supervising scientist report **188**

Bed-material grain size changes in the Ngarradj Creek catchment between 1998 and 2003

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Australian Government

Department of the Environment and Heritage

Supervising Scientist

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This report should be cited as follows:

MJ Saynor, WD Erskine & KG Evans 2006. *Bed-material grain size changes in the Ngarradj Creek catchment between 1998 and 2003*. Supervising Scientist Report 188, Supervising Scientist, Darwin NT.

The Supervising Scientist is part of the Australian Government Department of the Environment and Heritage.

Supervising Scientist
Department of the Environment and Heritage
GPO Box 461, Darwin NT 0801 Australia

ISSN 1325-1554

ISBN 0 642 24396 4

e-mail: publications_ssd@deh.gov.au

Internet: www.deh.gov.au/ssd (www.deh.gov.au/ssd/publications)

Printed and bound in Darwin by uniprint NT

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Executive summary

The catchment of Ngarradj Creek is located in the wet dry tropics of the Northern Territory, Australia, and is a major right-bank tributary of the Ramsar-listed Magela Creek wetlands. It contains the Energy Resources of Australia Jabiluka project area which is currently in a long-term care and maintenance phase. As part of a long-term study of rates of geomorphic processes within the catchment, a series of research projects were initiated in 1998 by the Environmental Research Institute of the Supervising Scientist (***eriss***). One of the projects involved determining baseline graphic grain size statistics of the bed material and other sediment stores within the catchment and evaluating any impacts of the Jabiluka project area on these statistics. The graphic grain size statistics investigated included graphic mean size, inclusive graphic standard deviation, inclusive graphic skewness, graphic kurtosis and normalised kurtosis.

Bulk sampling was used to collect mainly bed material but also bar, bench, floodout, splay and distributary channel sediments on the tributaries draining the Jabiluka project area as well as Ngarradj Creek at the Swift Creek gauge downstream of the junction with the Jabiluka project area tributaries. The gauging reaches on Ngarradj Creek at upper Swift Creek and on East Tributary, upstream of the Jabiluka project area, were also sampled at the same time and served as multiple reference sites that were not impacted by the Jabiluka project area. Bed-material was systematically sampled every dry season between 1998 and 2003 but other sediment storages were usually sampled only once between 1998 and 2000. The 56 permanently monumented cross sections used to assess channel changes served as the bed-material sample sites because they ensured that the sample sites could be accurately relocated each year. All samples were sieved and graphic grain statistics were calculated from the cumulative percentage grain size distributions.

The grain size statistics for the period 1998 to 2003 indicated that:

- Tributary Central had the coarsest graphic mean size and the greatest range in grain size statistics because three different types of river reaches were sampled. There was no change in graphic grain size statistics between 1998 and 2003.
- Tributary North main gully and Tributary North tributary gully have similar grain size statistics which are different from those for the Tributary Central and gauging station river reaches. There was no change in graphic grain size statistics between 1998 and 2003 on Tributary North main gully but inclusive graphic skewness and graphic and transformed kurtosis increased after 1998, most probably due to the effects of dry season fires.
- The East Tributary, upper Swift Creek and Swift Creek gauging station reaches have similar graphic grain size statistics. Graphic mean size increased at all three sites between 1998 and 1999 and the data analysis indicated that this increase was statistically significant at $\rho = 0.05$ level for East Tributary ($\rho = 0.01$) and Swift Creek ($\rho = 0.014$), although the increase was not significant ($\rho = 0.053$) at upper Swift Creek. Graphic and transformed kurtosis also changed significantly after 1998 at upper Swift Creek and inclusive graphic skewness changed significantly after 1998 at the Swift Creek gauge. After the increase between 1998 and 1999, graphic mean size remained relatively constant at all three main channel sites until 2003. The trend in graphic mean size recorded at the downstream Swift Creek gauge was also observed at the upstream East Tributary and upper Swift Creek sites indicating that it was an upper catchment-driven and not a project area-driven change. A coarse-grained phase of sand transport in the

main channel network commenced after 1998 but was not generated by the Jabiluka project area tributaries, despite the construction of the Jabiluka project area during the 1998 dry season. The multiple upstream reference sites that were not impacted by the Jabiluka project area were important to determine that this increase was caused by a similar change at both upstream reference sites. A longer record (greater sample size) is still required before the change is significant at $\rho = 0.05$ in the upper Swift Creek gauge reach.

The grain size statistics constitute thorough baseline information for the Ngarradj catchment and can now be used to determine any subsequent changes due to future activities on the Jabiluka project area. Box plots for each site, when combined with appropriate statistical tests, can be used to assess future departures from these baseline data. This will be important if the Jabiluka project area is reopened in the future as well as to assess the efficacy of the Jabiluka project area rehabilitation.

Acknowledgments

For their assistance with the field work we thank Bryan Smith, Gary Fox and Elice Crisp. Bryan Smith analysed the laboratory samples and entered the data onto spreadsheets. Ann Webb greatly assisted with the finalisation of the report. Dr Maria Schrieder provided helpful advice on statistics. We thank Dr Max Finlayson, Dr David Jones and Dene Moliere for their helpful comments on the draft manuscript.

This Supervising Scientist Report has been formally refereed by two external independent experts in line with Supervising Scientist publication policy – Professor Bob Wasson (Charles Darwin University) and Dr Stewart Franks (University of Newcastle). We thank them for their comments and recommendations.

Bed-material grain size changes in the Ngarradj Creek catchment between 1998 and 2003

MJ Saynor, WD Erskine & KG Evans

1 Introduction

Erskine et al (2001) proposed that the Environmental Research Institute of the Supervising Scientist (***eriss***) should adopt a sediment budget framework to assess the physical impacts, if any, of the Jabiluka project area on the Ngarradj catchment (fig 1). Thirteen projects were outlined to form the basis of this assessment, including the systematic sampling and grain size analysis of channel and floodplain sediments, and other sediment storages on Ngarradj Creek and the Jabiluka project area tributary channels (fig 1).

The bed-material on the two Jabiluka project area tributaries (Tributaries North (TN) and Central (TC)) and the main channel (Ngarradj (SC)) further downstream were sampled because these channels are the pathways for the movement of sediment from the Jabiluka project area and out of the drainage basin (Erskine et al 2001). Two reference river reaches were also selected upstream of any influence of the Jabiluka project area and they contain the gauging stations on East Tributary (ET) and Ngarradj (upper Swift Creek (UM)) (fig 1). A formal BACI (before-after, control-impact) design could not be used because the impact and reference sites included a range of different river typologies according to Erskine et al's (2005) classification, as outlined in Section 5. Hence the reference sites were not true sedimentological controls.

The purpose of this report is twofold:

- to analyse the extensive bed-material particle size data collected by ***eriss*** at each of the 56 permanently marked cross sections discussed by Saynor et al (2002a, 2004a) and at other discrete sediment storages in the Ngarradj Creek channel network (Saynor et al 2004b);
- to assess changes in grain size statistics for the six years from 1998 to 2003 inclusive, which can then be used for impact assessment.

The Jabiluka project area headworks and infrastructure were constructed during the 1998 dry season (Johnston & Prendergast 1999). The first sediment samples were collected before streamflow commenced for the 1998/1999 wet season and hence represent pre-impact data prior to possible erosion of sediment from the Jabiluka project area and subsequent supply to the channel network.

Saynor et al (2001) outline all the geomorphic field monitoring that is being conducted by ***eriss*** in the Ngarradj catchment. The current work forms part of a much larger program determining rates of various geomorphic processes in the Ngarradj catchment for an evaluation of the impact of mining (Erskine et al 2001).

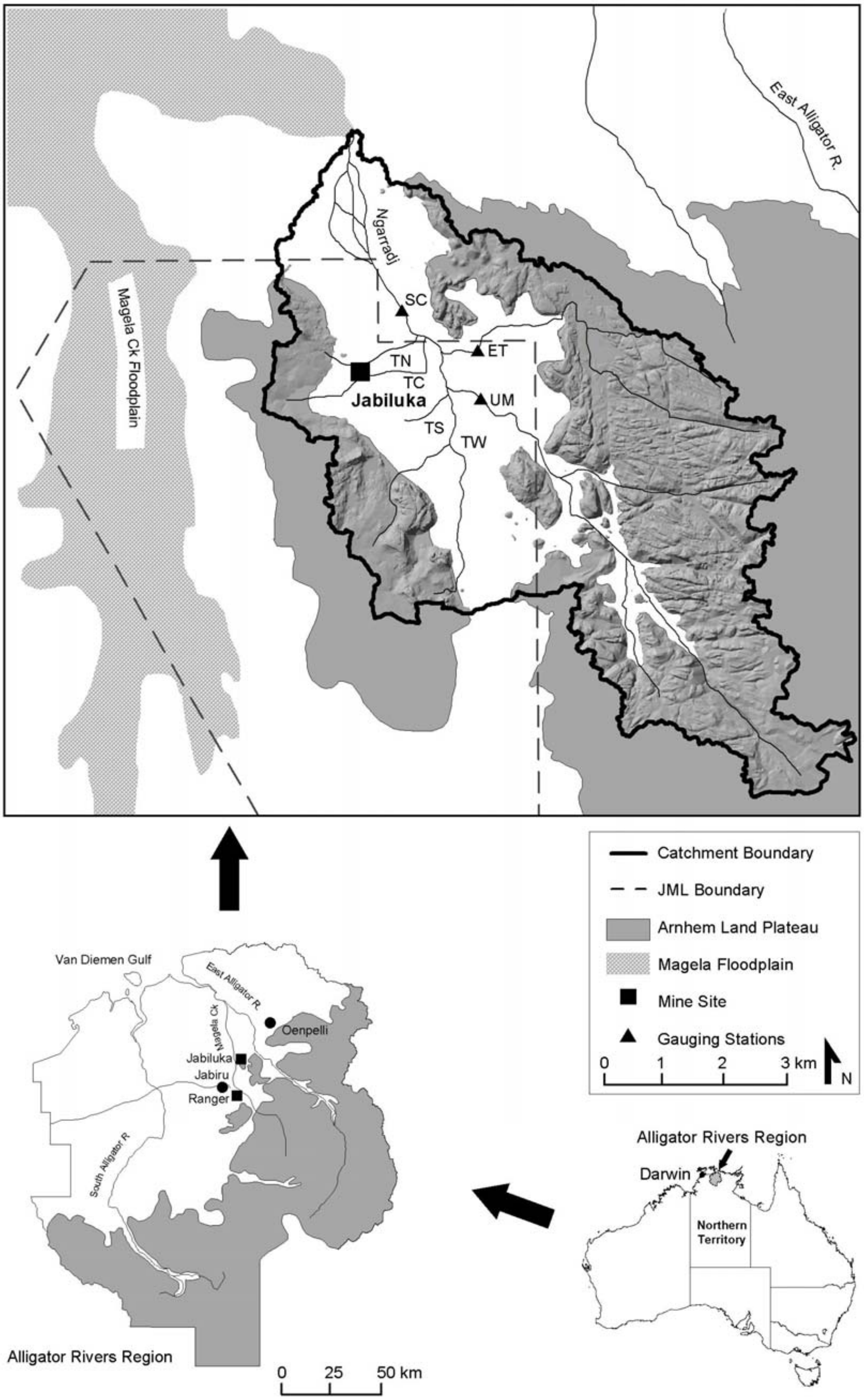

Figure 1 The Ngarradj catchment showing the Jabiluka project area and Mineral Lease (JML), gauging stations and local creek names. SC refers to Swift Creek gauging station, TN Tributary North, ET East Tributary gauging station, TC Tributary Central, TS Tributary South, TW Tributary West and UM upper Swift Creek gauging station. SC and UM gauging stations are located on Ngarradj Creek.

The processes being measured include suspended sediment transport (Moliere et al 2000, 2004, 2005, Evans et al 2003, 2004a, b), bedload transport (data currently being analysed), water quality (Evans et al 2003, 2004a, b), catchment hydrology (Moliere et al 2002a, b, Boggs et al 2003), gully initiation (Saynor et al 2004c), bank erosion (Saynor et al 2003, Saynor & Erskine 2006), contemporary channel changes (Saynor et al 2004d), scour and fill (Saynor et al 2004d), long-term landform evolution (Boggs et al 2000, 2004) and large wood loadings and their role in stabilising channels (data currently being analysed). Erskine et al (2003) describe the bed-material textures at the sites where scour chains were installed as well as floodplain sediment textures at four sites in the Ngarradj catchment. This report complements but significantly expands upon the data in Erskine et al (2003). The grain size data used in this report are presented in Saynor et al (2004b).

In the following section, the field and laboratory methods, procedures for calculating grain size statistics, the sediment textural classification adopted and the methods of statistical analyses are presented. Then catchment characteristics and the hydrology of each water year (September to August inclusive) between 1998 and 2003, are briefly outlined for the Ngarradj catchment. The grain size statistics and sediment textural groups are discussed next for each study reach for each year. The results of the statistical analyses for spatio-temporal changes in grain size statistics are then evaluated before outlining the major conclusions and recommendations of the study.

2 Methods

2.1 Field methods

Bulk samples of specific depositional environments are the accepted method of sampling fluvial sediments (Kellerhals & Bray 1971). This involves the collection of all material from a predetermined volume within a specific depositional or geomorphic environment (Kellerhals & Bray 1971). Where collection of all sediment from a specific depositional environment is impossible because the mass is too large for collection, transport and/or analysis, sub-sampling is practised. However, there are potential problems with bulk sampling that must be recognised. Very large sample masses are required to obtain reproducible measures of the grain size distributions of samples containing individual large clasts or gravels (de Vries 1970, Church et al 1987, Gale & Hoare 1992, Ferguson & Paola 1997). Recommended minimum sample mass also depends on sediment sorting or the dispersion of the grain size distribution (Gale & Hoare 1994, Ferguson & Paola 1997). For a particular depositional environment, poorly sorted sediments, such as found in mixed sand- and gravel-bed rivers, require larger masses than better sorted samples (Gale & Hoare 1994, Ferguson & Paola 1997). Bulk sampling is also usually restricted to small areas that may not be representative of all of a specific depositional environment (Wolman 1954, Muir 1969). This is a major concern for large rivers with spatially variable depositional environments (Mosley & Tindale 1985) but is not a problem on the small channels in the Ngarradj catchment (see below). Sample masses collected on each river for each year of the program are summarised in tables in section 5.

A total of 315 bulk sediment samples (table 1) were collected for the dry seasons between 1998 and 2003. There are 56 permanently monumented cross sections, which were installed to assess channel changes (Saynor et al 2002a, 2004a, 2004d). A total of 17 cross sections are located on Tributary North, 15 on Tributary Central and 8 on each of East Tributary, upper Ngarradj Creek and lower Ngarradj Creek at the ***eriss*** gauging stations (Saynor et al 2001, 2002a, 2004a, 2004d). Bulk bed-material samples were collected by a trowel or small spade from at least 3 equally spaced points across the stream bed and then combined into a single bulk sample for most cross sections on the Jabiluka project area tributaries (table 1). On the wider channels of Ngarradj Creek and East Tributary, at least 5 equally spaced points were sampled at each cross section and combined as a single bulk sample. Similar bulk samples were collected from other depositional environments, such as in-channel benches, splays, floodouts and floodplains (Saynor et al 2004b).

Table 1 Bulk bed-material and additional sediment samples collected for each year of the program for each study reach. See fig 1 for location of study reaches.

Study reaches	1998	1999	2000	2001	2002	2003	Total
Tributary North main gully	8	8	8	8	5*	8	45
Tributary North tributary gully	5	5	5	5	5	5	30
Tributary North additional sediment samples	10	-	1	-	-	-	11
Tributary Central	15	15	14**	14**	14**	14**	86
Tributary Central additional sediment samples	2	-	-	-	-	-	2
East Tributary gauge	7***	8	8	8	8	8	47
upper Swift Creek gauge	6****	8	8	8	8	8	46
Swift Creek gauge	8	8	8	8	8	8	48
Total	**61**	**52**	**52**	**51**	**48**	**51**	**315**

*Three samples were misplaced and consequently no results are available

**Cross section TC02 was not sampled after the 1999 dry season because the channel was totally infilled with sediment

***One sample was misplaced and consequently no result is available

****One sample was misplaced and one cross section (UMGW) had not been installed in 1998. Consequently there are no results for two cross sections in 1998.

2.2 Laboratory methods

All bulk bed-material samples were oven dried at 105°C for 24 hours before being subjected to particle size analysis. Initial field observations indicated that there was little mud (ie < 0.063 mm in diameter) present at the upper Swift Creek and Swift Creek gauging station reaches on Ngarradj Creek and at the East Tributary gauging station reach. Therefore, dry sieving through a nest of sieves at $\phi/2$ intervals using a 15 minute shake time was sufficient to accurately determine the grain size distributions. The phi (ϕ) notation system is often used to describe the grain size of clastic sediment by sedimentologists (Folk 1974, 1980). It is a logarithmic scale in which each grade limit is twice as large as the next smaller grade limit (Folk 1974, 1980) and is denoted by:

$$\phi = -\log_2 d \tag{1}$$

where d is the grain diameter in mm.

The gravel fraction of the samples was manually sieved in its entirety. If the fraction less than 2 mm in diameter was greater than 150 g, it was passed through a riffle box to obtain a sample of approximately 100 g to ensure that the analytical stainless steel sieves were not damaged by excessive loading. This sub-sample was then dry sieved through a nest of stainless steel sieves at $\phi/2$ intervals using a 15 minutes shake time. If the mass of the less than 2 mm fraction was less than 150 g, the sample was sieved in its entirety.

Field observations of the Jabiluka project area tributaries indicated that the mud fraction comprised a larger proportion of the bed material than in the other channels. All samples in these reaches (Jabiluka project area tributaries) were subjected to a simplified particle size analysis according to the sieve and hydrometer method of Gee and Bauder (1986). The samples were chemically dispersed with 25 mL of sodium hexametaphosphate before being mechanically dispersed on a shaking wheel or a shaking platform for at least 12 hours. The sample was then wet sieved through a 0.063 mm or 4 ϕ stainless steel sieve and the sand fraction oven dried, weighed and dry sieved through a nest of sieves at $\phi/2$ intervals, as outlined above. In the complete hydrometer method of Gee and Bauder (1986), the mud fraction passing through the 0.063 mm or 4 ϕ stainless steel sieve is usually transferred to a 1000 mL cylinder for hydrometer analysis. Given the relatively small amounts of material less than 0.063 mm that were generally obtained (Saynor et al 2004b), the mud fraction was oven dried at 105°C for 24 hours and then weighed. During the 1998 dry season, four samples were selected from the East Tributary, upper Swift Creek and Swift Creek gauging station reaches for the wet sieving method described above. The grain size distributions are included in Saynor et al (2004b).

In some cases, the grain size distributions had to be extended to ensure that they included the 95th percentile for calculation of the graphic grain size statistics (Folk & Ward 1957, Folk 1974). Where the calculated recovered percentage at 4 ϕ was 93 to 95% then the lower phi value was set at 4.5 ϕ for 100%. Where the calculated recovered percentage at 4 ϕ was less than 92.99% then the lower phi value was set at 8 ϕ for 100%. Few samples had to be treated in this way (section 5).

2.3 Grain size statistics

Graphic grain size statistics (ie graphic mean size, inclusive graphic standard deviation, inclusive graphic skewness, graphic kurtosis and transformed kurtosis) were calculated using the equations of Folk and Ward (1957) and Folk (1974, 1980). These equations are outlined below and only use, at most, 90% of the grain size distribution between the 5th and 95th percentiles (Folk & Ward 1974, 1980). Nevertheless, such graphic measures are preferred to the method of moments, which weights equally all grain size fractions. This assumption (ie equal weighting) is unjustified because there are major problems in accurately determining both the coarsest and finest fractions of the grain size distribution. As discussed above, very large sample masses may be required to reliably estimate the coarsest percentiles. Furthermore, there are methodological problems in accurately measuring the clay fraction, especially when present in relatively small amounts, such as for the present samples (Gee & Bauder 1986).

