Sand Slugs and Stream Degradation: The Case of the Granite Creeks, North-east Victoria

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Acronyms

ACS	average catchment slope
AHD	Australian height datum (height above sea level)
CR	circularity ratio
DNRE	Department of Natural Resources and Environment
GBCMA	Goulburn-Broken Catchment Management Authority
HCC	hillslope channel connectivity
HI	hypsometric integral
LSF	Land Selection Files
LWD	large woody debris
MSL	main stream length
NRE	see DNRE
PROV	Public Records Office of Victoria
PTC	Public Transport Corporation
RRR	relative relief ratio
RWC	Rural Water Corporation (or Commission)
SCA	Soil Conservation Authority
SRWSC	State Rivers and Water Supply Commission

Explanation of some terms

Bioturbation	disturbance or mixing of soil by organisms (animals living both above and below ground)
Drape	an overbank deposit of sediment, usually sand
Flocculation	process in which smaller particles join together to form larger particles
Pedogenesis	the process by which soil is formed or develops
Regolith	loose rock material that is the subject of weathering. Soil is the surface component of regolith.
Scour chain	a chain (of the order of 1 m long) partially inserted vertically into the bed of a stream. The remainder of the chain is laid horizontally on the streambed and measured. Changes in the lengths of the horizontal and vertical parts of the chain indicate the extent of scour and fill at that particular site.

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1. INTRODUCTION

1.1. Background and context

Stream and land degradation have occurred throughout south-eastern Australia since European settlement, resulting in gullying, channel incision and channel widening, and the release of large volumes of sediment (Rutherfurd 2000).

The fate of the sediment depends to a certain extent on its particle size distribution. Fine sediments (clays and fine silts) remain entrained in flow for sufficient time to be transported significant distances downstream from the site of erosion or out onto floodplain units where they are stored for long periods of time (Meade 1988). To transport the sand and gravel fraction, on the other hand, requires much more energy. As a result, this fraction remains in the stream channel and is transported slowly downstream in an episodic manner by large flood events. If the material eroded from a catchment is predominantly fine the major form of degradation is a deepening and widening of the channel, as well as sedimentation downstream on the floodplain. If the eroded material is predominantly coarse, degradation takes the form of changes in channel dimensions and stream sedimentation, or sand slug development.

A sand slug is a discrete body of sand deposited in a stream channel. Sand slugs were first described by Gilbert (1917) in relation to hydraulic mining debris deposited in the Sierra Nevada, in California. Since then, sand slugs have been reported in a variety of locations, both in Australia (e.g. Knighton 1989; Erskine 1994; Rutherfurd & Budahazy 1996) and throughout the world (e.g. Pickup, Higgins & Grant 1983; Lewin & Macklin 1987; Madej & Ozaki 1996).

Nicholas *et al*. have described slugs as ‘bodies of clastic material associated with disequilibrium in fluvial systems over time periods above the event scale’ (Nicholas *et al*. 1995 p. 502). In other words, a slug is a discrete volume of sand and/or gravel material that is released into a stream channel and only very slowly transported out of the stream network by the stream flow. The slug can fill the width of the channel to depths of the order of metres, and extend over distances of hundreds to thousands of metres. The front of the slug is referred to as its ‘snout’, and this can be a well-defined face or front, downstream of which negligible deposition is apparent.

The physical impact of a sand slug is to drown the stream’s natural bed form (e.g. submerge pool and riffle sequences)and alter the channel form (Nicholas *et al*. 1995). In many instances a sand slug will transform a stream channel, producing a shallow flat bed. This alters the channel roughness and reduces the channel capacity, altering the stream hydrology and hydraulics. The stream will break out of the channel more frequently, low flows may occur beneath the sand and pools will no longer persist during dry spells. Large woody debris is submerged by the sand and the channel boundary material is often altered. Such changes have an impact on in-stream habitat and thus the stream ecology. Alexander & Hansen (1986) found that the introduction of sand into a stream in the upper midwest of the USA resulted in the channel becoming shallower and wider. As a consequence the static water volume decreased, channel diversity was reduced, fish cover was reduced and velocities increased, all of which contributed to a more stressful environment for fish. Stream temperatures also increased slightly and benthic invertebrates were reduced to half. All these factors were found to contribute to a significant reduction in brook trout (*Salvelinus fontinalus*).

In south-eastern Australia sand slugs derived predominantly from stream erosion have tended to be associated mostly with granite catchments (Rutherfurd 1996). Granite catchments produce sediment that is dominated by sand-sized particles and so it is no surprise that when stream erosion and gullying occur in these catchments, sand slugs usually result. Large areas of south-eastern Australia are dominated by granitic geologies (Russell & Coupe 1984; Douglas & Ferguson 1988), and the influence of European settlement has been felt throughout the region, so stream degradation in the form of sand slug development is probably more widespread than is currently recognised. While sand movement in granite catchments has been studied at several sites in south-eastern Australia (e.g. Erskine 1994; Rutherfurd & Budahazy 1996; Brooks & Brierley 1997, 2000), those studies have been confined to large catchments (of the order of 1000 km^2 in area) and have been concerned primarily with the physical impact of sediment slugs on the streams. Similarly, the international literature detailing sand slugs is still limited and concentrates on gravel slugs or slugs resulting from mining waste (see review by Nicholas *et al*. 1995). Madej & Ozaki (1996) describe a sand slug derived from catchment erosion, but the Redwood Creek catchment in USA is very steep compared with the low gradient catchments common in Australia.

The work presented in this report is concerned with the development and movement of sand slugs in several small anabranching streams in central Victoria (the Granite Creeks, tributaries to the Goulburn River), with an emphasis on the effects on stream ecology and rehabilitation. We believe that similar conditions apply in small catchments elsewhere in Australia so that the lessons from this project should be useful to landholders, Landcare groups and river managers.

This report not only provides an insight into the triggers for sand slug development in small granite catchments, but also looks at the influence of anabranching on sand slug migration. The results from the investigation are also considered in relation to the probable effects on stream ecology and the implications for ecological restoration. The methods associated with the investigation are clearly described and so provide a template on which investigations of a similar nature might be modelled. Such a template could be of particular use to community groups contemplating stream rehabilitation activities.

1.2. Objectives and approach

This report presents some outcomes from the project called ‘Restoration of Degraded Rural Streams: the Granite Creeks Landcare Project, North-East Victoria’ (the Granite Creeks Project). The Granite Creeks Project has been developed to investigate the potential for ecological restoration of rural streams degraded by sand slugs. The Granite Creeks area has been chosen as the main field site for a variety of reasons, including the involvement of the local Landcare groups, the fact that preliminary ecological work has been carried out previously (O’Connor 1991) and because the site is readily accessible to researchers, being just two hours drive from Melbourne. The other advantage offered by the Granite Creeks site is that there are a number of streams with sand slugs which provide replicates and facilitate experimental investigations.

The project is multidisciplinary in nature and requires both ecological and geomorphological input. As a result the project has two components: an ecological component and a geomorphological component. This report gives the results of the geomorphological investigation.

Before restoration works can be planned, it is necessary to determine where the sand comes from and how it moves. Consequently the objective of the geomorphological component of the project was:

> 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.

Two key hypotheses were developed to investigate this objective:

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 in the catchments, post-settlement, is mitigated through sediment storage in the catchment slopes and tributary valleys.

There are more than ten creeks that could be considered part of the ‘Granite Creeks’ because they flow off the Strathbogie Ranges and across the Riverine Plain into the Goulburn River, but only three were selected for study in this project. Castle Creek, Creightons Creek and Pranjip–Nine Mile Creek are being studied during the ecological component of the project, and thus these three creeks have also been the subject of the geomorphological investigation.

The tasks required to address the two key hypotheses can generally be categorised as those associated with identifying historical stream condition and those associated with assessing present stream and catchment condition. In essence, the historical analysis was concerned with identifying the forms of the creeks at the time of European settlement, how those forms have adjusted since European settlement and the factors driving that change. The main objectives of the analysis of present condition were to find out if the processes driving change in the past are still active and whether or not the creeks are starting to stabilise. It was necessary to understand why the creeks are in the state they are in today before the fieldwork associated with current assessment was finalised and this led to the project being split into two parts. The first part, which consisted of the historical analysis, was carried out in the first half of 1998; and the assessment of present condition was conducted in the second half of 1998 and the first half of 1999.

1.3. Report outline

Chapter 2 of this report describes the physical attributes of the three selected catchments, and Chapter 3 details the methods associated with the historical analysis and the assessment of present condition. Chapter 4 presents the results of the historical analysis, and Chapter 5 gives the results of the assessment of present condition. The outcomes are discussed in relation to the overall project in Chapter 6 and final conclusions are presented in Chapter 7.

