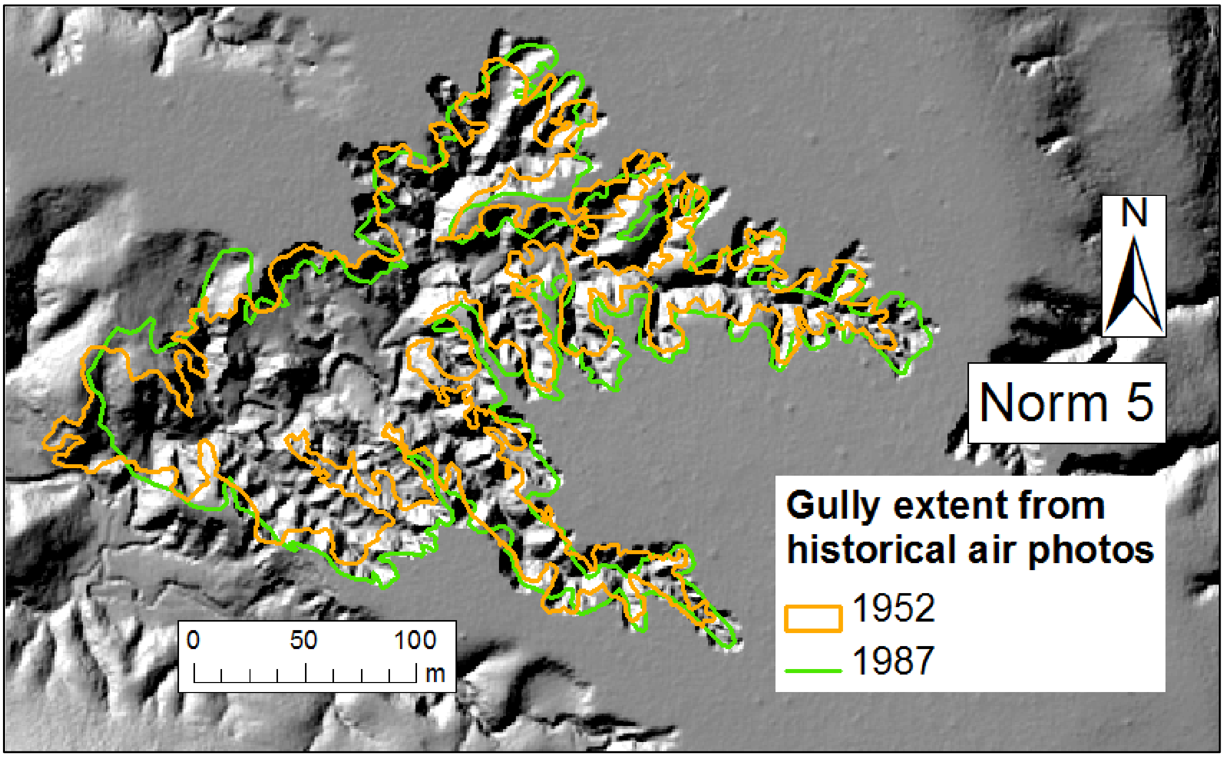


Figure 2: Detail of gully head wall location in 1952 and 1987 for N5 wg1 in Norm 5.

5. Normanby LiDAR Block 7

Normanby 7 LiDAR block was the highest in the catchment, a narrow corridor of alluvial geology between ranges rising to 320m above the alluvial flats. The main stream running through the block was the Normanby Granite River. This block had the second highest volume of alluvial gully erosion measured of the 14 repeat LiDAR blocks, 14,000 m3 over 2 years. Major erosion was seen along head walls of amphitheatre gullies encroaching virgin flood plain, also from incisions in floors of massive gullies and extension of linear gullies.

Figure 7.1: Norn 7 location.

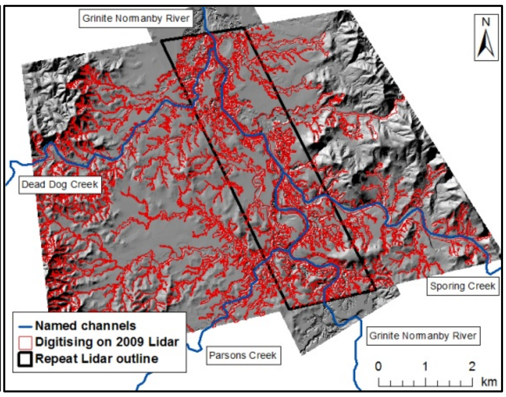


Figure 7.2: Digitising on LiDAR

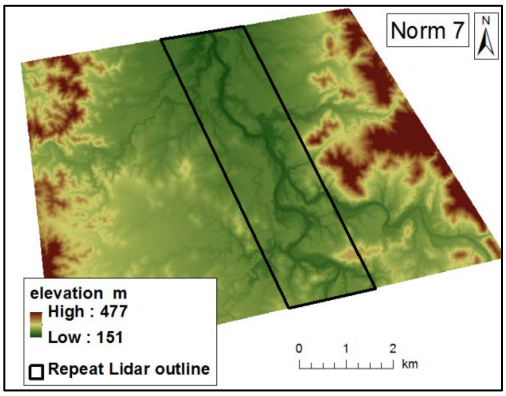


Figure 7.3: DEM from 2009 LiDAR

Table 7.1: General statistics for Normanby 7 LiDAR block.

2009 LiDAR area (ha)	5200
Reprocessed change raster area (ha)	150 – 240
Reprocessed extent elevation rang (m)	150 – 240
Number of LiDAR digitised features	655
Number of Google Earth mapped gullies	134

5.1 Alluvial and Colluvial geology

Though surrounded by colluvial geology, the narrow boundary of the repeat LiDAR footprint limited the colluvial zone to 5% of the area used for erosion detection from repeat LiDAR. 50% of the alluvial zone had erosion features that were digitised, whereas the colluvial zone had few erosional features, and only 15% of the foothills extending into the block were digitised.

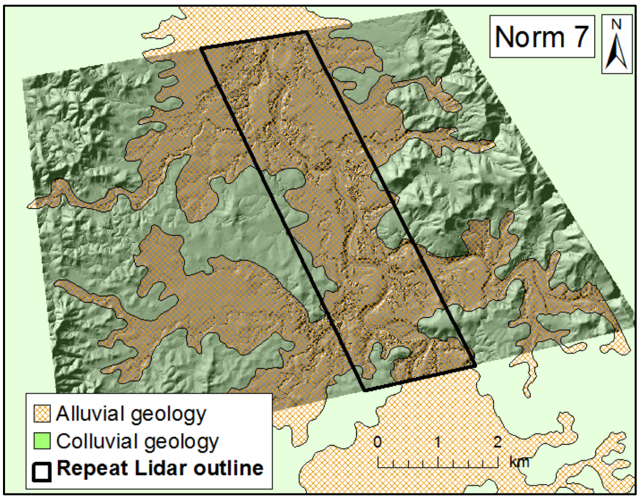


Figure 7.4: Alluvial and colluvial geology in Norm 7.

5.2 Google Earth mapped gullies

Gullies mapped from Google earth were very abundant in this highest part of the catchment. But despite looking to dominate the map, Figure 5, just 7.3% of the alluvial zone was mapped as gullies from Google Earth, compared to 24% of the alluvial area mapped as gullies from LiDAR, see table 2. Gullies did extend into the colluvial zone, 7% was mapped as gullies from LiDAR, but these gullies were not so visible in Google Earth imagery, as a bare 1% of the colluvial zone was mapped as being a gully from Google Earth.

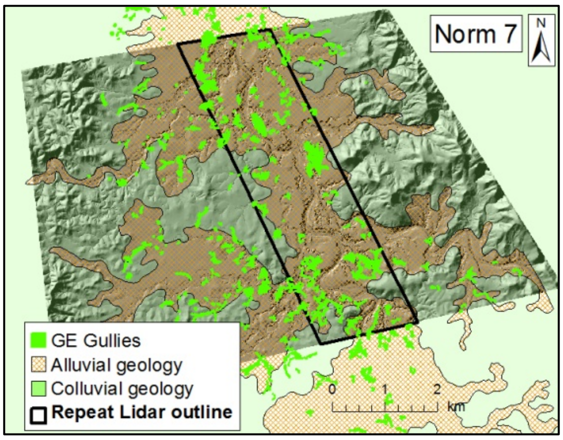


Figure 7.5: Distribution of gullies mapped from Google Earth.

Table 7.2: Gully area digitised from LiDAR and Google Earth in alluvial and colluvial geology.

Normanby 7	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	966	474.6	49.1	229.1	23.7	70.6	7.3
Colluvial zone	148	21.5	14.6	10.40	7.0	1.5	1.0

5.3 LiDAR derived data

5.3.1 Horizontal adjustments

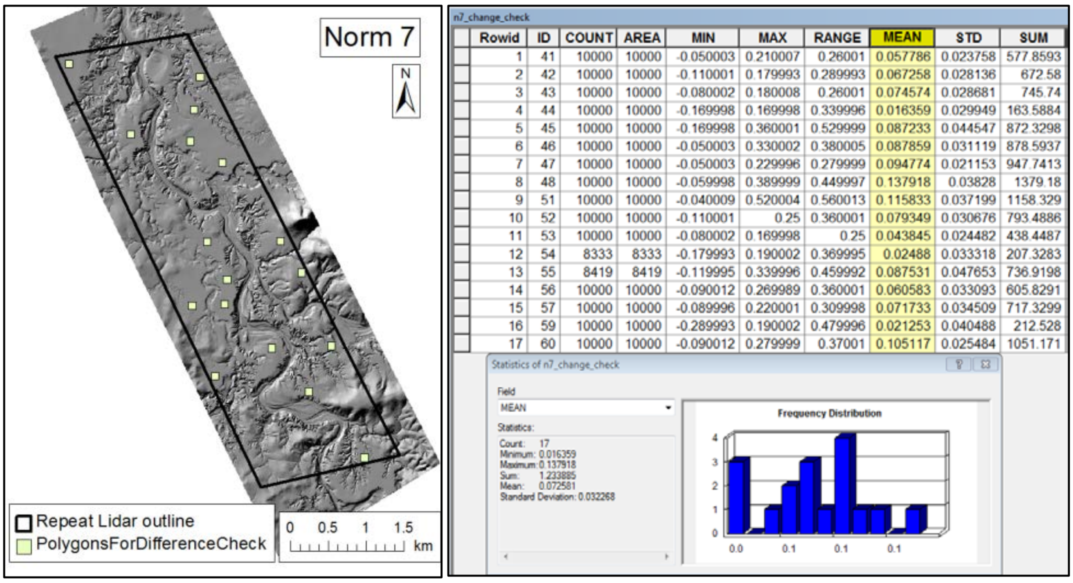
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

X,Y nudge (m)	1 , -1

5.3.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.



n7_change_check

Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	41	10000	10000	-0.050003	0.210007	0.26001	0.057786	0.023758	577.8593
2	42	10000	10000	-0.110001	0.179993	0.289993	0.067258	0.028136	672.58
3	43	10000	10000	-0.080002	0.180008	0.26001	0.074574	0.028681	745.74
4	44	10000	10000	-0.169998	0.169998	0.339996	0.016359	0.029949	163.5884
5	45	10000	10000	-0.169998	0.360001	0.529999	0.087233	0.044547	872.3298
6	46	10000	10000	-0.050003	0.330002	0.380005	0.087859	0.031119	878.5937
7	47	10000	10000	-0.050003	0.229996	0.279999	0.094774	0.021153	947.7413
8	48	10000	10000	-0.059998	0.389999	0.449997	0.137918	0.03828	1379.18
9	51	10000	10000	-0.040009	0.520004	0.560013	0.115833	0.037199	1158.329
10	52	10000	10000	-0.110001	0.25	0.360001	0.079349	0.030676	793.4886
11	53	10000	10000	-0.080002	0.169998	0.25	0.043845	0.024482	438.4487
12	54	8333	8333	-0.179993	0.190002	0.369995	0.02488	0.033318	207.3283
13	55	8419	8419	-0.119995	0.339996	0.459992	0.087531	0.047653	736.9198
14	56	10000	10000	-0.090012	0.269989	0.360001	0.060583	0.033093	605.8291
15	57	10000	10000	-0.089996	0.220001	0.309998	0.071733	0.034509	717.3299
16	59	10000	10000	-0.289993	0.190002	0.479996	0.021253	0.040488	212.528
17	60	10000	10000	-0.090012	0.279999	0.37001	0.105117	0.025484	1051.171

Figure 7.6: Locations of polygons for checking bias in the difference raster, and statistics table.

Table 7.3: Statistics of raw difference raster, and corrections applied to reduce bias on non-eroding surfaces.

Layer	min	max	Mean	s.d.
Norm_7_Difference_2009-2001_Reprocessed.tif (as supplied by Terranean)	-8.74	13.45	0.0378	0.17
N7change_extr (edges trimmed)	-8.74	13.45	0.038	0.17
(20 sampled areas of minimal change)	0.016	0.14	0.07258	0.03
N7chang_adj	-8.8126	13.3774	-0.035	0.17

Table 7.4: Values of change raster filtered to remove noise

raster	Values filtered
erosion	-0.2 to 0
deposition	0 to 0.4

Two layers were created from the modified difference data, one layer for erosion, and one layer for deposition.

Aggressive hand editing to remove erroneous erosion and deposition from LiDAR interactions with trees and steep slopes was done, but in this case, no details of how much data was edited were kept.

5.4 Observations from erosion and deposition analysis.

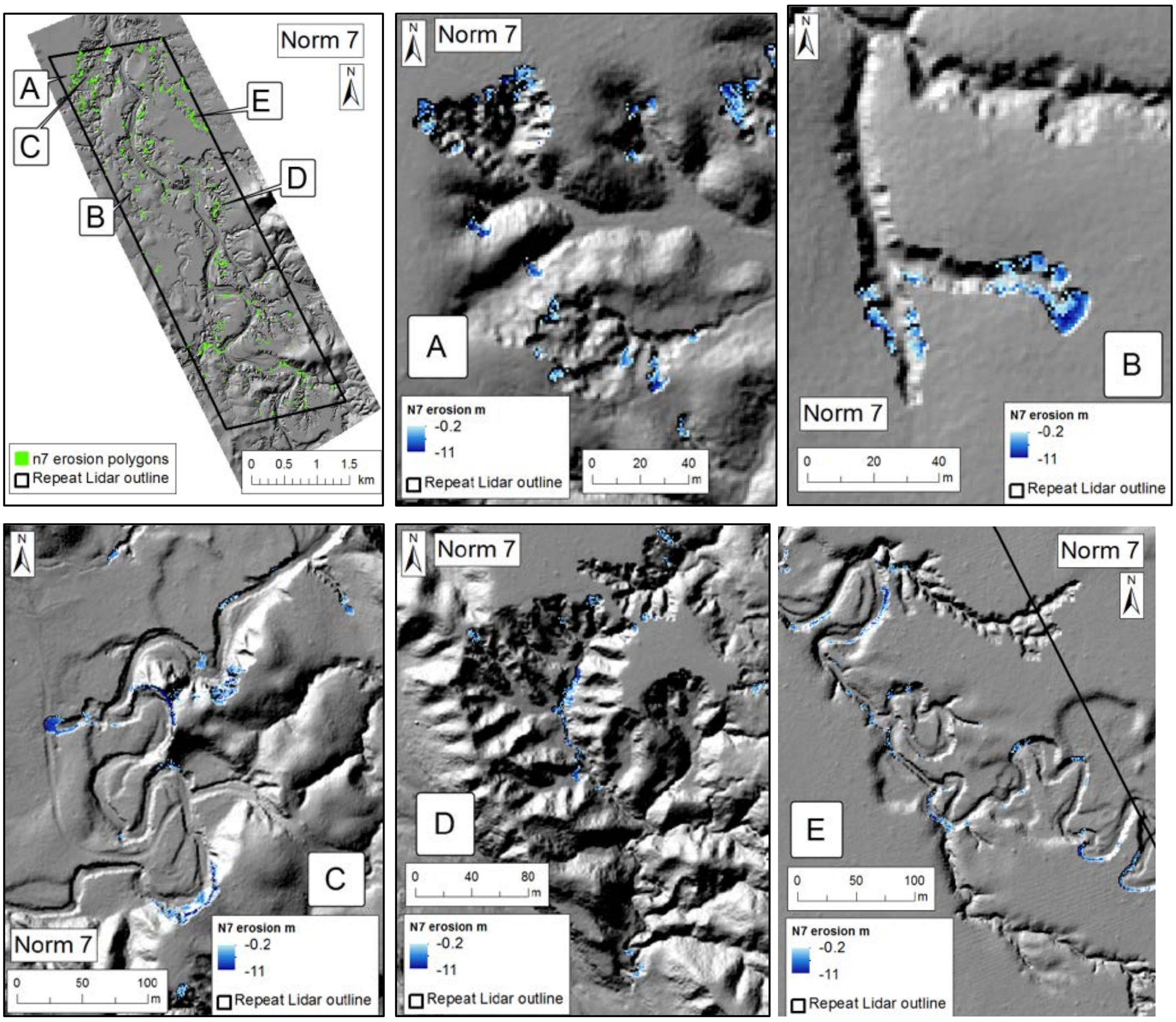


Figure 7.7: Location diagram and detail of erosion and deposition hotspots.

Location A: Multiple amphitheatre gullies with several active head walls in each.

Location B: Linear gully progressing across flood plain previously (recently) unscarred by gully erosion

Location C: Secondary channel with new gully initiation from the apex of a bend, also erosion of high banks on the outside of bends.

Location D: Down cutting in the floor of a massive gully complex. Gully will meet up with another on the "back slope" of the flood plain.

Location E: Secondary channel with multiple bends migrating. Large meanders have become cut off, others are forming.

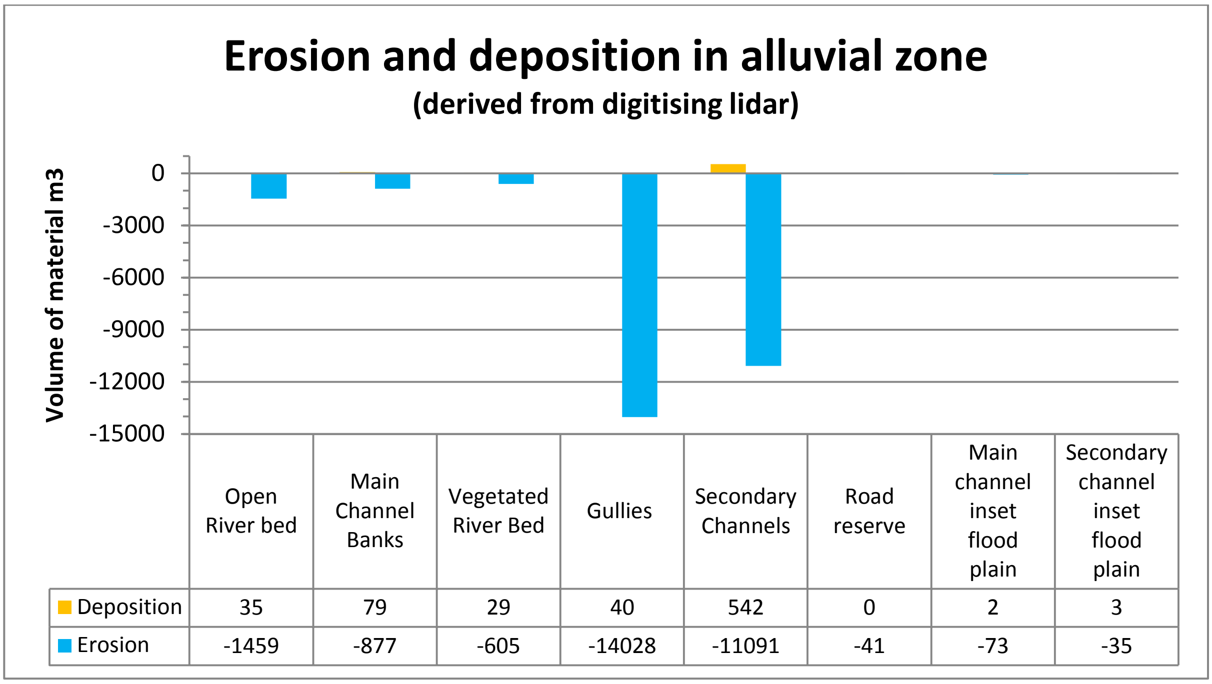


Figure 7.8: Quantifying erosion and deposition in alluvial and colluvial zones.

- Huge amounts of material have eroded from alluvial gullies between 2009 and 2011, 14,000 m3, which was nearly matched by erosion from within secondary channels, 11091 m3 over two years.
- Erosion from road runoff exceeded the amount of material removed from inset flood plains in secondary channels.
- 74% of deposition in this block occurred in secondary channels, but the volume of deposition was a mere 5% of the volume eroded from within secondary channels. A major export from secondary channels has occurred.
- Main channel landscape units each suffered large amounts of erosion, with little deposition measured in the main channel.

5.5 Comparison of alluvial gullies to colluvial gullies

Table 7.5: Comparison of erosion activity in alluvial and colluvial gullies.

Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
229.07	40	-14028	-31	10	0	-553	-27

The area of gullies in colluvial geology in the repeat LiDAR footprint was relatively small, 10 ha, but in keeping with the highly active nature of this landscape, the volume of erosion from those 10 ha of gullies, 553 m3, was similar to the volume of erosion from 14ha of vegetated river bed, 605 m3.

5.6 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

Table 7.6: Comparison of erosion activity in LiDAR and Google Earth gullies.

	Area ha	Erosion m^3	Yield m^3/ha/yr
LiDAR alluvial gullies	229	-14028	-31
GE alluvial gullies	71	-7842	-55

In Norm 7, the area of gullies visible and digitised from Google Earth imagery was 31% of then area of alluvial gullies defined from LiDAR, which was actually quite a high representation compared to other blocks. Google Earth gully foot print captured 56% of erosion that was measured in LiDAR gullies, also a high value compared to some blocks.

5.7 Gully Expansion 2009 – 2011

The active rates of erosion in Norm 7 were reflected in the number of locations where erosion was measured at the boundary of gullies between 2009 and 2011. Gully expansion occurred at 172 locations, with an average 7.7 m^2 lost in each instance over two years.

Table 7.7: Area of expansion of gullies between 2009 and 2011.

Gully Expansion 2009 - 2011	
Number of gully expansion locations	172
Sum area of gully expansions ha	0.13
Mean area of expansion m2	7.4

5.8 Landscape Classification

Several secondary channels have developed in parallel with the Granite Normanby River, the main drainage in the valley. Gullies on alluvial geology were the dominant landscape feature in the LiDAR block, being 51% of the alluvial area, or 49% of the total area. A proportion of the 117 ha of secondary channels could be reclassified as secondary channel flood plain if time had been available to add detail at that scale.

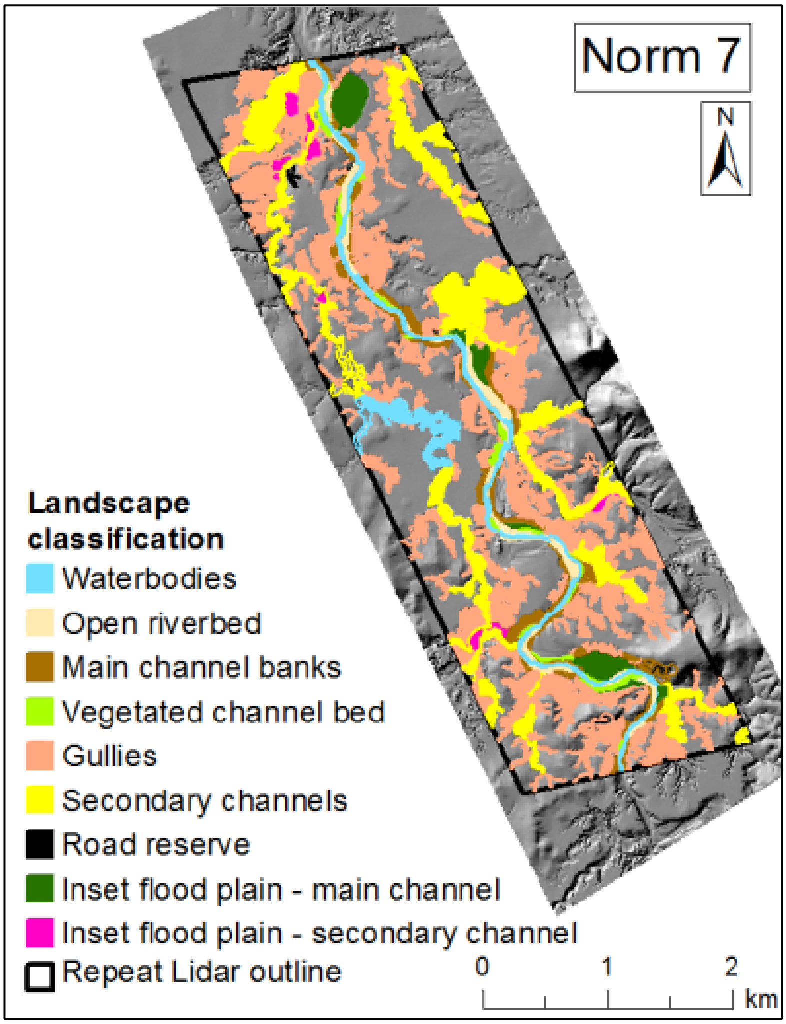
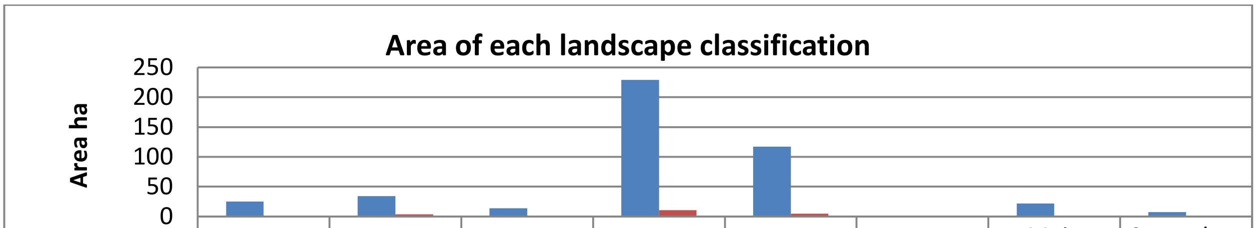


Figure 7.9: Landscape classification in Norm 7.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Alluvial ha	25	34	14	229	117	0	22	7
Colluvial ha	0	4	0	10	5	0	0	0

Figure 7.10: Area of each landscape unit in alluvial and colluvial zones.

5.9 Historical air photos

Despite many massive and active gullies throughout Norm 7, there was no success defining gully perimeters to acceptable levels of accuracy. Figure 7.11 shows digitising done at 4 time slices, with various problems such as miss-registration of air photo imagery, incomplete digitisation of gully walls due to poor definition of features, a lack of visible head walls, and vegetation on the walls of linear gullies radiating from the main complex.

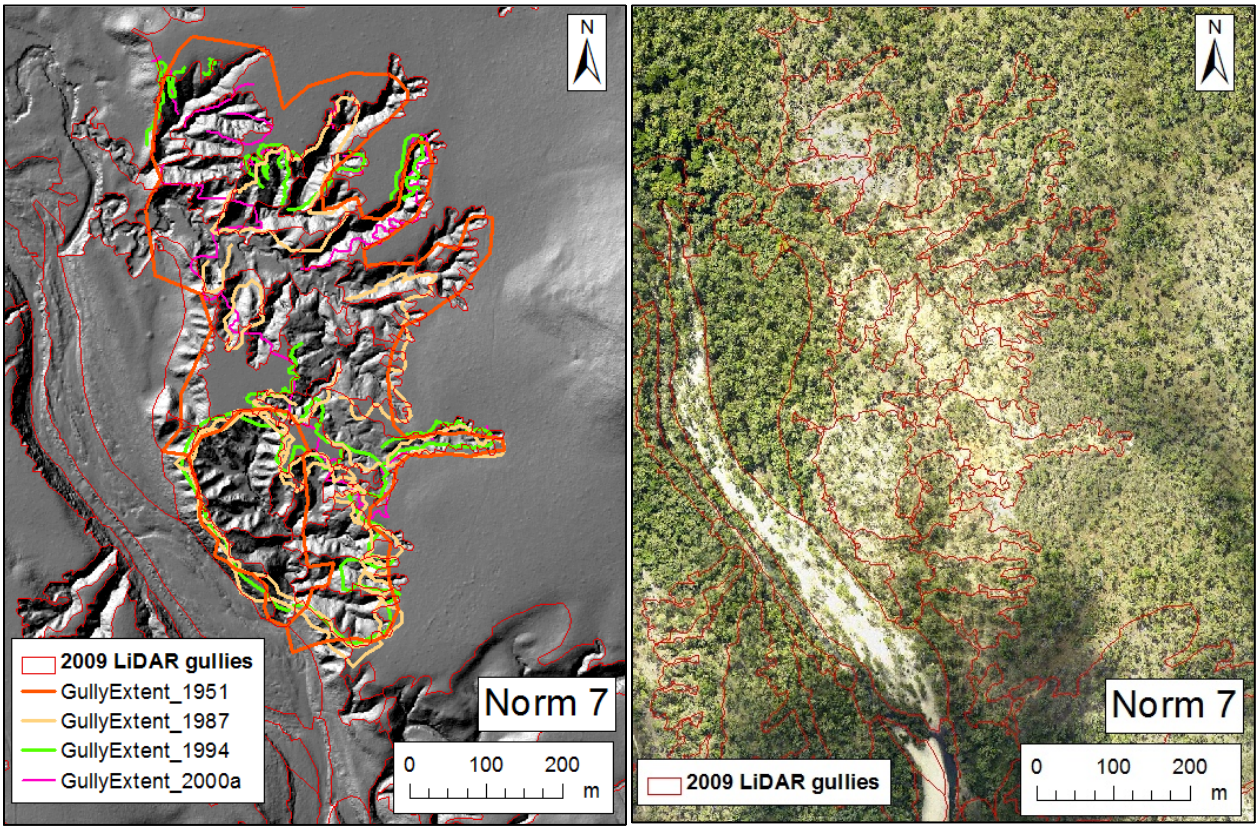


Figure 7.11: Example of a gully that looked so clear in LiDAR (left), but was frustratingly difficult to define from visual imagery (right).

6. Normanby LiDAR Block 9

Normanby LiDAR block 9 (Norm 9) was the furthest upstream block on the East Normanby River, lay 290 km inland, covered 501 ha at the junction of the East Normanby River and Welch Creek, and had the distinction of having the largest volume of erosion from main channel banks of all LiDAR study blocks. Elevation ranged from 145 m on alluvial flats to 255 m peaks to the south east of the repeat LiDAR footprint.

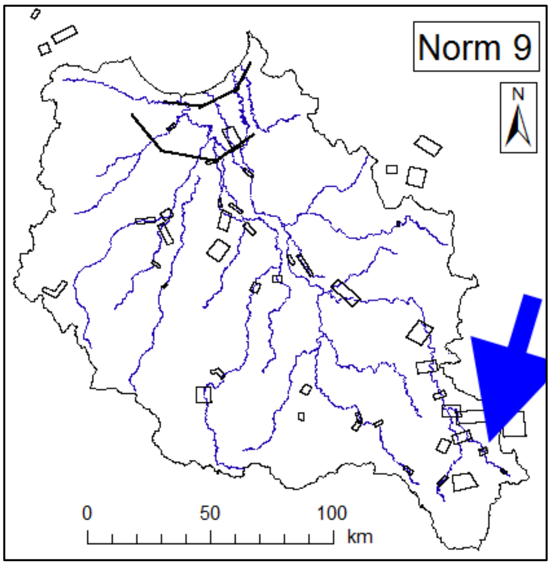


Figure 9.1: Location of Norm 9.

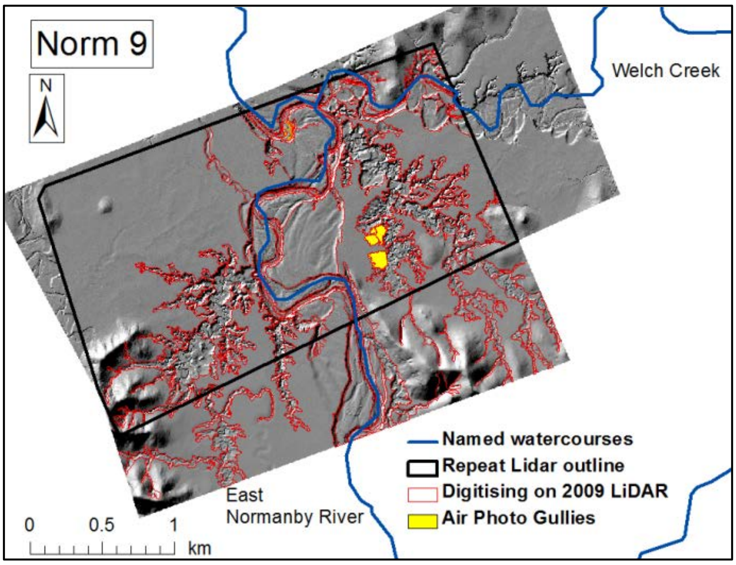


Figure 9.2: Features in Norm 9.

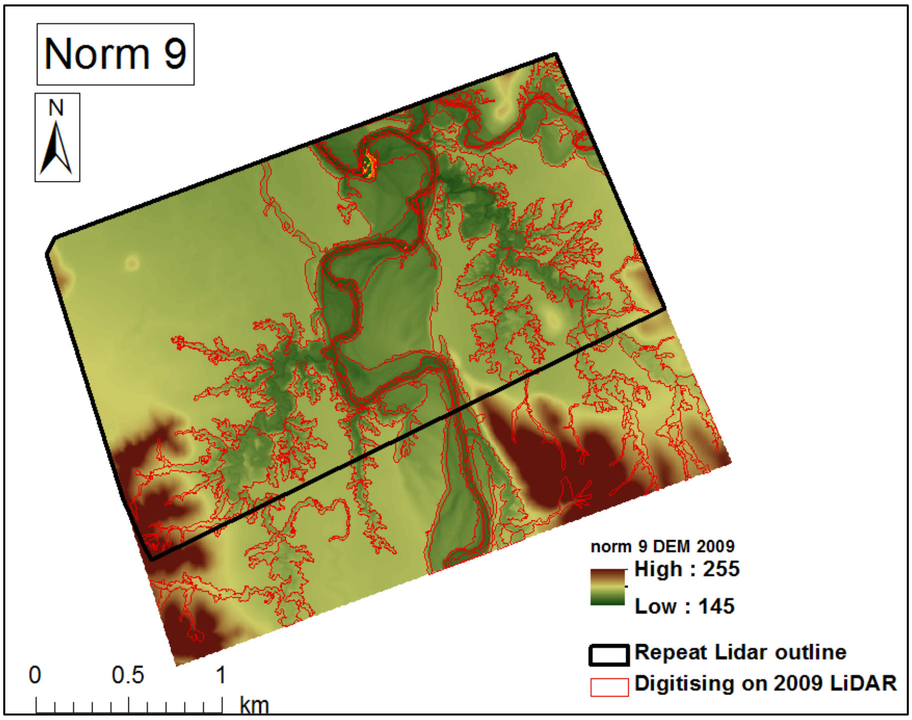


Figure 9.3: Elevation ranges in and around Norm 9.

Table 9.1: General statistics.

Reprocessed change raster area	ha	501.5162
Block elevation range	m	134 to 234
Number of LiDAR digitised features		236
Number of Google Earth mapped gullies		54

6.1 Alluvial and Colluvial geology

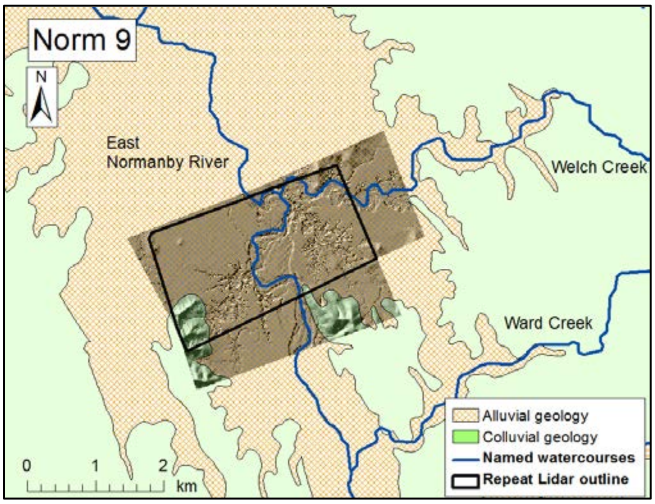


Figure 9.4: Norm 9 sits at the head of a broad alluvial plain. Narrower bands of alluvium follow water courses between rising slopes of colluvial geology to the east and south of the block. 93% of the repeat LiDAR footprint was alluvial geology.

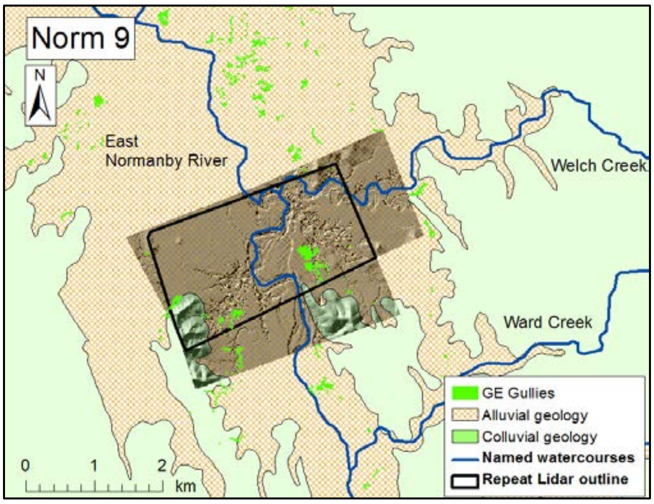


Figure 9.5: Distribution of Google Earth (GE) mapped gullies in and around Norm 9.

Table 9.2: Just under half the area of alluvial surfaces was eroded by gullies or channels at different stages of development. 15% of alluvial surfaces were eroded by gullies, but GE gullies captured under half of this extent. Few gullies extended into colluvial areas.

Norm 9	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	468.74	209.15	44.6	70.17	16.5	5.86	1.3
Colluvial zone	32.77	3.60	11.0	3.39	10.3	0.25	0.8

6.2 LiDAR derived data

6.2.1 Horizontal adjustments

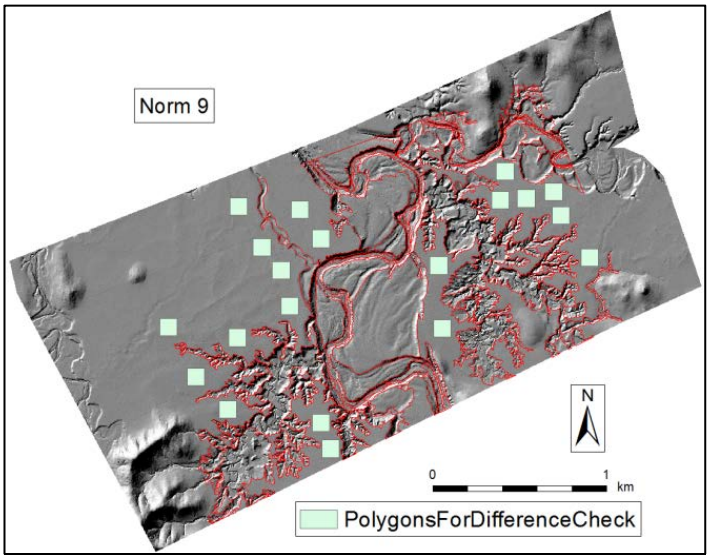
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

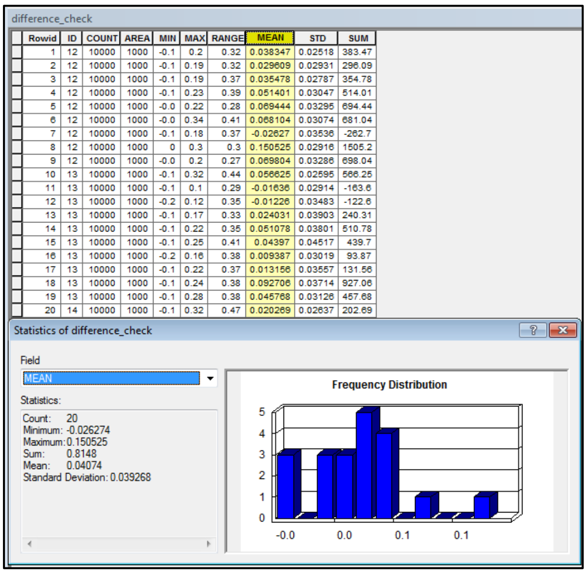
X,Y nudge (m)	2,-2

6.2.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.





Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	12	10000	1000	-0.1	0.2	0.32	0.038347	0.02518	383.47
2	12	10000	1000	-0.1	0.19	0.32	0.029609	0.02931	296.09
3	12	10000	1000	-0.1	0.19	0.37	0.035478	0.02787	354.78
4	12	10000	1000	-0.1	0.23	0.39	0.051401	0.03047	514.01
5	12	10000	1000	-0.0	0.22	0.28	0.069444	0.03295	694.44
6	12	10000	1000	-0.0	0.34	0.41	0.068104	0.03074	681.04
7	12	10000	1000	-0.1	0.18	0.37	-0.02627	0.03536	-262.7
8	12	10000	1000	0	0.3	0.3	0.150525	0.02916	1505.2
9	12	10000	1000	-0.0	0.2	0.27	0.069804	0.03286	698.04
10	13	10000	1000	-0.1	0.32	0.44	0.056625	0.02595	566.25
11	13	10000	1000	-0.1	0.1	0.29	-0.01636	0.02914	-163.6
12	13	10000	1000	-0.2	0.12	0.35	-0.01226	0.03483	-122.6
13	13	10000	1000	-0.1	0.17	0.33	0.024031	0.03903	240.31
14	13	10000	1000	-0.1	0.22	0.35	0.051078	0.03801	510.78
15	13	10000	1000	-0.1	0.25	0.41	0.04397	0.04517	439.7
16	13	10000	1000	-0.2	0.16	0.38	0.009387	0.03019	93.87
17	13	10000	1000	-0.1	0.22	0.37	0.013156	0.03557	131.56
18	13	10000	1000	-0.1	0.24	0.38	0.092706	0.03714	927.06
19	13	10000	1000	-0.1	0.28	0.38	0.045768	0.03126	457.68
20	14	10000	1000	-0.1	0.32	0.47	0.020269	0.02637	202.69

Figure 9.6: Distribution of sample polygons to test bias in the difference raster; and statistics table.

Table 9.3: Statistics from adjusting difference raster for bias.

Layer	min	max	Mean	s.d.
Norm_9_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-11.16	9.5	-0.03	0.18
Norm_9 with edge effect removed	-9.76	5.42	-0.016	0.17
Areas of minimal change	-0.026274	0.150525	0.04074	0.039268
N9_Diff_adjusted	-9.80	5.38	-0.057	0.17

Table 9.4: Values of adjusted change raster filtered to remove noise from ancient flood plain.

raster	Values filtered
erosion	-0.2 to 0
deposition	0 to 0.2

6.3 Observations

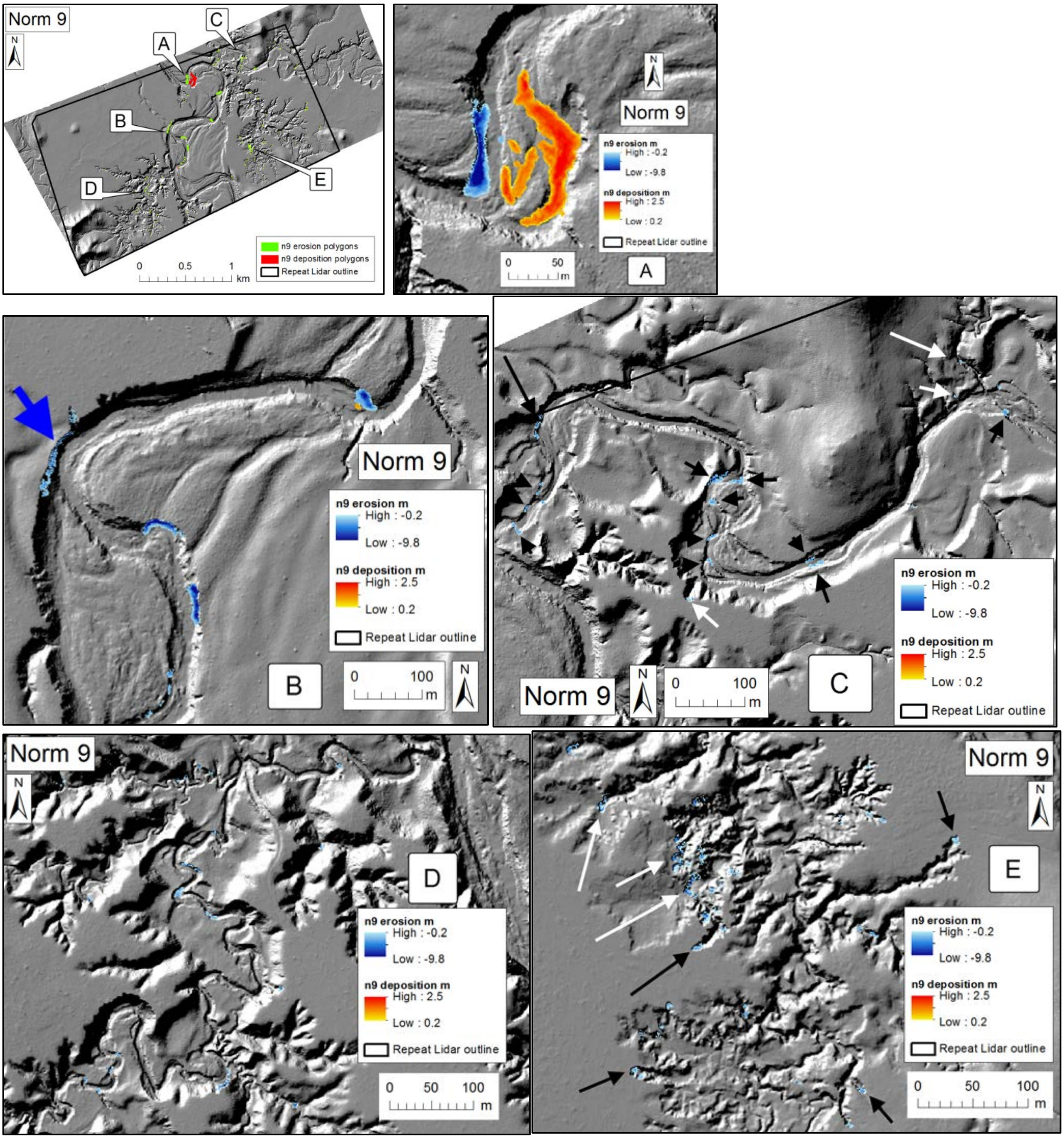


Figure 9.7: Location diagram and erosion and deposition hot spots in Norm 9.

Location A: The largest single deposition seen anywhere in this study, 4620m^3 material was deposited among trees on an old channel bed of the East Normanby River. Depth of deposit was up to 2.5m. A 100m section of bank opposite the deposition was cut back by up to 15 m, with the full height of the 6m bank losing material.

Location B: Erosion on both banks of the East Normanby River, cutting into inset flood plains at different levels. The blue arrow points to a 13 m high bank that appears to have collapsed along its upper edge, whereas other erosion sites have been eaten away from the waterline upwards. Volume of erosion from the sites in this picture alone was 5700m^3.

Location C: The tributary Welch Creek had numerous erosion sites along the channel (black arrows), but few sites of erosion in gullies along this reach (white arrows).

Location D: A secondary channel with numerous erosion sites.

Location E: A gully complex 700m by 300m shows 2 distinct phases of gully development; reworking of old gully scars (white arrows) and headwalls advancing into un eroded alluvium (black arrows).

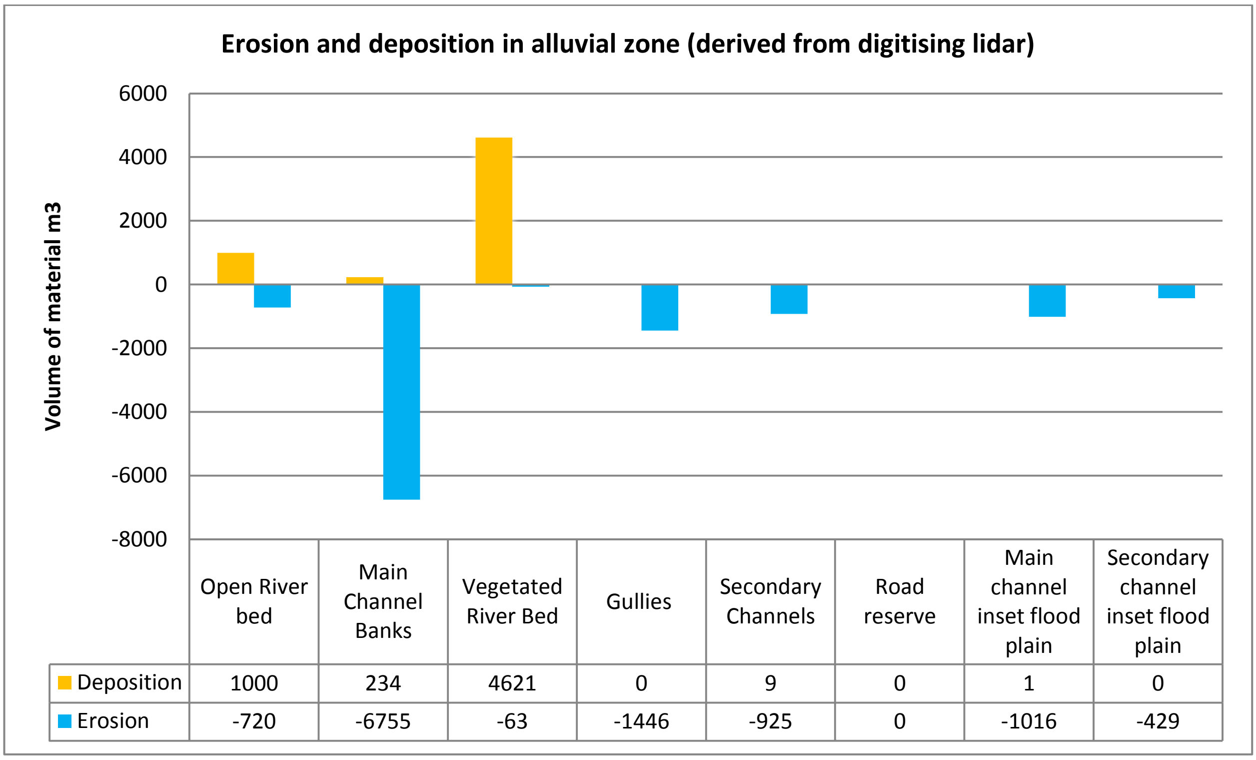


Figure 9.8: Sum of erosion and deposition for landscape classes in the alluvial zone. In a significant deviation from the pattern in other LiDAR blocks, erosion from main channel banks dominated losses from other sources. Deposition on open and vegetated river main channel bed in Norm 9 was the largest volumes measured of all LiDAR blocks except Norm 40, which covered a section of Morehead River that had many anabranching channels with significant movement of sandbanks and bars. These data suggests the upper East Normanby River to be actively reforming main channel dimensions.

6.4 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

The area of gullies identified from Google Earth was 8% of the area of gullies identified from LiDAR, but erosion captured from Google Earth mapped gullies was 30% of the volume of erosion from alluvial gullies. The average value (excluding outliers) over 11 blocks was 14%. Reworking of unvegetated old gully scars with incisions and down cutting explains this higher than average value.

Table 9.5: Comparison of erosion from LiDAR alluvial gullies and Google Earth mapped gullies.

	Area ha	Erosion m^3	yield m^3/ha/yr
LiDAR gullies alluvial	70.17	−1393.41	−9.93
GE gullies alluvial	5.86	−408.34	−34.84

6.5 Gully Expansion 2009 – 2011

Very little expansion of alluvial gullies occurred between 2009 and 2011, with no locations standing out as having rapid extension compared to other LiDAR blocks. Gully boundaries were expanded in 17 locations, with a total of 52.2 m^2 increase in gully area.

Large areas of bank erosion do not show up in these statistics. Gully expansion measures the advance of head scarps into ancient flood plain not eroded (or digitised) previously.

Table 9.6: gully expansion between 2009 and 2011.

Gully Expansion 2009 – 2011	
Number of gully expansion locations	17
Area of gully expansions m2	52.2
Mean area of expansion m2	3.1

6.6 Landscape Classification

The main channel has large areas of vegetated channel bed approximately 6m above the main channel, and extensive areas of inset flood plain approximately 2m above the vegetated channel bed. Three secondary channels join the main channel in this block, with the channel in the north east quarter of the block having a broad, vegetated bed.

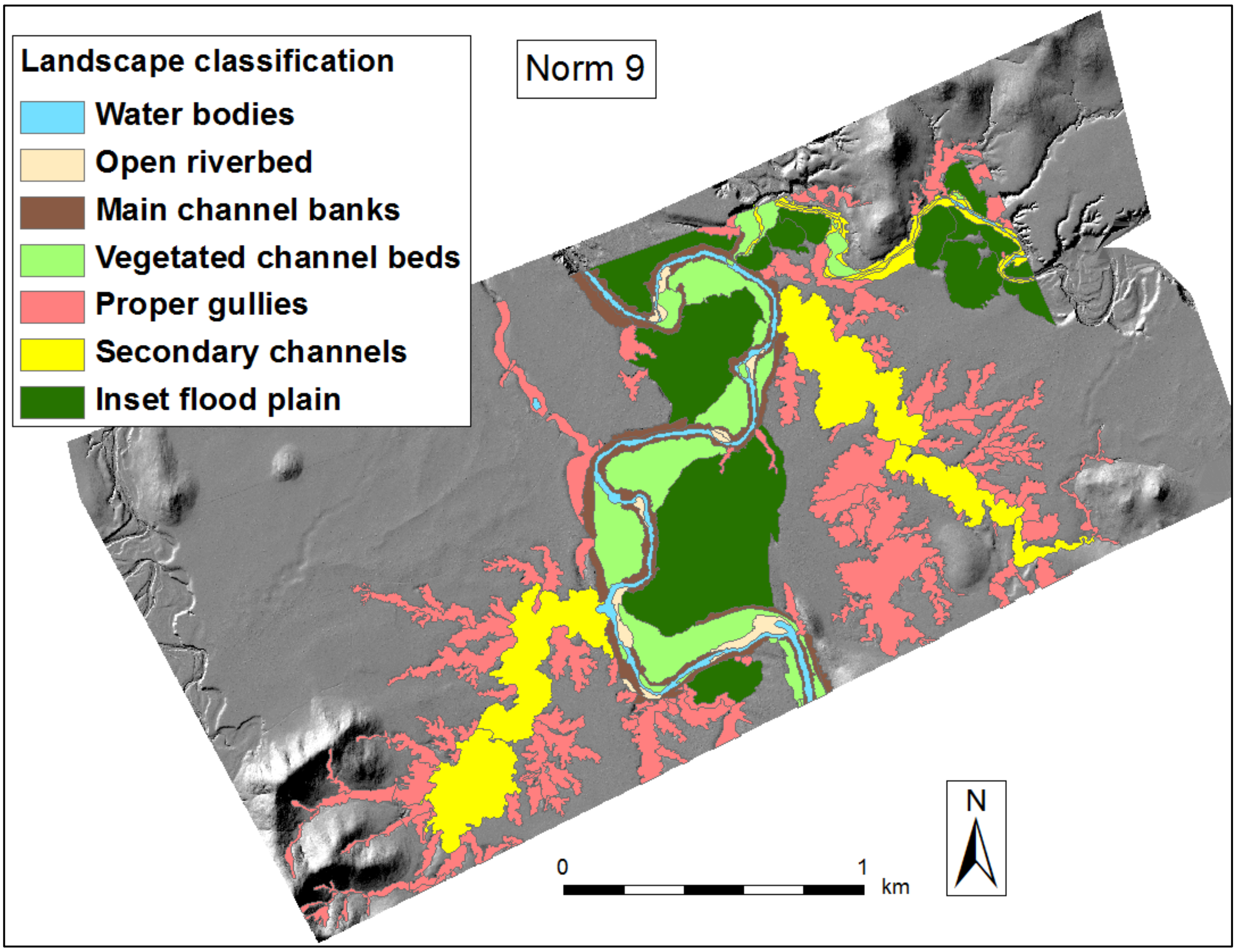
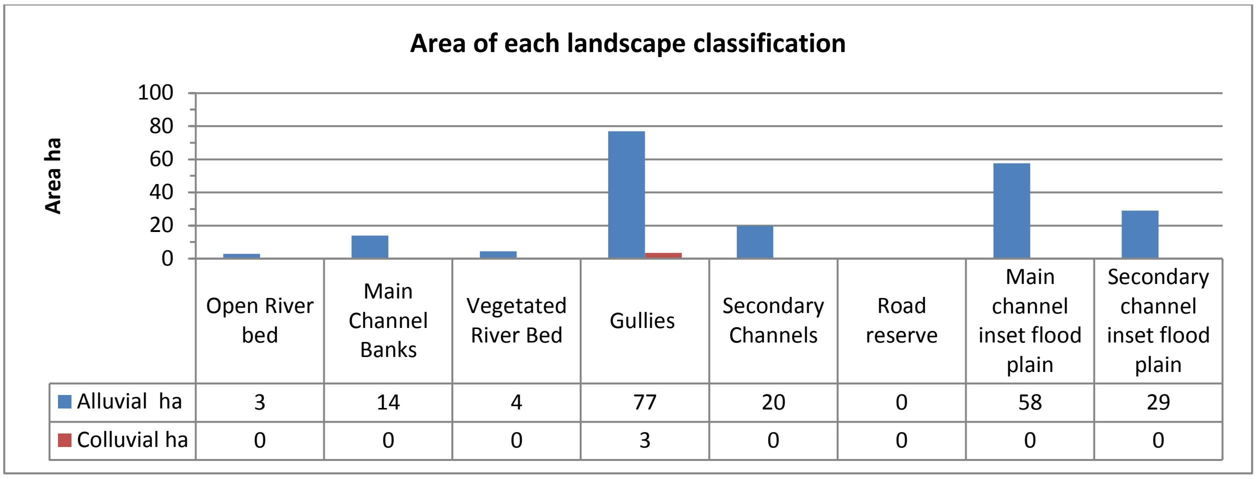


Figure 9.9: Landscape classification in Norm 9.

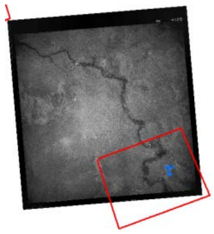
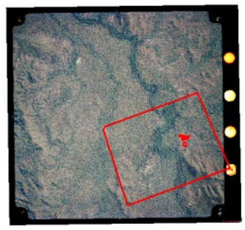


	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Alluvial ha	3	14	4	77	20	0	58	29
Colluvial ha	0	0	0	3	0	0	0	0

Figure 9.10: Gullies were 38% of the block area, combined area of main and secondary channel flood plains was 42%.

6.7 Historical air photos

Table 9.7: Details of air photos covering a broad expanse of gully to the east of the main channel in Norm 9.

Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block
1/01/1951	QAP0204_040	24000	12750ft	0.76140	
1/01/1987	QAP4112_093	25000	4310m	2.31157	
19/10/1994	QAP5321_046	25000	4630m	1.77000	
1/06/2000	QAP5818_101	25000	4610m	3.66543	

6.8 Historical gully extent

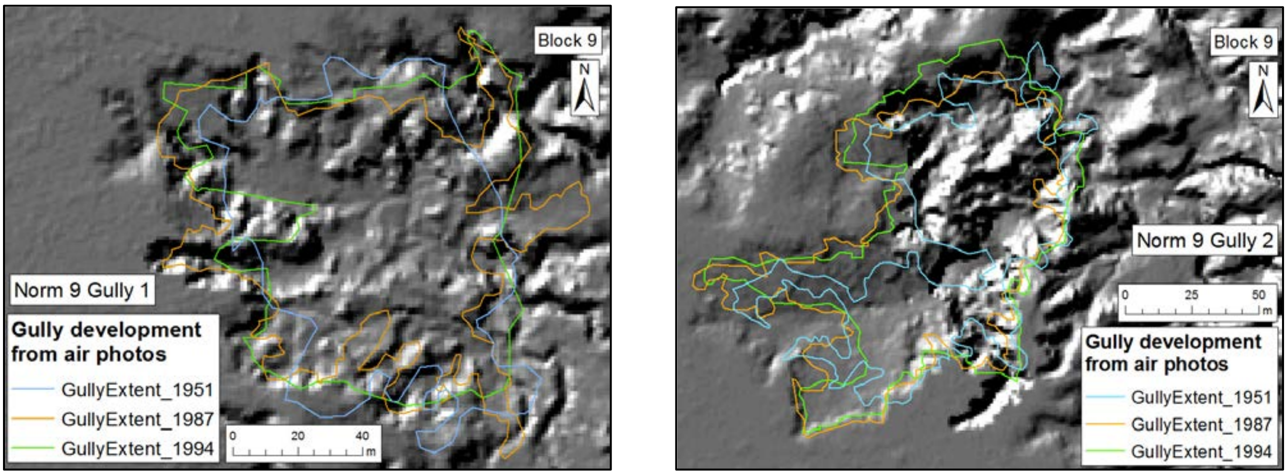


Figure 9.11: Development of gully one and 2 between 1951 and 2009

Table 9.8: Variability of erosion rates from different gullies over different time scales is highlighted by comparing N09g1 and N09g2. Yield calculated from gully 1 between 2009 and 2011 was 43% of 5 decade average, but 23% of 2 decade average. Erosion from gully 2 between 2009 and 2011 was 90% of 5 decade average, but 180% of 2 decade average. These values oscillated above and below the average yield of 13 air photo gullies over the same time scales.

		Yield: volume material lost divided by area of 2009 gully divided by interval m3/ha/yr	
		Air photo data	LiDAR data
	1950s to 2009	1980s to 2009	2009 to 2011
N09 g1	86	164	37
N09 g2	177	89	160
average of 13 air photo gullies	91	112	115

7. Normanby LiDAR Block 10

Normanby 10 LiDAR block (Norm 10) straddles the Normanby River approximately 7 km downstream of the junction of the East and West Normanby rivers. The block is centred on alluvial flats around the confluence of Deep Creek with the Normanby River. Elevation of the alluvial flats is approximately 95 m; to the west a significant hill rises to 495 m. Eroded into the flats is a complex arrangement of flood plains at different levels, with dramatic channel systems that tell a story of multiple evolutions in the landscape.

Though total erosion from alluvial gullies was 2700 m^3 between 2009 and 2011, the 8th highest of the 14 LiDAR blocks, very little expansion in gully area was measured from repeat LiDAR, a mere 23 m^2 over 2 years. Most of this expansion was measured in one gully, which was also the study gully in air photos.

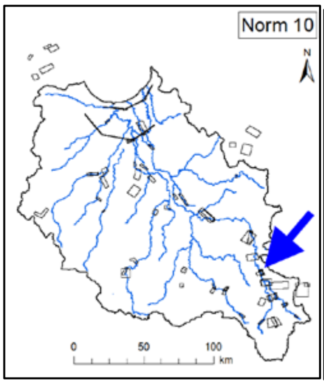


Figure 10.1: Norm 10 location

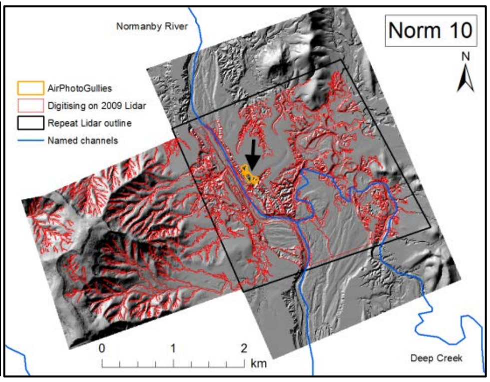


Figure 10.2: Digitising on LiDAR

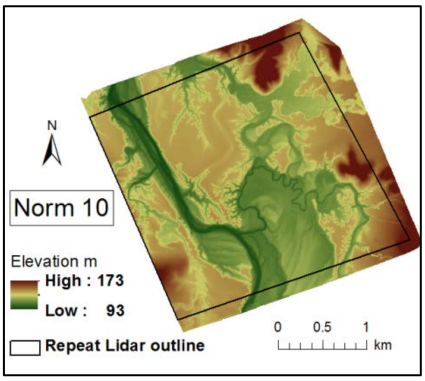


Figure 10.3: DEM from 2009 LiDAR

Table 10.1: General statistics for Normanby 10 LiDAR block.

2009 LiDAR area (ha)	1168
Reprocessed change raster area (ha)	690
Reprocessed extent elevation range (m)	92 – 173
Number of LiDAR digitised features	510
Number of Google Earth mapped gullies	36

7.1 Alluvial and Colluvial geology

Small areas of colluvial slopes were included in the repeat LiDAR footprint, 8% of the block area. The original extent of LiDAR in 2009 included large areas of colluvial slopes with many linear gullies running to the ridge top. The opportunity to measure gully erosion on colluvial slopes was here, though owing to technical issues with the repeat LiDAR collection and processing for this project, any changes over 2 years may have been below detectable limits.

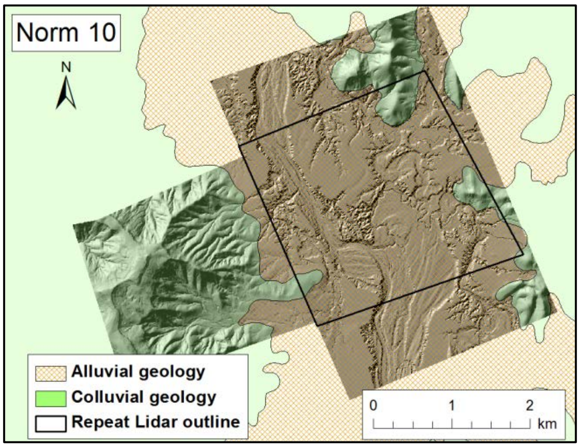


Figure 10.4: Alluvial and colluvial geology in Norm 10.

7.2 Google Earth mapped gullies

Mapping gullies from Google Earth imagery identified 36 bare earth gullies with total area of 7.3 ha within Norm 10. All gullies within the repeat LiDAR footprint were mapped on alluvial geology.

LiDAR imagery identified 346 gully units with a total area of 126 ha. Of these, 3.2 ha or 2.6% of total alluvial gullies were on colluvial geology.

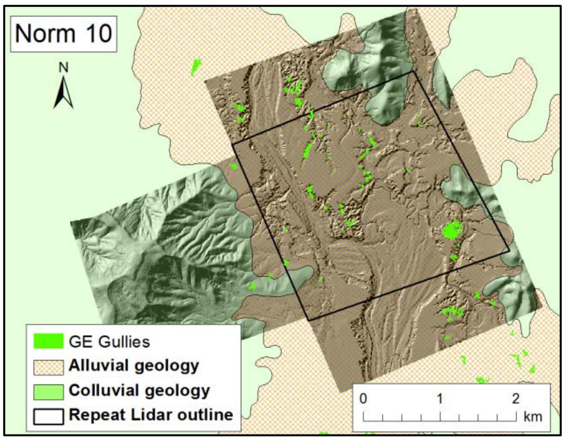


Figure 10.5: Distribution of gullies mapped from Google Earth.

Table 10.2: Gully area digitised from LiDAR and Google Earth in alluvial and colluvial geology.

Normanby 10	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	639	382.7	59.8	122.8	19.2	7.3	1.14
Colluvial zone	51	3.6	7.1	3.2	6.3	0	0

7.3 LiDAR derived data

7.3.1 Horizontal adjustments

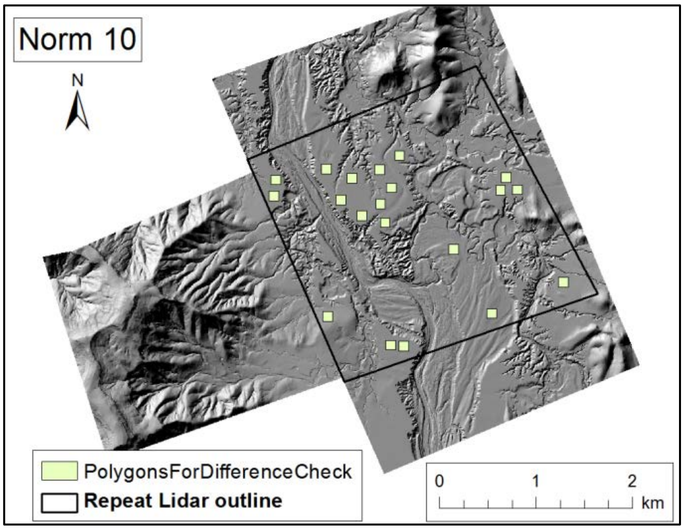
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

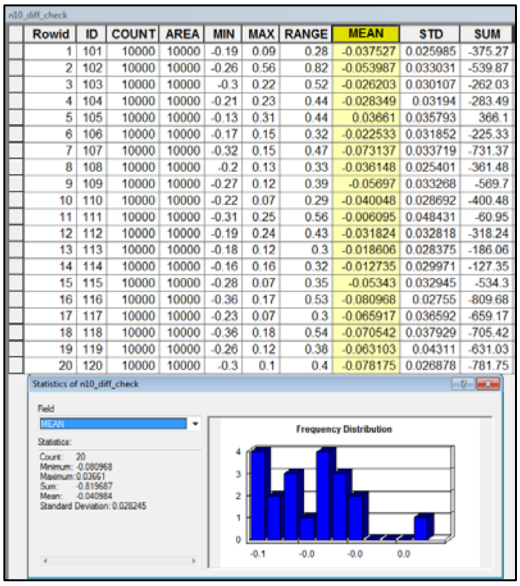
X,Y nudge (m)	1 , -3

7.4 Vertical adjustments

7.4.1 Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.




n10_diff_check

Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	101	10000	10000	-0.19	0.09	0.28	-0.037527	0.025985	-375.27
2	102	10000	10000	-0.26	0.56	0.82	-0.053987	0.033031	-539.87
3	103	10000	10000	-0.3	0.22	0.52	-0.026203	0.030107	-262.03
4	104	10000	10000	-0.21	0.23	0.44	-0.028349	0.03194	-283.49
5	105	10000	10000	-0.13	0.31	0.44	0.03661	0.035793	366.1
6	106	10000	10000	-0.17	0.15	0.32	-0.022533	0.031852	-225.33
7	107	10000	10000	-0.32	0.15	0.47	-0.073137	0.033719	-731.37
8	108	10000	10000	-0.2	0.13	0.33	-0.036148	0.025401	-361.48
9	109	10000	10000	-0.27	0.12	0.39	-0.05697	0.033268	-569.7
10	110	10000	10000	-0.22	0.07	0.29	-0.040048	0.028692	-400.48
11	111	10000	10000	-0.31	0.25	0.56	-0.006095	0.048431	-60.95
12	112	10000	10000	-0.19	0.24	0.43	-0.031824	0.032818	-318.24
13	113	10000	10000	-0.18	0.12	0.3	-0.018606	0.028375	-186.06
14	114	10000	10000	-0.16	0.16	0.32	-0.012735	0.029971	-127.35
15	115	10000	10000	-0.28	0.07	0.35	-0.05343	0.032945	-534.3
16	116	10000	10000	-0.36	0.17	0.53	-0.080968	0.02755	-809.68
17	117	10000	10000	-0.23	0.07	0.3	-0.065917	0.036592	-659.17
18	118	10000	10000	-0.36	0.18	0.54	-0.070542	0.037929	-705.42
19	119	10000	10000	-0.26	0.12	0.38	-0.063103	0.04311	-631.03
20	120	10000	10000	-0.3	0.1	0.4	-0.078175	0.026878	-781.75

Figure 3.6: Locations of polygons for checking bias in the difference raster, and statistics table.

Table 10.3: Statistics of raw difference raster, and corrections applied to reduce bias on non-eroding surfaces.

Layer	min	max	Mean	s.d.
Norm_10_Difference_2009-2001_Reprocessed.tif (as supplied by Terranean)	-9.97	34.18	-0.11	0.66
Extract_tif1 (edges trimmed)	-9.97	10.22	-0.08	0.18
Extract_tif1 (sampled area of minimal change)	-0.08	0.04	-0.04098	0.04
N10_Diff_adjusted	-9.93	10.26	-0.0421	0.16

Table 10.4: Values of change raster filtered to remove noise

raster	Values filtered
erosion	-0.2 to 0
deposition	0 to 0.4

Two layers were created from the modified difference data, one layer for erosion, and one layer for deposition.

Aggressive hand editing of erroneous erosion and deposition values from LiDAR interactions with trees and steep slopes removed approximately 11,000 patches of improbable erosion or deposition.

7.5 Observations from erosion and deposition analysis.

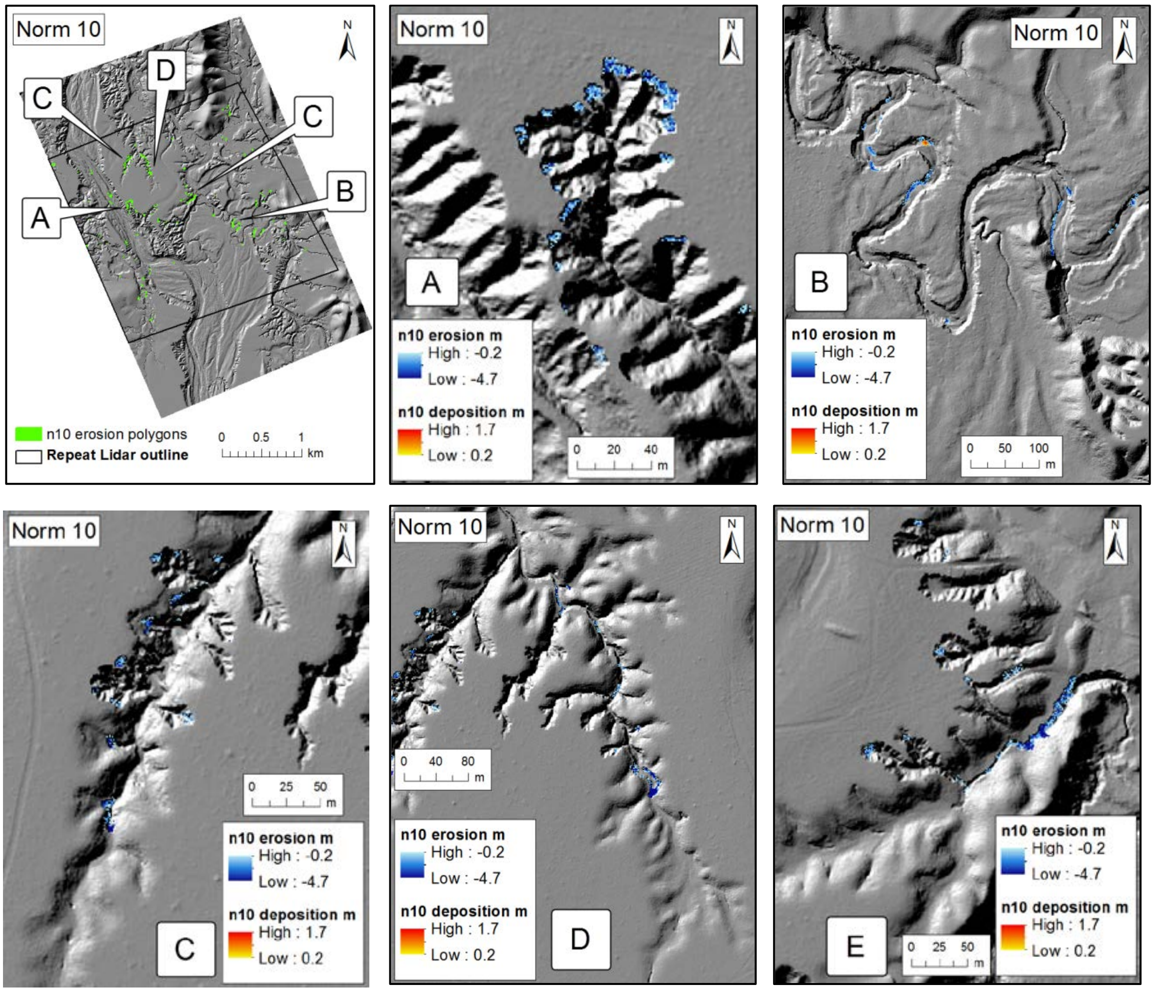


Figure 10.7: location diagram and detail of erosion and deposition hotspots in Norm 10.

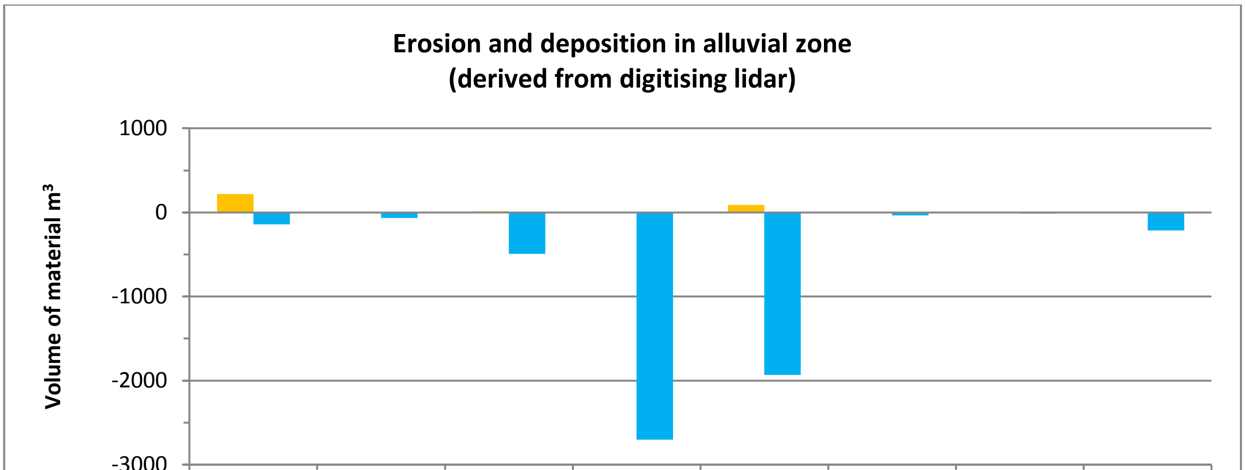
Location A: This gully accounted for all the measured expansion of gully area in Norm 10 between 2009 and 2012.

Location B: The flow path of Deep Creek has many looping bends, and has migrated significantly from historical paths.

Location C: The shallow rounded shoulders of the head of this gully show phases of greater activity in the past have slowed. Recent erosion activity has been on side walls where lateral amphitheatre gullies have formed.

Location D: This gully, adjacent to Location C, has dwn cutting of the gully floor as the main form of erosion. The head of this gullly also shows relative inactivity.

Location E: Multiple roads made up a 10m bank between small amphitheatre gullies.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Deposition	222	0	15	0	90	0	0	0
Erosion	-142	-64	-491	-2704	-1933	-35	-13	-215

Figure 10.8: Quantifying erosion and deposition in alluvial and colluvial zones.

