The quality of erosion and deposition volume estimates from remotely-sensed digital elevation models of large gravel-bed rivers

Richard Westaway
University of Cambridge, United Kingdom

Stuart Lane
University of Leeds, United Kingdom

Murray Hicks
National Institute of Water & Atmospheric Research, New Zealand

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Remote sensing = New views of landforms

- Remote sensing technologies allow synoptic measurement of large areas
- For large gravel riverbeds, this potentially represents a huge increase in morphological information (compared to conventional x-section surveys)
- Has led to possibility of "morphological method" of inferring bed load transport rate from measurements of topographic change
- However….is the topographic data produced using remote sensing methods of sufficient quality?

Aim

- To test quality of morphological change data acquired using two remote sensing methods for two large gravel-bed rivers:

River	Digital photogrammetry	Airborne laser scanning
North Ashburton	May 95; Feb 99	n/a
Waimakariri	Feb 99; Mar 99; Feb 00	May 00

  - Submerged topography recovered using through-water photogrammetry (North Ashburton, see Westaway et al., 2000 in ESP&L) or image analysis (Waimakariri, see Westaway et al., forthcoming in IJRS)

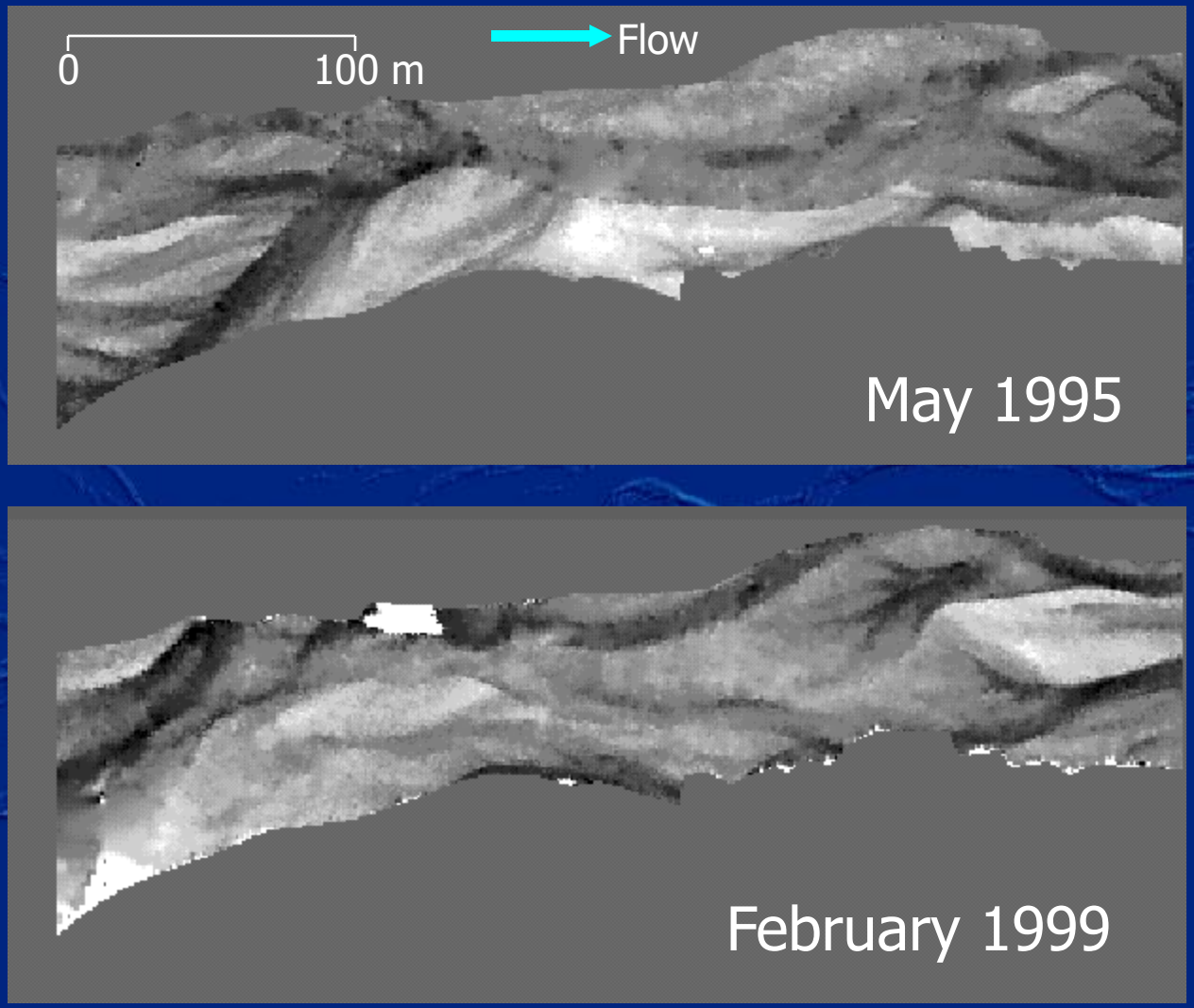
The North Ashburton River

The Waimakariri River

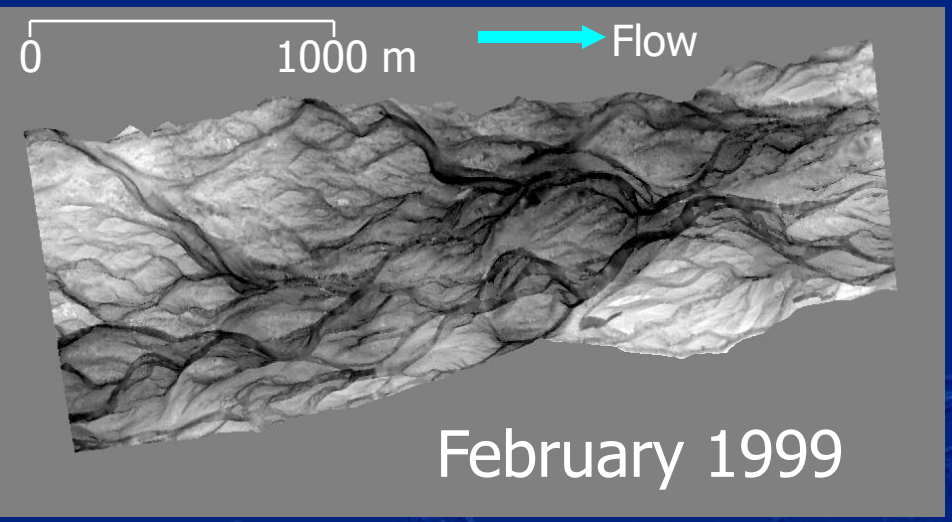
Results

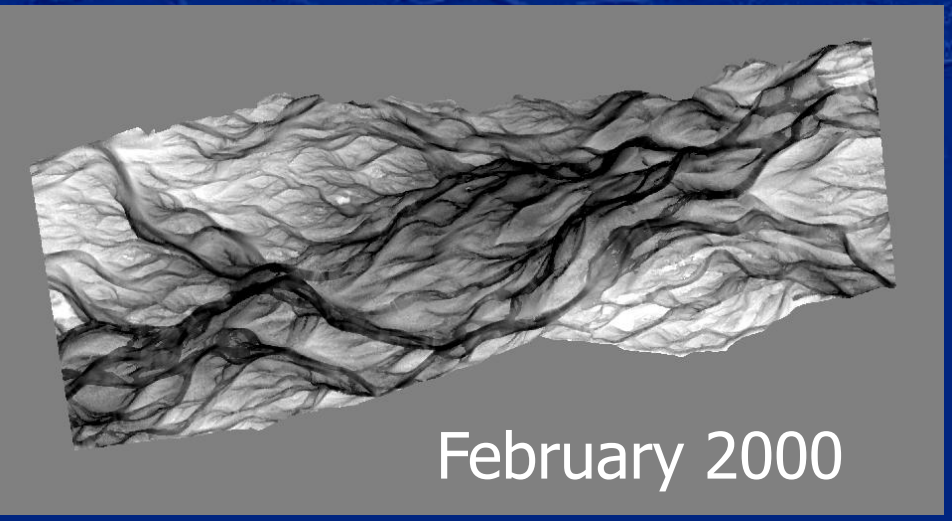
- 1 m spaced digital elevation models (DEMs)
  - North Ashburton River
    - 100 x 300 m study reach => 30000 points
    - 2 riverbed DEMs
    - 1 DEM of difference (May 95 to Feb 99)
  - Waimakariri River
    - 1000 x 3000 m study reach => 3000000 points
    - 4 riverbed DEMs
    - 3 DEMs of difference:
      - Flood-scale (Feb 99 to Mar 99; Feb 00 to May 00)
      - Annual-scale (Feb 99 to Feb 00)

