5. ASSESSING PRESENT CONDITION

This chapter presents the results of the assessment of present stream and catchment condition.

5.1. Field observations

5.1.1. Erosion

During field inspections three main types of erosion were observed: bed erosion, bank erosion and gullying. No tunnel erosion was observed by the authors, nor was there evidence of significant sheet erosion.

Bed erosion was evident in the main stem of Creightons Creek and several of the tributaries, in the form of erosion heads or knickpoints. These erosion heads were generally between 0.1 and 0.5 m high, though some were close to 1 m. Erosion heads were observed both above and below the Hume Freeway (i.e. in the hills and on the flats), with clusters evident at several locations, including on Branjee Creek, between Nelsons Rd and Drysdale Rd and on some of the headwater tributaries. Many of the erosion heads observed below the Hume Freeway were 'caught' on river rock (indurated river sediments) exposed in the bed of the creek (Fig. 5.1) and are consequently progressing very slowly upstream. The erosion heads observed above the Hume Freeway were in some instances caught on river rock, but were more commonly eroding through less resistant alluvial material (Fig. 5.2) and were, as a consequence, probably progressing upstream relatively quickly. Some work is currently being done by DNRE, the Goulburn-Broken Catchment Management Authority and a local land holder (Barrie Noye), which involves mapping erosion heads in the creek system to facilitate management.

Bank erosion was also observed along the main stem of Creightons Creek, both upstream and downstream of the Hume Freeway. At a large number of sites, bank erosion (channel widening) has followed bed erosion (channel deepening). Channel widening following incision was evident above the Hume Freeway, both in the middle reaches (Fig. 5.3) and in the upper reaches of the creek (Fig. 5.4), as well as below the Hume Freeway (Fig. 5.5). While channel widening processes associated with incision would appear to be the main cause of bank erosion on Creightons Creek there are some sites where bank erosion has occurred for other reasons. There are, for example, several sites where bank

Fig. 5.1. An erosion head in Creightons Creek caught on resistant river rock

Fig. 5.2. An erosion head in Ramages Creek moving through alluvial material

Fig. 5.3. Eroding streambanks in the middle reaches of Creightons Creek

Fig. 5.4. Eroding streambanks in the upper reaches of Creightons Creek

Fig. 5.5. Eroding streambanks in the lower reaches of Creightons Creek

Fig. 5.6. Bank erosion on Creightons Creek due to undercutting

Fig. 5.7. Bank erosion on Creightons Creek due to stock trampling

Fig. 5.8. A gully in the Creightons Creek catchment that has been fenced and planted with vegetation.

Fig. 5.9. A gully in the Creightons Creek catchment that has been fenced and planted with vegetation

erosion is occurring as a result of stream migration, where the creek is undercutting the stream bank. Such instances are localised and in general are not a significant sediment source, but where these processes are active within a deeply incised reach of stream (such as on Stan Artridge's property (Fig. 5.6)) the potential sediment yield could be large. Bank erosion is also occurring at several sites along Creightons Creek and its tributaries as a result of stock trampling the banks (Fig. 5.7).

The third type of erosion observed in the Creightons Creek catchment is gullying. Active gullying has obviously been a problem in the past, with regard to the sediment released and farm management, but in most instances landholders have taken steps to address the problem, usually by fencing the drainage line out and planting vegetation (e.g. see Figs 5.8, 5.9). This is not to say gullying will not be a problem in the future, because anecdotal evidence suggests that where gullying has occurred in the past it has been in response to an activity (e.g. ploughing) or an event (e.g. storm, bushfire) which could also occur in the future. Gully erosion releases large quantities of sediment and this could also occur in the future, under the right conditions.

Fig. 5.10. A completely sanded reach of Creightons Creek

5.1.2. Aggradation

Information on sedimentation in the Creightons Creek catchment (Chapter 4) indicates that since European settlement there have been a number of phases of incision and aggradation along Creightons Creek. Anecdotal evidence suggests that sediment may now be filling the remaining pools on the upper tributaries to Creightons Creek. However, other evidence, such as bed degradation (see Chapter 4) and channel lengthening (pers. comm. Claire Penniceard, landholder, April 1998), suggests that sediment transport and aggradation may be declining through the middle reaches of the creek, i.e. between the Hume Freeway and Stan Artridge's property.

Downstream of the Hume Freeway the creek can be split into three segments. From the Hume Freeway down to the Longwood–Pranjip Rd (Branjee Creek) the creek is completely sanded, the channel is almost rectangular in cross-section and there is no variation in bed form (Fig. 5.10). The reach between the Longwood–Pranjip Rd and Pranjip Rd is a transition zone. In this reach sand is certainly evident but the volumes are not yet so large as to drown out the pool–run bed form (Fig. 5.11). Below Pranjip Rd some sand is evident in Branjee–Creightons Creek, deposited as sand drapes on the banks and point bars, but the total volume of sand deposited is minor as is its impact on the morphology of the creek (Fig. 5.12). While sand transport is clearly evident in the sanded segment, via dune movement (Fig. 5.13) and saltation of individual grains, the rate of movement of the snout of the sand slug is difficult to assess. The only piece of evidence available comes from

Fig. 5.11. A partially sanded reach of Creightons Creek

Fig. 5.12. Creightons Creek below the sand slug

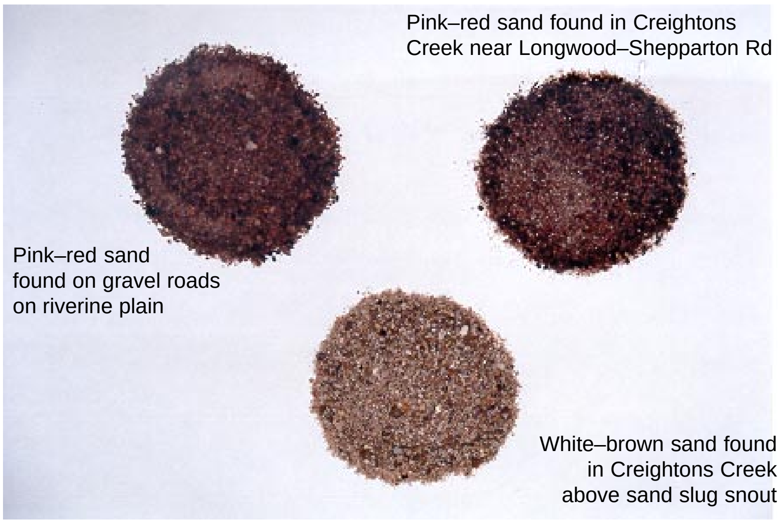
the description of the location of the sand slug by O'Connor (1991; pers. comm. Nick O'Connor, AWT, May 1998), and this suggests that there has not been significant downstream movement of the snout in the last 5–10 years (also see Section 4.8).

The features of the sand slugs in Castle and Pranjip–Nine Mile Creek are relatively similar to those of the Creightons Creek sand slug. All three sand slugs have indistinct snouts and tails that may be evacuating the middle reaches of their respective stream networks. Hence it appears that the Creightons Creek sand slug may well be typical of sand slugs found in the Granite Creeks.

The following observations were made in the laboratory and not in the field, but it is appropriate to discuss these observations here and to speculate about the possible implications. When creek bed sediment samples taken from Creightons Creek at the Longwood-Shepparton Rd were dry sieved it became obvious that a substantial proportion of the sand-sized grains were pink–red and not brown–white as had been observed for all the other samples (Fig. 5.14). Investigations in the field revealed that similar 'pink' sand was evident in Muddy-waterhole Creek at Kirwans Bridge Rd and on many of the gravel roads in the area. Discussions with the Works Foreman for the Strathbogie Shire Council revealed that the pink sand was not consistent with the gravel the council used on these roads. For the purposes of determining the source of sand in the lower reaches of Creightons Creek it was important that the origin of the pink sand be identified, so further investigations were carried out.

Fig. 5.13. Sand dunes migrating along Creightons Creek

Fig. 5.14. 'Pink' and 'white' sand samples taken from Creightons Creek catchment



When viewed under a microscope the pink sand grains appeared to be clear quartz grains with a pink–red surface coating. This was confirmed when several grains were cracked open. While the pink–red surface coating was visible on some of the fracture surfaces it was not visible on others, suggesting that the surface and the more open fracture planes had been stained. The mineral composition of the sand is consistent with it having been derived from the granitic Strathbogie Ranges but it has subsequently been stained. The most obvious explanation for the staining is that the sand has been stored on the Riverine Plain for some time and during this period it has been subject to flooding and waterlogging — conditions in which iron can be mobilised (Bloomfield 1981). When the sediments were exposed to oxidation during periodic lowering of the water table, iron precipitated (Bloomfield 1981) staining the quartz grains a red–pink colour. If this explanation is correct then the pink sand can be considered, in the management time scale, to be the material into which the channels on the Riverine Plain have been cut and is the material which, though originally derived from weathering and erosion of Strathbogie granites, has been in storage on the plain for a significant time span. One would also expect to find pink sand in other reaches of Creightons Creek on the Riverine Plain, but most reaches upstream of Pranjip Rd have been inundated with 'white' sand which would have substantially diluted the pink colouring and buried the underlying material.

The main implication of the above explanation for the existence of the pink sand is that the sand found in Creightons Creek at the Longwood–Shepparton Rd and in Muddy-Waterhole Creek at Kirwans Bridge Rd is derived locally. Since the pink sand found in these locations has not been diluted by 'white sand' released recently from the upper catchment, it can be assumed that the lower reaches of Creightons Creek and Muddy-Waterhole Creek have not yet been affected by the sand slug moving down the system.

5.2. Sediment budget

As described in Section 3.3.2, a sediment budget was developed to determine the main source of sand for the sand slug. Note that these calculations are based on very rough estimates of the volume of sediment eroded from the catchment and the amount of sediment deposited in the catchment (see Section 3.3.2). There are two main reasons for the approximate nature of these estimates: (i) it was not always easy to distinguish modern depositional material from old depositional material; and (ii) it was difficult to estimate the average depth of sediment deposited in the active channel. Given the errors associated with the sediment budget it was decided that the results would only be used to determine whether or not there was sufficient sand released from channel incision and gullying to account for the sediment deposited in the creek.

Three main sources of sediment were identified in the catchment, the three sites being incised reaches on Creightons Creek (adjacent to Stan Artridge and Laurie Davidson's properties), Baronga Creek (adjacent to Barrie Noye's property) and Ramages Creek (adjacent to Bill O'Connor's property). Minor examples of stream incision and gullying were also used to calculate the total volume of material liberated, but the three main sources accounted for more than 90% of the total. The total volume of material liberated by stream incision and gullying was estimated to be approximately 320 000 m^3. It was then estimated from the particle size analysis of bank samples that approximately 30% of the material would be finer than 63 mm, and in a worst case scenario all this would be washed through the system; hence only 70% would be retained in the catchment. Consequently it was estimated that approximately 225 000 m^3 of sand and gravel has been liberated from drainage lines in the Creightons Creek catchment.

The total volume of deposited sediment in the Creightons Creek catchment was estimated by assuming that on average 2 m of sediment has been deposited in the abandoned section of Creightons Creek, 0.75 m deposited in Branjee Creek above Pranjip Rd and 0.5 m of sediment deposited in Creightons Creek between the railway line and Laurie Davidson's property. Deposition was also estimated for the former swamp at Nelsons Rd (based on soil pit data) and overbank deposits adjacent to the creek at Stan Artridge's, Dino Furlanetto's and near Kelly's Bridge. Total deposition in these sinks was 113 000 m^3; this was rounded up to 120 000 m^3 to allow for in-stream extraction (see Section 4.7 for details). As no estimate could be made of overbank storage below the Hume Freeway the volume was doubled (increased by 100%) to give a final total. Hence it is estimated that approximately 240 000 m^3 of sediment is deposited in the Creightons Creek catchment.

A comparison between the estimated total volume of coarse sediment (larger than 63 mm) liberated from drainage lines in the Creightons Creek catchment (225 000 m^3) and the estimated total volume of sediment stored in the catchment (240 000 m^3) indicates that channel incision could account for the majority of sand and gravel deposits in the catchment.

5.3. Sediment tracing using particle size distributions

This study used sediment tracing to provide further information about possible sources and sinks for sediment in the Creightons Creek catchment (see Section 3.3.3). Particle size distribution was chosen as a method for tracing sediment movement, primarily because it is low cost. Four tracing techniques were used and the results are described below.

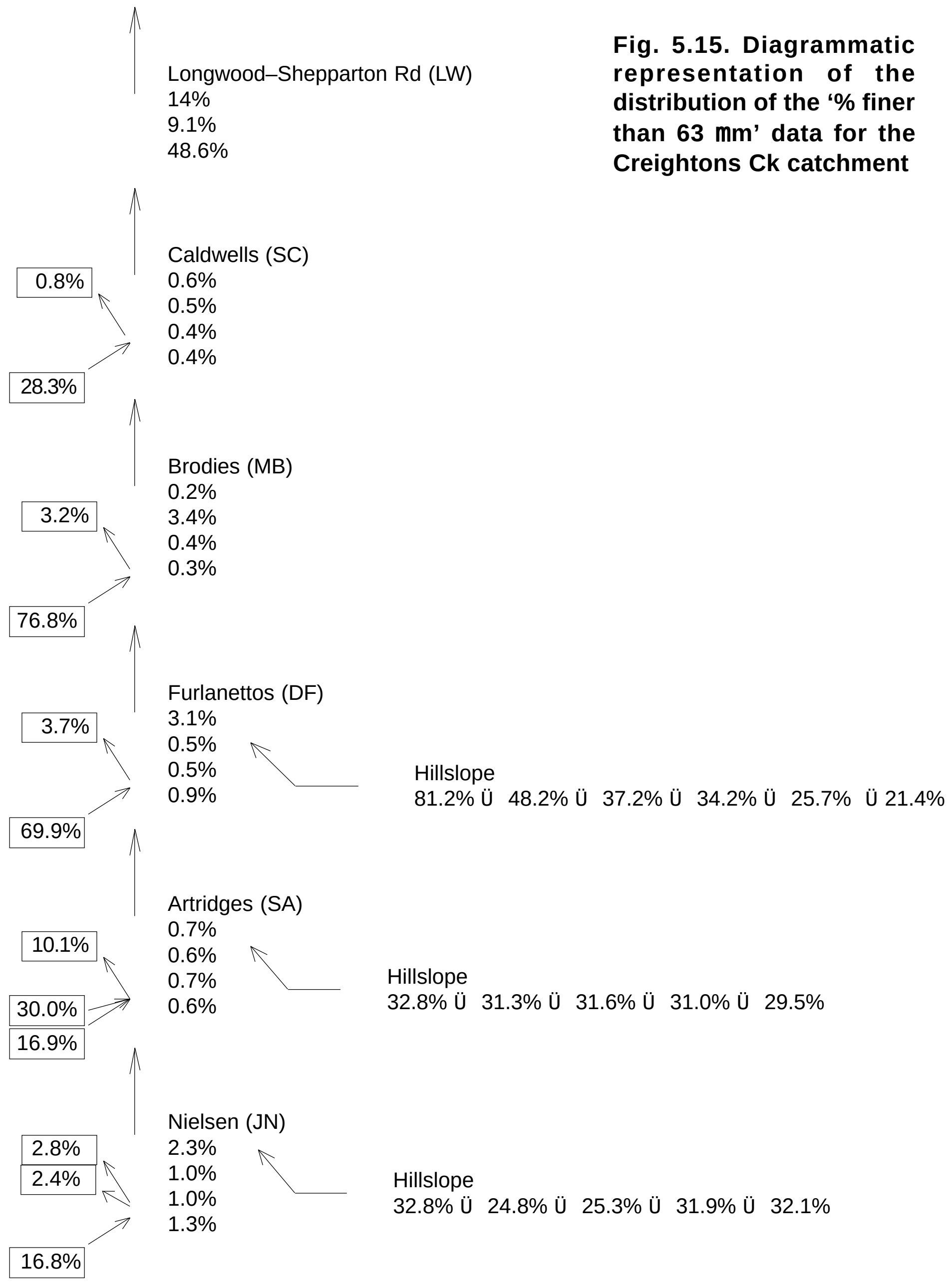
5.3.1. Fine fraction method

The results from the fine fraction method are summarised in Fig. 5.15. Because of concerns about abrasion (see Section 3.3.3) and the expectation that once the fine fraction enters the drainage network it is washed through, fine fraction transport patterns were only examined for the hillslope samples, although some general trends can be drawn out.