The equations used to calculate the graphic grain size statistics (Folk & Ward 1957, Folk 1974, 1980) are:

$$M_z = \frac{(\phi_{16} + \phi_{50} + \phi_{84})}{3} \qquad (2)$$

where M_z is graphic mean size in ϕ units and ϕ_n is the phi (ϕ) value corresponding to the nth percentile, (eg ϕ16 is the ϕ value corresponding to the 16th percentile)

$$\sigma_I = \frac{(\phi_{84} - \phi_{16})}{4} + \frac{(\phi_{95} - \phi_5)}{6.6} \qquad (3)$$

where, σ_I is inclusive graphic standard deviation and ϕ_{84} is as defined above.

$$\mathrm{Sk_I} = \frac{(\phi_{16} + \phi_{84}) - 2\phi_{50}}{2(\phi_{84} - \phi_{16})} + \frac{(\phi_5 + \phi_{95}) - 2\phi_{50}}{2(\phi_{95} - \phi_5)} \tag{4}$$

where, Sk_I is inclusive graphic skewness and ϕ_{16} etc. is as defined above.

$$\mathrm{K_G} = \frac{(\phi_{95} - \phi_5)}{2.44(\phi_{75} - \phi_{25})} \tag{5}$$

where, K_G is graphic kurtosis and ϕ_{95} etc is as defined above.

$$\mathrm{K'_G} = \frac{\mathrm{K_G}}{(1 + \mathrm{K_G})} \tag{6}$$

where, K'_G is transformed kurtosis.

The meaning of the graphic grain size statistics and the verbal scales of Folk (1974, 1980) to describe these statistics are briefly outlined below. The Wentworth grain size scale for sediments is used throughout this report and is outlined in table 2. ***Graphic mean size*** is a reliable estimate of the mean and is expressed in terms of the Wentworth scale in table 2.

Inclusive graphic standard deviation is a measure of sorting and is classified by the following verbal scale:

< 0.35 ϕ	very well sorted
0.35 – 0.50 ϕ	well sorted
0.50 – 0.71 ϕ	moderately well sorted
0.71 – 1.0 ϕ	moderately sorted
1.0 – 2.0 ϕ	poorly sorted
2.0 – 4.0 ϕ	very poorly sorted
> 4.0 ϕ	extremely poorly sorted

Skewness measures the degree of asymmetry of a grain size distribution. Positive skewness means an excess of fine sediment and vice versa. The more the inclusive graphic skewness value departs from 0 the greater the degree of asymmetry. The following verbal scale is used:

0.30 – 1.0	strongly fine skewed
0.10 – 0.30	fine skewed
0.10 – -0.10	near symmetrical
-0.10 – -0.30	coarse skewed
-0.30 – -1.0	strongly coarse skewed

Graphic kurtosis measures the ratio between the sorting in the tails of the grain size distribution and the sorting in the central portion. If the central portion is better sorted than the tails, the curve is leptokurtic; if the tails are better sorted than the central portion, the curve is platykurtic. The following verbal scale is used:

< 0.67	very platykurtic
0.67 – 0.90	platykurtic
0.90 – 1.11	mesokurtic
1.11 - 1.50	leptokurtic
1.50 – 3.00	very leptokurtic
> 3.00	extremely leptokurtic

Transformed kurtosis (equation 6) is used to normalise the kurtosis distribution. A normal curve has a value of 0.50 and most sediments range between 0.40 and 0.65.

2.4 Sediment texture

The sediment textural classification used for all samples is that of Folk (1954, 1974, 1980) for unconsolidated materials and is based on a ternary diagram showing the proportions of gravel, sand and mud on separate axes (fig 2). This texture triangle is split into 15 groups and the median diameter is determined, where possible, for each component fraction. Each sediment fraction can be expressed in terms of one of the Wentworth size classes (table 2). To place a sample into one of the 15 major groups, only two properties need to be determined namely the gravel percentage (boundaries at 80, 30, 5 and a trace or 0.01%) and the ratio of sand to mud with boundaries at 9:1, 1:1 and 1:9 (Folk 1954, 1974, 1980). The gravel content is partly a function of the highest current velocity and the maximum grain size of the supplied sediment. The sand:mud ratio reflects the amount of winnowing (washing away of fine sediment) that has occurred. For samples lacking gravel, a further ternary diagram (fig 3) is used which expands the bottom tier of fig 2. It is based on the proportions of sand, silt and clay (see Folk 1954, 1974, 1980) but is not used for the Ngarradj Creek sediment samples because of the low mud contents (see below). The Folk (1954, 1974, 1980) textural class of each sample is contained in Saynor et al (2004b) along with the grain size distribution data.

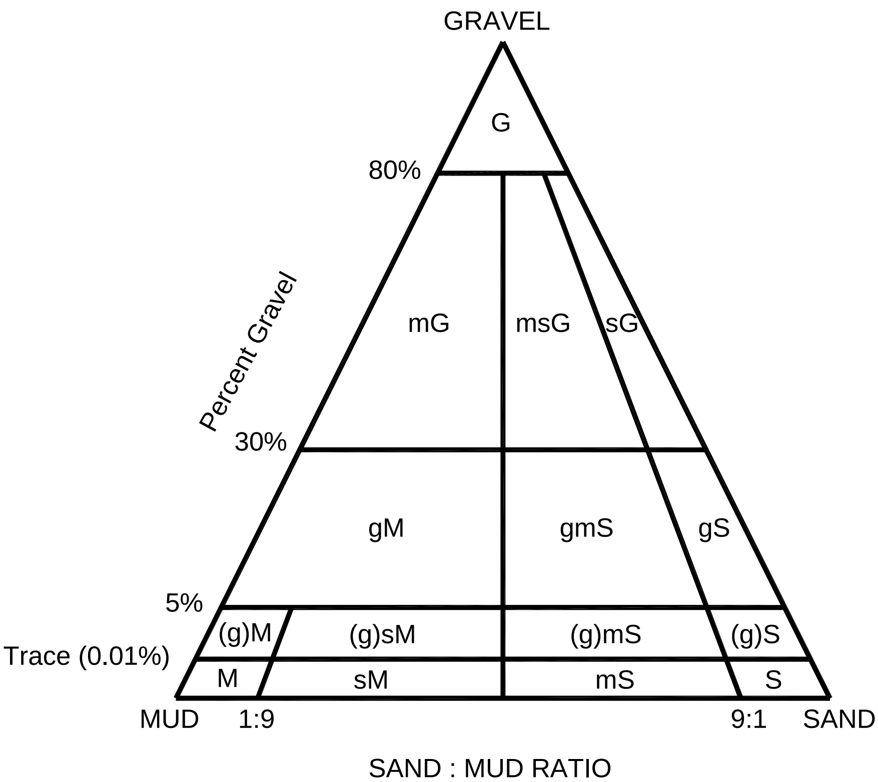

Figure 2 Folk's (1954, 1974, 1980) textural groups. G is gravel; sG sandy gravel; msG muddy sandy gravel; mG muddy gravel; gS gravelly sand; gmS gravelly muddy sand; gM gravelly mud; (g)S slightly gravelly sand; (g)mS slightly gravelly muddy sand; (g)sM slightly gravelly sandy mud; (g)M slightly gravelly mud; S sand; mS muddy sand; sM sandy mud; M mud.

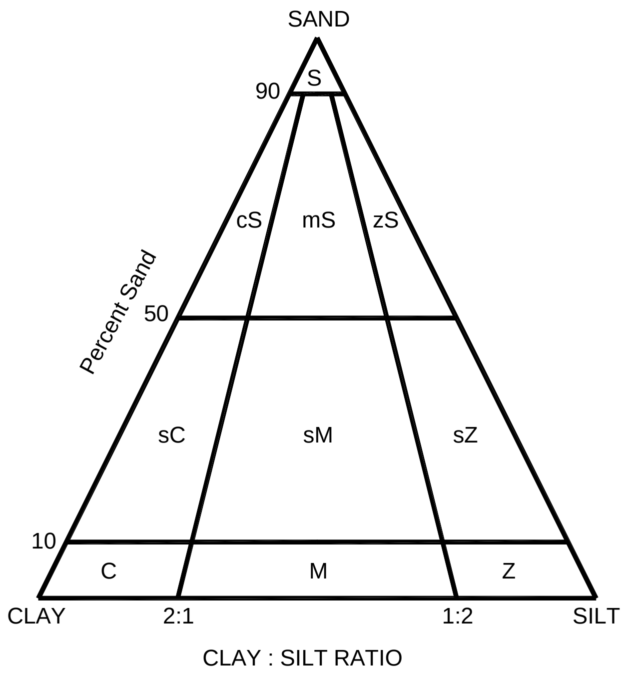

Figure 3 Folk's (1954, 1974, 1980) expansion of the bottom tier of figure 2 to show textural classes for sediments lacking gravel. S is sand; zS silty sand; mS muddy sand; cS clayey sand; sZ sandy silt; sM sandy mud; sC sandy clay; Z silt; M mud; and C clay.

Table 2 The Wentworth grain size scale for sediments (after Folk 1974). The sediment fraction finer than 0.063 mm is called mud.

Finest grain size (mm)	Finest grain size (ϕ)	Wentworth size class
256	-8	Boulder
64	-6	Cobble
4	-2	Pebble
2	-1	Granule
1.00	0	Very coarse sand
0.50	1	Coarse sand
0.25	2	Medium sand
0.125	3	Fine sand
0.063	4	Very fine sand
0.031	5	Coarse silt
0.0156	6	Medium silt
0.0078	7	Fine silt
0.0039	8	Very fine silt
0.00006	14	Clay

2.5 Statistical analyses

To test for normality, the grain size statistics were subjected to an Anderson-Darling test. This is a simple but powerful objective measure of how well data follow a particular distribution (Ryan & Joiner 1976). It is an empirical cumulative distribution function-based test (minitab

2004a). Where the data were normally distributed, the F test was used to determine whether there were significant differences in the variance of the various grain size statistics between years and between sites. Where the data were not normally distributed, Levene's test was used (minitab 2004b). Where the data were normally distributed and the variances were equal, the One-Way Analysis of Variance was used to determine whether the means of the various grain size statistics between years and between sites were significantly different. Where the data were non-normally distributed and/or the variances were not equal, the Kruskal-Wallis test was used to determine whether the differences in medians were significant. Boxplots based on the median, 25th and 75th percentiles and maximum and minimum values were constructed.

3 Catchment characteristics

The Jabiluka project area is located in the Ngarradj catchment which drains into the Ramsar listed wetlands of the Magela Creek floodplain (fig 1). Steep sandstone slopes with lower scarps form the Jabiluka outlier on the western side of the Ngarradj valley around the Jabiluka project area (fig 1). This is an eroded remnant of the Arnhem Land plateau, which is more extensively developed on the eastern side of the valley (Erskine et al 2001). Long colluvial footslopes and fans have accumulated between the sandstone outcrops and contemporary floodplains (Erskine et al 2001). Near the escarpment, Roberts (1991) found that sand fans in this area began to accumulate at 230–220 and 120–100 ka, which coincide with the start of the penultimate and last interglacials respectively. The extensive undulating lowlands to the west of the Jabiluka outlier are part of the Northern Lateritic Plains of Christian and Stewart (1953) or the lateritised Koolpinyah Surface of Hays (1967), which has an age range from Proterozoic to Pleistocene (Erskine & Saynor 2000). This geomorphic surface is contiguous with the footslopes and fans in the Jabiluka project area (Williams 1969).

The Jabiluka outlier is composed of resistant, horizontally bedded, vertically jointed, strongly ferruginous, medium quartz sandstone of the Palaeoproterozoic (Statherian) Mamadawerre Sandstone of the Kombolgie Subgroup (Needham 1988, Carson et al 1999). The sandstone is generally more than 95% medium to coarse grained, moderately well sorted, subrounded to subangular quartz grains with minor lithic fragments of quartzite and quartz-feldspar granophyric intergrowths (Needham 1988).

Wells (1979) mapped the soils of 38 km^2 of the Jabiluka Mineral Lease. The area surrounding the Jabiluka project area exhibits very shallow sands on steep sandstone slopes, shallow red or brown uniform sands at the base of bedrock outcrops and deep uniform sands on the footslopes. The regolith of the footslopes and fans is comprised largely of quartz sand and overlies deeply weathered lateritic saprolites (Bettenay et al 1981). Lateritic pallid zones are dominated by kaolinite in the clay fraction while the yellow and red sandy clays and mottled zones are largely kaolinite with some haematite and/or goethite (Bettenay et al 1981).

The Ngarradj catchment is included in the summer rainfall-tropical climatic zone (McQuade et al 1996). It is characterised by heavy periodic rains and generally hot and humid conditions from October to March, and slightly less humid and warm to hot conditions from April to September (McQuade et al 1996). Chiew and Wang (1999) found that the mean annual rainfall for the period 1971–1998 was 1500 mm at Oenpelli and 1480 mm at Jabiru (fig 1). For the complete period of record at each site, the mean annual rainfall was 1397 mm and 1483 mm at Oenpelli (1911–1998) and Jabiru Airport (1972–1998) respectively (Bureau of Meteorology 1999). These two stations are the nearest to the Jabiluka project area with long records.

4 Hydrology

Three gauging stations were installed by ***eriss*** in late 1998 on upper Ngarradj Creek (upper Swift Creek gauge) above the influence of the Jabiluka project area, on lower Ngarradj Creek (Swift Creek gauge) below the influence of the Jabiluka project area and on a right bank tributary between these two stations which is unimpacted by the Jabiluka project area (East Tributary gauge) (fig 1). The respective catchment areas are 18.8, 43.6 and 8.5 km^2. No gauging station could be installed on Tributary West because of the ill-defined, shifting sand-bed channel (Erskine et al 2001). The Jabiluka project area tributaries, Tributary North and Tributary Central (fig 1), were gauged by the mining company, Energy Resources of Australia (Moliere et al 2002b). The total catchment areas of Tributary North and Tributary Central are 0.6 and 2.5 km^2 respectively.

Rainfall is highly seasonal in the Ngarradj catchment with monthly totals greater than 150 mm being recorded at the peak of the wet season between December and March (Moliere et al 2002b, 2003). Much lower totals are recorded during both the build up to and during the recession from the wet season (September to November & April/May respectively). Little rainfall is usually recorded between June and August. The earliest rainfall during the present study was recorded on 20 September (1998) and the latest rainfall was recorded on 24 May (2000) (table 3; Moliere et al 2002b, 2003). Bed-material samples were collected during each dry season between 1998 and 2003, after the cross-sectional surveys had been completed. Four of the five wet seasons had above average rainfall (Moliere et al 2002b, 2003) and one had slightly below average (table 3).

Table 3 Total rainfall over the Ngarradj catchment and runoff at each gauging station for the monitoring period (1998 to 2003). Data sourced from Moliere et al (2002b, 2003).

Year	Total rainfall (mm) [ARI (y)]	Rainfall period	Station	Antecedent rainfall (mm)	Runoff period	Total runoff (ML) [Peak discharge (m^3s^{-1})]
1998/99	1826 [1:13]	20 Sep – 28 Apr	SC	430[(1)]	9 Dec – 27 May	33665 [22.3]
			UM	440[(1)]	12 Dec – 10 Jun	15666 [15.0]
			ET	415[(1)]	9 Dec – 27 May	7621 [8.5]
1999/00	2047 [1:71]	14 Oct – 24 May	SC	260	20 Nov – 14 Jul	34899 [18.1]
			UM	305	20 Nov – 20 Jul	17426 [12.2]
			ET	280	20 Nov[(2)] – 25 Jun	8532 [8.1]
2000/01	1897 [1:21]	14 Oct – 27 Apr	SC	250	29 Nov – 14 Jun	34781 [20.6]
			UM	250	3 Dec – 14 Jun	17052 [13.0]
			ET	245	28 Nov – 21 May	8275 [8.2]
2001/02	1390 [1:2]	17 Oct – 14 Apr	SC	420	31 Dec – 15 Apr	14382 [22.0]
			UM	370	31 Dec – 1 May	7495 [13.6]
			ET	330	28 Dec – 25 Apr	3963 [8.3]
2002/03	1769 [1:9]	13 Sep – 1 May	SC	225	22 Dec – 7 May	33245 [21.2]
			UM	250	20 Dec – 1 Jun	18101 [(3)] [12.9]
			ET	355	1 Jan – 7 May	7249 [8.2]

(1) Data partly provided by Energy Resources of Australia

(2) A small surge of runoff occurred on 8 Nov, 1900 – 2300 h (Moliere et al 2002 - Appendix A)

(3) Total runoff partly infilled using predicted discharge data generated from the HEC-HMS model (Moliere et al 2003)

The seasonal streams gauged by ***eriss*** (fig 1) commenced flowing on 8 November (1999) at the earliest (streamflow did not persist after this first flush and recommenced on 20 November 1999) but usually on or after 20 November each year (table 3). The amount of rainfall before streamflow commenced (antecedent rainfall in table 3) varied between 225 and 440 mm. Streamflow generally persisted until between May and July each year (table 3). The largest peak instantaneous discharges were recorded during the 1998/1999 wet season but the variation between years was minor (table 3), as was the variation in maximum flow velocity between years (Saynor et al 2004d).

5 Grain size statistics and textural groups for each reach

Oven-dry bulk sample sediment masses are contained in Saynor et al (2004b) and are summarised below for each study site. From the criteria of de Vries (1970), Church et al (1987) and Gale and Hoare (1992), the sample masses are adequate to obtain reproducible measures of the grain size distribution for these sediment samples, except where noted otherwise. The grain size statistics are listed in Appendices A to E inclusive for each Jabiluka project area tributary (Tributaries North and Central) and for each gauging reach (East Tributary gauge, upper Swift Creek gauge and Swift Creek gauge) for each dry season between 1998 and 2003 inclusive. The cumulative frequency grain size distributions and Folk (1954, 1974, 1980) texture groups for all sediment samples are contained in Saynor et al (2004b).

5.1 Tributary North

Figure 4 shows the location of the cross sections on Tributary North at which bed-material samples were collected. Both the Floodout and Gullied Reaches of Erskine et al (2001) were sampled (fig 4) although annual sampling was restricted to the Gullied Reach. According to the preliminary typology of Australian tropical rivers developed by Erskine et al (2005), the Floodout Reach corresponds to an ‘intermediate floodout’. Gullies were not included in the Erskine et al (2005) typology because they are not usually fish habitat which was the subject of their classification. As there is a major left bank tributary gully of the Gullied Reach with five cross sections (fig 4), the results for each gully are presented separately.

5.1.1 Tributary North main gully

Oven-dry bed-material sample masses for each year are summarised in table 4. Table A1 shows the grain size statistics for all bed-material samples collected for all years. Figure 5 shows the particle size distributions at all sections for all years.