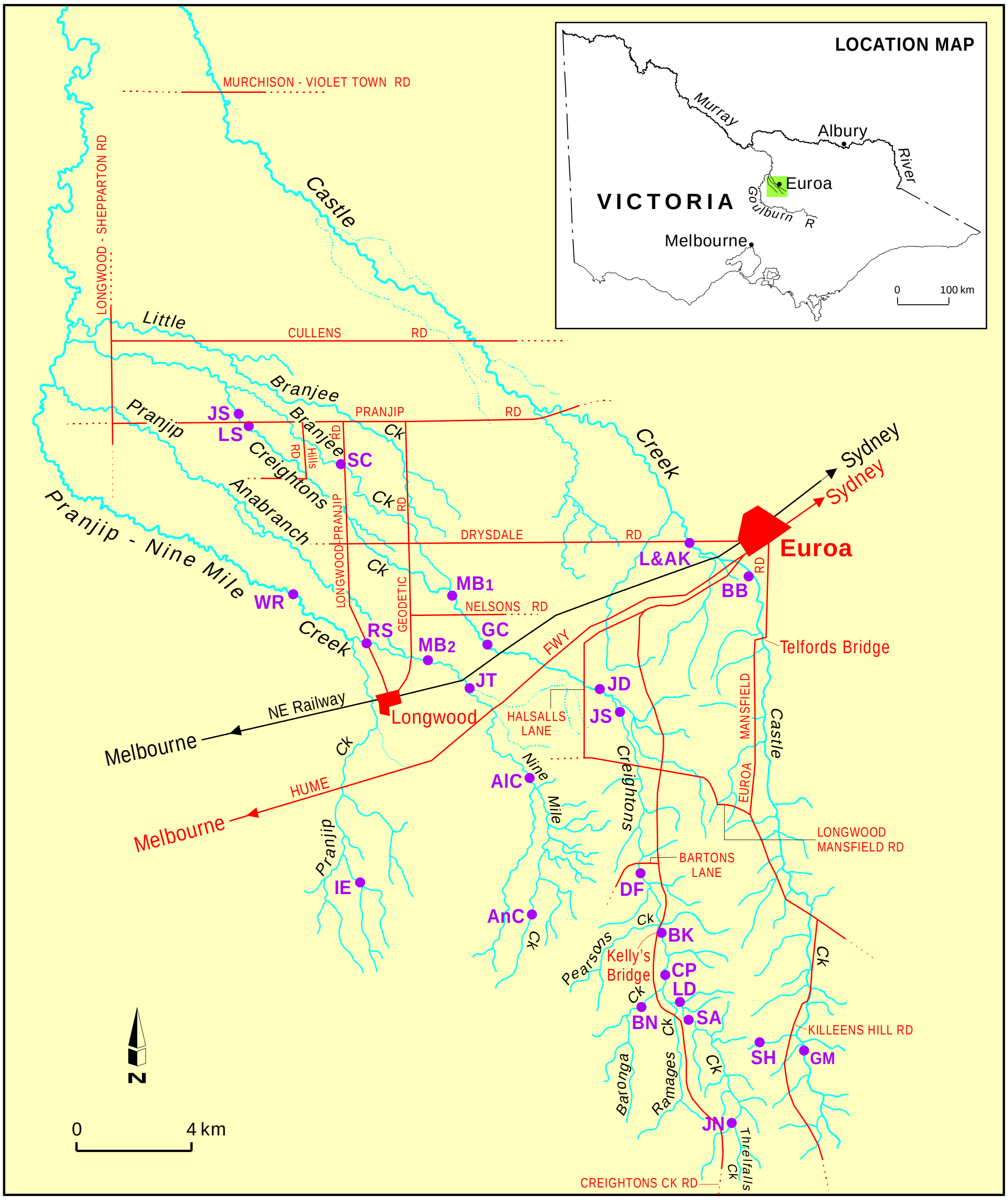

Fig. 2.1. Granite Creeks location map. Flow is from south to north.

Sites on map denoted by solid circles indicate locations referred to in the text. The letters next to each circle are the initials of one of the relevant property's owners. The abbreviations are as follows: AIC – Alastair Cameron, AnC – Andrew Cameron, BB – Brian Bamford, BK – Brian Kelly, BN – Barrie Noye, CP – Claire Penniceard, DF – Dino Furlanetto, GC – Greg Carlsson, GM – Geoff McLean, IE – Ian Elder, JD – Jim Dunn, JN – John Nielsen, JiS – Jim Shovelton, JaS – Jack Stevens, JT – Jim Threlfall, LK – Leo Kubeil, LD – Laurie Davidson, MB – Maurie Brodie, RS – Roy Seach SA – Stan Artridge, SC – Sue Caldwell, SH – Sue Haggard and WR – William Rennie.

2. CATCHMENT DESCRIPTIONS

2.1. Introduction

The physical attributes of Creightons Creek, Castle Creek and Pranjip–Nine Mile Creek are described in this chapter. The information sets the scene for the remainder of the report and provides the detail necessary for the reader to follow some of the descriptions and results presented later in this report, especially in relation to localities.

The physical descriptions provided here should enable the reader to understand these creek systems and how they compare with other more familiar systems. This chapter also discusses a number of extra physical characteristics that allow us to examine how similar the three creeks are to one another. Such an investigation also provides a method by which nearby creeks can be compared to the three creeks examined here, to determine if and how the results presented in this report apply to the other 'Granite Creeks'.

2.2. A general description

Castle Creek, Creightons Creek and Pranjip–Nine Mile Creek all run off the Strathbogie Massif, in central Victoria, and flow in a north-westerly direction until they meet the north flowing Goulburn River (Fig. 2.1). Pranjip–Nine Mile Creek is the most southerly of the three creeks being studied, rising in the hills immediately above Old Longwood. Maps of the area show Pranjip Creek extending from its headwaters near Old Longwood, across the Riverine Plain to its confluence with a number of southern tributaries, before turning north and picking up Creightons Creek and Little Branjee Creek as tributaries. It then continues north and meets the Goulburn River north-east of Murchison. For the purposes of this study, Pranjip–Nine Mile Creek refers to that part of the system upstream of the Creightons Creek confluence, and does not include any of the southern tributaries, i.e. Wormangal Creek, Burnt Creek, Muddy Waterhole Creek, Charles Creek or Reedy Creek. Consequently the Pranjip–Nine Mile Creek system here consists only of Nine Mile Creek, Pranjip Creek above the Creightons Creek confluence, and the Anabranch of Pranjip. In total the area of the Pranjip–Nine Mile Creek catchment is approximately 206 km^2 (Thompson & Associates 1992).

The Creightons Creek catchment, which sits between the Pranjip–Nine Mile and Castle Creek catchments, is approximately 174 km^2 in area (Thompson & Associates 1992). The creek itself has four main upstream tributaries and two downstream tributaries that are considered to be anabranches. The upstream tributaries are Threlfalls Creek, Ramages Creek, Baronga Creek and Pearsons Creek. The downstream anabranches are Branjee Creek and Little Branjee Creek. It is important to note that if one is to describe a creek by its low-flow course then between Nelsons Rd and the Creightons–Branjee confluence, Branjee Creek forms the main channel because the Creightons Creek segment has effectively been abandoned.

Castle Creek is the most northerly of the three creeks. It flows through the southern outskirts of Euroa. At a glance Castle Creek appears to differ from both Creightons Creek and Pranjip–Nine Mile Creek because it flows directly into the Goulburn River without merging with another creek system, and it does not have any obvious anabranches. The Castle Creek catchment covers an area of approximately 282 km^2 (Thompson & Associates 1992).

2.2.1. Climate and hydrology

The Granite Creeks area generally experiences hot dry summers and cool wet winters (LCC 1984). Monthly rainfall data for Euroa (representing the 'flats', the plains on the north-western or downstream side of the Hume Freeway) and for North Strathbogie, 20 km south-east of Euroa in the Strathbogie Ranges (representing the highlands), suggest that the local rainfall regime has a moderate winter maximum. For example, rainfall in Euroa is at minimum in February (33 mm) and at maximum in June (77 mm). Similarly rainfall at North Strathbogie is at a minimum in February (35 mm) and at a maximum in July (123 mm) (LCC 1984). In terms of the rainfall distribution, it is lowest on the flats (550–630 mm per year) and increases with altitude; rainfall may be as high as 800 mm per year in the headwaters of Castle Creek, Creightons Creek and Pranjip–Nine Mile Creek (LCC 1983, 1984). The mean daily maximum temperature for Euroa varies from 15.2°C in July to 30.2°C in January. The mean daily minimum for Euroa ranges from 3.5°C in July to 11.9°C in January (LCC 1984).

Heavy frosts (i.e. <0.0°C) occur most frequently in the Strathbogie Ranges, but they are also relatively common on the flats. Data from White (1990) indicate that on average 53 heavy frosts are recorded at Strathbogie between April and November each year, and that on the flats at Euroa 10 heavy frost days per year are recorded, primarily between May and September.

According to wind rose data (White 1990) for Euroa for January and July, 50% of wind observations in summer are from the south-east, south or south-west, but in winter more than 50% of observations are recorded in the north-west quadrant.

There are no flow regulation structures on Castle Creek or Creightons Creek, but water is pumped from both creeks for stock and domestic use. Pranjip–Nine Mile Creek provides a domestic water supply for Longwood as well as stock and domestic supply for those landholders with riparian rights. The water supply for Longwood is pumped from a dam on Nine Mile Creek which is situated on the edge of the Strathbogie Plateau.

There are flow gauging stations on Castle Creek at Arcadia (commenced in 1970) and Pranjip Creek at Moorilim (commenced in 1957), but the gauging station at Creighton, on Creightons Creek, was discontinued in 1989 (commenced in 1976) (RWC 1987; pers. comm. Steve Noble, TES Hydrographics, April 1998). All three creeks are spring fed, but the strength of the springs varies. Both Castle Creek and Pranjip–Nine Mile Creek cease to flow in summer, whilst Creightons Creek continues to flow all the way to its confluence with Pranjip Creek, in all years except drought years (O'Connor 1991). Even in drought years when Creightons Creek has ceased to flow on the flats, it has not dried up beyond the Longwood–Mansfield Rd at any time over the last 120 years (pers. comm. Brian Kelly, landholder, Feb. 1998; Stan Artridge, landholder, Feb. 1998).

2.2.2. Geology, geomorphology, pedology and stream condition

The Granite Creeks catchments contain two distinct geologies. In the headwater reaches of the Castle, Creightons and Pranjip–Nine Mile Creek catchments the geology is dominated by the granitic Strathbogie Massif. The Massif is a broad plateau with an undulating granite surface (LCC 1984). The creeks flow out of their granite-controlled headwaters and onto the lowlands where the geology is dominated by alluvial sediments (Geology Map Sheets, Geological Survey of Victoria, 1:250 000, Sheets: SJ 55-1 & SJ 55-2). Between the headwaters and the Goulburn River the creeks flow across the Riverine Plain, which consists for the most part of alluvial material, clay, silt, sand and gravel laid down in the Quaternary (Pleistocene and Pliocene). More recently deposited Quaternary alluvial sediments (Recent and Pleistocene) can be found immediately adjacent to the creeks. Small pockets of Lower Devonian sandstone and siltstone can also be found on the Riverine Plain (Geology Map Sheets, Geological Survey of Victoria, 1:250 000, Sheets: SJ 55-1 & SJ 55-2).