Several general patterns are visible in Fig. 5.15 (also see Fig. 3.1 for site locations) that are consistent with the expected movement of sediment that is less than 63 mm in size in a stream network. The percentage of fines is high on hillslopes and in the creek bed below the sand slug, low in creek beds and on adjacent banks (i.e. sand drapes deposited under moderate to high flow conditions) along the sand slug, and moderate or high in areas where deposition has occurred under low flow conditions (i.e. floodplain deposits that are now stream banks).

Examination of hillslope trends indicates that slightly different transport patterns may be occurring at each of the hillslope sites. The values of '% finer' at site JN are consistent with fines being eroded from the mid-slope area and being removed from the slope altogether. The '% finer' values from hillslope site SA could be indicating little movement of fine material and a fairly stable environment. The values of '% finer' from hillslope site DF indicate that the relative proportion of fines increases downslope,

Fig. 5.15. Diagrammatic representation of the distribution of the '% finer than 63 mm' data for the Creightons Ck catchment



Key

Smiths (WS)
a%
b% represents samples taken in Creightons Creek on the Smith's property (location WS),
c% where the samples have a%–d% of their total mass finer than 63 mm
d%

Hillslope
e% Ü f% Ü g% Ü h% Ü i%
represents samples taken along a hillslope, where the uppermost sample has i% finer than 63 mm and the lowest sample has e% finer than 63 mm

k% represents a sample of material deposited adjacent to the channel, which is k% finer than 63 mm

j% represents a sample of potential source sediment from the channel walls, which is j% finer than 63 mm

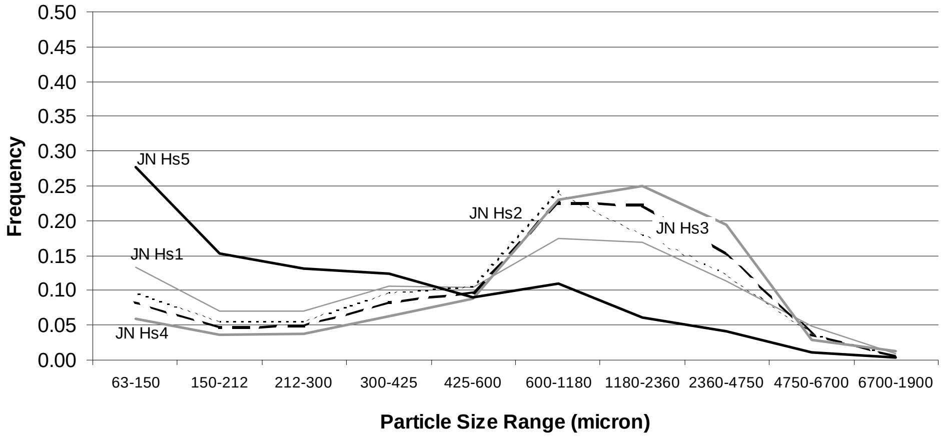


Fig. 5.16. Summary of hillslope particle size (mm) histograms for Site JN. Location ‘1’ represents the top of the slope and location ‘5’ is in the footslope.

which is consistent with fines being eroded from higher up the slope and being redistributed down the slope, with the greatest amount of deposition occurring at the toe of the slope.

These findings suggest that sediment less than 63 mm in size is being moved off some hillslopes in the Creightons Creek catchment. It may have been trapped high up in the catchment in the past (i.e. on floodplain/swampy meadow areas prior to incision) but is probably now being moved downstream, and either out onto the Riverine Plain (during high flow periods) or into the Goulburn River. However, the volume of material being removed from the upper catchment is not expected to be large.

5.3.2. Histogram comparison

It is important to recognise that abrasion (see Section 3.3.3) could be partially responsible for some of the potential source–sink relationships examined here. If abrasion has been an important process in producing downstream (or downslope) fining then the system’s ability to transport material, as identified here, is less than predicted.

As was stated in the methods section, histogram comparisons were only carried out for adjacent samples. Histograms were compared within groups (e.g. all the hillslope sample histograms taken on John Nielsen’s property (JNHs) were compared), but then group trends between adjacent sites were also compared if appropriate (e.g. creek bed histogram group trends were compared, but comparisons were not made between hillslope groups). No comparisons are made within creek sites because the purpose of taking four samples at each creek site was not to investigate sediment movement at a local scale, but to get an understanding of particle size distribution (PSD) variability at a single site and so allow a more rigorous assessment of variations in PSDs along the length of the creek.

Hillslope histogram comparisons

A comparison of the particle size frequency histograms for hillslope samples taken at site JN is presented in Fig. 5.16. Inspection of Fig. 5.16 indicates that, with the exception of the lowest sample site, as one moves downslope the PSDs become coarser and better sorted. The lowest hillslope sample (JNHs 5) is, on the other hand, finer and more poorly sorted. This is consistent with material in the range 425 mm to 4.75 mm (medium–coarse sand) being eroded and redeposited downslope, while 63–425 mm (fine sand) material leaves the slope to be deposited in the footslope (JNHs 5) or transported into the stream network. The comparatively poor sorting found in the footslope might be explained by the fact that transport conditions at the footslope are completely different to the upslope sites, i.e. this area may store all the material derived from upslope, and possibly some material derived from upstream.

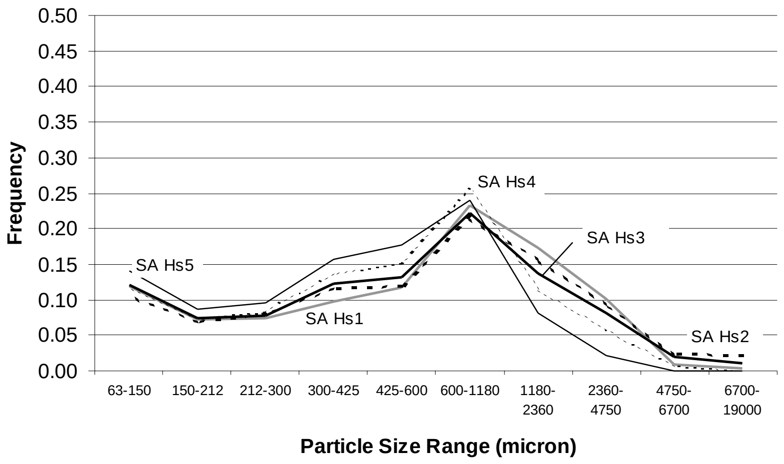


Fig. 5.17. Summary of hillslope particle size histograms, Site SA. Location 1 represents the top of the slope and location 5 is in the footslope

As can be seen from Fig. 5.17 the PSD histograms for hillslope samples taken at site SA are all similar in shape with the peak, or dominant size fraction (0.6–1.18 mm), remaining unchanged at all points down the slope. This could be consistent with the slope being relatively stable and little sediment movement occurring. The only change that appears to occur as one moves down the hillslope is that the relative proportion of coarse material (1.18–19 mm sediment) declines while the relative proportion of medium sand (300–600 mm) increases. One possible explanation for this observation is that medium sand is being mobilised and redeposited down the slope, while some fine sand is lost from the slope.

A comparison of PSD histograms for the hillslope at site DF (see Fig. 5.18) indicates a steady decline in the relative proportion of coarse material (1.18–19 mm) and steady increase in finer material (63 mm – 1.18 mm). Only at the base of the slope (DFHs 6) is there a substantial increase in the relative proportion of some size fractions (i.e. 63–150 mm, i .e. fine sand). These observations are consistent with fine–coarse sand being mobilised on the slope, medium–coarse sand being redeposited on the slope and fine sand being deposited in the footslope area.

Trends between creek sites

A comparison of PSD histograms along Creightons Creek was carried out by first averaging the four samples at each site to produce a single average curve for each site. A visual comparison of the average PSD histograms for each site (Fig. 5.19) appears to indicate three distinct groups of sites. The first group is made up of sites JN, SA, DF and MB. The samples from these four sites are relatively well sorted with about 80% of sediment in the size range 600 mm – 4.75 mm (coarse

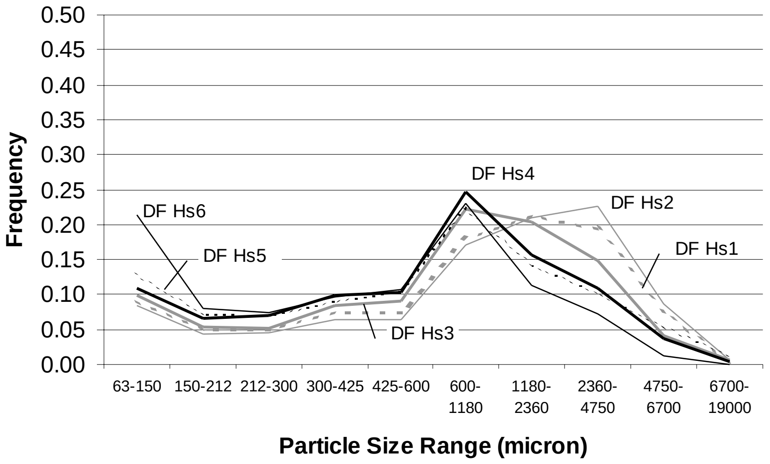


Fig. 5.18. Summary of hillslope particle size histograms — Site DF. Location '1' represents the top of the slope and location '6' is in the footslope.

sand–fine gravel). There is only one site, site SC, in the second group. Group 2 sediments are better sorted than group 1 sediments, with more than 80% of sediment falling into two sieves, the size range being 600 mm – 2.36 mm (coarse sand). The third group also consists of only one site, site LW. In comparison with groups 1 and 2, group 3 sediments are poorly sorted and finer, containing a higher proportion of material in the size range 63–600 mm (fine to medium sand).

A lack of variation in sorting and no trend in mean particle size for the four sites in group 1 is consistent with sediment at the four upstream sites (i.e. JN, SA, DF and MB, which are above the Hume Freeway) being derived predominantly from a local source. On the other hand, sediment at site SC could be derived from upstream because it is better sorted and finer than upstream sediment samples. Sediment at LW is poorly sorted and so could be locally derived.

5.3.3. Coarse fraction method

Results from dry sieving indicated that no samples contained particles with an equivalent diameter greater than 19 mm. However, a number of samples were found to contain particles with an equivalent diameter greater than 6.7 mm. All creek bed samples, except those taken downstream of the Longwood–Pranjip Rd, were found to contain particles greater than 6.7 mm in diameter (i.e. JNck 1–4, SAck 1–4 and DFck 1–4), as did three bank samples (JN Bank, SA Bank A and B) and most of the hillslope samples (JNHs 1–5, SAHs 1–3 and DFHs 1–5).

Several broad conclusions can be drawn from these results.

1. Particles greater than 6.7 mm in diameter may have been transported down to the base of hillslopes at some sites in the catchment (i.e. JN sites) and not at other sites (i.e. SA sites, DF sites).
2. Particles greater than 6.7 mm in diameter may have been derived from bank erosion high up in the catchment (i.e. JN sites and SA sites).
3. Particles greater than 6.7 mm in diameter have not been transported as far downstream as the Longwood–Pranjip Rd.

These conclusions are consistent with the results of the analyses, but assume that the samples analysed are representative of the sites at which they were taken. A method was designed to enable representative samples to be taken, but errors related to sample sizes might have caused this assumption to be violated with respect to coarse sediments in hillslope samples. Where coarse particles were observed in the field, larger samples were taken (as described in the method), but large particles were not observed during sampling on hillslopes and thus the samples taken were smaller than were needed. The effect of this potential source of error is that samples taken at hillslope sites where particles greater than 6.7 mm in diameter are present may not have contained particles greater than 6.7 mm in diameter. Observations made when sampling was carried out

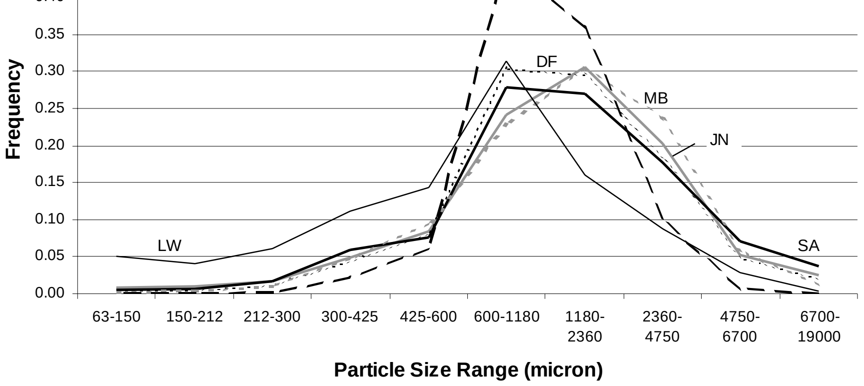


Fig. 5.19. Summary of average creek bed histograms

suggest that although this error could have influenced results at sites SAHs 4–5 it is not likely to have occurred at DFHs 6. Nevertheless, it can be concluded that coarse material in Creightons Creek may have originated from some hillslopes and/or stream banks in the headwaters of the catchment; this material is not, however, transported downstream beyond the Longwood–Pranjip Road.

5.3.4. McLaren technique

The mean, standard deviation and skewness of the particle size distributions of samples taken throughout the Creightons Creek catchment were compared as described in the method, and a matrix was produced (Fig. 5.20). The sites listed across the top of the matrix are possible sources and the sites listed down the side of the matrix are potential sinks. Cells are left blank where a relationship is impossible (e.g. SAck 1 as a source for JNck 1). Where one of the two possible trends is detected, Case 1 or Case 2 is recorded; otherwise a cross (X) is registered.

From the matrix a list of possible source–sink relationships was prepared (Table 5.1).