Table 4 Summary of oven-dry, bulk bed-material sample masses collected on Tributary North main gully for each year of the sediment program

Sample mass	1998	1999	2000	2001	2002	2003
Number of samples	8	8	8	8	5	8
Mean (g)	1247.6	1273.8	994.9	945.7	1435.6	1098.9
Standard error of estimate of the mean (g)	99.6	114.8	26.4	101.6	204.8	93.1
Minimum (g)	735.0	909.0	940.4	655.1	1047.8	686.8
Maximum (g)	1676.2	1707.3	1156.2	1560.1	2183.8	1504.2

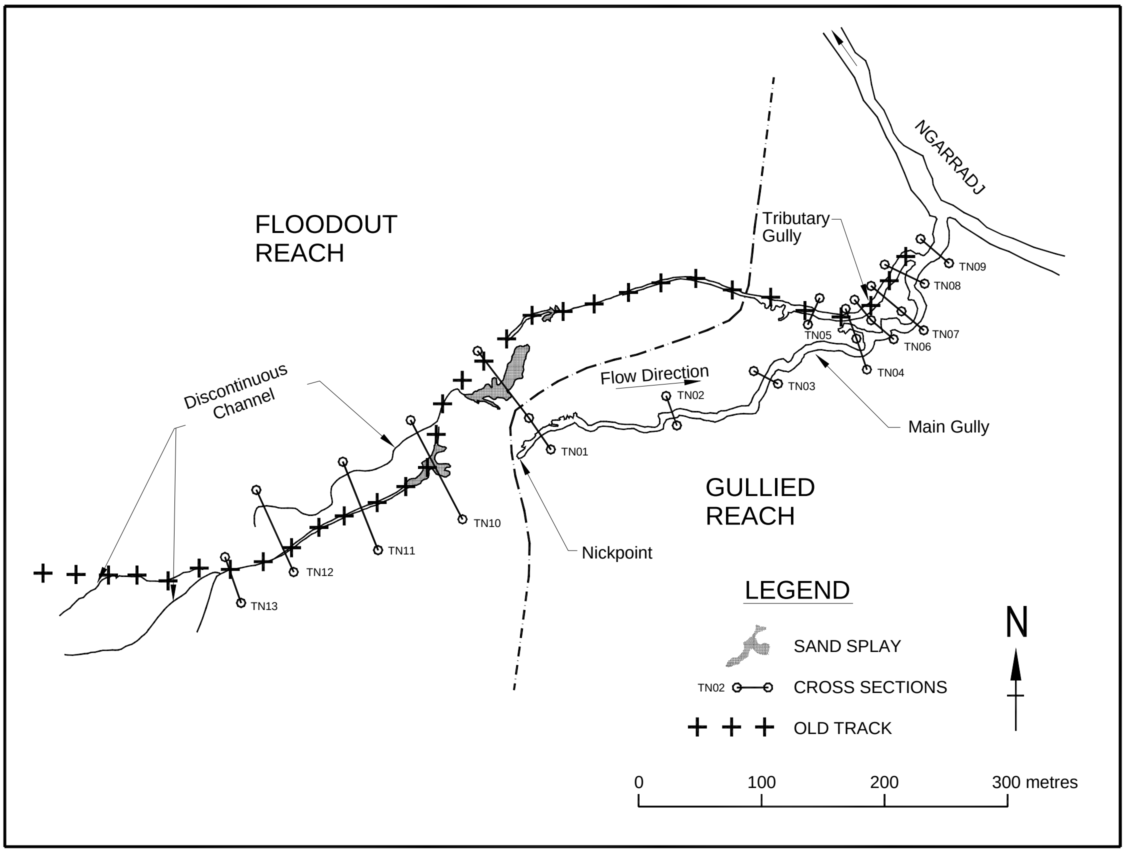

Figure 4 Location of cross sections on Tributary North at which bulk bed-material samples were collected

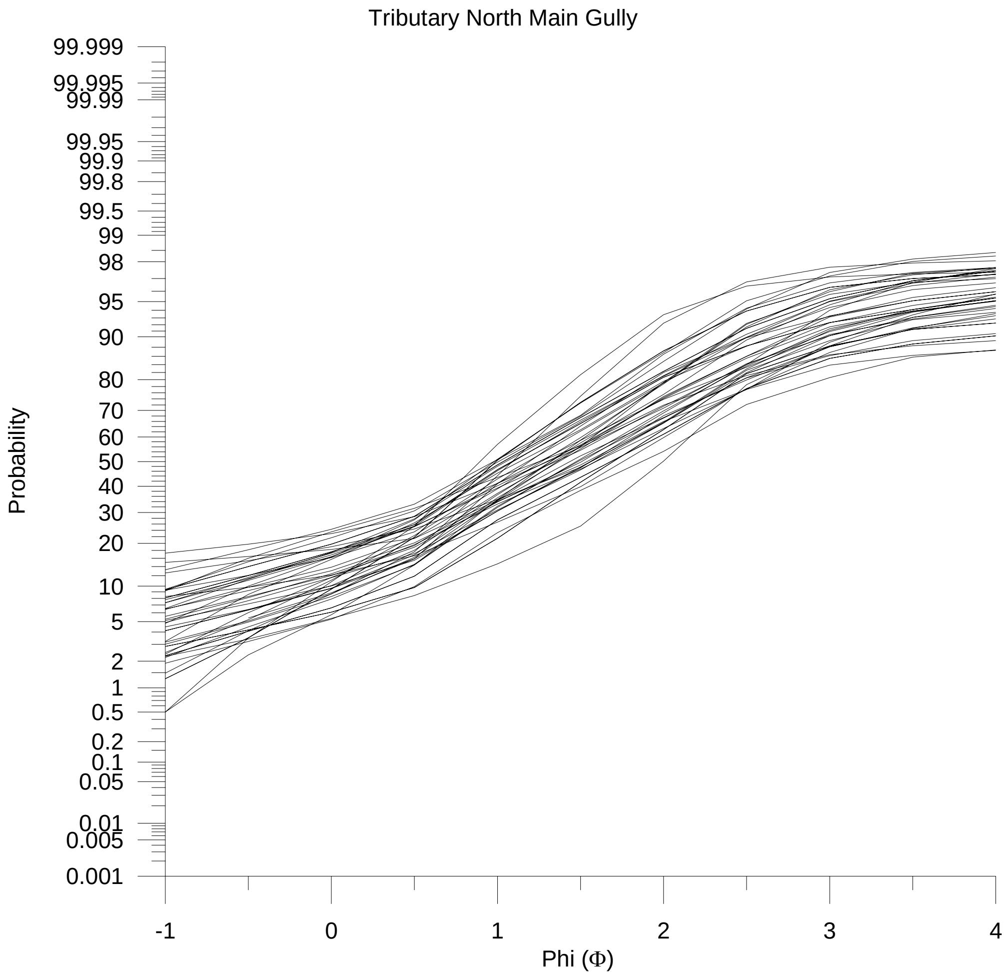

Figure 5 Particle size distributions for all bed-material samples at all cross sections for all years on Tributary North main gully

In 1998, the bed material generally exhibited a graphic mean size in the medium sand Wentworth size class (Appendix A table A1) and was poorly sorted, near-symmetrical and leptokurtic. The range in Folk (1954, 1974, 1980) textural groups was minor with all samples being either slightly granular medium sand or granular medium sand (Saynor et al 2004b). These textures agree closely with the results of Erskine et al (2003) for surficial bed sediments in 1998 at the scour chain sites.

Between 1999 and 2003 the bed-material grain size statistics were similar to the first year. While the range in Folk (1954, 1974, 1980) textural groups increased in 1999, the modal group remained the same (slightly granular medium sand) (Saynor et al 2004b). The above bed-material textures also agree closely with the results of Erskine et al (2003) for surficial bed sediments in 1999 at the scour chain sites. However, the range in Folk (1954, 1974, 1980) textural groups increased greatly in 2000 with no clear modal group. The range in bed-material textures included slightly granular fine sand, slightly granular medium sand, slightly granular muddy medium sand, granular medium sand and granular muddy medium sand (Saynor et al 2004b). In 2001 the modal class returned to slightly granular medium sand (Saynor et al 2004b) but in both 2002 and 2003, the dominant textural groups were slightly granular medium sand and granular medium sand. The bed material grain size statistics on the main gully of Tributary North were essentially constant during the six years study period. Figure 5 shows a consistent range in particle size distributions for all years at all cross sections.

The grain size statistics for additional samples from specific sedimentary environments that were collected in 1998 (one additional sample was collected in 2000) are presented in table 5.

Table 5 Grain size statistics for the additional bulk samples of the specified sedimentary environments collected on Tributary North during the late 1998 and 2000 dry seasons. See fig 4 for location of cross sections.

Date Collected	Sample	Graphic mean (ϕ)	Inclusive graphic SD (ϕ)	Inclusive graphic skewness	Graphic kurtosis	Transformed kurtosis
23-Oct-98	TN01 Sand deposit in track on far left bank	2.63	2.09	0.42	1.37	0.58
8-Oct-98	TN01 Bank	1.72	1.55	0.38	1.73	0.63
23-Oct-98	TN01 Splay	2.56	2.12	0.47	1.20	0.55
14-Oct-98	TN06 Bench	1.56	1.29	0.30	1.93	0.66
23-Oct-98	TN10 Splay in Floodout Reach	1.71	1.46	0.34	1.67	0.63
23-Oct-98	TN11 Bed of discontinuous channel	1.10	0.85	0.16	1.50	0.60
23-Oct-98	TN11 Gully	1.70	1.46	0.30	1.71	0.63
23-Oct-98	TN12 Bed of discontinuous channel	1.15	0.73	0.04	1.15	0.54
23-Oct-98	TN12 Gully	1.73	2.17	0.61	1.83	0.65
23-Oct-98	TN13 Bed of discontinuous channel	3.40	2.01	0.29	1.33	0.57
4-Oct-00	Retention pond seepage channel	2.63	2.09	0.42	1.37	0.58

Graphic mean size of these additional samples varied from medium to fine to very fine sand. The finest sediment was always found where the channel was ill-defined and well-vegetated in the Floodout Reach which is located upstream of the Gullied Reach (fig 4). Sorting ranged from moderately sorted to poorly sorted to very poorly sorted. All samples exhibited a positive inclusive graphic skewness and were usually fine- to strongly fine-skewed. Graphic kurtosis ranged from leptokurtic to very leptokurtic. The Folk (1954, 1974, 1980) textural groups were generally slightly granular muddy medium sand or slightly granular medium sand (Saynor et al 2004b).

5.1.2 Tributary North tributary gully

Oven-dry bed-material sample masses collected for each year are summarised in table 6. Table A2 shows the grain size statistics for all bed-material samples collected for all years. Figure 6 shows the particle size distributions at all sections for all years.

Table 6 Summary of oven-dry bulk bed-material sample masses collected on the tributary gully of lower Tributary North for each year of the sediment program

Sample mass	1998	1999	2000	2001	2002	2003
Number of samples	5	5	5	5	5	5
Mean (g)	1472.6	1568.6	843.4	693.1	1242.9	1053.0
Standard error of estimate of the mean (g)	300.7	75.4	62.7	21.4	138.9	97.0
Minimum (g)	912.6	1341.5	677.1	633.7	204.8	93.1
Maximum (g)	2241.3	1729.4	1038.3	762.8	2183.8	1504.2

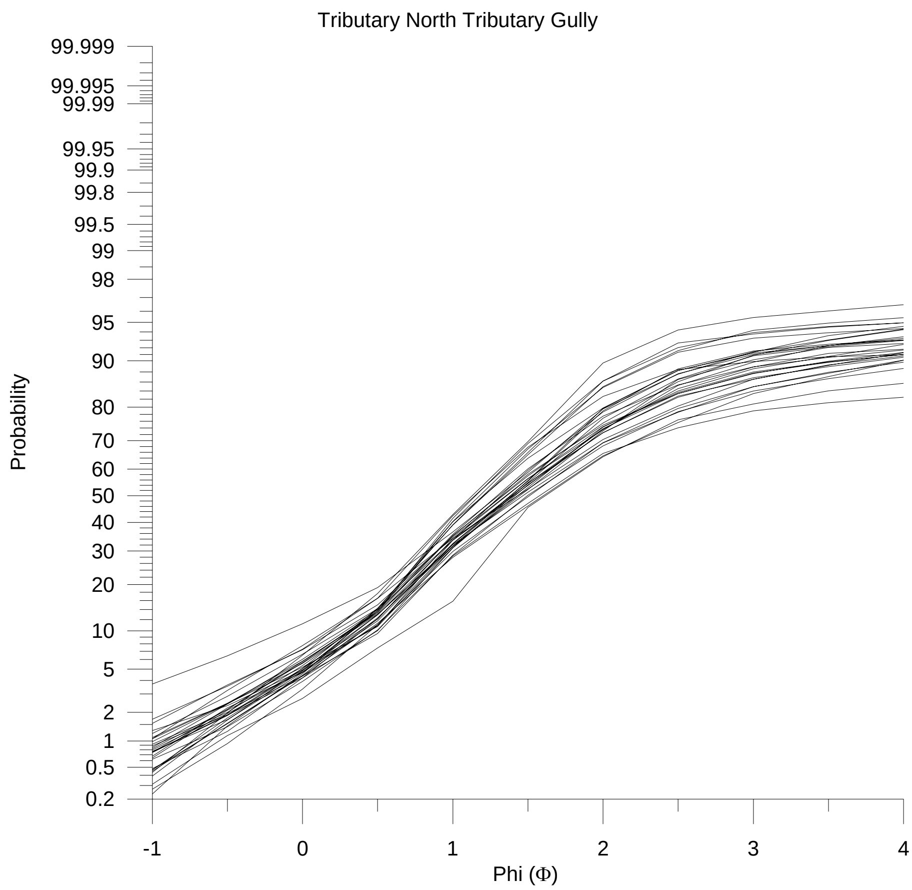

Figure 6 Particle size distributions for all bed-material samples at all cross sections for all years on Tributary North tributary gully

In 1998, the bed material generally exhibited a mean size in the medium sand Wentworth size class (Appendix A table A2) and was poorly sorted, fine-skewed and very leptokurtic. The range in Folk (1954, 1974, 1980) textural groups was minor with most samples classed as slightly granular medium sand (Saynor et al 2004b).

Between 1999 and 2003, the bed-material grain size statistics were similar to the first year. The range in Folk (1954, 1974, 1980) textural groups was the same (mainly slightly granular medium sand) in 1999 as for the previous year but in 2000 the modal group changed to slightly granular muddy medium sand (Saynor et al 2004b). The above bed-material textures agree closely with the results of Erskine et al (2003) for surficial bed sediments in 1999. In 2001 the modal textural group reverted back to slightly granular medium sand and remained the same for the last two years (2002 and 2003) of the study. Figure 6 shows a consistent range in particle size distributions for all years at all cross sections.

5.2 Tributary Central

Figure 7 shows the location of the cross sections where the bed material samples were collected. The Sinuous, Large Capacity and Small Capacity Reaches of Erskine et al (2001) were sampled (fig 7). According to the preliminary typology of Australian tropical rivers developed by Erskine et al (2005), the Sinuous Reach is a 'laterally migrating unconfined meandering river', the Large Capacity Reach is a 'straight river' and the Small Capacity Reach is an 'intermediate floodout'. Oven-dry bed-material sample masses for each year are summarised in table 7. From the criteria of de Vries (1970), Church et al (1987) and Gale and Hoare (1992), the sample masses were adequate to obtain reproducible measures of the grain size distribution for these bed-material sediments, with the exception of the sample at cross section TC06A in 2001. This sample is discussed further below. Table B1 shows the statistics for the samples collected between 1998 and 2003 inclusive. Samples were collected at cross section TC02 in 1998 and 1999 before the channel was completely infilled with sediment (Saynor et al 2004d). Bed-material samples were therefore not collected at cross section TC02 after 1999.

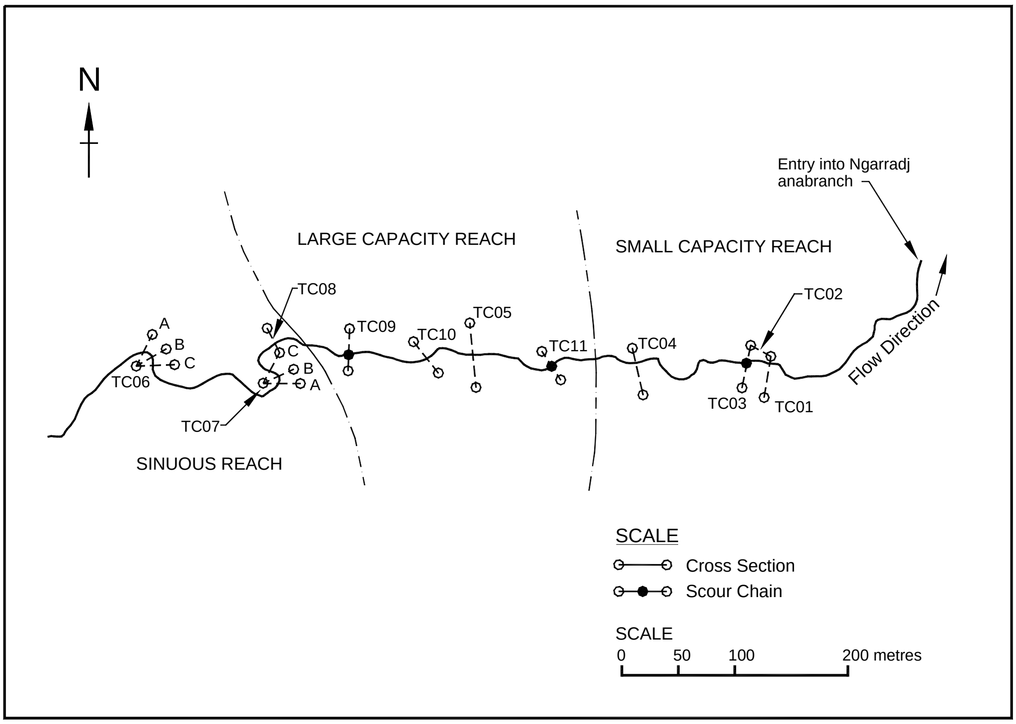

Figure 7 Location of the cross sections on Tributary Central and the boundaries between Erskine et al's (2000) river reaches

Table 7 Summary of oven-dry bulk bed-material sample masses collected on Tributary Central for each year of the sediment program

Sample mass	1998	1999	2000	2001	2002	2003
Number of samples	15	15	14	14	14	14
Mean (g)	1361.8	1564.4	1341.6	1112.9	1447.8	1550.8
Standard error of estimate of the mean (g)	155.6	68.8	75.7	102.5	71.8	87.6
Minimum (g)	1194.2	1256.6	801.1	787.1	1043.5	1140.7
Maximum (g)	1668.3	1834.3	1739.9	2300.5	1870.3	2114.9

The grain size statistics were not analysed on a reach basis because the sample size was too small. For example, only three cross sections were sampled in the Small Capacity Reach after 1999 and there are only four cross sections in the Large Capacity Reach. Therefore, all of the following analyses were undertaken on the whole data set for all three channel reaches. Figure 8 shows the particle size distributions at all sections for all years and clearly demonstrates that there is a greater range in distributions on Tributary Central than on Tributary North.