- Erosion from alluvial gullies accounted for 48% of erosion measured between 2009 and 2011.
- Erosion from secondary channels contributed 35% of the erosion total.
- Vegetated main channel bed erosion was 9% of total erosion.
- Open main channel bed had a nett gain of material of 120 m^3.
- Erosion from gullies receiving runoff from roads was 35 m^2 between 2009 and 2011.
- Deposition in secondary channels was 90 m^3, 5% of the 1933 m^3 eroded; again emphasising the role secondary channels play as nett producers of sediment from the landscape.

7.6 Comparison of alluvial gullies to colluvial gullies

Though Norm 10 was surrounded by rising colluvial slopes, the placement of the repeat LiDAR footprint essentially missed these slopes. Area of colluvial gullies in Norm 10 was 2% of area of alluvial gullies; 3 ha compared to 122.8 ha. Volume of erosion from colluvial gullies, 36 m^3 , or 1% of erosion from alluvial gullies.

Table 10.5: Comparison of erosion activity in alluvial and colluvial gullies.

Alluvial gullies				Colluvial gullies			
area ha	deposition m^3	erosion m^3	yield m^3/ha/yr	area ha	deposition m^3	erosion m3	yield m^3/ha/yr
122.8	0	-2704	-11	3	0	-36	-6

7.7 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

Area of alluvial gullies in Norm 10 was 122 ha but gullies mapped in Google Earth were 6% of this figure; slightly less than the average across 13 LiDAR blocks where Google Earth mapping identified 10% of the area of alluvial gullies mapped from LiDAR.

Table 10.6: Comparison of erosion activity in LiDAR and Google Earth gullies.

	Area ha	Erosion m^3	Yield m^3/ha/yr
LiDAR alluvial gullies	122.8	-2704	-11
GE alluvial gullies	7.3	-240	-17

Volume of material eroded from Google Earth gullies was 240 m^3 between 2009 and 2011, 9% of the volume eroded from alluvial gullies, a similar order of magnitude.

7.8 Gully Expansion 2009 – 2011

Erosion activity was almost entirely within 2009 gully perimeters. Ten lobes of expansion were identified from repeat LiDAR, mostly in one gully, with a total increase in area of 23 m^2 over 2 years; that's 11.5 m^2 per year, which about the size of a small bathroom, and not much at all spread over a 690 ha block. Allowing for shortcomings of repeat LiDAR for this project, the increase in gully area was negligible.

Table 10.7: Area of expansion of gullies between 2009 and 2011.

Gully Expansion 2009 - 2011	
number of gully expansion locations	10
sum area of gully expansions m^2	23
mean area of expansion m^2	2.3

7.9 Landscape Classification

A significant feature of Norm 10 was 2 levels of flood plain on either side of a bend in the main channel. Vegetated channel bed, with obvious flow sculptured patterns below a 20 m canopy, was 5 m above main channel bed. Ten metres above main channel height, but 10 m below ancient flood plain height, was an 82 ha surface with channels describing the path of the main channel in times gone by.

Secondary channels also had large areas of associated flood plain, 74 ha, on surfaces 8 to 12 m below the level of ancient flood plain.

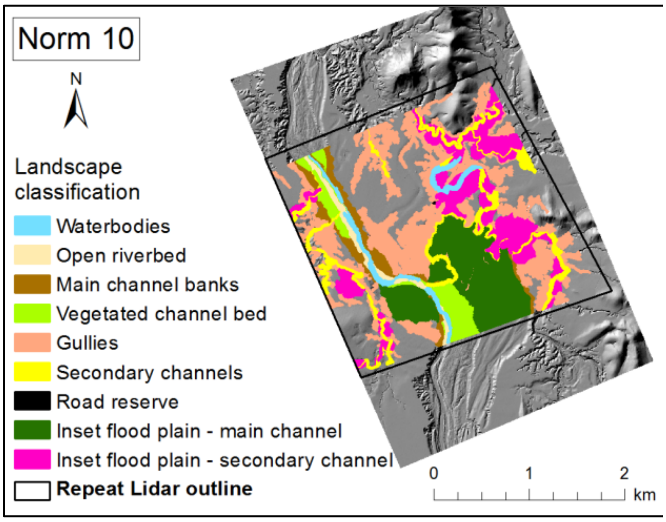
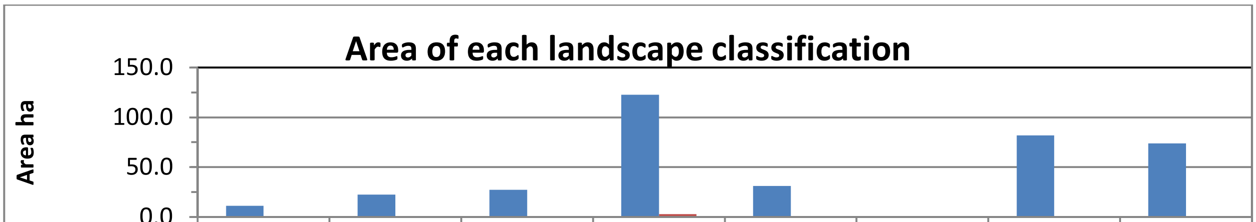


Figure 10.9: Landscape classification in Norm 10.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Alluvial ha	11.3	22.3	27.2	122.8	31.2	0.1	81.8	73.8
Colluvial ha	0	0	0	3	0	0	0	1

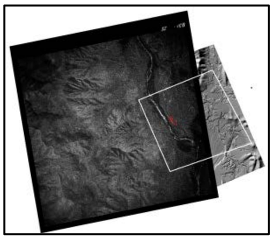
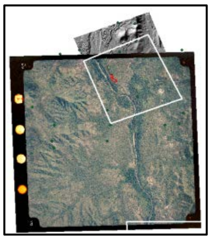
Figure 10.10 Area of each landscape unit in alluvial and colluvial zones.

7.10 Historical air photos

One gully was identified in historical air photos from 1952 and 1987. This gully had active erosion at the head scarp, and was responsible for all of the 23 m^2 of measured gully expansion in Norm 10 between 2009 and 2011.

Table 10.8 Meta data for air photos in Norm 10.

Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block

01-Jan-52	QAP 311-28	23900	12750ft	1.34	
01-Jan-87	QAP 4111-173	25000	4310m	3.79	

Gully perimeter defined in 1987 was, in some places, inside the perimeter digitised from 1952 air photo. A good match between gully perimeter in 1952 and 2009 LiDAR was consistent with the appearance of the gully as being relatively inactive on the older surfaces. Misalignment of gully perimeter in 1987 could be due to vegetation obscuring gully edges.

Gully area in 1952 was 20.07 ha, in 1987 2.10 ha.

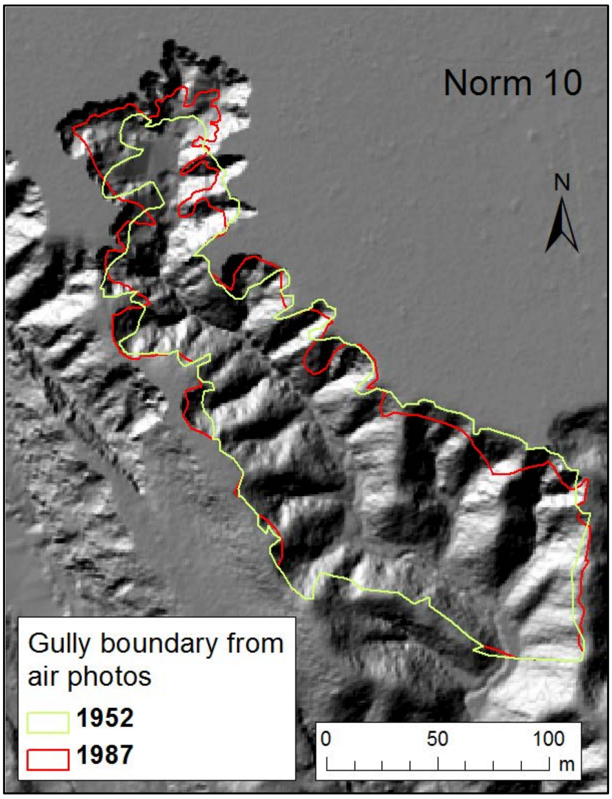


Figure 10.11: Gully perimeter in 1952, 1987 and 2009.Variability in rates of erosion over different time scales was found, with the rate over 5 decades from 1950s to 2009 being 81 m^2/ha/yr; over 2 decades from 1890's being 170 m^3/ha/yr, and over 2 years from 2009 to 2011 being 104 m^3/ha/yr.

Table 10.9: Erosion rates calculated from air photo records and repeat LiDAR analysis for N10 g1. Yield between 2009 and 2011 was 128% of 5 decade rate, but 61% of 2 decade rate. Rate of erosion over 5 decades in N10 g1 was below the average rate of 13 air photo gullies, but rate over 2 decades was greater than average. Yield calculated from Repeat LiDAR was slightly below average rate.

	Yield: volume material lost divided by area of 2009 gully divided by interval m3/ha/yr		
	Air photo data		LiDAR data
	1950s to 2009	1980s to 2009	2009 to 2011
N10 g1	81	170	104
average of 13 air photo gullies	91	112	115

8. Normanby LiDAR Block 13

Normanby 13 LiDAR block (Norm 13) is located 200km inland, with the main features within the repeat LiDAR footprint being an alluvial plain (90 m elevation) with a series of linear gullies, some of which have developed to secondary channels. A time lapse camera was located on one of the secondary channels.

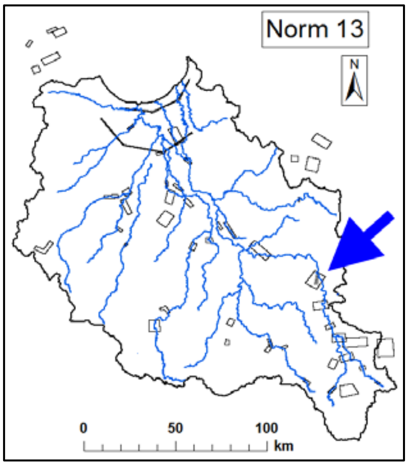


Figure 13.1: Location of Norm 13

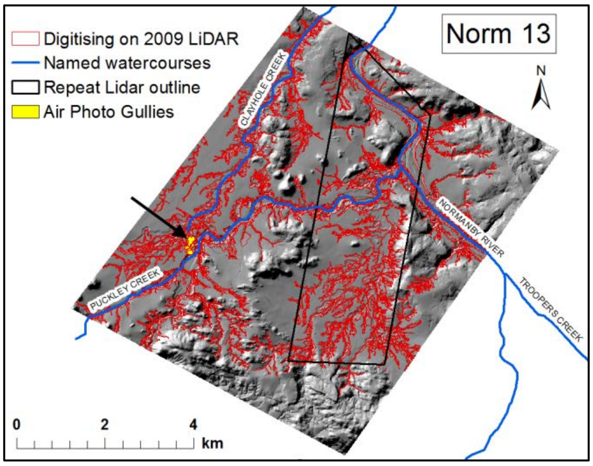


Figure 13.2: Features of Norm 13

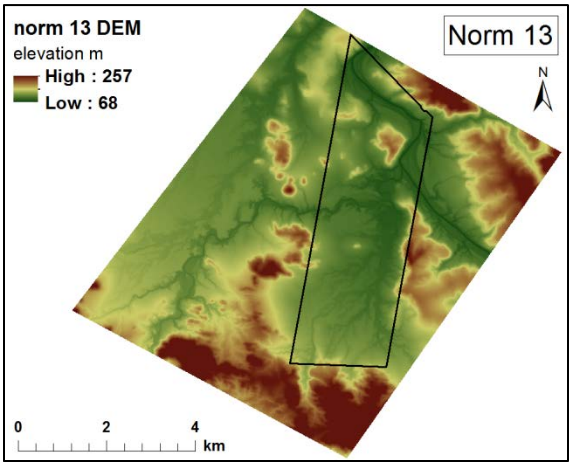


Figure 13.3: Elevation range and landform from 2009 DEM

Table 13.1: General statistics

Reprocessed Change raster	ha	1422
Block elevation range	m	68 to 176
Number of LiDAR digitised features		961
Number of Google Earth mapped gullies		132

8.1 Alluvial and Colluvial zones

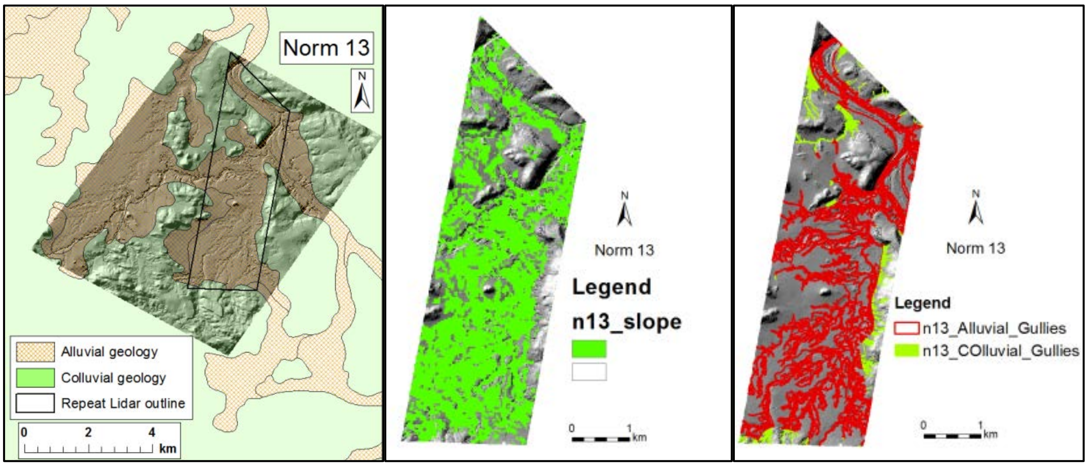


Figure 13.4: The mapped extent of alluvial geology was tested against a slope analysis derived from a 1 second (30m) DEM. Slopes 3 degrees or less, the threshold used to identify broad expanses of alluvial deposits are shown in green, and show a satisfactory match with alluvial mapping from 1:1 million geology. Gullies extending from alluvial surfaces to colluvial slopes are shown in panel 3.

Table 13.2: Comparison of features in alluvial and colluvial geology.

Normanby 13	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area alluvial gullies digitised from LiDAR ha	Area alluvial gullies as % of zone	Area of Google Earth digitised gullies ha	GE gullies as % of zone
Alluvial zone	1040	489	47	225	21.7	22.6	2.2
Colluvial zone	382	40	10	31	8.0	1.75	0.5

8.2 Google Earth mapped gullies

Within the repeat LiDAR footprint, 2.2% of the alluvial surfaces were mapped as gullies from Google Earth, which was approximately 10% of the area of gullies mapped from LiDAR.

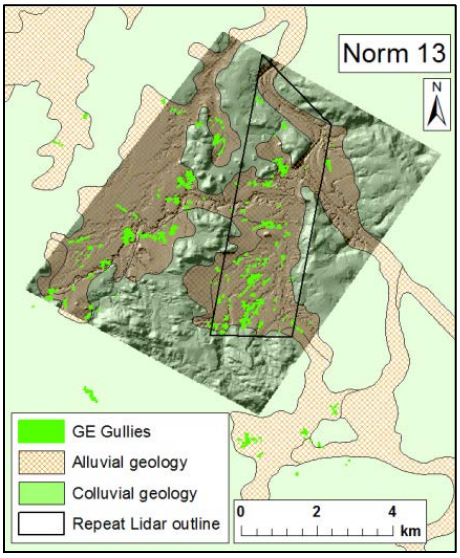


Figure 13.5: Distribution of Google Earth mapped gullies in and around Norm 13.

8.3 LiDAR derived data

8.3.1 Horizontal adjustments

Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

X,Y nudge (m)	1 , −1

8.3.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.

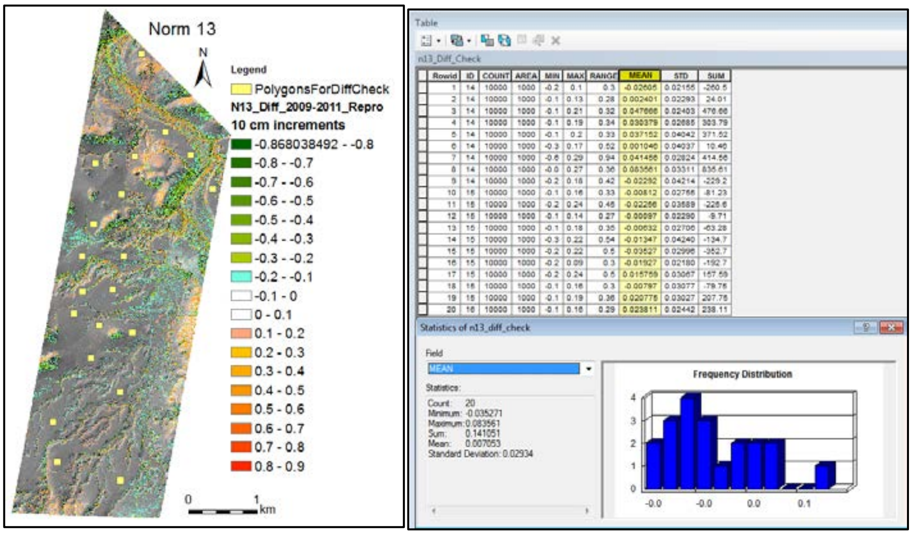


Figure 13.6: Location of polygons to test for bias in the difference raster, and statistics table.

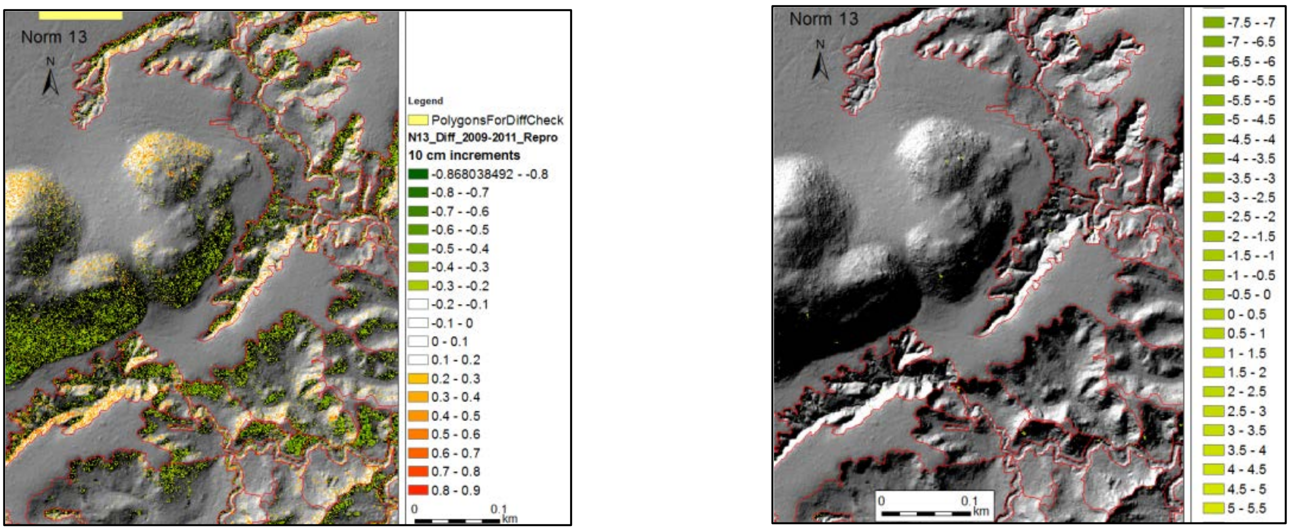


Figure 13.7: Result of misalignment of 2009 and 2011 DEMs showed up in difference raster.

A distinct pattern of erosion/deposition occurred in gullies depending on aspect. Flood plain is clear of noise after a filter of values 20cm above and below 0 had been applied to the difference raster.

Filtering values 1 metre above and below zero cleared noise from gullies. Erosion sites with head scarps greater than 1 m were still identified from the difference raster.

Table 13.7: : Statistics of raw difference raster, and corrections applied to reduce bias on non-eroding surfaces.

Layer	min	max	Mean	s.d.
Norm_13_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-25.98	45.97	-0.009	0.19
Norm_13 with edge effect removed	-9.32	7.29	-0.011	0.15
Areas of minimal change	-0.03527	0.083561	0.007053	0.02934
N13_Diff_adjusted	-9.327	7.283	-0.0178	0.15

The level of noise on flat flood plain areas has been ascertained, and these values removed from the erosion and deposition layers.

Table 13.8: Values of change raster filtered to remove noise on floodplain.

raster	Values filtered
erosion	-0.2 to 0
deposition	0 to 0.2

8.4 Aggressive filtering of erosion and deposition data

Table 13.9: Effect of aggressive filtering on erosion and deposition data

Area and value of erosion/deposition in gullies (after noise on flood plain cleared).	erosion	deposition
Area m^2	73,440	11,820
Sum total of all erosion/deposition cells	-67,613	14,644

Area and value of erosion/deposition in gullies AFTER aggressive hand editing		
Area m2	33,887	70
Sum total of all erosion/deposition cells	-10,608	53

8.5 Observations

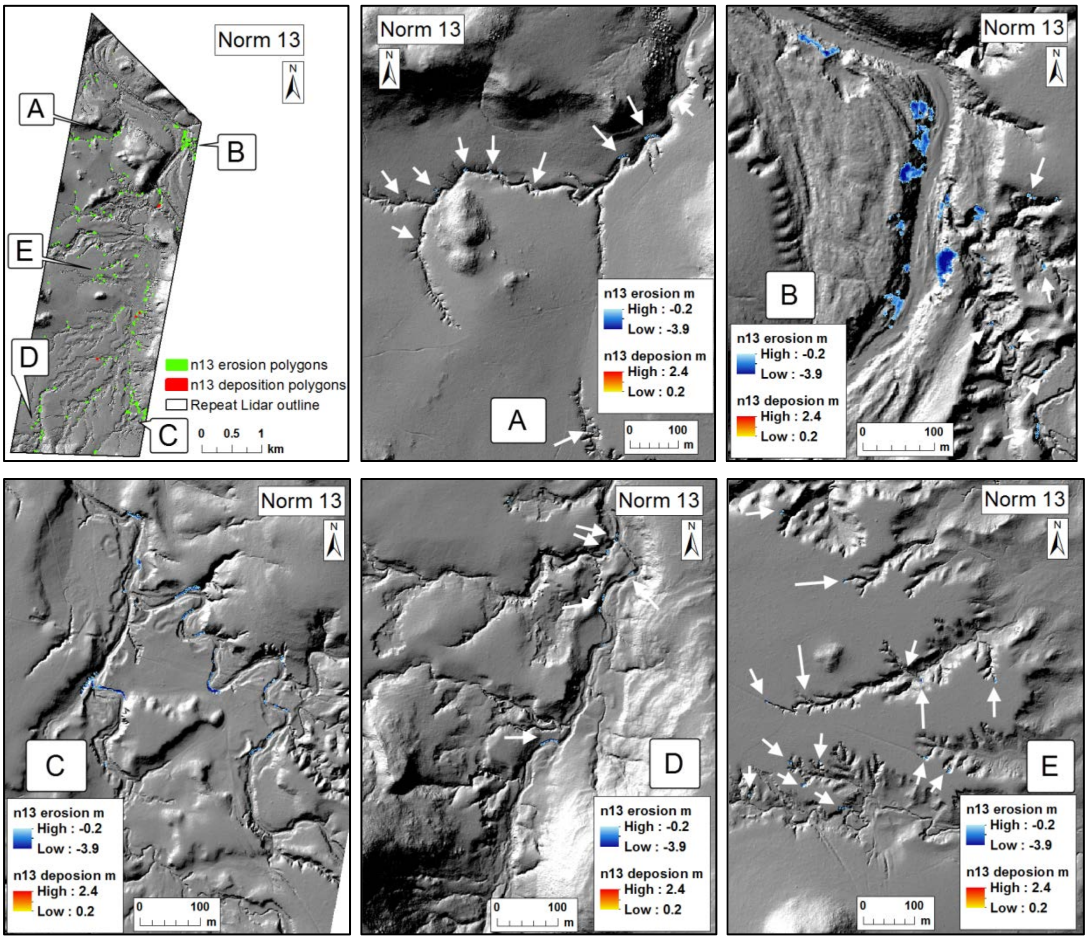


Table 13.8: Location diagram and erosion and deposition hot spots in Norm 13.

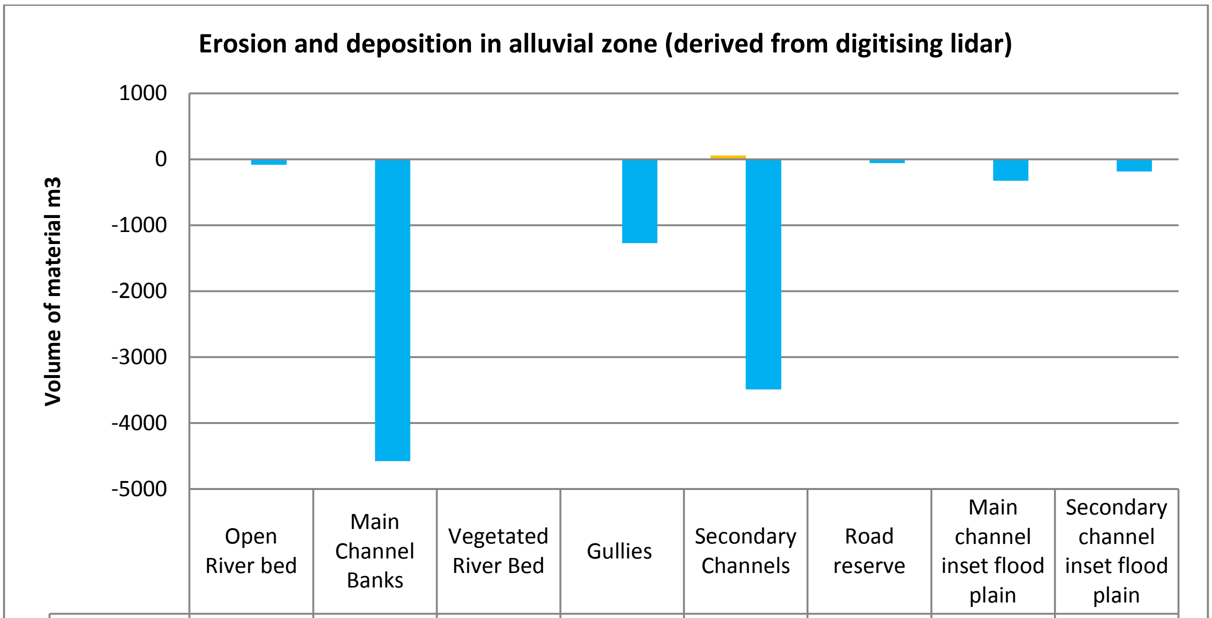
Location A: Small erosion sites along the path of a secondary channel.

Location B: Large erosion sites on banks of the main Normanby River, and small erosion sites (white arrows) in gullies and along a secondary channel. Main channel banks appear to have slumps along the relatively straight reach that is the inside of a large radius bend.

Location C: Erosion to the outsides of bends along a secondary channel.

Location D: No measurable gully erosion occurred between 2009 and 2011, though some secondary channel erosion has occurred.

Location E: Gully erosion occurring on very narrow head scarps. Areas of measured erosion were relatively small.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Deposition	0	0	0	0	54	0	0	0
Erosion	-86	-4577	0	-1273	-3488	-62	-326	-186

Figure 13.9: Sum of erosion and deposition for landscape classes in the alluvial zone

- Very little deposition has occurred in Norm 13
- Significant bank erosion has occurred along main channel and secondary channel banks
- Some shallow erosion channels were seen to extend, but were not deep enough to be picked up by the 1m deep threshold for detecting real change from data noise.
- Advancing step changes in the bed of some secondary channels was seen.

The largest volumes of erosion were found at two patches on the banks of the main channel, which were nearly opposite each other. Volumes were −1731 and −1434 respectively. These patches also had the highest yields seen in this block, being −1631 and −2481 m^3/ha/yr respectively.

Only 14 out of 124 Google Earth gullies had erosion, according to the aggressively filtered data.

8.6 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

The area of gullies identified from Google Earth was 10% of the area of alluvial gullies identified from LiDAR, but erosion from Google Earth gullies was 13.5% of the volume of erosion from alluvial gullies. The yield from Google Earth gullies was 134% of the yield from alluvial gullies.

Table 13.10: Comparison of erosion from LiDAR alluvial gullies and Google Earth mapped gullies.

	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial	225.08	-1745.83	-3.88
GE gullies alluvial	22.64	-235.73	-5.21

8.7 Gully Expansion 2009 – 2011

Very little expansion of alluvial gullies occurred between 2009 and 2011, with no locations standing out as having rapid extension compared to other LiDAR blocks. Gully boundaries were expanded in 44 locations to accommodate gully expansion, with a total of 73 m^2 increase in gully area.

The following table summarises gully expansion between 2009 and 2011.

Table 13.11: Gully expansion between 2009 and 2011.

Gully Expansion 2009 - 2011	
Number of gully expansion locations	44
Area of gully expansions m2	73
Mean area of expansion m2	1.7

8.8 Landscape Classification

The main channel in Norm 13 was mostly confined by banks about 5m high, there was very little open riverbed or vegetated riverbed near the water level for lateral flow expansion. Long sinuous secondary channels with shallow eroded banks and associated inset flood plain extended from the main channel towards hill country in the south of the block.

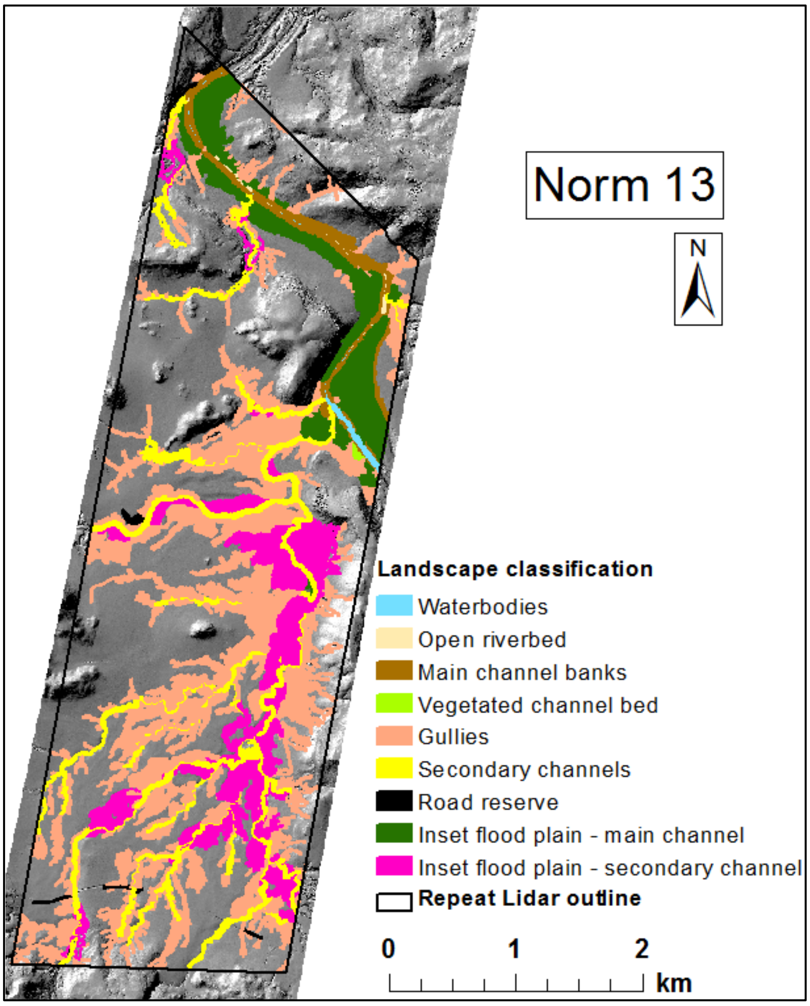
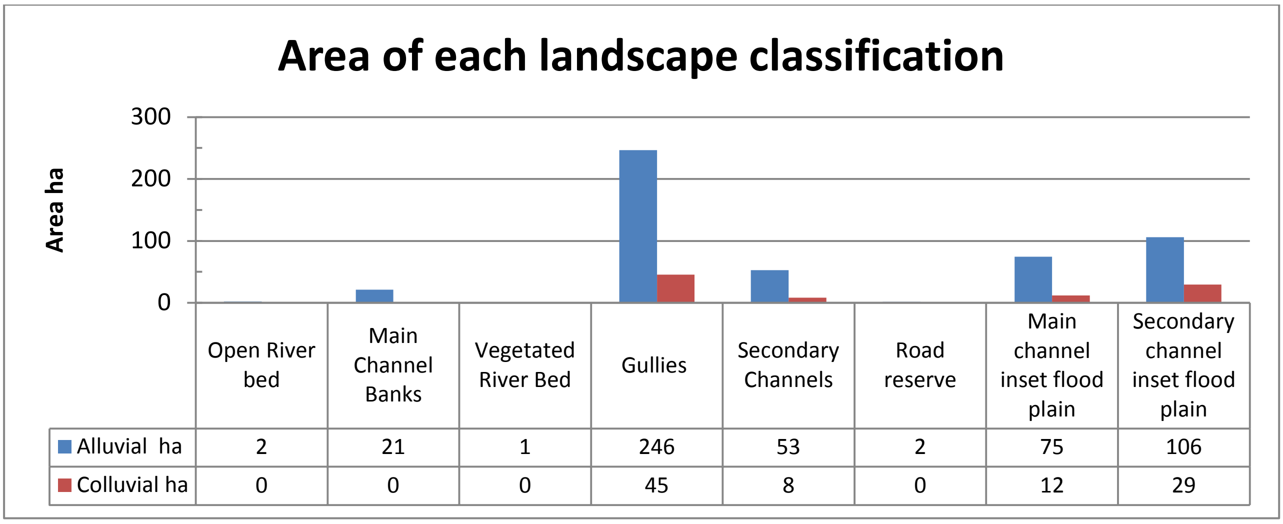


Figure 13.10: Landscape classification in Norm 13.



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Road reserve	Main channel inset flood plain	Secondary channel inset flood plain
Alluvial ha	2	21	1	246	53	2	75	106
Colluvial ha	0	0	0	45	8	0	12	29

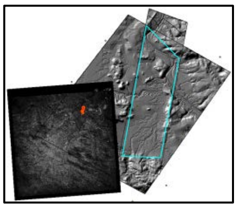
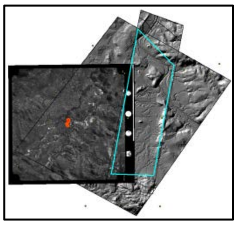
Figure 13.11: Broad, shallow alluvial gullies were the dominant landscape feature on the valley floor. Large areas of inset flood plain were adjacent to the secondary channel along the eastern boundary of the block. The main channel also had inset flood plain along its length.

8.9 Historical air photos

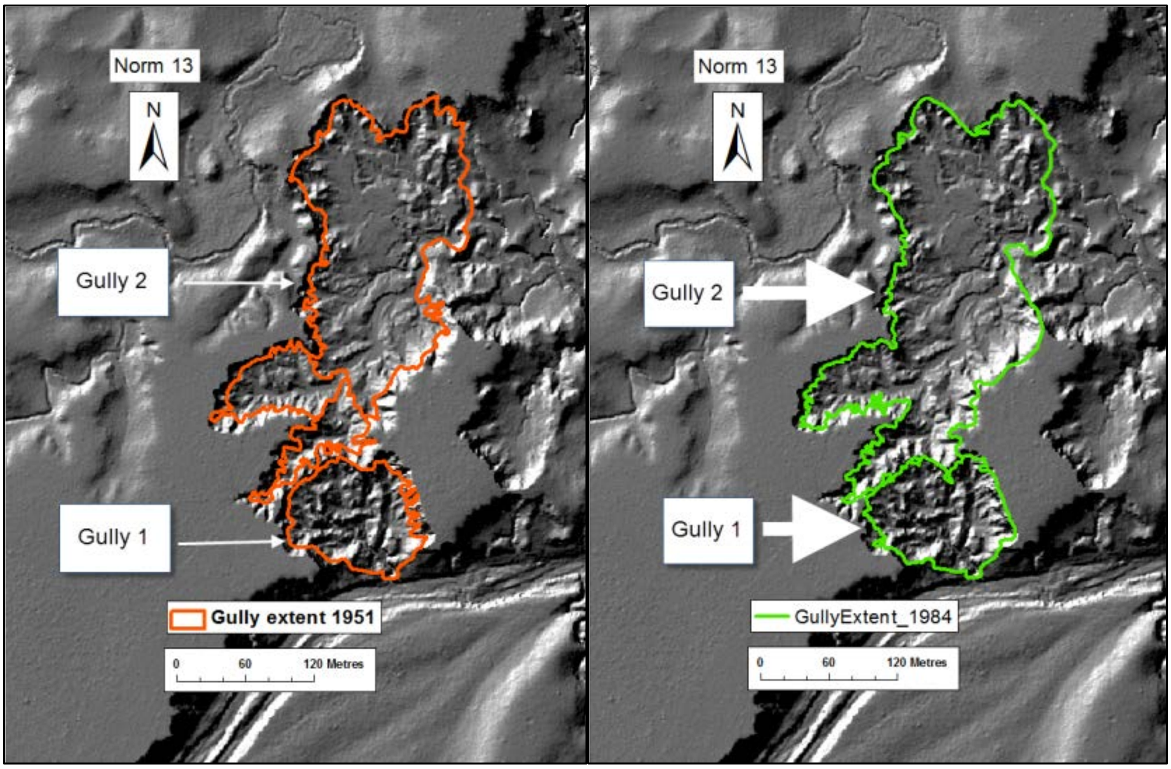
The following table summarises details of historical air photos identifying 2 adjacent gullies deeply cutting into the ancient flood plain. Both gullies exit into a large secondary channel.

Unfortunately both gullies identified in historical air photos were not covered by reprocessed LiDAR, so no valid rates of erosion could be calculated. These gullies appeared particularly active, so would be interesting to revisit if LiDAR data covering them was reprocessed at some future date.

Table 13.12: Meta data for 2 gullies identified from air photos.

Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block
1/01/1951	QAP307-20	25400	12750ft	1.76150	
3/07/1984	QAP-4186-053	24900	3950m	2.92806	

8.10 Historical gully extent



Gully one and two are massive excavations of around 10 m depth eating into ancient flood plain.

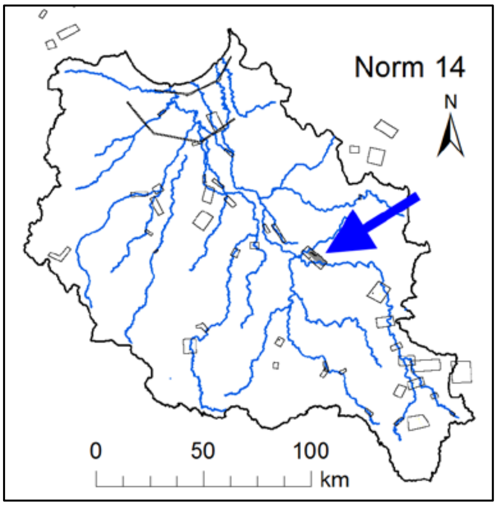
Though planemetric area has not increased markedly since 1951, the depth of walls means a lot of material would be eroded for small increases in surface area.

9. Normanby LiDAR Block 14

Normanby 14 LiDAR block (Norm 14) was located 13 km upstream of the junction of the Normanby and Laura rivers, and 160 km inland. The slope inside the repeat LiDAR footprint was particularly flat, with an elevation gain of 12 m over 10 km, allowing a great mixing bowl of flood waters from Cabbage Tree Creek, Brown Creek and the Normanby River to form during flood flows.

