The use of digital photogrammetry for the automated monitoring of large gravel-bed rivers

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1 Introduction

Surveys of riverbed topography are key requirements for effective river management. Monitoring bed levels and bank position identifies trends of lateral migration, aggradation, and degradation, which forewarn of problems such as bank erosion, bridge-pier scour, and reduced flood conveyance. Riverbed surveys are also used to compute budgets of bed material, required for apportioning gravel extraction. Given adequate detail, they can also be used to monitor bedload movement by linking "sources" (erosion sites) with downstream "sinks" (deposition sites).The traditional monitoring approach for New Zealand's riverbeds has been to establish a network of cross-sections which are periodically resurveyed. Typically, however, section spacing and frequency of re-surveying tend to be constrained by practical issues and cost, rather than being designed on a rational basis that relates section spacing to the uncertainty in the result.

Digital photogrammetry is an approach that may provide a cheaper, more efficient, and more accurate method of monitoring riverbed morphology. 'Raw' photogrammetry is only suitable for exposed areas of floodplain, and submerged areas require special treatment. Where water is clear, so that the submerged bed can be 'seen on aerial photographs', photogrammetrically-derived elevations can be obtained and a basic correction for the real versus apparent depth included by appropriate refraction modelling.

In this poster we present an automated technique for extracting bed topography data from relatively shallow, clear-water channels based on through-water digital photogrammetry, and test it with independent data from a braided riverbed.

2 Method

Digital photogrammetry allows automated extraction of topographic data from overlapping digital imagery (e.g., air-photographs scanned into a digital format). It stems from traditional photogrammetric methods that are based upon the special relationship that exists between points on the ground surface (the object space) and their position on images of that surface (the image space). In an ideal situation, a straight line passes through an object point, the centre of the camera lens, and the corresponding image point. This relationship is termed a perspective projection. Once the position and orientation of the camera at the time of exposure are known, the image position of a point that appears on two overlapping (or 'stereo') images is sufficient to estimate the actual ground coordinates of that point.

The presence of water has been long recognised as a complicating factor in photogrammetry, as refraction violates the perspective projection. However, if the water is clear and not too deep (a common situation in gravel-bed rivers at low flows), and the photography can 'see' the river bed, then accurate through-water photogrammetry is theoretically possible.

Light passing through an air-water interface is refracted according to Snell's law. This means that, if the refractive index of the medium is known, the relationship between apparent and actual depth can be calculated. The degree of refraction in clear water can be accurately calculated and has been shown to be remarkably constant (1.340 +/- 0.007). The approach developed in this paper is based on the premise that, given estimates of apparent depth derived from digital photogrammetric output, it is possible to derive estimates of actual depth,and hence correct the original photogrammetric estimates of bed elevation. This refraction correction was incorporated in an automated correction procedure (Figure 1).

This correction procedure does not deal with the distortion due to refraction directly, but *post hoc*, after initial bed elevations have been derived. During the stereo-matching process, the main effect of refraction will be vertical shifts in image position, such that it will be necessary for the stereo-matching algorithm to search more widely for matching pixels. Thus, after some testing, we have established that the maximum parallax parameter should be increased. This is important as it means that the stereo-matching process searches a greater *z*-elevation range, which is necessary given the effects of refraction upon the apparent depth of points.

3 Field data

The test field-site was a 430 m long reach of the North Branch of the Ashburton River, South Island, New Zealand (Figure 2a). The active braidplain is approximately 100 m wide and is characterised by low vertical relief (1–2 m). Aerial photography and concurrent ground survey were undertaken in May 1995, during a period of low river flow. A pair of stereo photographs at 1:3000 scale were taken with a calibrated Zeiss LMK15 camera. A logging Total Station instrument was used to survey six photo-control targets and 3500 check points, 54% of them under water. The stereo-pair was scanned at 12.5 microns into 256 shade grey-scale using a photogrammetric scanner, to give object space pixel dimensions of 0.038 m. DEM generation using digital photogrammetry was performed using the OrthoMAX professional module of ERDAS Imagine software installed on a SUN workstation. A second stereo-pair was flown at the same scale in February 1999, and the methodology repeated to allow a second DEM to be generated.