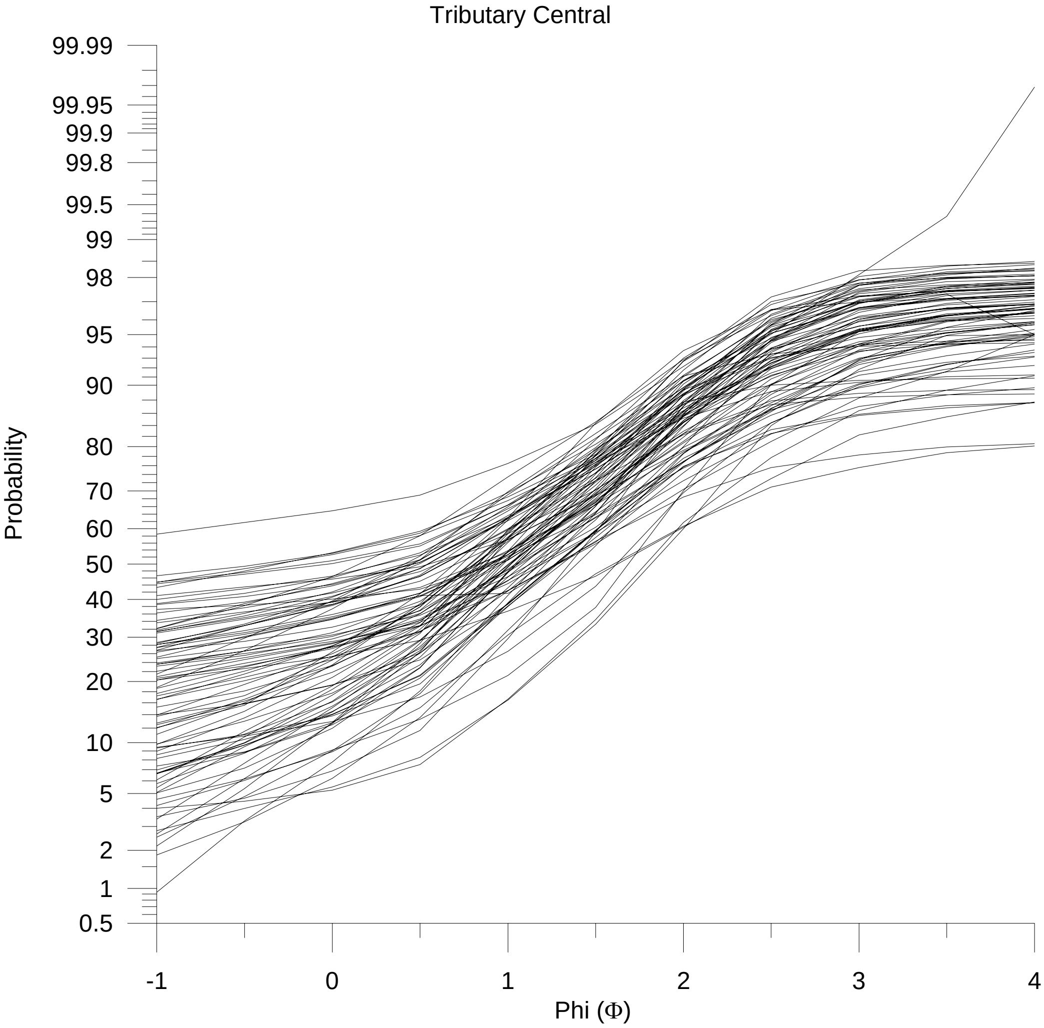

Figure 8 Particle size distributions for all bed-material samples at all cross sections for all years on Tributary Central

In 1998, the graphic mean bed-material size was variable ranging from very coarse sand to coarse sand to medium sand (Appendix B table B1). The three downstream cross sections in Erskine et al's (2001) Small Capacity Reach exhibited the finest mean size. Sorting was also variable ranging from moderately sorted to poorly sorted to very poorly sorted. Most samples exhibited a negative inclusive graphic skewness (coarse skew) with 53% being strongly coarse skewed. Graphic kurtosis was highly variable and covered the full range from very platykurtic to platykurtic to mesokurtic to leptokurtic to very leptokurtic. The range in Folk (1954, 1974, 1980) textural groups was also variable and included coarse sandy pebble gravel, medium sandy pebble gravel, pebbly coarse sand, pebbly medium sand, granular medium sand and slightly granular medium sand (Saynor et al 2004b). The above bed-material textures agree closely with the results of Erskine et al (2003) for surficial bed sediments in 1998 at the scour chain sites.

In 1999 and 2000 the graphic bed-material grain size statistics exhibited the same variability as in 1998. The largest value of the inclusive graphic standard deviation for the study period of 3.25 was recorded at cross section TC08 in 2000. While the range in Folk (1954, 1974, 1980) textural groups was also variable in 1999, the modal class was pebbly medium sand with a secondary mode of granular coarse sand (Saynor et al 2004b). However, in 2000 the range was even greater and included coarse sandy pebble gravel, medium sandy pebble gravel, pebbly coarse sand, pebbly medium sand, pebbly muddy medium sand, granular muddy coarse sand, slightly granular coarse sand and slightly granular muddy medium sand.

In 2001, the graphic mean bed-material size exhibited the highest variability for the study period ranging from pebble gravel to granule gravel to very coarse sand to coarse sand to medium sand. The coarsest graphic mean size for the study period was obtained in 2001 at cross section TC06A because the sample contained a single cobble. A much larger sample mass should have been collected on this occasion to avoid a single isolated cobble distorting the grain size statistics (Church et al 1987, Gale & Hoare 1992). As this was not done, the grain size statistics for cross section TC06A for 2001 are unreliable. Sorting was variable ranging from moderately sorted to poorly sorted to very poorly sorted. Again, most samples exhibited a negative inclusive graphic skewness (coarse skew) with 36% being strongly coarse skewed. Graphic kurtosis was again highly variable and covered the range from very platykurtic to mesokurtic to leptokurtic to very leptokurtic. While the range in Folk (1954, 1974, 1980) textural groups was variable, the modal class was once again pebbly medium sand. For the statistical analyses reported below, the values for TC06A for 2001 have been excluded.

The grain size statistics in 2002 and 2003 were similar to those in 1998. The range in graphic mean size was the same but sorting decreased in 2002 (poorly and very poorly sorted) only to return to the same range in 2003 as in 1998. All samples in 2002 and all but one sample in 2003 were negatively skewed. Graphic kurtosis was slightly less variable in 2002 than in 2003 when it covered the full range from very leptokurtic to very platykurtic. While the range in Folk (1954, 1974, 1980) textural groups was again variable, the modal class remained pebbly medium sand for both years. The bed-material grain size statistics on Tributary Central were essentially constant during the six years study period. Figure 8 shows a wide but consistent range in particle size distributions for all years at all cross sections on Tributary Central.

The grain size statistics for additional samples from specific sedimentary environments that were only sampled in 1998 are presented in table 8. The bed material on the upstream extension of cross section TC06C (table 8) was armoured in 1998 and consisted of extremely poorly sorted, strongly coarse skewed, leptokurtic pebble gravel. Armour layers are surficial gravels on the river bed that are usually one grain diameter thick and that are both coarser and better sorted than the sub-armour bed sediment (Gomez 1984, Erskine 1992). The distributary channel in the Large Capacity Reach of Erskine et al (2001) (ie cross section TC05) had bed material of moderately sorted, near symmetrical, platykurtic, fine sand in 1998. The distributary channel further downstream in the Small Capacity Reach (cross section TC01) had bed material of poorly sorted, coarse skewed, leptokurtic medium sand in 1998. The latter two samples were slightly granular medium sand and granular medium sand respectively.

Table 8 Grain size statistics for the additional bulk samples of the specified sedimentary environments collected on Tributary Central for the late 1998 dry season. See fig 5 for location of cross sections.

Date collected	Sample	Graphic mean (ϕ)	Inclusive graphic SD (ϕ)	Inclusive graphic skewness	Graphic kurtosis	Transformed kurtosis
26-Oct-98	Upstream extension of cross section TC06C across the channel	-4.19	6.75	-0.57	1.32	0.57
19-Oct-98	Left bank distributary channel at TC05	2.31	0.93	-0.04	0.70	0.41
19-Oct-98	Left bank distributary channel at TC01	1.32	1.23	-0.17	1.28	0.56

5.3 East Tributary

Figure 9 shows the location of the cross sections at which bed-material samples were collected. The gauge is located in Erskine et al's (2001) Forested Meandering Reach. According to the preliminary typology of Australian tropical rivers developed by Erskine et al (2005), the Forested Meandering Reach is a 'laterally stable, unconfined, meandering river'. Oven-dry bed-material sample masses collected for each year are summarised in table 9. Figure 10 shows the particle size distributions at all sections for all years.

Table 9 Summary of oven-dry bulk bed-material sample masses collected on East Tributary for each year of the sediment program

Sample mass	1998	1999	2000	2001	2002	2003
Number of samples	7	8	8	8	8	8
Mean (g)	1444.8	1330.0	1132.1	1123.9	1163.4	1376.5
Standard error of estimate of the mean (g)	156.3	183.8	97.0	86.7	71.6	68.2
Minimum (g)	985.6	939.0	934.1	906.0	932.0	1104.4
Maximum (g)	2208.7	2219.9	1721.4	1619.8	1606.3	1734.7

To determine the mud content of the bed material, every second bed-material sample collected in 1998 was dispersed and wet sieved through a 0.063 mm sieve. The percentage of the samples < 0.063 mm was as follows:

- cross section ET02 – 5.56%
- cross section ET04 – 1.59%
- cross section ET06 – 3.38%
- cross section ET08 – 1.21%

As three out of four samples contained less than 5% mud, samples collected in subsequent years were not chemically and physically dispersed so as to reduce laboratory time. Of the 47 samples collected at East Tributary (table1), there was only one sample with greater than 5%

mud. This sample was collected at cross section ET02 in 1998 (see above). Table C1 shows the grain size statistics for all samples collected for all years.

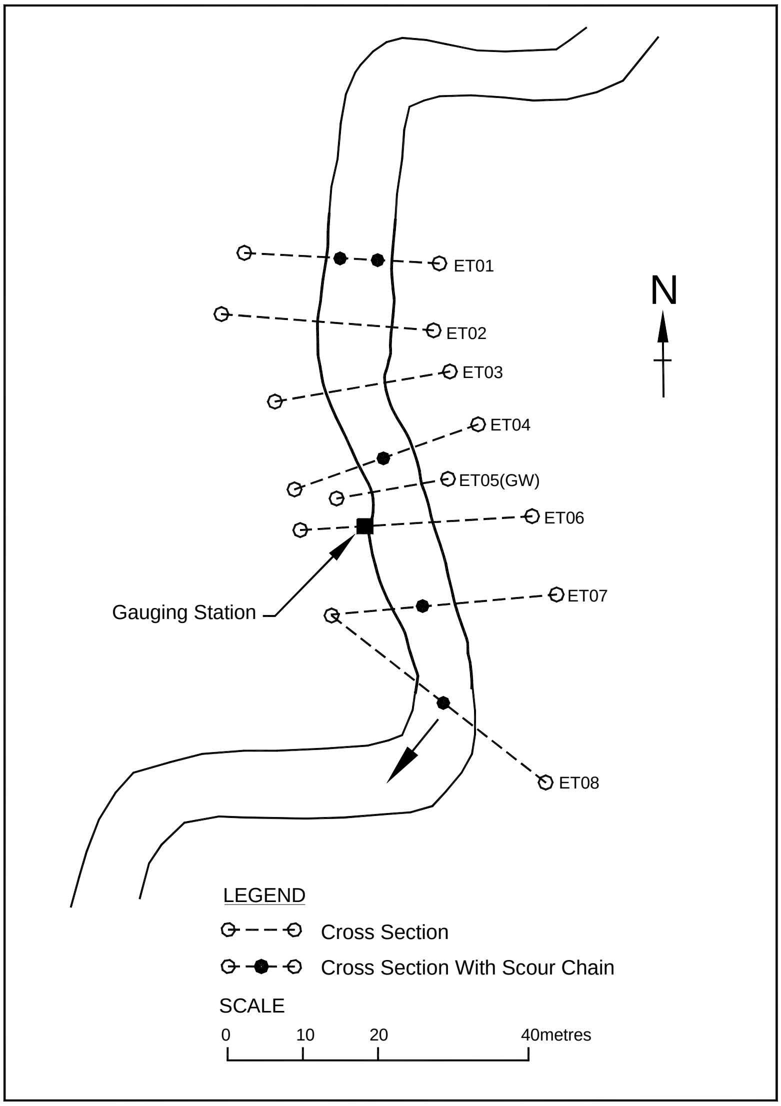

Figure 9 Location of the cross sections on East Tributary at the gauging station

In 1998, the bed material generally exhibited a graphic mean size in the medium sand Wentworth class (Appendix C table C1) and was moderately poorly sorted, near symmetrical to coarse skewed and mesokurtic to leptokurtic. The range in Folk (1954, 1974, 1980) textural groups was slightly granular medium sand, granular medium sand and pebbly medium sand (Saynor et al 2004b). These bed-material textures agree closely with the results of Erskine et al (2003) for surficial bed sediments in 1998 at the scour chain sites. Graphic mean size increased from generally medium sand in 1998 to generally coarse sand in 1999 and remained in the coarse sand Wentworth size class until 2003 (Appendix C table C1). Figure 10 clearly shows the coarsening of the particle size distributions after 1998 indicated by the shifting of the distribution curves to the left. Sorting generally remained in the range between moderately well sorted and poorly sorted between 1999 and 2003. The grain size distributions were usually coarse skewed although some samples were occasionally strongly coarse skewed between 1999 and 2003. The range in kurtosis was generally between mesokurtic and leptokurtic between 1999 and 2003 although occasional samples were platykurtic and very leptokurtic. After 1998, slightly granular coarse sand and granular coarse sand were additional Folk (1954, 1974, 1980) textural groups present (Saynor et al 2004b).

The most pronounced change in grain size statistics on East Tributary was the increase in graphic mean size from medium sand in 1998 to coarse sand in 1999 and remained as coarse sand until at least 2003 (fig 10). The statistical significance of this change is determined in section 6.

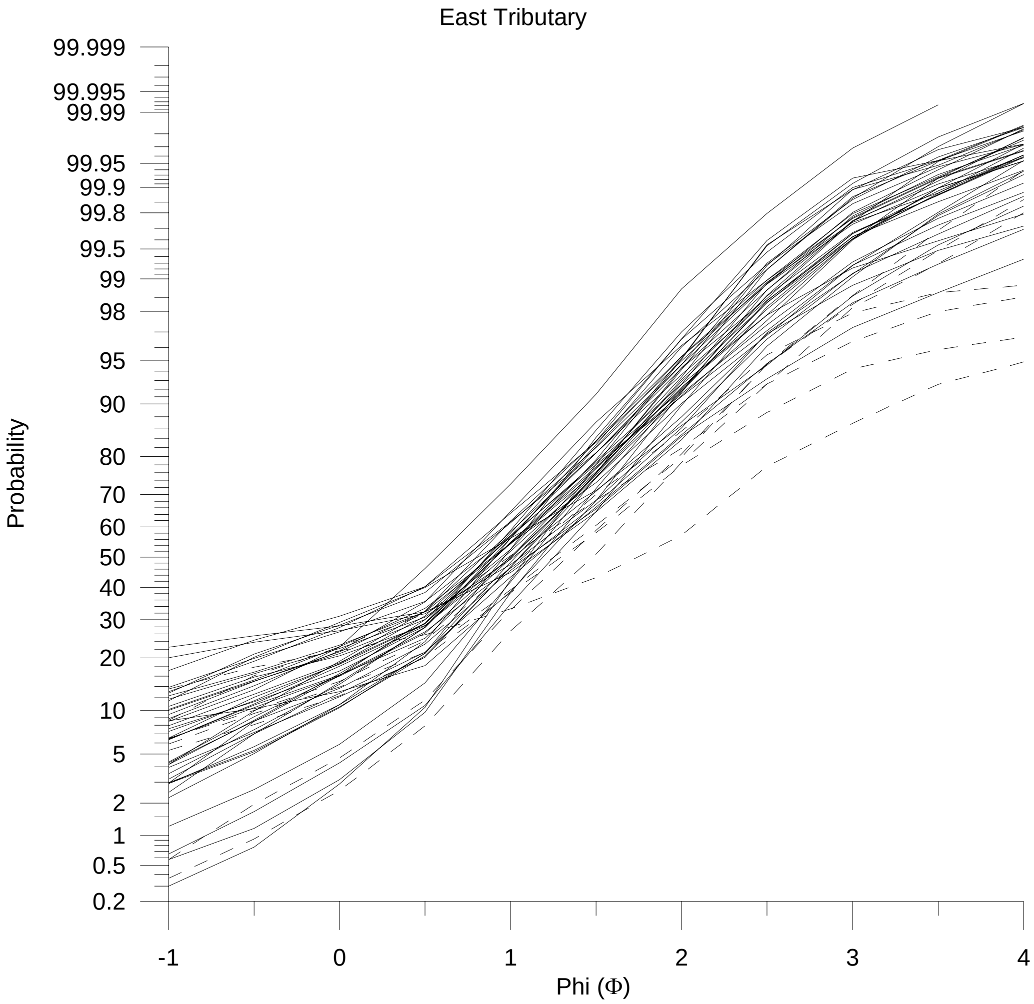

Figure 10 Particle size distributions for all bed-material samples at all cross sections for all years on East Tributary in the gauge reach. The 1998 samples are shown as dashed lines.

5.4 Upper Swift Creek

Figure 11 shows the location of the cross sections at which bed-material samples were collected. The gauge is located in Erskine et al's (2001) Forested Meandering Reach. According to the preliminary typology of Australian tropical rivers developed by Erskine et al (2005), the Forested Meandering Reach is a 'laterally stable, unconfined, meandering river'.

A sample was collected at cross section UM04 in 1998, however, it was misplaced and therefore the results are not contained in table D1. The cross section at the gauging wire (cross section UMGW) was not installed until after the 1998/1999 wet season and hence a sample was not collected during the 1998 dry season. Table 10 summarises the oven-dry bulk sample masses collected for each year of the monitoring program. Figure 12 shows the particle size distributions at all sections for all years.

To determine the mud content of the bed material, four (all odd numbered cross sections) of the 1998 samples were dispersed and wet sieved through a 63 μm sieve. The percentage of the samples <63 μm was as follows:

- cross section UM01 – 2.64%,
- cross section UM03 – 0.91%,
- cross section UM05 – 0.95%
- cross section UM07 – 0.76%

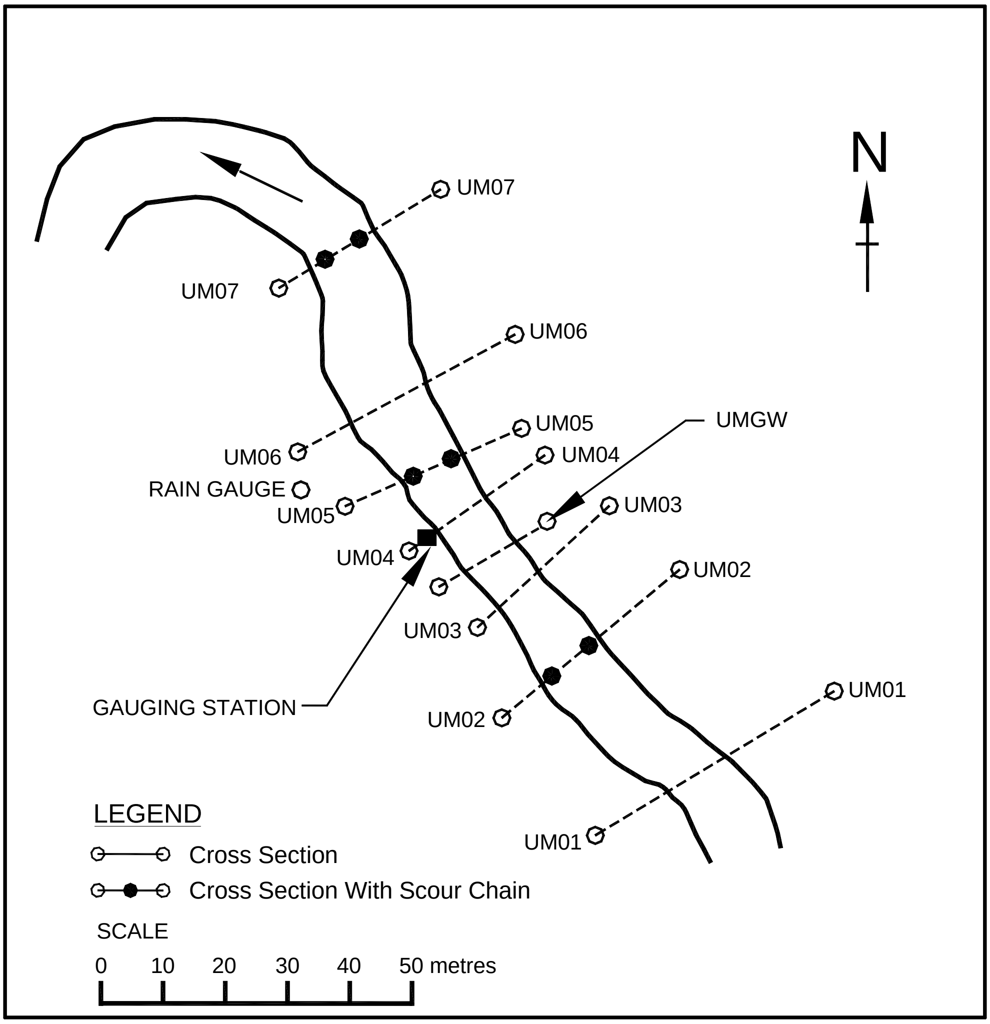

Figure 11 Location of the cross sections at the upper Swift Creek gauging station