Table 5.1. Possible source–sink relationships

Hillslope sources	*Store sources*
JNHs1 $\Rightarrow$ 2 $\Rightarrow$ 3 $\Rightarrow$ 4	JN Bk $\Rightarrow$ SA Bk, JN Dr, JNck1–4
SAHs1 $\Rightarrow$ 2 $\Rightarrow$ 4 $\Rightarrow$ 5	SA PSA $\Rightarrow$ SAck2–4, DF Dr
DFHs1 $\Rightarrow$ 2 $\Rightarrow$ 3 $\Rightarrow$ 4; DFHs5 $\Rightarrow$ 6	DF Bk $\Rightarrow$ DFck1–4, DF Dr
JNHs1–5 $\Rightarrow$ JNck1–4	DF Dr $\Rightarrow$ SC Dr
SAHs1–5 $\Rightarrow$ SAck1–4	MB Bk $\Rightarrow$ MBck1–4, MB Dr, SC Dr
DFHs1–6 $\Rightarrow$ DFck2,3; DFHs4–6 $\Rightarrow$ DFck2	SC Bk $\Rightarrow$ SCck1,3,4, SC Dr
JNHs1–4, SA1–5 $\Rightarrow$ SA PSA	
Creek sources	
JNck1–4 $\Rightarrow$ SAck1–4	
SAck1–4 $\Rightarrow$ DFck1,2	
DFck1–4 $\Rightarrow$ MBck1–3	
MBck1–4 $\Rightarrow$ SCck1_4	

Four main points can be drawn out of the data presented in Table 5.1.

1. Downslope movement of hillslope material is indicated for all three hillslope sites.
2. Hillslope material could have contributed sediment to the nearby creek bed, although another source may be indicated for one of the samples taken at site DF.
3. Local bank sources could have contributed sediment to all creek bed and bank drape samples, although another source may be indicated for one of the samples taken at site SC.
4. With the exception of site LW, upstream creek beds could be the source of sediment for downstream creek bed sites, although another source may be indicated for some of the samples taken at site DF and MB.

As was noted in Section 3.3.3, the presence of aggregates can confound the results of the McLaren analysis, and therefore dispersant was used to break up aggregates. However, it was observed during dry sieving that some aggregates were still present. While the presence of some aggregates can create difficulties with regard to assessing the actual type or size of material sampled (e.g. clay or silt material can appear to be fine sand), it might not necessarily be an error in the application of the McLaren technique for this project. If aggregates do not break down in the laboratory when dispersant is added it seems unlikely that these aggregates would break down in the field during transport. Since we wish to use the McLaren technique to provide information about transport processes it may be appropriate that the aggregates remain aggregated during analysis. Without a

Fig. 5.20. McLaren technique: matrix for comparison of particle size distributions

	Source							
Sink	**JNA**	**JNB**	**JNC**	**JND**	**JNE**	**SA1**	**SA2**	**SA3**
JNA		X	X	X	X			
JNB	X		X	X	X			
JNC	X	X		X	X			
JND	X	X	X		X			
JNE	Case 2	X	X	X				
SA1							Case 2	Case 2
SA2						Case 2		Case 2
SA3						X	X	
SA4						X	X	Case 2
SA5						X	X	X
DF1								
DF2								
DF3								
DF4								
DF5								
DF6								
JN Bank	Case 2	X	X	X	X			
JN Drape u	Case 2	X	X	X	X			
JN Drape d	Case 1	X	X	X	X			
SA Bank A	Case 2	X	X	X	X	X	Case 2	X
SA Bank B	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
SA PSA	X	X	X	X	X	X	X	X
DF Bank	X	X	X	X	X	X	X	X
DF Drape	Case 2	X	X	X	X	X	Case 2	X
MB Bank	Case 2	Case 1	Case 1	Case 1	X	Case 2	Case 2	Case 2
MB Drape	X	X	X	X	Case 2	X	X	X
SC Bank	X	Case 1	Case 1	Case 1	X	X	X	X
SC Drape	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1
JNck1	X	X	Case 1	Case 1	X			
JNck2	Case 2	Case 2	Case 2	X	Case 2			
JNck3	Case 2	Case 2	Case 2	Case 2	Case 2			
JNck4	Case 2	Case 2	Case 2	X	Case 2			
SAck1	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
SAck2	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
SAck3	Case 2	X	X	X	Case 2	X	Case 2	Case 2
SAck4	Case 2	X	X	X	Case 2	X	Case 2	Case 2
DFck1	Case 2	X	X	X	Case 2	Case 2	Case 2	Case 2
DFck2	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
DFck3	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
DFck4	X	X	X	X	Case 2	X	X	X
MBck1	Case 2	X	X	X	Case 2	Case 2	Case 2	Case 2
MBck2	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
MBck3	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
MBck4	Case 2	X	X	X	Case 2	Case 2	Case 2	Case 2
SCck1	Case 2	X	X	X	Case 2	Case 2	Case 2	Case 2
SCck2	X	X	X	X	Case 2	X	X	X
SCck3	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
SCck4	X	X	X	X	Case 2	X	X	X
LW1	Case 2	Case 2	X	X	Case 2	Case 2	Case 2	Case 2
LW2	Case 2	Case 2	X	X	Case 2	Case 2	Case 2	Case 2
LW3	Case 2	Case 2	X	X	Case 2	Case 2	Case 2	Case 2

Fig. 5.20. McLaren technique: matrix for comparison of particle size distributions, continued

	Source							
Sink	**SA4**	**SA5**	**DF1**	**DF2**	**DF3**	**DF4**	**DF5**	**DF6**
JNA								
JNB								
JNC								
JND								
JND								
SA1	X	X						
SA2	Case 2	X						
SA3	X	X						
SA4		X						
SA5	X							
DF1				Case 1	Case 1	Case 1	Case 1	Case 2
DF2			Case 1		Case 1	Case 1	X	Case 2
DF3			Case 1	Case 1		Case 1	X	X
DF4			X	X	X		Case 2	Case 2
DF5			Case 2	X	X	X		Case 2
DF6			Case 1	Case 1	X	X	Case 2	
JN Bank								
JN Drape u								
JN Drape d								
SA Bank A	X	X						
SA Bank B	Case 2	Case 2						
SA PSA	Case 2	Case 2						
DF Bank	X	X	X	X	X	X	X	X
DF Drape	X	X	Case 1	Case 1	Case 1	X	Case 2	Case 2
MB Bank	Case 2	Case 2	Case 1	Case 1	Case 1	Case 2	Case 2	Case 2
MB Drape	X	X	X	Case 1	X	X	X	X
SC Bank	X	X	Case 1	Case 1	Case 1	Case 1	X	X
SC Drape	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1
JNck1								
JNck2								
JNck3								
JNck4								
SAck1	Case 2	Case 2						
SAck2	Case 2	Case 2						
SAck3	X	Case 2						
SAck4	Case 2	Case 2						
DFck1	Case 2	Case 2	X	X	X	Case 2	Case 2	Case 2
DFck2	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
DFck3	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
DFck4	X	X	X	X	X	X	X	X
MBck1	Case 2	Case 2	X	X	X	Case 2	Case 2	Case 2
MBck2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2	Case 2
MBck3	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
MBck4	Case 2	Case 2	X	X	X	Case 2	Case 2	Case 2
SCck1	Case 2	Case 2	X	X	X	Case 2	Case 2	Case 2
SCck2	X	X	X	X	X	X	X	X
SCck3	Case 2	Case 2	Case 2	X	Case 2	Case 2	Case 2	Case 2
SCck4	X	X	X	X	X	X	X	Case 2
LW1	Case 2	Case 2	X	X	Case 2	Case 2	Case 2	Case 2
LW2	Case 2	Case 2	X	X	X	Case 2	Case 2	Case 2
LW3	Case 2	Case 2	X	X	Case 2	Case 2	Case 2	Case 2

Fig. 5.20. McLaren technique: matrix for comparison of particle size distributions, continued

	Source							
Sink	**JN Bank**	**JN Drape u**	**JN Drape d**	**SA Bank A**	**SA Bank B**	**SA PSA**	**DF Bank**	**DF Drape**
JNA								
JNB								
JNC								
JND								
JNE								
SA1								
SA2								
SA3								
SA4								
SA5								
DF1								
DF2								
DF3								
DF4								
DF5								
DF6								
JN Bank		X	X					
JN Drape u	X		X					
JN Drape d	X	X						
SA Bank A	X	X	X		X	X		
SA Bank B	Case 1	X	X	X		Case 2		
SA PSA	Case 1	X	X	X	X			
DF Bank	X	X	X	X	X	X		X
DF Drape	Case 1	X	X	Case 1	X	X	X	
MB Bank	Case 1	X	X	Case 1	X	X	X	X
MB Drape	Case 1	X	X	Case 1	X	X	X	X
SC Bank	Case 1	Case 1	X	Case 1	Case 1	Case 1	Case 1	X
SC Drape	Case 1	Case 1	X	Case 1	Case 1	Case 1	Case 1	X
JNck1	Case 1	Case 1	Case 1					
JNck2	Case 1	X	X					
JNck3	Case 2	Case 2	Case 2					
JNck4	Case 1	X	X					
SAck1	Case 2	Case 2	X	Case 2	Case 2	Case 2		
SAck2	Case 1	X	X	Case 1	Case 2	Case 2		
SAck3	Case 1	X	X	Case 1	X	X		
SAck4	Case 1	X	X	X	Case 2	X		
DFck1	X	X	X	X	Case 2	Case 2	Case 2	X
DFck2	Case 1	Case 1	X	Case 1	Case 2	Case 2	Case 2	Case 2
DFck3	Case 1	X	X	X	Case 2	Case 2	Case 2	Case 2
DFck4	Case 1	X	X	X	X	X	Case 2	Case 2
MBck1	Case 1	X	X	X	Case 2	Case 2	Case 2	Case 2
MBck2	Case 1	X	X	X	Case 2	Case 2	Case 2	Case 2
MBck3	Case 1	X	X	X	Case 2	Case 2	Case 2	Case 2
MBck4	Case 1	Case 1	X	Case 1	Case 2	X	Case 2	Case 2
SCck1	Case 1	X	X	X	Case 2	X	Case 2	Case 2
SCck2	Case 1	X	X	X	X	X	Case 2	Case 2
SCck3	Case 1	X	X	X	Case 2	Case 2	Case 2	X
SCck4	Case 1	Case 1	X	Case 1	X	X	Case 2	Case 2
LW1	Case 1	X	X	X	Case 2	Case 2	Case 2	Case 2
LW2	Case 1	X	X	Case 1	Case 2	Case 2	Case 2	Case 2
LW3	Case 1	Case 1	X	Case 1	Case 2	Case 2	Case 2	Case 2

Fig. 5.20. McLaren technique: matrix for comparison of particle size distributions, continued

	Source							
Sink	**MB Bank**	**MB Drape**	**SC Bank**	**SC Drape**	**JNck1**	**JNck2**	**JNck3**	**JNck4**
JNA								
JNB								
JNC								
JND								
JNE								
SA1								
SA2								
SA3								
SA4								
SA5								
DF1								
DF2								
DF3								
DF4								
DF5								
DF6								
JN Bank					X	X	X	X
JN Drape u					X	X	X	X
JN Drape d					X	X	X	X
SA Bank A					X	X	X	X
SA Bank B					X	X	X	Case 2
SA PSA					X	Case 1	X	X
DF Bank					X	X	X	X
DF Drape					X	X	X	X
MB Bank		X			X	X	X	X
MB Drape	X				X	X	X	X
SC Bank	Case 2	X		X	X	X	X	Case 1
SC Drape	X	X	Case 1		X	X	X	Case 1
JNck1						Case 1	Case 1	X
JNck2					X		X	X
JNck3					Case 2	X		Case 2
JNck4					X	X	X	
SAck1					Case 2	X	Case 2	Case 2
SAck2					X	X	X	Case 2
SAck3					X	X	X	X
SAck4					X	X	X	Case 2
DFck1					X	X	X	Case 2
DFck2					X	Case 1	Case 1	X
DFck3					X	Case 1	Case 2	Case 2
DFck4					Case 1	X	X	X
MBck1	Case 2	X			X	Case 1	X	Case 2
MBck2	Case 2	X			X	X	X	Case 2
MBck3	Case 2	X			Case 1	X	X	Case 2
MBck4	Case 2	X			Case 1	X	X	X
SCck1	Case 2	X	X	X	Case 1	X	X	Case 2
SCck2	Case 2	X	X	X	Case 1	Case 1	X	X
SCck3	Case 2	X	X	X	X	X	X	Case 2
SCck4	Case 2	X	Case 1	Case 1	Case 1	Case 1	Case 1	Case 1
LW1	Case 2	Case 2	X	Case 1	Case 1	Case 1	X	Case 2
LW2	Case 2	X	Case 1	Case 1	Case 1	Case 1	X	Case 2
LW3	Case 2	Case 2	Case 1	Case 1	Case 1	Case 1	Case 1	Case 2

Fig. 5.20. McLaren technique: matrix for comparison of particle size distributions, continued

	Source									
Sink	**SAck1**	**SAck2**	**SAck3**	**SAck4**	**DFck1**	**DFck2**	**DFck3**	**DFck4**	**MBck1**	**MBck2**
JNA										
JNB										
JNC										
JND										
JNE										
SA1										
SA2										
SA3										
SA4										
SA5										
DF1										
DF2										
DF3										
DF4										
DF5										
DF6										
JN Bank										
JN Drape u										
JN Drape d										
SA Bank A	X	X	X	X						
SA Bank B	X	X	X	X						
SA PSA	X	X	X	X						
DF Bank	X	X	X	X	X	X	X	X		
DF Drape	X	X	X	X	X	X	X	X		
MB Bank	X	X	X	X	X	X	X	X	X	X
MB Drape	X	X	X	X	X	X	X	X	X	X
SC Bank	Case 1	Case 1	X	X	X	X	X	X	X	X
SC Drape	Case 1	Case 1	X	X	X	X	X	X	X	X
JNck1										
JNck2										
JNck3										
JNck4										
SAck1		X	X	X						
SAck2	X		X	X						
SAck3	X	X		X						
SAck4	X	Case 1	X							
DFck1	X	X	X	X		X	X	X		
DFck2	X	X	X	X	X		Case 1	X		
DFck3	X	X	Case 2	X	X	X		X		
DFck4	Case 1	Case 1	X	X	X	X	X			
MBck1	Case 2	Case 1	X	X	Case 2	X	X	X		Case 2
MBck2	X	X	X	X	Case 2	X	X	Case 2	Case 2	
MBck3	X	X	X	X	X	X	X	X	X	X
MBck4	X	Case 1	X	X	X	X	X	Case 1	X	X
SCck1	X	Case 1	X	X	Case 2	X	Case 1	Case 1	Case 2	X
SCck2	Case 1	Case 1	X	X	X	Case 1	X	X	X	X
SCck3	X	X	X	X	X	X	X	X	X	X
SCck4	Case 1	Case 1	X	Case 1	X	Case 1	Case 1	Case 1	X	Case 1
LW1	X	X	X	X	Case 2	X	X	X	Case 2	Case 2
LW2	X	X	X	Case 1	X	X	Case 1	Case 1	Case 2	X
LW3	X	X	X	Case 1	X	X	Case 1	Case 1	Case 2	X

Fig. 5.20. McLaren technique: matrix for comparison of particle size distributions, continued

