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SEDIMENTOLOGICAL AND GEOMORPHOLOGICAL EFFECTS OF THE 1997 AND 1998 FLOOD SEQUENCE ON THE LOWER SNOWY RIVER, VICTORIA

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ABSTRACT: Three floods with flood peak ratios (peak discharge/mean annual flood) ranging between 0.65 and 5.35 occurred on the lower Snowy River in Victoria between June 1997 and August 1998. The June 1998 flood was the largest event downstream of the Rodger River junction where the flood peak ratio was >4. Pre- and post-flood investigations were carried out at the three Snowy River benchmarking sites in Victoria (McKillops Bridge, Sandy Point and Bete Bolong) to determine the impact of the floods on channel-boundary sediments and morphology. Few significant changes in graphic grain-size statistics for channel-boundary sediments were found at McKillops Bridge and Sandy Point. At Bete Bolong, there were many significant changes in the grain-size statistics of both the bed material and bank sediment. The variance and mean of a number of benchfull and bankfull channel morphologic parameters (width, area, mean depth, maximum depth, width–maximum depth ratio) did not change significantly at McKillops Bridge and Sandy Point. At Bete Bolong, benchfull mean depth and area increased significantly due to bed degradation. Floods with a flood peak ratio of at least 4 are important for mobilising channel-boundary sediments and hence modifying channel morphology on the lower Snowy River.

Keywords: Snowy River, Victoria, floods, inner bedrock channel, pools, bank deposition, bars

A major flood occurred on the lower Snowy River in Victoria in June 1998. As a result, the Snowy River benchmarking sites in Victoria downstream of the Deddick River confluence at McKillops Bridge (Erskine & Turner 1998) were resurveyed and channel-boundary sediments resampled to determine whether any flood-induced channel changes had occurred. This paper presents the results of the post-flood investigations (1998–2000) at the following three benchmarking sites (Figure 1) and compares them with the first survey in 1997:

1. *McKillops Bridge* (gauging station No. 222209) is a 631-m-long section of channel containing eight cross-sections at the high-level road bridge and river gauging station immediately downstream of the Deddick River junction (Figure 2). This site is closely bedrock-confined and is located in the Willis Sand Zone of Erskine et al. (2001). Bed and water surface slope are both 0.00206 (2.06 $m.km^{-1}$).
2. *Sandy Point* (station No. 222024) is a 650-m-long section of channel containing eight cross-sections at Sandy Point (Figure 3). This site includes a single, very long sand- and gravel-floored pool on the upstream limb of a pronounced bedrock-controlled loop. It is located at the boundary between the Lucas Point and Long Point reaches (Erskine et al. 2001). A bed slope of 0.00059 (0.59 $m.km^{-1}$) was measured on the relevant 1:25,000 topographic maps.
3. *Bete Bolong* (station No. 222025) is a 1623-m-long section of channel containing eight cross-sections at Bete Bolong, immediately downstream of the Jarrahmond gauging station (gauge No. 222200) (Figure 4). This site exhibits a straight, relatively uniform sand-bed stream with multiple thalwegs, separating longitudinal and/or transverse bars (Erskine et al. 1999a). It is located in the Orbost Alluvial Reach (Erskine et al. 2001). Bed slope is 0.00042 (0.42 $m.km^{-1}$) and water surface slope is 0.00046 (0.46 $m.km^{-1}$).

The channel-boundary sediment at these sites was initially sampled between 25 and 29 April 1997 as part of the Snowy River Benchmarking Project (Erskine & Turner 1998).

The aim of this work is to determine the impact of the 1997 and 1998 flood sequence on channel-boundary sediment size and morphology at these three benchmarking sites. Such information is required for the identification of threshold flows for channel maintenance and bed-material entrainment. Further details are in a limited distribution report (Erskine & Turner 2002). The combined effects of the 1997 and 1998 flood sequence have been investigated because fieldwork was only conducted before and after these events. More recent research (McLean & Hinwood 2015; Arrowsmith & Stoessell 2016) conducted on the Snowy River estuary during environmental flows complements the present work and that of Turner et al. (2006).

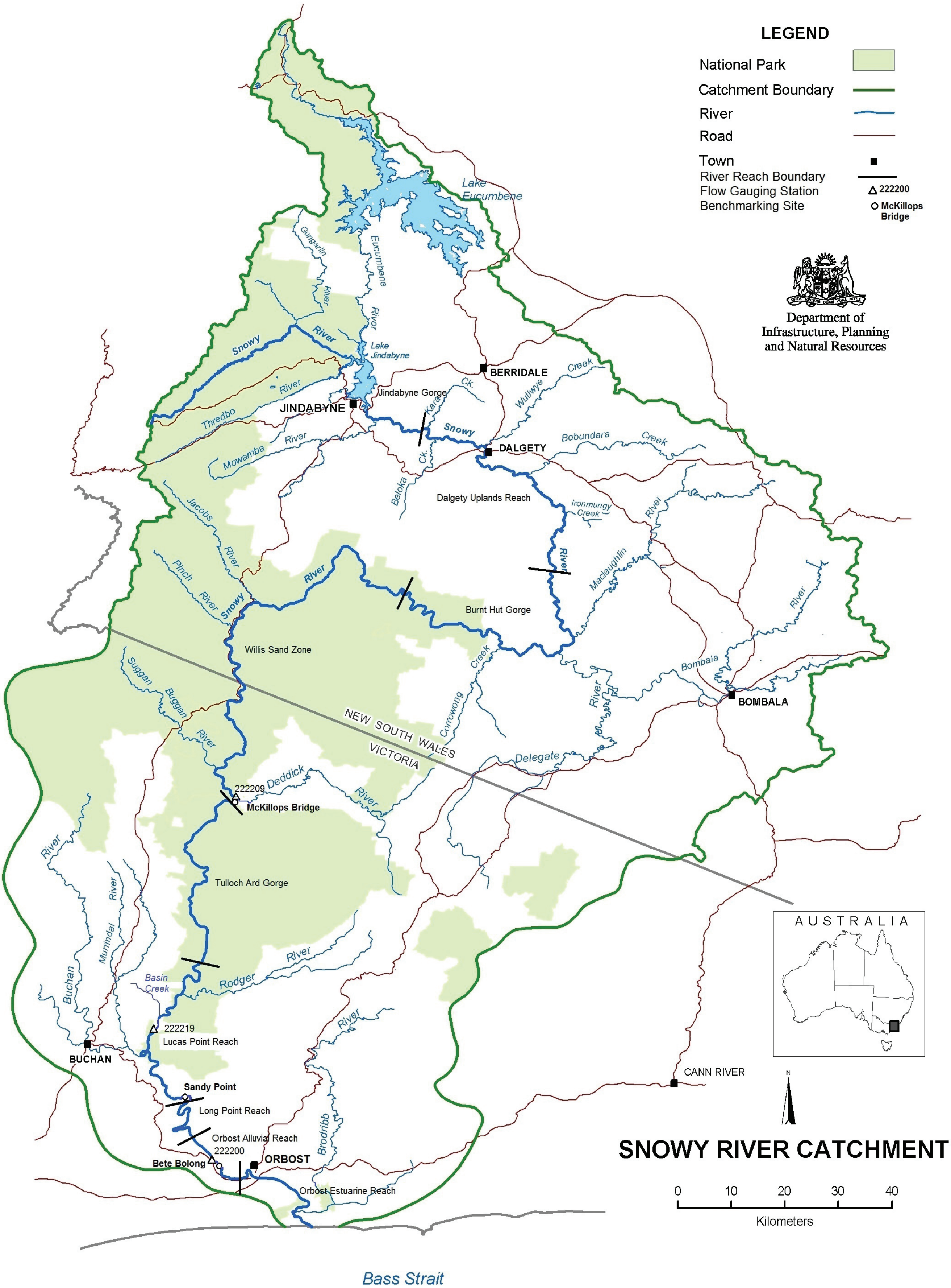

Figure 1: Snowy River catchment showing river reaches in which the McKillops Bridge, Sandy Point and Bete Bolong benchmarking sites are located.