Table 10 Summary of oven-dry, bulk bed-material sample masses collected on upper Swift Creek for each year of the sediment program

Sample mass	1998	1999	2000	2001	2002	2003
Number of samples	6	8	8	8	8	8
Mean (g)	1516.0	1542.5	1357.4	1206.7	956.0	1378.0
Standard error of estimate of the mean (g)	146.6	119.4	73.7	91.6	60.9	107.9
Minimum (g)	930.5	827.3	1130.7	928.5	655.1	855.9
Maximum (g)	1867.9	1901.9	1686.6	1622.7	1160.0	1757.0

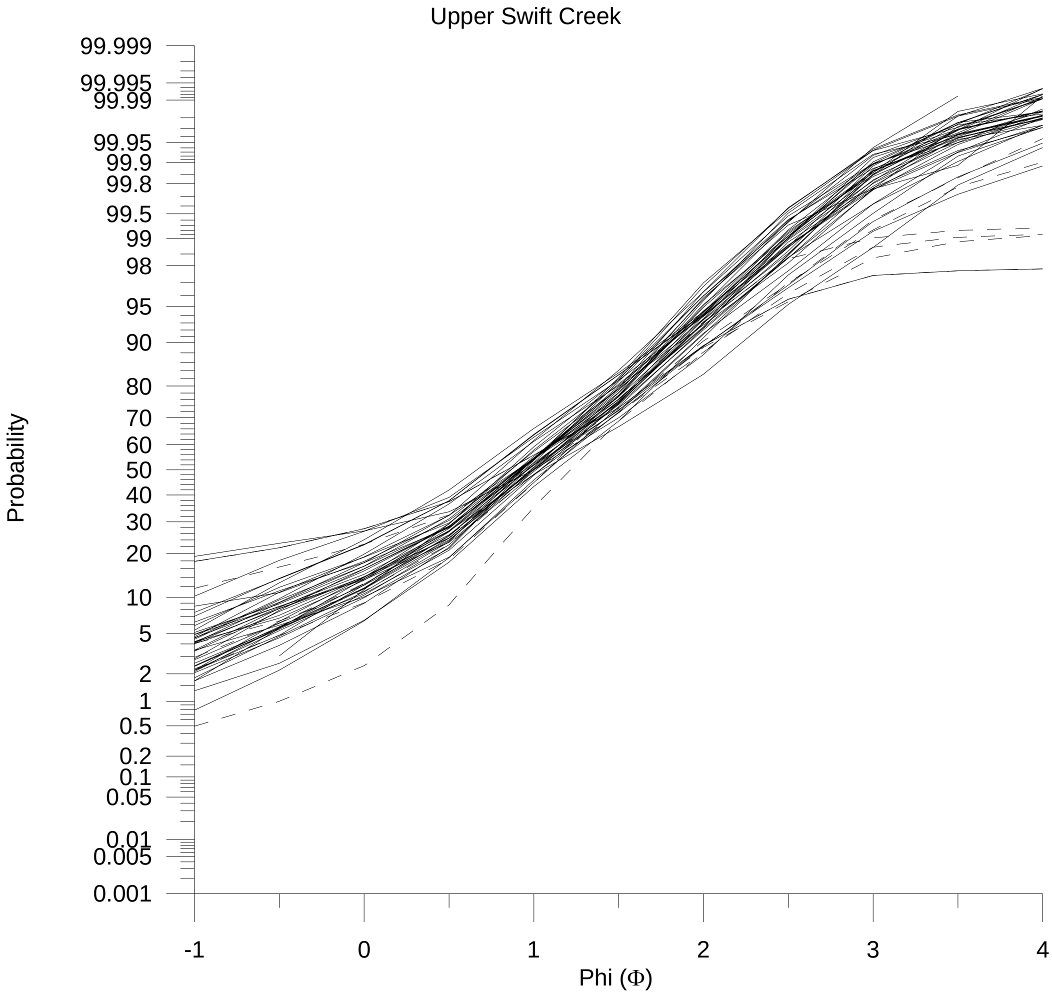

Figure 12 Particle size distributions for all bed-material samples at all cross sections for all years on Ngarradj Creek in the upper Swift Creek gauge reach. The 1998 samples are shown as dashed lines.

As all four samples had less than 5% mud, bed-material samples were oven dried and dry sieved in subsequent years. Of the 47 samples collected at upper Swift Creek (Table D1) there were no samples with greater than 5% mud.

In 1998, the bed material exhibited a graphic mean size in the medium and coarse sand Wentworth size classes (Appendix D table D1) and was moderately well sorted, near symmetrical to coarse skewed and mesokurtic to leptokurtic. The modal Folk (1954, 1974, 1980) textural group was slightly granular medium sand (Saynor et al 2004b), which also agrees with the results of Erskine et al (2003) for 1998 at the scour chain sites.

As previously noted on East Tributary, graphic mean size increased from medium and coarse sand in 1998 to coarse sand in 1999 and remained in the coarse sand Wentworth size class until 2003 (Appendix D table D1 and fig 12). Although not as pronounced as East Tributary (fig 10), there is a definite shift of size distribution curves to the left with time (fig 12) indicating a coarsening in grain size. Sorting was predominantly moderately sorted but varied from moderately well to poorly sorted over the six years study period. The bed material was mainly negatively or coarse skewed and kurtosis varied between mesokurtic and leptokurtic between 1999 and 2003. The modal Folk (1954, 1974, 1980) textural group varied between slightly granular medium sand and slightly granular coarse sand throughout the study period (Saynor et al 2004b).

As at East Tributary there was a increase in graphic mean size on upper Swift Creek from medium to coarse sand in 1998 to coarse sand in 1999, which persisted until at least 2003 (Appendix D table D1 and fig 12). The statistical significance of this change is determined in section 6.

5.5 Swift Creek

Figure 13 shows the location of the cross sections where the bed-material samples were collected. The gauge is located in Erskine et al's (2001) Sinuous Reach, which is flanked by a paperbark forest. According to the preliminary typology of Australian tropical rivers developed by Erskine et al (2005), the Sinuous Reach is a 'laterally stable, unconfined, meandering river'. Table 11 summarises the oven-dry bulk bed-material sample masses collected for each year of the monitoring program. Figure 14 shows the particle size distributions at all sections for all years.

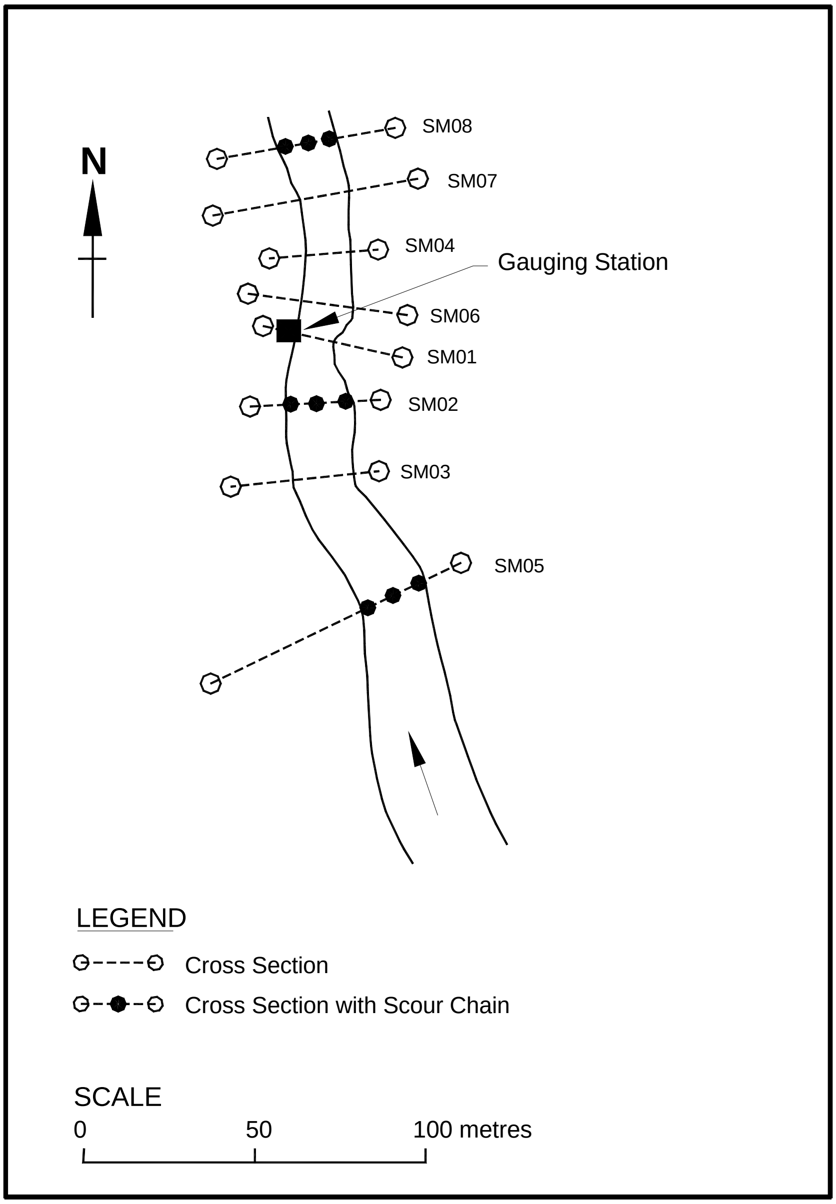

Figure 13 Location of the cross sections at the Swift Creek gauging station

Table 11 Summary of oven-dry, bulk bed-material sample masses collected on Swift Creek for each year of the sediment program

Sample mass	1998	1999	2000	2001	2002	2003
Number of samples	8	8	8	8	8	8
Mean (g)	1751.4	2122.0	1363.4	1541.2	2103.4	2355.8
Standard error of estimate of the mean (g)	114.0	194.9	69.2	76.7	168.1	165.1
Minimum (g)	1207.3	1494.4	1113.4	1283.9	1240.5	1749.5
Maximum (g)	2259.0	3031.3	1679.7	1904.1	2677.4	3035.6

To determine the mud content of the bed material, every second bed-material sample collected in 1998 was dispersed and wet sieved through a 0.063 mm sieve. The percentage of the samples < 0.063 mm was as follows:

- cross section SM02 – 1.01%
- cross section SM04 – 1.22%
- cross section SM06 – 0.76%
- cross section SM08 – 1.11%

As all four samples had less than 5% mud, bed-material samples were oven dried and dry sieved in subsequent years. Over the six years of sampling only one of the 48 samples (cross section SM02 in 2000) exhibited more than 5% mud (table E1). At cross section SM02 in 2000 parts of the bed had been scoured during the 1999/2000 wet season to expose clay which was sampled by the technique outlined in Section 2.1 (fig 14).

In 1998, the bed material exhibited a graphic mean size in the medium and coarse sand Wentworth size classes (predominantly medium sand) (Appendix E table E1) and was moderately to poorly sorted, near symmetrical to coarse skewed and mesokurtic to leptokurtic. The modal Folk (1954, 1974, 1980) textural group was slightly granular medium sand (Saynor et al 2004b) and Erskine et al (2003) found the same modal texture group for their surficial bed sediments in 1998 at the scour chain sites.

As at both East Tributary and upper Swift Creek sites, graphic mean size at the Swift Creek site increased between 1998 and 1999 to predominantly coarse sand and remained in the coarse sand Wentworth size class until 2003 (Appendix E table E1 and fig 14). The other grain size statistics were essentially constant for the six years of the study with only minor variations from that outlined above for 1998 (fig 14). The modal Folk (1954, 1974, 1980) textural group, however, did vary slightly between 1998 and 2003, and ranged from slightly granular medium sand (1998, 2002, 2003) to slightly granular coarse sand (1999, 2000, 2003) to granular coarse sand (2001). In 2003, bed material texture was bimodal, with modes in slightly granular medium sand and slightly granular coarse sand.

Not surprisingly, the most pronounced change in bed-material grain size statistics at the Swift Creek gauging station was the increase in graphic mean size from predominantly medium sand in 1998 to predominantly coarse sand in 1999, which persisted until at least 2003 (Appendix E table E1 and fig 14). The statistical significance of this change is determined in section 6.

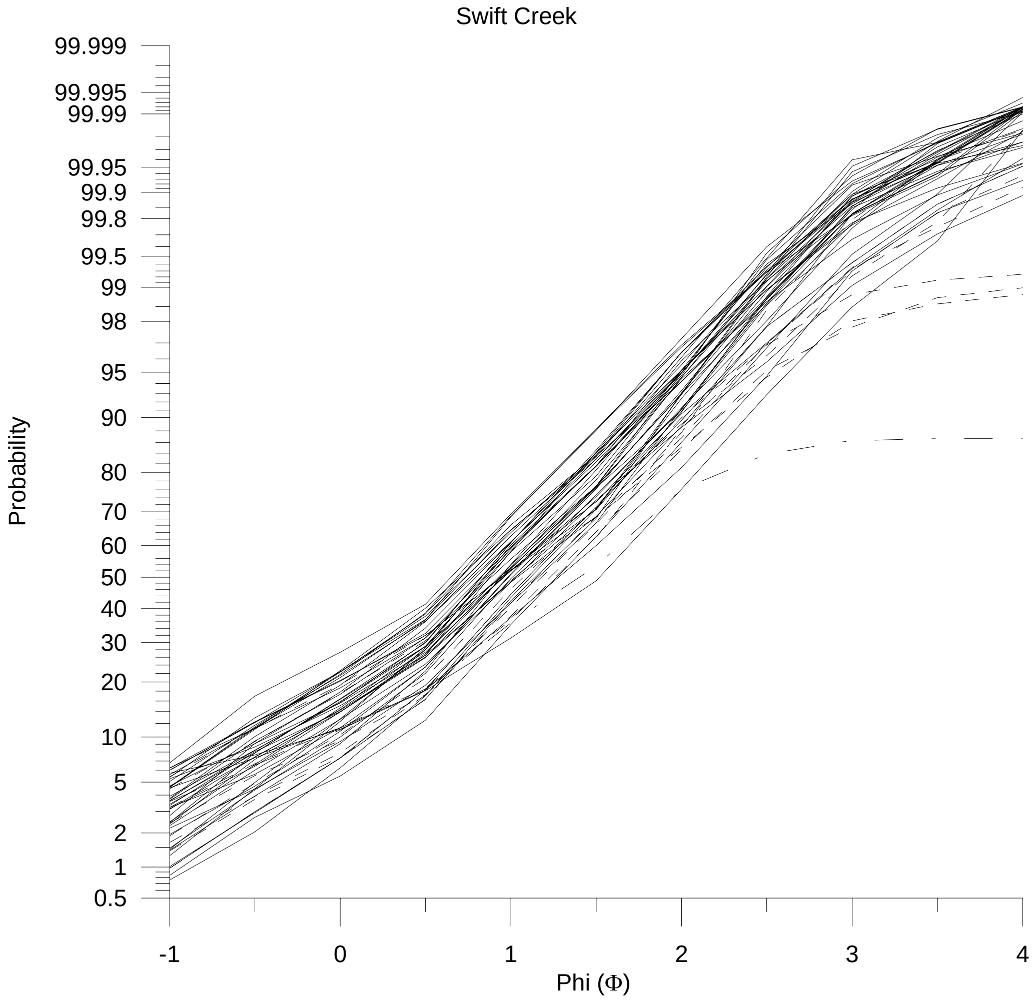

Figure 14 Particle size distributions for all bed-material samples at all cross sections for all years on Ngarradj Creek in the Swift Creek gauge reach. The 1998 samples are shown as dashed lines and the single sample from the root mat is shown as a dashed-dot line.

6 Spatio-temporal variations in grain size statistics

The purpose of this section is to determine whether the changes in grain size statistics between years for each study reach are statistically significant and whether there are statistical differences in grain size statistics for each year between study reaches.

6.1 Temporal changes

6.1.1 Tributary North

6.1.1.1 Tributary North Main Gully

The data for each grain size statistic for each year were normally distributed. The variance of each grain size statistic for each pair of consecutive years and between 1998 and 2003 was equal for graphic mean size, inclusive graphic skewness, graphic kurtosis and transformed kurtosis. The variance for inclusive graphic standard deviation was unequal between 1998 and 1999, 2002 and 2003, and 1998 and 2003 ($0.036 > \rho > 0.005$), but equal for the other years. One-Way Analysis of Variance showed that there were no significant differences for graphic mean size, skewness, graphic kurtosis and transformed kurtosis for all years. A Kruskal-Wallis test revealed that there were no significant differences for inclusive graphic standard deviation for all years. Clearly there were no changes in grain size statistics following construction of the Jabiluka project area during the 1998 dry season.

6.1.1.2 Tributary North Tributary Gully

The grain size statistics data for each year for each statistic were normally distributed, except for graphic mean size in 2003, and graphic and transformed kurtosis in 2000. The variance was unequal for graphic mean size between 2002 and 2003, and 1998 and 2003, and for inclusive graphic standard deviation between 1998 and 2003 ($0.021 > \rho > 0.001$). The variance of each grain size statistic for each pair of consecutive years and between 1998 and 2003 was equal for the remaining grain size statistics. One-Way Analysis of Variance showed that there was a significant difference between years for skewness ($\rho = 0.005$). Kruskal-Wallis tests revealed that there were no significant differences between years for graphic mean size and inclusive graphic standard deviation but that there was a significant difference between years for graphic and transformed kurtosis ($0.017 > \rho > 0.011$). The change in skewness and graphic and normalised kurtosis involved an increase after 1998 and was most likely caused by the severe fire discussed by Saynor et al (2004c). This fire mainly impacted on the tributary gully and not the main gully.

6.1.2 Tributary Central

The grain size statistics data for each year for each statistic were normally distributed, except for graphic mean size in 2001, inclusive graphic standard deviation in 1999 and transformed kurtosis in 1999 and 2001. The variance was unequal for graphic kurtosis between 1999 and 2000, 2000 and 2001, and 2001 and 2002 ($0.024 > \rho > 0.0001$). The variance of each grain size statistic for each pair of consecutive years and between 1998 and 2003 was equal for the remaining grain size statistics. Kruskal-Wallis tests showed that there were no significant differences between years for all grain size statistics. Clearly there were no changes in grain size statistics following construction of the Jabiluka project area during the 1998 dry season.

6.1.3 East Tributary Gauging Reach

The grain size statistics data for each year for each statistic were normally distributed, except for inclusive graphic standard deviation in 2003, graphic kurtosis in 1999 and 2001, and transformed kurtosis in 1999. The variance was unequal for skewness between 1999 and 2000, and 2000 and 2001, and for both graphic and transformed kurtosis between 2002 and 2003, and 1998 and 2003 ($0.044 > \rho > 0.001$). The variance of each grain size statistic for each pair of consecutive years and between 1998 and 2003 were equal for the remaining grain size statistics. One-Way Analysis of Variance showed that there was a significant difference between years for graphic mean size ($\rho = 0.01$). The ANOVA, grain size statistics, Folk's verbal descriptions and the graphic analysis (fig 10) indicate that the significant change occurred between 1998 and 1999. The same analytical techniques indicate that graphic mean size remained relatively constant between 1999 and 2003. Kruskal-Wallis tests revealed that there were no significant differences between years for all other grain size statistics. This is a site that has not been impacted by mining and hence the increase in graphic mean size is not related to Jabiluka project area construction.