	Source								
Sink	**MBck3**	**MBck4**	**SCck1**	**SCck2**	**SCck3**	**SCck4**	**LW1**	**LW2**	**LW3**
JNA									
JNB									
JNC									
JND									
JNE									
SA1									
SA2									
SA3									
SA4									
SA5									
DF1									
DF2									
DF3									
DF4									
DF5									
DF6									
JN Bank									
JN Drape u									
JN Drape d									
SA Bank A									
SA Bank B									
SA PSA									
DF Bank									
DF Drape									
MB Bank	X	X							
MB Drape	X	X							
SC Bank	X	Case 1	X	X	X	X			
SC Drape	X	X	X	X	X	X			
JNck1									
JNck2									
JNck3									
JNck4									
SAck1									
SAck2									
SAck3									
SAck4									
DFck1									
DFck2									
DFck3									
DFck4									
MBck1	X	X							
MBck2	X	X							
MBck3		Case 1							
MBck4	X								
SCck1	X	Case 1		X	X	X			
SCck2	X	X	X		X	X			
SCck3	X	X	X	X		X			
SCck4	X	Case 1	X	Case 1	Case 1				
LW1	X	X	X	X	X	X		Case 2	X
LW2	X	Case 1	X	Case 1	X	X	X		X
LW3	X	Case 1	X	Case 1	X	X	X	Case 2	

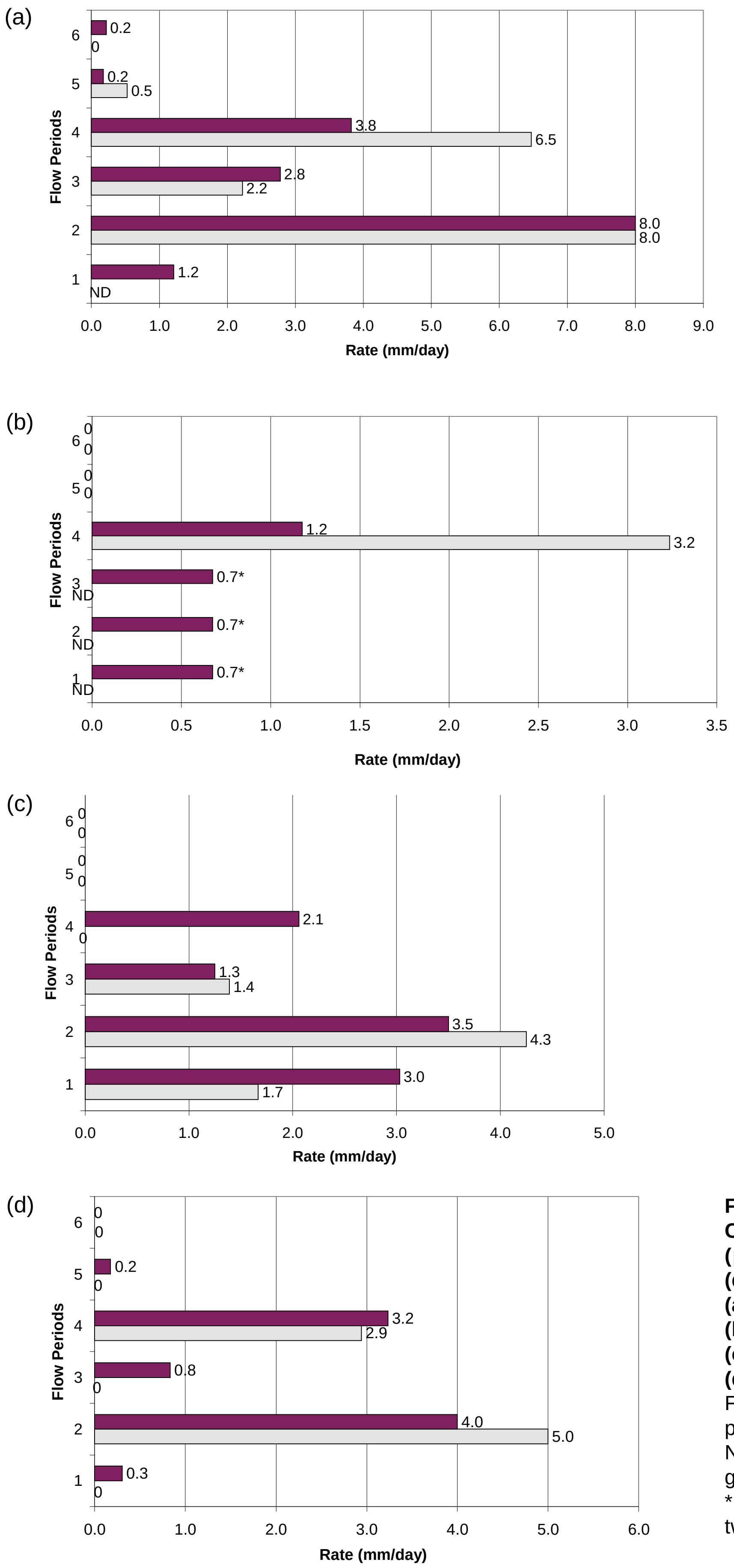


Fig. 5.21. Scour chain data for Castle Creek, showing scour (pale bars) and deposition (dark bars) in mm/day:
(a) Bamford Chain 1;
(b) Bamford Chain 2;
(c) Kubeil Chain 1;
(d) Kubeil Chain 2.
For a description of flow periods 1–6 see Table 5.2.
ND indicates no data for the given period.
* indicates rate averaged over two or more periods.

specific investigation it is difficult to determine the impact aggregates may have had on the outcome of the McLaren analysis, in fact it is only possible to say that the presence of such aggregates may or may not affect the results, and as a consequence the results of the McLaren analysis must be cross-checked with results from other techniques.

5.4. Scour chains

The raw data derived from the monitoring of scour chains placed in the beds of Castle, Creightons and Pranjip–Nine Mile Creeks are presented in Appendix C. The data show change in depth (scour and deposition) for each chain over each monitoring period. To assist with interpretation the data are also presented in Figs 5.21, 5.22 and 5.23 as well as Table 5.3, in a different form. The data presented in Figs 5.21, 5.22 and 5.23 represent the change in depth for each chain (scour and deposition) and each period, averaged over the length of the monitoring period to give a rate of change in mm/day. This removes the influence of monitoring period length and allows the data to be compared more readily. In Table 5.3 the changes in depth for each chain for each period have been added together to give a total change in depth (scour and deposition) for each chain for the entire monitoring period.

The scour chains were inserted in late July (Nine Mile Creek) and early August 1998 (Castle Creek and Creightons Creek) and were checked six times, the last check taking place in mid-May 1999. Thus changes were monitored over six different sets of flow conditions. Official stream gauging data applicable to the three catchments were not available for this period, so other sources of information were used to identify flow conditions during each period. Sources of information included rainfall at the head of Creightons Creek (data collected by a local landholder), flow depths recorded at half-hourly intervals in Creightons Creek at the Carlsson’s property (recorder installed 15/9/98) and observations of flow depths by the authors. These data were then used to roughly identify flow conditions during each of the six monitoring periods (Table 5.2).

Table 5.2. Estimated flow conditions for the six flow periods

Period	Rainfall and flow observations	Description of flow conditions
Period 1 8/98–15/9/98	*Nine Mile Ck:* chains were inserted at the tail end of an event *Castle & Creightons Ck:* low rainfall totals	*Nine Mile Ck:* falling limb of an event and winter baseflow *Castle & Creightons Ck:* winter baseflow
Period 2 15/9/98–5/10/98	During this period there were two significant rainfall events, the first on the 22–23/9 and the second on 3/10, that led to near bankfull flows in some areas	Possibly annual events*
Period 3 5/10/98–10/11/98	No significant rainfall totals during the period, but rainfall from the previous period produced a small event on 6/10	Small event and spring baseflow
Period 4 10/11/98–14/12/98	During this period there was a significant rainfall event on the 11–13/11, that led to bankfull flows in some areas	Possibly an annual event*
Period 5 14/12/98–9/2/99	No significant rainfall totals and baseflow indicated	Summer baseflow
Period 6 9/2/99–11/5/99	Several small rainfall events, but catchment so dry there was no real increase in discharge. Baseflow indicated.	Summer–autumn baseflow

* Description as an annual event is not based on flow data, because there are no gauge data; instead it is based on anecdotal evidence that flows of this size occur at least once a year.

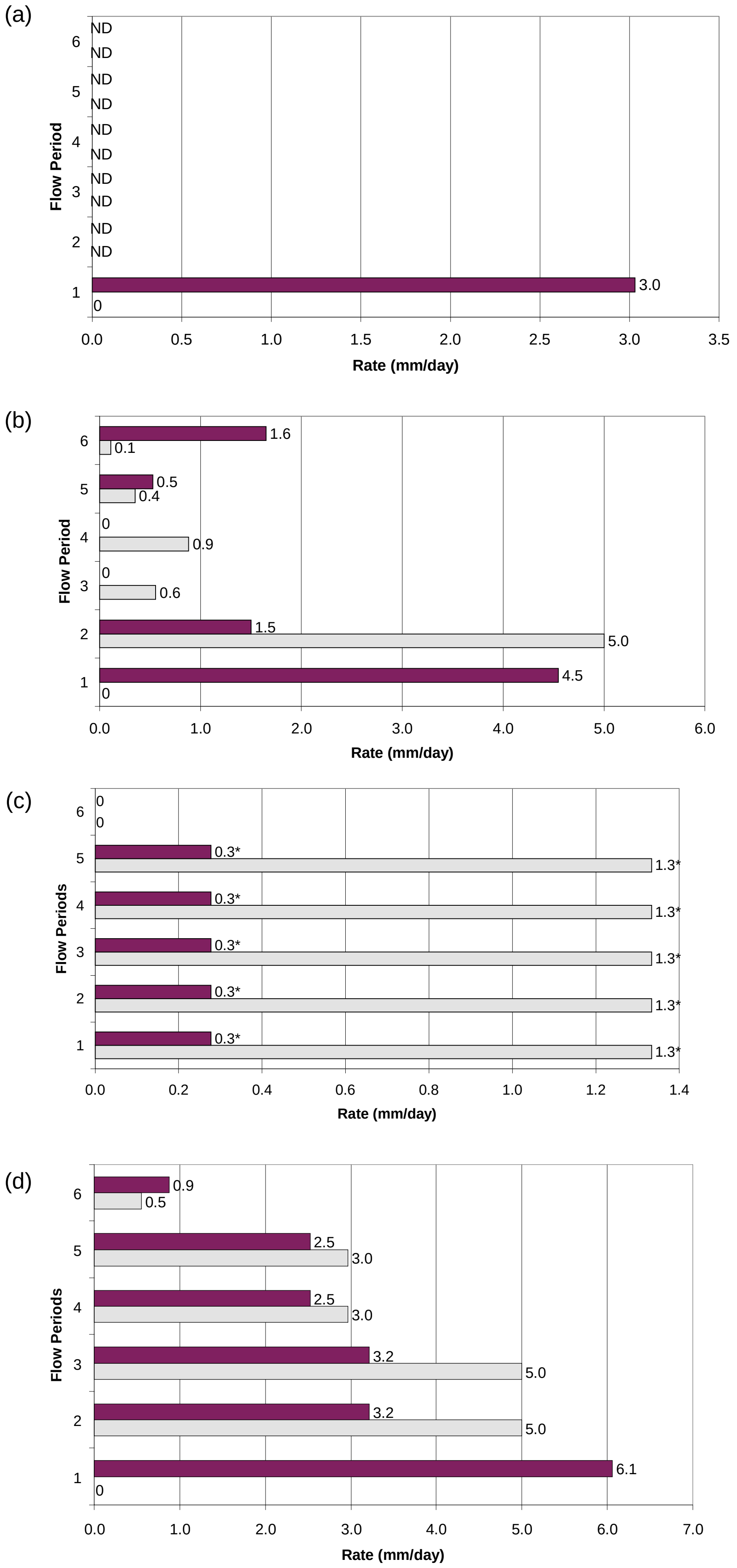


Fig. 5.22. Scour chain data for Creightons Creek, showing scour (pale bars) and deposition (dark bars) in mm/day:
(a) Carlsson Chain 1,
(b) Carlsson Chain 2,
(c) Caldwell Chain 1,
(d) Caldwell Chain 2.
For a description of flow periods 1–6 see Table 5.2. ND means no data collected for the given period.
* indicates rate averaged over two or more periods.

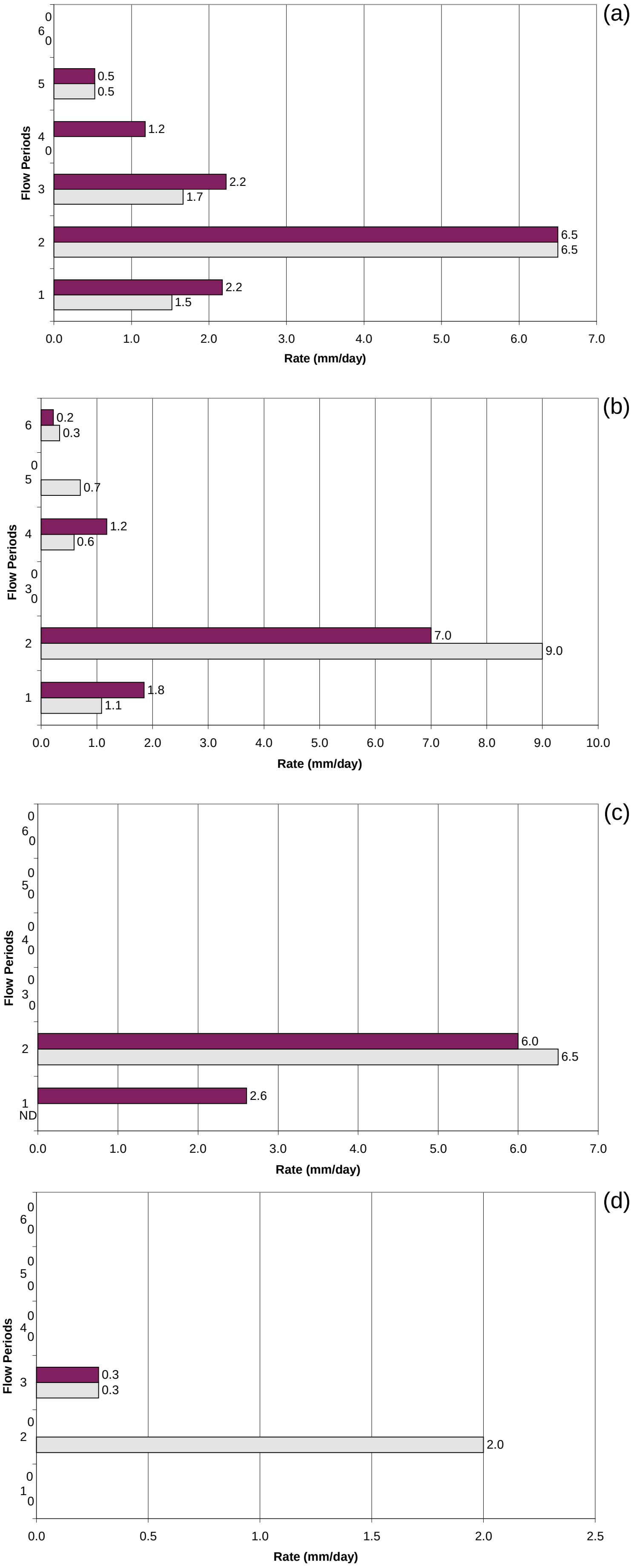


Fig. 5.23. Scour chain data for Nine Mile Creek, showing scour (pale bars) and deposition (dark bars) in mm/day:
(a) Cameron Chain 1,
(b) Cameron Chain 2,
(c) Threlfall Chain 1,
(d) Threlfall Chain 2.
For a description of flow periods 1–6 see Table 5.2. ND means no data collected for the given period. * indicates rate averaged over two or more periods.