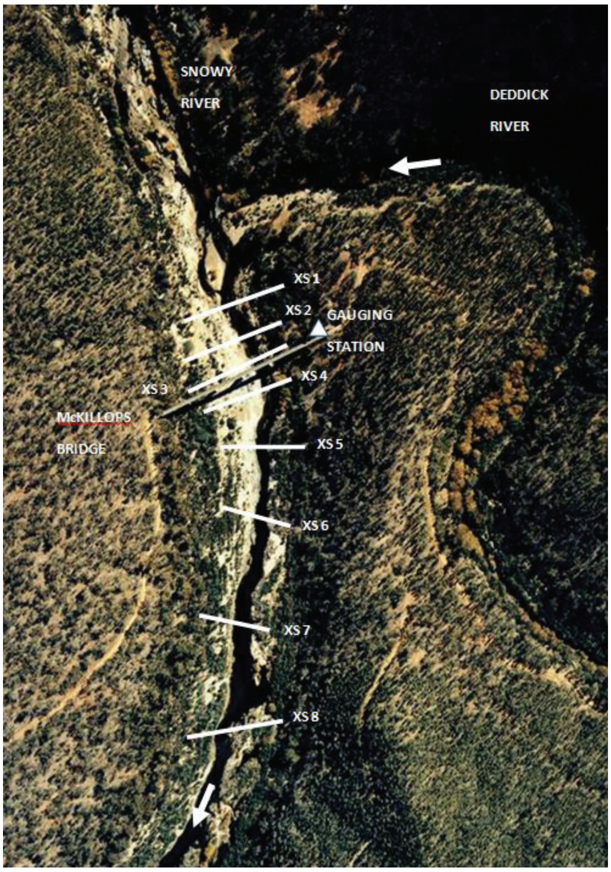

Figure 2: Vertical air photograph of benchmarking site 7 at McKillops Bridge in the Willis Sand Zone showing location of cross sections and gauge.

Figure 4: Vertical air photograph of benchmarking site at Bete Bolong in the Orbost Alluvial Reach showing location of cross sections. The Jarrahmond gauge is located about 0.5 km upstream on the left bank.

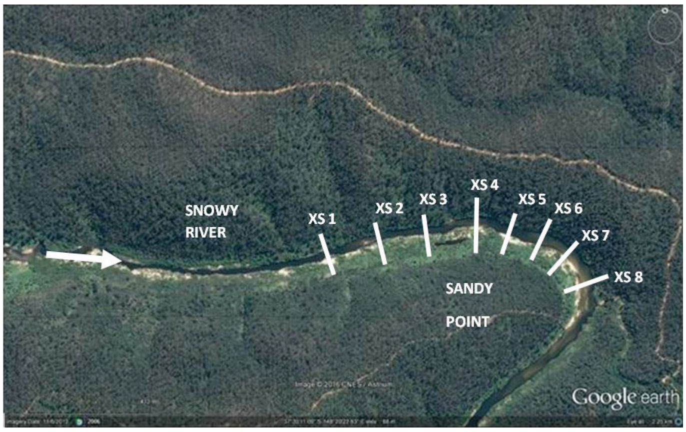

Figure 3: Vertical air photograph of the Sandy Point benchmarking site at the boundary between the Lucas Point and Long Point Reaches showing location of cross sections.

1997 AND 1998 FLOODS ON THE LOWER SNOWY RIVER

The data for the 1997 and 1998 flood sequence were obtained from Thiess Services for the McKillops Bridge, downstream (of) Basin Creek and Jarrahmond gauging stations (Figure 5) and included the largest floods between 1997 and 2000. While the McKillops Bridge and Jarrahmond gauges are located either at or near the gauging stations of the same name in Figure 1, the Basin Creek gauge is not located at a benchmarking site, but nevertheless measures the runoff generated from the catchment downstream of McKillops Bridge and upstream of the Buchan River junction. The hydrological data show that there had been three floods between the initial and post-flood surveys of the lower Snowy River. Details of the flood peak for each event at each station are outlined in Table 1.

The three floods occurred in June 1997, June 1998 and August 1998, with the second event being the largest at the two downstream stations and the first event being the largest at the upstream station (Table 1). The combined effects of all three events are reported below. The unit peak discharge of the June 1997 flood declined progressively downstream, indicating that the greatest runoff occurred upstream of McKillops Bridge. The flood peak ratios indicate that the peak instantaneous discharge exceeded the mean annual flood at all stations. The June 1998 flood had a triple peak at McKillops Bridge, with the first peak being the highest (Figure 5A). This was the smallest of the three floods at McKillops Bridge (Table 1). Unit peak discharge was low, as reflected by the high annual exceedance probability (Table 1). At Basin Creek, the June 1998 flood had a single peak, which occurred **before** the first peak at McKillops Bridge (Figure 5B). The much greater unit peak discharge and earlier occurrence of the flood peak (Table 1) indicates that the lower catchment

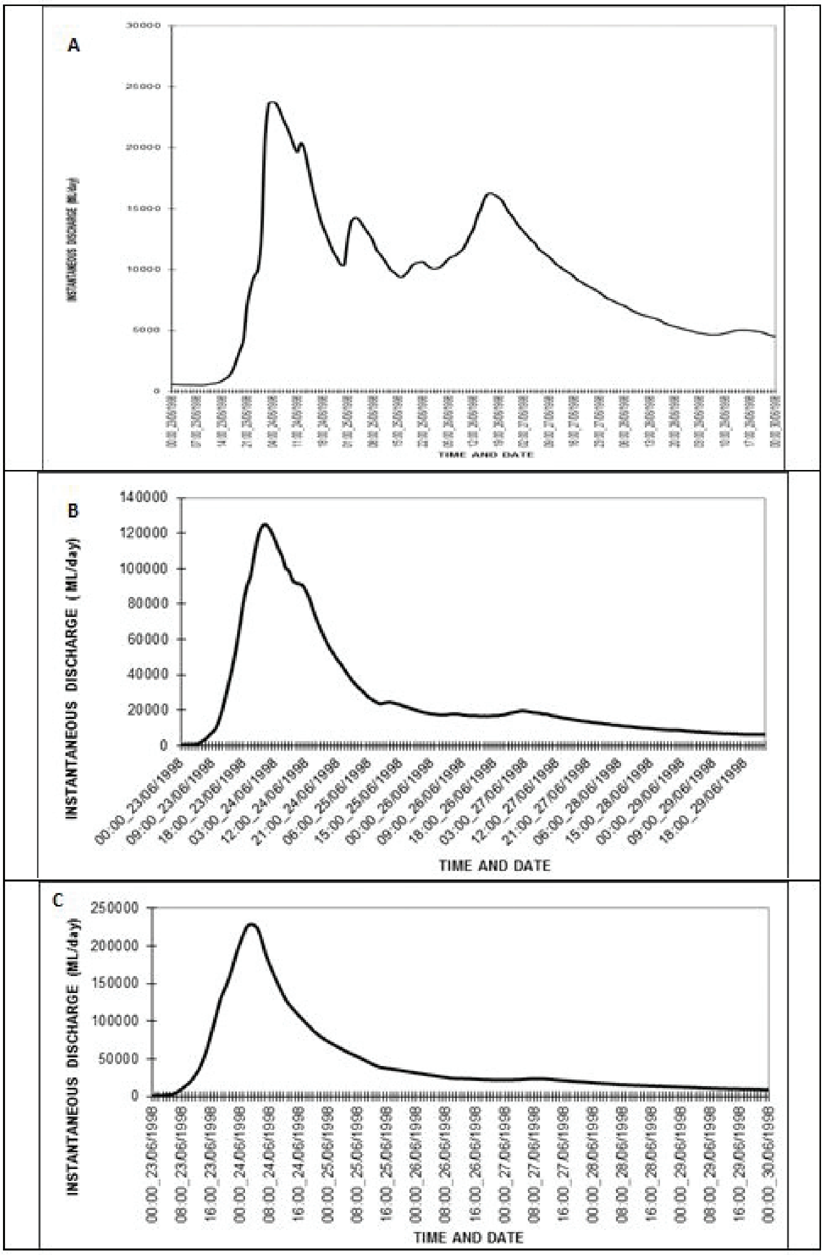

Figure 5: Hydrographs of the June 1998 flood at (A) McKillops Bridge, (B) Downstream of Basin Creek, and (C) Jarrahmond gauges. See Figure 1 for gauging station locations.

downstream of McKillops Bridge contributed most of the runoff. The Jarrahmond hydrograph also exhibited a single peak (Figure 5C), which was characterised by the greatest unit peak discharge on the Snowy River (Table 1). Both the Snowy and Buchan rivers contributed significantly to the flood at Jarrahmond. The June 1998 flood was much larger than the mean annual flood at the two downstream stations (Table 1). The August 1998 flood was a relatively small event, with the flood peak discharge not exceeding the mean annual flood at any station (Table 1). Again, the unit peak discharge declined progressively downstream, indicating that the greatest runoff occurred upstream of McKillops Bridge.

The flood peak ratios for the June 1998 flood are much smaller than those reported for other rivers in the region. These include the February 1971 floods on the Genoa River (12.4) (Erskine 1993) and the Cann River (>10) (Erskine 1999), and the April 1990 flood on the Avon River (>14) (Erskine 1999).