Castle Creek, Creightons Creek and Pranjip–Nine Mile Creek all rise at altitudes of over 500 m AHD. The long profiles of the creeks (Fig. 2.2) are quite similar, dropping steeply from 500 m to 200–250 m over less than 10 km, resulting in gradients of 0.05 up to 0.2. Once the creeks leave the foothills and enter the Riverine Plain their grade is reduced (0.002–0.004). The gradient of Castle Creek declines to approximately 0.001 at 40–50 km from its headwaters, but the gradient of the

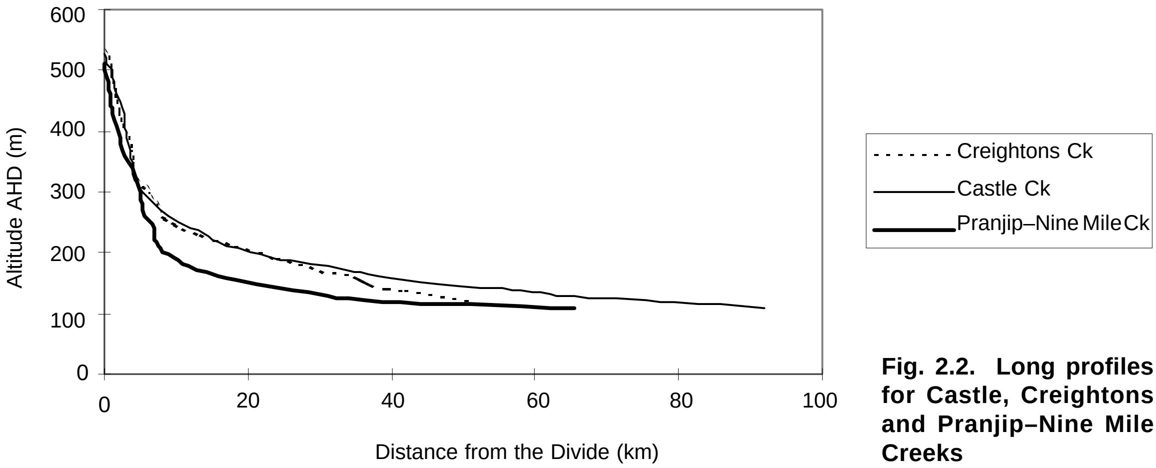

Fig. 2.2. Long profiles for Castle, Creightons and Pranjip–Nine Mile Creeks

lower reaches of Pranjip–Nine Mile and Creightons Creeks remains similar to that observed just below the foothills, i.e. approximately 0.002.

The headwater streams rise on the top of the Strathbogie Plateau in rolling country bounded by scarps, which form the Strathbogie Land System. Soils in this area vary from red duplex soils to weakly bleached friable gradational soils. The erosion hazard for this land system is generally low, although the streambank erosion hazard is moderate (LCC 1984). The streams move down the catchments into the Moonee Moonee Land System. This system is characterised by dissected granitic slopes of high relief, with soils varying from friable brown gradational soils to red gradational soils with weakly structured sub-soils. The erosion hazard here is generally low to moderate; the sheet erosion hazard on the steeper slopes and foothills is moderate (LCC 1984). Further downstream the creeks flow through the Swanpool Land System, which consists of rolling granitic hills and valley slopes and floors comprising Quaternary alluvium. Soils found in this system include yellow duplex soils, weakly bleached friable soils and massive gradational soils. The erosion hazard in the Swanpool Land System is generally low, although the hazard is probably higher (moderate) in the Granite Creeks area because it is drier (LCC 1984).

Several land systems are found on the flats. They include the Lurg Land System, the Benalla Land System, the Slopes Colluvial Land System and the Riverine Plain I Land System (LCC 1983, 1984). The Lurg Land System consists of undulating to rolling hills that have developed on Palaeozoic sediments. On western slopes, undifferentiated stony loams are common, while on eastern slopes red duplex soils and weakly bleached friable and massive gradational soils are found. On the Lurg Land System the streambank and gully erosion hazards are moderate, and the sheet erosion hazard is moderate to high (LCC 1984). The Benalla Land System, which consists of outwash fans, terraces, flats and swamps, is founded on Quaternary alluvium. Soils vary from yellow duplex soils (with some gilgai) to red and brown gradational soils with weakly structured sub-soils. The erosion hazard is generally low although the gully erosion hazard is moderate on gentle fan slopes (LCC 1984). The Slopes Colluvial Land System describes colluvial slopes developed on Quaternary granitic colluvium. Red duplex soils have developed where drainage is relatively good, and yellow to grey duplex soils have developed where drainage is poor. The gully erosion hazard is moderate (LCC 1983). The Riverine Plain I Land System consists of a flat plain sloping towards the north-west, with some prior stream levèes. Where drainage is good, yellow sodic soils develop on the Quaternary alluvium; otherwise the soils are generally grey calcareous sodic uniform clays. The main hazard on this land system is waterlogging.

In a survey of the environmental condition of Victorian streams Mitchell (1990) classified the upper reaches of Creightons Creek as very poor and the middle reaches as poor. The report describes the upper reaches of Creightons Creek as being ‘in very poor condition with heavily cleared eroding banks and sediment build up' (Mitchell 1990, p. 29). The upper reaches of Castle Creek are classed as being in a poor condition and the middle reaches as moderate. Of Pranjip Creek, Mitchell surveyed only the section below the Creightons Creek junction. No detail is provided for any of the other sites.

A more comprehensive survey of stream conditions in the area was carried out in 1992 as a part of an investigation into the Euroa catchments for the Euroa–Nagambie Regional Water Authority (Thompson & Associates 1992). In this survey substantial lengths of waterway in the upper sections of Pranjip, Nine Mile, Creightons and Castle Creeks were classified as unstable or showing severe instability, and some old incision was also noted. Conversely, the lower sections of these creeks were found to be subject to sedimentation, although some old incision and present instability was noted.

2.2.3. Land use and vegetative cover

The main land use in the Granite Creeks catchments is grazing of cattle and sheep (LCC 1983, 1984; Thompson & Associates 1992; Martin 1994). Some cropping occurs on relatively good agricultural land on the flats, whilst other agricultural activities include horse studs (personal observation), vineyards and apiculture (Thompson & Associates 1992; Martin 1994).

The conditions of land selection in Victoria in the 1800s led to the large-scale clearing of vegetation from the Granite Creeks catchments, so that by the 1920s there was little commercially valuable timber left on the flats and only small areas remaining in the hill country (see Section 4.4). Today remnant native vegetation can still be found in the area but it is restricted to some of the rocky ridges in the headwaters, reserves and road reserves. Up on the Strathbogie Plateau, messmate–stringybark open forest, narrow-leafed peppermint open forest and swamp gum open forest are common (LCC 1984). Downslope, the dominant vegetation varies slightly, with broad-leafed peppermint–red stringybark open forest and red stringybark–long-leafed box–red box open forest becoming more common (LCC 1984). The understorey is made up of a variety of shrubs and grasses, including Austral bracken, and there are soft tree ferns in the drainage lines (LCC 1984). In the broad valleys and foothills, red stringybark–long-leafed box–red box open forest is common and red gum open forest is also found. The understorey is dominated by silver wattle, Austral bracken and blackberries (LCC 1984). On the Riverine Plain, open forests/woodlands comprising grey box, yellow box, red gum and bulloak are found, with red gum common along the drainage lines (LCC 1983).

A survey of riparian vegetation in the area in 1992 by Thompson & Associates (1992) indicated that although there were areas where the riparian vegetation was in good condition with a good overstorey and some understorey, for the most part the vegetation was light and discontinuous. There were some segments in the upper catchment of Pranjip–Nine Mile Creek with relatively good riparian vegetation; but on Creightons Creek and Castle Creek the best sections of riparian vegetation were on the Riverine Plain.

2.3. Other physical characteristics

A number of catchment-based physical characteristics have been measured for all three catchments (Table 2.1) to compare the three creeks and determine how similar they are, and to provide further information about the nature of the creeks, e.g. their ability to transport and store sediment. The characteristics measured were catchment area, main stream length (MSL), minimum relief, maximum relief, relative relief ratio (RRR), circularity ratio (CR), average catchment slope (ACS), hypsometric integral (HI) and hillslope channel connectivity (HCC). The RRR is the average slope of the stream channel and the CR is a measure of how close the catchment area is to a perfect circle: the closer the CR to 1, the closer the catchment shape to a circle. The HI is the slope of the hypsometric curve at the point of inflection, where the hypsometric curve represents the way in which mass is distributed within a drainage basin (Strahler 1952). The HCC is a measure of how well the catchment is connected to the drainage network: in other words, how efficiently sediment can be delivered from

Table 2.1. Physical catchment characteristics for the three Granite Creeks catchments and for a number of other catchments in south-eastern Australia

Catchment	Area (km^2)	MSL (km)	Max relief (m)	Min relief (m)	RRR	CR	ACS	HI	HCC
Granite Creeks catchments									
Pranjip–Nine Mile[a]	206	36	510	123	0.011	0.60	3.74°	0.28	~11%
Creightons[b]	174	52.6	545	120	0.008	0.23	4.22°	0.31	~7%
Castle[c]	282	92	530	110	0.005	0.24	3.57°	0.21	~3%
Other catchments									
Lake Eildon	~2500	61	1805	290	0.025	0.31	20.1°	0.34	90%
Candowie Res.	18	5	240	60	0.036	0.63	12.5°	0.47	63%
Lance Ck	17	7	260	70	0.027	0.53	10.4°	0.43	51%
Melton Res.	1155	68	876	70	0.013	0.61	6.2°	0.42	49%
Pykes Ck Res.	120	18	840	360	0.022	0.39	7.3°	0.44	43%
Jerrabombera Ck	133	30	1194	550	0.021	0.35	7.7°	0.30	17%
Lake Eppalock	2028	70	1001	195	0.010	0.50	4.9°	0.30	9%
Lake Albert	77	17	480	195	0.017	0.75	4.4°	0.27	8%
Pekina Res.	135	19	782	440	0.018	0.65	4.5°	0.34	2%

Catchment outlets: [a]Pranjip anabranch confluence, [b]Pranjip Creek confluence, [c]Goulburn River confluence

hillslopes to the catchment outlet (Davis 1996). The higher the HCC value the better the connection, and thus the more efficient the sediment delivery.