The two gullies within the repeat LiDAR footprint have evolved to secondary channels for most of their length. Gully extension at the terminal end of these two gullies was spectacular between 2009 and 2011, in excess of 99m in one case.

Patterns seen in LiDAR imagery suggest the driving forces for such rapid gully advance to be overland flow from the Normanby River.



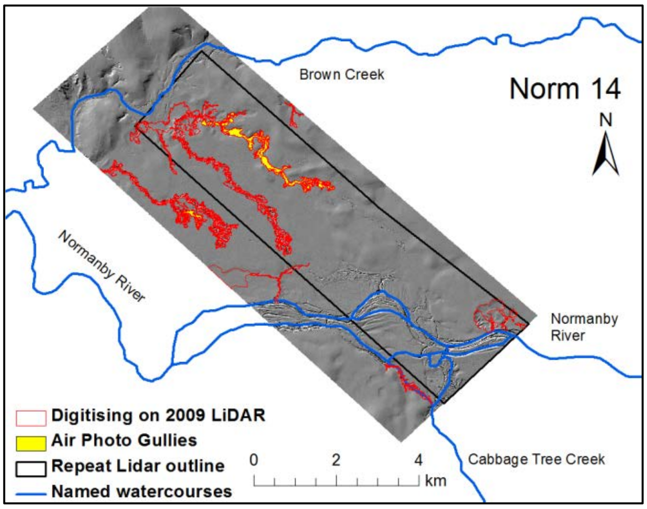


Figure 14.1: Location of Norm 14.

Figure 14.2: Features in Norm 14.

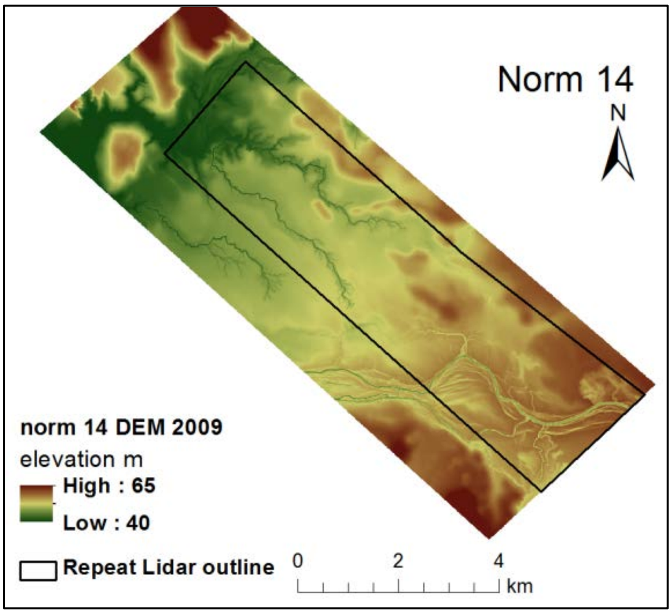


Figure 14.3: Elevation ranges in and around Norm 14.

Table 14.1: General Statistics.

Reprocessed change raster area	ha	2580.4636
Block elevation range	m	60.22 to 42.73
Number of LiDAR digitised features		218
Number of Google Earth mapped gullies		1

9.1 Alluvial and Colluvial zones

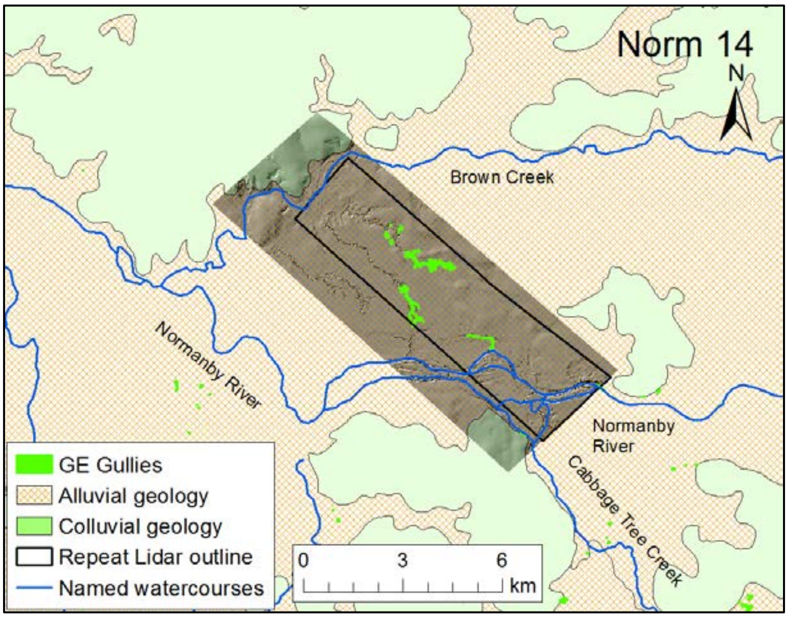


Figure 14.4: Norm 14 repeat LiDAR foot print was entirely on alluvial geology. The main linear gullies digitised from Google Earth imagery rapidly change from pure gully to channel geometry, so the true extent of their "gulliness" was subjective.

Table 14.2: Comparison of area of alluvial gullies and channels to area captured from Google Earth mapping. Approximately 65% of features digitised from LiDAR were gullies. Google Earth mapping of gullies picked up 20% of the gully area mapped from LiDAR.

Normanby 14	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area alluvial gullies digitised from LiDAR ha	Area alluvial gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	2580.5	198.4	7.7	127.0	4.9	25.1	1.0
Colluvial zone	0	0	0	0	0	0	0

9.2 LiDAR derived data

9.2.1 Horizontal adjustments

Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

X,Y nudge (m)	1 , -2

9.2.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.

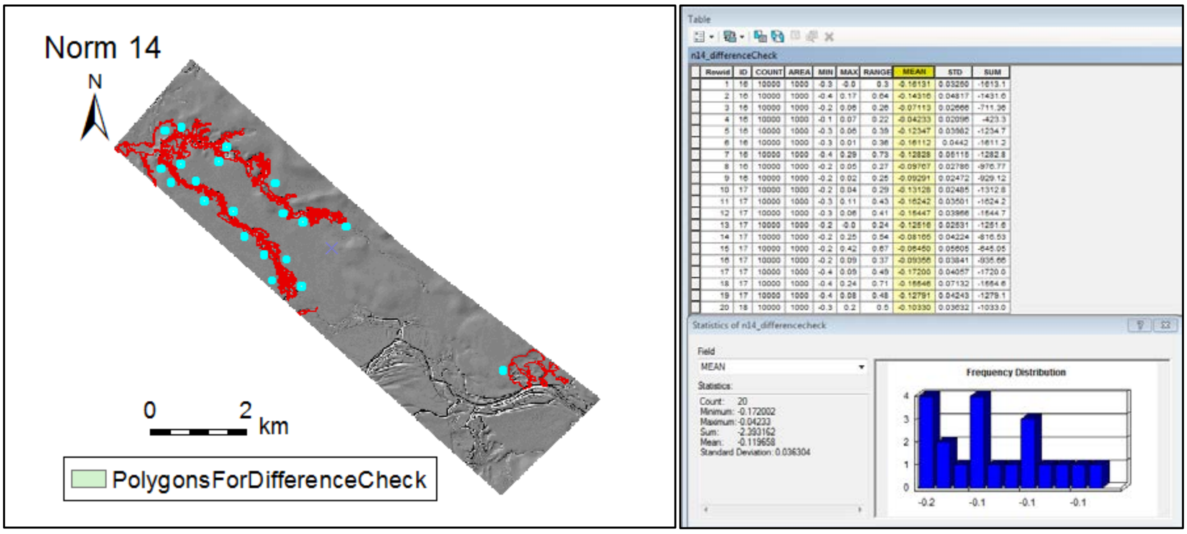


Figure 14.4: Distribution of sample polygons to test bias in the difference raster; and statistics table.

9.3 Statistics

Table 14.3: Locations of polygons for checking bias in the difference raster, and statistics table.

Layer	min	max	Mean	s.d.
Norm_14_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-6.699	3.95	-0.1264	0.11
Norm_14 with edge effect removed	-6.69	3.95	-0.12633	0.11
Areas of minimal change	-0.17	-0.04	-0.119658	0.04
N14_Diff_adjusted	-6.58	4.07	-0.0066	0.11

The level of noise on flat flood plain areas has been ascertained, and these values removed from the erosion and deposition layers.

Values of change raster filtered to remove noise on floodplain.

Table 13.4: Values of change raster filtered to remove noise

raster	Values filtered
erosion	0 to -0.2
deposition	0 to 0.2

9.4 Aggressive filtering of erosion and deposition data

Norm 14 sits on a relatively flat alluvial flood plain and has little of the steep gully walls and vegetation interactions that have caused problems with spurious erosion and deposition values in blocks with steeper slopes in the landscape. Depth of gullies near rapidly extending headwalls was in the range of 2 to 3m. But filtering erosion values in the range -1 to 0 resulted in many extending gullies not being represented; filtering values -0.5 to 0 allowed many shallow gullies to be included in the analysis. It was decided to filter values between -0.5 and 0.5 in this block.

Table below shows the volume of data removed by hand thinning erroneous erosion and deposition data.

Table 13.5: Volume of data removed by aggressive hand editing process.

	erosion		deposition	
	area ha	raster sum	area ha	raster sum
Prior to hand thinning	16.8151	-123,665	34.6027	34.6027
After hand thinning	5.8955	-51,237	3.8476	6,535

9.5 Observations

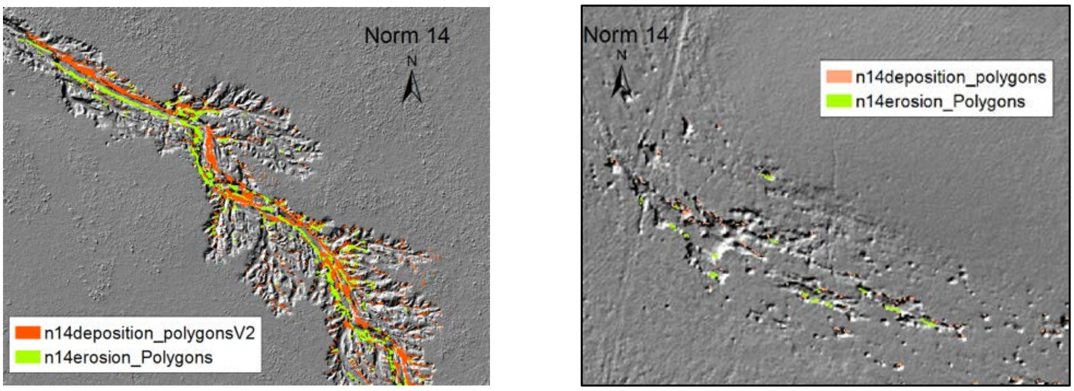
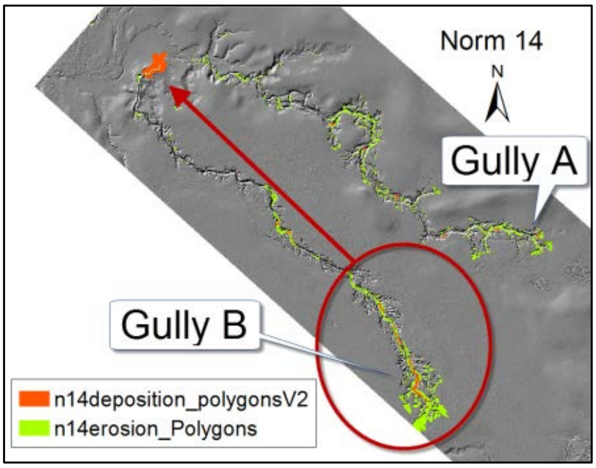
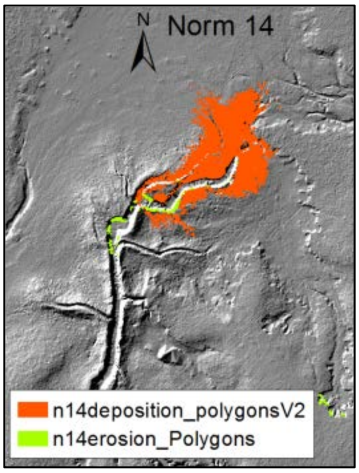


Figure 14.5: Pattern of erosion and deposition.

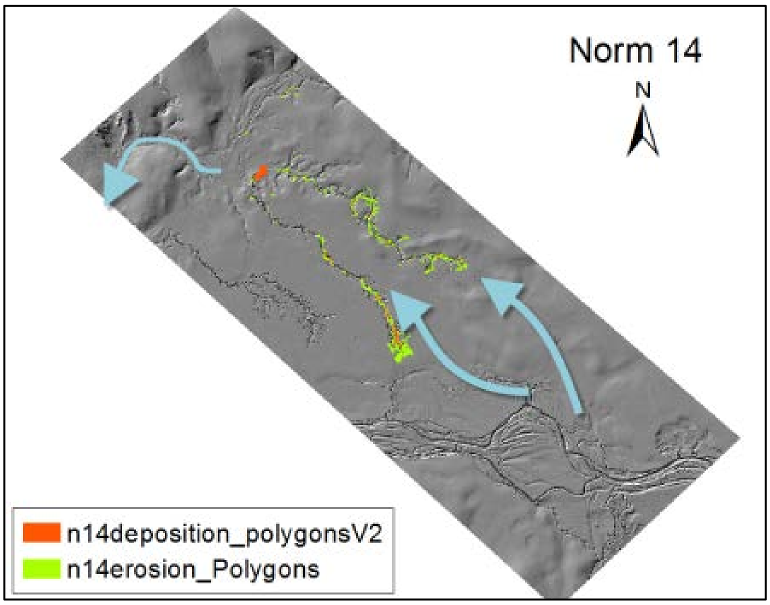
A pattern of deposition on N and NE banks and erosion on S and SW banks was obvious. Is it possible the channel is migrating towards the SW?

Pig rooting areas did not seem to be expanding appreciably.





In-channel as well as delta style end-of-channel deposition was seen in the rapidly extending gully B.



This gully process seems to be driven by overland flow from the main Normanby channel. These 2 gullies will probably join with the main channel and re-route high flows.

9.6 Erosion and deposition

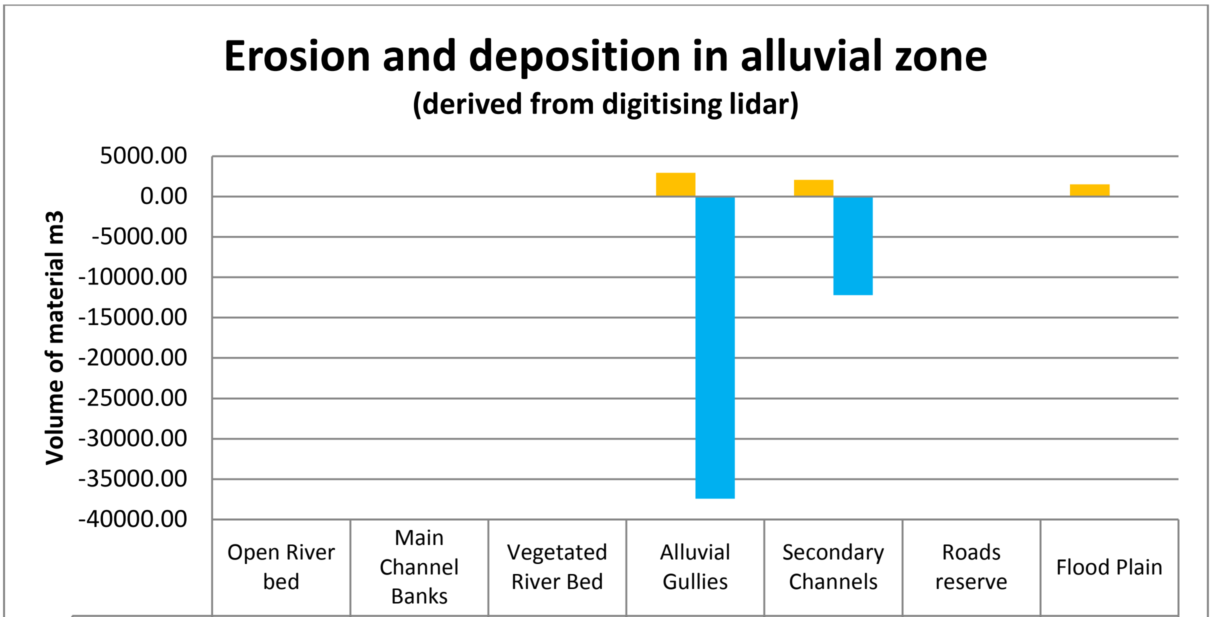
The surface area all gullies and channels in this block expanded by 1.5566 ha between 2009 and 2011, from 164.338 ha to 165.8957 ha. This was approximately a 1% expansion in surface area.

Linear gully extension up to 99m was measured at the head of gully B. Unfortunately the 2011 LiDAR swath did not capture the full extent of this gully extension to quantify this in the fullest.

Erosion of -41,289m^3 within the gully B complex resulted in a total deposition of 5916m^3. This comprised of 2762m^3 within alluvial gullies, 1650 m^3 in channel beds and 1503 m^3 onto the flood plain at the exit of the gully.

The 2 main gullies discharged onto a broad shallow basin. The less active gully A did not appear to be actively depositing into the basin, according to this data set; where-as the very active gully B was actively depositing into a delta zone.

Erosion from alluvial gullies and channel bed of the gully A was -4545 and -3553m^3 respectively. Deposition in the gully A was 113 and 422m^3 respectively. Most material would seem to be transported out the study area.



	Open River bed	Main Channel Banks	Vegetated River Bed	Alluvial Gullies	Secondary Channels	Roads reserve	Flood Plain
Deposition	0.00	0.00	0.00	2931.11	2073.21	0.00	1503.26
Erosion	0.00	0.00	0.00	-37413.65	-12210.56	0.00	-16.06

Figure 14.6: Volumes of erosion and deposition in Norm 14.

9.7 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

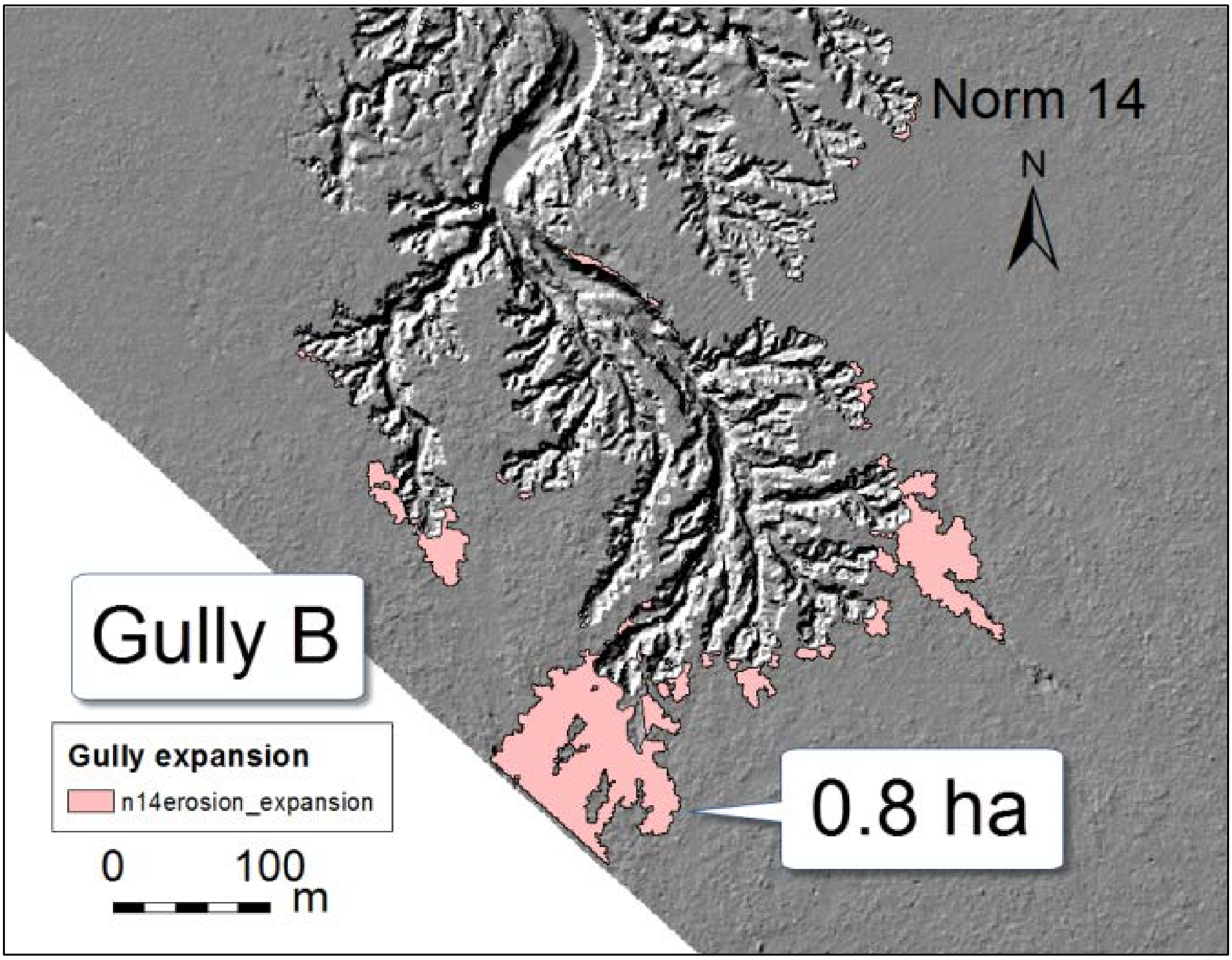
	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial	127	-37391	-136
GE gullies alluvial	0	-176	-674

9.8 Gully Expansion 2009 – 2011

During the 2 years between LiDAR surveys, 1.6 ha of land was lost to gullies in this block. Nearly half this sum, 0.8 ha, was lost in one patch at head of gully B, where the linear extension of the gully was well over 99m.

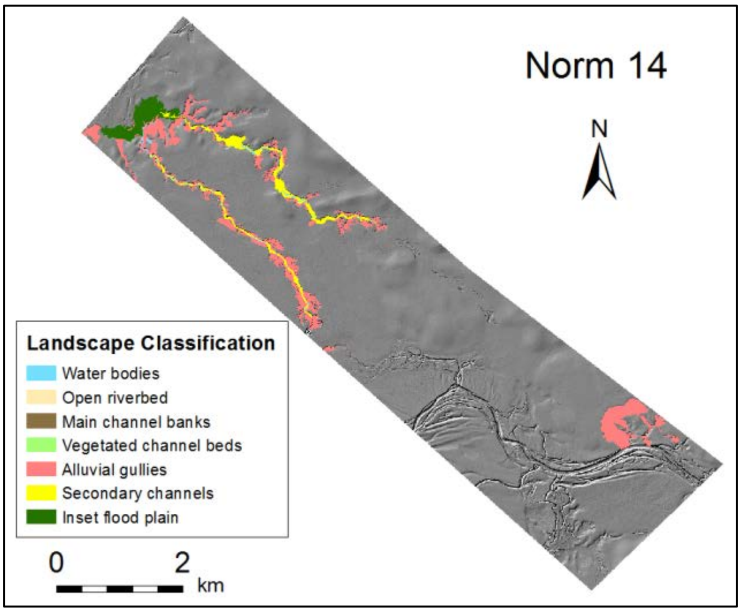
The following table summarises total gully expansion between 2009 and 2011.

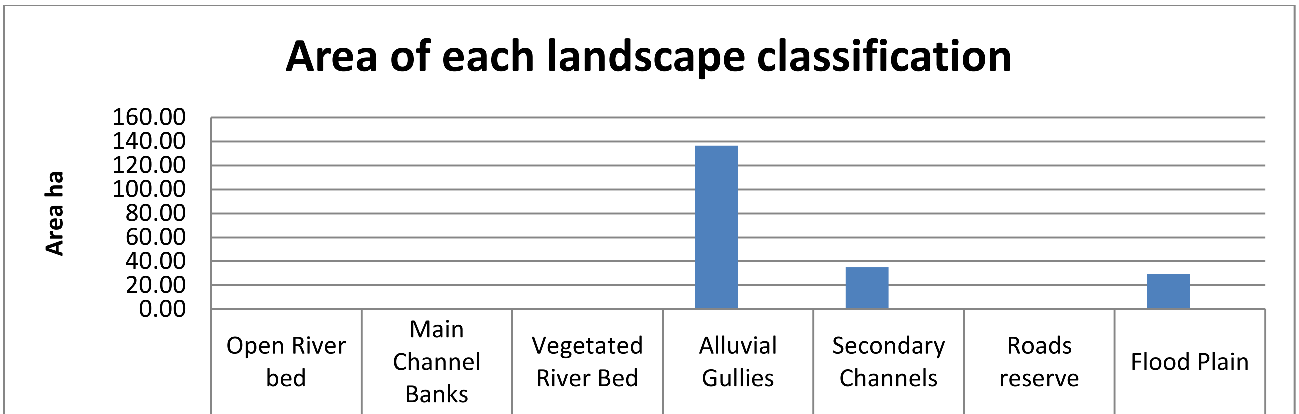
Gully Expansion 2009 – 2011	
number of gully expansion locations	247
area of gully expansions ha	1.5577
mean area of expansion m2	63



9.9 Landscape Classification

The main channel of the Normanby River had not been digitised in this block, so details for open river bed, main channel banks and vegetated river beds are not available. Alluvial gullies, secondary channels and an area of flood plain at the mouth of the 2 prominent gullies have been quantified in the table below.



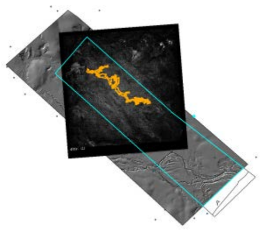


	Open River bed	Main Channel Banks	Vegetated River Bed	Alluvial Gullies	Secondary Channels	Roads reserve	Flood Plain
Alluvial ha	0.00	0.00	0.00	136.51	35.01	0.00	29.38
Colluvial ha	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

9.10 Historical air photos

The following table summarises details of historical air photos identifying a broad expanse of gully to the east of the main channel.

Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block

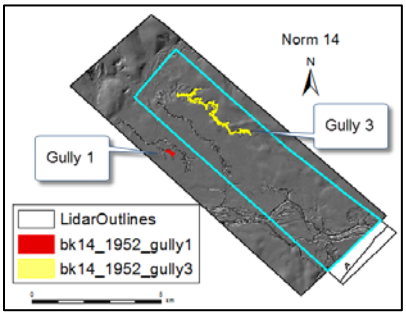
1/01/1952	QAP303-123	23900	12750ft	2.33578	

9.11 Historical gully extent

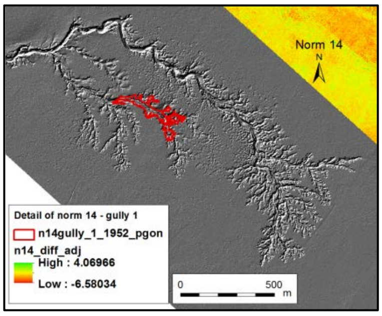
9.11.1 Gully 1

Gully 1 was a branch of a multi headed gully/channel expansion that extended approximately 230m between 1952 and 2009. Unfortunately gully 1 fell outside the area of repeat LiDAR that would allow calculation of recent erosion rates. However, volume of material lost has been calculated by reconstructing the surface of the gully from 2009 LiDAR data.

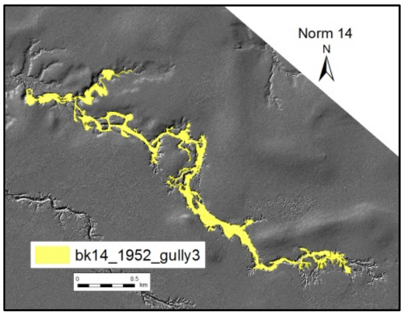
1952 Gully outlines



1952 Gully 1 detail



1952 Gully 3 details



Interval	Gully area ha	Rate of loss m^3/yr	Yield m3/ha/yr Based on 2009 gully area
1952 – 2009	5.97	354	1687

9.11.2 Gully 2

(Gully 2 calculations were abandoned due to poor aerial photo details)

9.11.3 Gully 3

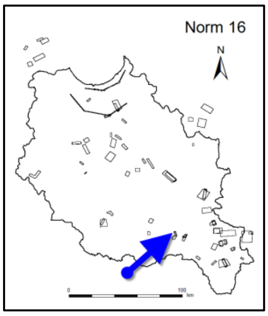
The loss of 4,418m^3/yr of material from Gully 3 seemed an unrealistically large volume. As this was calculated from the original “dodgy” 2009 LiDAR data, a check was run using reprocessed 2009 LiDAR data. The reprocessed 2009 LiDAR returned a rate of loss of 3,135m^3/yr, approximately 70% of the value calculated in the first instance.

A yield of 33.95m³/ha/yr calculated from repeat LiDAR was 58% of the yearly rate of erosion calculated from the air photo and surface reconstruction method.

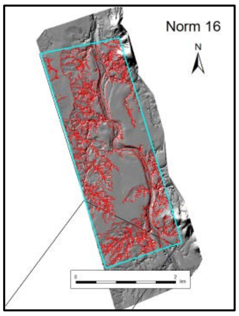
Interval	Gully area ha	Rate of loss m³/yr	Yield from air photo m³/ha/yr Based on 2009 gully area	Yield from repeat LiDAR m³/ha/yr
1952 – 2009 Using original 2009 LiDAR data	53.85	4,419	82.05	
1952 – 2009 Using reprocessed 2009 LiDAR data to check validity	53.8541	3,135	58.21	33.95

10. Normanby LiDAR Block 16

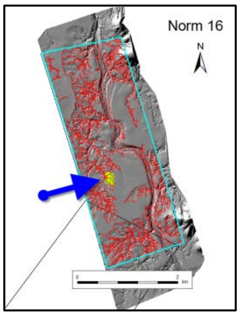
Block location



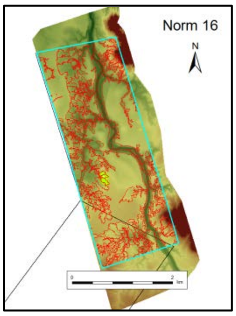
Digitising on LiDAR



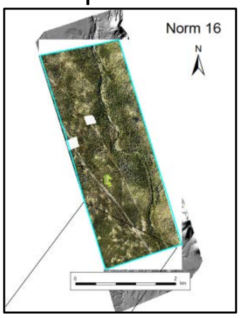
Air photo study gullies



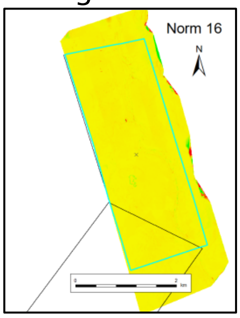
DEM



Orthophoto



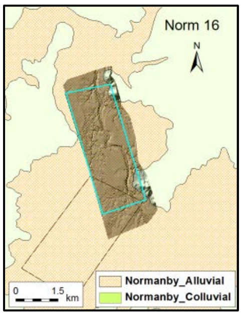
Change raster footprint



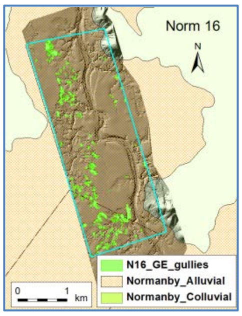
Reprocessed change raster area ha	701.7636
Block elevation range m	98 – 221
Number of LiDAR digitised features	443
Number of Google Earth mapped gullies	140

10.1 Alluvial and Colluvial zones

Alluvial and Colluvial soil



Google Earth mapped Gullies



Norm 16	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	678.27	262.16	38.7	179.22	26.4	29.57	4.4
Colluvial zone	23.49	13.36	56.9	13.36	56.9	0.00	0.0

10.2 LiDAR derived data

10.2.1 Horizontal adjustments

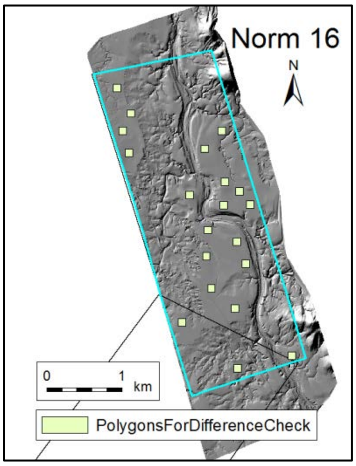
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

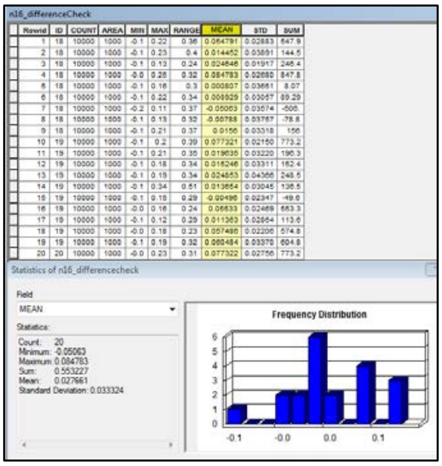
X,Y nudge (m)	2 , -1

10.2.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.





10.3 Statistics

Layer	min	max	Mean	s.d.
Norm_16_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-16	83	-0.078	0.13
Norm_16 with edge effect removed	-7.12	4.01	0.016	0.12
Areas of minimal change	-0.05	0.08	0.028	0.03
N16_Diff_adjusted	-7.14	3.98	-0.012	0.12

The level of noise on flat flood plain areas has been ascertained, and these values removed from the erosion and deposition layers.

Values of change raster filtered to remove noise on floodplain.

raster	Values filtered
erosion	0 to -0.2
deposition	0 to 0.2

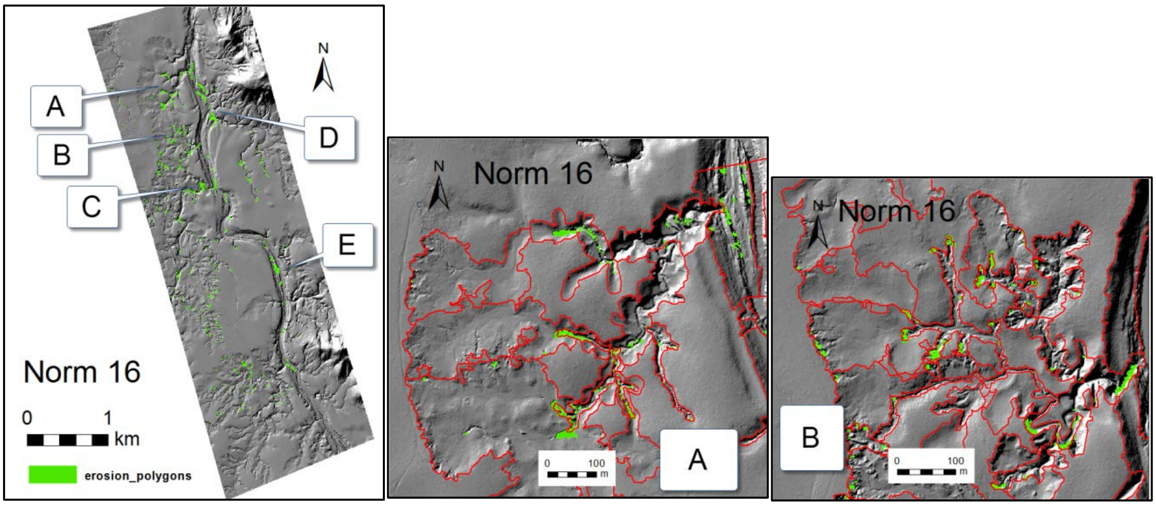
10.4 Aggressive filtering of erosion and deposition data

Broad, shallow gullies advancing with wide head scarps Norm 16 were not picked up using a 1m threshold for the change raster, as were many mobile bars in the channel bed. These changes were picked up satisfactorily using a 0.5m threshold.

Table below shows the volume of data removed by hand thinning erroneous erosion and deposition data.

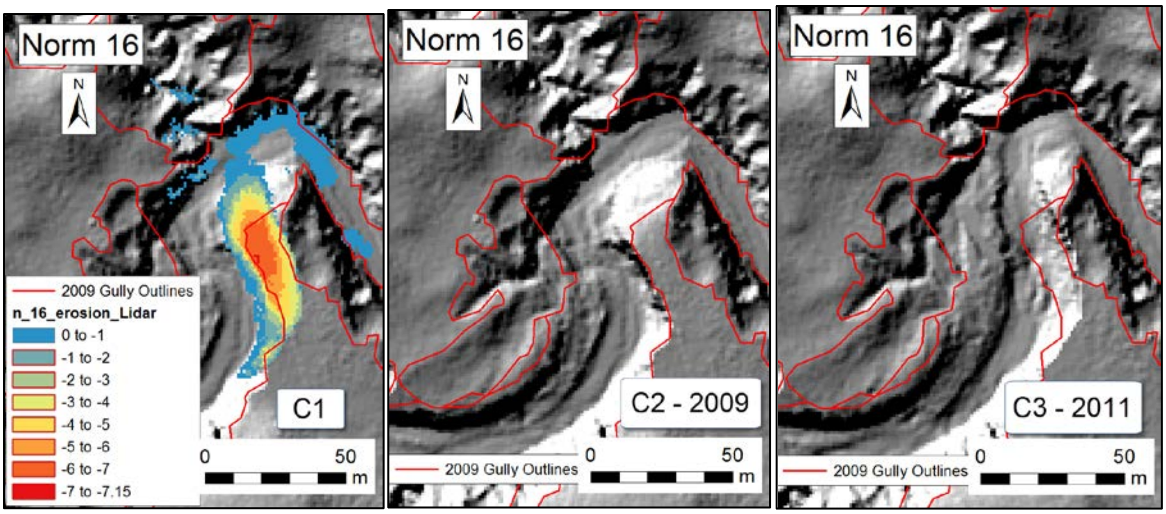
	erosion		deposition	
	area ha	raster sum	area ha	raster sum
Prior to hand thinning	57823	-38,221	61297	28,097
After hand thinning	23,678	-17,297	4,944	2,167

10.5 Observations

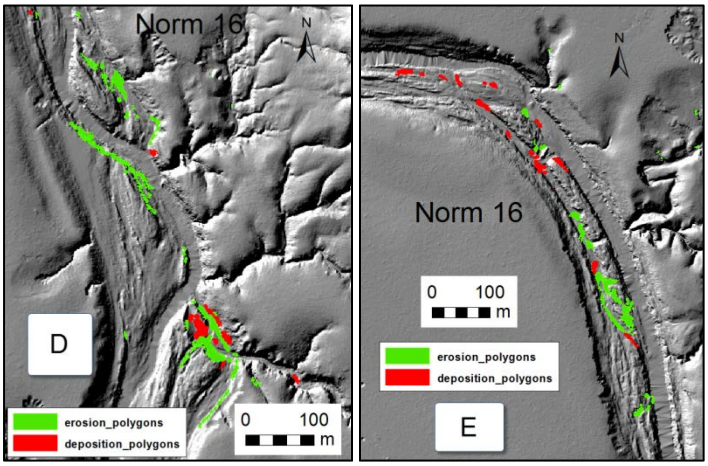


Location A: Recent erosion activity occurred as deepening and extension of incisions into channels that drained aged gully complexes. Each of the main 4 advancing headwalls had erosion activity zones between 40 to 70m.

Location B: A similar pattern to location A, though the areas of erosion activity were in the range of 7 to 20m. Some erosion activity occurred at the ultimate gully head scarp, which was more than occurred at the head scarp of location A.



Location C: A narrow finger of land creating a sharp loop in a secondary channel suffered heavy erosion forces, losing up to 13m of horizontal distance, and over 7m of material vertically. If this continues, a major straightening of the channel will occur.



Location D : High water channels within the meta channel were re-sculptured in the vicinity of a junction with a secondary channel. Stripping occurred along the outside bank of the main flood channel, and possibly a meeting of turbulent flood flows from the secondary channel eroded the confluence zone, kicking up material that was deposited on both banks immediately downstream of the confluence.