The flood frequency analyses in Table 1 were determined by fitting a log Pearson type III distribution to the annual maximum flood series for the longest continuous period of record since 1967 (the closure of Jindabyne Dam) at each station. The annual exceedance probability of the June 1998 flood declined downstream (Table 1), indicating that the flood was only a rare event downstream of McKillops Bridge. While the June 1997 and August 1998 floods were much smaller than the June 1998 flood on the lower Snowy River, this was not the case at McKillops Bridge. For the two benchmarking sites on the Snowy River downstream of the Buchan River junction, differences in confinement — bedrock-confined at Sandy Point and artificial levee at Bete Bolong — were reflected in their response to the floods, as expected from the results of Erskine (1996).

Table 1: Details of the June 1997 and June and August 1998 flood peaks on the lower Snowy River in Victoria.

Station	**Time of Peak**	**Peak Instantaneous Discharge (ML/d)**	**Unit Peak Discharge (ML/d. km²)**	**Flood Peak Ratio[1]**	**Annual Exceedance Probability (%)/Return Period (years on the annual maximum series)**
McKillops Bridge (No. 222209)	0200 h on 30 June 1997	52800	4.97	1.66	42 2.38
Downstream of Basin Creek (No. 222219)	1100 h on 30 June 1997	52900	4.42	1.76	38 2.63
Jarrahmond (No. 222200)	2100 h on 30 June 1997	44800	3.34	1.05	53 1.89
McKillops Bridge (No. 222209)	4000 h on 24 June 1998	22000	2.07	0.69	62.5 1.60
Downstream of Basin Creek (No. 222219)	0000 h on 24 June 1998	125000	10.45	4.16	15.5 6.45
Jarrahmond (No. 222200)	0300 h on 24 June 1998	228000	16.99	5.35	10 10
McKillops Bridge (No. 222209)	0900 h on 20 August 1998	25100	2.36	0.79	59 1.70
Downstream of Basin Creek (No. 222219)	1800 h on 20 August 1998	25300	2.12	0.84	59.5 1.68
Jarrahmond (No. 222200)	0100 h on 21 August 1998	27600	2.06	0.65	66.5 1.50

[1] Flood peak discharge divided by mean annual flood

CHANNEL BOUNDARY SEDIMENTS: METHODS

The same methods were used to sample channel-boundary sediments in 1998 as in 1997 (Erskine & Turner 1998) to ensure that the results are directly comparable. These are briefly reviewed below.

Bulk samples

The accepted method of sampling fluvial sediments is by the collection of all material from a predetermined volume within a specific depositional or geomorphic environment (Kellerhals & Bray 1971). Following air drying, bulk sieving analysis has been recommended as the standard for use in rivers (Kellerhals & Bray 1971).

Bulk samples were collected of soil, sand, fine gravel and mixed sand and fine gravel by spade at multiple sites on the cross-section when the sites were either dry or located in shallow water. At least eight points on the cross-section were combined for a bulk bed sample. A scoop sampler with an inside-mouth diameter of 150 mm (Figure 6) was used out of a boat to obtain bulk samples of bed sediments in deep water (i.e. too deep to wade). According to British Standards Institution (1975), an unbiased sample is only obtained for those gravel clasts with a size smaller than one-quarter of the dimensions of the sampler mouth. This means that the scoop obtains unbiased samples of gravel clasts smaller than 37.5 mm. Bank sediments were collected at levels 0.25, 0.5 and 0.75, the height of each bank up to the floodplain or the main valley flat level, following the method of Pickup (1976).

Where an armour layer (Leopold 1970; Kellerhals & Bray 1971) was present, it was sampled. Very large sample masses are required to obtain reproducible measures of the grain-size distributions of samples containing individual large clasts (de Vries 1970; Church et al. 1987; Gale & Hoare 1992; Ferguson & Paola 1997). According to the relationship of Church et al. (1987) for modern fluvial gravels, a sample mass of 1 kg is adequate to obtain reproducible measures of the grain-size distribution for sediments with a maximum size of about 9.5 mm. According to de Vries (1970), 'high accuracy' definition of a 16th percentile of 1 mm requires a mass of 200 g, whereas

Figure 6: The scoop bed sediment sampler in use at a benchmarking site in the Dalgety Uplands Reach. For location of river reach, see Figure 1.

'normal accuracy' requires a mass of only 20 g. Sample masses ranged from 988 to 10,012 g, depending on the largest size present. It was impossible to collect, transport and sieve larger bulk samples due to a combination of the large masses (tonnes) required, difficult terrain, limits on vehicle capacity and lack of laboratory space and equipment.

For a particular depositional environment, poorly sorted sediments, such as found in mixed sand- and gravel-bed rivers, require larger samples than do better sorted samples (Gale & Hoare 1994; Ferguson & Paola 1997). It is also difficult to collect bulk samples under water (Muir 1969). This is particularly a problem on the Snowy River, which, in some reaches, is characterised by long deep pools. Bulk sampling is usually restricted to small areas that may not be representative of a specific depositional environment (Wolman 1954; Muir 1969). This is a major concern on large rivers with spatially variable depositional environments (Mosley & Tindale 1985).

Gravel counts

To overcome some of the above problems, the grid-by-number surface sampling technique of Wolman (1954) was devised (herein called gravel count method). Slight variations of this technique have been recommended (Leopold 1970; Kellerhals & Bray 1971) and these have been adopted here. Gravel counts by trained operators produce acceptably accurate results for practical purposes (Wolman 1954; Hey & Thorne 1983; Kondolf & Li 1992). Where more than 5% of the sample was finer than 8 mm, a bulk sample of the finer sediment was collected then sieved and combined with the gravel count data using a weighting factor equivalent to its percentage surface exposure. The above method implicitly assumes that the surficial sediment is the most important for characterising bed sediment and resistance to flow (Kellerhals & Bray 1971).

Laboratory methods

All bulk sediment samples were air dried before being weighed and subjected to grain-size analysis. The gravel fraction of all samples was manually sieved in its entirety through a set of sieves at $\phi/2$ intervals. Phi is a notation system used by sedimentologists to describe the grain size of clastic sediments. It is a logarithmic scale in which each grade limit is twice as large as the next smaller grade limit (Folk 1974). Phi (ϕ) is formally defined as:

$\phi = -\log_2 d$, where d is the grain diameter in mm

The sand fraction was coned and quartered until an approximately 100 g subsample was obtained. This subsample was then dry sieved through a nest of sieves at $\phi/2$ intervals using a 15 minutes shake time. Gravel counts were obtained by measurements of gravel clast b-axis diameters in the field because sieving measures the b-axis diameter. If 5% or more of the sample was finer than 8 mm (-3 ϕ), a bulk sample of the finer textured sediment was collected, air dried and sieved through a nest of sieves at $\phi/2$ intervals. Of the 52 samples, three (5.8%) were gravel counts only, seven (13.4%) were combined gravel counts and sieving, and 42 (80.8%) were sieved only.

Sediment textural characteristics

Grain-size data were plotted as cumulative per cent coarser distributions on arithmetic probability paper (Folk 1974). Graphic grain-size statistics (median size, graphic mean size, inclusive graphic standard deviation, inclusive graphic skewness, graphic kurtosis and transformed kurtosis) were calculated by Excel™ using the relevant percentiles, which were extracted from the grain-size distributions, and the equations of Folk & Ward (1957) and Folk (1974). These equations only use, at most, 90% of the grain-size distribution between the 5th and 95th percentiles (Folk 1974). Nevertheless, such graphic measures are preferred to the method of moments, which weights equally all grain-size fractions. This assumption (i.e. equal weighting) is unjustified because there are major problems in accurately determining both the coarsest and finest fractions of the grain-size distribution. As discussed above, very large sample masses are required to reliably estimate the coarsest percentiles, but it was physically impossible to collect such samples. Furthermore, there are methodological problems in accurately measuring the clay fraction, especially when present in relatively small amounts (Gee & Bauder 1986). Some samples containing gravel started at greater than the 5th percentile. The coarse tail of the grain-size distribution was extrapolated by straight-line extension to 0.01% for the next coarser sieve on which no sediment was retained. The sediment textural classification of Folk (1954, 1974) for unconsolidated materials was used and is based on a ternary diagram showing proportions of gravel, sand and mud (silt and clay) on separate axes.

CHANNEL BOUNDARY SEDIMENTS AT SNOWY BENCHMARKING SITES

The post-flood channel-boundary sediments were collected between 1 and 3 December 1998 during a period of declining baseflow. To determine changes in grain-size statistics between 1997 and 1998, the variances and means were compared for each statistic. The 'F test' was used to assess changes in variance and the relevant version of the 't test' was used to assess changes in mean.

