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NIWA

Taihoro Nukurangi

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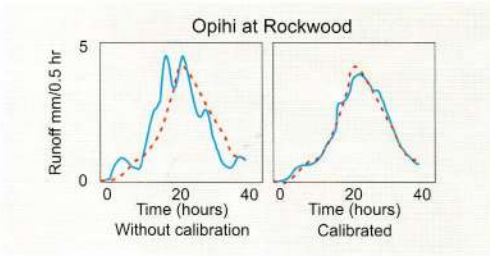


When raingauge data were used instead of modelled rain, the rain-to-flow model required virtually no calibration. From this, our expectation is that the full system could eventually be used in areas where there are no supporting flow data.

In other model runs on Southern Alps catchments, flood events were well modelled over 48 hours in advance.

A new era

The prospect of rain forecasts several days ahead by meso-scale model is exciting. The fact that such rain forecasts could give values anywhere is an added bonus. Combine this with a sophisticated rain-to-flow model that covers the whole country, and a new era of flood forecasting – that can provide realistic flow predictions anywhere in New Zealand, with warning times of 24 hours or more – is not that far away. ■

Roddy Henderson and Richard Ibbitt are based at NIWA in Christchrch; Jeff Copeland and David Wratt are at NIWA in Wellington.

above left: *Modelled river flow (blue solid lines) compared with that measured (red dotted lines), when the rain-to-flow model is given recorded rainfall data.*

Further reading

Wratt, D.S. and Sinclair, M. 1996. SALPEX – the Southern Alps Experiment. *Water & Atmosphere 4*(2): 26-28.

Wratt, D.S. *et al.* (and 13 others) 1996. The New Zealand Southern Alps Experiment. *Bulletin of the American Meteorological Society 77*: 683-692.

The SALPEX web page address is: http://katipo.niwa.cri.nz/salpex/index.html

RIVERBED MANAGEMENT

A metric eye in the sky: photogrammetric tools for riverbed surveys

Murray Hicks
Stuart Lane
Richard Westaway

Scientists from NIWA and the University of Cambridge have been developing and testing new digital-image-based tools capable of detailed and economical mapping of the topography of braided gravel riverbeds.

TRADITIONALLY, trends of erosion or deposition of gravel on riverbeds have been monitored by infrequent surveys of cross-sections, which are carried out by making vertical measurements of bed elevations along transects across the river. On large braided riverbeds, such as those on the Canterbury Plains, practical considerations mean that cross-sections may be spaced up to 1 km apart, and a full survey along a 30-km reach may require several years and substantial expense. Even then, the sparse spacing of sections means that any calculations made using the data – such as riverbed sediment storage – could be quite unreliable.

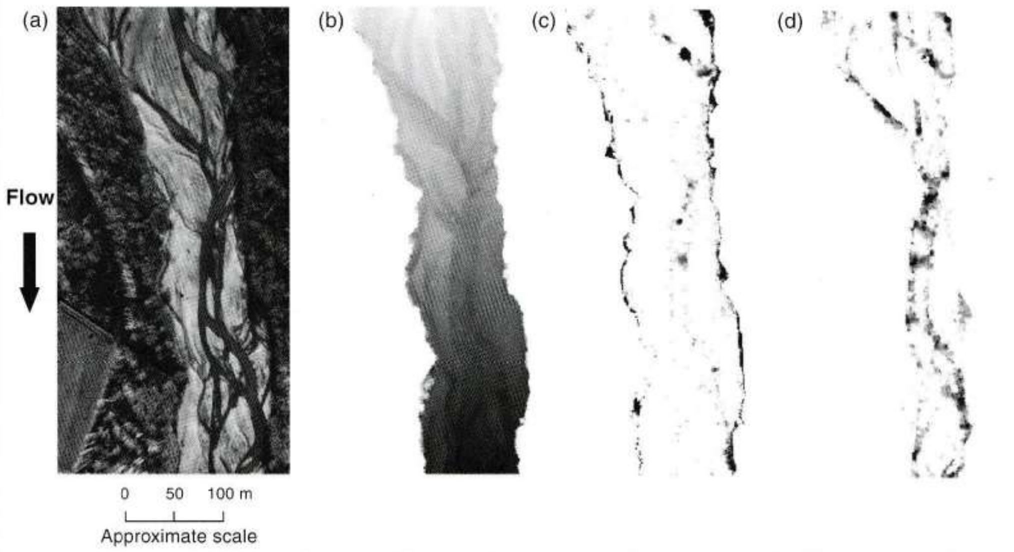
A more accurate way to map riverbed topography is with photogrammetry – in other words, surveying using photography. The technique has been available for many years but until recently it too has been an expensive, labour-intensive exercise. A further problem has been the difficulty in dealing with wetted channels – those parts of a riverbed that contain water.