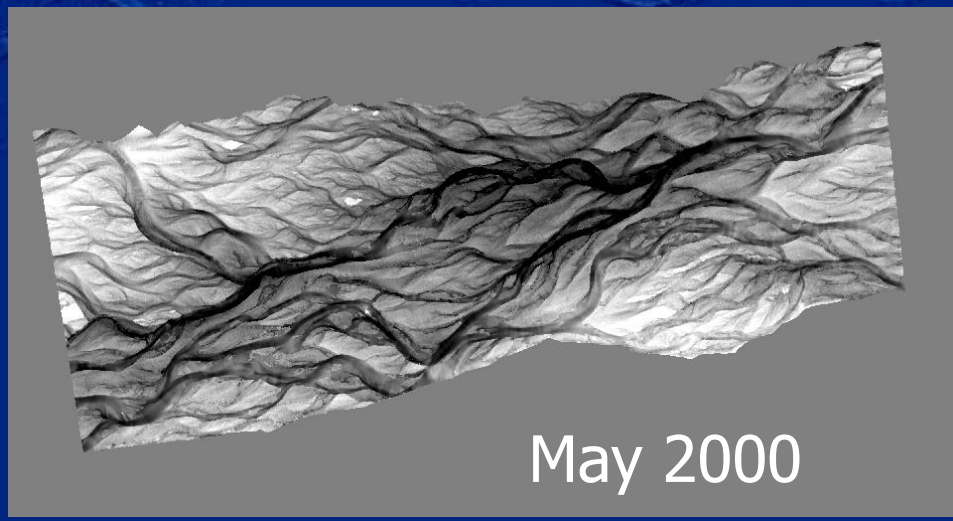
Final DEMs: North Ashburton



Final DEMs: Waimakariri

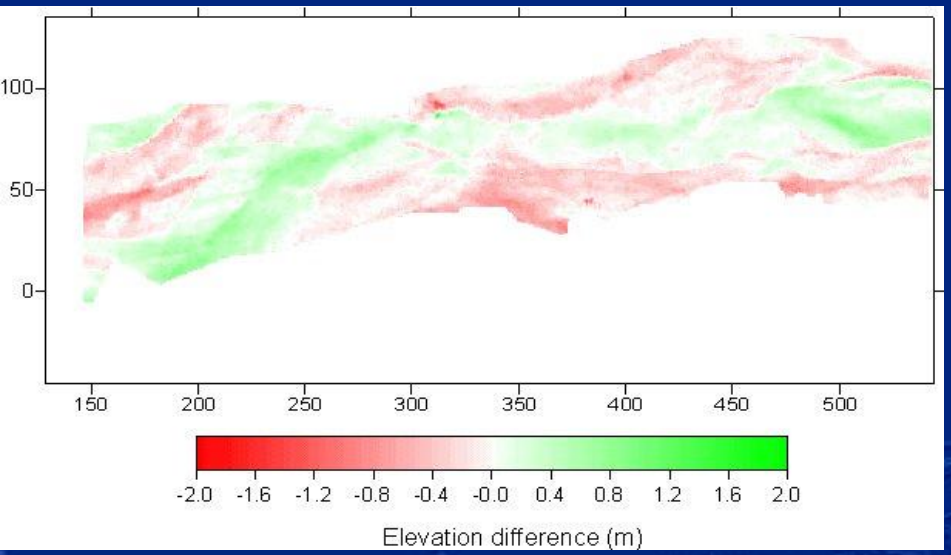




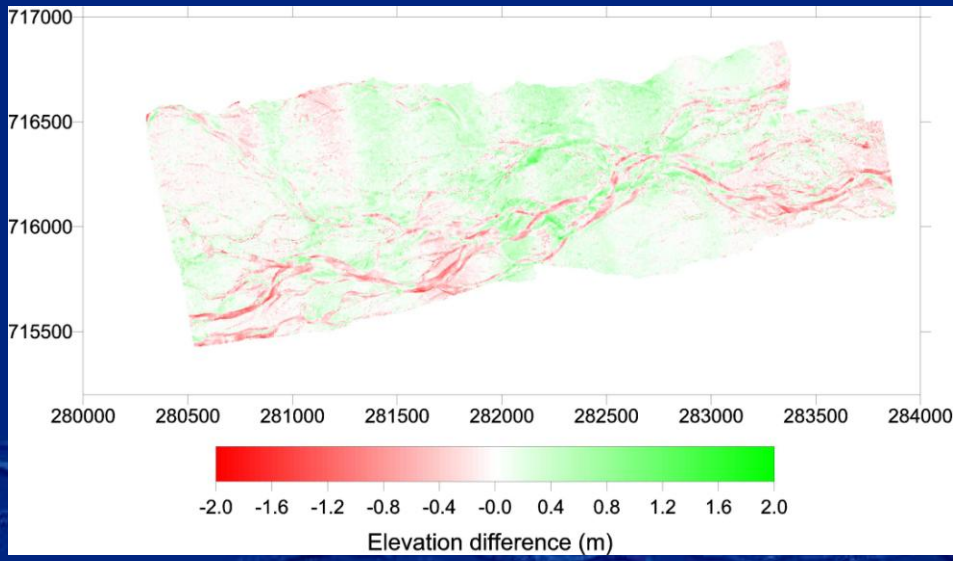


Difference DEMs

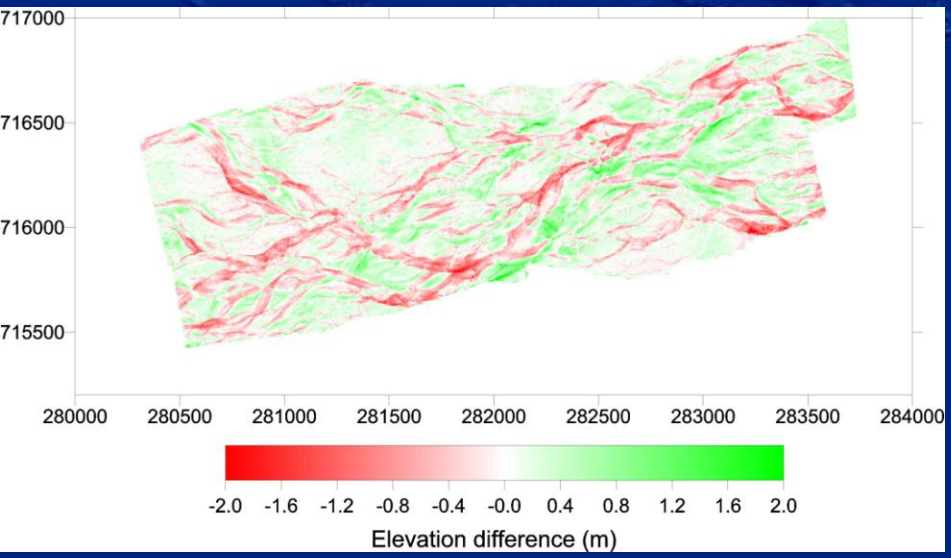
North Ashburton - May 95 to Feb 99



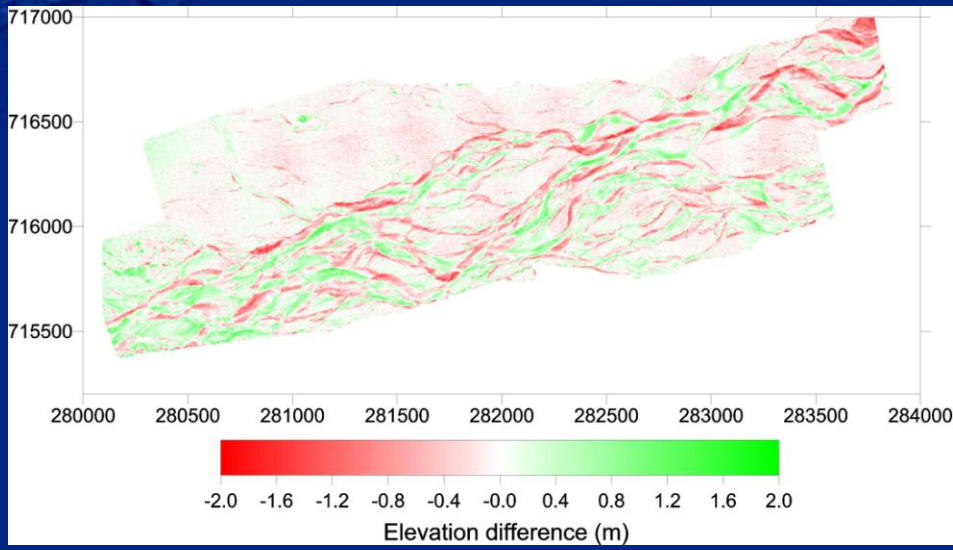
Waimakariri - Feb 99 to Mar 99



Waimakariri - Feb 99 to Feb 00



Waimakariri - Feb 00 to May 00



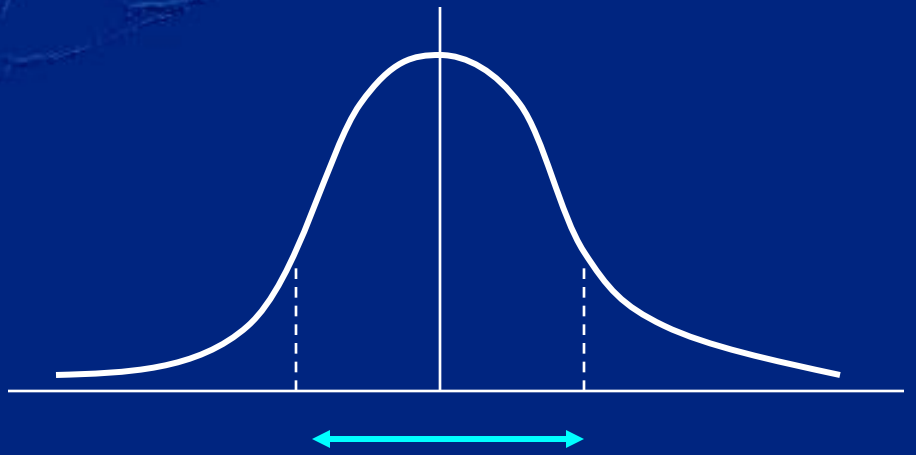
Errors?

- But just how confident can we be in the quality of these DEMs of difference?
- Requires recognition of different types of errors in DEM surfaces

Types of error (1)

RANDOM ERROR

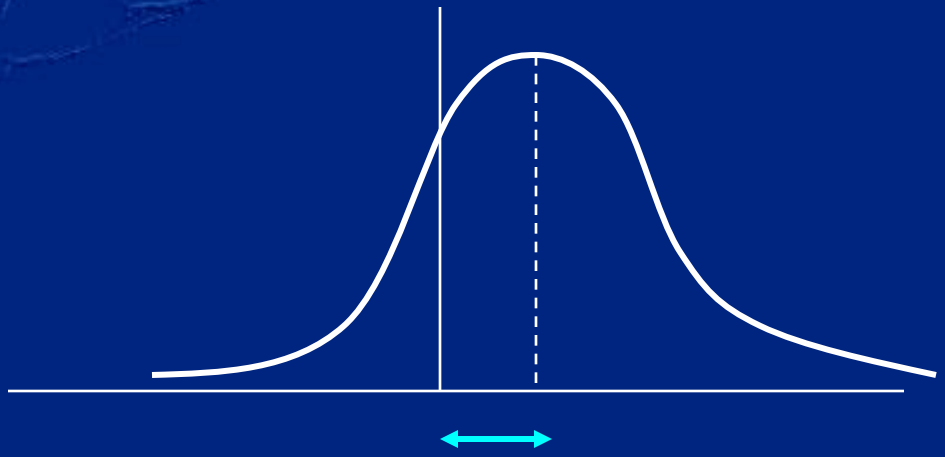
- Inherent in all measurements
- Cause variation from true value