McKillops Bridge

Sediment sampling was conducted on 1 December 1998 when mean daily flow was 944 ML/day. The rapid at cross-section 4 was not sampled because it was impossible to stand up in the inner bedrock channel due to supercritical flow. Therefore, only the side channel was sampled and results cannot be compared directly to those for 1997. Flow was much higher than on 25 and 27 April 1997 (160–164 ML/day) when the original sampling was conducted. As a result, bedforms or channel units (Grant et al. 1990) were often more turbulent than on the first visit. Grain-size statistics of each bed-material sample in 1997 and 1998 are outlined in Table 2 and those for each bank sample for each year in Table 3.

Major channel units were gravel and bedrock rapids, riffles, runs and pools cut in a slot of Amboyne Granodiorite (Orth et al. 1993), which discontinuously outcrops throughout the site. A narrow inner channel with polished low bedrock banks and a gravel or sand bed was present at each cross-section. A secondary channel on the right bank paralleled the main channel between cross-sections 1 and 7. While field evidence indicated that bed material had been entrained at all locations, there was no significant difference in either average median (d_{50}) or average graphic mean (M_z) bed-material size between 1997 and 1998 (0.34

Table 2: Grain size statistics of the bed material in 1997 and 1998 at the McKillops Bridge benchmarking site. For location of cross sections, see Fig. 2.

Grain Size Statistic	Cross Section 1	Cross Section 2	Cross Section 3	Cross Section 4	Cross Section 5	Cross Section 6	Cross Section 7	Cross Section 8
Median Size (ϕ)	-5.65[1] -5.35[2]	-4.05 -5.25	-6.01 -5.40	-6.80 -6.10	-0.15 -0.35	-0.55 0.30	-0.02 -0.65	-7.50 -7.40
Graphic Mean Size (ϕ)	-5.78[1] -5.53[2]	-3.22 -3.93	-6.09 -3.90	-6.68 -6.13	-0.24 -0.53	-0.52 0.05	-0.06 -0.42	-7.25 -6.93
Inclusive Graphic Standard Deviation (ϕ)	1.00[1] 2.22[2]	2.77 2.82	1.14 2.86	1.08 0.79	0.69 1.32	0.56 1.34	0.50 1.25	1.47 1.96
Inclusive Graphic Skewness	-0.17[1] 0.09[2]	0.26 0.57	-0.07 0.56	0.32 -0.06	-0.22 -0.47	0.05 -0.20	-0.15 0.38	0.37 0.59
Graphic Kurtosis	0.98[1] 1.17[2]	0.66 1.76	0.91 1.92	1.51 1.07	0.92 2.11	0.96 0.73	1.43 1.07	1.06 1.74
Transformed Kurtosis	0.49[1] 0.54[2]	0.40 0.64	0.48 0.66	0.60 0.52	0.48 0.68	0.49 0.42	0.59 0.52	0.51 0.64

[1]- 1997
[2]- 1998

Table 3: Grain size statistics of the bank sediments in 1997 and 1998 at the McKillops Bridge Benchmarking site. For location of cross sections, see Fig. 2.

Grain Size Statistic	Cross Section 1	Cross Section 2	Cross Section 3	Cross Section 4	Cross Section 5	Cross Section 6	Cross Section 7	Cross Section 8
Median Size (ϕ)	1.30[1] 1.98[2]	1.65 2.25	2.05 2.03	1.95 2.02	1.96 2.25	1.70 1.97	1.70 1.40	1.90 1.80
Graphic Mean Size (ϕ)	1.43[1] 2.00[2]	1.90 2.15	2.17 2.01	2.02 1.66	2.07 2.18	2.00 1.89	1.78 0.99	1.91 1.85
Inclusive Graphic Standard Deviation (ϕ)	1.07[1] 1.01[2]	1.12 0.98	0.98 1.08	1.11 1.66	0.95 0.83	1.31 1.11	0.97 1.81	0.88 0.99
Inclusive Graphic Skewness	0.24[1] 0.11[2]	0.33 -0.06	0.18 0.01	0.07 -0.38	0.23 -0.11	0.32 -0.05	0.18 -0.42	0.08 0.08
Graphic Kurtosis	1.01[1] 0.97[2]	0.90 0.97	0.93 1.06	1.06 1.27	1.02 1.11	1.76 0.91	1.06 1.25	0.93 0.96
Transformed Kurtosis	0.50[1] 0.49[2]	0.47 0.49	0.48 0.51	0.51 0.56	0.50 0.53	0.64 0.48	0.52 0.56	0.48 0.49

[1]- 1997
[2]- 1998

< ρ < 0.8) (Table 2). There was a non-significant decrease in both the average median and average graphic mean bed-material size (-3.84 to -3.78 ϕ or 14.3 to 13.7 mm in average d_{50} and -3.73 to -3.42 ϕ or 10.7 to 13.3 mm in average M_z). Mean inclusive graphic standard deviation (σ_I) of bed material increased significantly between 1997 and 1998 (σ_I changed from 1.15 to 1.82 ϕ or 0.28 to 0.45 mm; ρ = 0.02). Nevertheless, both values are still within the poorly sorted range (Folk 1974). Field evidence indicated that there were many sand shadow deposits and sand ribbons formed by the 1997 and 1998 floods. Sand influx was responsible for the decrease in sorting (i.e. increase in inclusive graphic standard deviation) (Table 2). There was no significant change in mean inclusive graphic skewness and mean graphic kurtosis between 1997 and 1998 (0.15 < ρ < 0.35).

The 1998 floods were relatively small events with peak heights less than 3.12 m. As a result, they did not inundate all of the river bank. There were no significant changes in the mean and variance of most of the grain-size statistics for bank sediment (Table 3). The two exceptions were the variance of inclusive graphic standard deviation which increased (ρ= 0.021) and the mean inclusive graphic skewness which changed from fine skewed (Sk_I = 0.20) to coarse skewed (Sk_I = -0.103) (ρ= 0.0029).

Table 4: Grain size statistics of the bed material in 1997 and 1998 at Sandy Point. For location of cross sections, see Figure 3.

Grain Size Statistic	Cross Section 1	Cross Section 2	Cross Section 3	Cross Section 4	Cross Section 5	Cross Section 6	Cross Section 7	Cross Section 8
Median Size (ϕ)	-0.50[1] 0.55[2]	0.30 -4.90	0.85 0.58	-0.35 -4.90	-2.00 -4.90	0.00 0.45	0.00 0.75	-4.60 0.15
Graphic Mean Size (ϕ)	-1.58[1] 0.50[2]	0.25 -3.45	0.85 0.51	-1.61 -3.75	-2.32 -3.73	-0.03 0.33	0.04 0.62	-3.27 -1.49
Inclusive Graphic Standard Deviation (ϕ)	2.41[1] 0.59[2]	0.64 2.45	0.51 0.59	2.42 2.66	2.57 2.16	0.62 0.66	1.07 0.53	2.40 2.82
Inclusive Graphic Skewness	-0.57[1] -0.17[2]	-0.16 0.72	-0.01 -0.21	-0.63 0.53	-0.14 0.66	-0.07 -0.26	0.08 -0.67	0.67 -0.68
Graphic Kurtosis	0.59[1] 1.20[2]	1.03 0.57	1.17 1.24	0.61 0.60	0.56 1.94	1.43 1.17	0.98 1.02	0.56 0.51
Transformed Kurtosis	0.37[1] 0.55[2]	0.51 0.36	0.54 0.55	0.38 0.38	0.36 0.66	0.59 0.54	0.50 0.51	0.36 0.34

[1]- 1997
[2]- 1998

Table 5: Grain size statistics of the bank sediments in 1997 and 1998 at the Sandy Point Benchmarking site. For location of cross sections, see Fig. 3.

Grain Size Statistic	**Cross Section 1**	**Cross Section 2**	**Cross Section 3**	**Cross Section 4**	**Cross Section 5**	**Cross Section 6**	**Cross Section 7**	**Cross Section 8**
Median Size (ϕ)	1.30[1] 1.00[2]	1.00 0.95	1.10 1.30	1.30 0.95	0.98 1.05	0.95 -0.35	1.30 0.85	1.25 0.95
Graphic Mean Size (ϕ)	1.29[1] 1.07[2]	1.07 0.99	1.13 1.32	1.36 1.00	1.09 1.13	0.97 -0.23	1.32 0.93	1.27 0.97
Inclusive Graphic Standard Deviation (ϕ)	0.47[1] 0.59[2]	0.63 0.50	0.48 0.58	0.70 0.54	0.58 0.49	0.53 0.42	0.59 0.51	0.57 0.46
Inclusive Graphic Skewness	0.02[1] 0.18[2]	0.21 0.20	0.16 0.07	0.25 0.23	0.29 0.19	0.08 0.41	0.13 0.25	0.14 0.13
Graphic Kurtosis	0.99[1] 1.07[2]	1.28 1.24	1.04 0.97	1.22 1.25	1.17 1.05	1.08 0.97	1.01 1.16	1.27 1.24
Transformed Kurtosis	0.50[1] 0.52[2]	0.56 0.55	0.51 0.49	0.55 0.56	0.54 0.51	0.52 0.49	0.50 0.54	0.56 0.55

[1]- 1997
[2]- 1998

Sandy Point

All sediment sampling was conducted on 2 December 1998 when the mean daily flow was 2174 ML/day at Jarrahmond. A boat was used to access the river bed and the scoop sampler was used to sample at least part of the bed on cross-sections 1, 2, 3, 4, 6 and 7. The original sampling was conducted on 28 April 1997 when the mean daily flow at Jarrahmond was 215 ML/day. The grain-size statistics of each bed-material sample in 1997 and 1998 are outlined in Table 4 and those for each bank sample for each year in Table 5. The armour and subarmour sediments on the longitudinal bar at cross-section 8 are shown in Figure 7.