Table 5.3. Total change in bed elevation

Creek	Site	Chain 1	Chain 2	Description
Castle Ck	Bamford	–7 cm*	–7 cm*	minor scour
	Kubeil	+9.5 cm	+3cm	minor deposition
Creightons Ck	Carlsson	NL	+18 cm	possibly moderate deposition
	Caldwell	–19 cm	+9cm	minor deposition and moderate scour
Nine Mile Ck	Cameron	+9 cm	–3.5 cm	no change to minor deposition
	Threlfall	–1 cm*	–4 cm	no change

*Totals calculated by ignoring periods where there was an error; NL signifies chain not located.

The information presented in Table 5.2 indicates that scour chain observations made for periods 2 and 4 could be related to flow events, while observations made for period 1 (Castle and Creightons Creek) could be related to winter baseflow and observations for periods 5 and 6 could be related to summer–autumn baseflow.

As expected, all the scour chain graphs for which there are sufficient data (Figs 5.21a,b,c; Figs 5.22b,d; Figs 5.23a,b) suggest that greater scour and deposition occur during flow events than during periods of baseflow. Depending on the creek and the location of the scour chain in the channel, scour of between 10 and 25 cm was observed following flow events (Appendix C), with 0–5 cm of scour observed under winter–spring baseflow and 0–3 cm observed under summer–autumn baseflow. Quite often deposition levels were similar to scour levels (i.e. the ratio of deposition to scour was 100%) over a period, but ratios as low as 0% and as high as 180% were also observed (Appendix C).

As expected, there were substantial variations in the relative amounts of scour and deposition, both within a site and within a creek. One example of intra-site variation comes from Castle Creek (Appendix C) where, following period 4, scour of 0 cm and 10 cm with deposition of 7 cm and 11 cm was observed at one site (Kubeil). A second example comes from Nine Mile Creek (Appendix C) where, following period 3, scour of 6 cm and 0 cm with deposition of 8 cm and 0 cm was observed at the one site (Cameron). There was no clear pattern of major or minor scour and deposition in the channel. In some instances scour and deposition were largest in or adjacent to the low flow channel; at other sites and at other times scour and deposition were higher away from the low flow channel.

Intra-creek variation is illustrated by the depth of total change over the measurement period given in Table 5.3. The table shows that scour and deposition and consequent changes in bed elevations can vary from site to site along a creek, at least in the short term.

Table 5.3 also shows that while scour of 25–30 cm and deposition of 20–30 cm may occur as a result of flow events, over the short term at least there is relatively little impact on bed elevations. Nevertheless these results may be indicating that during flow events the top 20–30 cm of the streambed is being mobilised and significant sand transport taking place. While the depth of sand mobilised during winter–spring baseflow is not as great as during flow events (i.e. ~5 cm, cf. 20–30 cm) the length of time over which winter–spring baseflow persists is such that it may transport substantial volumes of sand and thus be of similar significance, with regard to sand transport volumes, as flow events.

5.5. Bedload sampling

Bedload sampling was carried out at two sites on Creightons Creek. Sampling was conducted on Stan Artridge’s property (SA) six times between September 1998 and February 1999 and four times on Maurie Brodie’s property (MB, shown as MB1 on Fig. 2.1) between October 1998 and February 1999. At each sampling time, discharge was measured and the total volume of bedload

Table 5.4. Bedload data for Creightons Creek

Date	Site	Discharge (L/s)	Bedload trans. rate (kg/hr)	Flow description
14/09/98	SA	106	41	spring baseflow
05/10/98	SA	172	72–84	spring baseflow
19/10/98	MB	432	130–320	spring baseflow
19/10/98	SA	126	30–137	spring baseflow
13/11/98	MB	1140	390–490	falling limb of an event
13/11/98	SA	170	90–135	falling limb of an event
14/12/98	MB	91	55–63	early summer baseflow
14/12/98	SA	43	5	early summer baseflow
13/02/99	MB	est. 15	0	late summer baseflow
13/02/99	SA	est. 5	0	late summer baseflow

movement was determined. Some of the bedload samples were dry sieved. These results and observations of dune movement are discussed at the end of this section.

5.5.1. *Bedload transport rates*

The data collected during bedload sampling at Creightons Creek are presented in Table 5.4; they include approximate flow conditions at the time, based on rainfall data, flow depth records measured on the Carlsson's property and observations made by the authors in the field. As was the case for analysing the scour chain data it was considered useful to know qualitatively what the relative flow conditions were in Creightons Creek at the time of bedload sampling, e.g. baseflow condition, rising limb of a flow hydrograph. Such information enables a better understanding of the relevance of the bedload data measured on a particular day.

The bedload transport rate data for both sites are plotted against discharge in Fig. 5.24. Where a maximum and minimum bedload was measured at a site, both values are plotted. The data presented in Fig. 5.24 indicate that within the range of events sampled (baseflow and the falling limb of a small event) the bedload transport rate appears to increase linearly with discharge. Bedload transport rates are also controlled by bed slope. At site SA the relationship is steeper, indicating bedload transport rates increase at a faster rate with discharge, compared with site MB where the bed slope is lower.

A relationship showing that bedload transport rates increase with discharge is not surprising and in fact would probably have been predicted. Bedload samples were not, however, taken during the

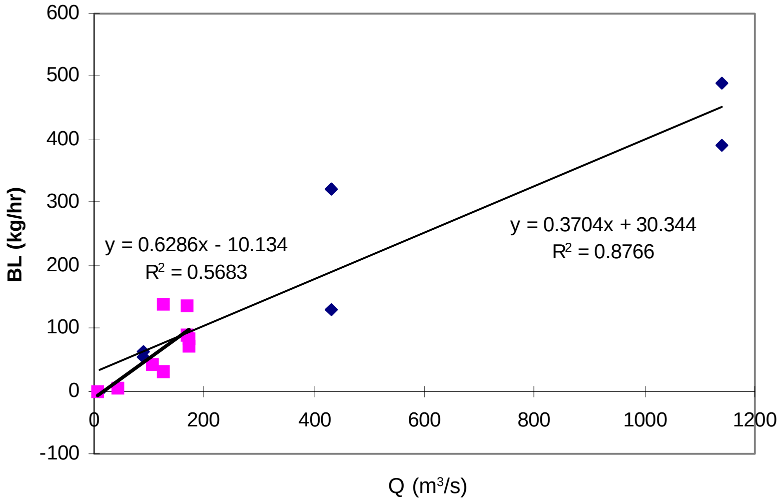


Fig. 5.24. Bedload (BL) transport rates vs. discharge (Q):
■ = SA, ◆ = MB
▬ = line of best fit (SA)
— = line of best fit (MB)

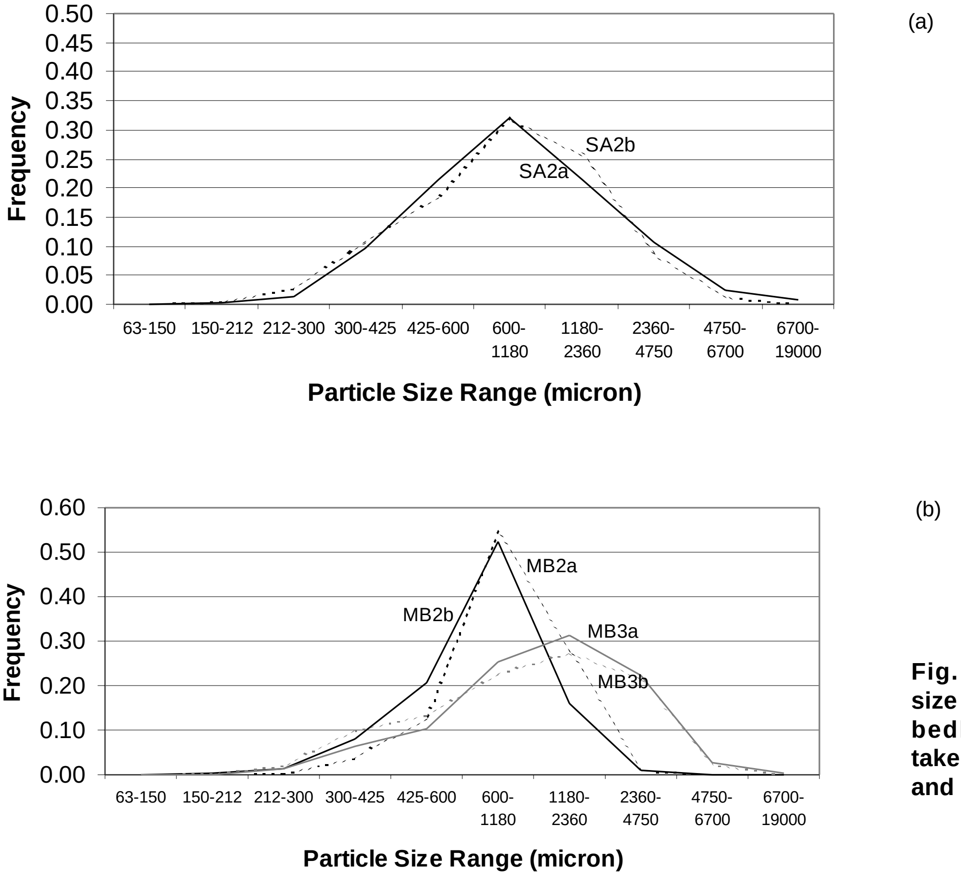


Fig. 5.25. Particle size distributions of bedload samples taken at (a) site SA and (b) site MB

rising limb or peak of a flow hydrograph, nor was a large event sampled and consequently it is not possible to say anything about bedload transport rates during periods when transport rates would be expected to be at their peak. The collected data, nonetheless, provide us with important information about bedload transport during low flows. Bedload transport rates during baseflows in late summer were negligible, but bedload transport rates were quite high during spring (30–140 kg/hr at site SA and 130–320 kg/hr at site MB). Because of a lack of bedload event data and discharge data, as well as the errors associated with bedload measurement, it is neither possible nor appropriate to estimate the relative contribution made by baseflow to overall bedload transport. However, the data collected in Creightons Creek suggest that baseflow, particularly in winter and spring may make a substantial contribution to bedload transport.

5.5.2. Particle size distributions

Bedload samples taken at sites SA and MB (site MB1 on Fig. 2.1) on the 19/10/98 were dry sieved and the particle size distributions (PSDs) were compared. The results of the dry sieve analysis are presented graphically in Figs 5.25a, b. The numbering of the bedload samples relates to the sampling location along the cross-section. When bedload sampling was conducted an appropriate cross-section was selected and split into several segments which were numbered consecutively across the section. The cross-sections sampled at SA and MB were both split into four segments. The samples taken at segments 1 and 4 at site MB were very small (<10 g) and were not dry sieved. The samples taken at segments 2 and 3 at site MB, on the other hand, were large (>0.5 kg) and so the segments were sampled twice, to give samples MB2a, MB2b, MB3a and MB3b. At site SA samples taken at segments 1, 3 and 4 were small, consequently only two samples (SA2a and SA2b) were sieved.

Despite large variations in the mass of material collected at a given site on a cross-section the particle size distributions of the bedload samples are distinctly similar (Figs 5.25a, b). This

Fig. 5.26. An example of dune formation observed on Castle, Creightons and Pranjip–Nine Mile Creeks at various times

observation suggests that at a given site on a cross-section, under a steady discharge, particle size distributions are consistent regardless of variations in the rate of bedload transport. However, a comparison of particle size distributions taken at different sites on a cross-section under the same discharge indicates that particle size distributions can vary significantly across the bed (Fig 5.25b).

5.5.3. Dune movement

Dune formation was observed on many occasions in the sanded sections of Castle, Creightons and Pranjip–Nine Mile Creek, in both high and baseflow conditions (e.g. Fig. 5.26). Dune movement was monitored on one occasion at site MB following a bedload sampling run. The dunes observed on this occasion had an amplitude of 10 cm, a wavelength of 140 cm and a period of 5 minutes. The dune sequence was also observed to cover approximately one quarter of the channel width. The implications of these observations are that during spring baseflow up to 25% of the bed scours to a depth of 10 cm and refills every 5–6 hours.

5.6. Synthesis

Combining the results of the analyses undertaken to assess current condition for the Creightons Creek catchment it is possible to arrive at a number of preliminary conclusions.

Sediment sources

The results from the particle size distribution analysis suggest that downslope movement of sediment is occurring on the hillslopes, although the patterns vary over the three hillslopes sampled. At site JN, medium to coarse sand is being mobilised and redistributed on the slope, while fine sand, silt and clay are being transported to the footslope; parts of these fractions are being moved into the stream network. At site SA the hillslope appears to be relatively stable, although some redistribution of fine–medium sand may be occurring. At site DF medium to coarse sand is being mobilised and redistributed on the slope, while fine sand, silt and clay are being transported to the footslope. The differences between the three slopes could be explained by variations in slope steepness and land management, but these results still indicate that while fine sands, silts and clay might be transported off some hillslopes in the catchment, other slopes are relatively stable. Consequently while the McLaren technique and the coarse fraction analysis both suggest that the hillslopes could be sources of material for the creek bed it seems unlikely that sufficient coarse material is being mobilised under current conditions for the hillslopes to be a significant source.

The results from the four analysis techniques for particle size distribution for the creek bed samples taken above the Longwood–Pranjip Rd suggest that these creek bed sediments have been derived from local streambanks and in-stream sources higher up in the catchment, which is consistent with the results of the sediment budget and field observations. Below the Longwood–Pranjip Rd, creek bed sediments appear to have two distinctly different sources. At site SC, creek bed sediments appear to be derived predominantly from sources upstream, whereas at site LW creek bed sediments appear to be derived from local sources. This final observation is consistent with the explanation for the pink sand found at site LW but not at other sites on Creightons Creek (see Section 5.1.2).

Field observations suggest that the main sources of sediment in the Granite Creeks systems today are bed and bank erosion, with some minor gullying. The results of the sediment budget suggest that erosion of drainage lines via stream incision and gullying, has been the main source of sediment to the Granite Creeks over the last 150 years and not just recently.

It is important to be aware that the relationships between sediment sources and sinks discussed above refer only to the present period (i.e. the last 150 years). Ultimately (i.e. on a geological time scale) all material has been derived from the hillslopes, but relationships at such a time scale are not relevant for management of the Granite Creeks today.

Movement of the sand slug

The results from the scour chains indicate that in the short term there are no clear trends in scour or deposition at any of the sites or creeks. However, the results suggest that in small annual events, scour of 25–30 cm and deposition of 20–30 cm is not unusual, while scour of up to 5 cm can occur under winter–spring baseflow. Observations of dune movement suggest that up to 25% of the streambed can be scoured to a depth of 10 cm and refilled 3–4 times a day under spring baseflow conditions.