Recent advances in digital photography and computer hardware have led to much faster and cheaper photogrammetry. In addition, joint research by scientists from NIWA and the University of Cambridge, UK, has provided some solutions to the wetted channel problem. This article describes what has been done and compares the accuracies of the old and new survey methods.

Mapping dry riverbed topography with digital photogrammetry

Digital photogrammetry allows automated extraction of topographic data from overlapping digital imagery (e.g., air-photographs scanned into a digital format). Like traditional photogrammetric methods, it is based on the relationship between points on the ground surface (the object space) and their position on images of that surface (in the image space). This relationship depends on the position and orientation of the camera and the properties of the camera lens. To carry out a survey, we use stereo-pairs of photographs – two pictures of the same area taken from different positions so as to meet certain geometrical requirements. The position of a point that appears on both images is measured. If the object/image relationship is known, then we can estimate the ground coordinates of that point.

Until the early 1970s, photogrammetry was completely manual. The relationship between object and image space had to be reconstructed mechanically using a device called a "stereo-



(a) The North Ashburton River study area; (b) an uncorrected digital elevation model of this area, scaled from elevations of 55 m (white) to 48 m (black); (c) the changes in elevation due to the correction procedure, scaled from 0 m (white) to –0.5 m (black); (d) the water depths derived during the correction process, scaled from 0.0 m (white) to 0.8 m (black).

comparator". By the 1980s, the analytical approach had become the standard. This involved treating the object/image relationships mathematically rather than mechanically. It used an expensive piece of hardware called an analytical plotter and still required manual digitisation.

In digital photogrammetry we replace manual digitisation with automated stereo-matching. Digital data are analysed by identifying a point (i.e., a pixel) on one image and then trying to find the corresponding point on the second image by comparing the properties of surrounding pixels. The necessary software can be mounted on work-stations and even on high-specification personal computers. Not only is the procedure over 1000 times faster than the manual method, it is also very much cheaper. Several software packages for stereo-matching are now commercially available.

Digital photogrammetry has several steps:

- Field surveys are conducted on about six ground-control points for each pair of stereo photographs.
- The photographs are taken and scanned into a digital format.
- On the computer, the ground-control points are identified and transferred into an appropriate coordinate system.
- Triangulation is used to calculate the camera orientation and position.
- Finally, the topographical data are extracted automatically using the selected software.

The result is a high-density, rectangular-gridded "digital elevation model" (DEM).

The figure above (b) shows a DEM of a 430-m-long reach of the braided North Ashburton River.

Mapping submerged channel beds

To map areas of riverbed that contain water, we use a combination of image-analysis and digital photogrammetric techniques. The procedure is based on the DEM derived for the whole riverbed, in which all areas are treated as dry. The steps are:

- From the original aerial photographs of the river identify wetted areas and water edges using "image-analysis" software.
- Overlay the water edges on the riverbed DEM and, from this, work out the water-surface levels.
- Map water depth using one of the approaches outlined below; the method used depends on the clarity of the water.
- Subtract water depth from estimated local water-surface elevation to obtain channel-bed elevation.