- Revealed and minimised by repeated measurements
- Called DEM precision



Types of error (2)

SYSTEMATIC ERROR

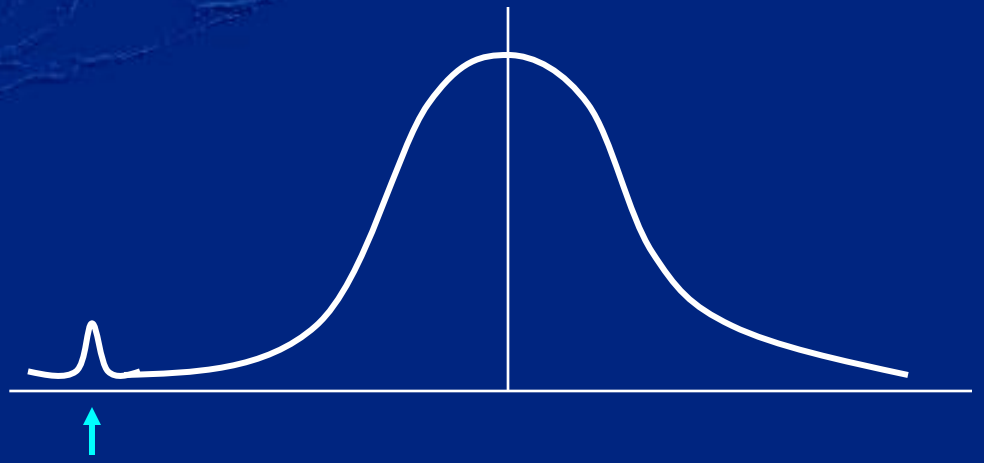
- Consistent across DEM
- Not revealed or minimised by repeated measurements
- Called DEM accuracy



Types of error (3)

GROSS ERROR

- 'Blunders'
- Revealed but not minimised by repeated measurements
- Called DEM reliability



Error in DEMs of difference

- For DEMs of difference:
  - Gross errors can be identified (as outliers) and removed
  - Systematic errors can be identified and removed if calibration data is available (e.g. areas of known/no change)
  - Random errors cannot be removed, and limit the morphological change that can be detected *("Minimum level of detection", Brasington et al., 2000)*