4 Results

4.1 Initial DEM

Figure 2b shows the uncorrected DEM, collected with a grid-spacing of 1 m. This shows that the method generates an excellent basic topographic representation, even without any through-water correction, with clear identification of the braidplain morphology. Figure 2c shows the elevation changes due to the correction procedure. The magnitude of these varies spatially. The maximum change is about 0.5m and occurs where the water is deep and the photogrammetry sees the water surface; these points are removed by the correction algorithm. This type of correction is likely to result in an important basic improvement in topographic representation. The smaller changes are where the refraction component of the correction is important. Figure 2d shows water depths derived during the correction process, following refraction correction and removal of points where it was felt that the water surface (not the riverbed) was detected.

4.2 DEM accuracy

The accuracy of the photogrammetry-generated DEM was assessed by comparison with the independently-acquired ground measurements (Table 1). The mean error (*ME*) for the exposed, dry areas of the floodplain shows only small, systematic, cm-scale bias in the mean bed level. The standard deviation of error (*SDE*) can be compared with a best expected theoretical precision for individual points of 0.04 m. Thus the photogrammetric results are downgraded from what would be expected. This arises both from the triangulation stage of the analysis and, more importantly in this case, from the difficulty of sampling complex gravel surfaces. This is a sampling problem where at the scale of the DEM resolution (1 m), there will be surface variation due to individual clasts which, given the point sampling by survey pole during the ground survey, will produce an elevation range that is greater that the best precision of the survey.

The values of *ME*and *SDE*for the uncorrected wet bed points are significantly greater (p less than 0.05). Evidence suggests that this is water depth dependent (Figure 3). This reflects two processes: (i) as water depth increases, errors due to refraction increase (both the real *versus*apparent depth effect and the stereo-matching effect); and (ii) in very deep reaches, the photography will see the surface rather than the bed. Introduction of the correction procedure results in a reduction in mean error (Table 1), while the explained variance (R^2) falls slightly. This is as expected: the correction procedure cannot improve the level of correspondence, but it can improve the bias in the correspondence. In essence, the correction removes the systematic error that arises from the combined effects of refraction and deep water.

4.3 DEM reliabilty

DEM reliability was assessed in two ways: analysis of a derived parameter (water depth) and estimations of gross floodplain sediment storage. Both measures are relevant to river management. The spatial distribution of water depth influences a river's ecological and recreational value, and changes in sediment storage are valuable for assessing catchment scale sediment budgets.

Water depth was derived from the DEM during the automated correction procedure. The distributions of water depth before and after correction were then compared to the distribution of actual water depth obtained from the ground survey measurements (Figure 4). Correction has the effect of reducing the proportion of very shallow depths (less than 0.12m), while increasing the number of points with intermediate depths (0.12 to 0.36m). As a result, the final water depth distributions are far more similar in shape to the actual distribution of water depths.

Sediment storage in a river reach can be represented by the mean bed level (MBL) over the reach area.

As shown in Table 1, the uncorrected and corrected photogrammetry approaches induced residual biases (i.e., ME) in the mean bed level over wetted areas that locally ranged up to 0.19 m. However, wetted channels covered only a small proportion of the North Ashburton braidplain, and for the whole study reach (wet and dry) the MBL obtained by the corrected photogrammetry procedure was within 2 mm of the ground-truth value obtained from the Total Station dataset (Figure 5a). Cross-section surveys simulated from the Total Station dataset showed that sections would have to be spaced less than 45 m apart to match this accuracy of reach mean bed level determination (Figure 5b). Conventionally in New Zealand, a river the size of the North Ashburton would be surveyed using cross-sections spaced 200-300 m apart.

4.4 Applications

There are many potential uses for high-resolution, accurate DEMs of gravel-bed rivers. One use is for hydraulic modelling. Physically-based computer simulations of water flow are of interest to hydrologists and river engineers for a variety of reasons, including estimation of spatially-distributed shear stresses and bedload transport, and predictions of their response to increased (and flood) flows. Corrected DEMs are ideally suited to providing the input boundary conditions needed to run these models. A second application, given DEMs at two or more epochs, is to examine channel change through time. The resulting 'DEMs of difference' (Figure 6) can be used to calculate morpholgical change, estimate bed load transport rate, or to validate output from numerical bedload transport models.