Clear water

If the water is clear and shallow enough for the channel bottom to be seen on the photographs, then clear-water photogrammetry is used to extract a DEM of the channel bed.

Light refraction across the water surface causes the water to appear shallower than it actually is. This means that on the original DEM those parts of the bed under clear water have elevations that are too high. To correct this, we first work out the apparent water depths by subtracting the channel-bed elevations on the original DEM from the water-surface levels (as described above). These apparent depths are then scaled up by 1.35 (the refractive index of water) to provide approximate actual water depths (see (d) above). Subtracting the actual water depth from the local water-surface elevation gives the corrected channel bottom elevation.

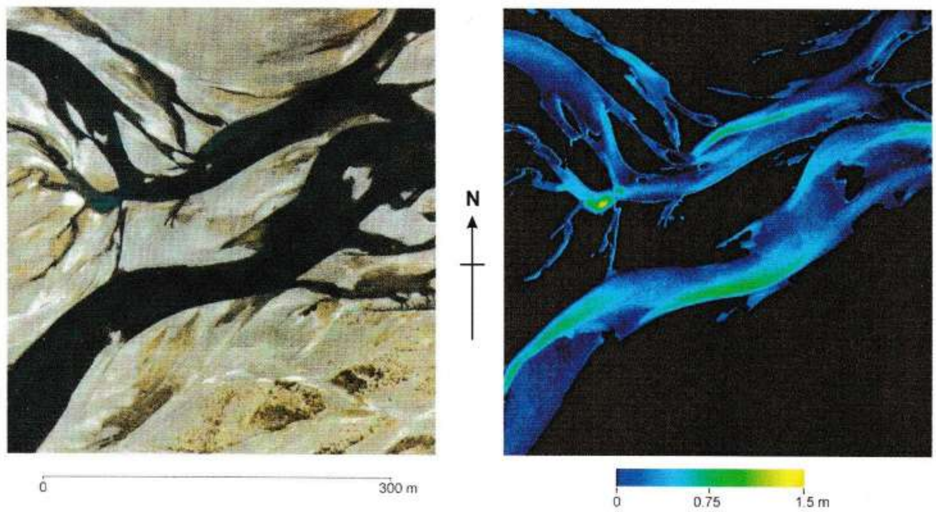
Why survey riverbeds?

SURVEYS of riverbeds have several applications. Typically they are used to monitor riverbed erosion (degradation) or deposition (aggradation). Degradation occurs naturally when the river transports more gravel out of a reach than it brings to it, but it can also arise when gravel is mined from the riverbed at a rate faster than the river can replace it. Chronic degradation can result in the undermining of bridge pier foundations and river banks.

Aggradation can be a serious problem because, as a riverbed rises, the size of flood flow that can be contained in the river channel is reduced. Thus, there is an increased risk of overtopping the banks during high flows.

By monitoring long-term changes in riverbed levels the budget of gravel in the riverbed can be estimated and managed, e.g., by setting limits to rates of gravel mining.

(a) The study areas of the Waimakariri River used to develop the relationship between water colour and water depth; (b) a map of water depth using the relationship derived.



Turbid water

If the water is too turbid for the bottom to be seen clearly (but not so turbid that light penetration and scattering occurs only near the surface), then the depth may be mapped from the relationship between depth and water colour. To do this we need to survey a range of depths at the time of the photography, match each survey point to a pixel on the photographs and, from this, develop a depth/colour relationship.

We have tested this method on a 500-m-long reach of the braided Waimakariri River (see figure at right). Our results suggest that for turbidities of up to at least 2–3 Nephelometric Turbidity Units (NTU) this method predicts depths of up to about 1 m with an accuracy of ±0.1 m. The method has a couple of complications:

1. Sometimes the material causing the turbidity – usually clay-grade suspended sediment – is not uniformly mixed. For example, groundwater inflows into "dead-end" braids lead to less turbid areas that require separate calibration measurements.
2. Different colours of bottom sediment may confuse the depth/colour relationship. In the case of the Waimakariri, we observed two "classes" of substrate – gravel and sand – and different depth-prediction models were developed for each.