6.1.4 Upper Swift Creek Gauging Reach

The grain size statistics data for each year for each statistic were normally distributed, except for graphic mean size in 2000, inclusive graphic standard deviation in 2000, skewness in 2000 and both graphic and transformed kurtosis in 2000 and 2001. The variance was unequal for at least one pair of years for all grain size statistics ($0.023 > \rho > 0.001$). Kruskal-Wallis tests showed that there were no significant differences between years for graphic mean size, inclusive graphic standard deviation and skewness but a significant difference between years for graphic and transformed kurtosis ($0.011 > \rho > 0.008$). However, the difference in graphic mean size had an associated probability level of 0.053 and could be significant if the increase persists for another year. This is a site that has not been impacted by mining.

6.1.5 Swift Creek Gauging Reach

The grain size statistics data for each year for each statistic were normally distributed, except for inclusive graphic standard deviation in 2000, skewness in 2000, graphic kurtosis in 2000, 2002 and 2003, and transformed kurtosis in 2000 and 2002. The variance was unequal for skewness between 1999 and 2000, inclusive graphic standard deviation, and graphic and normalised kurtosis between 1999 and 2000, and 2000 and 2001 ($0.013 > \rho > 0.0001$). The variance of each grain size statistic for each pair of consecutive years and between 1998 and 2003 was equal for the remaining grain size statistics. One-Way Analysis of Variance showed that there was a significant difference between years for graphic mean size ($\rho = 0.014$). Similar to East Tributary, the ANOVA, grain size statistics, Folk's verbal descriptions and the graphic analysis (fig 14) indicate that the significant change at Swift Creek occurred between 1998 and 1999. The same analytical techniques indicate that graphic mean size remained relatively constant between 1999 and 2003. Kruskal-Wallis tests revealed that there were no significant differences between years for inclusive graphic standard deviation and graphic and normalised kurtosis but a significant difference between years for skewness ($\rho = 0.029$).

6.1.6 Summary of temporal changes at main channel sites

A significant increase in graphic mean size from medium to coarse sand was observed at East Tributary ($\rho = 0.01$) upstream of the Jabiluka project area between 1998 and 1999. A graphic mean size increase was also observed at the upper Swift Creek site that was not statistically significant ($\rho = 0.053$). Upper Swift Creek, like East Tributary was not impacted by the Jabiluka project area. A significant increase in graphic mean size from medium to coarse sand was also observed at Swift Creek ($\rho = 0.014$), downstream of the Jabiluka project area, between 1998 and 1999. At all three main channel sites, graphic mean size remained relatively constant in the coarse sand range from 1999 to 2003. No significant changes in graphic mean size in the Jabiluka project area tributaries were observed during the study period. Since similar coarsening trends were observed both upstream and downstream of the project area in the main channel it is concluded that the increase in graphic mean size was an upper catchment-driven change and not caused by sediment routed down from the Jabiluka project area, through Tributary Central and Tributary North, to the main channel.

6.2 Spatial changes

Graphic mean size, inclusive graphic standard deviation and inclusive graphic skewness were significantly different between sites for each year between 1998 and 2003 ($0.004 > \rho > 0.0001$). Graphic and normalised kurtosis were significantly different between sites for all years ($0.016 > \rho > 0.0001$), except 1998 ($0.286 > \rho > 0.188$). These differences should be expected given the range in catchment areas (0.6 to 43.6 km^2) and the difference in river types between sites (Saynor et al 2004d).

Box plots of each grain size statistic for each site between 1998 and 2003 are shown in figure 15. The greatest range in grain size statistics was found for Tributary Central because the study site covered three different river reaches, unlike the other sites. The East Tributary, upper Swift Creek and Swift Creek gauging station reaches have similar graphic mean sizes. Tributary North main gully and Tributary North tributary gully have the finest graphic mean size but are similar to each other.

Figure 15 can now be used to assess any changes in bed-material grain size statistics after 2003 following the placement of stockpile material back down the decline and removal of all building infrastructure from the Jabiluka project area site during the late 2003 dry season. Similarly, the present program can be used to determine whether bed-material grain size statistics at the study sites have changed from the conditions quantified between 1998 and 2003 using fig 15 and the same statistical tests as used herein.

6.3 Spatio-temporal trends

Figure 16 shows a series of bivariate plots or scatter diagrams of the various grain size statistics against graphic mean size for the whole Ngarradj catchment data set. The relationship between inclusive graphic standard deviation and graphic mean size (fig 16A) is best represented by a highly significant second order polynomial equation ($\rho = 0.0001$) where the best sorted sediments have a mean size of 1.11 ϕ (0.46 mm). This is only a truncated segment of the complete relationship of a broadened M-shaped trend (Folk & Ward 1957) because of the small range of grain sizes found in the Ngarradj catchment due to the restricted grain sizes in the source rocks (sandstone) and the winnowing of mud from the bed material by bedform migration during the wet season. The percentage explained variance (47%) is relatively low because of the restricted data range. Sorting declines as mean size both increases and decreases away from 1.11 ϕ for the Ngarradj Creek data. This is caused by variable mixing between the separate gravel and sand modes (Folk & Ward 1957). While such a relationship is well documented in the sedimentological literature, the best sorted sediment usually exhibits a mean size between about 0.10 and 0.23 mm (2.12 and 3.32 ϕ)(Inman 1952, Folk & Ward 1957). However, there is little such size sand in the Ngarradj catchment. The mud is transported as suspended sediment and is deposited further downstream in the Magela backwater plain (Wasson 1992). This mud mode, if present in the study area, would produce a second peak in the inclusive graphic standard deviation in the mud fraction (ie graphic mean size < 4 ϕ).

The relationship between inclusive graphic skewness and graphic mean size (fig 16B) is also best represented by a highly significant second order polynomial equation ($\rho = 0.0001$). This is a truncated segment of a sinusoidal relationship (Folk & Ward 1957). Sediment with a mean size finer than 1.25 ϕ (0.42 mm) is positive or fine skewed but skewness increases progressively at mean sizes coarser than -0.37 ϕ (1.3 mm) although it remains negative or coarse skewed. The percentage explained variance (57%) is greater than for the sorting-mean size relationship.

There is a highly significant relationship ($\rho < 0.0001$) between graphic kurtosis and graphic mean size (fig 16C) with mesokurtic samples often having a graphic mean size in the coarse-medium sand range and with platykurtic samples usually having a graphic mean size in the very coarse sand and granule range. However, very leptokurtic samples also had a graphic mean size in the coarse-medium sand range. The percentage explained variance (33%) is too low to be physically significant.

Folk and Ward (1957) found that the relationship between inclusive graphic standard deviation and inclusive graphic skewness is a scatter trend in the form of a nearly circular ring. However, the scatter for the Ngarradj Creek data is so great that no meaningful relationship is apparent (fig 17A). While Folk and Ward (1957) found that a complicated inverted double V best described the relationship between inclusive graphic standard deviation and graphic kurtosis, the Ngarradj Creek data are probably best represented by a quadratic relationship (fig 17B), which is currently non-significant ($\rho = 0.37$). No meaningful relationship exists between graphic kurtosis and inclusive graphic skewness for the Ngarradj Creek data (fig 17C).

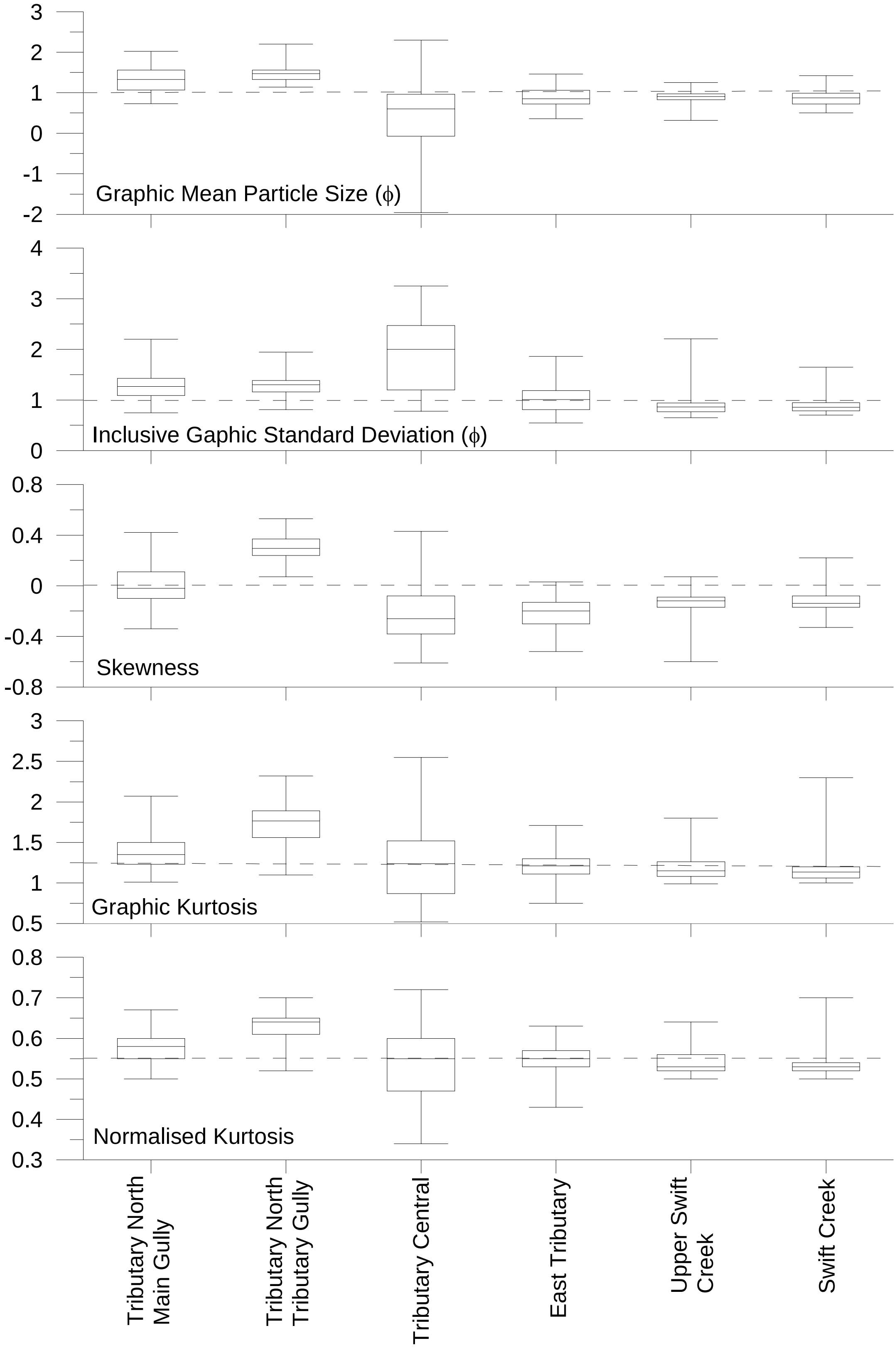

Figure 15 Box plots for each study reach using the total data set for each grain size statistic between 1998 and 2003. Whiskers represent maximum and minimum values. Dashed line is only intended to assist visual comparison between sites.

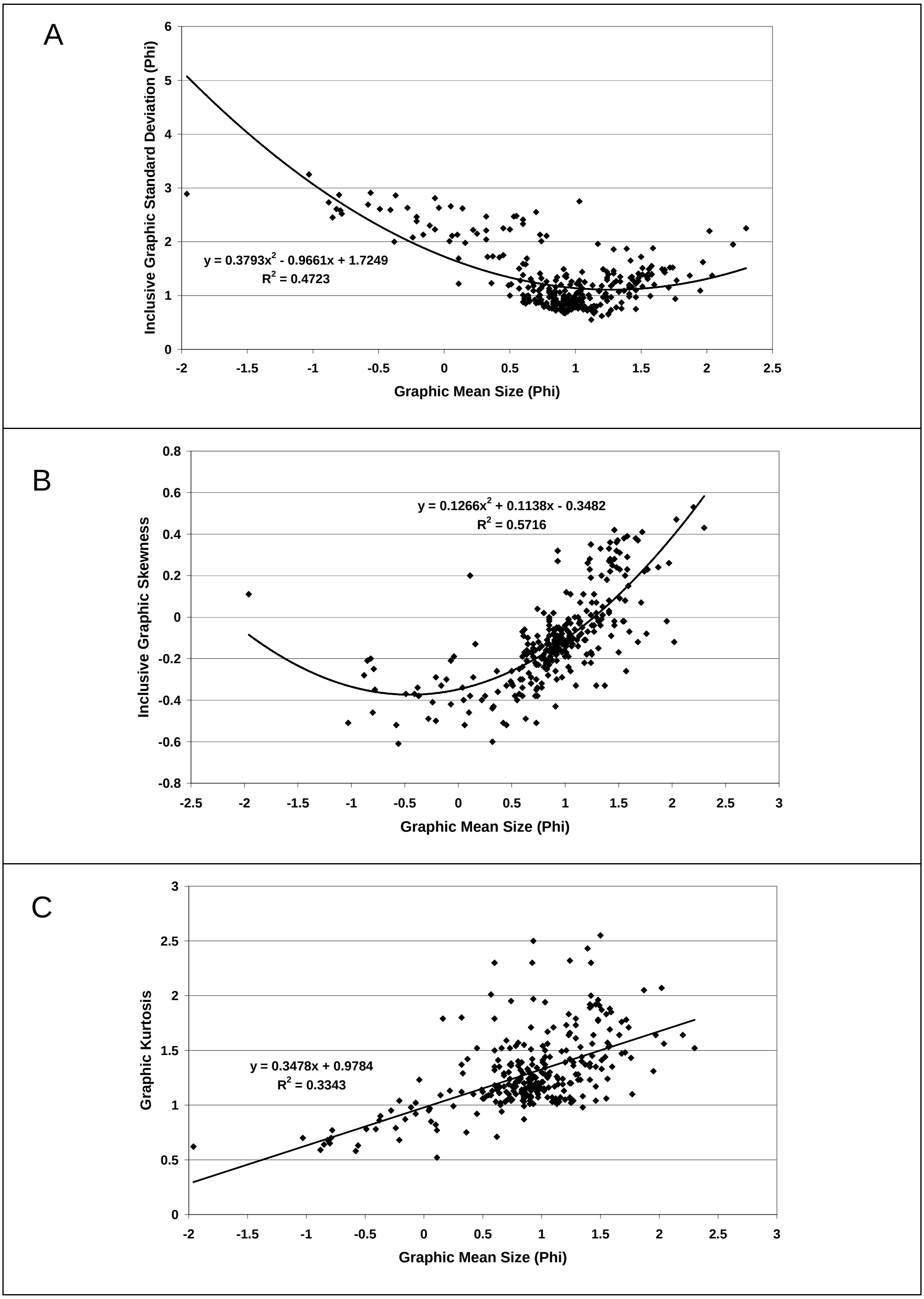

Figure 16 Bivariate plots of (A) inclusive graphic standard deviation against graphic mean size, (B) inclusive graphic skewness against graphic mean size, and (C) graphic kurtosis against graphic mean size

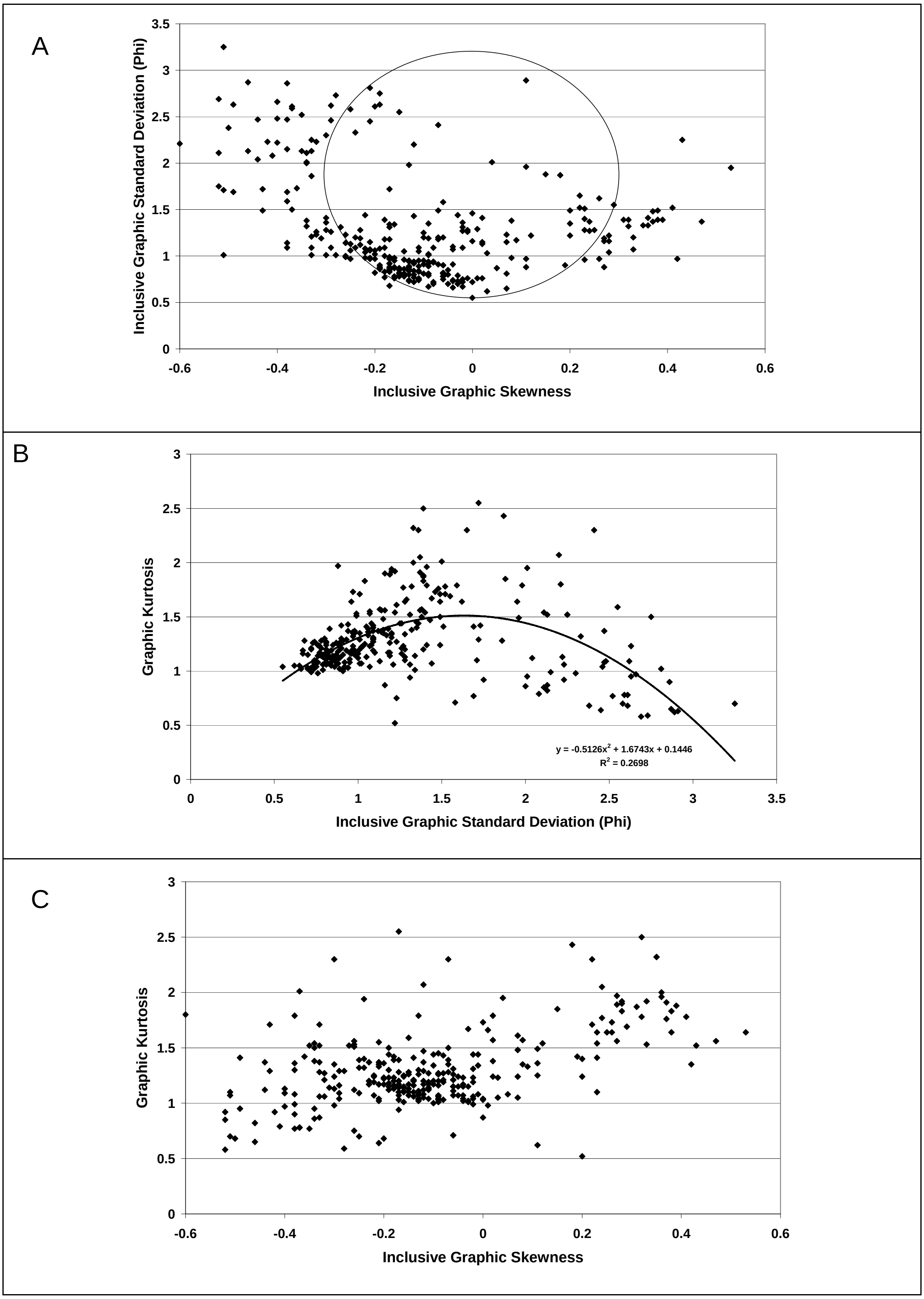

Figure 17 Bivariate scatter plots of (A) inclusive graphic standard deviation and inclusive graphic skewness, (B) graphic kurtosis and inclusive graphic standard deviation and (C) graphic kurtosis and inclusive graphic skewness

7 Discussion and conclusions

The experimental design implemented in the Ngarradj catchment for assessment of the Jabiluka project area impacts on bed-material graphic grain size statistics involved the comparison of reach-averaged values for three Jabiluka project area impacted reaches versus two upstream reference reaches not impacted by mining. A range of different river typologies were sampled because true sedimentological controls could not be found. Furthermore, it was essential that streamflow and sediment load data were also available. Therefore, all five measurement sections were located at or immediately downstream of gauging stations.