5 Conclusions

This study demonstrates the utility of digital photogrammetry to surveying braided gravel riverbeds. Using 1:3000 scale imagery it is possible to get very small surface elevation errors (standard errors less than 8 cm) for exposed areas, comparable with the size of the riverbed gravel and therefore the sampling error of point measurements by ground-survey. Errors in submerged zones were greater, but introduction of a fully-automated correction procedure resulted in the removal of at least some of the systematic bias. The overall error in mean bed-level for the 430 m long reach of channel was 2 mm. Thus, this method has the potential to revolutionise monitoring of wide gravel-bed rivers, particularly those with clear-water, as the time required for field data collection is substantially reduced.

6 Acknowledgments

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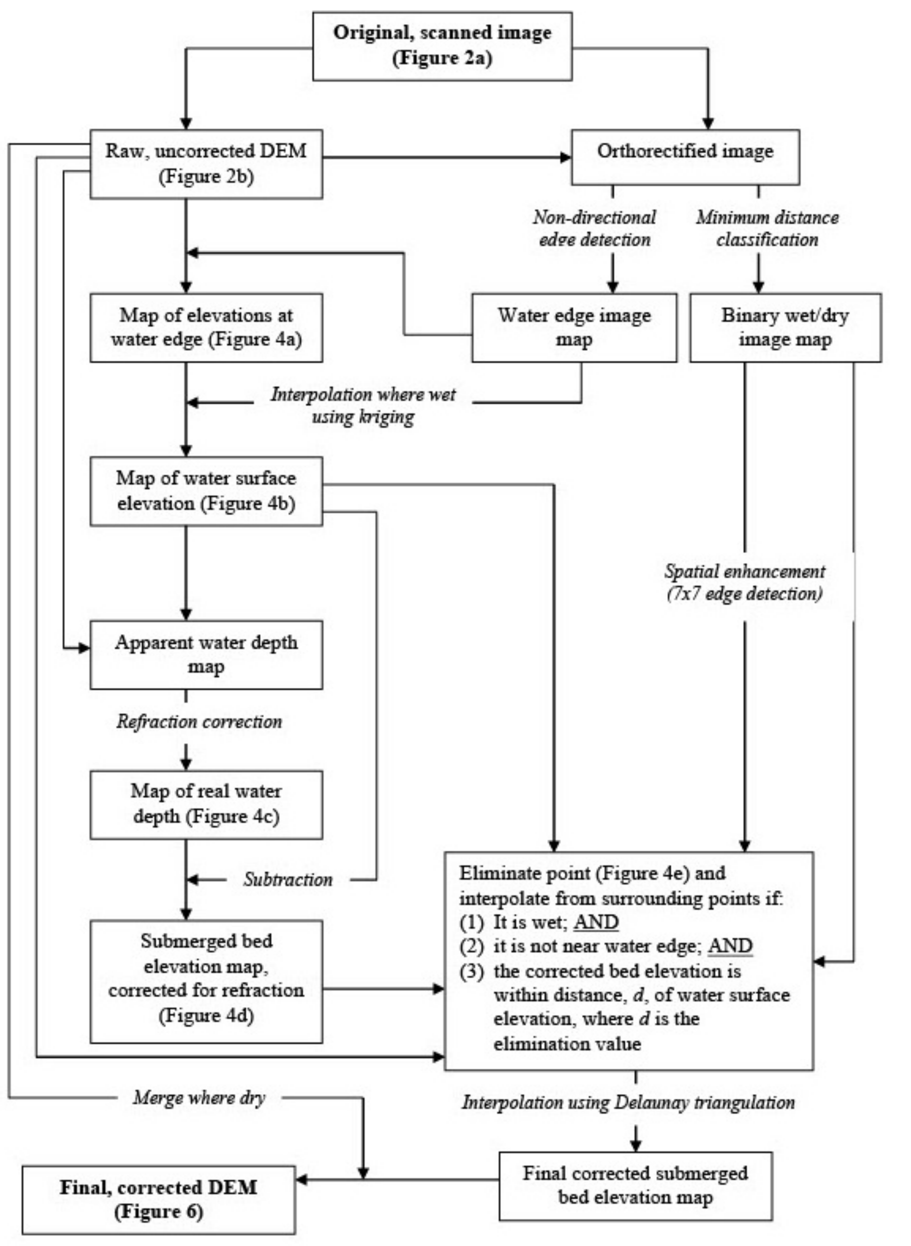