A comparison of the characteristics of the Granite Creeks catchments with some other catchments in south-eastern Australia (Table 2.1) suggests that the three Granite Creeks catchments form a distinct group. Rivers with main stream lengths similar to those of the Granite Creeks have much larger catchments, and this is reflected in the unusually low circularity ratios of the Creightons Creek and Castle Creek catchments. It is generally accepted that as catchments increase in size the average slope in the catchment declines and sediment storage within the catchment increases (Walling 1983); consequently stream networks become more poorly connected. The three Granite Creeks catchments studied here are moderately small in size and, on the basis of the model just descibed, would be expected to be relatively steep and well connected. However, the data presented in Table 2.1 show that the Granite Creeks catchments are flat and poorly connected.

The HI can be useful for identifying the extent of geomorphic development of a basin. Strahler (1952) suggests that where HI is greater than 0.60, a basin is in the inequilibrium phase and there is considerable mass at relatively high elevation, while HI between 0.35 and 0.60 represents a basin that has a more uniform distribution of mass across the elevation range. Values of HI smaller than 0.35 occur where most of the basin is at low elevation. The data presented in Table 2.1 indicate that it is relatively common for catchments in south-eastern Australia to have HI values of 0.35 or less, indicating an overall low elevation, and therefore low gradient, landscape. However, the Granite Creeks catchments appear to have HIs among the lowest measured here. Similarly the Granite Creeks catchments have some of the lowest HCC values.

This brief analysis of catchment characteristics for the three Granite Creeks catchments investigated suggests that they have distinctive elongated catchments, dominated by low relief and low gradients. The HIs indicate that the catchments are dominated by extensive low elevation surfaces with isolated relief features, while the HCC values suggest that delivery of sediment from hillslopes in the catchments is inefficient and that the main sources of sediment for the Granite Creeks are the drainage lines.

3. METHODS

3.1. Introduction

When the Granite Creeks Project was conceived it was envisaged that the key hypotheses (see Section 1.2) could be addressed by undertaking the following tasks:

- investigate the history of erosion (gully, sheet and streambank) and stream sedimentation using aerial photos, archival information and local consultations;
- determine present catchment condition with regard to erosion hazard and location of sediment stores, using aerial photos, on-ground fieldwork and local consultations; attempt to map the location of PSA (post-settlement alluvium) using stratigraphic techniques;
- apply sediment tracing techniques to determine potential sediment sources;
- install scour chains to determine the degree of streambed disturbance associated with high discharge events;
- investigate past efforts to control erosion and sedimentation via SCA/DNRE files, on-ground fieldwork and local consultations.

Most of these tasks have been carried out in this study. The mapping of PSA and investigation of past attempts to control erosion were initiated but not completed, because of physical constraints (i.e. difficulties associated with differentiating between modern and old depositional material) and insufficient data (i.e. insufficient data available on past erosion control efforts). Other tasks were substituted for these, so that the study's capacity to address the key hypotheses was not compromised. The substitute tasks included measuring bedload transport rates and monitoring sand movement in the water column at high flows, and both of these have given insight into how sand migrates down the Granite Creeks.

The research questions that are addressed in this study require two distinct methodological components, as outlined in Chapter 1: historical analysis, and a field-based assessment of present conditions. This chapter describes the methods used for the historical analysis and assessment of present condition.

3.2. Historical analysis

The historical analysis used three sources of evidence: (i) documentary evidence, i.e. written historical records; (ii) anecdotal evidence; and (iii) historical cross-section data. For each main source of evidence the specific sources of data are detailed, and where appropriate the methods by which these sources were identified are described.

3.2.1. Documentary evidence

For the purposes of this study an attempt was made to identify all written records which might provide information relating to the form and state of Creightons Creek, Castle Creek and Pranjip–Nine Mile Creek, at any time in the past. The following potential sources of information were investigated: local histories, diaries (e.g. belonging to local squatters, explorers, overlanders); historical maps and plans, and the relevant surveyors' notebooks; Land Selection Files; local paintings and drawings; Shire records; and files held by the Department of Natural Resources and Environment (DNRE) (e.g. local Soil Conservation Authority files and Water Course files). Relevant information on creek morphology was found in all these sources with the exception of paintings and drawings of the creeks because no paintings or drawings were located.

There was a large amount of information and a limited amount of time available to analyse it, so a decision was made to concentrate on one of the three creeks. Creightons Creek was selected, for two reasons: (i) there were more data and information available for Creightons Creek than the other two creeks; and (ii) Creightons Creek was the creek of greatest interest to the researchers working on the ecological component of the project. This meant that although information was collected for Castle Creek and Pranjip–Nine Mile Creek, the Land Selection Files for those two creeks (a main data source) were not investigated.

3.2.2. Anecdotal evidence

To supplement the written information gathered on Creightons Creek, Castle Creek and Pranjip–Nine Mile Creek, local landholders were interviewed to collect undocumented information, such as observations of changes in the creeks over the years. To identify landholders, past and present, who would have such information an article was published in the local newspaper together with a request for information about the creeks. Contacts in each of the catchments also helped identify landholders who might have relevant information. Again, because of time limitations, the information collection focused on Creightons Creek, although landholders living along Castle Creek and Pranjip–Nine Mile Creek were also interviewed. In total 30 people who live or have lived adjacent to the three creeks were interviewed, six from Castle Creek, 20 from Creightons Creek and six from Pranjip–Nine Mile Creek.

In all but four instances the interviews were conducted face to face, generally while walking along the relevant parts of the three creeks. The interviews were not formal in the sense that set questions were given; instead the interview was based on the general question, ‘How has the creek changed over the years and what do you think has contributed to that change?’

While anecdotal evidence can be very useful because it can provide information that cannot be obtained from other sources, its usefulness can be compromised by the interviewee’s ability to clearly recall events in the past, and the potential for exaggeration; and stories that have been passed down through a family can have become distorted over time. Therefore, anecdotal evidence must be treated with some caution. The anecdotal information collected during this study was cross-checked with physical evidence and/or documentary evidence wherever possible, and if the veracity of the information could not be confirmed in some way, it was ignored.

3.2.3. Historic cross-section data

To determine if and how creek morphology has changed since European settlement, historical cross-section data were sought for Creightons Creek, Castle Creek and Pranjip–Nine Mile Creek. Creek cross-section data are often collected in relation to the construction of bridges, and relevant data for this study were held by the Public Transport Corporation (PTC) (railway bridges), the Strathbogie Shire Council (local road bridges) and VicRoads (Hume Freeway bridges).

Cross-sectional data were located for four sites on Castle Creek (Old Hume Highway, North-Eastern Railway, Pranjip Rd, Murchison–Violet Town Rd), five sites on Creightons Creek (Hume Freeway, North-Eastern Railway, Creightons Ck Rd, Longwood–Mansfield Rd, Longwood–Pranjip Rd), and three sites on Pranjip–Nine Mile Creek (Hume Freeway, North-Eastern Railway, Longwood–Pranjip Rd).

At all bridge sites at which historic cross-sectional data were available the creek cross-sections were resurveyed in 1998. The historical data were then plotted against the 1998 survey data to determine if there had been any change in bed level over the periods for which data were available. In interpreting any changes that are apparent from cross-sectional comparisons it is very important to consider local conditions and activities. For example, bed level changes that threaten the integrity of the bridge, either by undermining bridge supports (degradation) or by blockage of the channel (aggradation), would initiate a maintenance program to address the ‘threat’, i.e. the bridge ‘owner’ might place rock beaching in the channel or extract material from the bed in order to protect the bridge. Records of such action are not always available, so in interpreting changes in bed levels one needs to recognise that such activities may have taken place. There was both documentary evidence and physical evidence to suggest that material had been extracted from beneath a number of the bridges under consideration; consequently all bed level changes were interpreted with this information in mind.

3.3. Assessing present condition

When assessing present condition one can use a range of techniques. The type of information sought and the resources available to the project determine which technique is used. This study needed information about the source of sand in the channel, the rate and means by which sand is moving downstream, and the depth of scour and fill associated with downstream movement of sand. Information on the source of sand for the creeks was obtained using field inspections, an approximate sediment budget, and variations in particle size distribution across the catchment. The rate at which sand is moving down the creeks was estimated by measuring bedload transport. An attempt was made to sample the sediment being transported in the water column during high flow events, to determine how sand is moving down the creeks (see Section 3.3.5), but there were no suitable flow events during the monitoring period. Scour chains were installed to measure the extent of cut and fill associated with sand mobilisation along the creek bed.

Just as for the historical analysis, time limitations precluded assessment of all three creeks; hence present condition was assessed for Creightons Creek only.

3.3.1. Field inspections

Field inspections simply involved inspecting a substantial proportion of the creek and its catchment to identify potential sediment sources, i.e. erosion heads, channel widening, tunnelling and sheet erosion. During fieldwork, sediment deposition zones were also inspected.