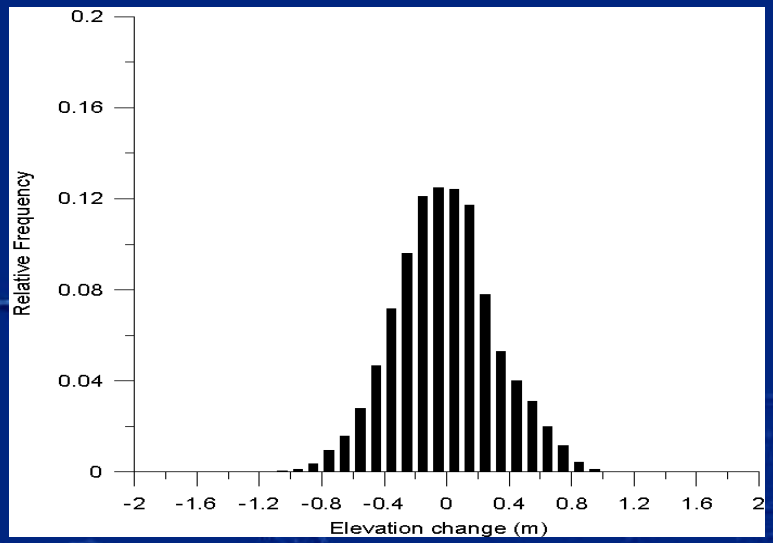
- Are these errors present in the DEMs of difference?

1. Gross errors

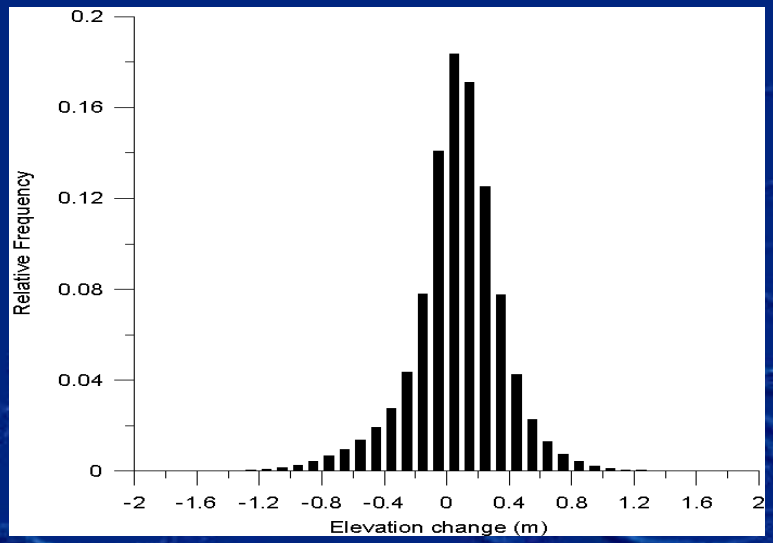
- Indicated by outliers on histograms of elevation change