Means and standard deviations of the differences in bed elevations determined by photogrammetry and by ground survey for the North Ashburton River study reach.

	Mean difference (mm)	Standard deviation of the difference (mm)
Dry areas of river bed (61% total area)	-14	129
Wet areas (39% total area)	35	177
Total area of study reach	5	148

Comparison with ground surveys

A thorough test of the dry riverbed/clear-water photogrammetry method was conducted for the North Ashburton River study reach. A highly accurate surveying method (a Total Station instrument) provided detailed check-data at a grid density of 4 m over dry areas of riverbed and 2 m over wetted channels. Vertical aerial photographs were taken at a scale of 1:3000, scanned, and analysed with the Erdas OrthoMAX digital photogrammetry software package. We used the procedure outlined above to obtain elevations of wetted channel beds.

The table (left) shows statistics of the agreement between the riverbed surfaces derived from the ground-surveyed elevations and the photogrammetry-derived elevations. Over dry areas, the standard deviation of the difference in elevations calculated by the two methods at individual points was approximately 130 mm. Part of this difference is likely to be related to the 38-mm median size of the riverbed cobbles and whether the survey target pole was placed on or between cobbles. However, this difference is substantially random and tends to cancel out over many points, so that the mean difference was only 14 mm. In wetted areas, the standard deviation of the differences was larger, as expected, but the mean difference was still relatively small, showing negligible bias in the depth determination. For the reach as a whole, the mean difference in elevations was only 5 mm.

Comparison with traditional cross-section survey

Suppose now that we want to survey how much gravel is stored in our study reach of the North Ashburton River, perhaps to monitor gravel-extraction or aggradation (i.e., unwanted deposition). This volume (above a datum plane) can be represented by the mean bed level over the reach area. Traditionally, our study reach might have been surveyed using a small number

Further reading

Lane, S.N., Hicks, D.M. and Westaway, R.M. 1999. Monitoring riverbed topography by digital photogrammetry, with particular reference to braided channels. *NIWA Technical Report 64*, NIWA, Wellington.

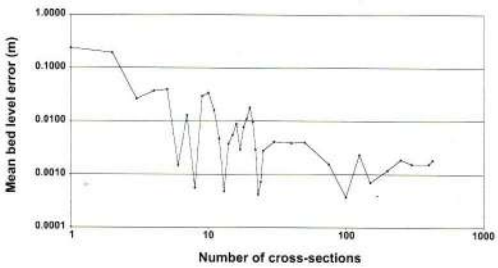
of cross-sections. With this approach, each cross-section is considered representative of a sub-reach of riverbed.

Using the North Ashburton DEM dataset, we simulated cross-section surveys at a range of section spacings. We compared the reach mean bed level estimated using these cross-section sets with the "true" mean bed level indicated by the full dataset. As might be expected (and as shown on the figure, right), the error in the mean bed level decreases as the section spacing is decreased.

A traditional rule of thumb for cross-section networks is that sections should be spaced one or two channel-widths apart (80–160 m in the case of the North Ashburton). Our simulations indicated that the error in the reach mean bed level for 80-m section spacings was approximately ±40 mm. This is poorer than the ±5 mm uncertainty in mean bed level achieved by the photogrammetry. Indeed, to match the photogrammetry accuracy, the sections would need to be spaced about 20 m apart, which would be difficult to achieve for a routine monitoring programme.

Conclusion

With minimal field measurements, photogrammetry can deliver cost-effective DEMs that can be used to provide accurate reach-scale and section mean bed levels and to map channel positions, water depths and other variables. Another great advantage is that all the data are gathered simultaneously in the time taken for a plane to traverse the river reach. Finally, we caution that in some areas of riverbed, such as those hidden by vegetation or where pools are too deep for the techniques described above, there may still be a need for ground-based surveys. ■



Relationship between the number of cross-sections used in the calculation and the error in estimate of reach mean bed level. See text for details.

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