Location E: Highwater flows moving from the main channel to a flood channel have stripped material from a vegetated bar. Deposition has occurred within the flood channel, downstream of the erosion, but not within the vegetated bar.

10.6 Erosion and deposition

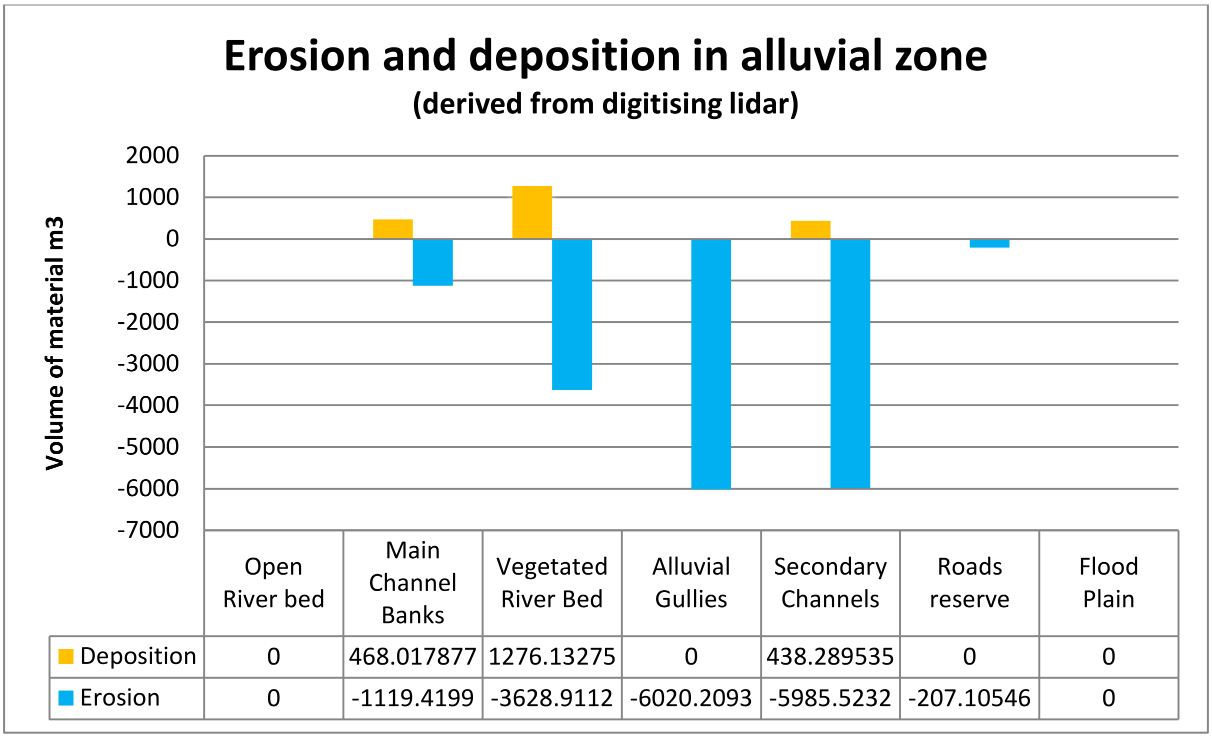
Secondary channels were 10% of the area of alluvial gullies, but similar volumes of erosion at around 6000m^3.

Values of erosion and deposition for open riverbed were not calculated, as digitising of LiDAR had not been done to isolate these areas. Values for main channel banks include values for open riverbed.

Gullies eating out some vehicle tracks had extended by up to 20m in some places.

Vegetated patches of the main channel gained 1276m3 of materials, but had a net loss of material due to stripping of material as flood waters tore preferential channels through the trees.

Patterns of erosion in alluvial gullies generally followed advancing incisions along the bottom of aged, broad and shallow fan shaped gullies.



10.7 Comparison of alluvial gullies to colluvial gullies

Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
179.22	0	−6020.2	−16.79	22.83	0	−8.2	−0.18

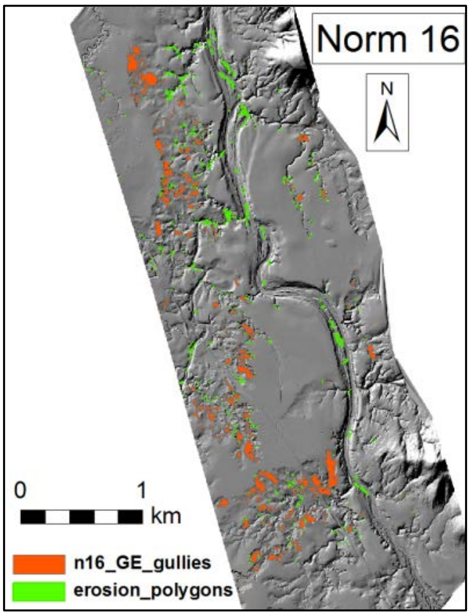
The area of colluvial gullies was 7.5% of the area of alluvial gullies in norm 16, and volume of erosion from colluvial gullies was 0.1% of the volume eroded from alluvial gullies. The contribution of erosion from colluvial sources in the Norm 16 block was very minor.

10.8 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

The area of Google Earth gullies was 17% of area of alluvial gullies from LiDAR digitising, but erosion from GE gullies was 8% of the volume eroded calculated from alluvial gullies.

Many of the recent active and highly productive incisions were in areas that appeared vegetated in the orthophoto, and so would not have been obvious in Google Earth.

	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial gullies	179.22	-6020.21	-16.80
GE alluvial gullies	30.35	-455.06	-7.50



10.9 Gully Expansion 2009 – 2011

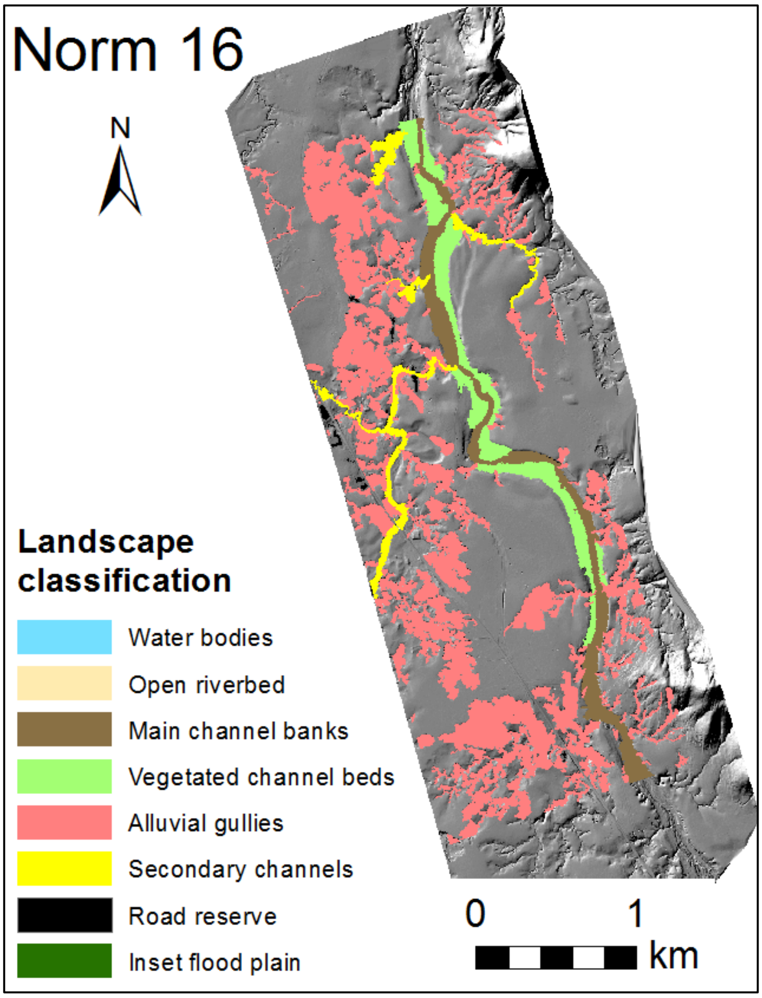
After hand thinning, 2.4ha of erosion surfaces remained across all landscape classes. Over half of the erosion surfaces were within the existing boundaries of alluvial gullies, secondary channels and main channel features. The 2 largest areas of expansion were 452m^2 where a secondary channel cut deeply into a bank, and 91m^2 where a sloping vehicle track was becoming a canyon.

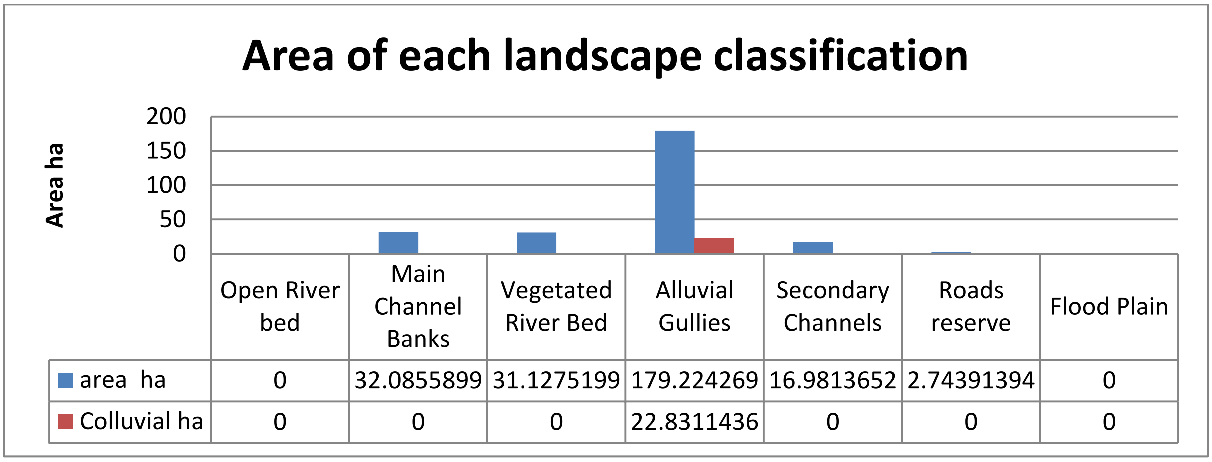
The following table summarises total gully expansion between 2009 and 2011.

Gully Expansion 2009 – 2011	
Number of gully expansion locations	131
Sum area of gully expansions ha	0.1049
Mean area of expansion m2	8

10.10 Landscape Classification

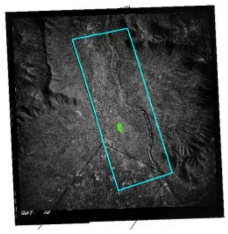
This dominant landform in Norm 16 was broad, shallow alluvial gullies that had active incision channels advancing into them. Significant formal and informal roads were visible in the LiDAR, and gullies were classed as road reserve where erosion was following road surfaces and drainage channels.





10.11 Historical air photos

One gully in this block has been identified in air historical air photos from 1952 and 1987.

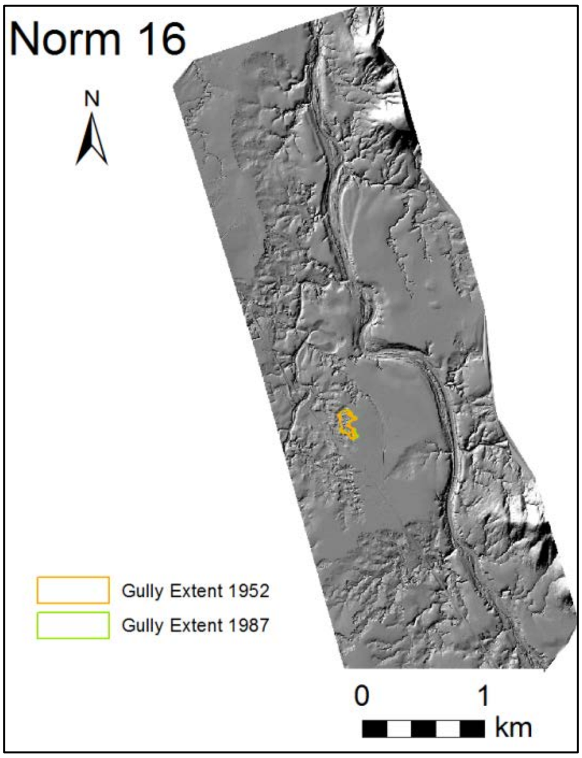
Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block
1/01/1952	QAP 317-10	23900	12750ft	1.89378	
1/01/1987	QAP 4110-115	25000	4310m	0.80831	

10.12 Historical gully extent

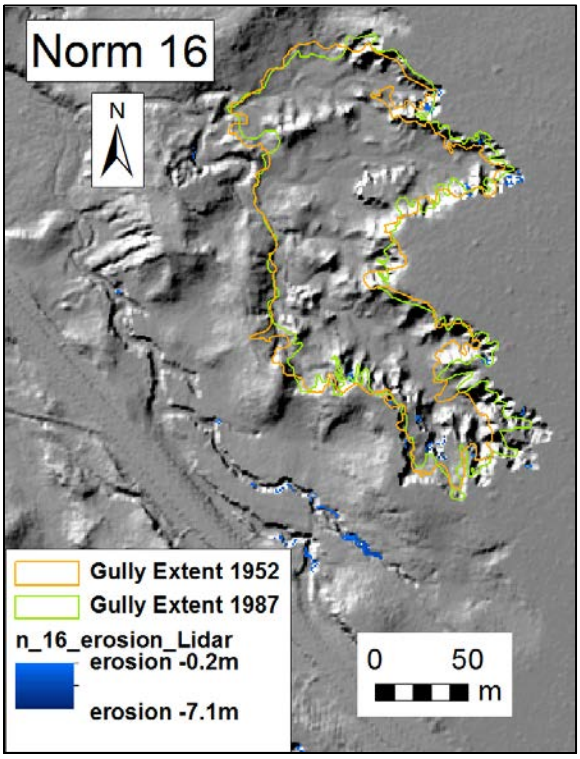
Gully one: The gully floor was approximately 4m deep across most of its extent, with the remains of a previous floor perched at 2m below the gully rim. Erosion at the north eastern lobe was proceeding at the 3m high headwall, while at the south eastern lobe erosion was occurring at an incision of the floor as well as extension of the headwall in several places.

Between 2009 and 2011 the gully area expanded 4m^2.

Location diagram



Gully 1 detail



According to these data, the rate of loss over the 57 year period from 1957 to 2009 was less than half the rate of loss over the 22 year period from 1987 to 2009. There was relatively little increase in gully area between 1952 and 1987, indicating a dry spell with little gully expansion happening, or problems recognising the full extent of the gully from historical air photos.

The rate of erosion between 2009 and 2011 was 10% of the rate between 1987 and 2009.

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	1.7813	207	74
1987 – 2009	1.8636	430	154
2009 – 2011	2.7952	42	15

10.13 Comparison of gully volume and erosion calculations using reprocessed 2009 LiDAR and original 2009 LiDAR.

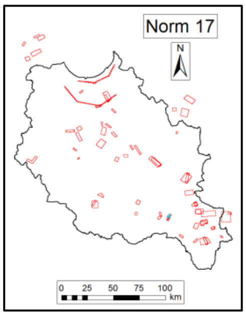
In this instance, there was very little difference in values of the original 2009 DEM and the reprocessed 2009 DEM, and hence, only small differences in the volume of erosion and yields calculated from both data sets.

This gully was largely spared the foibles of vegetation removal algorithms that also remove terrestrial features, or the human decisions of where and how much to accentuate abrupt edges in LiDAR derived DEMs.

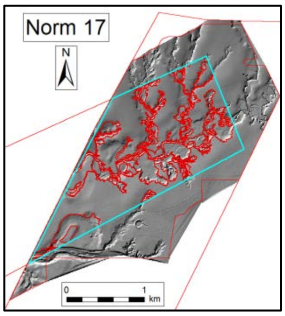
Gully and Interval	Volume of erosion, using reprocessed 2009 LiDAR, m3	Volume erosion from original 2009 LiDAR m3	% difference in volume 2009repro/ 2009original*100	yield using reprocessed LiDAR m3/ha/yr (using 2009 gully area)	yield using original LiDAR m3/ha/yr (using 2009 gully area)	% difference in yield reprocessed/original*100
Gully 1 1957-2009	11912.5	11803	101	75	74	101
Gully 1 1987-2009	9853.5	9465	104	160	154	104

11. Normanby LiDAR Block 17

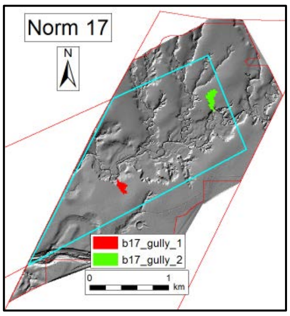
Block location



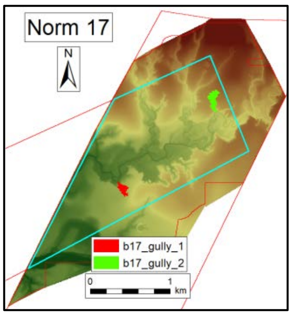
Digitising on LiDAR



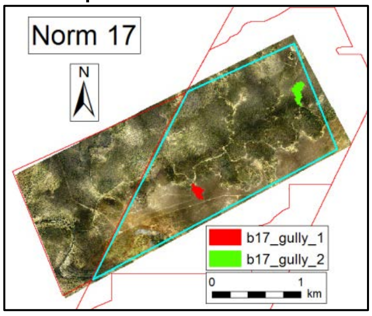
Air photo study gullies



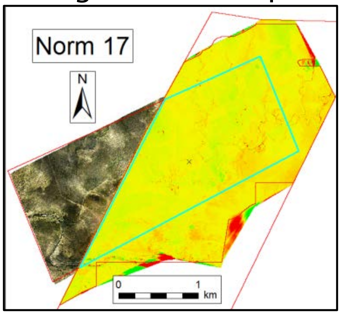
DEM



Orthophoto



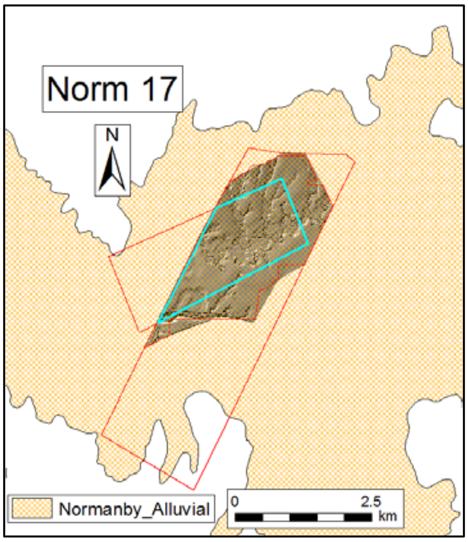
Change raster footprint



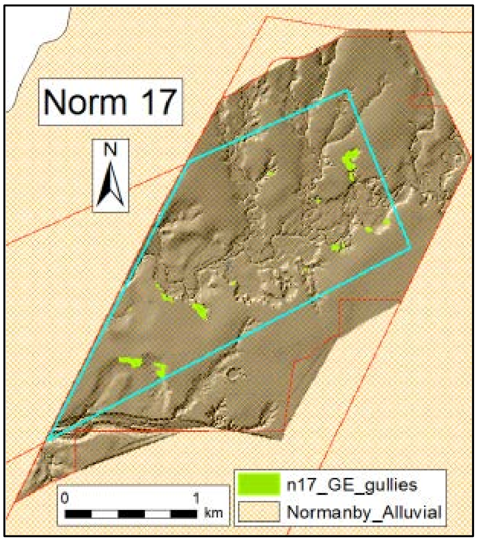
Reprocessed change raster area	ha	297.6646
Block elevation range	m	122 – 162
Number of LiDAR digitised features		185
Number of Google Earth mapped gullies		26

11.1 Alluvial and Colluvial zones

Alluvial and Colluvial soil



Google Earth mapped Gullies



Norm 14	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area alluvial gullies digitised from LiDAR ha	Area alluvial gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	297.6646	99.39	33.4	42.14	14.2	1.76	0.6
Colluvial zone	0.00	0.00	0.0	0.00	0.0	0.00	0.0

11.2 LiDAR derived data

11.2.1 Horizontal adjustments

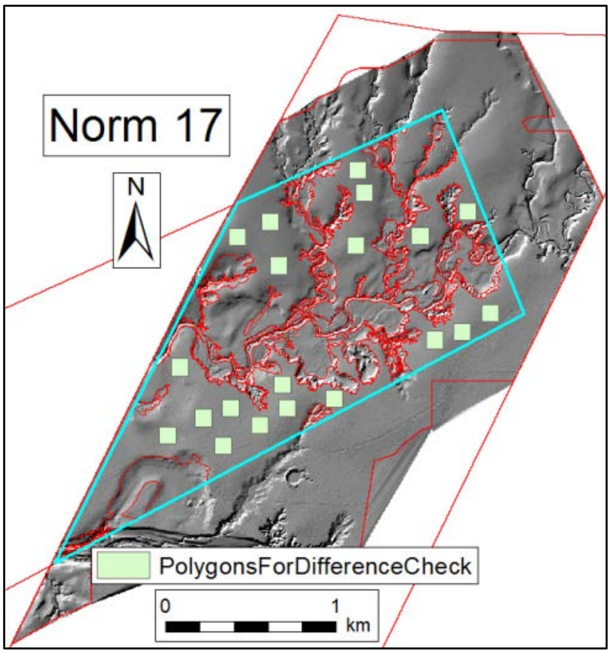
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

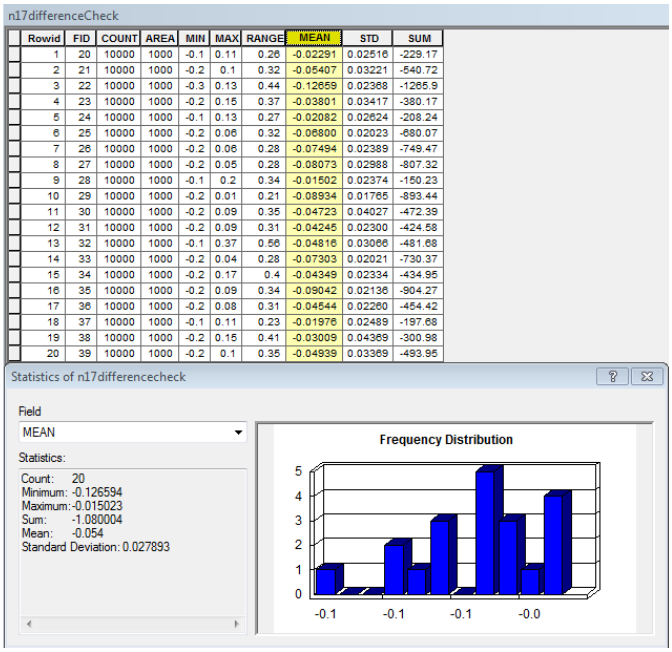
X,Y nudge (m)	1 , -1

11.2.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.





Rowid	FID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	20	10000	1000	-0.1	0.11	0.26	-0.02291	0.02516	-229.17
2	21	10000	1000	-0.2	0.1	0.32	-0.05407	0.03221	-540.72
3	22	10000	1000	-0.3	0.13	0.44	-0.12659	0.02368	-1265.9
4	23	10000	1000	-0.2	0.15	0.37	-0.03801	0.03417	-380.17
5	24	10000	1000	-0.1	0.13	0.27	-0.02082	0.02624	-208.24
6	25	10000	1000	-0.2	0.06	0.32	-0.06800	0.02023	-680.07
7	26	10000	1000	-0.2	0.06	0.28	-0.07494	0.02389	-749.47
8	27	10000	1000	-0.2	0.05	0.28	-0.08073	0.02988	-807.32
9	28	10000	1000	-0.1	0.2	0.34	-0.01502	0.02374	-150.23
10	29	10000	1000	-0.2	0.01	0.21	-0.08934	0.01765	-893.44
11	30	10000	1000	-0.2	0.09	0.35	-0.04723	0.04027	-472.39
12	31	10000	1000	-0.2	0.09	0.31	-0.04245	0.02300	-424.58
13	32	10000	1000	-0.1	0.37	0.56	-0.04816	0.03066	-481.68
14	33	10000	1000	-0.2	0.04	0.28	-0.07303	0.02021	-730.37
15	34	10000	1000	-0.2	0.17	0.4	-0.04349	0.02334	-434.95
16	35	10000	1000	-0.2	0.09	0.34	-0.09042	0.02136	-904.27
17	36	10000	1000	-0.2	0.08	0.31	-0.04544	0.02260	-454.42
18	37	10000	1000	-0.1	0.11	0.23	-0.01976	0.02489	-197.68
19	38	10000	1000	-0.2	0.15	0.41	-0.03009	0.04369	-300.98
20	39	10000	1000	-0.2	0.1	0.35	-0.04939	0.03369	-493.95

11.3 Statistics

Layer	min	max	Mean	s.d.
Norm_14_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-7.25	5.55	-0.0753	0.25
Norm_14 with edge effect removed	-4.79	3.39	-0.0572	0.08
Areas of minimal change	-0.13	-0.02	-0.054	0.06
N14_Diff_adjusted	-4.74	3.44	-0.003	0.08

The level of noise on flat flood plain areas has been ascertained, and these values removed from the erosion and deposition layers.

Values of change raster filtered to remove noise on floodplain.

raster	Values filtered
erosion	0 to -0.2
deposition	0 to 0.2

11.4 Aggressive filtering of erosion and deposition data

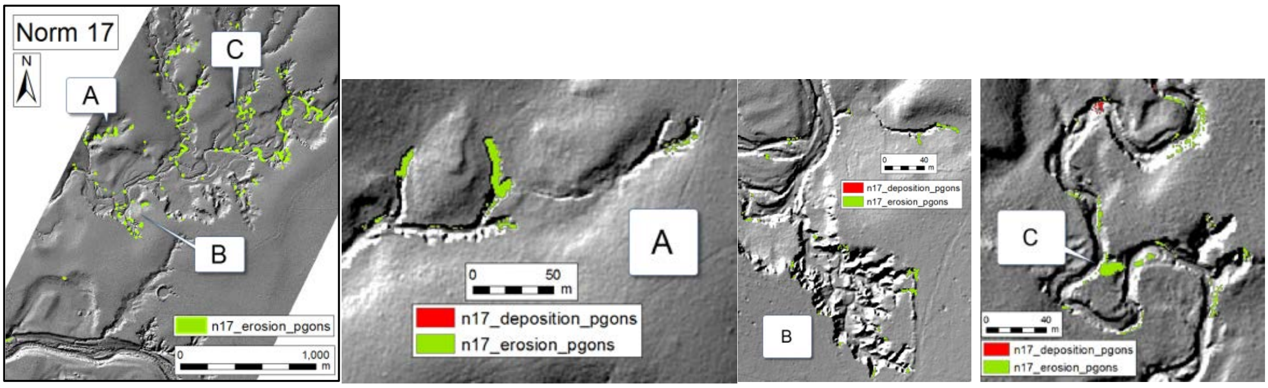
Gully extension in Norm 17 was generally not picked up using a 1m threshold for the change raster, but was picked up satisfactorily using a 0.5m threshold for the difference raster.

Some credible patches of erosion or deposition in the significant secondary channel have not been picked up with the 0.5m threshold, and hand drawn polygons will be used to include these patches in the data set.

Table below shows the volume of data removed by hand thinning erroneous erosion and deposition data.

	erosion		deposition	
	area ha	raster sum	area ha	raster sum
Prior to hand thinning	1.1072	-12,820	0.1597	6,387
After hand thinning	0.6164	-3,495	0.0181	148

11.5 Observations



Location A : A narrow gully with elongation at 5 headwalls, longest advance 40m.

Location B: Headwall extension past windrow in the large gully, also 12m extension in the narrow gully above the scale bar

Location C: A breakthrough of a meander, an example of channel straightening.

11.6 Erosion and deposition

The major location of erosion in Norm 17 was within secondary channels, with some channels having continuous erosion activity along one side or the other, rather than isolated pockets of deep erosion.

Erosion in secondary channels increased with distance from the junction with the main channel.

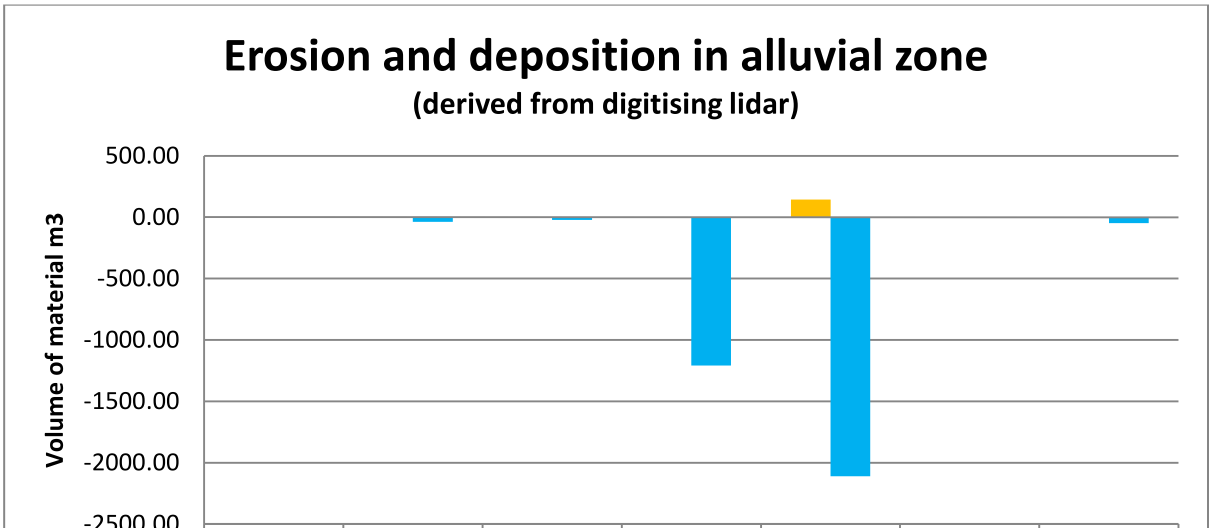
Truncating of meanders occurred in two locations, with looping bends of 150m and 230m being reduced to a direct path of 18m and 80m respectively.

Many gully extensions were along narrow finger like pathways.

Distance of main channel included in the repeat LiDAR was about 200m, limiting the comparisons of erosion/deposition activity with locations removed from the main channel.

Erosion of flood plains occurred in locations where bank erosion of secondary channels cut into the surface area of the flood plain.

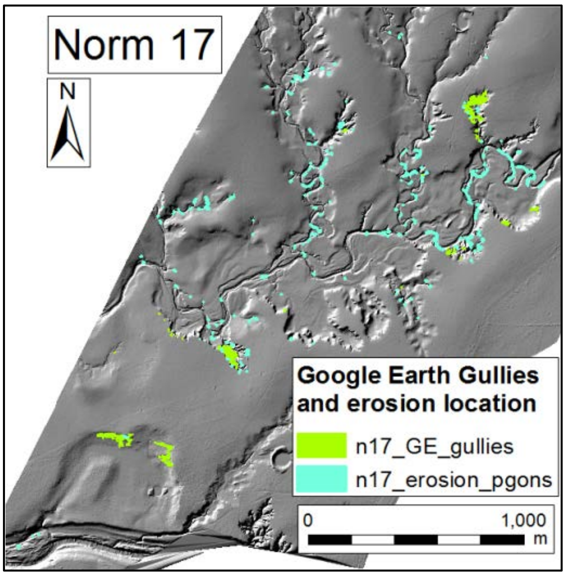
Secondary channels contributed 62% of total erosion, though being only 14% of the area of digitised landscape features.



	Open River bed	Main Channel Banks	Vegetated River Bed	Alluvial Gullies	Secondary Channels	Roads reserve	Flood Plain
Deposition	0.00	0.00	0.00	2.31	144.07	0.00	0.00
Erosion	0.00	-37.19	-22.65	-1208.56	-2109.67	0.00	-48.60

11.7 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

Erosion activity in Norm 17 was poorly represented by gullies digitised from Google Earth, with only 4% of alluvial gully area represented, and 3% of the erosion volume from alluvial gullies occurring within the GE gullies.



	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial gullies	42.16	-1208.56	-14.31
GE alluvial gullies	1.76	-30.59	-8.67

11.8 Gully Expansion 2009 – 2011

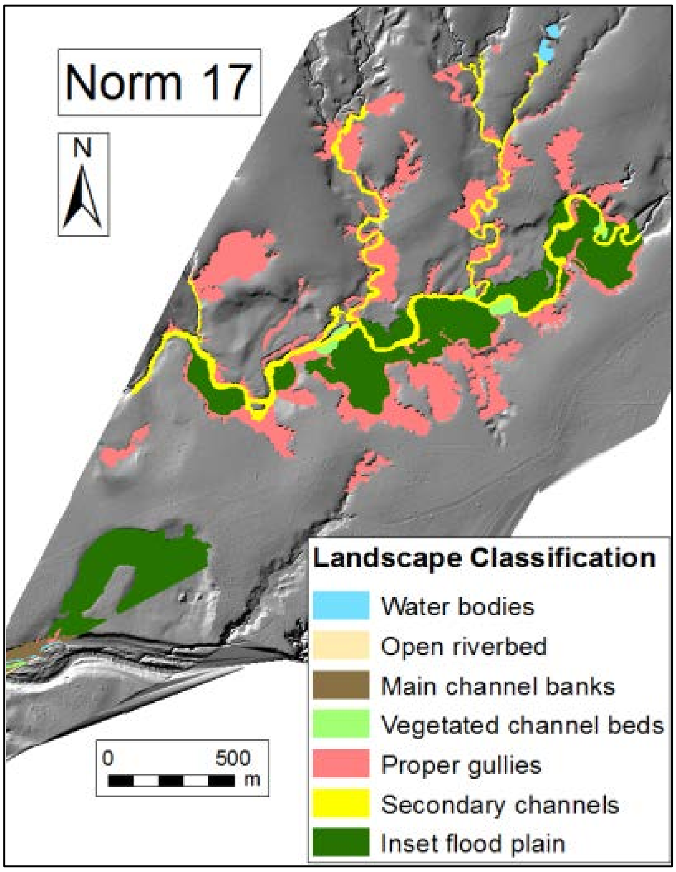
Of the 146 polygons digitised to capture alluvial gullies, gully expansion beyond 2009 boundaries occurred in only 40 locations, with an average expansion area of 7m². Most of the expansion activity was occurred in a few gullies that had multiple head scarps. Erosion activity was measured in 65 out of 146 alluvial gullies and active trench like incisions were advancing in the floor of many old gullies.

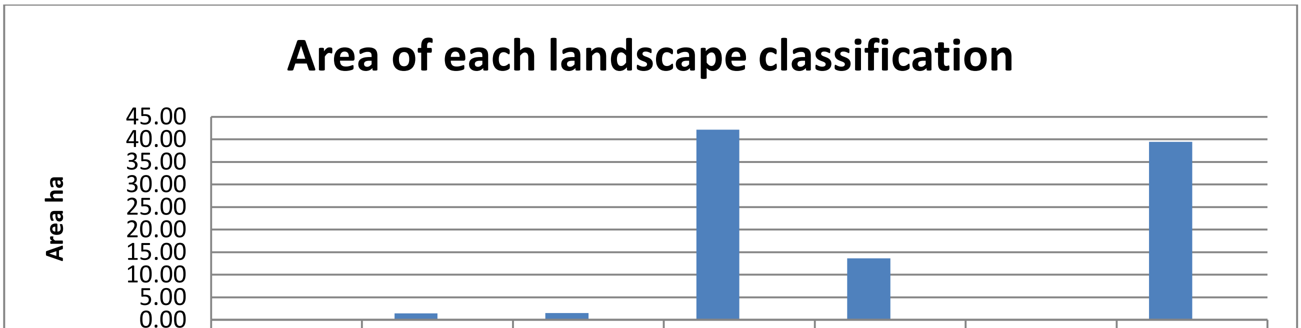
The following table summarises total gully expansion between 2009 and 2011.

Gully Expansion 2009 – 2011	
number of gully expansion locations	40
sum area of gully expansions ha	0.0285
mean area of expansion m2	7

11.9 Landscape Classification

The area of alluvial gullies and flood plain in Norm 17 was similar, with 42.16ha and 39.44ha respectively. The major secondary channel running diagonally across norm 17 has areas of associated floodplain, mostly to the south side of the channel. Height gain from channel bed to flood plain was 1m near the upstream limit of this block, and 2m for the patch of flood plain closest to where the channel exited this LiDAR block. Of the 1.49ha of vegetated channel bed, 1.3ha was located along the secondary channel, perched between the bed and the flood plain.

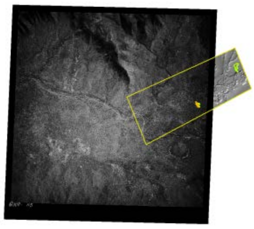
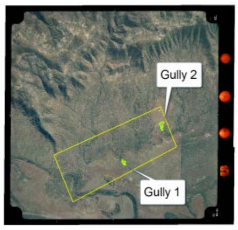




	Open River bed	Main Channel Banks	Vegetated River Bed	Alluvial Gullies	Secondary Channels	Roads reserve	Flood Plain
area ha	0.10	1.45	1.49	42.16	13.65	0.00	39.44
Colluvial ha	0.00	0.00	0.00	0.00	0.00	0.00	0.00

11.10 Historical air photos

Two gullies were identified in historical air photos, gully one having coverage in 1952 and 1987, and gully 2 having coverage in 1987 only.

Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block
1/01/1952	QAP 309-115	23900	12750ft	1.28400	
1/01/1987	QAP 4110-112	25000	4310m	1.88456	

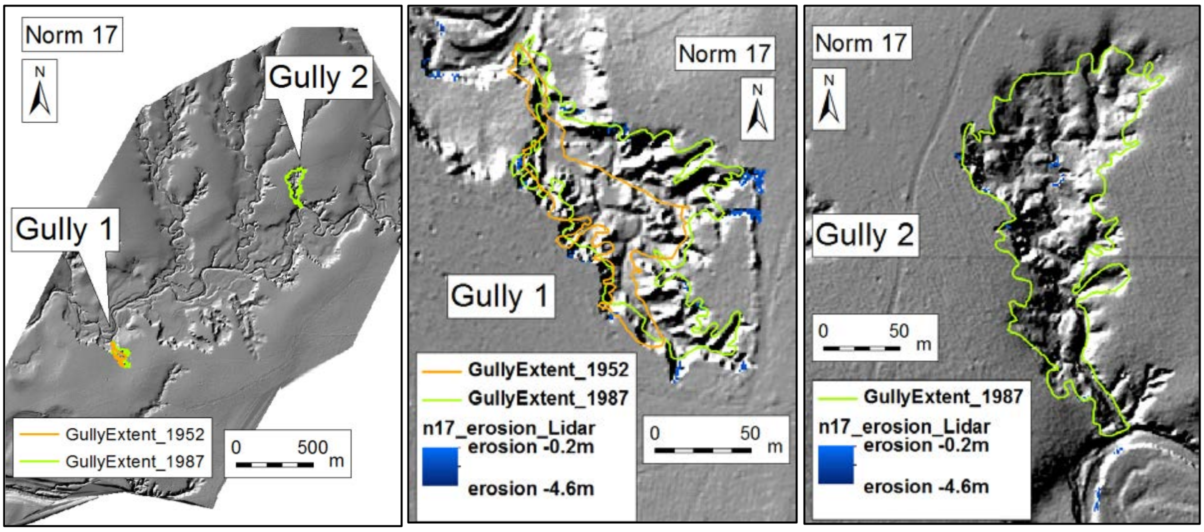
11.11 Historical gully extent

11.11.1 Gully 1

Gully 1 has been intensively studied by Jeff Shellberg, and has the id code CRGC1, Crocodile Gully Complex 1.