Field observations indicate that the sand front on Creightons Creek has not moved a substantial distance over at least the last decade.

Bedload sampling did not extend to cover the rising limb or event peaks, but the results suggest that relatively high rates of sediment transport occur during the falling limb of an event as well as during spring baseflow (30–140 kg/hr in the upper reaches of the catchment and 130–320 kg/hr in the lower reaches of the catchment). These data suggest that while high flow events can transport high volumes of sediment and scour streambeds, spring baseflow can also be significant because it persists for a far longer time than an event. Therefore, in terms of volume of sediment transported and streambed stability for in-stream biota, it could be as important as, or more important than, high flow events. The incongruity of apparent high bedload transport rates and the seemingly slow migration rate of the snout of the sand slug are discussed in Chapter 6.

6. DISCUSSION OF RESULTS

6.1. Introduction

This chapter discusses the results presented in Chapters 4 and 5. This discussion specifically relates to: (i) the original objective and hypotheses, as outlined in Chapter 1; and (ii) the implications the results have for the rehabilitation of the Granite Creeks.

6.2. Objective and hypotheses

The objective being addressed by this component of the Granite Creeks project is:

> to determine the levels of sediment input into selected streams from the catchments of the Strathbogie Ranges, and the movements of such sediments within the streams.

The objective was investigated via the development of two key hypotheses:

1. that increased inputs of sediment (sand) to Strathbogie Range streams have resulted from post-settlement catchment land-use;
2. that downstream sedimentation associated with accelerated erosion, post-settlement, in the catchments is mitigated through sediment storage in the catchment slopes and tributary valleys.

Hypothesis 1

Activities associated with European settlement have caused stream incision and gullying in the catchments of the Granite Creeks which has led to severe aggradation of the middle and lower reaches of these systems. While there is evidence to suggest that incision and gullying had occurred prior to European settlement it seems likely that these were isolated episodes in response to disturbances such as bushfires. The incision and gullying that has occurred since European settlement has been widespread and synchronised across the Granite Creeks catchments.

The conclusions drawn from this project have been based on the results of analyses and assessment conducted on only a few of the Granite Creeks. However, other information (e.g. see Appendix A) and the distinctive physical characteristics (and history) of the Granite Creeks suggests that what has occurred on Castle, Creightons and Pranjip–Nine Mile Creek has probably been repeated on the other Granite Creeks.

Hypothesis 2

Storage plays an important role in mitigating sediment pulses released by accelerated erosion. Sediment can be stored at a number of locations throughout a catchment for varying periods of time before it is remobilised (e.g. from one day to hundreds of thousands of years). The effect of this storage is that pulses of sediment released by erosion can be attenuated, so that the peak of the sediment load is much lower, but the period over which levels above background levels persist is increased. Such behaviour has implications for management, particularly if sediment stores can be identified and appropriate management techniques can be applied for minimising remobilisation.

In Section 2.3 of this report the hillslope channel connectivity (HCC) values for the three Granite Creeks being studied were calculated. The HCC is effectively a measure of a catchment’s ability to store sediment and the HCC values for all three catchments indicate that, in general, sediment mobilised on hillslopes would be stored in the catchment in footslope areas. However, the sediment released in the Granite Creeks catchments over the last 150 years has been derived from drainage lines (i.e. creek beds and banks, as well as gullying) and this has tended to affect the capacity of the catchments to store and attenuate the sediment pulse.

There are two reasons for this. First, the sediment released by erosion of drainage lines is pumped directly into the stream network, by-passing important footslope stores. Second, substantial segments of the Granite Creeks have incised (particularly in the upper reaches of the catchments), so the creeks are subject to overbank flows relatively infrequently. Because overbank flows are the mechanism by which sediment is stored on floodplains, a number of floodplain stores would also have been by-passed. Consequently, the type of erosion that has occurred in the Granite Creeks catchments has reduced the accessibility of sediment stores in the upper catchment, and thus the capacity of the upper catchment to attenuate the sediment pulse.

This is not to say that there has been no storage in the catchments. In fact the majority of sediment released has been stored in the catchment, in floodplain stores that were still accessible, on the Riverine Plain, and in in-channel stores, i.e. the sand slugs (see Section 5.2). However, more sediment may have been delivered to these stores, including the sand slug, than would have occurred had the upstream erosion stores not been by-passed.

These observations imply that management needs to prevent or minimise further erosion to stop other stores being by-passed; and to protect the existing sediment stores. The storage delay times associated with stores on the riverine plain would range from thousands to hundreds of thousands of years, and so such stores are not vulnerable on a management time frame. Storage delay times associated with floodplain storage are also reasonably high and are again not likely to be vulnerable in a management time frame. Sand stored in the sand slugs is at greatest risk of mobilisation. Consequently efforts should be made to prevent mobilisation of in-stream stores by appropriate management of the riparian zone, particularly in relation to revegetation and stock access.

6.3. Implications for rehabilitation

6.3.1. Introduction

When considering the implications of the findings reported here, for the rehabilitation of the Granite Creeks, three issues require discussion: (i) control of further sand delivery to the sand slugs; (ii) the rate of migration of the sand slug; and (iii) how to improve in-stream habitat on a sand slug. Each of these issues is discussed below.

6.3.2. Minimising further sediment input

Results presented in Chapter 5 indicate that drainage lines in the Granite Creeks catchments are the main source of the sediment now forming sand slugs in the creeks. Thus any project which is developed to rehabilitate the Granite Creeks must also address the issue of minimising further sediment inputs from the drainage lines.

The analysis of historical information (Chapter 4) revealed that a number of activities or incidents appear to have contributed to the initiation of erosion heads in the past, including clearing, agriculture, channelisation, channel dredging and clearing, bushfires and droughts. Today, erosion heads are still being initiated by activities such as channel dredging and clearing, and by uncontrolled stock access to drainage lines. Thus to minimise further sediment input to the Granite Creeks, in the first instance, unauthorised activities in local streams must cease and stock access to drainage lines must be controlled. These controls require landholder cooperation, which generally can only be achieved by education. The landholders need to understand why their current activities might be detrimental and the benefits that could result (both on and off farm) if cooperation is achieved. The cost of fencing and off-stream water supplies for stock may also be a deterrent to fencing-out drainage lines, but it does not appear to be the primary obstacle.

Secondly, best practice land management techniques need to be applied throughout the Granite Creeks catchments. This approach is needed because droughts and bushfires have triggered erosion in the past; it is clearly important to maintain adequate vegetative ground cover under all conditions.

The evidence presented in Chapter 4 indicates that the upper catchment of Creightons Creek (i.e. above the Hume Freeway) may be more sensitive to disturbance than the lower catchment. This has implications for the sequence in which activities are undertaken to mitigate erosion. A surprising outcome of the discussion of possible sources of erosion heads was that one of the most significant disturbances for all the Granite Creeks, i.e. the construction of the North-Eastern Railway, appears to have produced little response in the creeks. The upper catchment, on the other hand, appears to have responded to a range of disturbances — from bushfires and droughts to clearing and stock access to streams. This variation in response can be explained by variations both in soil type and in channel slope. There is a tendency for the soils downstream of the Hume Freeway to contain a higher proportion of fines, particularly clay; so stream banks below the Freeway are probably more cohesive and therefore more resistant to erosion. Similarly, the channel slope below the Hume Freeway is low, leading to reduced stream power and hence a decreased propensity for channel erosion.

While this observation suggests that activities in the upper catchment should take priority, it is important to remember that erosion heads initiated in the lower catchment can migrate upstream some distance, so certain activities in the lower catchment may also need to be prioritised.

6.3.3. Sand slug movement

Migration of the snout

The migration of the sand slug front (or snout) downstream is threatening reaches of stream that appear, geomorphologically at least, to be in good condition. It is important to have some understanding of what is influencing the sand slug's rate of migration.

As indicated in Section 5.1.2, there is evidence to suggest that the front of the sand slug in Creightons Creek has not moved a significant distance downstream in the last decade. Yet the bedload transport rates measured in the creek suggest that even at low flow (winter–spring) there is substantial sand migration, and these rates would be expected to be substantially higher in high flow events. To reconcile these two apparently conflicting pieces of evidence, the potential of Creightons Creek to mobilise and transport sand was investigated.

Stream power (w) is the amount of work done by a stream per unit time at a given point in the stream. Thus stream power is a useful way of determining how much energy might be available in the stream for activities such as mobilising sand. Madej & Ozaki (1996) found that the transit rate of a sand slug in Redwood Creek in the USA varied directly with stream power.

Stream power is a function of discharge and the stream's energy slope:

$$w = \rho g Q s\ ,$$

where ρ = density of water (1000 kg/m^3),

g = acceleration due to gravity (9.81 m/s^2),

Q = discharge (m^3/s),

s = slope of the energy line.

For the purposes of examining how stream power varies along Creightons Creek, only relative measures of stream power are required. Neither discharge nor energy slope data are available, so surrogates were used for each: catchment area was used as a surrogate for discharge, and stream-bed slope was used as a surrogate for energy slope. Catchment area can be used as a surrogate for discharge because discharge is a function of rainfall characteristics, runoff coefficient and catchment area, and if it is assumed that rainfall characteristics and runoff coefficient are the same for the entire catchment, then discharge varies directly with catchment area. Stream-bed slope can be used as a surrogate for energy slope when streamflow is uniform (Gordon *et al*. 1992), which is an acceptable assumption for the purposes of this investigation.

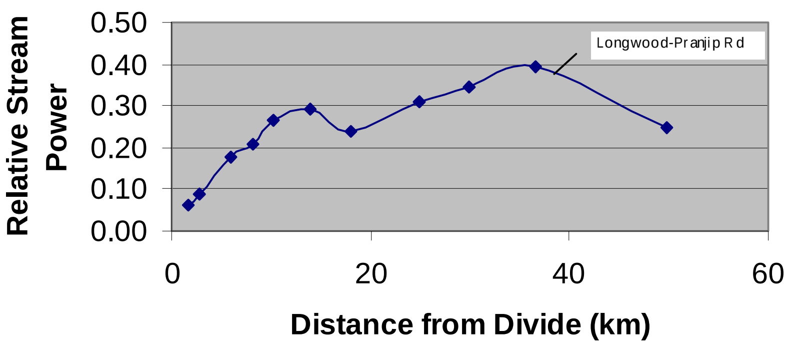


Fig. 6.1. Relative stream power vs stream length

A relative value of stream power was calculated for 11 points along Creightons Creek, starting in the headwaters, by multiplying catchment area by stream-bed slope (both catchment area and stream-bed slope were obtained from 1:25 000 topographic maps). The relative stream power against stream length is plotted in Fig. 6.1.

Figure 6.1 suggests that stream power generally increases downstream, although it appears to decline downstream of the Longwood–Pranjip Rd. The decline in stream power downstream of the Longwood–Pranjip Rd would account for the migration rate of the sand slug declining near this point, but it would not account for migration stopping altogether. It is interesting to note that before flow was diverted to Branjee Creek (below Nelsons Rd) the sand slug in the old Creightons Creek channel had also migrated as far as the Longwood–Pranjip Rd. This observation could be coincidental, or it could indicate that a decline in stream power at this point also stalled sand transport in the old channel.

This analysis assumes that the flow or combination of flows that are primarily responsible for the migration of the sand slug are contained in the channel. If the relevant flows are low flows then this assumption would be valid, but if they are high flows then this assumption may be violated. Due to channel enlargement via erosion of Creightons Creek particularly through the foothills and downstream as far as Drysdale Rd, high flows can be retained in the channel. Below Drysdale Rd, however, the channel is not enlarged and less flow can be retained in the channel; and at high flows this can result in a lower than expected stream power. The reduced flow retained in the channel during high flow events downstream of Drysdale Rd is further lessened by flow losses to anabranches. Hence the lower reaches of Creightons Creek, during high-flow events, cannot contain the discharge predicted using catchment area as a surrogate for discharge; and so stream power in these reaches could be even lower than predicted in Fig. 6.1. This analysis then indicates that the bedload transport rates in Creightons Creek declines downstream of the Longwood–Pranjip Rd. Given that bedload transport rates are relatively high upstream of the Longwood–Pranjip Rd, it must be assumed that sand is accumulating in the bed in this area, as well as moving into anabranches.

The anabranching may also have another effect on sand slug migration in the Granite Creeks. As was noted in Section 3.3.5 in relation to the development of a suspended sediment sampler, it is probable that sand is carried high up in the water column during high flow events. Under these conditions, some proportion of the sand in transport would be carried into the anabranches (e.g. the old Creightons Creek channel) where it would be deposited, effectively removing sand from the sand slug. It was not possible to collect the data required to test this hypothesis during this project (see Section 3.3.5), but it can be speculated that such losses not only occur but may be significant enough to affect the migration rate of the sand slug.

The migration rate of the sand slug in Creightons Creek appears to be insufficient to account for the rate of bedload movement measured and observed during the fieldwork undertaken for this report. The apparently low migration rate may, however, be due to two factors. First, there is reduced stream power (due to a relatively low gradient and discharge) in the reach where the snout of the sand slug is located. Second, the flows diverted into anabranches during high flows may be carrying substantial amounts of sand, effectively removing sand from the slug.

These results have some implications for rehabilitation, the most important of which is that any rehabilitation works carried out in the lowland reaches of the Granite Creeks (i.e. on the flats) should not lead to channel enlargement which might increase stream power and reduce the volume of sand being stored in the anabranches. Similarly every effort should be made to maintain anabranch connections with the main channel to ensure sand can still be delivered to the anabranches for storage.

Evacuation of the sand slug

Slugs do not remain in a stream system forever. It should be expected that the sand slugs in the Granite Creeks will leave these streams eventually. However, given the apparent effect of low stream power and anabranching on the slug migration rate in the lower reaches of Creightons Creek, it appears unlikely that the sand slugs will leave these systems quickly or in the foreseeable future. This is not to say that the slugs will not evacuate from the upper and middle reaches of the Granite Creeks in the coming years. For example, it is possible that the tail section of the Creightons Creek sand slug may have evacuated the middle reaches of Creightons Creek, i.e. between Kellys Bridge and Bartons Lane (see Section 4.8).

It should not be assumed that a reach will immediately return to pre-slug conditions once a sand slug has passed through it. Nicholas *et al*. (1995) noted that ‘the zone of disequilibrium generated by the slug passes downstream at a variable rate, eventually exiting the system, although not necessarily leaving it in a condition similar to that prior to the introduction of the slug’ (Nicholas *et al*. 1995, p. 507). Rutherfurd & Budahazy (1996) noted, where sand slugs had evacuated from some streams in the Glenelg River system, that stream incision had followed. Several factors may have contributed to this response, including commercial sand extraction and the fact that stream incision had been active prior channel aggradation. Madej & Ozaki (1996) have reported pools returning to stream segments previously affected by sand slugs in Redwood Creek. It can be hypothesised, however, that for pools to return to Creightons Creek, conditions conducive to pool formation must exist and one of the most important elements for pool formation in the Granite Creeks appears to be large woody debris (see Section 6.3.4). If, as suspected, large woody debris is vital to the re-establishment of pools in the Granite Creeks following slug evacuation, efforts will need to be made to effectively manage large woody debris in these reaches.