There were no significant changes in the variance and mean of the grain-size statistics for the bed material before and after the June 1998 flood. While both average median and average graphic mean size increased, as expected (mean d_{50} decreased from -0.79 to -1.53 ϕ or 0.58 to 0.34 mm and mean M_z decreased from -0.96 to -1.31 ϕ or 0.51 to 0.40 mm), the variance of the data was very large and hence the changes were not significant. The lack of change in grain-size statistics before and after the June 1998 flood did not mean that there was no transport of the bed material, only that there were no significant changes in the grain-size distributions. The June 1998 flood was a large event downstream of the Buchan River junction (Table 1) and consequently there were substantial changes in river-bed levels (see next section). Side and longitudinal bars were extensively reworked and armoured by gravels deposited by receding flood flows on top of low-density, liquified sands (Figure 7). In December 1998, the side and longitudinal bars were still 'soft' with low bearing strength, subarmour sediment (Figure 7).

Unlike at McKillops Bridge, the June 1998 flood at Sandy Point inundated the river banks. However, there were no changes in the variance and mean of the grain-size statistics for the bank sediment before and after the June 1998 flood, with two exceptions. The variance of median and graphic mean bank-sediment size increased significantly ($\rho > 0.0049$). The lack of change in bank-sediment grain-size statistics after the June 1998 flood

Figure 7: Moderately well sorted, fine skewed, mesokurtic, pebble gravel armour layer overlying low bearing strength very poorly sorted, coarse skewed, very platykurtic, sandy pebble gravel sub-armour sediment on longitudinal bar at cross section 8 at Sandy Point. See Figure 3 for location of cross section.

is due to the bedrock-confined nature of the channel and the consequent high in-channel stream power, which was sufficient to keep sand in suspension.

Bete Bolong

All post-flood sediment sampling was conducted on 3 December 1998 when the mean daily flow was 1907 ML/day at Jarrahmond. The original sampling was conducted on 29 April 1997 when the mean daily flow at Jarrahmond was 210 ML/day. Bed samples were obtained by wading and/or diving with a trowel on both occasions. The grain-size statistics of each bed-material sample collected in 1997 and 1998 are presented in Table 6 and those for each bank-sediment sample are presented in Table 7.

The June 1998 flood significantly changed the channel-boundary sediment at this site. The only change in variance of the bed material was in graphic kurtosis where the increase (0.0047 to 0.099) was highly significant ($\rho = 0.00066$).

Table 6: Grain size statistics of the bed material collected in 1997 and 1998 at the Bete Bolong benchmarking site. For location of cross sections, see Figure 4.

Grain Size Statistic	**Cross Section 1**	**Cross Section 2**	**Cross Section 3**	**Cross Section 4**	**Cross Section 5**	**Cross Section 6**	**Cross Section 7**	**Cross Section 8**
Median Size (ϕ)	0.70[1] 0.76[2]	0.70 0.60	0.75 0.45	0.70 0.48	0.60 0.58	0.80 0.55	0.75 0.41	0.90 0.78
Graphic Mean Size (ϕ)	0.65[1] 0.80[2]	0.68 0.64	0.75 0.44	0.70 0.48	0.62 0.60	0.78 0.57	0.72 0.41	0.93 0.79
Inclusive Graphic Standard Deviation (ϕ)	0.58[1] 0.49[2]	0.58 0.52	0.49 0.50	0.51 0.49	0.65 0.43	0.53 0.41	0.52 0.47	0.50 0.52
Inclusive Graphic Skewness	-0.09[1] 0.18[2]	-0.06 0.12	-0.03 -0.04	-0.02 -0.01	0.04 0.02	-0.07 0.03	-0.09 0.01	0.00 0.10
Graphic Kurtosis	1.15[1] 1.03[2]	1.14 0.31	1.15 1.15	1.18 1.16	1.14 1.18	1.07 1.37	1.16 1.13	0.97 1.05
Transformed Kurtosis	0.53[1] 0.51[2]	0.53 0.57	0.53 0.54	0.54 0.54	0.53 0.54	0.52 0.58	0.54 0.53	0.49 0.51

[1]- 1997
[2]- 1998

Table 7: Grain size statistics of the bank sediments collected in 1997 and 1998 at the Bete Bolong benchmarking site. For location of cross sections, see Figure 4.

Grain Size Statistic	**Cross Section 1**	**Cross Section 2**	**Cross Section 3**	**Cross Section 4**	**Cross Section 5**	**Cross Section 6**	**Cross Section 7**	**Cross Section 8**
Median Size (ϕ)	2.70[1] 1.60[2]	2.75 1.45	2.25 1.98	2.55 1.45	2.97 1.68	1.97 1.78	1.80 1.70	1.55 1.36
Graphic Mean Size (ϕ)	3.47[1] 1.77[2]	3.55 1.62	2.29 2.01	3.32 1.57	3.64 1.61	2.60 1.77	1.82 1.71	1.52 1.39
Inclusive Graphic Standard Deviation (ϕ)	2.22[1] 1.03[2]	2.41 0.89	1.30 1.04	2.34 0.80	2.17 0.93	2.35 0.82	0.75 0.96	1.40 0.79
Inclusive Graphic Skewness	0.49[1] 0.25[2]	0.54 0.31	-0.04 0.07	0.55 0.23	0.51 -0.15	0.54 0.05	0.17 0.06	-0.24 0.05
Graphic Kurtosis	0.99[1] 0.85[2]	1.23 0.96	1.52 0.99	1.29 0.90	1.04 1.01	1.45 1.16	1.58 1.12	2.99 0.92
Transformed Kurtosis	0.50[1] 0.46[2]	0.55 0.49	0.60 0.50	0.56 0.47	0.51 0.50	0.59 0.54	0.61 0.53	0.75 0.48

[1]- 1997
[2]- 1998

Average median bed-material size increased significantly from 0.74 to 0.58 ϕ or 0.6 to 0.67 mm (ρ = 0.014) and, as expected, average graphic mean bed-material size exhibited the same trend (M_z decreased from 0.73 to 0.59 ϕ or 0.60 to 0.66 mm; ρ = 0.045). Nevertheless, median and graphic mean bed-material sizes are still coarse sand. The sorting of the bed material improved significantly with the mean inclusive graphic standard deviation decreasing from 0.55 to 0.48 or 0.72 to 0.68 mm (ρ = 0.024). This represents a change from moderately well sorted to well sorted. While mean inclusive graphic skewness significantly increased, the change was only from -0.04 to 0.05 (ρ= 0.036) and is still within the near symmetrical range. Mean graphic kurtosis of the bed material did not change significantly before and after the June 1998 flood.

Changes in the bank-sediment grain-size statistics before and after the June 1998 flood were much greater than those outlined for bed material. They resulted from the large-scale deposition of suspended bed material (sand) caused by local roughness effects of willows and kikuyu. The variance of median and graphic mean size, inclusive graphic standard deviation and graphic kurtosis of the bank sediment all decreased significantly (0.029 > ρ > 0.0002). Average median bank-sediment size increased significantly from 2.32 to 1.63 ϕ or 0.2 to 0.32 mm (ρ = 0.028) and, as expected, average graphic mean bank-sediment size exhibited the same trend (M_z decreased from 2.78 to 1.68 ϕ or 0.15 to 0.31 mm; ρ = 0.008). This represents a change in Wentworth size class from fine to medium sand. Mean inclusive graphic standard deviation decreased significantly from 1.87 to 0.91 ϕ or 0.27 to 0.53 mm (ρ = 0.00232) with the consequent change in sorting being from poorly to moderately sorted. Changes in mean inclusive graphic skewness and graphic kurtosis were not significant at ρ = 0.05.