The gully area doubled in the 35 years between 1952 and 1987, from 3655ha to 7235ha, and increased in area by 50% in the 22 year period from 1987 to 2009. Erosion measured by LiDAR is mainly advancing along 4 narrow headwalls on the east and southern perimeter, with lesser activity along the western edge.

Location diagram Gully 1 detail Gully 2 detail



The volume of material loss per year from Gully 1 decreased as the time step became shorter and more recent. This would indicate a slowing of erosion activity. However, the massive increase in yield over the 2009–2011 period runs counter to the rate of loss, and again shows the problems of how to normalise rates of erosion from the same gully at different gully age where the gully has different areas and volumes.

Interval	Gully area at start of period m^2	Rate of loss m^3/yr	Yield m3/ha/yr Based on 2009 gully area
1952 – 2009	3655	205	194
1987 – 2009	7235	153	144
2009 – 2011	10577	67	571

11.11.2 Gully 2

Gully 2 has significantly reduced erosion loss in recent years as measured by volume per year and yield.

Interval	Gully area at start of period m^2	Rate of loss m^3/yr	Yield m3/ha/yr Based on 2009 gully area
1987 – 2009	13876	151	85
2009 – 2011	17834	16	9

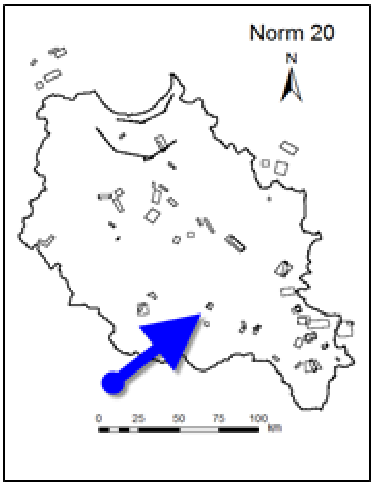
11.12 Comparison of gully volume and erosion calculations using reprocessed 2009 LiDAR and original 2009 LiDAR.

It appears that the reprocessed 2009 LiDAR consistently has gully volume, and hence yield, as less than at first calculated. Toggling between the 2 HS rasters shows some gully structures such as pedestals and ridges absent in the original data, but present in the reprocessed data.

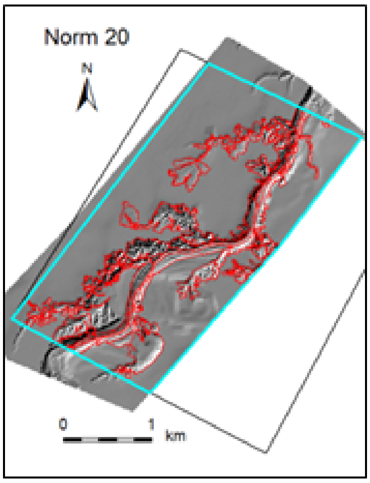
Gully and Interval	Volume of erosion, using reprocessed 2009 LiDAR, m3	Volume erosion from original 2009 LiDAR m3	% difference in volume 2009repro/ 2009original*100	yield using reprocessed LiDAR m3/ha/yr (using 2009 gully area)	yield using original LiDAR m3/ha/yr (using 2009 gully area)	% difference in yield reprocessed/original*100
Gully 1 1957-2009	10564	11666	90.5	175	194	91
Gully 1 1987-2009	2805	3360	83	121	144	83
Gully 2 1987-2009	2780	3331	83	71	85	83

12. Normanby LiDAR Block 20

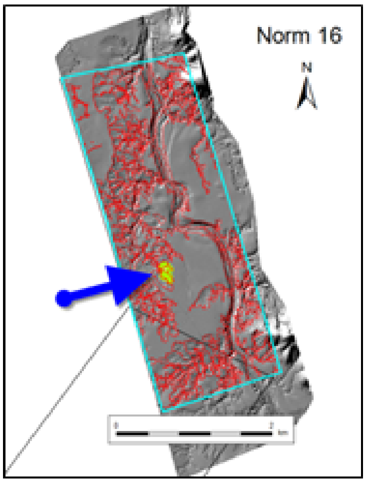
Block location

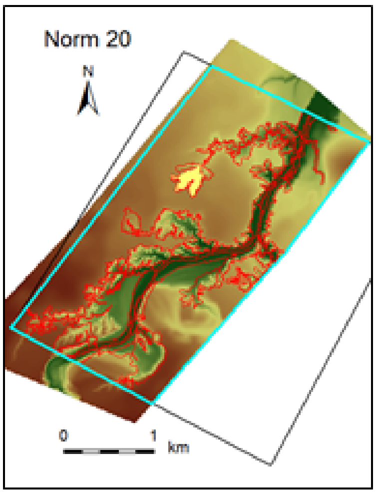


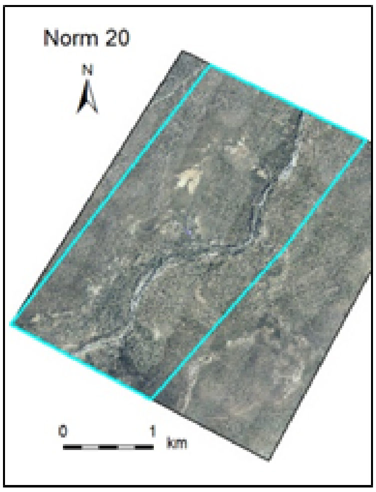
Digitising on LiDAR

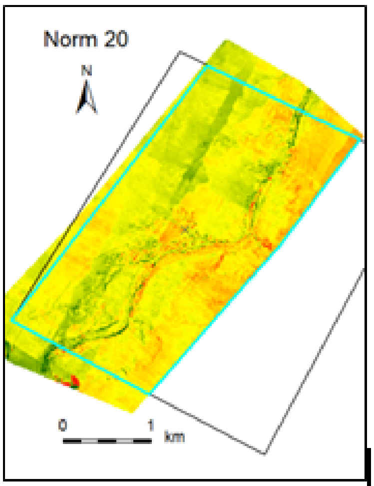


Air photo study gullies





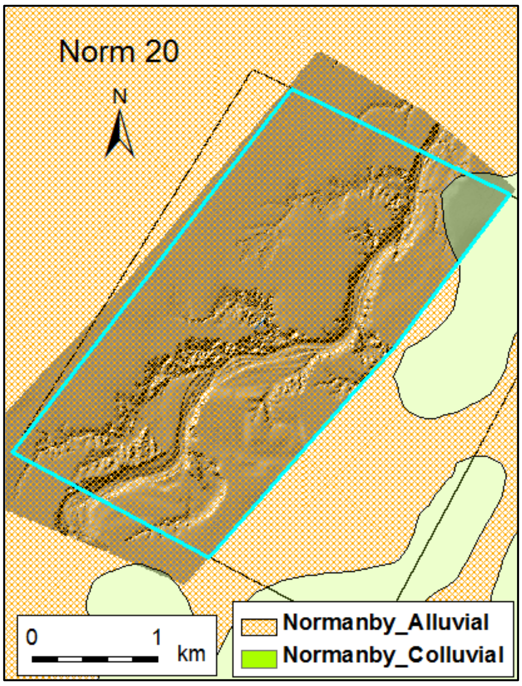




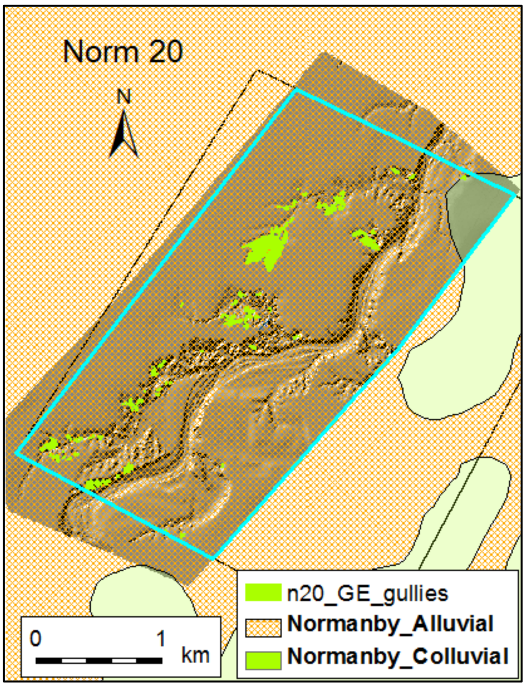
Reprocessed change raster area	ha	688.3906
Block elevation range	m	107 – 73
Number of LiDAR digitised features		146
Number of Google Earth mapped gullies		55

12.1 Alluvial and Colluvial zones

Alluvial and Colluvial soil



Google Earth mapped Gullies



Normanby 20	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies	GE gullies as % of zone
Alluvial zone	667.28763	227.44	34.1	128.85	19.3	12.16	1.8
Colluvial zone	21.10	0.13	0.6	0.13	0.6	0.05	0.2

12.2 LiDAR derived data

Horizontal adjustments – Surprisingly, no horizontal adjustments needed to be made to Norm 20.

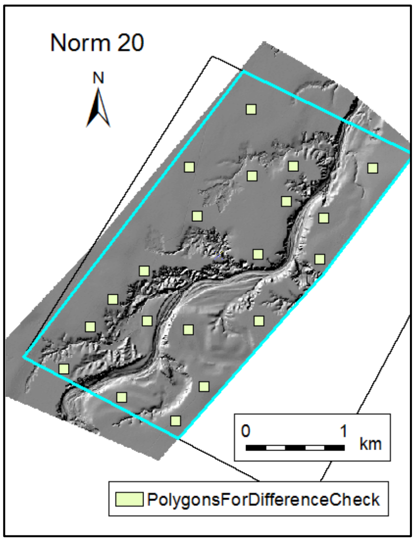
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

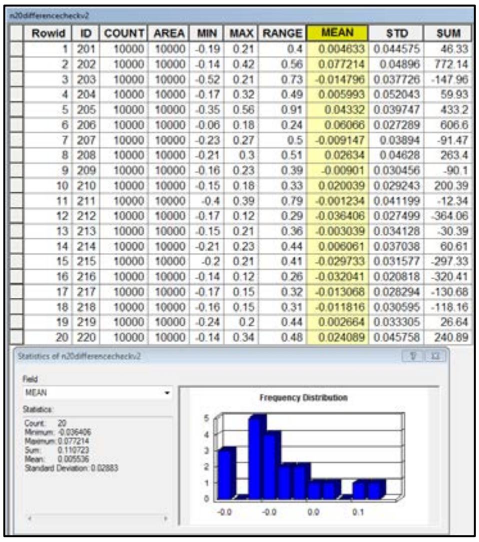
X,Y nudge (m)	0 , 0

12.2.1 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.





n20differencecheckv2

Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	201	10000	10000	-0.19	0.21	0.4	0.004633	0.044575	46.33
2	202	10000	10000	-0.14	0.42	0.56	0.077214	0.04896	772.14
3	203	10000	10000	-0.52	0.21	0.73	-0.014796	0.037726	-147.96
4	204	10000	10000	-0.17	0.32	0.49	0.005993	0.052043	59.93
5	205	10000	10000	-0.35	0.56	0.91	0.04332	0.039747	433.2
6	206	10000	10000	-0.06	0.18	0.24	0.06066	0.027289	606.6
7	207	10000	10000	-0.23	0.27	0.5	-0.009147	0.03894	-91.47
8	208	10000	10000	-0.21	0.3	0.51	0.02634	0.04628	263.4
9	209	10000	10000	-0.16	0.23	0.39	-0.00901	0.030456	-90.1
10	210	10000	10000	-0.15	0.18	0.33	0.020039	0.029243	200.39
11	211	10000	10000	-0.4	0.39	0.79	-0.001234	0.041199	-12.34
12	212	10000	10000	-0.17	0.12	0.29	-0.036406	0.027499	-364.06
13	213	10000	10000	-0.15	0.21	0.36	-0.003039	0.034128	-30.39
14	214	10000	10000	-0.21	0.23	0.44	0.006061	0.037038	60.61
15	215	10000	10000	-0.2	0.21	0.41	-0.029733	0.031577	-297.33
16	216	10000	10000	-0.14	0.12	0.26	-0.032041	0.020818	-320.41
17	217	10000	10000	-0.17	0.15	0.32	-0.013068	0.028294	-130.68
18	218	10000	10000	-0.16	0.15	0.31	-0.011816	0.030595	-118.16
19	219	10000	10000	-0.24	0.2	0.44	0.002664	0.033305	26.64
20	220	10000	10000	-0.14	0.34	0.48	0.024089	0.045758	240.89

Statistics of n20differencecheckv2

Field
MEAN
Statistics:
Count: 20
Minimum: -0.036406
Maximum: 0.077214
Sum: 0.110723
Mean: 0.005536
Standard Deviation: 0.02883

12.3 Statistics

Layer	min	max	Mean	s.d.
Norm_20_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-11.109	8.119	0.002165	0.12
Norm_20 with edge effect removed	-8.460	8.119	0.003595	0.10
Areas of minimal change	-0.036	0.077	0.005536	0.03
N20_Diff_adjusted	-8.465	8.114	– 0.001940	0.10

The level of noise on flat flood plain areas has been ascertained, and these values removed from the erosion and deposition layers.

Values of change raster filtered to remove noise on floodplain.

raster	Values filtered
erosion	-0.2 to 0
deposition	0 to 0.2

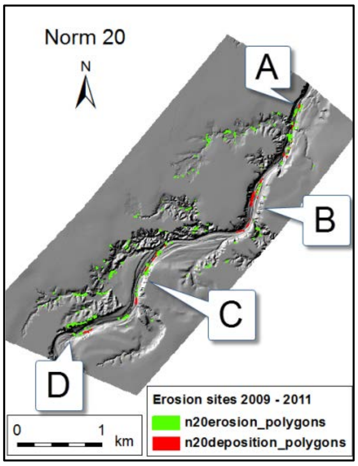
12.4 Aggressive filtering of erosion and deposition data

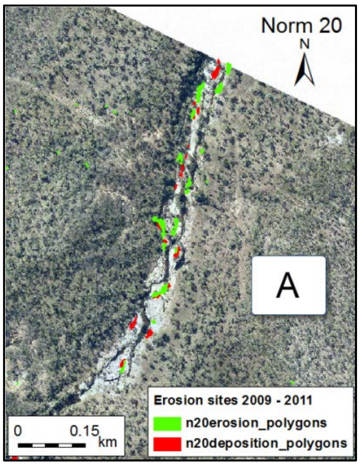
Broad, shallow gullies with depth of around 1m in Norm 20 were not picked up using a 1m threshold for the change raster, as were many areas of change in the channel bed. These changes were picked up satisfactorily using a 0.5m threshold.

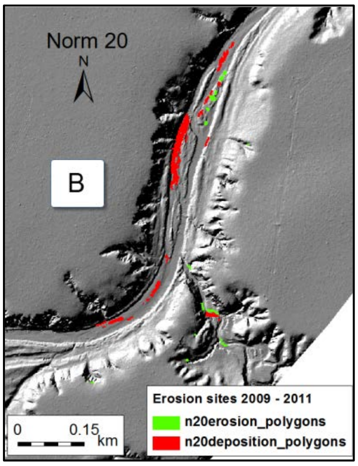
Table below shows the volume of data removed by hand thinning erroneous erosion and deposition data.

	erosion		deposition	
	area ha	raster sum	area ha	raster sum
Prior to hand thinning	35083	-19,663	100763	39,162
After hand thinning	8746	-5,439	6580	2,172

12.5 Observations

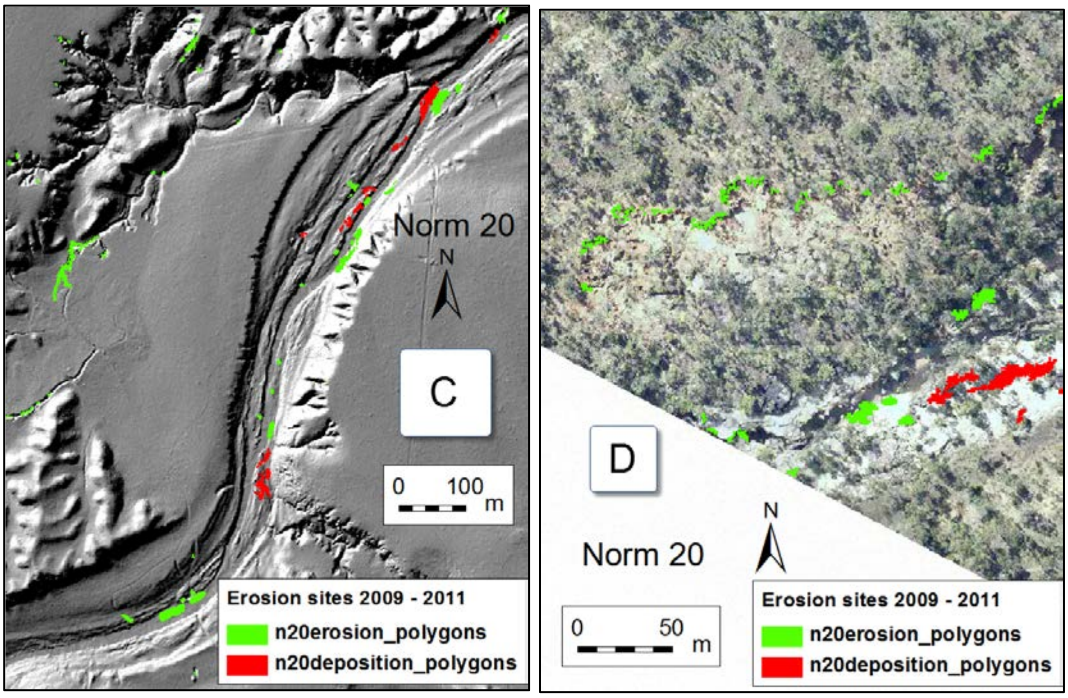






Location A: The main watercourse wends between bedrock reefs at low flow. Scouring and deposition of material along rocky platforms at high flows has occurred. Scouring and deposition has also occurred on the gravel riverbed where the constricted flow widens out nearer the top of the picture.

Location B: Significant deposits have been laid down on the open river bed of the main channel. A secondary channel entering from the south east corner of the picture has seen one bend in particular eroded on the outside of the corner, with deposition on the inside of the bend.



Location C: It appears that a drainage cut-out from a vehicle track has been the site of a 135m long erosion zone, the longest measured in this project to data. The main channel has had more deposition than erosion along the bars and swales in this reach.

Location D: From the water level in the main channel to the top of the alluvial plain is a height gain of 18m. This high bank is topped with a headwall of 2-3m that has retreated 2-3m between 2009 and 2011. The selection of "real" erosion here was carefully considered, as edge detection processes in LiDAR processing may have differed between 2009 and 2011. Some secondary channels in this block appeared to have rocky cliff or undercut banks that seemed very unlikely to have erosion indicated by the difference raster. In these cases, eroding "pixels" along gully edges were deleted from the data set.

12.6 Erosion and deposition

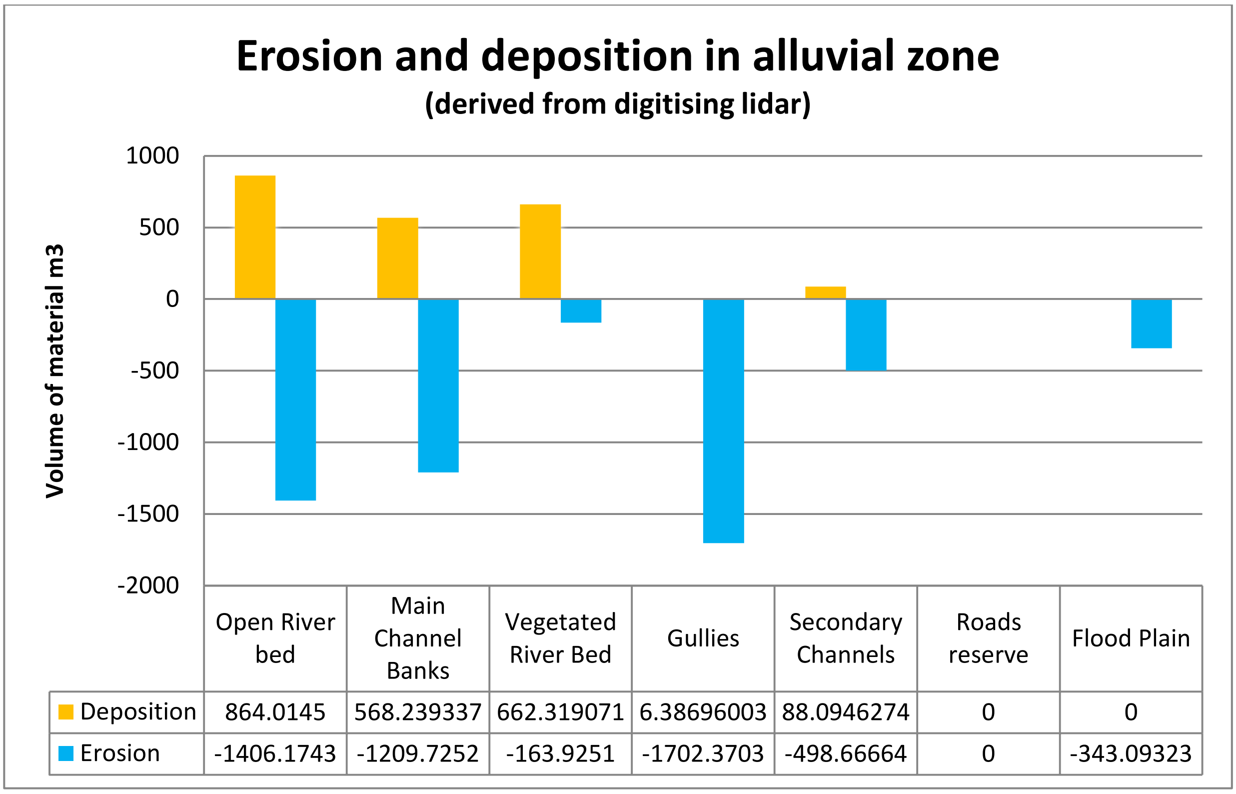
Norm 20 received significant deposition of2112 m^3 in total on the open and vegetated river bed, and main channel banks. Erosion from these surfaces was slightly greater at 2778m^3 in total.

The continuous nature of erosion and deposition along the main channel is standout different to patterns seen in other LiDAR blocks.

Areas of mapped as vegetated main channel received 662m^3 material, though losing 163m^3 to erosion.

Secondary channels in this block were a minor contributor to total erosion.

The largest source of erosion was alluvial gullies, contributing 32% of total erosion in this block.



12.7 Comparison of alluvial gullies to colluvial gullies

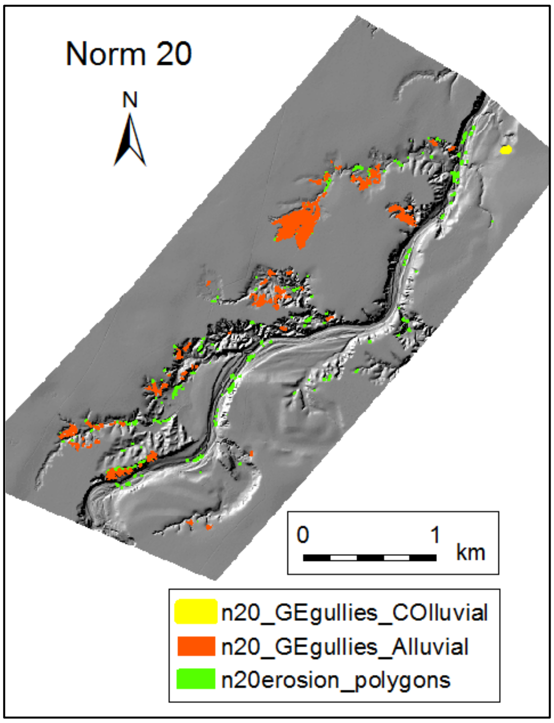
Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
128.85	6.38	-1702.37	-6.58	0.13	0	0	0

LiDAR block Norm 20 sat on an alluvial plain, with a very small area of land in the north east corner mapped as colluvial. No erosion or deposition was measures in the colluvial area.

12.8 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

The area of gullies digitised from Google Earth was 10% of the gully area digitised from LiDAR. The volume of erosion from GE gullies was 14% of the total erosion from alluvial	Area ha	erosion m3	Yield m^3/ha/yr

gullies between 2009 and 2011. Gullies visible in Google Earth had a yield of 9.96 m^3/ha/yr, in this instance, more productive than yield from all alluvial gullies at 6.58m^3/ha/yr.			
LiDAR alluvial gullies	128.85	-1702.37	-6.58
GE alluvial gullies	12.16	-242.11	-9.96



12.9 Gully Expansion 2009 – 2011

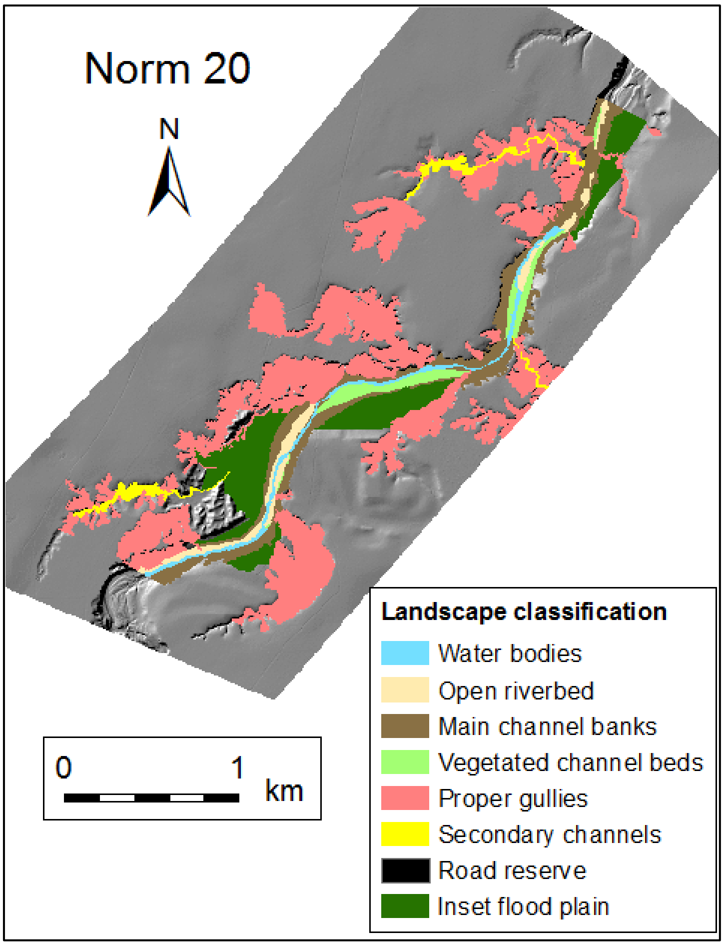
A modest increase in gully area of 136m^2 shows erosion was not particularly active in Norm 20 between 2009 and 2011. Inspection of the orthophoto showed many gullies, secondary channels and the main channel to have rocky structures in the bed or walls of the watercourse. May it be inferred Norm 20 sits on an erosion landscape?

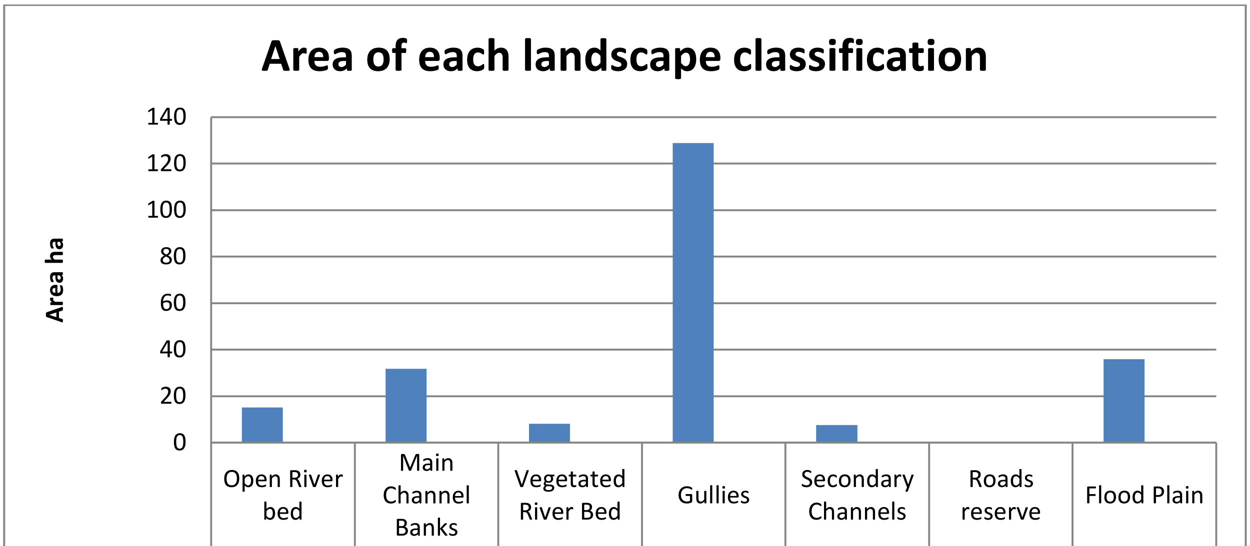
The following table summarises total gully expansion between 2009 and 2011.

Gully Expansion 2009 – 2011	
number of gully expansion locations	28
sum area of gully expansions ha	0.0136
mean area of expansion m2	9.1

12.10 Landscape Classification

Norm 20 LiDAR block was essentially an alluvial plain, though a small area of rising land in the northeast of the block was mapped as colluvial, and this had a gully of area 0.13ha creeping up it. The dominant landscape feature here was alluvial gullies. Vegetated and open riverbed accounted for 46.8ha of the block. Secondary channels were 7.6ha in area.

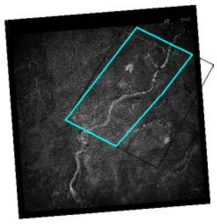
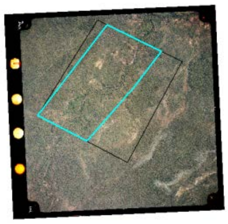




	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Roads reserve	Flood Plain
area ha	15.1471	31.7163	8.1856	128.8496	7.6353	0	35.9058
Colluvial ha				0.130775636			

12.11 Historical air photos

One gully in this block has been identified in air historical air photos from 1952 and 1987.

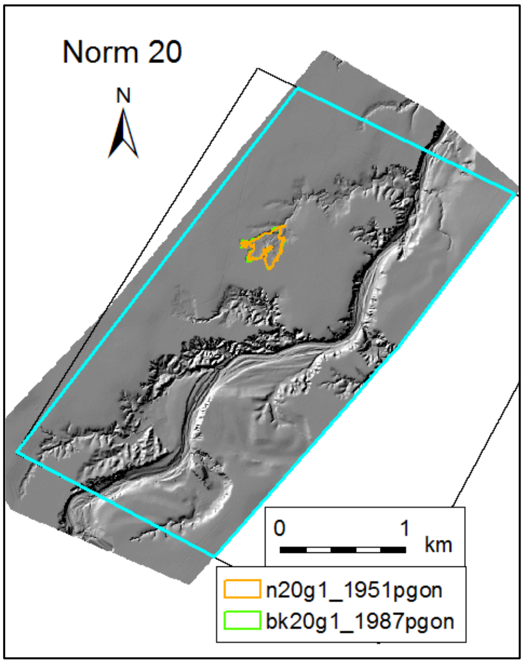
Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block
1/01/1951	QAP 166-27	25400	12750ft	0.98409	
1/01/1987	QAP4109-103	25000	4310m	0.64744	

12.12 Historical gully extent

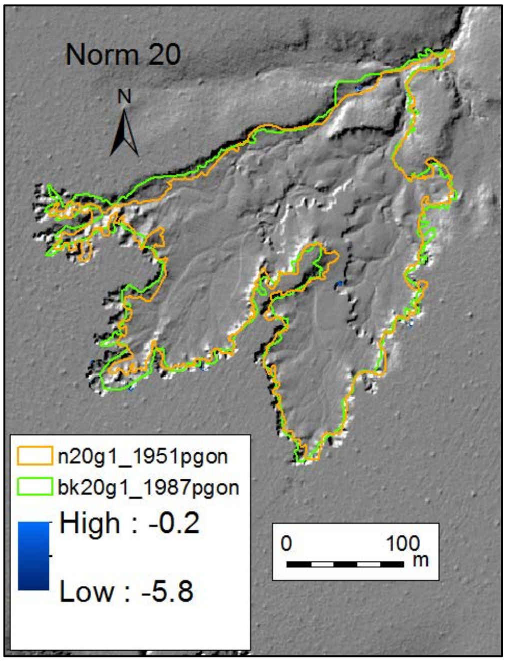
Gully one: This gully was 6.3ha in area, and lost 35.2m^3 to erosion between 2009 and 2011, which calculates to a yield of 2.8m^3/ha/yr. Active erosion was confined to 6 locations along the gully perimeter, one location along a broad incision front, and two locations of incision near the gully exit.

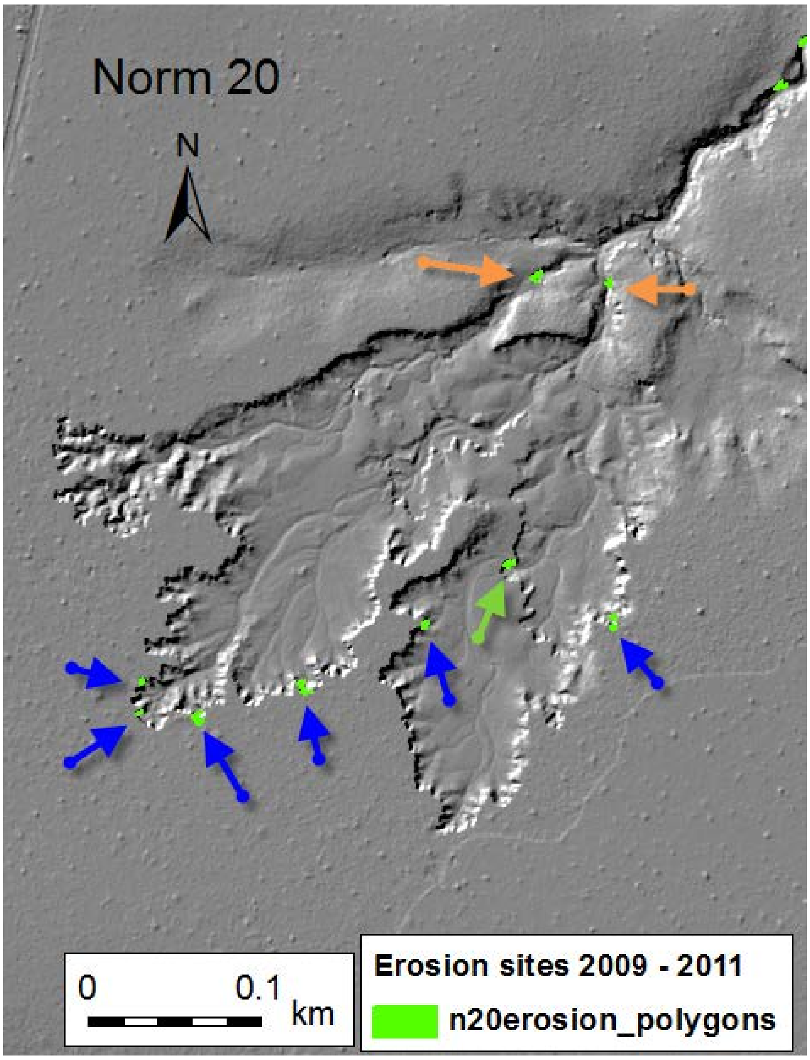
Between 2009 and 2011 the gully area expanded 3m^2.

Location diagram



Gully 1 detail





A similar pattern of erosion has occurred in Norm 20 as in Norm 16, with the rate of loss over the 1987-2009 period being nearly double the rate over the 1951-209 period, but the rate of loss over the 2009-2011period being a small fraction of the rate between 1987 and 2009.

This might be explained by a dry spell with little gully expansion happening, or problems recognising the full extent of the gully from historical air photos.

The rate of erosion between 2009 and 2011 was 10% of the rate between 1987 and 2009.

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	4.8582	168	27
1987 – 2009	5.1868	310	49
2009 – 2011	6.3156	18	3

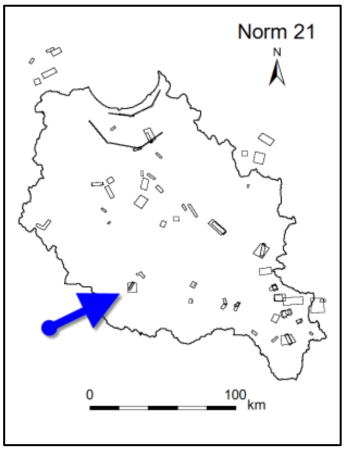
12.13 Comparison of gully volume and erosion calculations using reprocessed 2009 LiDAR and original 2009 LiDAR.

Many pedestals and ridges deleted from the original 2009 DEM due to vegetation removal processes were restored in the reprocessed 2009 data. Subtle adjustments to swath mosaicking and elevations of the reprocessed DEM have resulted in an increase in erosion volume of 6% for the 1951-2009 period, and 7% for the 11987-2009 period.