3.3.2. Sediment budget

To determine where most of the sand in the channel might have come from, an approximate sediment budget was developed. During field inspections, sediment sources and sinks (channel and floodplain or bank storage) were identified and the size of each was estimated. Particle size analyses of channel material and sand drapes along Creightons Creek indicated that fine sediment, i.e. silts and clays (diameter less than 63 μm) are washed through the system. Therefore the budget considered only material that was sand-size and larger. Consequently, all the source material volumes were adjusted to give the sand and gravel content only (the adjustments were based on particle size analyses of bank and hillslope material).

The two main difficulties associated with applying this method were: (i) identifying modern sediment deposits; and (ii) estimating the volume of sediment deposited in the channel. In the initial field inspections, as noted in Section 3.1, it was not always clear if the depositional material that was evident on floodplains and the Riverine Plain had been deposited recently (i.e. post-European settlement, referred to here as Modern alluvium) or before European settlement. In many environments Modern alluvium is easily distinguished from surrounding soil and sediments because it is different in colour and texture, and it usually overlies the old A horizon. On the Riverine Plain, deposition is the dominant process and therefore, while different depositional layers can be seen in exposed creek banks, the age of each layer cannot be readily determined. Where the age of depositional material was unclear, it was assumed to be old.

Estimation of the volume of material deposited in channels is difficult because the original level of the bed prior to deposition cannot always be identified. Two sets of data were used to estimate the original depth of the creek relative to the banks: (i) anecdotal evidence regarding the original depth of pools in the creek; and (ii) probe depths (a steel rod pushed into the creek bed until it reaches a resistant layer which is assumed to be the original creek bed). Neither data set is free of error or complete, so both were used to estimated recent channel storage. Based on estimates of the depth of deposition in pools and on runs or riffles, an average depth of sedimentation was estimated for the width and length of the channel. Deposition of material in old or inactive channels has not been considered because, like the rest of the Riverine Plain, these channels are depositional features and old depositional material and Modern alluvium cannot be differentiated readily.

As a result of the problems associated with estimating the volume of Modern alluvium stored on the Riverine Plain this budget underestimates the stored volume of sediment. In an attempt to adequately account for the stored volume the calculated total deposition volume was doubled to give a final total, in other words a positive error margin of 100% was assumed. This estimate was thought to be reasonable because the Granite Creeks' catchments narrow at the bottom end, indicating that potential storage areas do not increase significantly at the downstream end of the catchments.

3.3.3. Sediment tracing using particle size distributions

Descriptions of techniques

Particle size distributions can provide useful information about sediment movement without the expense associated with some other sediment tracing techniques (e.g. use of radionuclides). Comparison of the particle size distributions of sediment samples taken from different parts of a catchment can tell us something about the origin of material found in sediment sinks. Hence in this section of the investigation, possible source/sink relationships within the Creightons Creek catchment were identified on the basis of particle size distributions.

Four methods were used here to provide information about sediment transport in the catchment, based on particle size distribution data. The Fine Fraction method tracks the proportion of fine material (sediment finer than 63 mm in diameter) in samples taken along a transect of the catchment. The fine fraction at any given site (source or sink sites) is the first fraction to be eroded, so variations in the percentage of fine material between samples from a small area can be interpreted in terms of sediment transport locally.

The Comparison of Histograms method is similar to the Fine Fraction method, but it tracks all sediment larger than 63 mm. The method consists of comparing histograms for sand-size and gravel-size material between nearby samples. By again assuming that finer particles will be mobilised first, patterns of sediment movement can be identified.

The Coarse Fraction method measures the distribution of the coarsest material in the catchment, which in this case is sediment with a particle-size diameter between 6.7 mm and 19 mm. If this material is found in sediment deposits, then its source must also contain such coarse material. This method was used here to narrow down the list of potential sediment sources.

The fourth method employed here was the McLaren technique (McLaren 1981; McLaren & Bowles 1985) which uses trends in particle size parameters to suggest possible sediment sources and sinks for a suite of samples. The technique is based on work conducted primarily in the marine environment which suggests that when the particle size measures (namely, the average particle size, standard deviation and skewness) of a source and a deposit are compared, there can be three outcomes: (i) lag (Case 1); (ii) sequential deposit A (Case 2); and (iii) sequential deposit B (Case 3). The three cases produce two possible sets of trends in measures of particle size (McLaren & Bowles 1985). Material remaining as lag (Case 1) is relatively coarse, relatively well sorted and relatively positively skewed. Sequential deposit A (Case 2) is indicated if the material is relatively fine, relatively well sorted and relatively negatively skewed,and sequential deposit B (Case 3) is probable if material is found to be relatively coarse, relatively well sorted and relatively positively skewed. Case 1 and

Case 3 produce the same trend. Although this technique was developed for use in marine conditions, it has been tested in fluvial conditions and found to be appropriate (e.g. Haner 1984; McLaren & Bowles 1985; Davis 1996).

Four exceptions or limitations associated with use of the McLaren method (McLaren 1981) need to be carefully considered, because if they apply to a case study they render the results of the analysis invalid.

First, when there is more than one source contributing sediment to a sediment sink the technique may fail. This will occur when the relative contributions of the sources are the same, i.e. no one source is dominant. However, it has been hypothesised that where there is one dominant source of sediment to a particular sink the trends will still be visible and valid (Davis 1996). This limitation needs to be carefully considered when the results of the investigation are interpreted.

Second, McLaren (1981) recognised that individual particle size does not always determine sediment transport characteristics, i.e. the assumption that a small particle will be transported farther than a larger particle can be false if flocculation occurs. In this situation, the clay flocs may not be transported as far as they would have been transported as individual clay particles. Hence a comparison of the sediment characteristics of the sediment source and sink may result in the relationship that might have been expected had the source material been coarser. It is difficult to determine whether or not flocculation would have occurred in the field, and so it is important to be aware of this problem as a potential source of error.

The third exception described by McLaren (1981) is closely related to the second exception, but relates to soil aggregates rather than flocculated clay particles. An aggregate can be transported and deposited as a single large particle, but when a sample of sediment is analysed the aggregate may break up (disperse) and be treated as a number of smaller particles. To determine the relevance of this limitation the presence of undispersed aggregates was noted during the laboratory analysis of the samples and is discussed in conjunction with the results in Section 5.3.

The fourth exception recognised by McLaren again relates to changes in grain size during transport. In this case, abrasion during transport, pedogenesis or bioturbation could result in particles becoming finer or coarser.

The relative importance of abrasion and selective transport processes for a given river system is the subject of debate. A number of studies find that abrasion is the dominant process (e.g. Shukis & Etheridge 1975; Kodama 1994), while others find that selective transport is the more important process (e.g. Breyer & Bart 1978; Brierley & Hickin 1985). Not only is this lack of consensus confusing, but most of the work done on abrasion has not considered small systems such as Creightons Creek. Recent work by Dyer (1998) on soil samples taken from a catchment just west of Melbourne indicates that when granite-derived soils are transported along a stream system for a distance of approximately 8 km, sand and gravel material (i.e. material larger than 63 mm in diameter) is abraded, resulting in a reduction of 3–30% in the total mass of coarse material. Most of the abraded material is converted to particles with a diameter of less than 10 mm. These data suggest that the movement of sand and gravels along Creightons Creek may result in abrasion, which is a potential source of error for the McLaren Technique.

The precise effects of bioturbation and pedogenesis on the particle size distributions of soil samples is unclear. These two processes can either fine or coarsen soil material. Bioturbation affects particle size distributions mainly via mixing (Hole 1981; Conacher & Dalrymple 1977), whereas pedogenesis has a less clear effect and thus is very difficult to predict, because although fining generally results, coarsening can also occur in some parts of the soil profile (Brady 1984).

The effects of bioturbation and pedogenesis on the particle size distributions of the samples taken in the Creightons Creek catchment may only be important where these processes have different effects on the samples. For example, it is probable that bank samples taken throughout the sub-catchment are affected to the same degree by bioturbation and pedogenesis, but the effects on samples from the hillslopes, creek bed and sand drapes can be different. It could be assumed that creek bed and sand drape samples would not be affected significantly by either bioturbation or pedogenesis because they have been recently deposited. Conversely samples on the hillslopes might be differentially affected by bioturbation and/or pedogenesis. Therefore, for example, it may not be correct to attribute fining in the footslopes to deposition of material from upslope. However, it appears unlikely that either would have any substantial effect. Bioturbation, for example, can result in the mixing of the A and B horizons. However, the deeper horizons consist of weathered regolith and then bedrock — that is, the soil material coarsens with depth — so mixing normally results in coarsening of the sampled footslope material. Because the samples were not taken in obviously bioturbated areas, it may be possible to assume that bioturbation did not have a significant influence on comparative results.

Similarly pedogenesis may not have a significant effect on the particle size distributions of the hillslope samples. Although one might expect pedogenesis to result in differences in the particle size distributions of samples found on different parts of the hillslope, the literature suggests that these differences may be the result of lateral slope processes (e.g. Dalrymple *et al*. 1968; Conacher & Dalrymple 1977; Paton 1978). Hence the effect of pedogenesis on the particle size distributions of the hillslope samples is probably of minor significance when compared with the impact of sediment transport processes, particularly in relation to the time period of relevance here, i.e. just 150 years.

It is concluded that neither bioturbation nor pedogenesis would have had a significant impact on particle size distributions in the Creightons Creek catchment. However, abrasion may be significant during creek transport and thus may be a source of error for the McLaren technique. In this study, to reduce the impact of abrasion-related errors, potential source/sink relationships were limited to those in which sediment transport distances were relatively small, i.e. only local samples were compared.

To apply the McLaren technique the three particle size distribution parameters (average particle size, standard deviation and skewness) must be calculated for each sample. For the purposes of this analysis moment measures were used to derive these parameters. The phi mean, standard deviation and skewness were calculated as described by Krumbein & Pettijohn (1938) and used to set up a sediment trend matrix, as indicated in Table 3.1.