Frequency distribution plots

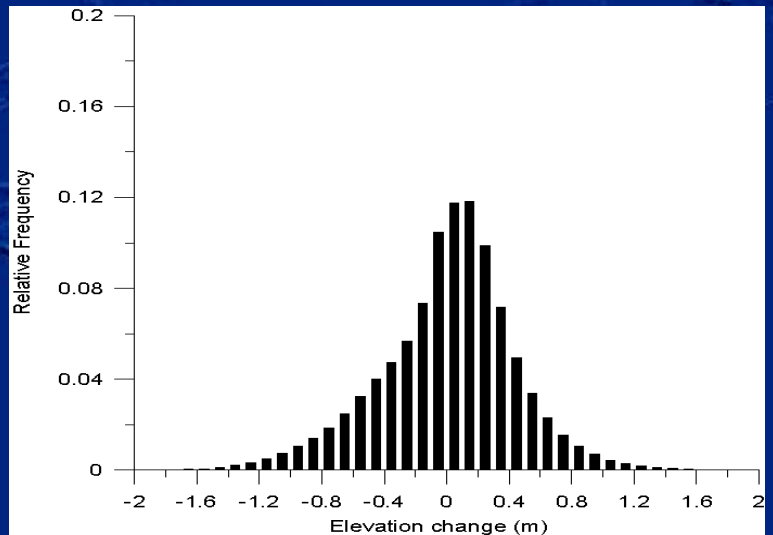
North Ashburton 05/95-02/99



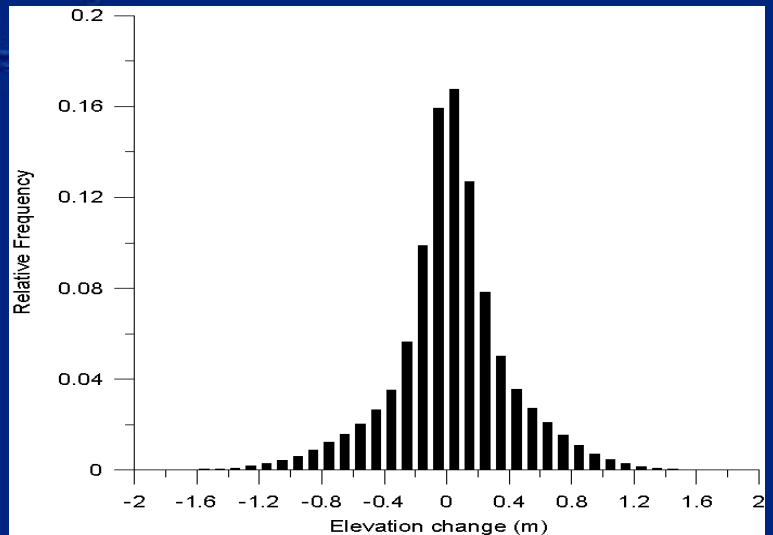
Waimakariri 02/99-03/99



Waimakariri 02/99-02/00



Waimakariri 02/00-05/00

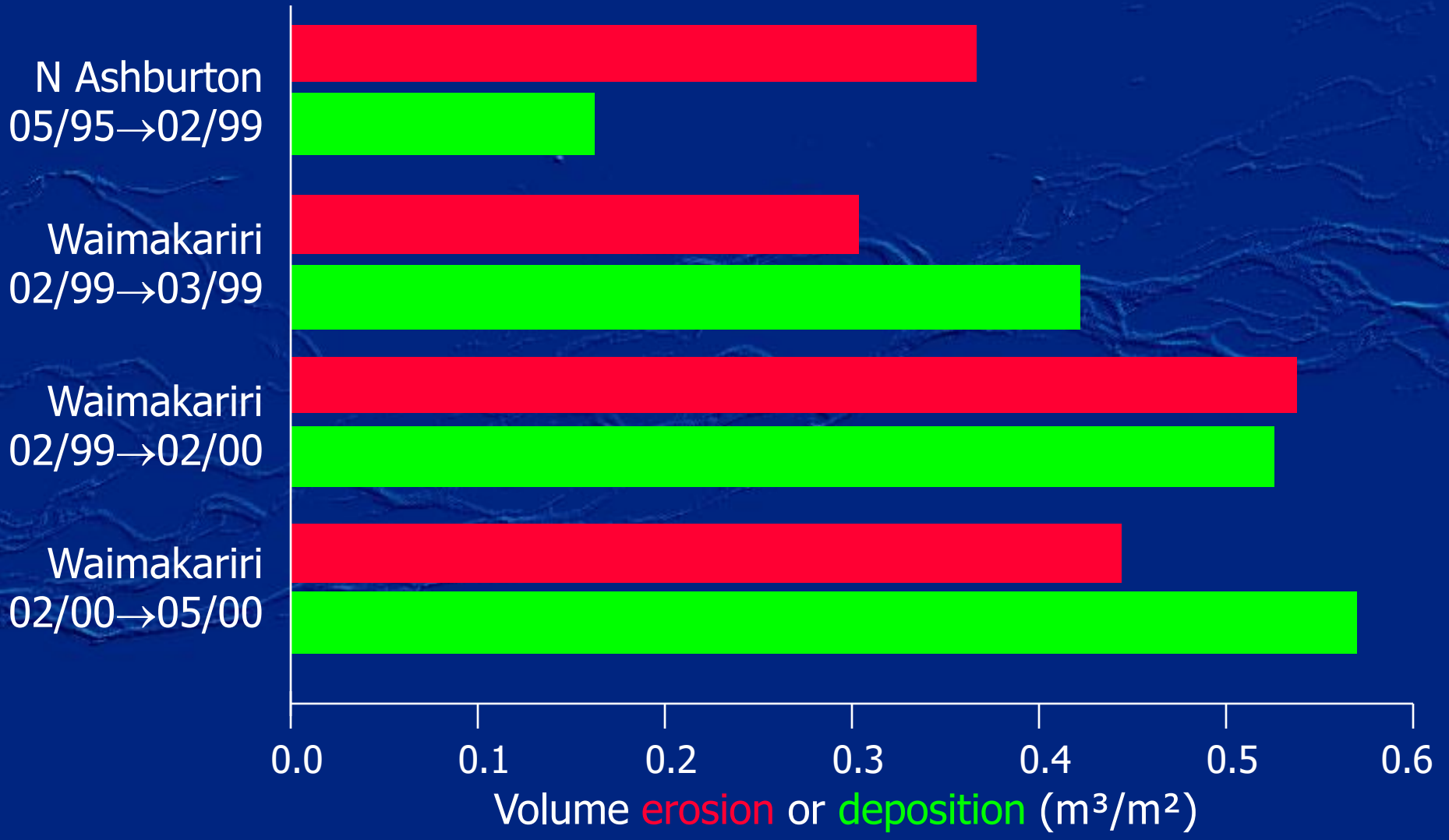


2. Systematic errors

- Geomorphological assumptions can be used to inform assessment of systematic errors in DEM of difference:
  - Dry→wet areas show erosion but no deposition
  - Wet→dry areas show deposition but no erosion
  - Bar-top areas show little change in elevation
- Large deviations from these assumptions indicate presence of systematic error

Systematic error assessment

3. Bar-top areas - No change (Waimak only)



3. Random errors

- Cannot be removed from DEM of difference
- Limits morphological change that can be deemed significant (over random noise)
- For $u = a - b$, minimum level of detection (LOD_{min}) is:

$$LOD_{min} = \sqrt{(p_a^2 + p_b^2)}$$

(where p is a measure of DEM precision)

$\Rightarrow$ DEM precision measurement is critical

DEM precision

- Three measures of DEM precision are commonly used:
  - Theoretical precision
    - for DP, *p* = photo scale x scanning resolution
    - for ALS, *p* = *c.* 1 cm per 1000 m flying height
  - Photo control point (PCP) precision (DP only)
    - Standard deviation of photo-block vs PCP elevations
  - Check point precision
    - Standard deviation of DEM vs check point elevations

Estimated DEM precision (m)