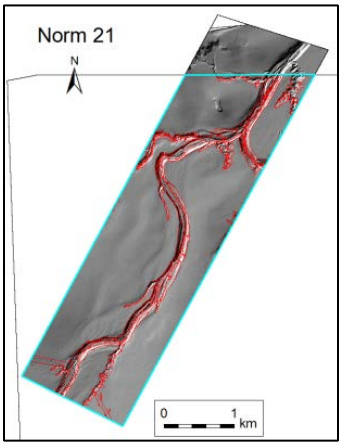
Gully and Interval	Volume of erosion, using reprocessed 2009 LiDAR, m3	Volume erosion from original 2009 LiDAR m3	% difference in volume 2009repro/ 2009original*100	yield using reprocessed LiDAR m3/ha/yr (using 2009 gully area)	yield using original LiDAR m3/ha/yr (using 2009 gully area)	% difference in yield reprocessed/original*100
Gully 1 1957-2009	10379.5	9767	106	28	27	106
Gully 1 1987-2009	7327.75	6821	107	53	49	107

13. Normanby LiDAR Block 21

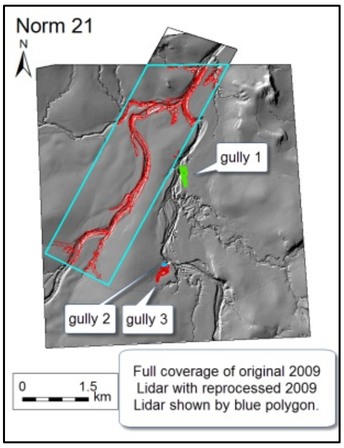
Block location



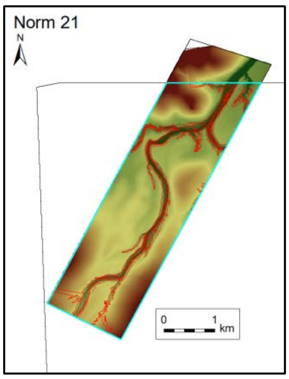
Digitising on LiDAR



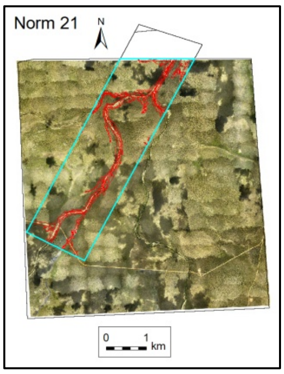
Air photo study gullies



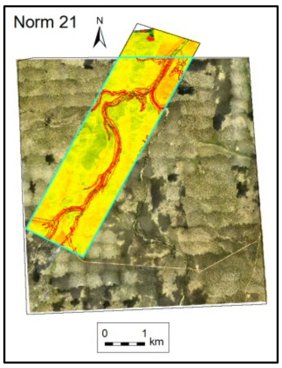
DEM



Orthophoto



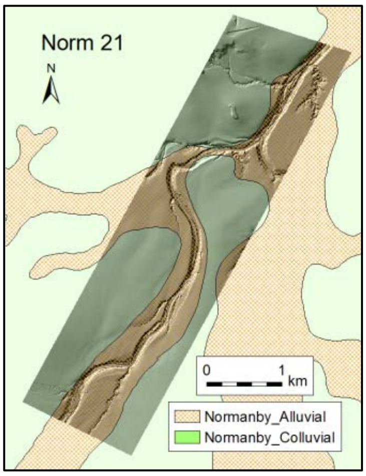
Difference raster

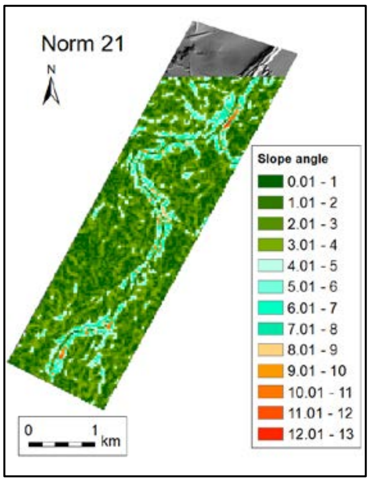


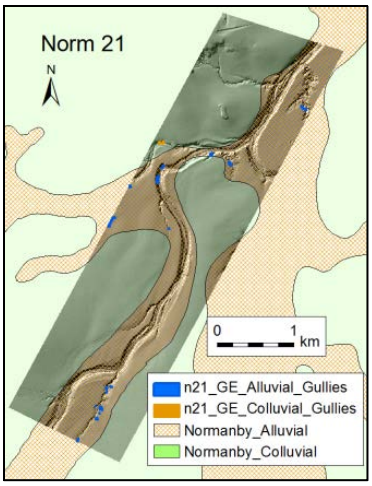
Reprocessed change raster area	ha	863.5818
Block elevation range	m	108 – 160
Number of LiDAR digitised features		136
Number of Google Earth mapped gullies		18

13.1 Alluvial and Colluvial zones

Alluvial and Colluvial soil   Slope angle   Google Earth mapped Gullies







The Queensland soils mapping layer has the majority of Norm 21 as colluvial soils, though the slope of the land, as derived from QLD 30m DEM, rarely exceeds 4%.

Normanby 21	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies ha	GE gullies as % of zone
Alluvial zone	383.30	127.94	33.4	30.13	7.9	0.93	0.2
Colluvial zone	480.28	19.43	4.0	5.81	1.2	0.14	0.03

13.2 LiDAR derived data

13.2.1 Horizontal adjustments

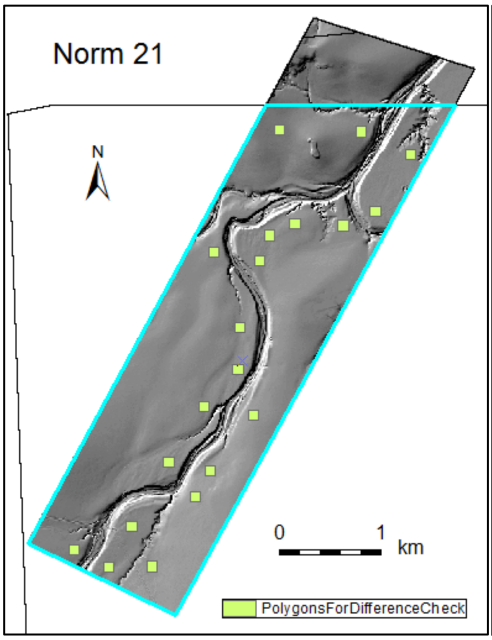
Polygons digitised from 2009 LiDAR, CHM and PFC rasters have been nudged to align with reprocessed 2009 LiDAR by:

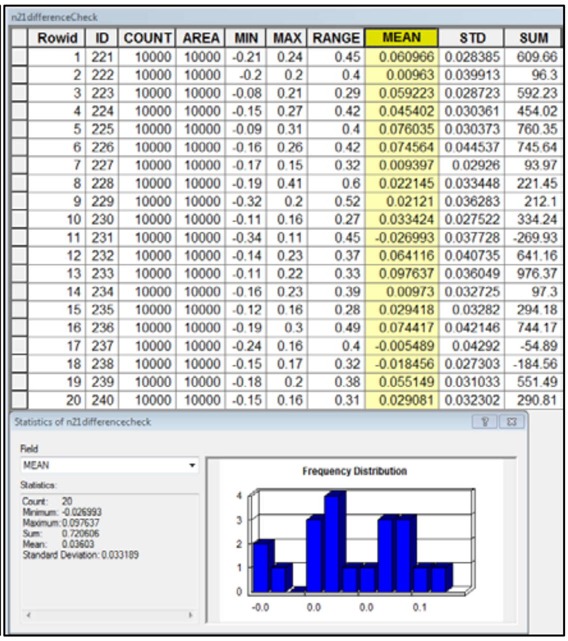
X,Y nudge (m)	1 , -1

13.2.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.




n21differenceCheck

Rowid	ID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	221	10000	10000	-0.21	0.24	0.45	0.060966	0.028385	609.66
2	222	10000	10000	-0.2	0.2	0.4	0.00963	0.039913	96.3
3	223	10000	10000	-0.08	0.21	0.29	0.059223	0.028723	592.23
4	224	10000	10000	-0.15	0.27	0.42	0.045402	0.030361	454.02
5	225	10000	10000	-0.09	0.31	0.4	0.076035	0.030373	760.35
6	226	10000	10000	-0.16	0.26	0.42	0.074564	0.044537	745.64
7	227	10000	10000	-0.17	0.15	0.32	0.009397	0.02926	93.97
8	228	10000	10000	-0.19	0.41	0.6	0.022145	0.033448	221.45
9	229	10000	10000	-0.32	0.2	0.52	0.02121	0.036283	212.1
10	230	10000	10000	-0.11	0.16	0.27	0.033424	0.027522	334.24
11	231	10000	10000	-0.34	0.11	0.45	-0.026993	0.037728	-269.93
12	232	10000	10000	-0.14	0.23	0.37	0.064116	0.040735	641.16
13	233	10000	10000	-0.11	0.22	0.33	0.097637	0.036049	976.37
14	234	10000	10000	-0.16	0.23	0.39	0.00973	0.032725	97.3
15	235	10000	10000	-0.12	0.16	0.28	0.029418	0.03282	294.18
16	236	10000	10000	-0.19	0.3	0.49	0.074417	0.042146	744.17
17	237	10000	10000	-0.24	0.16	0.4	-0.005489	0.04292	-54.89
18	238	10000	10000	-0.15	0.17	0.32	-0.018456	0.027303	-184.56
19	239	10000	10000	-0.18	0.2	0.38	0.055149	0.031033	551.49
20	240	10000	10000	-0.15	0.16	0.31	0.029081	0.032302	290.81

13.3 Statistics

Layer	min	max	Mean	s.d.
Norm_21_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-7.04	5.88	0.0306373	0.12
Norm_20 with edge effect removed	-7.04	5.88	0.0294731	0.11
Areas of minimal change	–0.026993	0.097637	0.03603	0.03
N20_Diff_adjusted	-7.08	5.84	-0.007	0.11

The level of noise on flat flood plain areas has been ascertained, and these values removed from the erosion and deposition layers.

Values of change raster filtered to remove noise on floodplain.

raster	Values filtered
erosion	-0.2 to 0
deposition	0 to 0.2

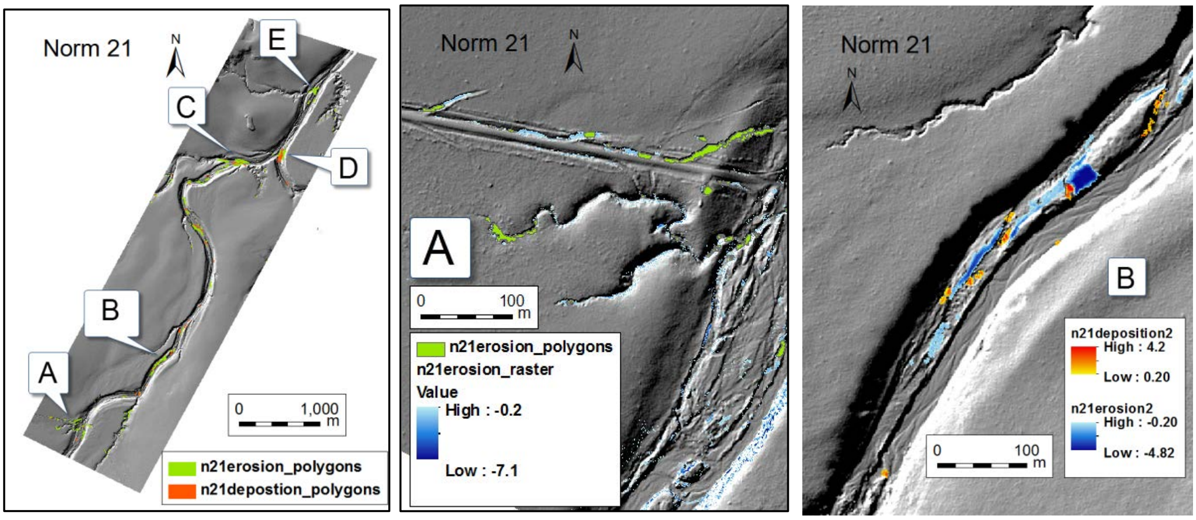
13.4 Aggressive filtering of erosion and deposition data

Changes in location of gravel bars and other temporary features were not well represented using a 1m threshold for “real” erosion or deposition. A threshold of 0.5m was used in Norm 21, which picked up a majority of what could be thought of as real change. The wide open and mainly dry nature of one of the main channels allowed subtle changes in bed structure between 2009 and 2011 to really stand out, though most of these changes were less than 20cm in the difference raster.

Table below shows the volume of data removed by hand thinning erroneous erosion and deposition data.

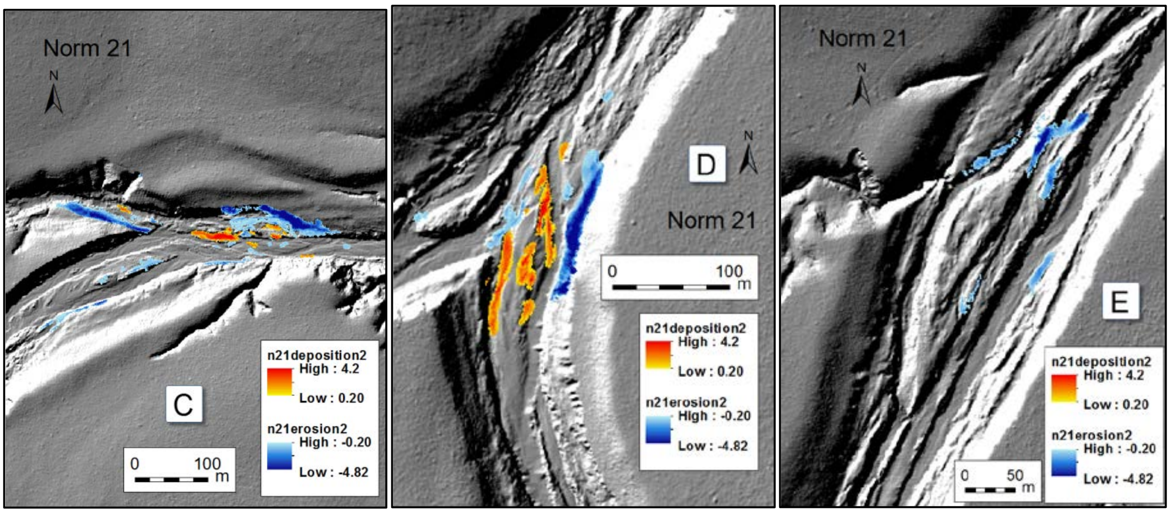
	erosion		deposition	
	area ha	raster sum	area ha	raster sum
Prior to hand thinning	81353	-71,652	40748	42,982
After hand thinning	17226	-19,055	7418	3,490

13.5 Observations



Location A: Scouring of the road drainage cut-outs on the north side of the road contributed 897m^3 to the erosion budget between 2009 and 2011. This value was divided between alluvial and colluvial zones thanks to the Queensland soils mapping layer.

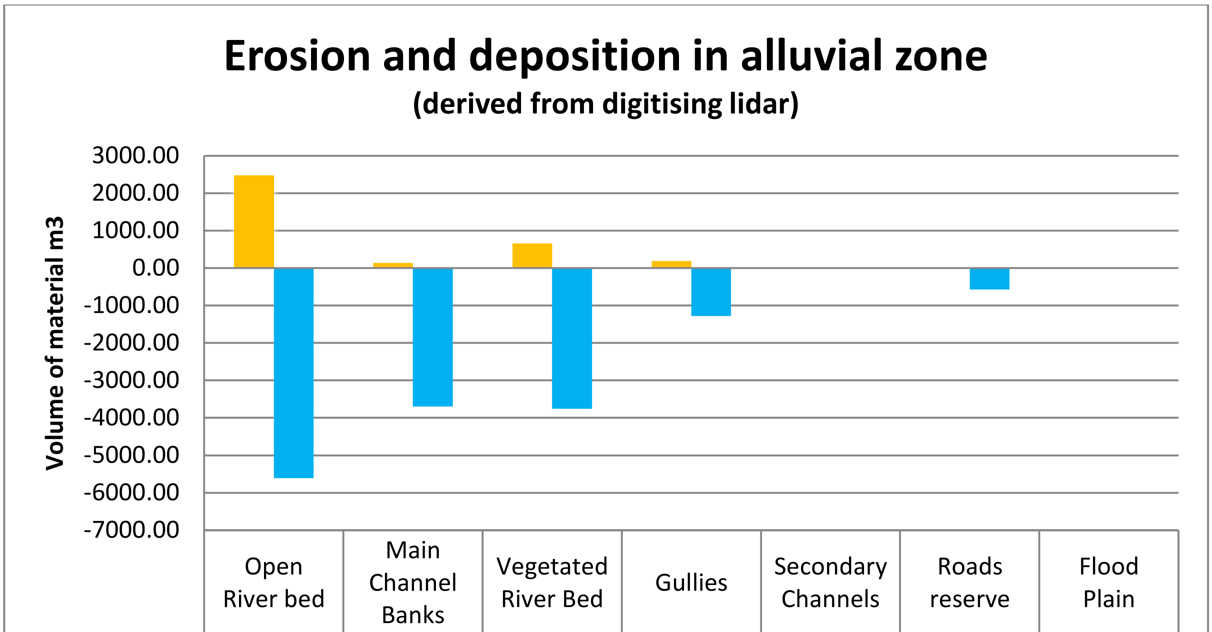
Location B: A vegetated “island” in mid channel lost an area 30m by 25m by (up to) 2.5m in depth, seen as the large dark blue patch above the label B. Other material removed upstream of the island was on open river bed.



Location C: Immediately downstream of the junction of 2 main channels an area of bank erosion 100m by 20m (3300m^2) by up to 4.5m deep remodelled the vegetated northern bank of the main channel, resulting in the loss of 3470m^3 of material. Immediately upstream of the junction, erosion on the point of land between the two channels covered 130m by 17m (1458m2), and lost 1590m^3 from that area.

Location D: An example of main channel reshaping that covered areas classified as open river bed, vegetated riverbed and main channel bank.

13.6 Erosion and deposition



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Roads reserve	Flood Plain
Deposition	2478.26	134.45	659.24	191.39	0.00	0.00	0.00
Erosion	-5608.93	-3698.12	-3758.26	-1278.06	0.00	-571.80	0.00

Alluvial gully erosion of 191m^3 was 23% of that from open riverbeds, 5600 m^3.

Norm 21 had 27ha open riverbed, whilst the area of alluvial gullies was 30ha.

Deposition into main channel vegetated/ open beds and banks was 3271m^3, but was far exceeded by erosion from the same area of 13065m^3.

Volume of erosion from road reserves was 572m3, though this was undoubtedly an underestimate of the true volume.

The volume eroded from road reserves was just under half the amount eroded from alluvial gullies in Norm 21.

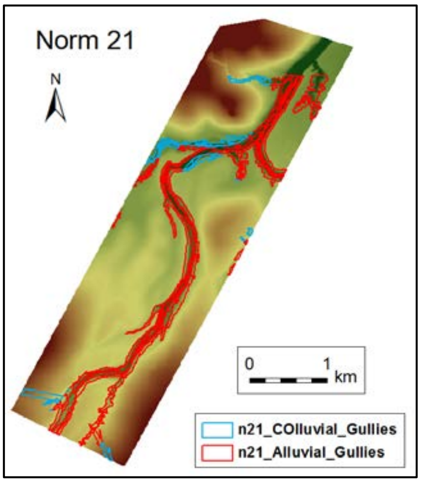
The largest patch of erosion was 1458m2, at the junction of the westerly watercourse and the main channel stem. Of the nine patches of erosion greater than 500m^2, scouring of a road runoff cut-out was 7th largest at 646m^2.

13.7 Comparison of alluvial gullies to colluvial gullies

Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha /yr

30.13	191.39	-1278	-18	5.8	36.6	-1463.3	-122.8

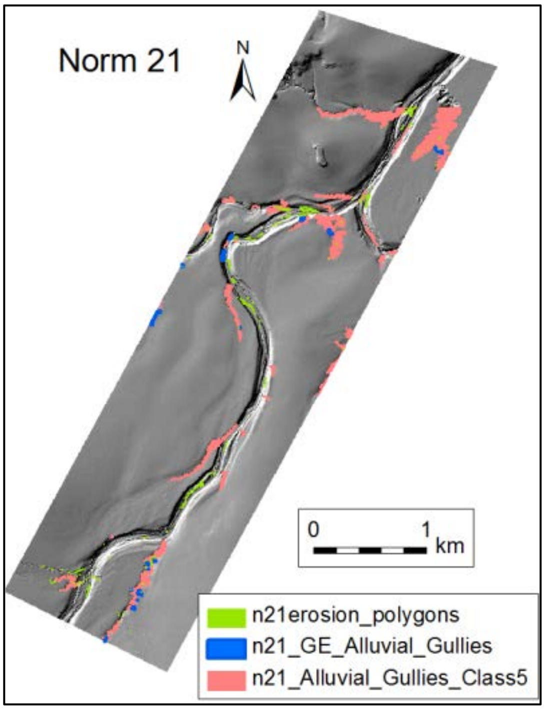
Though colluvial gully area is listed as one fifth of the area of alluvial gullies, the erosion from colluvial gullies is listed as slightly higher than alluvial gullies; 1463m^3 compared to 1278m^3. These figures miss represent the reality on the ground, as the Queensland soils mapping layer has parts of the 2 main channels near their junction as colluvial, when it would be more correct to map them as alluvial. There has also been significant erosion in the junction area.



13.8 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial	30.13	-1278.06	-18.03
GE gullies alluvial	0.93	-9.16	-4.93

Digitising gullies from Google Earth captured 3% of the alluvial gully area digitised from LiDAR. The volume of erosion occurring in the GE gullies was 0.7% of the volume of erosion occurring in alluvial gullies, a similar low figure to other LiDAR blocks.



13.9 Gully Expansion 2009 – 2011

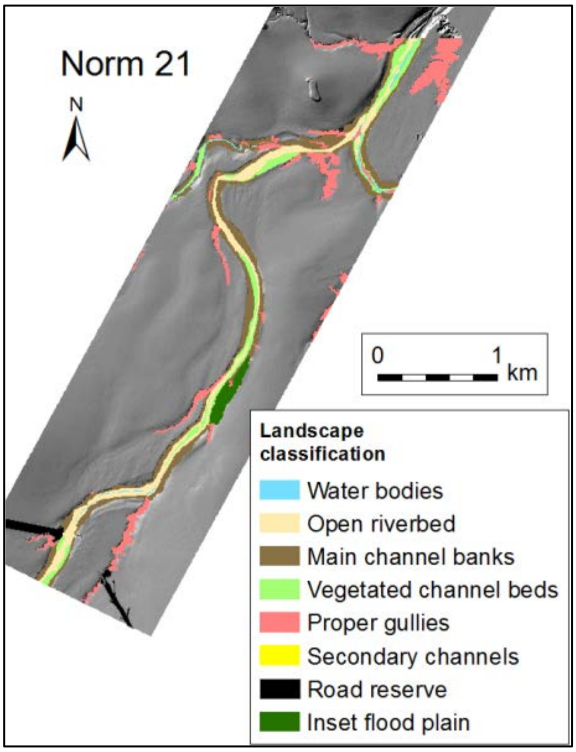
Of the 367m² expansion in gully area between 2009 and 2011, 112m² were associated with drainage of the road where it crosses the river in the south of the block. A further 137m2 of gully expansion was in the gully immediately to the south of the road-river crossing. This gully receives runoff from the road at a point 200m below the current gully headwall, and some erosion has occurred below the junction of road runoff.

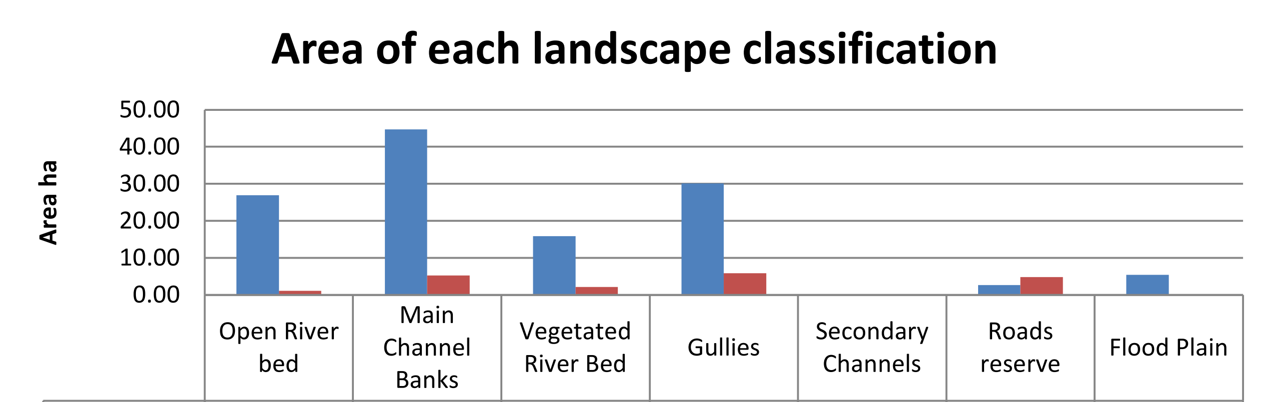
The following table summarises total gully expansion between 2009 and 2011.

Gully Expansion 2009 - 2011	
number of gully expansion locations	21
sum area of gully expansions ha	367.5
mean area of expansion m2	17.5

13.10 Landscape Classification

Norm 21 was different to most other LiDAR blocks in that the 94ha area of main channel was far larger than the area of alluvial gullies, 30ha. Three main watercourses were in the block, each having similar stature to others, and each was classified as main channel. No secondary channels were in the block. As discussed earlier, the area of features classified as colluvial has been over represented due to inaccuracies of the Queensland soils mapping layer.



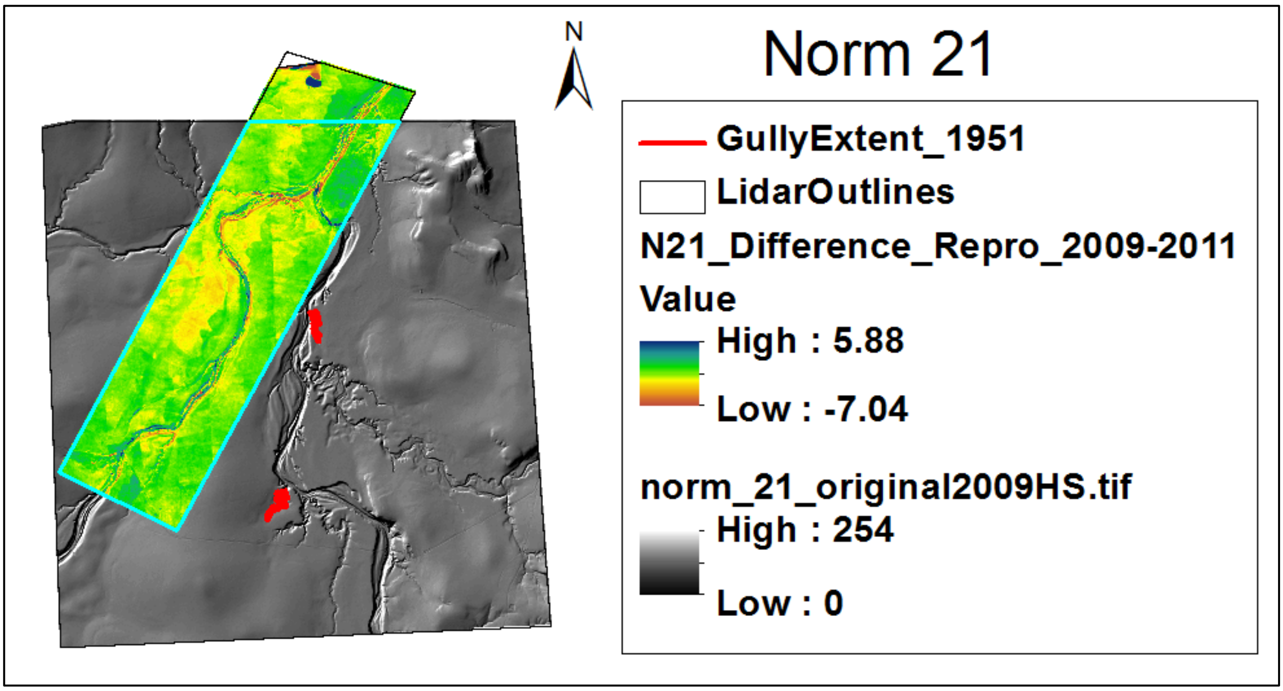


	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Roads reserve	Flood Plain
area ha	26.95	44.71	15.83	30.13	0.00	2.62	5.37
Colluvial ha	1.10	5.21	2.14	5.81	0.00	4.79	0.00

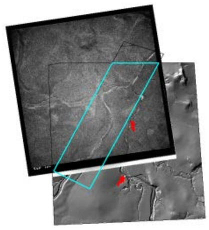
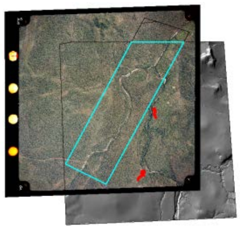
13.11 Historical air photos

Unfortunately the reprocessed difference raster does not cover the 3 gullies identified from air photos.

Volumes of erosion have been calculated using the original 2009 LiDAR. It is noted there are differences in DEM values between the original and reprocessed 2009 LiDAR, and erosion values listed here may vary between 20% less and 7% more than stated.



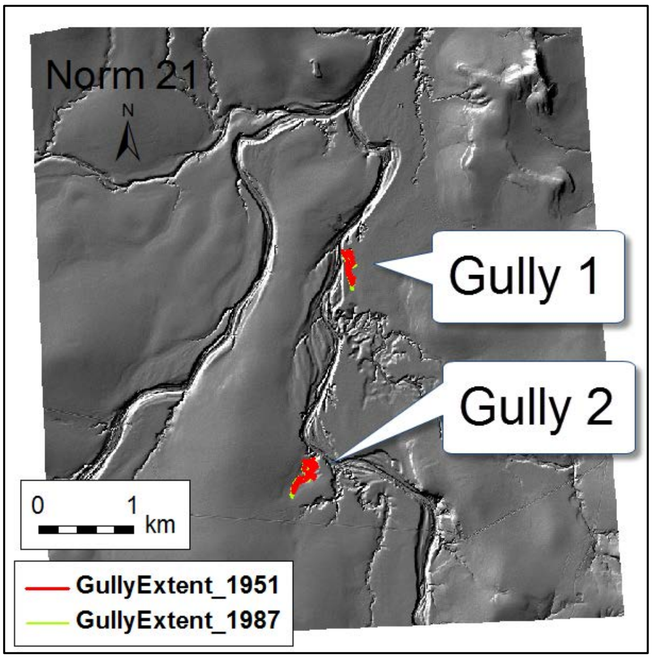
Gully one in this block has been identified in air historical ai rphotos from 1951 and 1987.

Image date	Photo ID	Scale	Flying height	RMS error of georeferenced air photo	Air photo position relative to 2009 LiDAR block
1/01/1951	QAP 165-144	25400	12750ft	0.43610	
1/01/1987	QAP 4109-84	25000	4310m	4.96693	

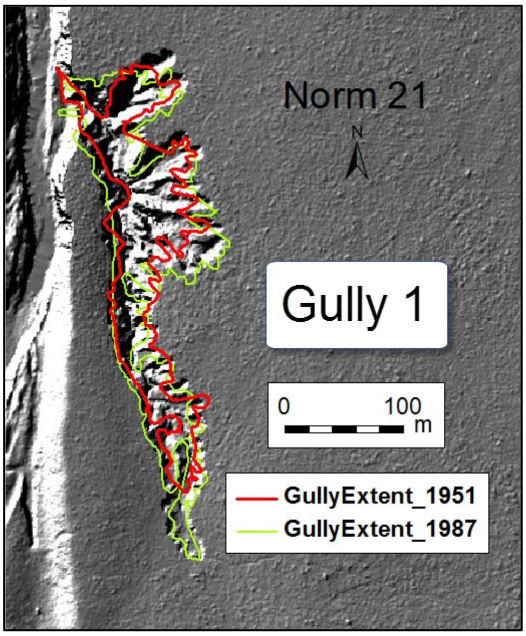
13.12 Historical gully extent

13.12.1 Gully one

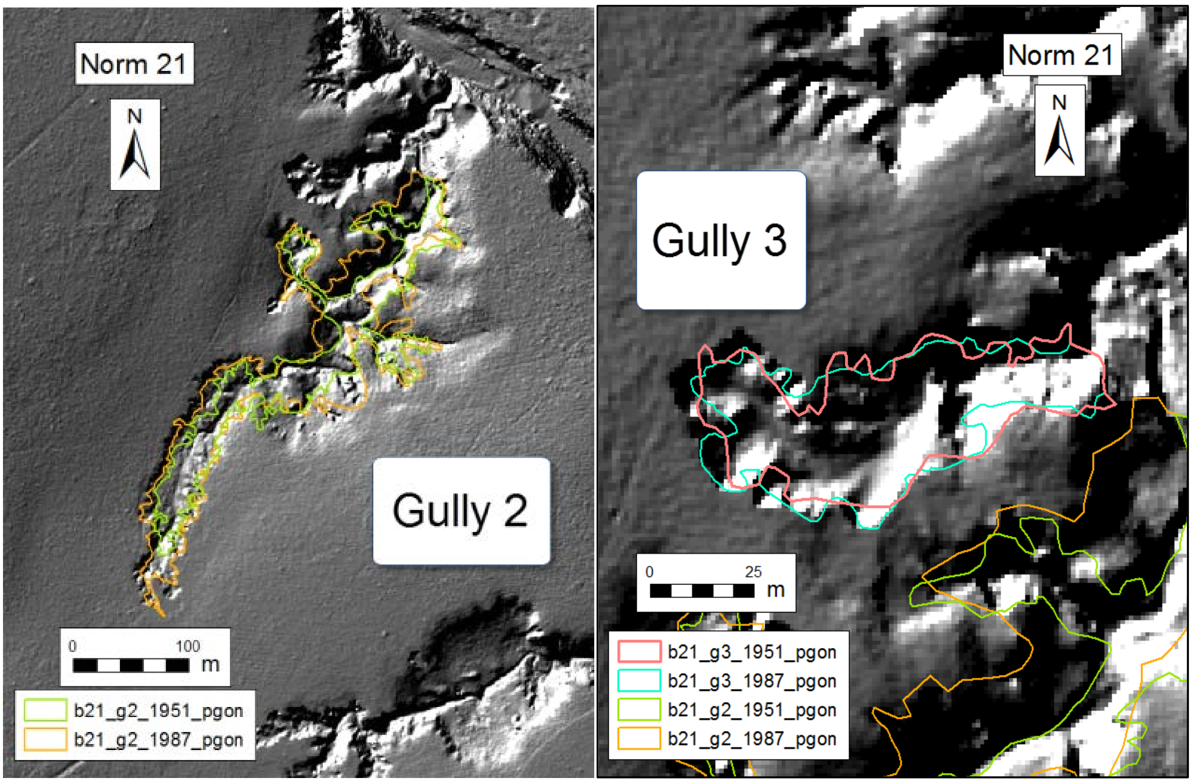
Location diagram



Gully 1 detail



13.12.2 Gully 2 and 3

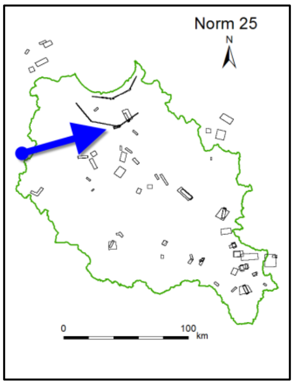


	Interval	Gully area at start of period ha	Rate of loss m^3/yr	Yield m3/ha/yr ased on 2009 gully area
Gully 1	1952 – 2009	1.4564	291	118
	1987 – 2009	1.8831	604	244
	2009 – 2011	2.4746	No data	No data
Gully 2	1952 – 2009	1.3354	528	159
	1987 – 2009	2.0827	581	175
	2009 – 2011	3.3295	No data	No data
Gully 3	1952 – 2009	0.2375	16	44
	1987 – 2009	0.2449	44	117
	2009 – 2011	0.3743	No data	No data

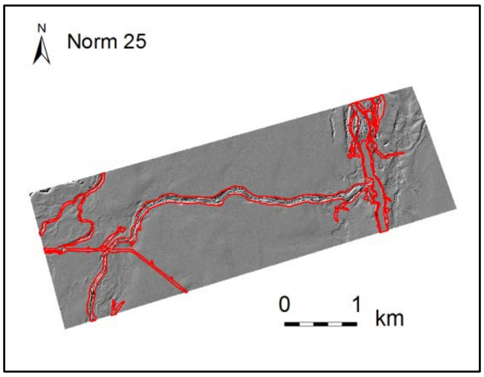
It is interesting to note that rate of loss from gully 1 and 3 between 1952-2009 was in the order of 50% of the rate of loss from 1987-2009; but the rate of loss from gully 2 was roughly similar over the same time periods. Could this be a reflection of actual productivity, or the foibles of digitising gullies from historical air photos?

14. Normanby LiDAR Block 25

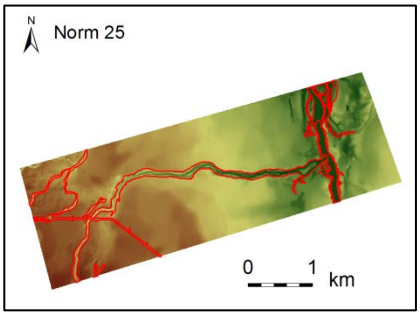
Block location



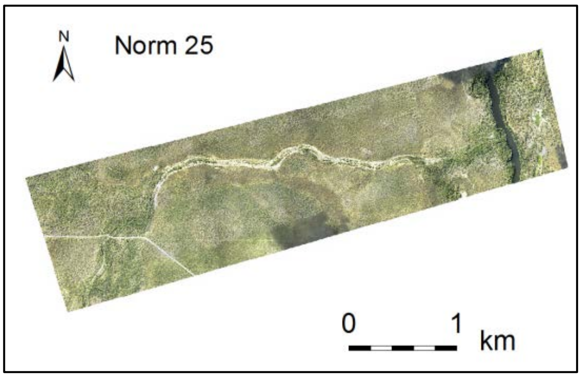
Digitising on LiDAR



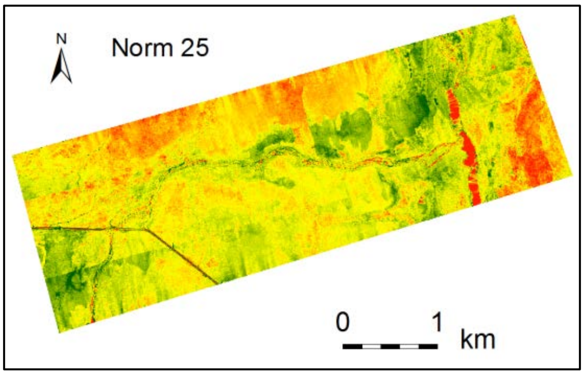
DEM



Orthophoto



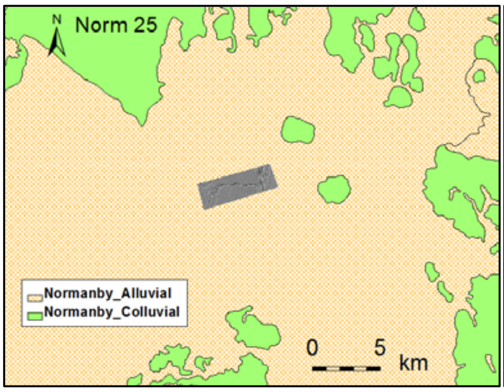
Difference raster



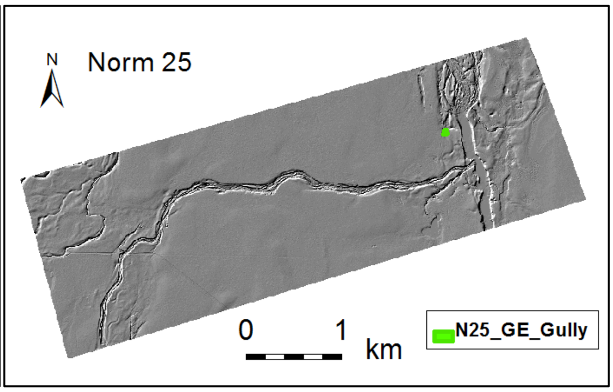
Reprocessed change raster area	ha	1050.8
Block elevation range	m	0.7 to 10
Number of LiDAR digitised features		38
Number of Google Earth mapped gullies		1

14.1 Alluvial and Colluvial zones

Alluvial and Colluvial soil



Google Earth mapped Gullies



N25 LiDAR block sits on a large extent of alluvial soils. No colluvial zone is in this block.

Normanby 25	Area ha	Area of all features digitised from LiDAR ha	Features as % of zone	Area of gullies digitised from LiDAR ha	Area of gullies as % of zone	Area of Google Earth digitised gullies ha	GE gullies as % of zone
Alluvial zone	1050.8	108.66	10.3	23.45	2.2	0.11	0.01
Colluvial zone	0	0	0	0	0	0	0

14.2 LiDAR derived data

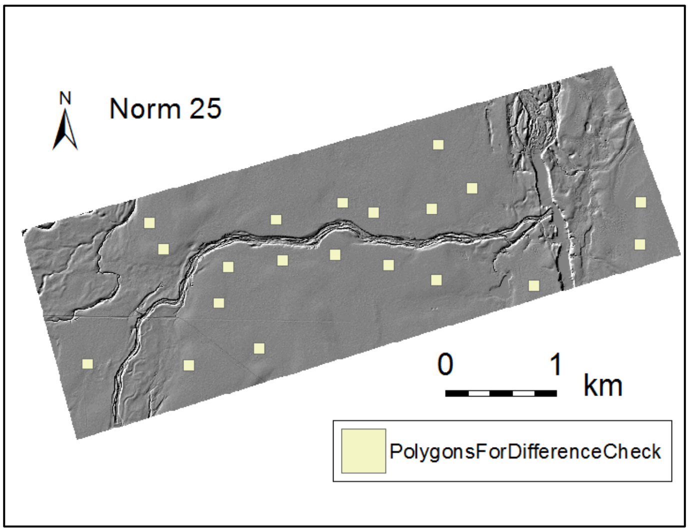
14.2.1 Horizontal adjustments

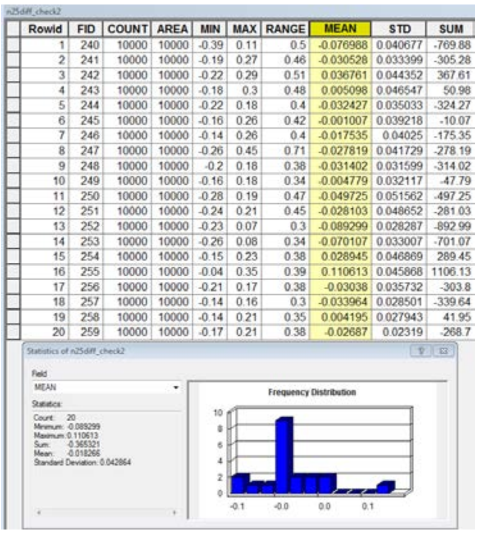
No horizontal adjustment was necessary, as digitising was done from reprocessed 2009 LiDAR.