Bulk sampling was used to collect mainly bed material but also bar, bench, floodout, splay and distributary channel sediments on the tributaries draining the Jabiluka project area as well as Ngarradj Creek at the Swift Creek gauge downstream of the junction with the Jabiluka project area tributaries. The gauging reaches on Ngarradj Creek at upper Swift Creek and at East Tributary upstream of the Jabiluka project area were also sampled at the same time and served as reference sites. Bed-material was systematically sampled every dry season between 1998 and 2003 but other sediment storages were usually sampled only once between 1998 and 2000. The 56 permanently monumented cross sections used to assess channel changes (Saynor et al 2004d) served as the bed material sample sites because they ensured that the sample sites could be accurately found each year.

The grain size statistics data for the period 1998 to 2003 indicate that:

- Tributary Central had the coarsest graphic mean size and the greatest range in grain size statistics because three different river reaches were sampled.
- The East Tributary, upper Swift Creek and Swift Creek gauging station reaches had similar graphic grain size statistics.
- Tributary North main gully and Tributary North tributary gully had similar grain size statistics, which were different to those for the gauging stations and Tributary Central river reaches.

The statistically significant increase in graphic mean size recorded at the Swift Creek gauge between 1998 and 1999 was not related to any activities on the Jabiluka project area. The multiple upstream reference sites were essential to determine that this increase was caused by a similar change at both upstream reference sites although a longer record (greater sample size) is still required before the change is significant at $\rho = 0.05$ in the upper Swift Creek gauge reach. A coarse-grained sand pulse commenced in the main channel network between 1998 and 1999 and continued to 2003. A similar temporal trend was not observed in the project area tributaries, despite the construction of the Jabiluka project area during the 1998 dry season. No significant changes in any of the graphic grain size statistics were recorded on Tributary North main gully and Tributary Central between 1998 and 2003. On Tributary North tributary gully, there were significant changes in skewness and graphic and normalised kurtosis between 1998 and 2003, which were more likely related to the fires discussed by Saynor et al (2004c).

The grain size statistics data constitute thorough baseline information for the Ngarradj catchment and can be used to determine any subsequent changes due to future activities on the Jabiluka project area site. Figure 15, when combined with appropriate statistical tests, such as those used herein, provide a means to assess future departures from these baseline data. This will be important if the Jabiluka project area is reopened in the future as well as to assess the efficacy of the Jabiluka project area rehabilitation.

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Appendices A to E
Grain size statistics

These appendices contain the grain size statistics for all bulk bed-material samples collected in the Ngarradj catchment between 1998 and 2003. The data are usually presented for the cross sections at which the sediment was sampled. Cross sections are arranged in the tables in downstream sequence at each site for each year. Standard Error of Estimate of the Mean (SEE) is also presented for the data.

Appendix A
Grain size statistics for bulk bed-material samples on Tributary North for the period 1998 to 2003

The grain size statistics are shown separately for the main gully and tributary gully of Tributary North in tables A1 and A2 respectively. The location of the cross sections where the bulk bed-material samples were collected is shown in figure 4.

Table A1 Grain size statistics for the bulk bed-material samples at the cross sections on the main gully of Tributary North between 1998 and 2003 inclusive. See figure 4 for location of cross sections.

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Transformed Kurtosis
8-Oct-98	TN01	1.71	Medium Sand	1.34	0.16	1.89	0.65
8-Oct-98	TN02	1.35	Medium Sand	0.87	0.05	1.08	0.52
28-Oct-98	TN03	1.20	Medium Sand	1.18	-0.18	1.39	0.58
28-Oct-98	TN04	1.41	Medium Sand	1.15	0.02	1.38	0.58
14-Oct-98	TN06	1.55	Medium Sand	1.31	-0.02	1.06	0.52
14-Oct-98	TN07	0.95	Coarse Sand	1.01	-0.09	1.20	0.54
14-Oct-98	TN08	1.25	Medium Sand	1.39	-0.18	1.20	0.55
14-Oct-98	TN09	1.33	Medium Sand	1.07	-0.04	1.23	0.55
	Average	1.34		1.16	-0.03	1.30	0.56
	SEE	0.08		0.06	0.04	0.09	0.02
21-Oct-99	TN01	1.58	Medium Sand	1.55	0.29	1.69	0.63
21-Oct-99	TN02	1.34	Medium Sand	1.28	0.17	1.27	0.56
21-Oct-99	TN03	0.78	Coarse Sand	2.11	-0.34	1.54	0.61
21-Oct-99	TN04	1.18	Medium Sand	1.09	-0.11	1.19	0.54
21-Oct-99	TN06	0.93	Coarse Sand	0.88	0.27	1.97	0.66
21-Oct-99	TN07	1.31	Medium Sand	1.27	-0.02	1.23	0.55
21-Oct-99	TN08	1.46	Medium Sand	1.10	-0.04	1.17	0.54
21-Oct-99	TN09	1.41	Medium Sand	1.03	0.03	1.23	0.55
	Average	1.25		1.29	0.03	1.41	0.58
	SEE	0.10		0.14	0.07	0.10	0.02
3-Oct-00	TN01	1.97	Medium Sand	1.62	0.26	1.64	0.62
3-Oct-00	TN02	1.46	Medium Sand	0.97	0.42	1.35	0.58
3-Oct-00	TN03	1.95	Medium Sand	1.05	-0.05	1.23	0.55
3-Oct-00	TN04	1.17	Medium Sand	1.96	0.11	1.49	0.60
3-Oct-00	TN06	1.59	Medium Sand	1.88	0.15	1.85	0.65
3-Oct-00	TN07	1.61	Medium Sand	1.34	0.03	1.43	0.59
3-Oct-00	TN08	1.56	Medium Sand	1.27	0.01	1.37	0.58
3-Oct-00	TN09	1.03	Medium Sand	1.28	-0.01	1.34	0.57
	Average	1.54		1.42	0.12	1.46	0.59
	SEE	0.12		0.13	0.06	0.07	0.01
2-Oct-01	TN01	1.74	Medium Sand	1.52	0.22	1.71	0.63
2-Oct-01	TN02	1.05	Medium Sand	0.88	0.11	1.25	0.55
2-Oct-01	TN03	0.93	Coarse Sand	1.34	-0.16	1.01	0.50
2-Oct-01	TN04	1.54	Medium Sand	1.32	-0.05	1.37	0.58
2-Oct-01	TN06	1.24	Medium Sand	1.47	-0.19	1.13	0.53
2-Oct-01	TN07	1.13	Medium Sand	1.19	-0.09	1.26	0.56
2-Oct-01	TN08	1.07	Medium Sand	1.25	-0.10	1.44	0.59
2-Oct-01	TN09	1.58	Medium Sand	1.40	0.23	1.54	0.61
	Average	1.22	1.26	1.26	-0.04	1.28	0.56
	SEE	0.10	0.07	0.07	0.06	0.08	0.01

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Transformed Kurtosis
18-Jun-02	TN01	Sample misplaced					
18-Jun-02	TN02	Sample misplaced					
18-Jun-02	TN03	Sample misplaced					
18-Jun-02	TN04	0.73	Coarse Sand	1.41	-0.30	1.24	0.55
18-Jun-02	TN06	0.97	Coarse Sand	1.26	-0.29	1.16	0.54
18-Jun-02	TN07	1.51	Medium Sand	1.17	0.09	1.33	0.57
18-Jun-02	TN08	0.85	Coarse Sand	1.28	-0.23	1.20	0.55
18-Jun-02	TN09	1.34	Medium Sand	1.26	-0.01	1.44	0.59
	Average	1.08		1.28	-0.15	1.27	0.56
	SEE	0.15		0.04	0.08	0.05	0.01
14-Aug-03	TN01	2.02	Fine Sand	2.20	-0.12	2.07	0.67
14-Aug-03	TN02	0.89	Coarse Sand	0.76	0.02	1.24	0.55
14-Aug-03	TN03	1.09	Medium Sand	0.75	-0.06	1.07	0.52
14-Aug-03	TN04	1.27	Medium Sand	0.97	0.11	1.36	0.58
14-Aug-03	TN06	1.68	Medium Sand	1.43	-0.12	1.47	0.60
14-Aug-03	TN07	1.43	Medium Sand	1.35	-0.09	1.45	0.59
14-Aug-03	TN08	1.21	Medium Sand	1.49	-0.07	1.50	0.60
12-Aug-03	TN09	1.05	Medium Sand	1.44	-0.03	1.67	0.63
	Average	1.23		1.17	-0.03	1.40	0.58
	SEE	0.13		0.17	0.03	0.11	0.02

Table A2 Grain size statistics for the bulk bed-material samples at the cross sections on the tributary gully of Tributary North between 1998 and 2003 inclusive. See fig 4 for location of cross sections.

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
28-Oct-98	TN04	1.51	Medium Sand	1.28	0.30	1.81	0.64
28-Oct-98	TN05	1.77	Medium Sand	1.51	0.34	1.56	0.61
14-Oct-98	TN06	1.14	Medium Sand	0.81	0.07	1.24	0.55
14-Oct-98	TN07	1.29	Medium Sand	1.23	0.07	1.61	0.62
14-Oct-98	TN08	1.56	Medium Sand	1.49	0.30	1.65	0.62
	Average	1.46		1.26	0.22	1.57	0.61
	SEE	0.11		0.13	0.06	0.09	0.02
21-Oct-99	TN04	1.55	Medium Sand	1.39	0.38	1.83	0.65
21-Oct-99	TN05	1.66	Medium Sand	1.49	0.38	1.64	0.62
21-Oct-99	TN06	1.42	Medium Sand	1.02	0.22	1.55	0.61
21-Oct-99	TN07	1.24	Medium Sand	0.90	0.19	1.42	0.59
21-Oct-99	TN08	1.44	Medium Sand	1.15	0.20	1.38	0.58
	Average	1.46		1.19	0.27	1.56	0.61
	SEE	0.07		0.11	0.04	0.08	0.01
3-Oct-00	TN04	2.04	Fine Sand	1.37	0.47	1.56	0.61
3-Oct-00	TN05	1.33	Medium Sand	1.04	0.31	1.44	0.59
3-Oct-00	TN06	1.23	Medium Sand	0.96	0.23	1.63	0.62
3-Oct-00	TN07	1.24	Medium Sand	1.33	0.35	2.32	0.70
3-Oct-00	TN08	2.20	Fine Sand	1.95	0.53	1.64	0.62
	Average	1.61		1.33	0.38	1.72	0.63
	SEE	0.21		0.17	0.05	0.15	0.02
2-Oct-01	TN04	1.72	Medium Sand	1.52	0.41	1.78	0.64
2-Oct-01	TN05	1.58	Medium Sand	1.39	0.39	1.88	0.65
2-Oct-01	TN06	1.41	Medium Sand	1.05	0.27	1.55	0.61
2-Oct-01	TN07	1.23	Medium Sand	0.98	0.26	1.67	0.63
2-Oct-01	TN08	1.43	Medium Sand	1.09	0.24	1.41	0.58
	Average	1.47		1.21	0.31	1.66	0.62
	SEE	0.08		0.10	0.04	0.08	0.01
18-Jun-02	TN04	1.51	Medium Sand	1.39	0.31	1.87	0.65
18-Jun-02	TN05	1.68	Medium Sand	1.48	0.37	1.76	0.64
18-Jun-02	TN06	1.41	Medium Sand	1.19	0.27	1.89	0.65
18-Jun-02	TN07	1.21	Medium Sand	0.97	0.26	1.73	0.63
18-Jun-02	TN08	1.49	Medium Sand	1.37	0.37	1.91	0.66
	Average	1.46		1.28	0.32	1.83	0.65
	SEE	0.08		0.09	0.02	0.04	0.00
14-Aug-03	TN04	1.48	Medium Sand	1.27	0.24	1.77	0.64
14-Aug-03	TN05	1.48	Medium Sand	1.32	0.32	1.78	0.64
14-Aug-03	TN06	1.42	Medium Sand	1.33	0.36	2.00	0.67
14-Aug-03	TN07	1.46	Medium Sand	1.22	0.28	1.92	0.66
14-Aug-03	TN08	1.48	Medium Sand	1.41	0.36	1.96	0.66
	Average	1.46		1.31	0.31	1.89	0.65
	SEE	0.01		0.03	0.02	0.05	0.01

Appendix B
Grain size statistics for bulk bed-material samples on Tributary Central for the period 1998 to 2003

The grain size statistics are shown in table B1. The location of the cross sections where the bulk bed-material samples were collected is shown in figure 7.

Table B1 Grain size statistics for the bulk bed-material samples at the cross sections on Tributary Central between 1998 and 2003 inclusive. See fig 7 for location of cross sections.

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
26-Oct-98	TC06A	1.03	Medium Sand	0.94	-0.12	1.37	0.58
26-Oct-98	TC06B	0.92	Coarse Sand	1.36	-0.30	2.30	0.70
26-Oct-98	TC06C	0.92	Coarse Sand	0.85	-0.05	1.24	0.55
26-Oct-98	TC07A	-0.58	Very Coarse Sand	2.69	-0.52	0.58	0.37
26-Oct-98	TC07B	-0.21	Very Coarse Sand	2.38	-0.50	0.68	0.40
26-Oct-98	TC07C	0.73	Coarse Sand	1.01	-0.51	1.07	0.52
26-Oct-98	TC08	-0.80	Very Coarse Sand	2.87	-0.46	0.65	0.39
29-Oct-98	TC09	0.11	Coarse Sand	1.22	0.20	0.52	0.34
29-Oct-98	TC10	-0.82	Very Coarse Sand	2.61	-0.20	0.68	0.40
19-Oct-98	TC05	-0.38	Very Coarse Sand	2.00	-0.34	0.86	0.46
29-Oct-98	TC11	0.25	Coarse Sand	2.15	-0.38	0.99	0.50
19-Oct-98	TC04	0.22	Coarse Sand	2.22	-0.40	1.13	0.53
19-Oct-98	TC03	1.04	Medium Sand	1.09	-0.08	1.27	0.56
19-Oct-98	TC02	1.87	Medium Sand	1.37	0.24	2.05	0.67
19-Oct-98	TC01	1.16	Medium Sand	0.80	-0.05	1.07	0.52
	Average	0.36		1.70	-0.23	1.10	0.50
	SEE	0.21		0.19	0.06	0.13	0.03
21-Oct-99	TC06A	1.41	Medium Sand	0.98	0.08	1.35	0.57
21-Oct-99	TC06B	0.89	Coarse Sand	1.20	-0.06	1.31	0.57
21-Oct-99	TC06C	0.92	Coarse Sand	1.09	-0.18	1.42	0.59
21-Oct-99	TC07A	-0.78	Very Coarse Sand	2.52	-0.35	0.77	0.44
21-Oct-99	TC07B	0.85	Coarse Sand	1.16	0.00	0.87	0.47
21-Oct-99	TC07C	0.73	Coarse Sand	2.13	-0.35	1.52	0.60
21-Oct-99	TC08	-0.11	Very Coarse Sand	2.30	-0.30	0.98	0.49
21-Oct-99	TC09	0.88	Coarse Sand	1.06	-0.21	1.33	0.57
21-Oct-99	TC10	-0.41	Very Coarse Sand	2.59	-0.37	0.78	0.44
21-Oct-99	TC05	0.45	Coarse Sand	2.25	-0.33	1.52	0.60
21-Oct-99	TC11	0.04	Coarse Sand	2.01	-0.34	0.95	0.49
21-Oct-99	TC04	1.29	Medium Sand	1.41	0.02	1.79	0.64
21-Oct-99	TC03	1.01	Medium Sand	1.22	0.12	1.54	0.61
21-Oct-99	TC02	1.76	Medium Sand	0.94	-0.08	1.43	0.59
21-Oct-99	TC01	1.03	Medium Sand	2.75	-0.19	1.50	0.60
	Average	0.66		1.71	-0.17	1.27	0.55
	SEE	0.18		0.17	0.04	0.08	0.02
3-Oct-00	TC06A	0.93	Coarse Sand	1.39	0.32	2.50	0.71
3-Oct-00	TC06B	0.60	Coarse Sand	2.41	-0.07	2.30	0.70
3-Oct-00	TC06C	0.16	Coarse Sand	1.92	-0.16	1.70	0.63
3-Oct-00	TC07A	-0.04	Very Coarse Sand	2.63	-0.19	1.23	0.55
3-Oct-00	TC07B	-0.21	Very Coarse Sand	2.42	-0.31	1.01	0.50
3-Oct-00	TC07C	-0.07	Very Coarse Sand	2.81	-0.21	1.02	0.50
3-Oct-00	TC08	-1.03	Granule	3.25	-0.51	0.70	0.41

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
3-Oct-00	TC09	0.55	Coarse Sand	2.48	-0.40	1.09	0.52
3-Oct-00	TC10	0.14	Coarse Sand	2.62	-0.29	1.09	0.52
3-Oct-00	TC05	0.60	Coarse Sand	2.64	-0.12	1.68	0.63
3-Oct-00	TC11	-0.16	Very Coarse Sand	2.13	-0.33	0.87	0.46
3-Oct-00	TC04	2.30	Fine Sand	2.25	0.43	1.52	0.60
3-Oct-00	TC03	0.74	Coarse Sand	2.01	0.04	1.95	0.66
3-Oct-00	TC01	1.39	Medium Sand	1.87	0.18	2.43	0.71
	Average	0.42		2.35	-0.12	1.51	0.58
	SEE	0.21		0.12	0.07	0.16	0.03
2-Oct-01	TC06A	-2.93	Pebble	2.50	1.10	0.60	0.38
2-Oct-01	TC06B	0.80	Coarse Sand	1.13	0.02	1.57	0.61
2-Oct-01	TC06C	0.60	Coarse Sand	1.59	-0.38	1.79	0.64
2-Oct-01	TC07A	-0.07	Very Coarse Sand	2.23	-0.42	0.92	0.48
2-Oct-01	TC07B	0.32	Coarse Sand	2.04	-0.44	1.12	0.53
2-Oct-01	TC07C	0.05	Coarse Sand	2.66	-0.40	0.97	0.49
2-Oct-01	TC08	-1.96	Granule	2.89	0.11	0.62	0.38
2-Oct-01	TC09	1.24	Medium Sand	1.29	0.01	1.66	0.62
2-Oct-01	TC10	-0.88	Very Coarse Sand	2.73	-0.28	0.59	0.37
2-Oct-01	TC05	0.66	Coarse Sand	1.31	-0.27	1.52	0.60
2-Oct-01	TC11	1.31	Medium Sand	0.78	-0.15	1.28	0.56
2-Oct-01	TC04	0.37	Coarse Sand	1.73	-0.36	1.42	0.59
2-Oct-01	TC03	0.73	Coarse Sand	1.12	-0.23	1.37	0.58
2-Oct-01	TC01	0.70	Coarse Sand	2.55	-0.15	1.59	0.61
	Average	0.07		1.89	-0.13	1.22	0.53
	SEE	0.32		0.19	0.11	0.11	0.03
24-Jul-02	TC06A	0.64	Coarse Sand	1.15	-0.21	1.35	0.57
24-Jul-02	TC06B	1.01	Medium Sand	1.05	-0.14	1.41	0.58
24-Jul-02	TC06C	0.96	Coarse Sand	1.20	-0.10	1.34	0.57
24-Jul-02	TC07A	-0.37	Very Coarse Sand	2.86	-0.38	0.90	0.48
24-Jul-02	TC07B	0.10	Coarse Sand	2.13	-0.46	0.82	0.45
24-Jul-02	TC07C	1.50	Medium Sand	1.72	-0.17	2.55	0.72
24-Jul-02	TC08	0.06	Coarse Sand	2.11	-0.52	0.85	0.46
24-Jul-02	TC09	-0.28	Very Coarse Sand	2.63	-0.49	0.95	0.49
24-Jul-02	TC10	-0.49	Very Coarse Sand	2.61	-0.37	0.78	0.44
24-Jul-02	TC05	0.60	Coarse Sand	1.38	-0.34	1.50	0.60
24-Jul-02	TC11	0.63	Coarse Sand	1.69	-0.49	1.41	0.58
24-Jul-02	TC04	1.03	Medium Sand	1.20	-0.24	1.94	0.66
24-Jul-02	TC03	0.68	Coarse Sand	1.18	-0.17	1.17	0.54
24-Jul-02	TC01	0.50	Coarse Sand	2.23	-0.32	1.06	0.51
	Average	0.47		1.80	-0.31	1.29	0.55
	SEE	0.16		0.17	0.04	0.13	0.02

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
15-Aug-03	TC06A	0.57	Coarse Sand	1.50	-0.37	2.01	0.67
15-Aug-03	TC06B	1.05	Medium Sand	1.14	-0.26	1.56	0.61
15-Aug-03	TC06C	1.19	Medium Sand	0.83	-0.11	1.13	0.53
15-Aug-03	TC07A	-0.79	Very Coarse Sand	2.58	-0.25	0.70	0.41
15-Aug-03	TC07B	0.32	Coarse Sand	2.47	-0.44	1.37	0.58
15-Aug-03	TC07C	1.57	Medium Sand	0.99	-0.26	1.53	0.60
15-Aug-03	TC08	-0.56	Very Coarse Sand	2.91	-0.61	0.63	0.39
15-Aug-03	TC09	0.53	Coarse Sand	2.47	-0.38	1.08	0.52
15-Aug-03	TC10	-0.85	Very Coarse Sand	2.45	-0.21	0.64	0.39
15-Aug-03	TC05	-0.24	Very Coarse Sand	2.08	-0.41	0.79	0.44
15-Aug-03	TC11	0.91	Coarse Sand	1.49	-0.43	1.71	0.63
15-Aug-03	TC04	1.29	Medium Sand	1.46	0.00	1.73	0.63
15-Aug-03	TC03	0.62	Coarse Sand	1.58	-0.06	0.71	0.41
15-Aug-03	TC01	0.11	Coarse Sand	1.69	-0.38	0.77	0.43
	Average	0.41		1.83	-0.30	1.17	0.52
	SEE	0.21		0.18	0.04	0.13	0.03

Appendix C
Grain size statistics for bulk bed-material samples on East Tributary in the gauge reach for the period 1998 to 2003

The grain size statistics are shown in table C1. The location of the cross sections where the bulk bed-material samples were collected is shown in figure 9.