FLOOD-INDUCED CHANNEL CHANGES

The 1997 and 2000 cross-sections at each of the three benchmarking sites were surveyed by Mr Kevin Brown, NSW Department of Land and Water Conservation. Channel morphology is conventionally determined at either bankfull or benchfull stage (for example, see Warner et al. 1975; Riley 1972, 1976). Bankfull stage corresponds to the channel–floodplain junction so that discharge above bankfull flows across the floodplain surface (Wolman & Leopold 1957; Leopold et al. 1964; Riley 1972; Williams 1978). Bed level dynamics are often related to the passage of bedload waves through the channel with alternating phases of aggradation and degradation (Erskine 1994, 1996; Erskine & Livingstone 1999).

Williams (1978) found that objective measures of bankfull determination are no more accurate than a subjectively determined stage identified in the field. However, most of the Snowy River downstream of Jindabyne is closely vertically constrained and laterally confined by bedrock and hence does not exhibit a well-developed floodplain (Erskine et al. 1999a, 2001). Bedrock-confined rivers are usually characterised by compound channels, with up to six benches, and by essentially straight channel patterns (Erskine & Livingstone 1999). Furthermore, regulated rivers that experience significant flood suppression often respond by channel contraction via rapid bench construction in the over-wide pre-regulation river (Gregory & Park 1974; Petts 1977; Sherrard & Erskine 1991; Benn & Erskine 1994). This has also been documented on sections of the Snowy River (Erskine et al. 1999a; 1999b). Benchfull stage corresponds to the channelward edge or mean level of specific in-channel benches (Warner et al. 1975; Erskine & Livingstone 1999). Woodyer (1968) and Erskine & Livingstone (1999) found that vertically adjacent benches are separate in terms of their flood frequency distributions and hence are distinct morphological features.

Various channel geometric parameters (width, cross-sectional area, mean depth, maximum depth, width–maximum depth ratio) have been determined for the main in-channel bench (Erskine & Livingstone 1999) and bankfull. Where a floodplain was not present (McKillops Bridge), bankfull was defined as the highest morphological feature composed of fluvial sediment.

To determine changes in channel morphology between 1997 and 2000, the variances and means were compared for each parameter. The F test was used to assess changes in variance and the relevant version of the t test was used to assess changes in mean in Excel™.

McKillops Bridge

The river has eroded a slot into the resistant bedrock which is often polished on the sides by abrasion. Flutes, potholes and chutes are common erosional features in the granodiorite. A small inner channel (Schumm et al. 1987) eroded into bedrock is evident downstream of cross-section 3 (Figure 2). The minimum width–maximum depth ratio always coincides with the inner channel, where it is present. The inner channel is not considered further here because the rate of bedrock erosion is too slow to be measured by standard surveying.

All channel geometric parameters have been determined for the same benchfull and bankfull levels for both surveys at each cross-section (Table 8). The bench levels in Table 8 may not refer to the same contiguous bench because there was insufficient time during fieldwork to correlate benches between cross-sections, as carried out by Woodyer (1968) and Erskine & Livingstone (1999). Bankfull stage is also difficult to identify on the cross-sections. While a bankfull stage has been identified for each cross-section in Table 8, it usually corresponds to a narrow, ill-defined sloping shoulder of high level alluvium or slackwater deposits that may have no morphological significance. The minimum width–maximum depth ratio occurs at the bench on three cross-sections and at bankfull stage at the other five cross-sections (Table 8).

Table 8: Channel morphology at McKillops Bridge in 1997 and 2000. The location of the channel cross sections is shown in Figure 2.

Cross Section	Landform	Reduced Level (m)	Width (m)	Area (m^2)	Mean Depth (m)	Maximum Depth (m)	Width-Maximum Depth Ratio (m/m)
1	Bench	74.34	54.9[1]	66.6	1.21	1.78	31
			46.1[2]	54.4	1.18	1.73	27
	Bankfull	79.01	150.7[1]	597	3.96	6.45	23
			149.8[2]	600	4.00	6.40	23
2	Bench	74.73	62.7[1]	104	1.65	2.45	26
			62.0[2]	96.2	1.55	2.35	26
	Bankfull	79.24	155.7[1]	678	4.36	6.96	22
			156.3[2]	668	4.28	6.86	23
3	Bench	75.22	72.8[1]	112	1.54	3.19	23
			73.6[2]	111	1.50	2.80	26
	Bankfull	80.39	179.2[1]	863	4.82	8.36	21
			178.0[2]	866	4.87	7.97	22
4	Bench	77.67	138.6[1]	466	3.37	5.99	23
			138.0[2]	470	3.41	5.85	24
	Bankfull	79.89	174.0[1]	817	4.70	8.21	21
			176.0[2]	832	4.73	8.06	22
5	Bench	75.34	69.4[1]	139	1.97	5.21	13
			70.0[2]	142	2.02	5.48	13
	Bankfull	79.54	156.6[1]	712	4.55	9.40	17
			158.9[2]	728	4.58	9.04	18
6	Bench	75.67	86.1[1]	207	2.39	5.47	16
			86.3[2]	205	2.38	5.78	15
	Bankfull	79.29	158.2[1]	695	4.39	9.10	17
			165.0[2]	710	4.30	9.41	18
7	Bench	75.03	47.4[1]	143	3.01	4.57	10
			47.7[2]	136	2.84	4.36	11
	Bankfull	79.29	157.9[1]	743	4.71	8.80	18
			158.0[2]	765	4.84	8.60	18
8	Bench	76.27	149.3[1]	482	3.23	5.01	30
			154.4[2]	474	3.07	5.01	31
	Bankfull	78.39	181.3[1]	831	4.58	7.13	25
			182.2[2]	832	4.57	7.13	26

[1]-1997
[2]-2000

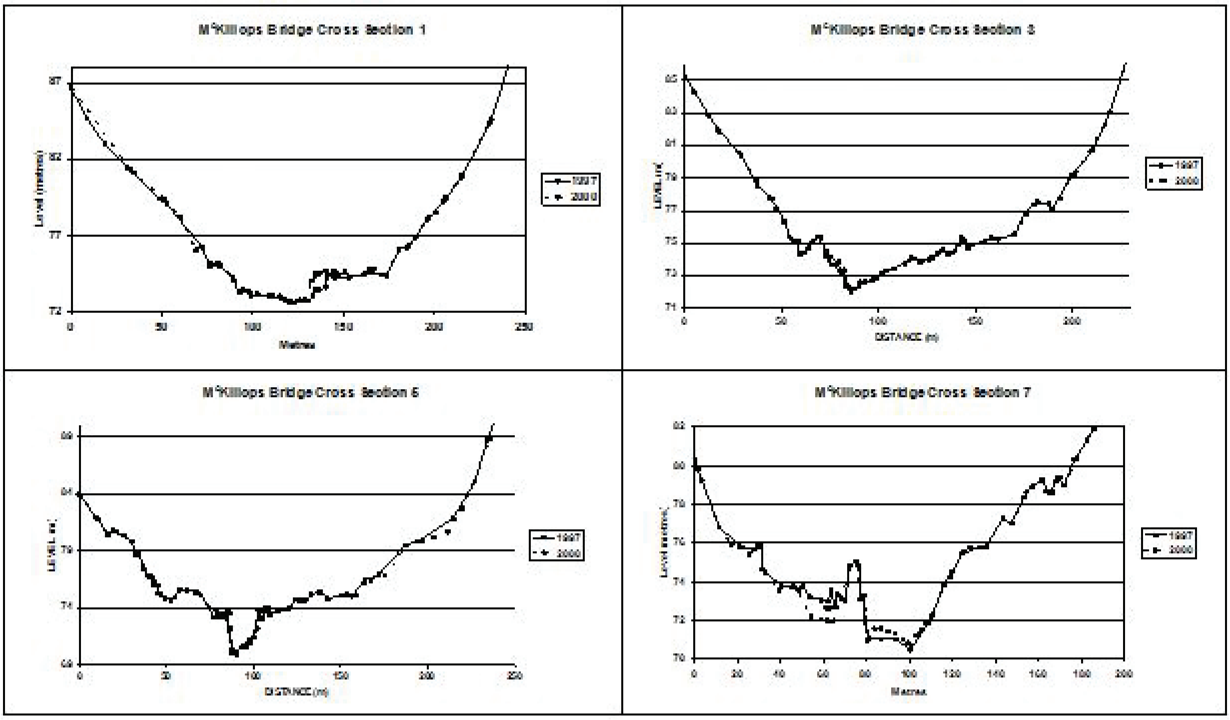

Figure 8: Cross-sections surveyed in 1997 and 2000 at McKillops Bridge. See Figure 1 for location of site and Figure 2 for location of cross-sections.