Fig. 6.2. Pranjip–Nine Mile Creek on the ‘flats’. The trunk of a large tree lying across the creek has created a large scour pool.

6.3.4. Improving the in-stream environment on the sand slug

Incidental observations made by the authors during fieldwork suggest that even where sand aggradation is severe some variability of bedform can develop with the introduction of large woody debris (LWD) (e.g. Fig. 6.2). It is probable that LWD would have been an important feature of the Granite Creeks (both physically and biologically) before European settlement, but it has disappeared as a result of removal by authorities and landholders (in the belief that removal would reduce flooding and erosion), and by being buried under sand slugs. In all instances, where LWD is still present it would have been derived from the local riparian zone which is in at least a moderate condition. So, clearly, stream fencing and landholder education would help preserve and regenerate riparian zones which would in turn aid stream rehabilitation. In areas where the riparian zone is so impacted that supply of LWD to the stream is negligible, LWD may need to be sought from elsewhere and placed in the stream. The process by which LWD is reintroduced to streams, particularly those affected by sand slugs, is an emerging area of research, and an experimental study may need to be set up in the Granite Creeks catchments to guide the use of LWD in stream rehabilitation.

7. CONCLUSION

7.1. The Granite Creeks

Activities associated with European settlement in the Granite Creeks catchments, such as clearing of vegetation, agriculture, channelisation and channel dredging and clearing, have initiated erosion heads in the Granite Creeks which have caused extensive channel incision and gullying. While other forms of erosion have also occurred in the Granite Creeks catchments, it is erosion of gullies and streambeds and banks that has produced most of the sediment that now forms sand slugs in the three Granite Creeks studied here. Incision and gullying occurred in the Granite Creeks catchments before European settlement, but it is probable that such incidents were either related to some external stimulus (such as climate change) or, more commonly, to specific local conditions. Erosion in the Granite Creeks catchments over the last 150 years appears to have been synchronised over a wide area and this synchronisation can be attributed to European settlement. The effects of settlement, in terms of the geomorphic effect on the channels, can be likened to a substantial climate change.

The sand slug observed in Creightons Creek is typical of those found elsewhere in the Granite Creeks. The snout of the slug is indistinct, with the completely sanded and unsanded stream segments separated by a transition zone. Stream incision in the middle of Creightons Creek may be indicative of the passing of the sand slug downstream. Sanding along the main body of the sand slug has buried pools and large woody debris, producing a flat sand bed in most reaches.

Because of the nature of erosion and sediment storage in the Granite Creeks catchments there are two main issues that need to be addressed in any rehabilitation program that is developed for the Granite Creeks:

1. minimisation of further sediment inputs. While the main sources of sediment for the sand slugs are no longer active, some erosion is still continuing. Activities responsible for initiating erosion heads today are channel dredging and clearing and uncontrolled stock access. These problems will be best dealt with via landholder education and cooperation. Best practice land management techniques will also be important to minimise gullying that has resulted in the past from the combination of high rainfall totals and low levels of vegetative cover. While the upper catchment would appear to be more fragile and in need of priority action, prevention of erosion head initiation in the lower reaches of the creeks will also be important.
2. management of existing sand slugs. The most important aspect of managing the existing sand slugs is to minimise the migration rate of the snout of the sand slug to protect unaffected downstream reaches. It would appear that natural features of the Granite Creeks (e.g. anabranching, low gradients and discharge) help to slow the snout migration rate at the lower end of these systems. Any management strategies should recognise this and seek to prevent channel enlargement and the restriction of flow to anabranches.

Rehabilitation activities on those sections of the Granite Creeks already affected by sand deposition should focus on the creation of better habitat conditions through the re-establishment of bed features such as pools. Observations made during this study suggest that the reintroduction of large woody debris will assist the development of such bedforms, but further research is required in this area.

7.2 Beyond the Granite Creeks

7.2.1. Methodological outcomes

In the introduction it was suggested that the methods employed during this study might be useful as a template upon which similar investigations in the future could be based. The methods employed here fell into two parts. The first part comprised the historical analysis and the second part consisted of the assessment of current condition. The activities conducted as part of the historical analysis, i.e. deriving evidence of historical stream condition from Land Selection Files, Local Government records, explorers' diaries, etc., could be readily undertaken by someone from the community without previous experience. The only prerequisite for such a person would be the ability to ignore all preconceived ideas and objectively assess the available evidence. As has been demonstrated in this report, archives can be extremely useful sources of information about historical stream condition, with Land Selection Files, explorers' diaries and historical maps proving to be the most valuable resources for this study.

However, assessment of current condition is not a task that could or should be undertaken without technical input. While the techniques applied in the current stream condition assessment (e.g. observation, sediment budget, sediment tracing, scour chains) provided limited information individually, when the information generated by all the techniques was combined and considered with the benefit of technical understanding, a number of useful conclusions were reached.

7.2.2. Final outcomes

The conclusions derived from this investigation have implications for small granitic catchments elsewhere in south-eastern Australia, and for anabranching streams affected by sand slugs. The evidence available for the three streams studied here suggests that a range of activities associated with European settlement have initiated erosion heads that have led to channel incision and gullying, and while this is not new, the fact that activities in the riparian zones of these streams are still initiating erosion heads, is unusual. It is commonly accepted that many streams in south-eastern Australia are now recovering from disturbances initiated by European settlement (Rutherfurd 2000) and it is not widely acknowledged that some activities are still causing stream degradation today, particularly in relatively sensitive environments such as small granitic catchments. While the erosion being caused by recently initiated erosion heads is minor compared to that which occurred historically, it still threatens areas where recovery has commenced, as well as potential rehabilitation sites. Clearly small granitic catchments require careful management from the top to the bottom of the catchment, which in turn requires managers to be aware of threatening activities and to educate land owners accordingly.

While a good deal of research has been carried out on sand slug migration in single-thread channels (e.g. Gilbert 1917; Knighton 1989; Erskine 1994; Rutherfurd & Budahazy 1996), little if any work has focused on migration through multiple channel systems. The anabranching nature of the Granite Creeks, and the stream systems' subsequent response to sand slugs, suggest that anabranching streams may have the same effect on sand as they do on water moving through the systems, i.e. during flood events they distribute material out onto the floodplain via the anabranches. While water distributed on the floodplain will evaporate, find its way back into the main channel further downstream, or enter groundwater stores, sand enters long-term storage on the floodplain. Not only is sand lost to the floodplain but the rate of migration of the sand that remains in the main channel is slowed, due to both reduced discharge and declining stream gradients. These observations are based on the Granite Creeks but the evidence suggests that, in general, anabranching streams play an extremely important role in removing and storing both fine and coarse sediment from streams and rivers, and as such must be preserved from modification, to protect downstream reaches from sedimentation.

Observations of the changes in stream condition brought about by sand slug development in the Granite Creeks indicate that all aspects of the stream environment are affected, from stream hydrology and hydraulics to stream chemistry and ultimately in-stream habitat. The sanding of the stream bed has filled deep pools and removed all bed variability, leaving a shallow rectangular channel. The change in channel shape and substrate has altered the stream hydrology and hydraulics. Low flows now sink into the deep sand bed, reducing the frequency of surface flows during the summer months. The change in channel shape has reduced channel resistance (with both bedforms and large woody debris being largely submerged by the sand) and thus has probably resulted in increased in-stream velocities. The loss of deep pools has reduced the areas of low velocities in the creeks to a minimum.

Stream chemistry has been affected in several ways. The sand bed acts as a filter producing a clear water stream where previously turbid water would be found. This is compounded by the loss of pools which would provide an environment in which tannins would leach out of vegetable material and stain the water. Clear, shallow water has two effects: it makes fish and other stream inhabitatants more vulnerable to predation, and it facilitates water temperature changes.

Finally, the sand slugs have submerged two important habitat elements: large woody debris and the original stable substrate. The habitat that remains is an unstable sand bed that is mobile, either by saltation or by dune migration at all flows except summer–autumn baseflows. The complete change in the stream environment brought about by the development of sand slugs in the Granite Creeks is likely to have dramatically changed the ecology of these streams also. This hypothesis is partially supported by work conducted in Creightons Creek in the late 1980s. O’Connor (1991) found that the sanded sections of Creightons Creek were species-poor during high discharges, compared with low-flow periods. Further investigation of the ecological impact of the sand slugs on the Granite Creeks is now underway.

The Granite Creeks Project is a case study which also has implications for catchment management activities more generally. It shows the importance of a rigorous analysis of the history of a catchment in laying the foundation for rehabilitation. All too frequently, unsubstantiated anecdotes and casual observations are accepted uncritically as an accurate representation of the history of an area. The history must be researched with the same rigour as is used in any branch of science.

In the management of river channels, individual sections cannot be treated in isolation from the whole. In the Granite Creeks, individual landholders have intervened in the stream channel to solve their local problems and have unwittingly set in train problems both for their downstream and their upstream neighbours. Effective rehabilitation of these systems requires that individual riparian landholders subjugate their own local interests in favour of the integrity of the whole channel system. To achieve this coordination along the length of the channel is a challenge for catchment managers.

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DNRE Files:

85/22219 — Castle Creek

2020 WW (62/19071) — Castle Creek (RWC Watercourse File)

Goulburn-Murray Water Files:

2020 WW — Creightons Creek (RWC Watercourse File)

Land Selection Files

The following files are held by the Public Records Office of Victoria. The notation used is VPRS/unit/file. e.g. PROV VPRS 626/603/16871 refers to PROV, VPRS 626, unit 603, file 16871.

Creightons Creek, the Flats:

PROV VPRS: 626/603/16871, 16872; 626/605/16966, 16968, 16972, 16982; 626/614/17419 (Branjee); 626/640/19003; 626/2119/4694; 626/2068/2725; 626/2097/3867, 3866; 626/2064/2576; 626/2121/4747 (Longwood); 626/2047/1871; 626/2123/4823; 626/2015/152; 626/2084/3346; 626/2071/2820; 626/2080/3170, 3171; 626/2029/987; 629/62/11338, 11339 (Molka); 626/2056/2140; 626/2141/5567; 626/2055/2134; 626/2096/3793, 3798, 3801; 626/2093/3713; 626/2145/5728; 626/2144/5689; 626/2093/3708; 626/2054/2081; 626/2119/4671, 4673, 4692; 626/2137/5435; 626/2121/4740; 626/2142/5601, 5606; 626/2129/5116, 5120; 626/2132/5232, 5233; 626/2134/5308; 626/2140/5540; 626/2139/5528; 440/1878/284; 5357/5502/2477; 5714/364/458; 5714/344/288; 5714/501/1050 (Pranjip).

Creightons Creek, the Hill Country:

PROV VPRS: 626/21/1315; 626/43/3019; 626/44/3079; 626/23/1486; 626/54/3752; 626/61/4280, 4281; 440/20/2946; 5357/583/296; 5357/587/337 (Garratanbunell); 626/2097/3839; 626/2026/815; 626/2069/2731, 2760; 626/2146/5751; 626/2071/2815, 2816; 626/2095/3774; 626/2043/1697; 625/595/48050; 626/2044/1743; 626/2056/2152; 626/2014/113; 626/2022/636; 626/2086/3494; 626/2039/1495; 626/2066/2640; 625/365/25452; 626/2021/589; 626/2035/1271; 626/2082/3259; 626/2061/2476; 626/2020/539; 626/2017/315; 626/2021/610; 626/2025/782; 625/397/28381; 626/2022/620; 625/194/11996; 626/2058/2287; 626/2110/4368; 439/274/305; 5714/305/101; 5714/1674/1008; 5714/351/281 (Longwood); 626/2025/787; 626/2026/814; 626/2092/3665; 440/1877/261; 5357/5428/2786; 5357/5435/0230; 5357/5483/2035; 5357/5528/2258 (Ruffy).

PTC Bridge Files:

Somerton to Wodonga Line, Index: 143, 150, 160 & 186.

Local Government Records:

Strathbogie Shire Council Bridge Plans: 002, 018, 019, 022, 038, 054, 076, 099, 129, 135, 168, 182, 294, 331, 518, 529, 554 & 554-3.

APPENDIXES

Appendix A: Recollections of Streams in North East Victoria
By Mr Robert (Bert) McKenzie

The following letter was written by Bert McKenzie, who resided on the Strathbogie Ranges for most of the 20th century. The original letter was handwritten and difficult to read. Question marks indicate that a word or phrase could not be deciphered. Italics indicate words added by the translator.

Recollections of Streams in the North East Victoria. By Mr Robert (Bert) McKenzie

Years 1906 to 1913

All the creeks of the Tableland (i.e. Terip, Ruffy, Dropmore, Caveat, Tarcombe and Kobyboyn) were packed with Black fish and Silver minnows. All were crystal clear and it was possible to see to the bottom , down to six or eight feet at midday and (as a cousin and I used to do), it was possible to grind up a few worms with sand and drop them in the pool. We would fish for the bigger ones. Fourteen inches was our best. Most of our haul would be round 13 inches down to 9 inches. However, someone caught one 15 inches.

In 1912 or 1911, Mr Jimmy Hobart acquired, from Ballarat, 2000 brown trout and, from somewhere, 6 tench which were all released at the Boathole, Hughes Creek, Ruffy. They spread and bred rapidly down stream and were being taken up to seven pounds by 1914.

In 1912, 2000 rainbow(trout) were released.

In the spring of 1914, I landed my best some twenty yards behind me and about the same *height..???* and by the autumn was handling fish up to four and a half pounds.

Prior to this, in 1903, my father had taken me down twice to the Dropmore on the lower Hughes Creek, just a mile above the Homestead, and using worms and caught small cod (Trout Cod) up twelve inches and saw my father take several of two and three pounds.

On a later trip with a party of four, everybody caught cod up to six pounds and every hole had six to ten inch fish galore if worms were used.

Our next trip in 1913 was a disaster. A cousin was killed and virtually ended our Cod trips.

The Hughes Creek for two miles above Dropmore up until 1916 was a slow running stream with a series of very deep holes mostly edged with Capungi (*Phragmites?)* reeds. In 1916, a flash flood ripped through and tore the creek bed down to bedrock and left a long channel of sand and in my opinion swept away the Trout Cod breeding grounds in those Capungi edged pools for the whole of the Hughes Creek.

Whether or not that flood carried the whole of the Cod population down into the Goulburn and the Nagambie Lake area, I do not know. But around 1918 to 1924, Nagambie was the Mecca for Cod fishermen from all over and in that period and was probably the supply area for all the Trout Cod that inhabited the National Channel which filled Waranga Basin and the Wilson Channel feeding Shepparton, Tatura, etc. Even the smaller channels carried small Cod and an occasional four pound Catfish. I had Cod to Four and a half pounds from both the National and Wilson. Old Nagambie residents could probably supply the exact dates of this era when suddenly the whole catfish population were wiped out in the Goulburn River system. The same thing happened in the Murray River system, I think after the second stage of the Hume Weir or when???

Anyhow that flash flood was the end of the Trout Cod in the Hughes Creek in the Dropmore area. I certainly caught a few while fishing for trout in 1919 to 1934 or 1924. These were mainly around the four to five and a half pound weight and an odd two pounder, suggesting that there may have been some fluke breeding.