14.2.2 Vertical adjustments

Adjustment for vertical offset of 2009 and 2011 DEMs

20 polygons of 1000 m^2 were put in areas where very little change would be expected to occur; ancient flood plain. Mean value of change raster within the 20 locations was used as a correction to the whole change raster.




n25diff_check2

Rowid	FID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	240	10000	10000	-0.39	0.11	0.5	-0.076988	0.040677	-769.88
2	241	10000	10000	-0.19	0.27	0.46	-0.030528	0.033399	-305.28
3	242	10000	10000	-0.22	0.29	0.51	0.036761	0.044352	367.61
4	243	10000	10000	-0.18	0.3	0.48	0.005098	0.046547	50.98
5	244	10000	10000	-0.22	0.18	0.4	-0.032427	0.035033	-324.27
6	245	10000	10000	-0.16	0.26	0.42	-0.001007	0.039218	-10.07
7	246	10000	10000	-0.14	0.26	0.4	-0.017535	0.04025	-175.35
8	247	10000	10000	-0.26	0.45	0.71	-0.027819	0.041729	-278.19
9	248	10000	10000	-0.2	0.18	0.38	-0.031402	0.031599	-314.02
10	249	10000	10000	-0.16	0.18	0.34	-0.004779	0.032117	-47.79
11	250	10000	10000	-0.28	0.19	0.47	-0.049725	0.051562	-497.25
12	251	10000	10000	-0.24	0.21	0.45	-0.028103	0.048652	-281.03
13	252	10000	10000	-0.23	0.07	0.3	-0.089299	0.028287	-892.99
14	253	10000	10000	-0.26	0.08	0.34	-0.070107	0.033007	-701.07
15	254	10000	10000	-0.15	0.23	0.38	0.028945	0.046869	289.45
16	255	10000	10000	-0.04	0.35	0.39	0.110613	0.045868	1106.13
17	256	10000	10000	-0.21	0.17	0.38	-0.03038	0.035732	-303.8
18	257	10000	10000	-0.14	0.16	0.3	-0.033964	0.028501	-339.64
19	258	10000	10000	-0.14	0.21	0.35	0.004195	0.027943	41.95
20	259	10000	10000	-0.17	0.21	0.38	-0.02687	0.02319	-268.7

Statistics of n25diff_check2

Field
MEAN
Statistics:
Count: 20
Minimum: -0.089299
Maximum: 0.110613
Sum: -0.365321
Mean: -0.018266
Standard Deviation: 0.042864

14.3 Statistics

Layer	min	max	Mean	s.d.
Norm_21_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-2.24	2.06	-0.023	0.08
Norm_20 with edge effect removed	-2.24	2.06	-0.023	0.08
Areas of minimal change	-0.08	0.11	-0.018266	0.04
N20_Diff_adjusted	-2.22	2.08	-0.005	0.08

The level of noise on flat flood plain areas has been ascertained, and these values removed from the erosion and deposition layers.

Values of change raster filtered to remove noise on floodplain.

raster	Values filtered
erosion	-0.25 to 0
deposition	0 to 0.25

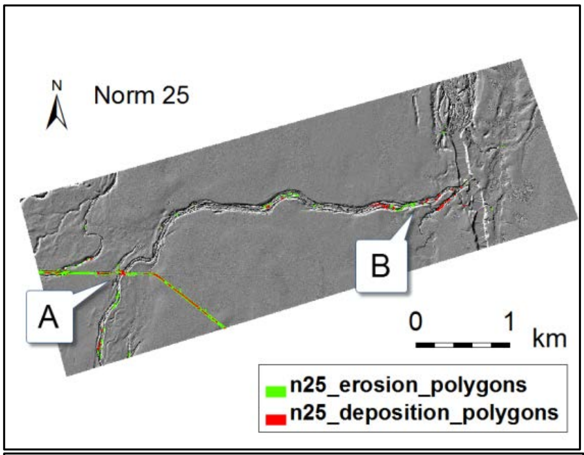
14.4 Aggressive filtering of erosion and deposition data

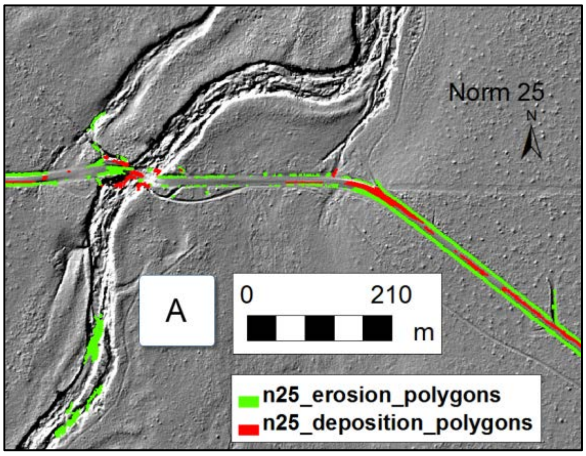
Norm 25 block was particularly flat with relatively open vegetation. LiDAR penetration to ground level was superior to steeper, more heavily vegetated blocks in the upper catchment. A threshold of 0.25m was used to remove noise from the floodplain, and also as the threshold for detecting real change in this block.

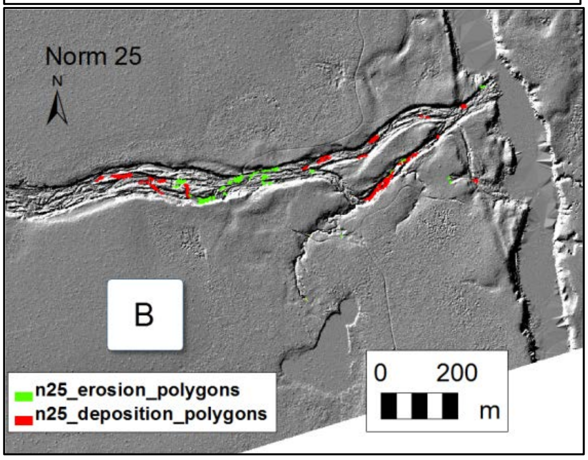
Table below shows the volume of data removed by hand thinning erroneous erosion and deposition data.

	erosion		deposition	
	area ha	raster sum	area ha	raster sum
Prior to hand thinning	6.4097	-21,862	5.8177	24,661
After hand thinning	2.1650	-9,569	0.7956	3,523

14.5 Observations



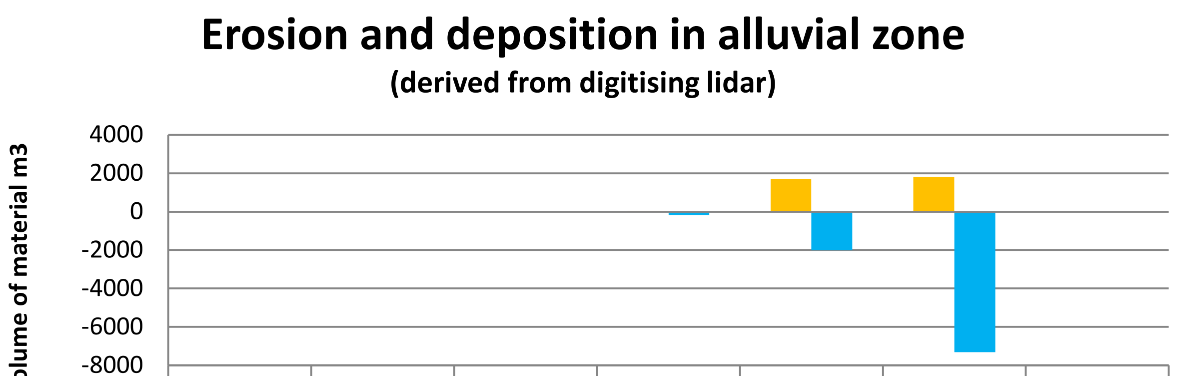




Location A: An upgrade to the road was in progress when the 2011 LiDAR was taken. A long pile of material from side tipper trucks was visible in the middle of the road. Widening and deepening of the table drain on either side of the road, and work about the stream crossing were to be seen. No flow-on effect from these works was evident in the 2 watercourses that crossed the road, but it would be interesting to see the situation after the next wet season.

Location B: Deposition exceeded erosion in the lower reaches of the secondary channel.

14.6 Erosion and deposition



	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Roads reserve	Flood Plain
Deposition	0	0	0	36.4799614	1696.22605	1811.18994	0
Erosion	0	0	-7.97121	-168.93333	-2015.466	-7315.0898	0

The main feature from the erosion and deposition graph is the 7315m³ of "erosion" from the road reserve – which is entirely due to the road works expanding the drainage along both sides of the road.

A smaller amount of material, 1811m³, was added to the crown of the road, possible different material to that used to build up the road surface. Where has the difference gone?

Deposition of 1696m³ in secondary channels, , was 14% less than the 2015m³ of erosion from secondary channels. This near parity could be explained by the low gradient of the secondary channels as they near the main channel, resulting in settling of transported material.

Erosion and deposition activity in gullies was minimal, possible as there were very few gullies, only 18.7ha, and those did not show signs of being active.

14.7 Comparison of alluvial gullies to colluvial gullies

Norm 25 did not have any area mapped as a colluvial zone.

Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
18.68	36.5	-168.9	-4.47	0	0	0	0

14.8 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial	18.68	-168.93	-4.47
GE gullies alluvial	0.11	0.00	0.00

The one gully in Norm 25 digitised from Google Earth covered 0.6% of the area of alluvial gullies digitised from LiDAR. The GE gully was a pondage area that fed to a larger waterbody, and had no measured erosion or deposition.

14.9 Gully Expansion 2009 – 2011

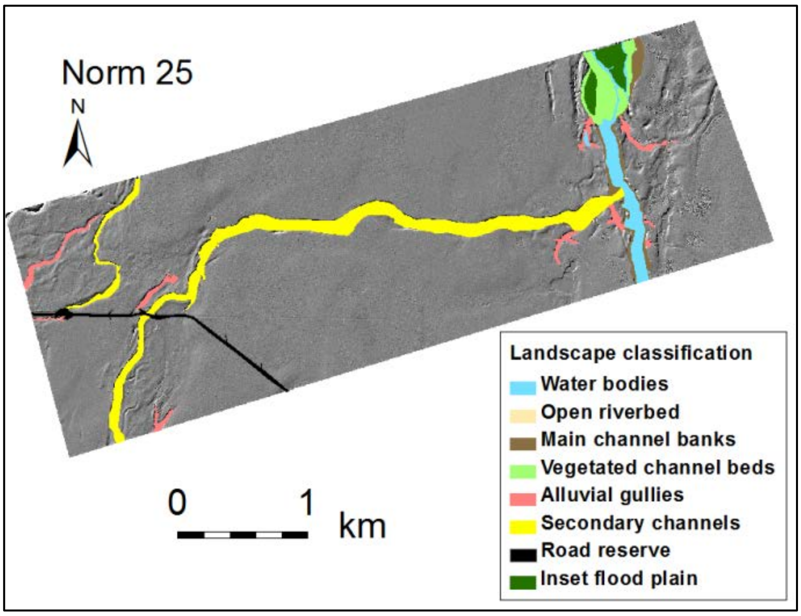
There was no measured expansion of gullies in Norm 25 between 2009 and 2011. There was no expansion of area of secondary channels either.

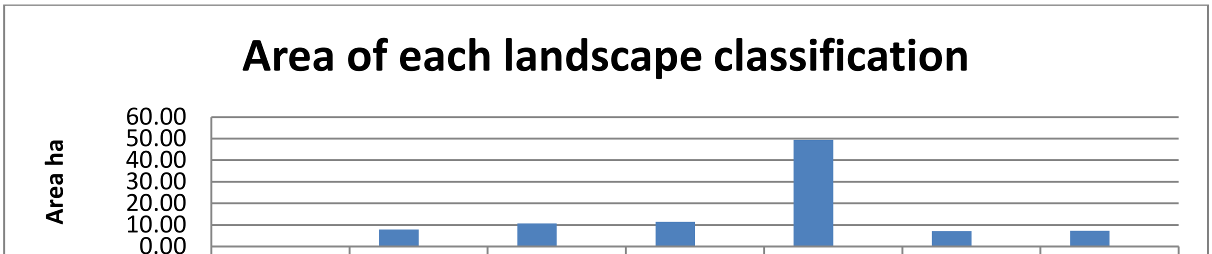
The following table summarises total gully expansion between 2009 and 2011.

Gully Expansion 2009 - 2011	
number of gully expansion locations	0
sum area of gully expansions ha	0
mean area of expansion m2	0

14.10 Landscape Classification

Secondary channels had an area of 49.46ha, the largest area of features classified in Norm 25, and the only bock to have secondary channels with a far larger area than alluvial gullies. There were few alluvial gullies, and these were relatively small, having a total area of 11.37ha.The main water body reduced to narrow wet channels at the northern end, with wide vegetated channel bed and flood plain to either side. The area of road reserve, 7.16ha, was similar to the area of main channel banks, 7.85ha.





	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Roads reserve	Flood Plain
area ha	0.00	7.85	10.71	11.37	49.46	7.16	7.31
Colluvial ha	0.00	0.00	0.00	0.00	0.00	0.00	0.00

14.11 Historical air photos

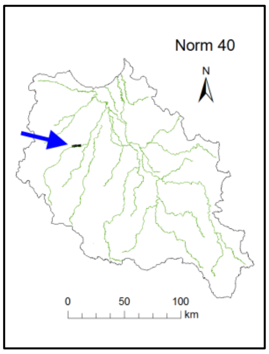
No details from historical air photos were available for Norm 25.

Coverage was limited to 1 image from 1955, which was part of the CAB series, and not a part of the collection for this project.

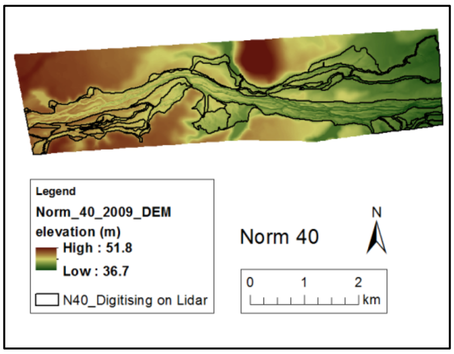
15. Normanby LiDAR Block 40

Normanby 40 block is located on the Morehead River in the west of the Normanby catchment, and is 1429 hectares. The main channel loses 5m over 7km, and is comprised of many anabranching channels between 10 and 20m wide. The main character of this block is the large volume of erosion and deposition within the main channel. The floodplain is elevated 1-2m above the main channels, but in some places is below the height of the main channel. Deposition onto the floodplain has occurred where side channels peter out on very flat land, or end at pondage areas where deltas are forming.

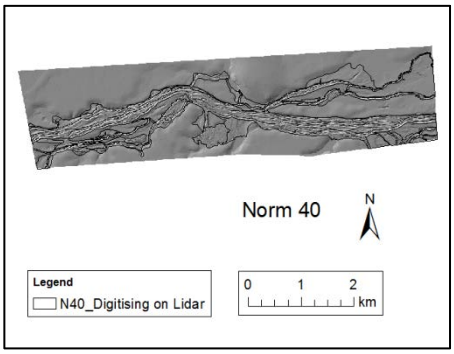
Block location



Elevation

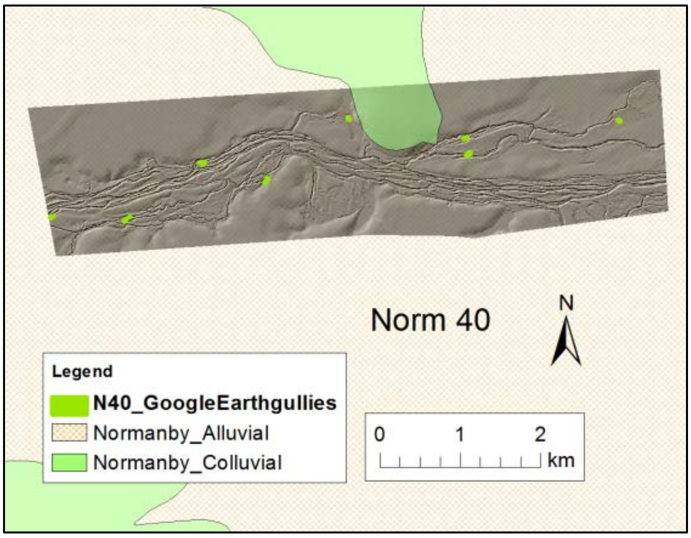


Air photo gully location (none)



A low hill rising 10m above the main channel has been mapped as colluvial. This occupies 70ha, or 4% of the area. No gullies extend into the colluvial area. Ten gullies have been mapped from Google Earth, with a total area of 0.45ha. Norm 40 is the only block to have the area of Google Earth gullies anywhere close to the area of LiDAR digitised gullies, being 0.45ha and 0.56ha respectively. However, the 10 Google earth mapped gullies were actually open river bars and bare earth patches on shallow banks. This again shows the limitations of identifying alluvial gullies from Google Earth.

Alluvial/colluvial zones, and Google Earth gullies



Areas of digitised features and gullies in alluvial and colluvial zones.

Norm 40	Area (ha)	Area of all digitised features ha	Features as % of zone	Area of LiDAR gullies ha	Area of gullies as % of zone	Area of GE digitised gullies ha	GE gullies as % of zone
Alluvial zone	1359.01	559.97	41.2	0.56	0.7	0.45	0.03
Colluvial zone	70.59	0.00	0.0	0.00	0.0	0.00	0.00

15.1 Adjustments to LiDAR derived data

Horizontal adjustments

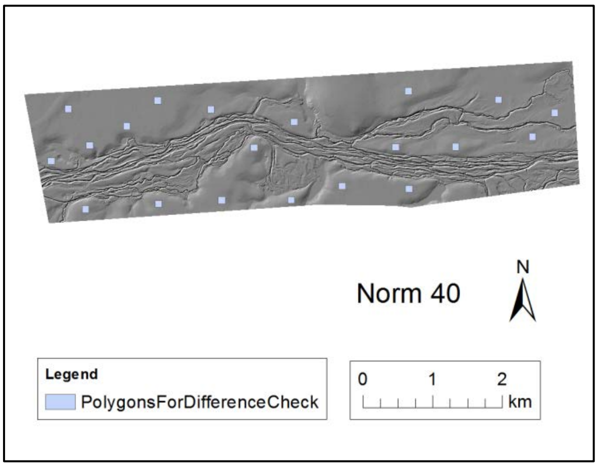
The X, Y shift of data to align with the position of reprocessed LiDAR is listed in the table below.

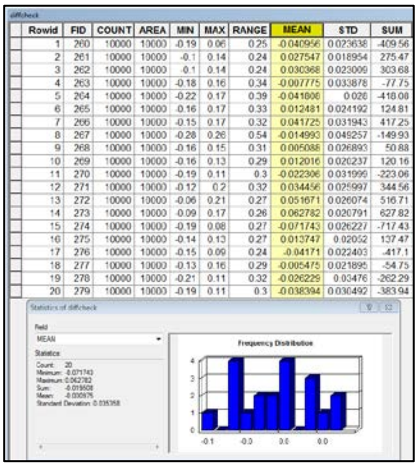
X,Y nudge (m)	0 , 0

Vertical adjustments: to correct vertical offset of 2009 and 2011 DEMs

The difference raster was sampled at 20 locations on the alluvial flood plain where very little change would be expected to occur, using polygons of 1000 m^2. The average of mean values of the difference raster within the 20 locations was used as a correction to the whole change raster.

Location of sample polygons and table of mean values.





Rowid	FID	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM
1	260	10000	10000	-0.19	0.06	0.25	-0.040956	0.023638	-409.56
2	261	10000	10000	-0.1	0.14	0.24	0.027547	0.018954	275.47
3	262	10000	10000	-0.1	0.14	0.24	0.030368	0.023009	303.68
4	263	10000	10000	-0.18	0.16	0.34	-0.007775	0.033878	-77.75
5	264	10000	10000	-0.22	0.17	0.39	-0.041808	0.026	-418.08
6	265	10000	10000	-0.16	0.17	0.33	0.012481	0.024192	124.81
7	266	10000	10000	-0.15	0.17	0.32	0.041725	0.031943	417.25
8	267	10000	10000	-0.28	0.26	0.54	-0.014993	0.049257	-149.93
9	268	10000	10000	-0.16	0.15	0.31	0.005088	0.026893	50.88
10	269	10000	10000	-0.16	0.13	0.29	0.012016	0.020237	120.16
11	270	10000	10000	-0.19	0.11	0.3	-0.022306	0.031999	-223.06
12	271	10000	10000	-0.12	0.2	0.32	0.034456	0.025997	344.56
13	272	10000	10000	-0.06	0.21	0.27	0.051671	0.026074	516.71
14	273	10000	10000	-0.09	0.17	0.26	0.062782	0.020791	627.82
15	274	10000	10000	-0.19	0.08	0.27	-0.071743	0.026227	-717.43
16	275	10000	10000	-0.14	0.13	0.27	0.013747	0.02052	137.47
17	276	10000	10000	-0.15	0.09	0.24	-0.04171	0.022403	-417.1
18	277	10000	10000	-0.13	0.16	0.29	-0.005475	0.021895	-54.75
19	278	10000	10000	-0.21	0.11	0.32	-0.026229	0.03476	-262.29
20	279	10000	10000	-0.19	0.11	0.3	-0.038394	0.030492	-383.94

15.2 Statistics

Layer	min	max	Mean	s.d.
Norm_40_Difference_2009-2011_Reprocessed.tif (as supplied by Terranean)	-3.47	5.35	-0.015	0.09
Areas of minimal change	-0.07	0.06	-0.000975	0.04
NORM 40_Diff_adjusted (with edge effect removed)	-3.47	5.35	-0.015	0.09

Values of change raster filtered to remove noise on floodplain.

raster	Values filtered

erosion	-0.2 to 0
deposition	0 to 0.2

15.3 Aggressive filtering of erosion and deposition data

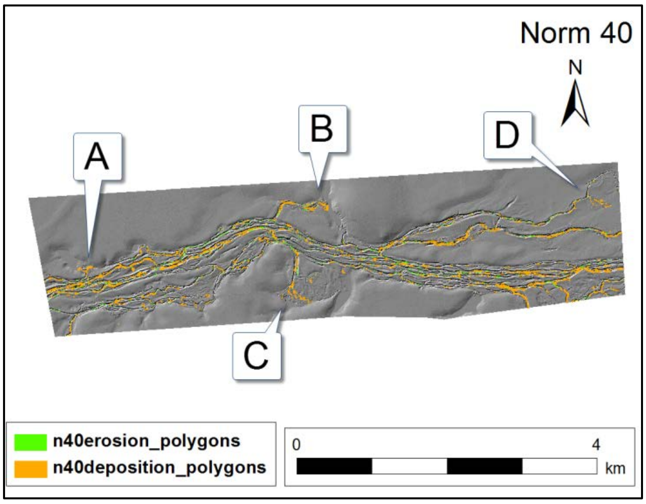
Norm 40 is essentially flat, with a relatively open canopy. Relocation of flow lines within existing channel banks has occurred along most of the length of channel in the block.

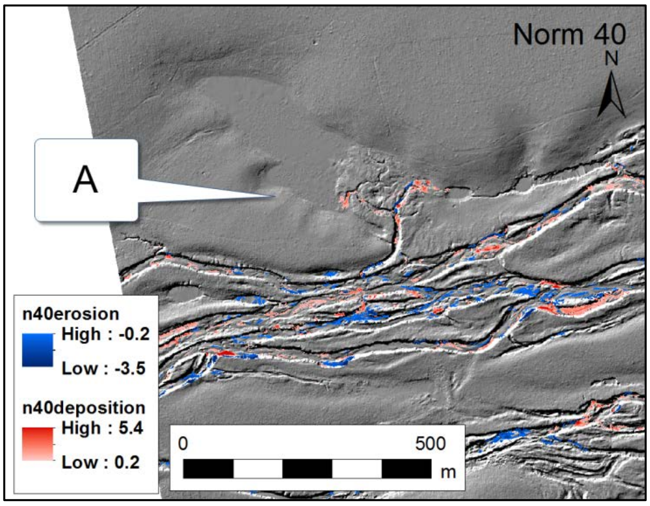
A threshold for real change of 0.2m above and below zero was used in this block to pick up the fine scale movement of material in the channels. The task of hand thinning the selected erosion and deposition cells was not too onerous, as the difference raster was not unduly cluttered with spurious values.

Table below shows the volume of data removed by hand thinning erroneous erosion and deposition data.

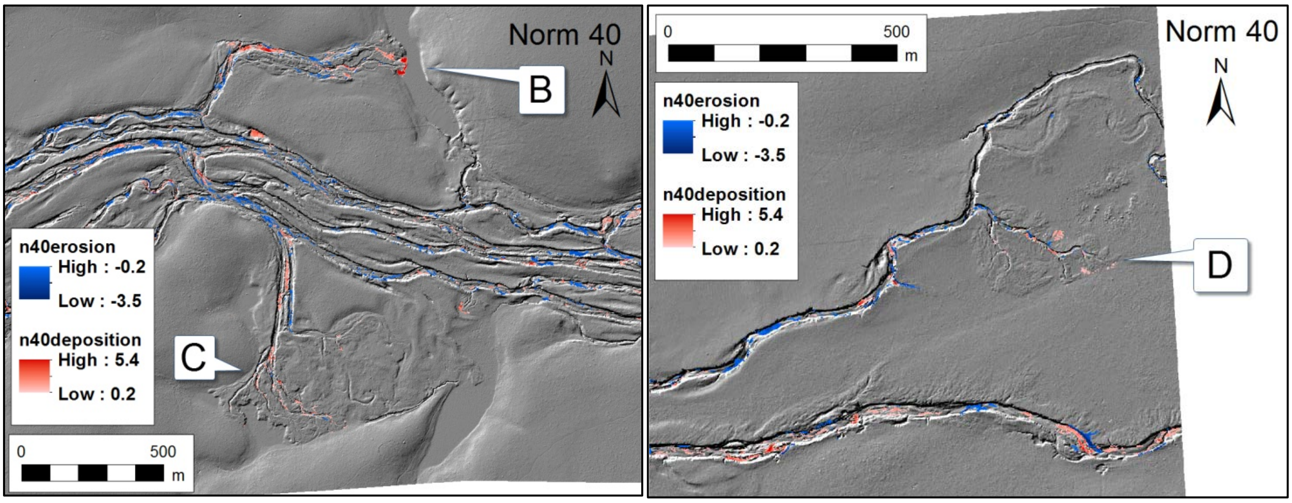
	erosion		deposition	
	area ha	raster sum	area ha	raster sum
Prior to hand thinning	23.27	-102,716	18.95	69,675
After hand thinning	11.05	-49,818	11.00	37,748

15.4 Observations of erosion and deposition





Location A: A pondage area to the north of the main channel has been filling in with deposits from a small branch of the main channel system. Redistribution of material with in the main channel system can also be seen.



Location B: What appears to be an ancient channel, identifiable in Google Earth, runs in a north-south direction, with the current anastomosing channel system running east-west, cutting perpendicularly across the old channel, and breaching the bank to the east of the old channel. Deposition into the ponded area has built a delta, which will eventually cut the pond.

Location C: An offshoot of the main channel system delivers material to a low lying area, which backs on to an isolated pond from an ancient channel system.

Location D: Deposition onto a low lying area.

15.5 Erosion and deposition summary

The majority of erosion and deposition was between 0.2 and 0.5m deep, and occurred within narrow, anabranching channels with overhanging vegetation with a mean height of 7m.

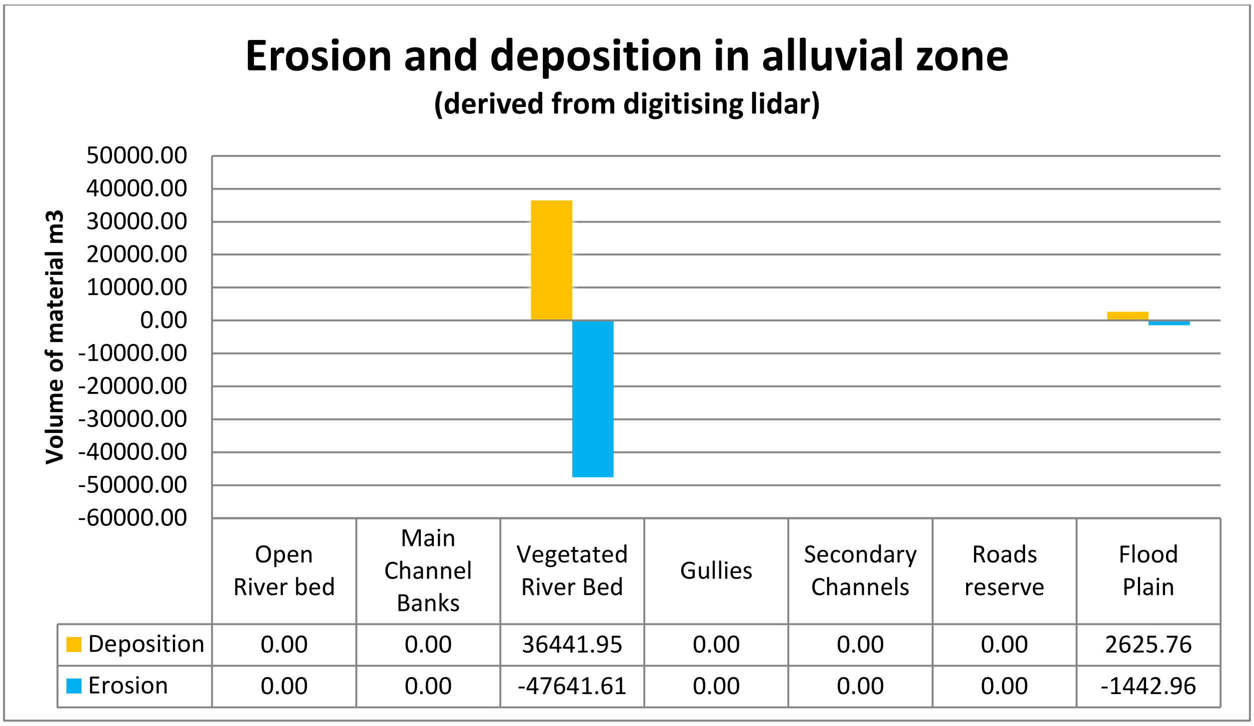
Minimal erosion of channel banks was seen. The channel system did not expand laterally.

The sum of deposition in vegetated channel beds and flood plains and gullies was 39,072m3. This was 6 times larger than the next highest total deposition load in Norm 14.

Deposition in channels delivering to low lying flood plains was 2582m3. If this was considered lost to the main channel transport system, and included as flood plain deposition, the total would rise from 2625 to 5207m3.

Despite the enormous volume of deposition into this block, there was a net loss of material due to 47640m3 of erosion from the channel system.

No erosion or deposition was measured from the 0.6ha of alluvial gullies.



15.6 Comparison of alluvial gullies to colluvial gullies

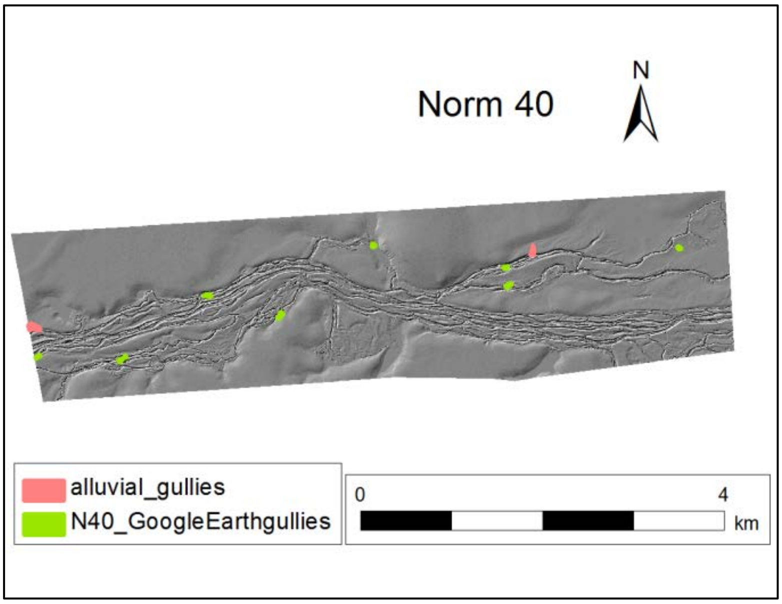
Alluvial gullies				Colluvial gullies			
area ha	deposition m3	erosion m3	yield m3/ha/yr	area ha	deposition m3	erosion m3	yield m3/ha/yr
0.58	0.00	0.00	4.33	0.00	0.00	0.00	0.00

No gullies extended into the colluvial zone. The 2 small alluvial gullies in Norm 40 did not have any erosion measurable by LiDAR differencing between 2009 and 2011.

15.7 Comparison of Google Earth gullies to LiDAR gullies in the alluvial zone

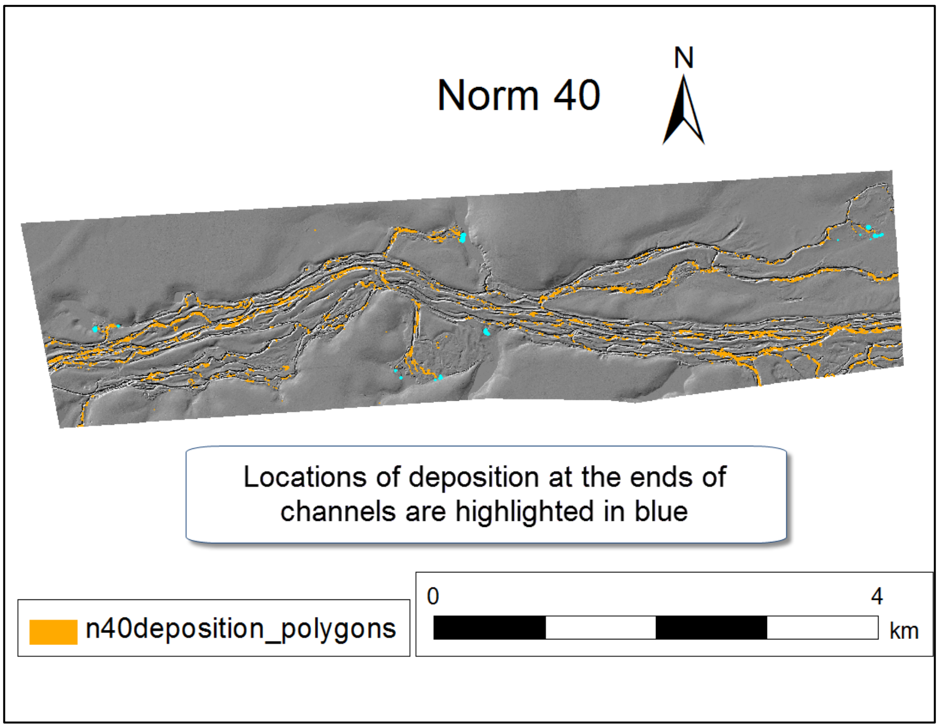
	Area ha	erosion m3	Yield m3/ha/yr
LiDAR alluvial	0.58	0.00	4.33
GE gullies alluvial	0.45	−93.04	29.13

Norm 40 was unique in this study as having virtually no alluvial gullies, and the areas mapped as Google Earth gullies were not gullies at all, but open riverbanks among anabranching channel country. The erosion captured but GE gullies here is actually river bed erosion. This situation is further evidence of the difficulties of using GE gullies as a proxy for alluvial gullies.



15.8 Gully Expansion 2009 – 2011

Though substantial shifting of material along the channel bed has occurred between 2009 and 2011, there has been virtually no expansion of channel width from 2009 limits, and no expansion of gully area either. This reach appears to be a transport and depositional region, rather than an area of active erosion into the alluvial floodplain. The area of deposition of new material at the ends of active channels was 0.25ha, shown in the picture below.

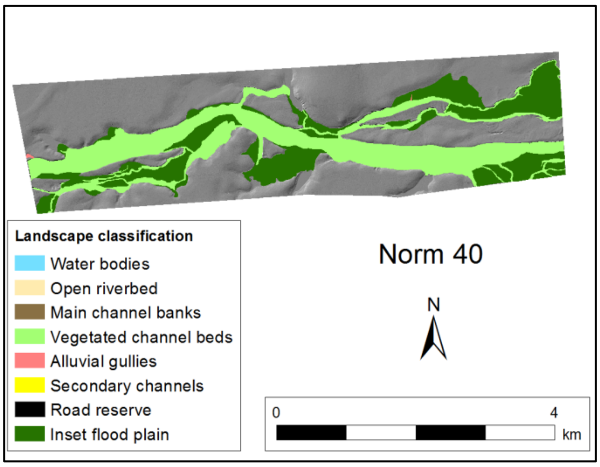


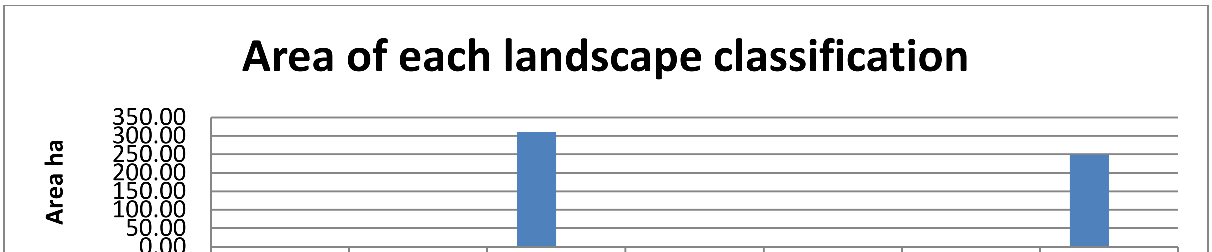
15.9 Landscape Classification

Norm 40 has many threads of anabranching channel system, each thread between 10 and 20m wide, running mainly parallel, but with multiple junctions and splits of channels within the system. Very little open riverbed was visible in the orthophoto, and no one channel was dominant, so collectively the system was classified as vegetated riverbed.

The height gain from channel bed to surrounding flood plain was between 2-3m, and the channel banks were not digitised due to the complexity of the system and the time available.

In some areas the elevation of flood plain receiving deposition was only centimetres above the channel bed, and in some areas, at a lower elevation.





	Open River bed	Main Channel Banks	Vegetated River Bed	Gullies	Secondary Channels	Roads reserve	Flood Plain
area ha	0.00	0.00	310.44	0.58	0.00	0.00	248.96
Colluvial ha	0.00	0.00	0.00	0.00	0.00	0.00	0.00

15.10 Historical air photos

The 2 historical air photos listed in the database were black and white images from 1969, and were from the CAB series, which was not readily available to this project.