Benchfull and bankfull channel geometric parameters did not change between 1997 and 2000, except for mean bankfull width–maximum depth ratio which increased by only 2.2% from 20.7 to 21.2 (ρ = 0.0069). This was the largest percentage change in any bankfull-channel geometric parameter although some slightly larger but non-significant changes were recorded in benchfull parameters. Clearly, there were only minor changes in channel geometry as a result of three small floods in 14 months. Many of the channel changes are very minor (see cross-sections 1, 2 and 3), despite the mobilisation of bed material at most cross-sections (Figure 8). Close bedrock confinement limits channel sensitivity to flood-induced change by small events. Many of the benches are founded on a bedrock nucleus and colonised by riparian vegetation, limiting changes in benchfull channel dimensions by such small events.

Sandy Point

This site is located on a long sand- and gravel-floored pool on the upstream limb of a deeply entrenched bedrock loop cut into Ordovician metasediments (VandenBerg 1977). There is a high sandy bench present on the right bank which has been mapped as alluvium at a scale of 1:250,000 by VandenBerg (1977). The bench has a bedrock nucleus that is often exposed at the base of the right bank. A chute containing scour pools has been eroded along the right bank valley side at the upstream end of the bench. The left bank is very steep and cut largely into bedrock.

All channel geometric parameters have been determined for the same benchfull and bankfull levels for both surveys at each cross-section (Table 9). The steep left bank had to be extended on some cross-sections to reach bankfull stage. Linear extrapolation was used because of the steep bank. The minimum width–maximum depth ratio usually coincided with the high bench, and lower benches were very fragmentary.

There was no significant change in the variance of benchfull and bankfull channel geometric parameters between 1997 and 2000. However, there was a significant increase in bankfull mean depth (ρ = 0.024). Mean bankfull width–maximum depth ratio decreased significantly (ρ = 0.031). While mean maximum depth increased by 8.1%, the change was significant at only ρ = 0.068. However, mean bankfull width decreased by -1.15% and so the resultant change in mean width–maximum depth ratio (-8.5%) was significant. The percentage increases in the mean that were significant ranged between only 2.7% and 7.1%.

The bed was scoured during the June 1998 flood and fill did not always match scour, as predicted by Erskine et al. (1999a, 1999b). As a result, cross-sections 2, 3, 4 and 6 experienced localised scour that persisted after the flood (Figure 9). As the frequency of net scouring floods has been reduced by flow regulation, the resultant pools often do not persist until the next such event (Erskine et al. 1999a). The sand entrained from the bed was often deposited as bars and laterally redistributed onto benches (cross-sections 1, 3 and 5). However, some bench erosion also occurred (cross-

Table 9: Channel morphology at Sandy Point in 1997 and 2000. The location of the channel cross sections is shown in Figure 3.

Cross Section	Landform	Reduced Level (m)	Width (m)	Area (m^2)	Mean Depth (m)	Maximum Depth (m)	Width-Maximum Depth Ratio (m/m)
1	Bankfull	84.40	61.2[1]	229	3.74	6.60	9
			60.8[2]	237	3.89	6.29	10
2	Bankfull	85.34	76.7[1]	320	4.17	6.32	12
			76.8[2]	348	4.53	7.53	10
3	Bench	82.70	42.9[1]	154	3.59	4.61	9
			43.5[2]	173	3.98	5.21	8
	Bankfull	84.00	53.5[1]	217	4.06	5.90	9
			51.9[2]	233	4.50	6.50	8
4	Bankfull	86.42	79.9[1]	432	5.40	7.64	11
			79.9[2]	451	5.64	7.91	10
5	Bench	82.97	53.4[1]	166	3.12	4.78	11
			52.6[2]	158	3.01	4.49	12
	Bankfull	84.41	72.5[1]	260	3.59	6.21	12
			68.5[2]	238	3.48	5.93	12
6	Bench	83.53	63.0[1]	199	3.17	4.30	15
			63.2[2]	217	3.43	5.98	11
	Bankfull	85.22	80.5[1]	320	3.98	5.99	13
			81.2[2]	336	4.14	7.67	11
7	Bench	83.86	76.5[1]	264	3.44	4.78	16
			76.6[2]	276	3.61	5.00	15
	Bankfull	85.78	105.5[1]	457	4.34	6.70	16
			104.5[2]	468	4.48	6.93	15
8	Bankfull	86.32	93.0[1]	486	5.22	7.67	12
			92.0[2]	484	5.25	8.59	11

[1]-1997
[2]-2000

sections 1, 2 and 3). The close lateral bedrock confinement combined with bend curvature induced significant bed scour at this site because the bed material is much finer than at McKillops Bridge.

Bete Bolong

Longitudinal and transverse sandy bars (Miall 1977; Smith 1971) have largely replaced rhythmically-spaced, alternating, bank-attached side bars (Brush et al. 1966) that were evident on air photographs taken in February 1940 and May 1965 since the commencement of flow regulation by the Jindabyne Dam in 1967 (Erskine et al. 1999a). A floodplain continuously borders the straight channel on the left bank but a bedrock spur confines the channel on the right bank in the middle of the site. The channel is contiguous with the deep upstream valley cut into Ordovician metasediments (VandenBerg 1977). High extensive Tertiary terraces also increasingly flank the floodplain downstream of the site (VandenBerg 1977).

All channel geometric parameters have been determined for the same benchfull and bankfull levels for both surveys at each cross-section (Table 10). There are many vegetated erosion scars on the banks so minor shoulders on the bank profiles have **not** been identified as benches. Well-developed alluvial benches are present at five of the eight

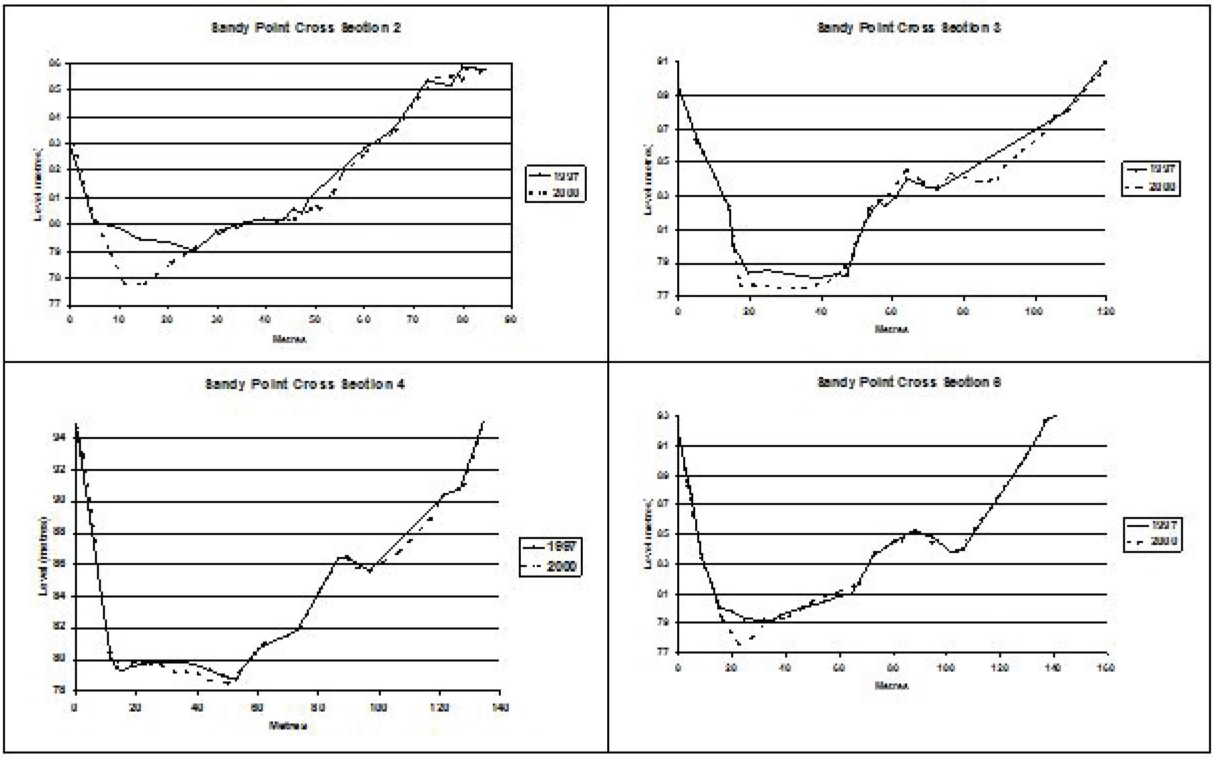

Figure 9: Cross-sections surveyed in 1997 and 2000 at Sandy Point. See Figure 1 for location of site and Figure 4 for location of cross-sections.

cross-sections (Table 10). The minimum width–maximum depth ratio always coincided with the floodplain.