Table C1 Grain size statistics for the bulk bed-material samples at the cross sections on East Tributary in the gauging station reach between 1998 and 2003 inclusive. See fig 9 for location of cross sections.

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
4-Nov-98	ET01	1.46	Medium Sand	0.75	-0.02	1.04	0.51
4-Nov-98	ET02	1.29	Medium Sand	1.86	-0.33	1.28	0.56
4-Nov-98	ET03	1.35	Medium Sand	0.76	0.01	0.98	0.49
4-Nov-98	ET04	0.86	Coarse Sand	1.34	-0.17	1.14	0.53
21-Oct-98	ET05	No data available. Sample misplaced					
3-Nov-98	ET06	1.27	Medium Sand	1.18	-0.07	1.39	0.58
9-Nov-98	ET07	1.18	Medium Sand	1.08	-0.22	1.24	0.55
9-Nov-98	ET08	1.03	Medium Sand	1.08	-0.19	1.44	0.59
	Average	1.21		1.15	-0.14	1.21	0.55
	SEE	0.07		0.13	0.04	0.06	0.01
16-Aug-99	ET01	1.12	Medium Sand	0.55	0.00	1.04	0.51
16-Aug-99	ET02	0.45	Coarse Sand	1.75	-0.52	0.92	0.48
16-Aug-99	ET03	0.74	Coarse Sand	1.14	-0.38	1.36	0.58
16-Aug-99	ET04	0.68	Coarse Sand	1.09	-0.29	1.29	0.56
16-Aug-99	ET05	0.72	Coarse Sand	1.09	-0.38	1.30	0.57
16-Aug-99	ET06	0.78	Coarse Sand	1.26	-0.32	1.21	0.55
16-Aug-99	ET07	1.00	Coarse Sand	0.90	-0.19	1.30	0.57
16-Aug-99	ET08	0.80	Coarse Sand	1.06	-0.20	1.36	0.58
	Average	0.79		1.11	-0.29	1.22	0.55
	SEE	0.07		0.34	0.16	0.16	0.04
3-Oct-00	ET01	0.80	Coarse Sand	0.97	-0.20	1.23	0.55
3-Oct-00	ET02	1.00	Coarse Sand	0.78	-0.14	1.21	0.55
3-Oct-00	ET03	1.06	Medium Sand	0.96	-0.14	1.16	0.54
3-Oct-00	ET04	0.66	Coarse Sand	1.31	-0.17	0.94	0.48
3-Oct-00	ET05	0.83	Coarse Sand	0.84	-0.13	1.11	0.53
3-Oct-00	ET06	1.02	Medium Sand	1.05	-0.11	1.13	0.53
3-Oct-00	ET07	0.92	Coarse Sand	0.98	-0.21	1.37	0.58
3-Oct-00	ET08	0.75	Coarse Sand	1.19	-0.23	1.17	0.54
	Average	0.88		1.01	-0.17	1.16	0.54
	SEE	0.05		0.06	0.02	0.04	0.01
2-Oct-01	ET01	1.20	Medium Sand	0.62	0.03	1.05	0.51
2-Oct-01	ET02	0.42	Coarse Sand	1.71	-0.51	1.10	0.52
2-Oct-01	ET03	0.49	Coarse Sand	1.19	-0.31	1.14	0.53
2-Oct-01	ET04	0.85	Coarse Sand	1.07	-0.21	1.55	0.61
2-Oct-01	ET05	0.78	Coarse Sand	0.82	-0.20	1.17	0.54
2-Oct-01	ET06	1.11	Medium Sand	0.95	-0.11	1.17	0.54
2-Oct-01	ET07	1.01	Medium Sand	0.83	-0.17	1.39	0.58
2-Oct-01	ET08	0.51	Coarse Sand	1.21	-0.33	1.06	0.52
	Average	0.80		1.05	-0.23	1.20	0.54
	SEE	0.11		0.12	0.06	0.06	0.01

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
20-Jun-02	ET01	0.91	Coarse Sand	0.99	-0.26	1.51	0.60
20-Jun-02	ET02	1.25	Medium Sand	0.66	-0.04	1.02	0.50
20-Jun-02	ET03	1.10	Medium Sand	1.01	-0.33	1.71	0.63
20-Jun-02	ET04	0.36	Coarse Sand	1.23	-0.26	0.75	0.43
20-Jun-02	ET05	0.84	Coarse Sand	1.01	-0.28	1.29	0.56
20-Jun-02	ET06	0.68	Coarse Sand	1.23	-0.32	1.27	0.56
20-Jun-02	ET07	0.72	Coarse Sand	0.87	-0.16	1.10	0.52
20-Jun-02	ET08	0.80	Coarse Sand	1.09	-0.24	1.40	0.58
	Average	0.83		1.01	-0.24	1.26	0.55
	SEE	0.27		0.19	0.10	0.30	0.06
14-Aug-03	ET01	0.89	Coarse Sand	0.72	-0.08	1.21	0.55
14-Aug-03	ET02	0.60	Coarse Sand	1.01	-0.30	1.35	0.57
14-Aug-03	ET03	0.91	Coarse Sand	0.68	-0.17	1.28	0.56
14-Aug-03	ET04	0.58	Coarse Sand	1.28	-0.30	1.13	0.53
14-Aug-03	ET05	0.80	Coarse Sand	0.77	-0.18	1.23	0.55
14-Aug-03	ET06	1.14	Medium Sand	0.67	-0.02	1.19	0.54
14-Aug-03	ET07	0.83	Coarse Sand	0.78	-0.16	1.14	0.53
14-Aug-03	ET08	1.04	Medium Sand	0.81	-0.09	1.27	0.56
	Average	0.85		0.84	-0.16	1.22	0.55
	SEE	0.07		0.07	0.04	0.03	0.01

Appendix D Grain size statistics for bulk bed-material samples in the upper Swift Creek gauge reach of Ngarradj catchment for the period 1998 to 2003

The grain size statistics are shown in table D1. The location of the cross sections where the bulk bed-material samples were collected is shown in figure 11.

Table D1 Grain size statistics for the bulk bed-material samples at the cross sections at upper Swift Creek gauge between 1998 and 2003 inclusive. See fig 11 for location of cross sections.

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
30-Oct-98	UM01	0.33	Coarse Sand	1.72	-0.43	1.29	0.56
30-Oct-98	UM02	1.25	Medium Sand	0.65	0.07	1.05	0.51
30-Oct-98	UM03	1.00	Coarse Sand	0.91	-0.04	1.15	0.53
26-Sep-98	UM04		No data available. Sample misplaced				
30-Oct-98	UM05	1.03	Medium Sand	0.91	-0.07	1.28	0.56
3-Nov-98	UM06	0.74	Coarse Sand	1.32	-0.34	1.38	0.58
3-Nov-98	UM07	1.06	Medium Sand	0.74	-0.11	1.27	0.56
	Average	0.90		1.04	-0.15	1.23	0.55
	SEE	0.13		0.17	0.08	0.05	0.01
3-Sep-99	UM01	0.64	Coarse Sand	1.00	-0.18	1.16	0.54
3-Sep-99	UM02	0.85	Coarse Sand	0.81	-0.06	1.11	0.53
3-Sep-99	UM03	0.61	Coarse Sand	0.94	-0.09	1.03	0.51
3-Sep-99	UMGW	0.85	Coarse Sand	0.72	-0.02	0.99	0.50
3-Sep-99	UM04	0.74	Coarse Sand	0.92	-0.09	1.04	0.51
3-Sep-99	UM05	0.85	Coarse Sand	0.94	-0.13	1.03	0.51
3-Sep-99	UM06	0.63	Coarse Sand	0.99	-0.17	1.15	0.53
3-Sep-99	UM07	0.96	Coarse Sand	0.80	-0.12	1.12	0.53
	Average	0.77		0.89	-0.11	1.08	0.52
	SEE	0.04		0.03	0.02	0.02	0.00
3-Oct-00	UM01	0.32	Coarse Sand	2.21	-0.60	1.80	0.64
3-Oct-00	UM02	0.87	Coarse Sand	0.85	-0.15	1.10	0.52
3-Oct-00	UM03	0.83	Coarse Sand	0.89	-0.11	1.12	0.53
3-Oct-00	UMGW	0.90	Coarse Sand	0.79	-0.09	1.01	0.50
3-Oct-00	UM04	0.90	Coarse Sand	0.88	-0.13	1.07	0.52
3-Oct-00	UM05	1.05	Medium Sand	1.02	-0.09	1.07	0.52
3-Oct-00	UM06	0.91	Coarse Sand	0.95	-0.13	1.08	0.52
3-Oct-00	UM07	0.95	Coarse Sand	0.82	-0.06	1.15	0.53
	Average	0.84		1.05	-0.17	1.17	0.54
	SEE	0.07		0.16	0.06	0.08	0.01
2-Oct-01	UM01	0.95	Coarse Sand	0.88	-0.16	1.25	0.56
2-Oct-01	UM02	0.57	Coarse Sand	1.13	-0.25	1.09	0.52
2-Oct-01	UM03	0.70	Coarse Sand	0.86	-0.19	1.12	0.53
2-Oct-01	UMGW	0.93	Coarse Sand	0.73	-0.13	1.26	0.56
2-Oct-01	UM04	0.82	Coarse Sand	1.04	-0.22	1.25	0.55
2-Oct-01	UM05	0.82	Coarse Sand	0.97	-0.25	1.32	0.57
2-Oct-01	UM06	1.01	Medium Sand	0.93	-0.12	1.29	0.56
2-Oct-01	UM07	0.94	Coarse Sand	0.87	-0.15	1.26	0.56
	Average	0.84		0.93	-0.18	1.23	0.55
	SEE	0.05		0.04	0.02	0.03	0.01

Date Collected	Cross Section	Graphic Mean (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
18-Jun-02	UM01	1.13	Medium Sand	0.73	-0.03	1.01	0.50
18-Jun-02	UM02	1.02	Medium Sand	0.76	-0.11	1.14	0.53
18-Jun-02	UM03	0.89	Coarse Sand	0.81	-0.15	1.17	0.54
18-Jun-02	UMGW	0.90	Coarse Sand	0.75	-0.11	1.04	0.51
18-Jun-02	UM04	0.86	Coarse Sand	0.87	-0.19	1.15	0.53
18-Jun-02	UM05	0.90	Coarse Sand	0.72	-0.12	1.20	0.54
18-Jun-02	UM06	0.91	Coarse Sand	0.83	-0.18	1.13	0.53
18-Jun-02	UM07	0.97	Coarse Sand	0.74	-0.13	1.10	0.52
	Average	0.95		0.78	-0.13	1.12	0.53
	SEE	0.09		0.05	0.05	0.06	0.01
15-Aug-03	UM01	1.09	Medium Sand	0.72	0.00	1.03	0.51
15-Aug-03	UM02	0.98	Coarse Sand	0.84	-0.11	1.19	0.54
15-Aug-03	UM03	0.95	Coarse Sand	0.77	-0.12	1.17	0.54
15-Aug-03	UMGW	0.92	Coarse Sand	0.67	-0.09	1.16	0.54
15-Aug-03	UM04	1.07	Medium Sand	0.80	-0.13	1.30	0.56
15-Aug-03	UM05	0.97	Coarse Sand	0.93	-0.08	1.19	0.54
15-Aug-03	UM06	0.83	Coarse Sand	1.06	-0.25	1.39	0.58
15-Aug-03	UM07	0.91	Coarse Sand	0.81	-0.06	1.26	0.56
	Average	0.97		0.83	-0.11	1.21	0.55
	SEE	0.08		0.11	0.07	0.10	0.02

Appendix E Grain size statistics for bulk bed-material samples in the Swift Creek gauge reach of Ngarradj Catchment for the period 1998 to 2003

The grain size statistics are shown in table E1. The location of the cross sections where the bulk bed-material samples were collected is shown in figure 13.

Table E1 Grain size statistics for the bulk bed-material samples at the cross sections at Swift Creek gauge between 1998 and 2003 inclusive. See fig 13 for location of cross sections.

Date Collected	Cross Section	Graphic Mean Size (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
21-Oct-98	SM05	1.11	Medium Sand	0.76	-0.01	1.10	0.52
21-Oct-98	SM03	1.19	Medium Sand	0.77	-0.01	1.11	0.53
21-Oct-98	SM02	1.21	Medium Sand	0.86	-0.11	1.18	0.54
26-Oct-98	SM01	1.18	Medium Sand	0.78	-0.08	1.08	0.52
21-Oct-98	SM06	1.16	Medium Sand	0.87	-0.23	1.21	0.55
22-Oct-98	SM04	0.90	Coarse Sand	1.11	-0.10	1.03	0.51
22-Oct-98	SM07	1.06	Medium Sand	0.83	-0.06	1.14	0.53
22-Oct-98	SM08	0.89	Coarse Sand	0.99	-0.09	1.08	0.52
	Average	1.09		0.87	-0.09	1.12	0.53
	SEE	0.04		0.04	0.02	0.02	0.00
16-Aug-99	SM05	0.99	Coarse Sand	0.98	-0.16	1.15	0.54
16-Aug-99	SM03	0.65	Coarse Sand	0.91	-0.10	1.00	0.50
16-Aug-99	SM02	0.93	Coarse Sand	0.89	-0.09	1.26	0.56
16-Aug-99	SM01	0.90	Coarse Sand	0.84	-0.13	1.08	0.52
16-Aug-99	SM06	0.70	Coarse Sand	0.86	-0.13	1.04	0.51
16-Aug-99	SM04	0.78	Coarse Sand	0.86	-0.14	1.10	0.52
16-Aug-99	SM07	0.75	Coarse Sand	0.84	-0.12	1.05	0.51
16-Aug-99	SM08	1.02	Medium Sand	0.79	-0.03	1.15	0.54
	Average	0.84		0.87	-0.11	1.11	0.52
	SEE	0.05		0.02	0.01	0.03	0.01
3-Oct-00	SM05	0.93	Coarse Sand	0.95	-0.10	1.17	0.54
3-Oct-00	SM03	0.85	Coarse Sand	0.81	-0.09	1.06	0.51
3-Oct-00	SM02	1.42	Medium Sand	1.65	0.22	2.30	0.70
3-Oct-00	SM01	1.15	Medium Sand	0.70	-0.08	1.03	0.51
3-Oct-00	SM06	0.91	Coarse Sand	0.82	-0.15	1.07	0.52
3-Oct-00	SM04	0.65	Coarse Sand	0.89	-0.13	1.02	0.51
3-Oct-00	SM07	0.94	Coarse Sand	0.70	-0.05	1.15	0.53
3-Oct-00	SM08	0.85	Coarse Sand	0.74	-0.04	1.07	0.52
	Average	0.96		0.91	-0.05	1.23	0.54
	SEE	0.08		0.11	0.04	0.15	0.02
2-Oct-01	SM05	0.72	Coarse Sand	0.98	-0.22	1.19	0.54
2-Oct-01	SM03	0.64	Coarse Sand	0.95	-0.16	1.11	0.53
2-Oct-01	SM02	1.27	Medium Sand	0.73	-0.04	1.04	0.51
2-Oct-01	SM01	0.60	Coarse Sand	0.88	-0.19	1.18	0.54
2-Oct-01	SM06	0.62	Coarse Sand	0.85	-0.17	1.14	0.53
2-Oct-01	SM04	0.50	Coarse Sand	1.00	-0.26	1.12	0.53
2-Oct-01	SM07	0.76	Coarse Sand	0.79	-0.15	1.13	0.53
2-Oct-01	SM08	0.82	Coarse Sand	0.76	-0.16	1.24	0.55
	Average	0.74		0.87	-0.17	1.14	0.53
	SEE	0.08		0.04	0.02	0.02	0.00

Date Collected	Cross Section	Graphic Mean Size (ϕ)	Wentworth Classification from Table 2	Inclusive Graphic Standard Deviation (ϕ)	Inclusive Graphic Skewness	Graphic Kurtosis	Tranformed Kurtosis
24-Jul-02	SM05	1.13	Medium Sand	0.70	-0.03	1.02	0.50
24-Jul-02	SM03	1.12	Medium Sand	0.79	-0.14	1.06	0.52
24-Jul-02	SM02	1.37	Medium Sand	1.09	-0.33	1.37	0.58
24-Jul-02	SM01	0.84	Coarse Sand	1.07	-0.21	1.04	0.51
24-Jul-02	SM06	0.97	Coarse Sand	0.88	-0.17	1.07	0.52
24-Jul-02	SM04	0.91	Coarse Sand	0.92	-0.12	1.08	0.52
24-Jul-02	SM07	0.85	Coarse Sand	0.76	-0.01	1.08	0.52
24-Jul-02	SM08	0.81	Coarse Sand	1.02	-0.20	1.22	0.55
	Average	1.00		0.90	-0.15	1.12	0.53
	SEE	0.07		0.05	0.04	0.04	0.01
12-Aug-03	SM05	0.97	Coarse Sand	0.81	-0.10	1.20	0.55
12-Aug-03	SM03	0.78	Coarse Sand	0.81	-0.14	1.20	0.54
12-Aug-03	SM02	1.24	Medium Sand	0.97	-0.17	1.20	0.55
12-Aug-03	SM01	0.64	Coarse Sand	0.97	-0.21	1.17	0.54
12-Aug-03	SM06	0.69	Coarse Sand	0.92	-0.17	1.03	0.51
12-Aug-03	SM04	0.97	Coarse Sand	0.78	-0.06	1.15	0.53
12-Aug-03	SM07	1.01	Medium Sand	0.90	-0.06	1.21	0.55
12-Aug-03	SM08	0.87	Coarse Sand	0.86	-0.17	1.10	0.52
	Average	0.90		0.88	-0.13	1.16	0.54
	SEE	0.07		0.03	0.02	0.02	0.00