Each sample was listed across the top and down the left side of the matrix. Every sample was then compared and classified in terms of particle size (coarser or finer), standard deviation (poorer or better sorting) and skewness (more positive or negative). The results contained in each cell were compared to the two transport indicative trends described by McLaren & Bowles (1985).

Relationships that did not fit one of these two trends were discarded. For each of the remaining cells the proposed relationship was examined, and impossible or highly improbable relationships were also discarded (e.g. the creek bed as a source for the top of the hillslope). To reduce the effect of abrasion and multiple sources on the application of this technique only local source/sink relationships were considered; in other words, only immediate downslope or downstream sinks were considered for a given source. The remaining relationships indicate probable sources, deposits and sediment transport paths.

Clearly all four methods (i.e. the Fine Fraction method, the Comparison of Histograms, the Coarse Fraction method and the McLaren technique) are subject to assumptions and limitations, the effects of which cannot be readily assessed. However, because four independent techniques were applied and assessments are based on *all* the results, the errors associated with the assessment should be minimal. Furthermore the results derived from particle size analyses are combined with sediment budget data and field observations to give an assessment of the primary sediment source. By using a range of techniques in this manner it is possible to qualitatively assess the validity of the results.

Table 3.1. Sediment trend matrix format

		Source			
	Sample	**A**	**B**	**C**	**D**
Deposit	**A**				
	B				
	C				
	D				

Sediment sampling and analysis procedure

To help identify the possible sources of sediment for various sinks in the Creightons Creek catchment, a sampling scheme was devised which recognised all possible sediment sources (hilltop sites, mid-slope and footslope sites, creek bed and banks) and sinks (creek bed, sand drapes, mid-slope and footslope sites). Figure 3.1 shows the locations of sampling sites. At the three upstream sites (i.e. JN, SA and DF), hillslope, streambank, creek bed and drape samples were taken. At the three sites down on the flats (i.e. MB, SC and LW) where there are no hillslopes, only streambank, creek bed and drape samples were taken. Sand drapes were not present at all sites, so drape samples were not taken at every site.

Two aspects of sampling techniques need to be considered. The first is sample size in relation to mass: this is a statistical problem. From an engineering point of view, the sample should be of sufficient size that 'accidental exclusion or inclusion of a single large particle will not significantly affect the result' (SAA AS 1289.1 1991, p. 5). The samples taken in this study were between 400 g and 3 kg, as prescribed in Australian Standard 1289.1. The second aspect to be considered is the depth of sampling because it will affect the time resolution of the study. This is not such a problem in source areas where depth variations are not very critical and a sample of 5 cm will suffice. However, in depositional areas different sampling depths may result in the collection of samples derived from different sources, e.g. drape sediments. In some places it may be useful to sample to different depths to detect changes in the sediment source, but because of the time constraints associated with this exercise it was necessary to limit the sediment path tracing investigation to recent movement. Hence sediment samples from the creek bed and the drapes were taken from deposits thought to be of most recent origin; e.g. creek bed samples were taken in the main channel, within 5 cm of the bed surface.

One other issue that needed to be addressed was representative sampling. For hillslope samples and creek bed samples, this issue was dealt with by taking three widely spaced samples at each site and bulking the samples. As a result of this procedure, and the need to sample the active channel when taking creek bed samples, a method was required which allowed samples to be taken beneath flowing water without the loss of the fine fraction that is trapped in the sediment matrix. This problem was overcome by used a yabby pump to draw up sediment and pore water, thus retaining the fines. Representative bank samples were difficult to obtain because of the variability of bank material in some parts of the catchment. Exposed banks allowed bank material to be observed; it was relatively homogeneous in some areas, but quite variable in others (e.g. at site SA). The noted variability has probably arisen where valley fill has been incised. The valley fill would be expected to consist of material deposited under a variety of climatic conditions, resulting in a range of particle size distributions.

To overcome this difficulty, each of the apparent bank sediment types was sampled and then all were bulked together. In each instance, the proportion of each bank source was estimated relative to another,

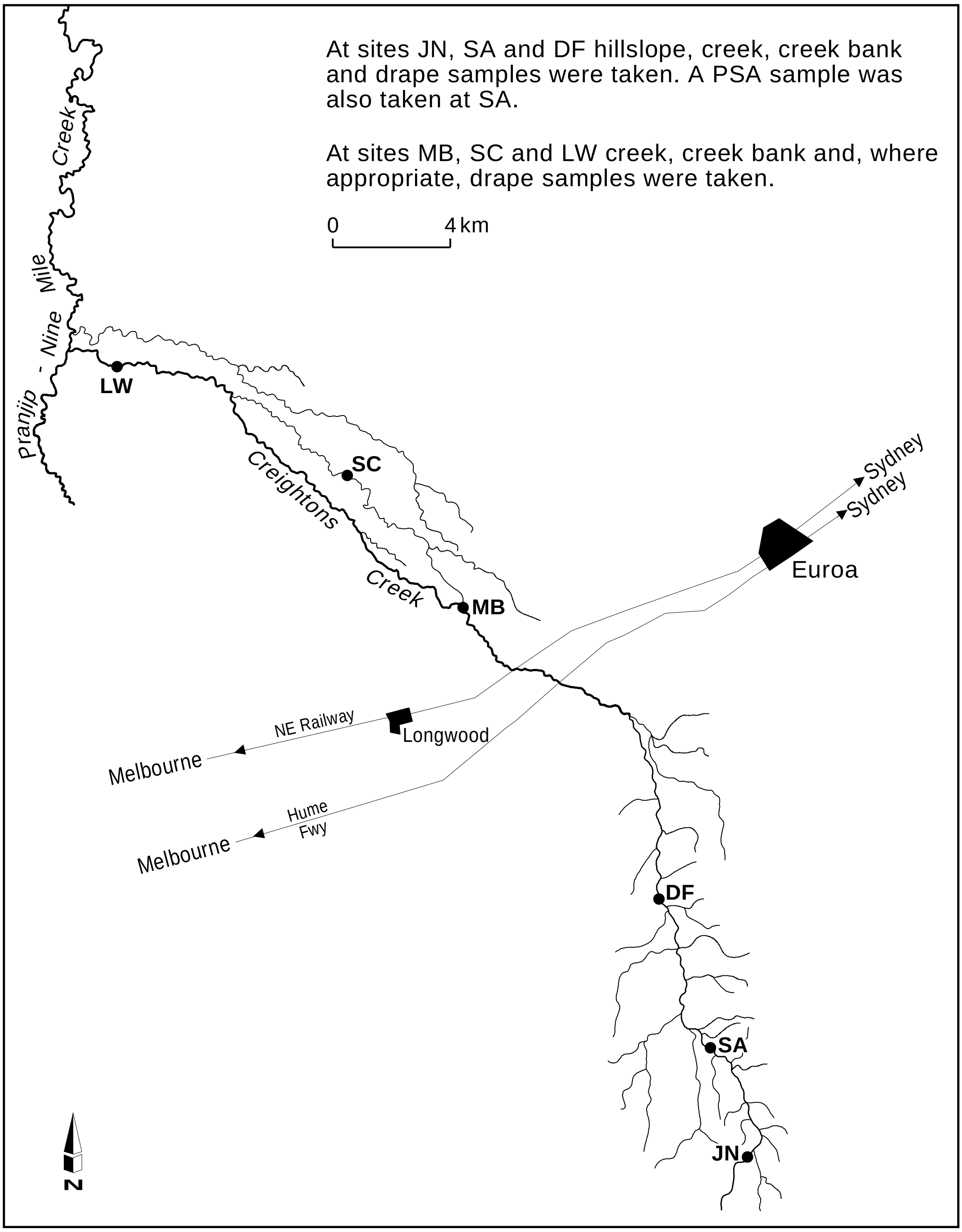

Fig. 3.1. Creightons Creek sediment sampling sites

and the sample size was scaled accordingly, i.e. where a bank was dominated by material type A, and only a small amount of material type B was available the bulked sample consisted mostly of material type A.

The samples were returned to the laboratory where they were analysed to determine their particle size distribution. The analysis procedure is described below and is based on procedures outlined in Australian Standard 1289 (SAA 1991).

1) All samples were air dried (at which time organic material was removed by hand).
2) Where appropriate, aggregates were crumbled with a roller and the sample was sub-sampled (using a sample divider) to provide two samples: one for oven drying and the second for particle size analysis.
3) The first sub-sample was placed in an oven at 105–110°C until a constant mass was obtained on repeated weighing; the moisture content of the air dried sample was calculated.
4) The second sub-sample was weighed, then covered with dispersing solution (sodium hexametaphosphate ($Na(PO_3)_n.Na_2O$), agitated and left for one hour.
5) The second sub-sample was wet sieved using a 63 mm sieve; a sample of the wash solution (containing the fine fraction) was taken to allow further analysis if required, and the coarse fraction was oven-dried at 105–110°C until a constant mass was obtained.
6) After oven drying, the coarse fraction of the second sub-sample was dry sieved using a mechanical shaker for 15 minutes, with the following sieve mesh sizes:

   19 mm (–4.25f); 6.7 mm (–2.75f); 4.75 mm (–2.25f); 2.36 mm (–1.25f); 1.18 mm (–0.25f); 600 mm (0.75f); 425 mm (1.25f); 300 mm (1.75f); 212 mm (2.25f); 150 mm (2.75f); and 63 mm (4f).
7) The weights of the samples collected in each sieve were used to calculate the percentage passing the 63 mm sieve (i.e. the percentage of clay and silt), as well the particle size distribution of the coarse fraction (>63 mm).

This procedure was applied to all except the hillslope samples. As is indicated by the above procedure, samples were generally not treated for organic matter. Most samples had a negligible organic content and the small amount of material could be removed by hand during processing. The hillslope samples, however, appeared to contain a significant proportion of organic material and manual removal was not judged to be sufficiently successful; consequently an extra step was added after step 5 for these samples. They were ashed to remove all organic matter by placing all the sample or a sub-sample into a furnace at 550°C until constant weight was obtained (Franson 1995). Then the hillslope samples were dry sieved as described in step 6 and the data were analysed as in step 7.