This site significantly responded to the June 1998 flood. While there was no change in variance of any of the benchfull and bankfull morphologic parameters, mean benchfull area and mean depth all increased significantly ($0.0135 > \rho > 0.0017$). The only bankfull morphologic parameters to change significantly were mean bankfull area and mean bankfull width ($0.031 > \rho > 0.003$), with percentage increases of between 2.4% and 3.8%. Clearly, most of the channel changes were associated with the variations in bed level and hence there were more significant and larger benchfull changes.

Bed degradation is shown on most cross-sections (Figure 10) and is corroborated by the increases in benchfull mean depth and area (Table 10). Maximum depth did not increase because it only reflects changes in thalweg level which, in this case, have been compensated by erosion across most of the bed (see Figure 10). The thalweg is only a narrow section of the bed between bar avalanche faces and secondary channels (Erskine et al. 1999a). There was also substantial erosion and deposition of in-channel benches, as shown by cross-sections 1, 6, 7 and 8 in Figure 10. These changes support the coarsening of bank sediments documented above. Benchfull channel morphology is a more sensitive indicator of flood impacts than bankfull channel morphology. Floods with a flood peak ratio much greater than 4 are required to substantially modify the bankfull channel of sand-bed streams. Abrahams & Cull (1979) suggested that a flood peak ratio of at least 4 was appropriate to define a catastrophic flood. However, Erskine (1993, 1994, 1996, 1999; Erskine & Livingstone 1999; Erskine & Warner 1999) found that floods with a flood peak ratio greater than 10 cause large-scale channel erosion. Nevertheless, the June 1998 flood transported large amounts of sand in suspension and deposited a large proportion on the banks and benches. McLennan (1972) found significant erosion here during the February 1971 flood. However, the benches represent post-1971 channel contraction, as has been documented on many flood-disturbed, sand-bed channels in Australia (Erskine 1994, 1996, 1999; Erskine & Livingstone 1999).

CONCLUSIONS

One of the floods (June 1998) that occurred on the Snowy River in the 14 months between June 1997 and August 1998 was a large event with a flood peak ratio greater than four times the mean annual flood downstream of the Rodger River junction. Although the combined effects of all three floods were determined, the impacts of the flood sequence on channel-boundary sediments and morphology were most significant downstream of the Buchan River junction. Floods at least four times greater than the mean annual flood are capable of entraining and maintaining

Table 10: Channel morphology at Bete Bolong in 1997 and 2000. The location of the channel cross-sections is shown in Figure 4.

Cross Section	Landform	Level (m)	Width (m)	Area (m^2)	Mean Depth (m)	Max. Depth (m)	Width-Max. Depth Ratio (m/m)
1	Bench	90.94	122.8[1]	107	0.87	1.73	125
			124.3[2]	157	1.26	1.67	87
	Bankfull	97.36	172.5[1]	1055	6.12	8.15	21
			177.0[2]	1136	6.42	8.08	22
2	Bench	92.42	136.6[1]	330	2.42	3.23	43
			139.0[2]	365	2.63	3.25	42
	Bankfull	96.00	162.4[1]	868	5.34	6.80	25
			165.6[2]	921	5.56	6.98	24
3	Bankfull	96.16	171.3[1]	970	5.66	6.57	26
			176.9[2]	1038	5.87	6.98	25
4	Bankfull	97.77	166.7[1]	1106	6.63	8.41	20
			171.2[2]	1187	6.93	8.62	20
5	Bankfull	97.90	140.6[1]	1071	7.62	9.27	15
			140.7[2]	1030	7.32	8.49	17
6	Bench	91.01	107.7[1]	147	1.37	2.10	53
			109.0[2]	168	1.54	2.37	46
	Bankfull	97.60	148.4[1]	1024	6.90	8.65	17
			149.5[2]	1047	7.01	8.93	17
7	Bench	91.97	104.0[1]	234	2.25	3.08	36
			97.1[2]	249	2.56	2.99	33
	Bankfull	97.14	150.8[1]	961	6.37	8.25	18
			154.9[2]	978	6.32	8.17	19
8	Bench	92.60	113.8[1]	329	2.89	4.06	28
			116.3[2]	354	3.04	4.03	29
	Bankfull	97.84	164.6[1]	1123	6.82	9.30	18
			172.4[2]	1154	6.69	9.27	19

[1]-1997
[2]-2000

clean bed material on the lower Snowy River. We have also documented the overturn of the upper estuary by the June 1998 flood, which destratified strongly salt- and oxygen-stratified pools (Turner & Erskine 2005).

At McKillops Bridge, the bed material was mobilised, there was an influx of sandy bed material and coarse sediment was deposited on the banks. At both Sandy Point and Bete Bolong, there was a significant reworking of the bed material. At Bete Bolong, the bank sediment was changed by the deposition of sand by the June 1998 flood.

Channel morphology did not change significantly at McKillops Bridge and Sandy Point between 1997 and 2000. However, the percentage change in width−maximum depth ratio was very small, except for a significant increase in bankfull mean depth at Sandy Point. At Bete Bolong, benchfull mean depth and area increased significantly due to bed degradation during the June 1998 flood. Mean bankfull width and area also increased.

The geomorphic component of the Snowy River Benchmarking Project should be repeated immediately after every event with a flood peak discharge greater than four times the mean annual flood. Resistant bedrock

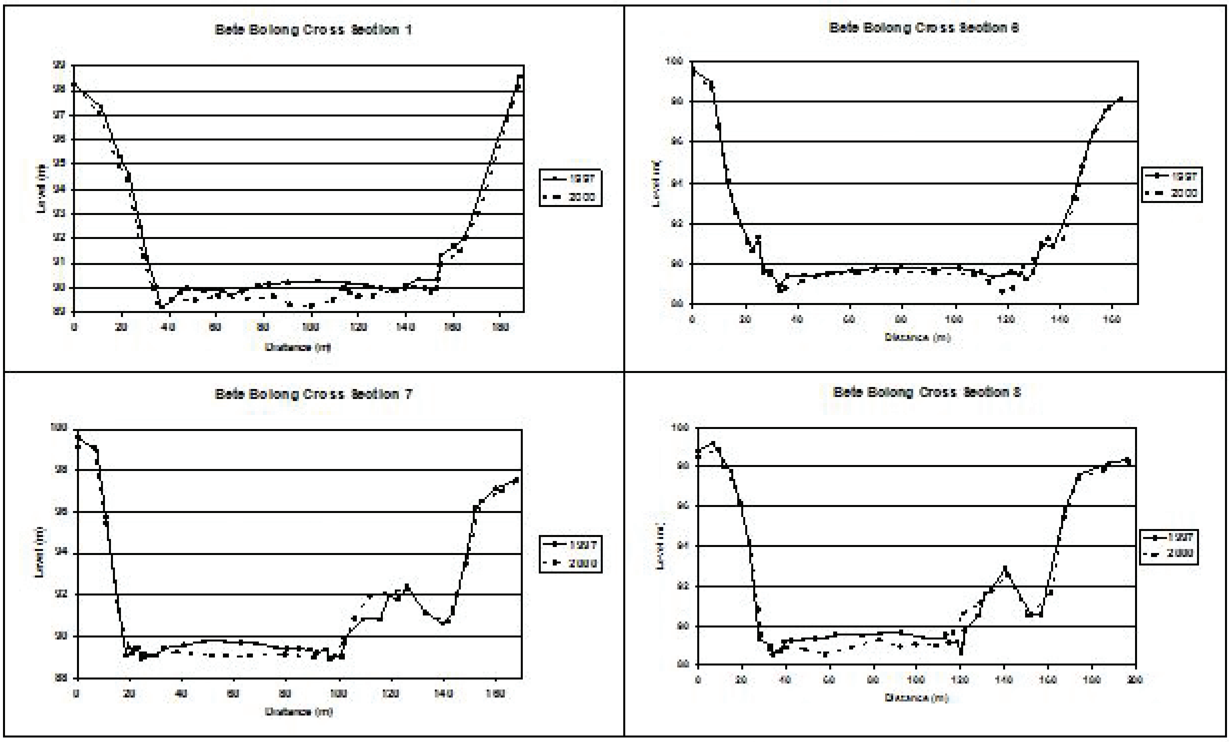

Figure 10: Cross-sections surveyed in 1997 and 2000 at Bete Bolong. See Figure 1 for location of site and Figure 3 for location of cross-sections.

laterally confines and vertically constrains the channel to such an extent at McKillops Bridge that little flood-induced change is possible. Sandy Point is a critical site for determining the significance of flood scour for pool formation and persistence in the Lucas Point Reach and for assessing the rate of pool infilling by events smaller than the June 1998 flood. Bedrock induces bed scour along the left bank and the sandy bench on the right bank is subject to flood change. At Bete Bolong, the whole channel boundary is sandy and subject to bed scour and bank deposition by floods.

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