Figure 1. The automated correction procedure

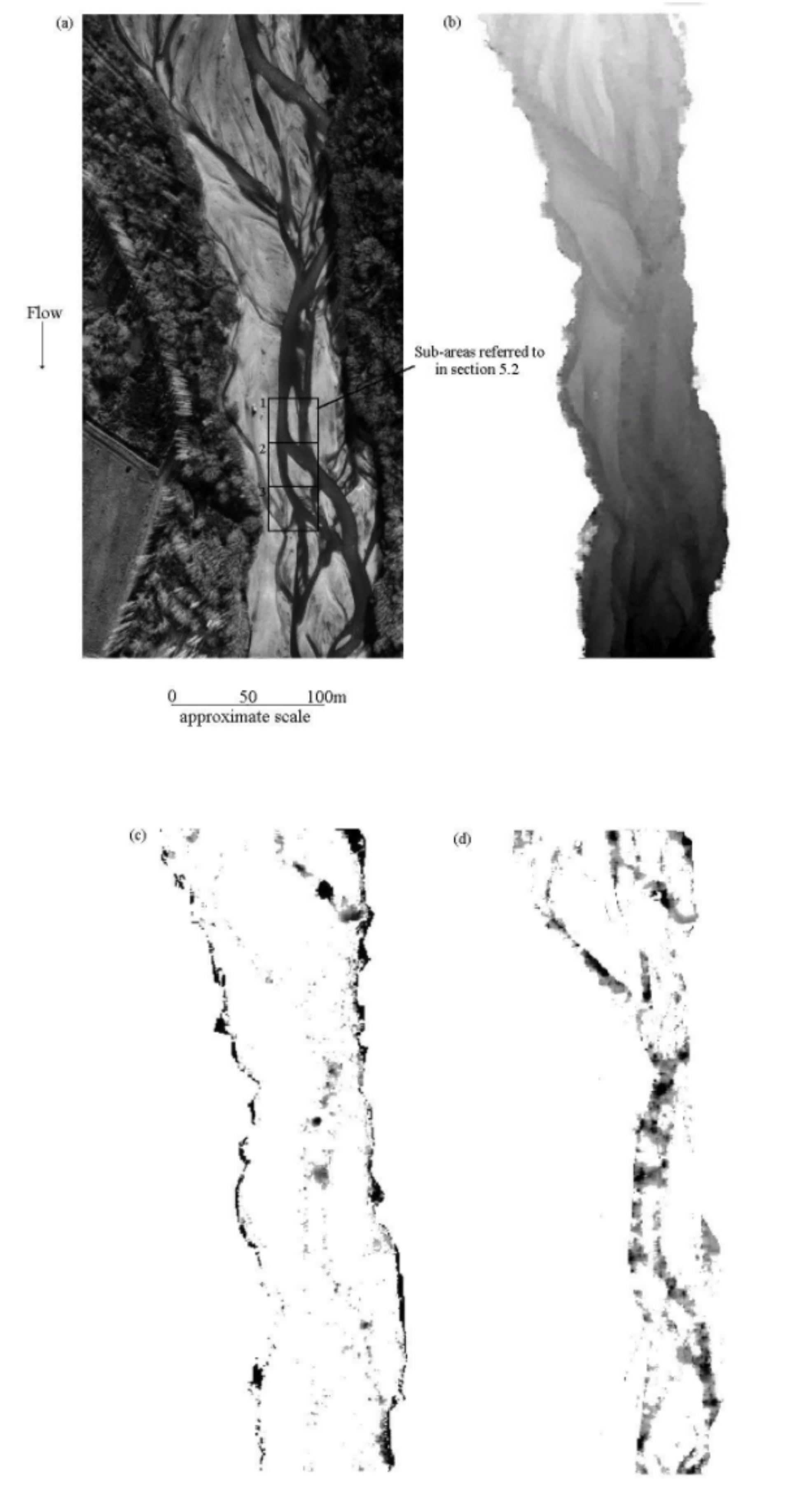
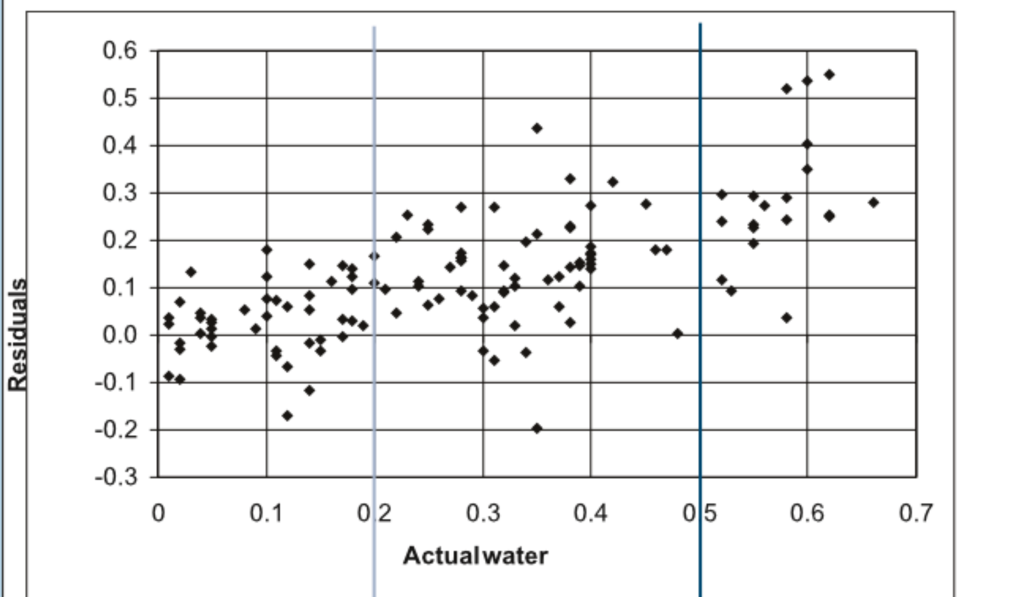