3.3.4. Scour chains

Scour chains were used in this project with the objective of gaining information about the depth of scour and fill that occurs in the sanded sections of the creeks. Scour chains were installed in the creek beds at various locations and under a variety of flow conditions. The depth of scour and fill is of interest for two reasons: (i) it provides information about the way in which sand is being transported down the creeks, with respect to the size of bedforms; and (ii) it indicates the depth at which the bed material becomes mobile and thus the extent of habitat disturbance for benthic organisms.

Scour chains have been used in a range of fluvial environments to measure scour and fill during a flow event (Laronne *et al*. 1994). Although scour chains do not provide as much detail as continuous monitoring using a depth sounder for example, they are a low cost alternative. Their use involves placing a chain vertically in the creek bed with a small proportion of the chain protruding from the surface and lying on the creek bed (see Fig. 3.2). The length of chain protruding from the creek bed is measured. When the bed is scoured out, the chain drops down to the scour level and it is buried under the fill material. Consequently once the chain is relocated (i.e. after a flow event) the depth of scour and fill can be estimated simply by measuring the length of chain protruding from the bed at the bed level at which it is found and measuring the length of chain protruding from the bed after the area around the chain is refilled to the new bed height (see Fig. 3.2).

Twelve scour chains were inserted into the beds of the three creeks using a pipe inserter which allowed the chains to be inserted to a depth of 0.5–0.8 m with minimal disturbance to the bed, as

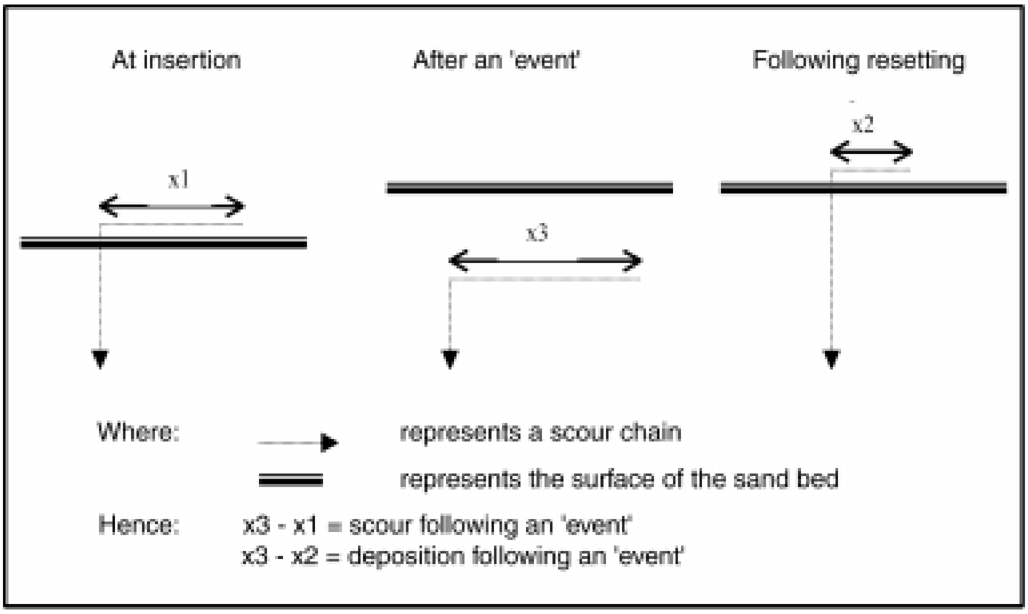

Fig. 3.2. Diagrammatic representation of scour chain measurements

follows. At each site a brass point was attached to a 1.2 m length of chain which was then fed into a pipe 1.7 m long with a collar halfway along its length. Extra chain was attached to the end of the scour chain so that it extended from the end of the pipe and could be pulled tight to keep the scour chain straight during insertion. A hollow post-hole driver was then placed over the pipe and used to strike the collar and drive the pointed end of the apparatus into the creek bed. Once the point had been driven far enough into the bed the pipe and driver were carefully pulled out, leaving the chain and point in place. The extra chain was disconnected from the scour chain and the protruding length of scour chain (surface chain) was measured. Upon return to the site following scour and fill activity the chain was located in the bed using metal probes and a hole was dug down to expose the chain sitting at the maximum scour level. The length of surface chain was then measured, the hole backfilled (while the chain was held vertical) to the new bed level and the remaining protruding chain length measured. The depth of scour was then calculated by subtracting the surface chain length measured after back fill on the previous visit (x_1) from the surface chain length measured at maximum scour level for the current visit (x_3). The depth of fill was calculated by subtracting the surface chain length measured after back fill on the current visit (x_2) from the surface chain length measured at maximum scour level for the current visit (x_3) (see Fig. 3.2).

Scour chains were placed at six sites on the three creeks, two chains at an upstream site and two at a downstream site on each creek. The sites were selected for two reasons: (i) to determine if scour and fill behaviour varied between sites at different locations on the sand slug; and (ii) to measure scour and fill at sites adjacent to biological sampling sites associated with the ecological component of the project. At each site a cross-section was selected on a straight section of stream (to avoid obvious sites of long-term degradation and aggradation) and two chains were placed in the creek bed along the cross-section to detect differential scour and fill. The locations of the six sites are shown in Fig. 3.3 and Table 3.2.

3.3.5. Suspended load sampling

Traditionally, suspended load sampling has been conducted to determine the rate at which fine sediment (i.e. silt and clay) suspended above the streambed has been moving down the stream. Clearly, fine sediments are not at issue in the Granite Creeks, but it is important to know if coarser

Table 3.2. Scour chain site locations

Site no.	Creek	Approximate location	Property owner
1	Castle Ck	Below the Hume Freeway	Bamford
2	Castle Ck	Below Drysdale Rd	Kubeil
3	Creightons Ck	Below the railway line	Carlsson
4	Creightons Ck	Below Pranjip–Longwood Rd	Caldwell
5	Pranjip NM Ck	Killeen (above Longwood–Mansfield Rd)	Cameron
6	Pranjip NM Ck	Above Longwood–Avenel Rd	Threlfall

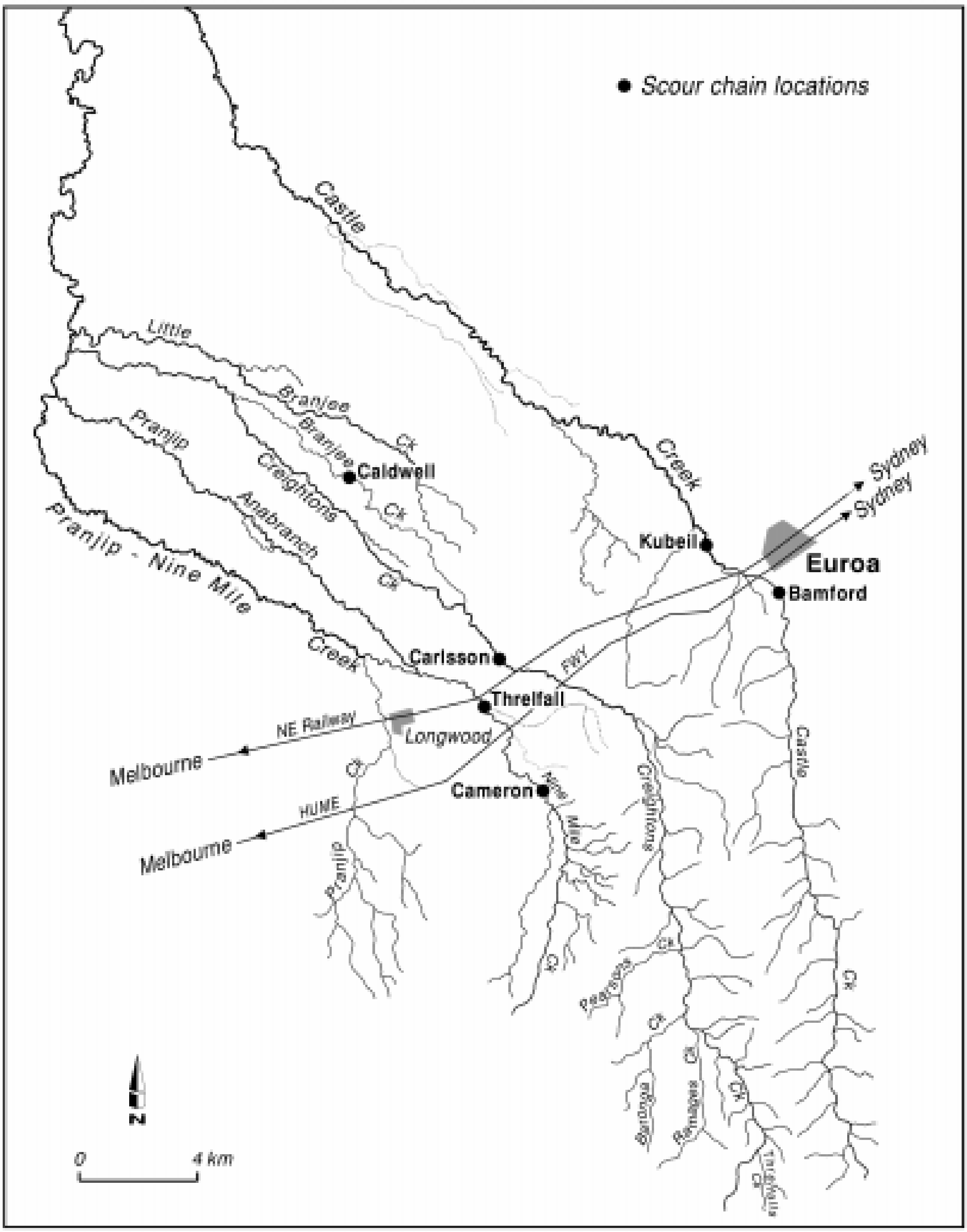

Fig. 3.3. Map of scour chain locations

Fig. 3.4. An example of a high-level sand drape

sediment (sand) is being transported suspended in the water column during high flow events, because this affects the places to which the system delivers the sand. As was noted in Chapter 2, once the Granite Creeks reach the Riverine Plain they begin to anabranch; therefore, during high flow events only a portion of the flow remains in the main creek channels, and the rest moves out into the anabranches. Many of the anabranch off-takes observed on the Granite Creeks are well above bed level and more often than not flow must overtop the banks to enter an anabranch. As a result, sand being transported as bed load would be unlikely to enter these anabranches. However, sand drapes visible on stream banks after high flows (Fig. 3.4) suggest that sand might be transported high in the water column during high flow events, in which case it could be expected that sand would be delivered to and possibly stored in the streams' anabranches, with implications for sand slug migration along the lower reaches of the Granite Creeks.