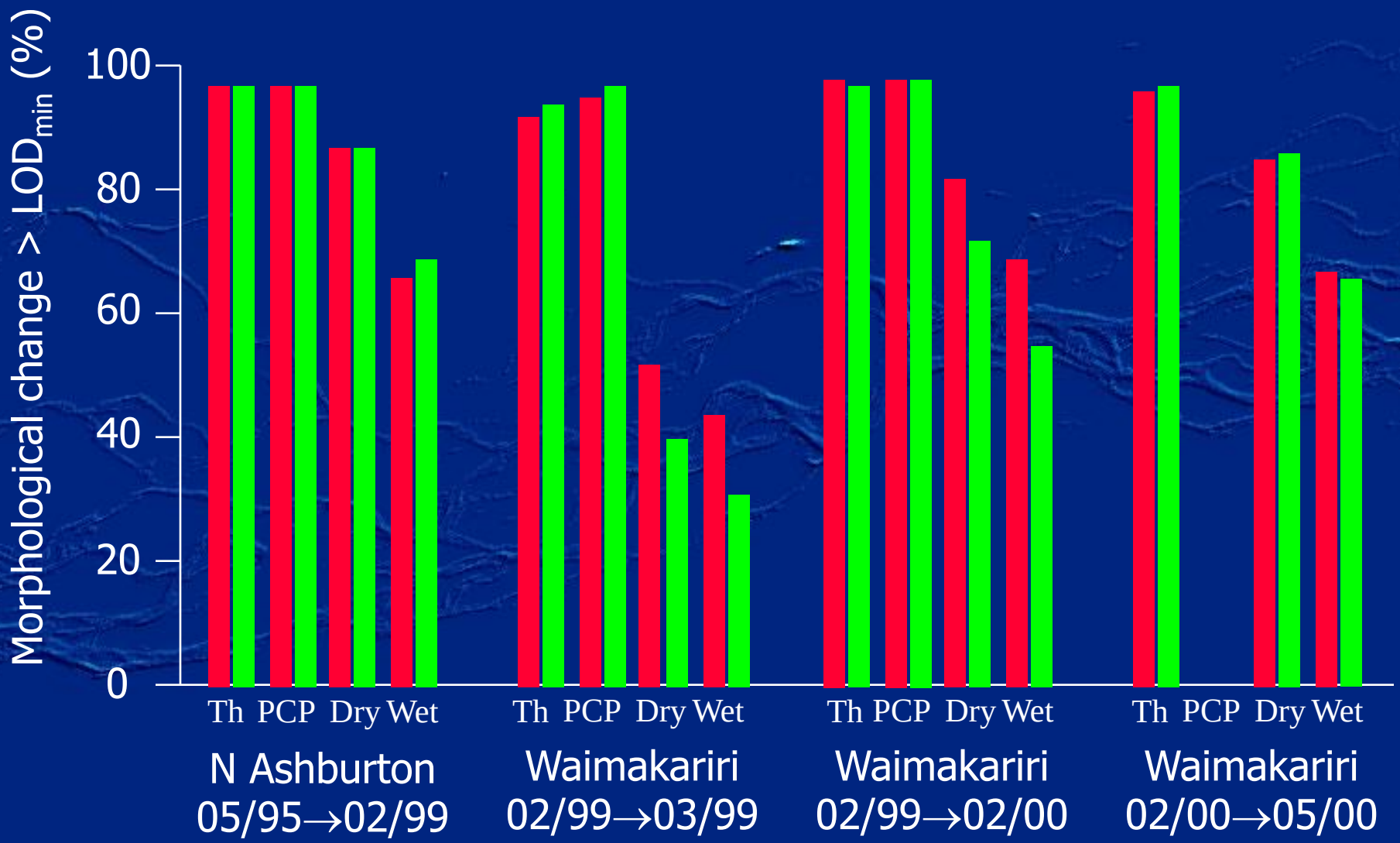
DEM	Theoretical precision	PCP precision	Check point precision Dry	Check point precision Wet
N Ashburton - May 95	± 0.075	± 0.071	± 0.116	± 0.238
N Ashburton - Feb 99	± 0.038	± 0.032	n/a	± 0.168
Waimakariri - Feb 99	± 0.070	± 0.052	± 0.262	± 0.336
Waimakariri - Mar 99	± 0.070	± 0.051	± 0.274	± 0.280
Waimakariri - Feb 00	± 0.056	± 0.049	± 0.137	± 0.239
Waimakariri - May 00	± *c.*0.05	n/a	± 0.105	± 0.217

$\Rightarrow$DEM of difference LOD_{min} (m)

DEM of difference		Theoretical LOD	PCP LOD	Check point LOD Dry-Dry	Wet-Wet
N Ashb	05/95→02/99	± 0.084	± 0.078	± 0.164*	± 0.291
Waimak	02/99→03/99	± 0.099	± 0.073	± 0.379	± 0.437
Waimak	02/99→02/00	± 0.090	± 0.071	± 0.296	± 0.412
Waimak	02/00→05/00	± 0.075	n/a	± 0.173	± 0.323

* Assuming dry check point precision of 0.116 for both DEMs

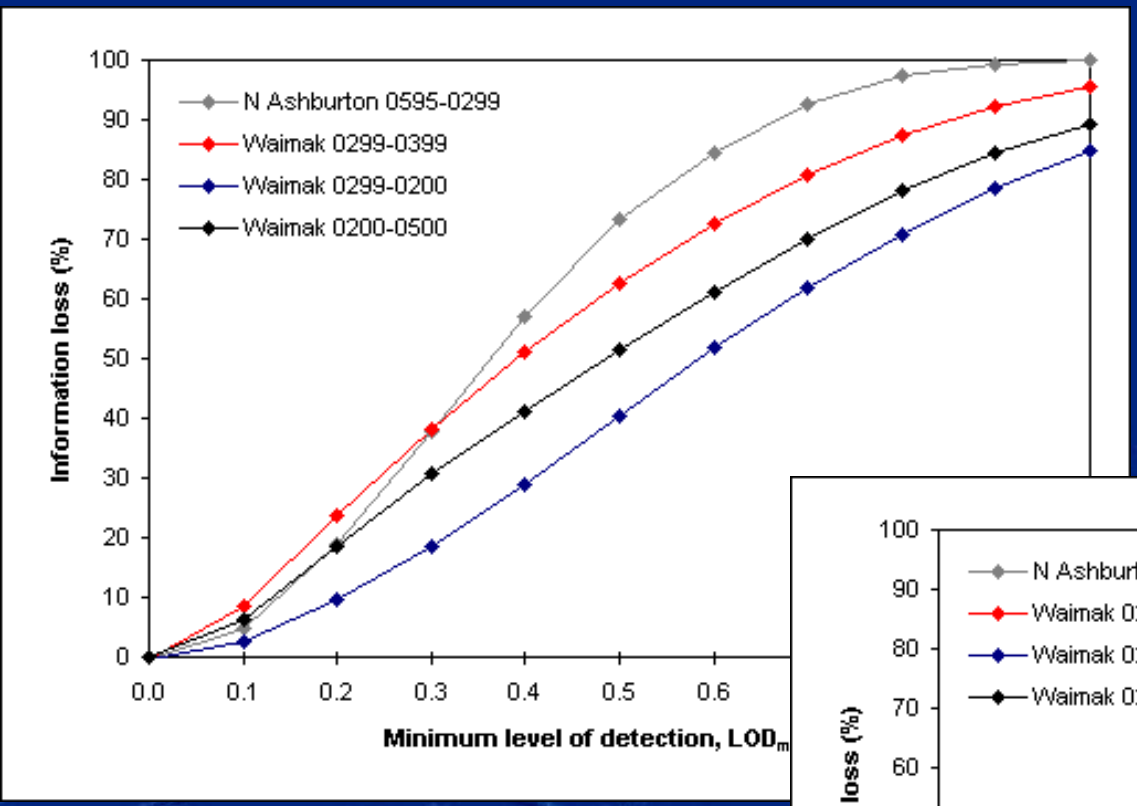
Effect on calculated volumes of erosion and deposition