In 1920/21 we had one hundred acres rented around the Dhuringile Homestead, Toolamba, hence the fishing in the channels. At the same time the home base was one farm on the Sevens Creek followed by one on the Castle Creek in the Branjee area.

The Castle Creek had quite a lot of Macquaries and Blackfish and the Seven Creeks, from the farm, five miles from Euroa was loaded with small Trout Cod, Macquaries and Blackfish. The Seven Creeks in drought years often stopped running from Euroa down, concentrating the fish in the deeper pools and for a few weeks the fishing was fast and furious. Fish in the main were Trout Cod and Macquaries to two pounds. In those days there were miles of those waters, all heavily stocked with trout cod (small) and Macquaries likewise.

In those days it seemed impossible that mere fishing would overtake supply in the Goulburn River which I fished at Molesworth, Cathkin, Alexandra and Thornton. In these stretches of the Goulburn in those days at Christmas and Easter, it was estimated that the campers numbered 500 to the mile of river. They came from Melbourne by train and the local farmers carted their camping gear to the river and I have no doubt profited considerably by doing just that. It would seem at the time that it would be utterly impossible to eliminate the Trout Cod and the Macquaries from the waters they inhabited. But around 1922 or 1923, the old Eildon Weir was built and acted, I believe, as a settling dam and the water became crystal clear and I believe the smaller fish became easy prey for the large Trout Cod and Redfin then inhabiting the river.

In the Eildon itself, various stretches were teaming (Big River) with small Macquaries and in the UT Creek area, I landed at least 20 small cod proclaiming at least two breeding grounds for Trout Cod and Macquaries.

The Cod fishing deteriorated in the Goulburn and the Macquaries to a lesser extent, but after the greater Eildon Weir was built in the late Forties, both fish have been practically wiped out, at least as a fishing proposition.

In so far as the Macquaries are concerned, the breeding grounds have been destroyed by the colder water or siltation. I believe that where the main streams enter our reservoirs, new breeding grounds will have to be established not by releasing fry but establishing natural breeding places by the use of spawn or eggs in a natural setting in the river beds to which mature fish will return when their turn comes to drop their spawn. From what some of the older residents have told me in the Riverina, streams completely dried up in severe droughts (before Samuel McCackie *spelling* built dams on them) but the small cod and big appeared back in the streams as soon as those streams began to flow again. Their breeding grounds would be headwater streams that did not stop flowing.

Appendix B: Plots of Stream Cross-sections Measured at the Hume Freeway and the North-Eastern Railway Line

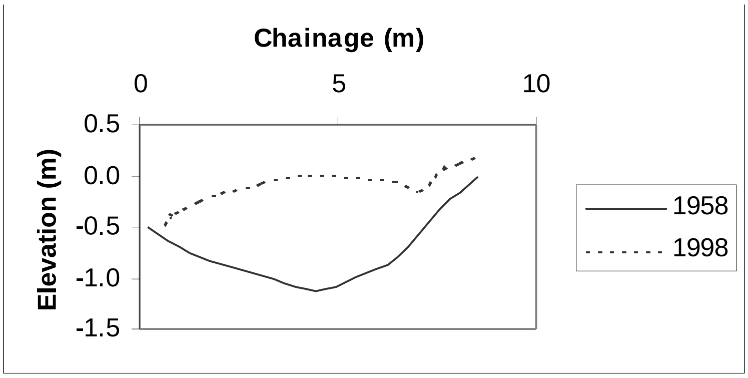


Fig. B1. Bed elevations for Pranjip Creek at the Hume Freeway for 1958 and 1998

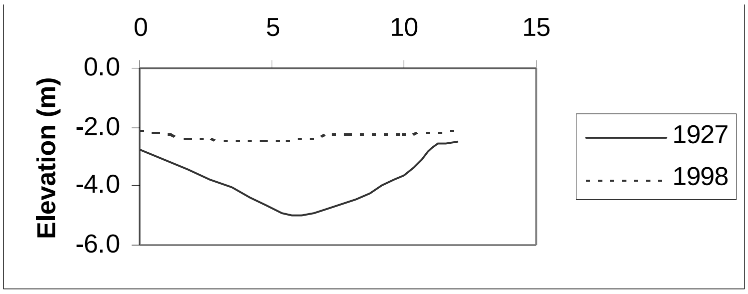


Fig. B2a. Bed elevations for Nine Mile Creek Span A at the Hume Freeway for 1927 and 1998

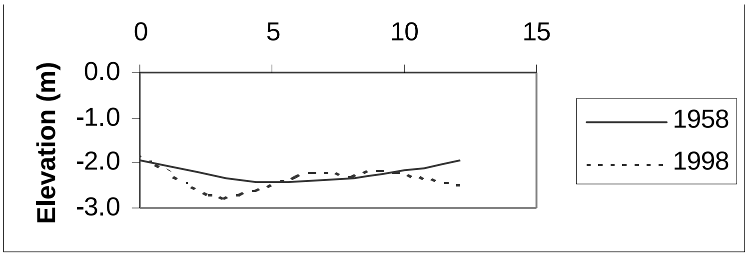


Fig. B2b. Bed elevations for Nine Mile Creek Span B at the Hume Freeway for 1958 and 1998

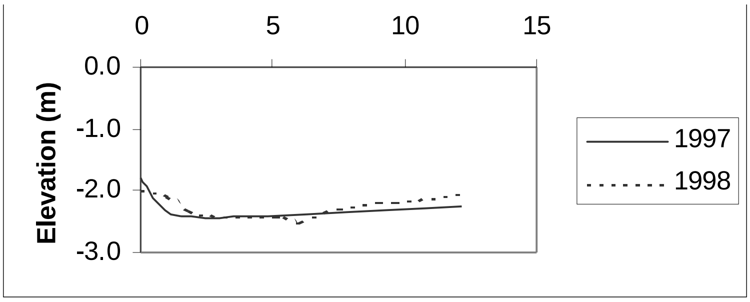


Fig. B2c. Bed elevations for Nine Mile Creek Span C at the Hume Freeway for 1997 and 1998

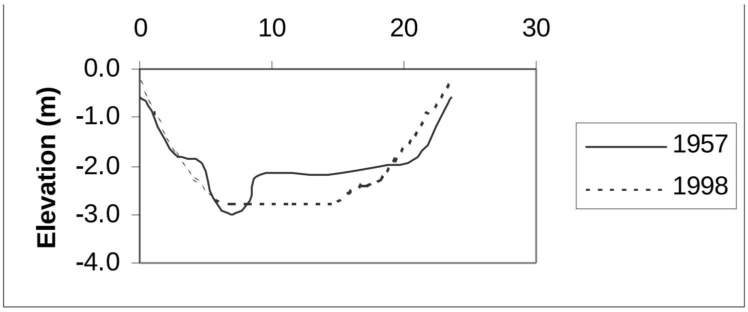


Fig. B3. Bed elevations for Creightons Creek at the Hume Freeway for 1957 and 1998

Fig. B4. Bed elevations for Castle Creek at the Old Hume Highway for 1938 and 1998 (upstream and downstream)

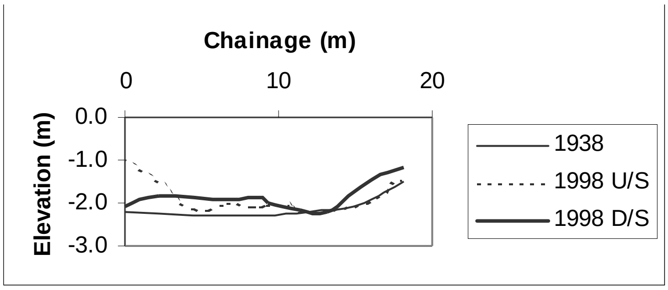


Fig. B5. Bed elevations for Pranjip West bridge over Pranjip Creek at the railway line for 1871, 1922, 1947, 1995 and 1998

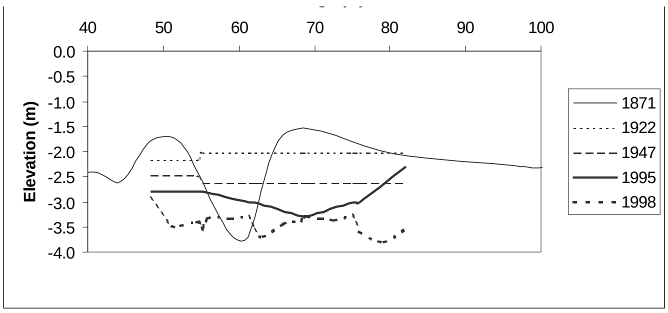


Fig. B6. Bed elevations for Pranjip West Bridge over Nine Mile Creek at the railway line for 1871, 1926, 1995 and 1998

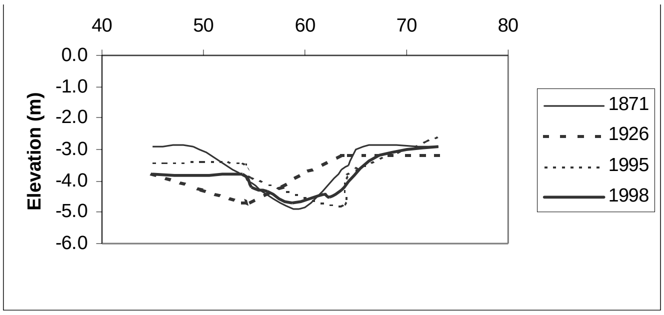


Fig. B7. Bed elevations for Creightons Creek at the railway line for 1871, 1872, 1922, 1995 and 1998

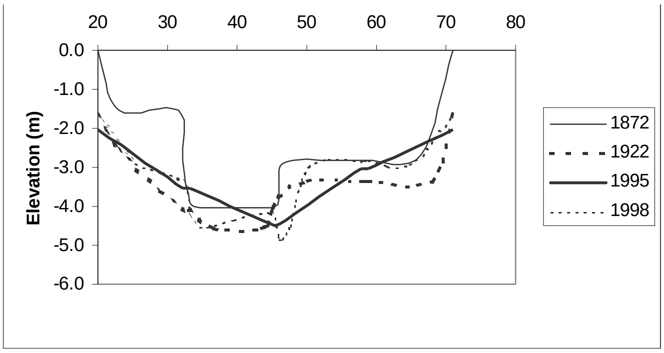
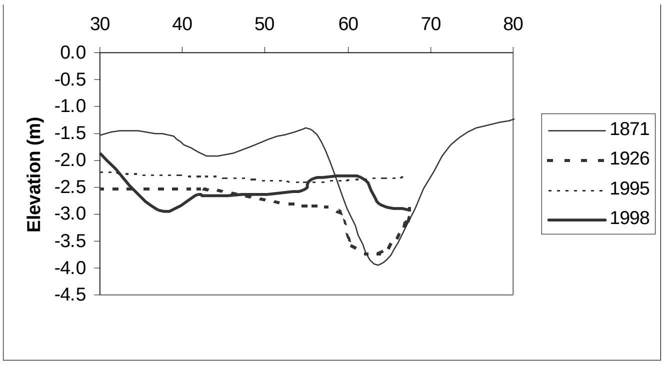


Fig. B8. Bed elevations for Castle Creek at the railway line for 1871, 1926, 1995 and 1998



APPENDIX C

Table of results from scour chain monitoring

	Date checked					
	15/9/98	5/10/98	10/11/98	14/12/98	9/2/99	11/5/99
Castle Ck						
Bamford						
Scour 1	E	16 cm	8 cm	22 cm	3 cm	0 cm
Deposit 1	4 cm	16 cm	10 cm	13 cm	1 cm	2 cm
Scour 2	NL	NL	E	11 cm	0 cm	0 cm
Deposit 2	NL	NL	6 cm	4 cm	0 cm	0 cm
Kubeil						
Scour 1	5.5 cm	8.5 cm	5 cm	0 cm	0 cm	0 cm
Deposit 1	10 cm	7 cm	4.5 cm	7 cm	0 cm	0 cm
Scour 2	0 cm	10 cm	0 cm	10 cm	0 cm	1 cm
Deposit 2	0 cm	8 cm	3 cm	11 cm	1 cm	0 cm
Creightons Ck						
Carlsson						
Scour 1	0 cm	NL	NL	NL	NL	NL
Deposit 1	10 cm	NL	NL	NL	NL	NL
Scour 2	0 cm	10 cm	2 cm	3 cm	2 cm	1 cm
Deposit 2	15 cm	3 cm	0 cm	0 cm	3 cm	15 cm
Caldwell						
Scour 1	NL	NL	NL	NL	24 cm	0 cm
Deposit 1	NL	NL	NL	NL	5 cm	0 cm
Scour 2	0 cm	NL	28 cm	NL	27 cm	5 cm
Deposit 2	20 cm	NL	18 cm	NL	23 cm	8 cm
Nine Mile Ck						
Cameron						
Scour 1	7 cm	13 cm	6 cm	0 cm	3 cm	0 cm
Deposit 1	10 cm	13 cm	8 cm	4 cm	3 cm	0 cm
Scour 2	5 cm	18 cm	0 cm	2 cm	4 cm	3 cm
Deposit 2	8.5 cm	14 cm	0 cm	4 cm	0 cm	2 cm
Threlfall						
Scour 1	E	13 cm	0 cm	0 cm	0 cm	0 cm
Deposit 1	12 cm	12 cm	0 cm	0 cm	0 cm	0 cm
Scour 2	0 cm	4 cm	1 cm	0 cm	0 cm	0 cm
Deposit 2	0 cm	0 cm	1 cm	0 cm	0 cm	0 cm

E: Error, chain indicated change that was physically impossible or highly improbable (assumed to be caused by error in placement or reading). NL: Not Located, chain could not be found.

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The Cooperative Research Centre for Freshwater Ecology publishes a range of books, guidelines, newsletters, technical reports and brochures. These publications can be ordered from the Cooperative Research Centre for Freshwater Ecology at its Albury centre, by phoning 02 6058 2310, or by email to enquiries@mdfrc.canberra.edu.au.

Many reports are also available on our web site at http://freshwater.canberra.edu.au

Books

CRC for Freshwater Ecology. 1997. *Living on Floodplains*. Limited copies available.

Brochures

- Billabongs, floodplains and river health
- Chaffey Dam project
- Effects of a drying phase on the ecology of Menindee Lakes
- Environmental flows for the Campaspe River
- Lowland rivers
- Providing an ecological basis for the sustainable management of Menindee Lakes
- Rivers and fish in stress
- Sustainable rivers: the Cap and environmental flows

Guidelines

Lawrence, I. & Breen, P. 1998. *Design Guidelines: Stormwater Pollution Control Ponds and Wetlands*.

Identification Guides

The CRC for Freshwater Ecology sells 31 different Identification Guides to the Invertebrates of Australian Inland waters, including Hawking, J. & Smith, F. 1997. *Colour Guide to Invertebrates of Australian Inland Waters*. ID Guide no. 8. ($24.00)

Technical reports

Cottingham, P. 1999. *Scientific Forum on River Condition and Flow Management of the Moonie, Warrego, Paroo, Bulloo and Nebine River Basins*.

Cottingham P., Whittington J. & Hillman, T. 1999. *Riverine Management and Rehabilitation Scoping Study*.

Cottingham, P. & Hart, B. 2000. *Nutrient Loads from the Macalister Irrigation District*. Technical report no. 5/2000.

(continued overleaf)

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