To better understand how sand migrates along a sand slug during high flows and the potential for anabranches to divert sand from the main channel, a suspended sediment sampling scheme was set up. This consisted of taking samples of water and suspended sediment at several levels above the bed during high flows and determining the average concentration of sand in the water column. While conceptually this sampling exercise was simple it was not easy to find equipment that could be used to sample sand-size sediment under the physical conditions described here. Most suspended sediment samplers, e.g. the P61, are designed to sample fine sediment and so have only a small inlet. Consequently a 'suspended sand sampler' had to be designed and built for the purpose.

The suspended sand sampler was designed as an open tube aligned with the flow, through which sediment and water pass until the ends are sealed simultaneously. The trapped water and sand provide a snap shot of the sediment concentration at a particular height above the creek bed at some point during a high flow event. The final design of the suspended sand sampler is depicted in Figs 3.5 and 3.6. Essentially the sampler consists of four pieces of 100 mm diameter PVC pipe held in a metal rack which sits above the creek bed. The lowest tube is 30 cm above the creek bed, the next two tubes are 60 cm and 90 cm above the bed, and fourth tube is 120 cm above the bed. One-way swing valves are attached to the ends of each tube and can only open out. A piece of elastic cord runs through the centre of each tube and is attached to the inside of each valve, the cord being tensioned so as to hold the valves shut and prevent all but minor water leakage.

Before installation a test sampler was tested for leakage. A set of sand samples with various particle size ranges was prepared: >64 mm, >212 mm, 64–150 mm, 150–212 mm and 212–600 mm. Samples were placed in the sampler (which was full of water) for 1 hour and 24 hours and the sediment that leaked from the sampler was collected to determine leakage. Sand losses for all particle size ranges and leakage periods were negligible — less than 1% on average.

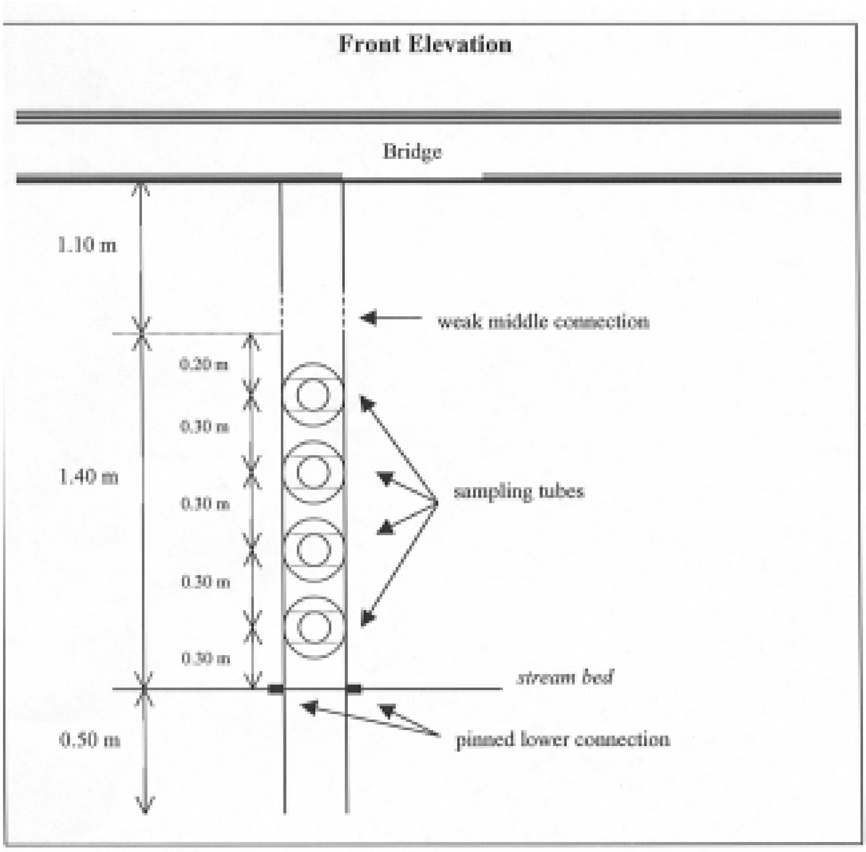

Fig. 3.5. A diagrammatic representation of the suspended sediment sampler

Fig. 3.6. Two views of the suspended sediment sampler

Fig. 3.7. A small Helley-Smith Bedload Sampler being used to sample bed load in Creightons Creek

The valves are pinned open prior to an event, with the pins attached to a mechanism that releases them all at once, thus allowing all four levels in the water column to be sampled at once. To prevent the apparatus being undermined, four support posts are inserted 0.5 m into the creek bed and the top of the rack is attached, via extension legs, to a bridge. During a storm event, debris might become caught on the apparatus, ultimately leading to the failure of the bridge, so the three connection points (Fig. 3.5, Points A, B and C) were either pinned or made relatively weak so the apparatus would collapse before a debris build-up caused damage.

Initially it was intended that the release mechanism would be triggered by a float; in other words the tubes would close when the flow reached a particular height. However, the load required to release all eight valves was found to be far higher than could be supported by a float and so instead the apparatus was set up to be triggered by a person from the bridge. A landholder who lives adjacent to the site agreed to trigger the sampler when preferred conditions occurred for triggering. Preferred conditions were: (i) on the rising limb of the storm event; and (ii) close to the peak of the event. The landholder would also record the time at which the apparatus was triggered so that the sampling stage could be estimated from continuous stage monitoring equipment that was installed at the site.

Despite the fact the sampler had been installed for more than six months (18/1/99–16/7/99) when the geomorphic study drew to a close, no appropriate high flow events had occurred and thus no data had been collected. While the sampler will continue to be monitored and data will eventually be collected, they could not be included in this report. It is anticipated that a separate report on the results of the suspended sediment sampling investigation will be released later, once sufficient data have been collected.

3.3.6. Bedload sampling

For estimating bedload transport rates there are two alternatives: direct measurement or estimation via bedload equations. Both alternatives are difficult and as a result bedload estimation is problematic. Hean & Nanson (1987) have reported that there are serious problems with using bedload equations to estimate bedload in south-eastern Australia, indicating that the equations cannot be used to provide reliable evaluation of catchment sediment yields. Measurement of bedload is complex (Gaweesh & van Rijn 1994) and accurate measurement is difficult to achieve (Gordon *et al*. 1992). Measurement is further complicated by the need to monitor bedload transport over a range of flow conditions which would require at least several years of data, and such a program could not be accommodated within the confines of this project. Given these difficulties it was not feasible to try to estimate average bedload transport rates, but it was clear that it would be useful to have some idea of the magnitude of bedload transport under various flow conditions. Consequently bedload transport was measured at two sites on Creightons Creek on several occasions: adjacent to Stan Artridge's property (SA in Fig. 2.1) on six occasions and adjacent to Maurie Brodie's property (MB1 in Fig. 2.1) on four occasions.

Bedload transport rates were measured using a Helley–Smith pressure difference sampler (Helley & Smith 1971) (see Fig.3.7). The Helley-Smith sampler is a portable device which sits on the streambed and captures bedload in a mesh bag, allowing water and fine sediment to pass through. This type of device is said to be most practical for measuring bedload (Hubbell *et al*. 1985) and the Helley–Smith bedload sampler is considered to be one of the most successful models (Richards 1982).

There are procedures available for using the Helley-Smith bedload sampler for measuring bedload at a given cross-section, but they are generally directed at sampling large rivers during high flow events (e.g. Gaweesh & van Rijn 1994; Locher 1997), so a modified procedure was devised for sampling in the Granite Creeks. The main sources of error for bedload sampling are: instrument error; spatial variability; and temporal variability (Gaweesh & van Rijn 1994), so effort was made to minimise these errors in the modified procedure. The problem of spatial variability was dealt with by inspecting bedload movement at each cross-section and splitting the cross-section up into segments in which similar rates of bedload movement were apparent. Bedload movement was then measured at each segment. Once (during a high flow event) the bed was obscured by turbid water; in this instance the cross-section was divided up on the basis of variations in velocity and depth (factors which influence bedload transport rates). The problem of temporal variability was addressed by resampling those segments at which bedload transport rates were highest (i.e. those segments which would contribute the most error).

Instrument error generally occurs because of disturbance of the bed, development of a gap between the sampler and the bed and scooping of the bed with the sampler (Gaweesh & van Rijn 1994). These errors were more difficult to address, but on most occasions the sampler could be watched during sampling and adjusted if such problems were observed. Each segment was sampled for 10 minutes. This period was found to give reasonable size samples when bedload transport rates were highest, without over-filling the sample bag, which can cause sampling errors (Gaweesh & van Rijn 1994).

After sampling, the bedload samples were washed into a sample bag and transported back to the laboratory where they were oven dried at 105–110^{o}C until constant mass was achieved. From these data, transport rates were calculated in the form of mass per unit time. Some samples were also analysed to determine particle size distributions.