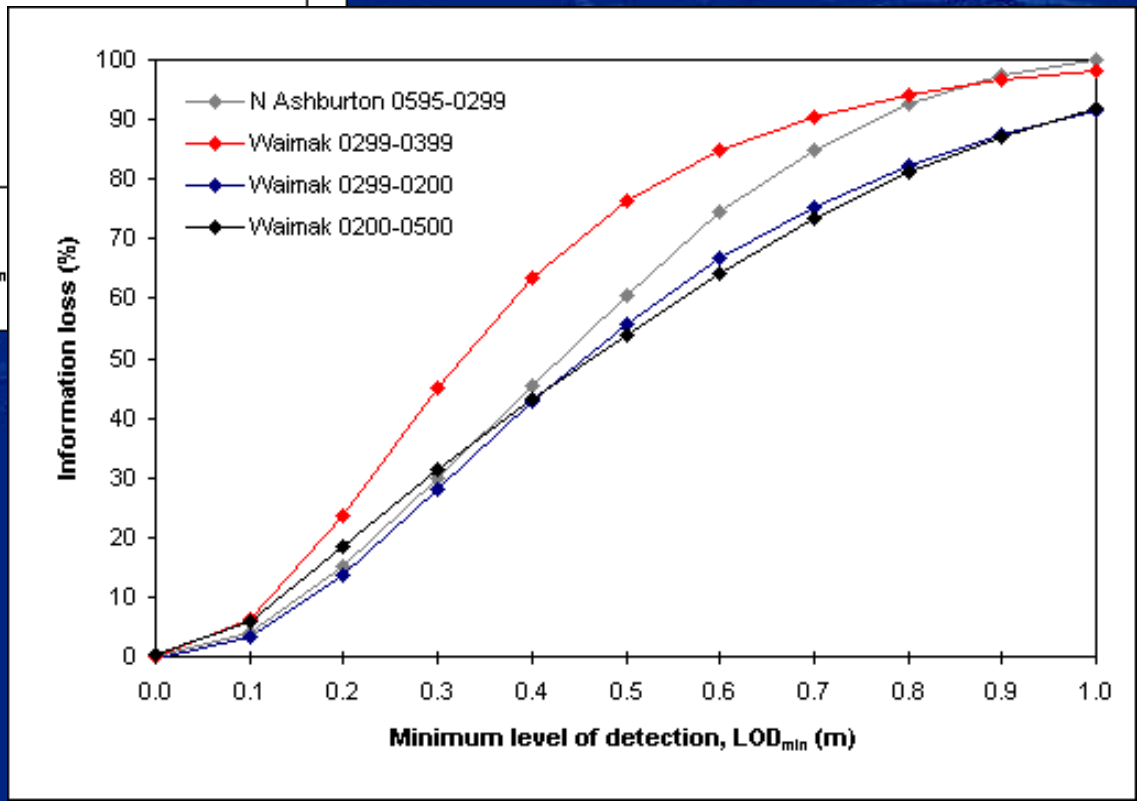
What is optimum LOD_{min}?

- Estimated by reversing the method, and calculating information loss for a range of arbitrary LODs

Information loss plots



Volume of erosion



Volume of deposition

Quality of DEMs of difference

- Gross errors
  - Based on outliers, appear small and identifiable
  - No real effect on DEM of difference quality
- Systematic error
  - Based on geomorphological assumptions, appear negligible
  - Most significant in areas of little change
- Random errors
  - Based on minimum level of detection calculations, potentially large effect on morphological change detected
  - LOD_{min} of ~0.2 m recovers 80-90% of morphological change
- Overall, we can be relatively confident about quality

Conclusions

- This paper has examined the quality of 4 DEMs of difference based on identifying different types of potential error
- From this, remote sensing methods DO appear to offer data quality sufficient to estimate morphological change in gravel-bed riverbeds

Conclusions (2)

- However, survey planning and execution is critical:
  - e.g. importance of image scale for photogrammetric survey:
    - Waimak 02/99 & 03/99 surveys used 1:5000 scale photography
      - dry check point precision of ~0.25 m
      - ~50% of morphological change detected deemed significant
    - Waimak 02/00 survey used 1:4000 scale photography
      - dry check point precision of ~0.15 m
      - ~75% morphological change significant
    - N Ashburton surveys used 1:3000 photography
      - dry check point precision of ~0.10 m
      - ~85% morphological change significant

  (Recommended LOD_{min} of ~0.2 m given by DEM precision of ~0.15 m)
- Also better parameterisation of 'precision' is needed:
  - Theoretical and PCP precision values probably too low
  - Check point precision values probably too high