Figure 2. Figure 2a shows the North Ashburton study area. Figure 2b shows an uncorrected DEM scaled from elevations of 48m (black) to 55m (white). Figure 2c shows the changes in elevation made by the correction procedure, scaled from 0m (white) to -0.5m (black). Figure 2d shows the water depths derived during the correction procedure, following correction, scaled from 0m (white) to 0.8m (black).

	R	ME (m)	SDE (m)
Exposed areas	0.987	-0.020	0.112
Uncorrected submerged areas	0.861	0.170	0.276
Corrected submerged areas	0.852	0.105	0.276

Table 1. Results from basic accuracy assessment for exposed areas, uncorrected submerged areas and corrected submerged areas.



	Zone 1	Zone 2	Zone 3
ME	0.029	0.139	0.284
R	0.056	0.017	0.186
Slo	0.306	0.192	1.501

Figure 3. Residuals of corrected water depth derived by photogrammetry and actual, surveyed water depth vs. surveyed water depth.

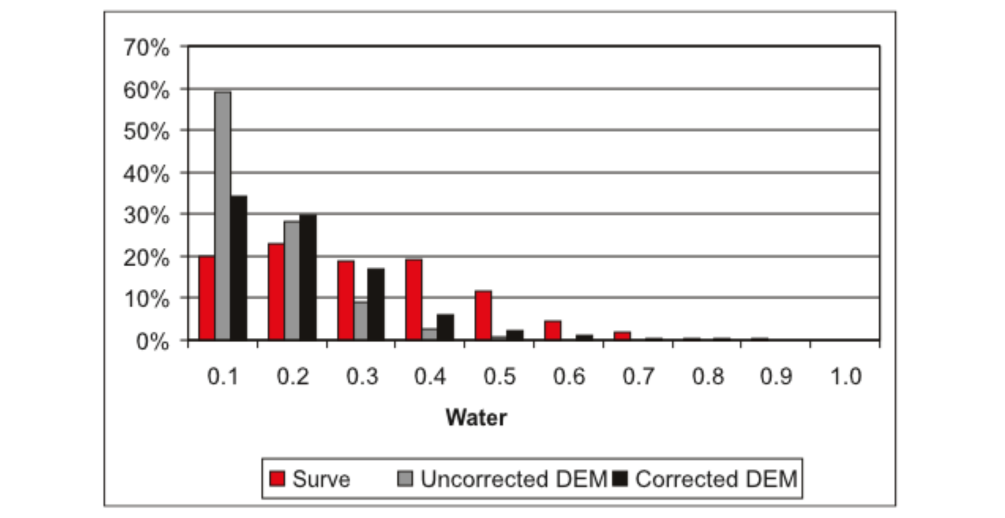


Figure 4. A comparison of water depth distributions estimated from survey measurements and from both uncorrected and corrected photogrammetrically-derived DEMs

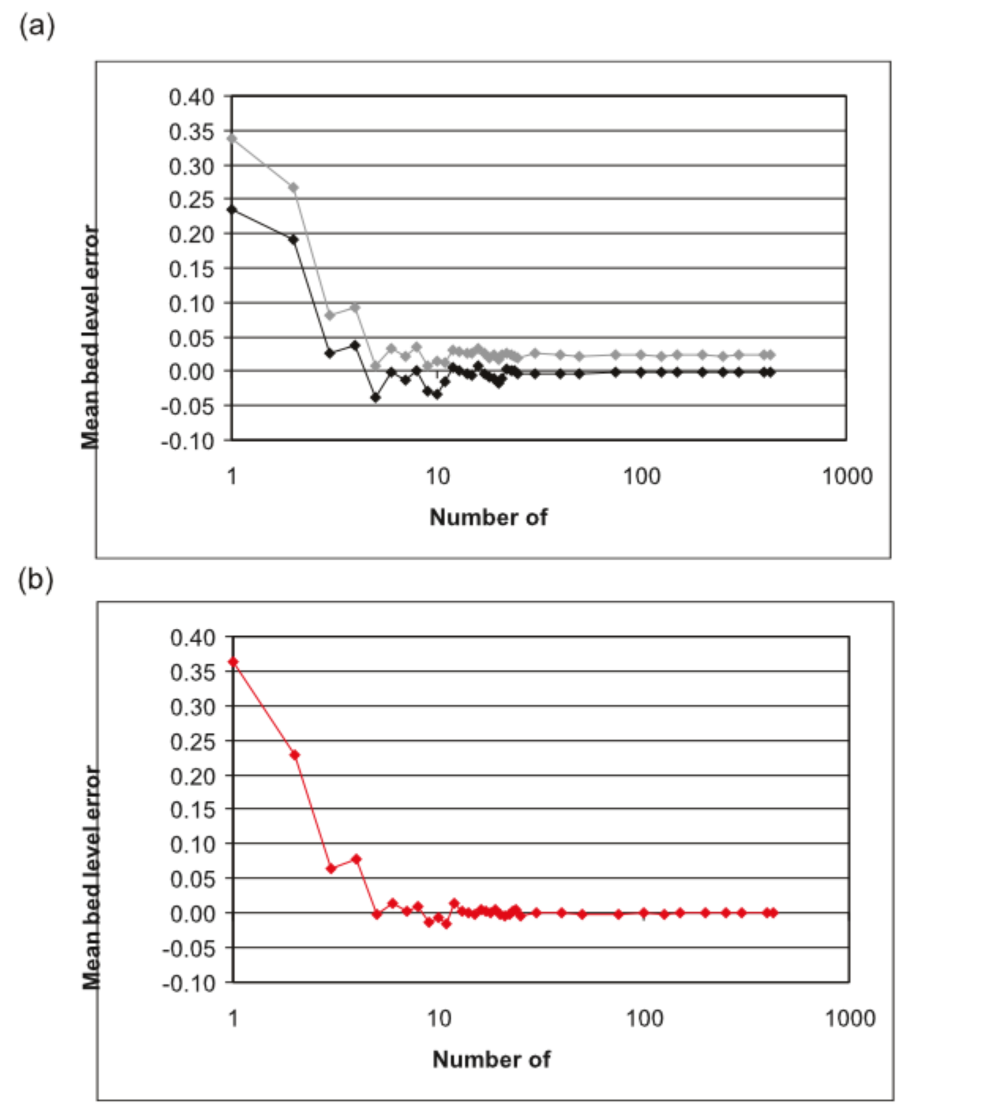


Figure 5. Error in mean bed level vs. number of cross-sections used to represent reach. Figure compares mean bed level error calculated from photogrammetrically-derived DEMs before (grey line) and after (black line) correction. Figure 5b shows the same analysis performed for the survey measurements.

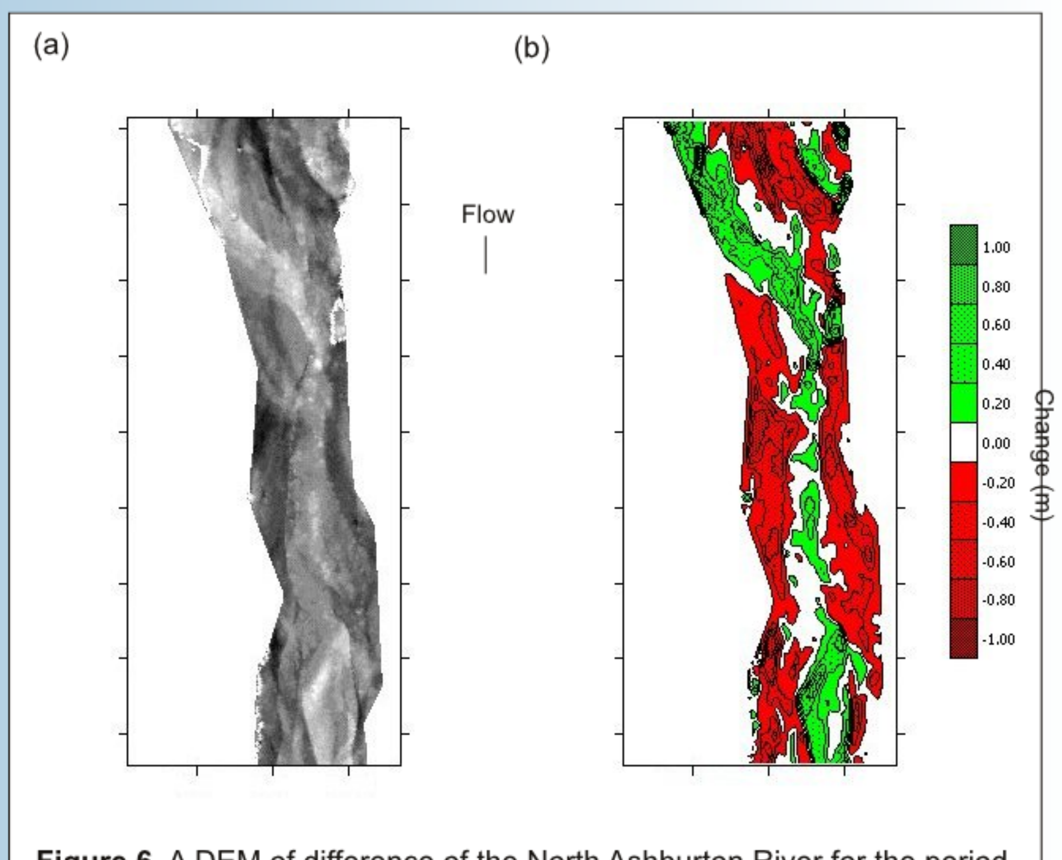


Figure 6. A DEM of difference of the North Ashburton River for the period May 1995 to February 1999. Figure 6a shows the raster image scaled from 1m of deposition (white) to 1m of erosion (black). Figure 6b shows the same information, with zones of erosion and deposition more clearly defined. It is easy to visualise the morphological change that has occured: new channels have been carved on either side of the floodplain, while the 1995 central channel has experienced deposition of sediment.