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SEDIMENT REGIME OF THE DARLING RIVER

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ABSTRACT: The Darling River is predominantly a wash-load stream. Deposition of fine suspended sediment occurs within the channel. Rates of deposition on benches within the channel range from 9 to 64 mm per year. Flocculation of montmorillonitic clays may explain these high rates of deposition in favourable locations where shear forces are low. The channel consists of straight and sinuous reaches. The sinuous reaches reflect the time when the channel meandered freely. Under the present flow regime the deposition of montmorillonitic clays has stabilised the channel in this sinuous form. The straight reaches represent recent channel diversion due to blocking of the channel by sediment deposition and vegetation. Absence of natural levees may reflect the relationship of the sediment peak to the flood peak in wash-load streams, and the calibre of wash-load sediment.

INTRODUCTION

The sediment and flow regimes of a river are major determinants of channel form and stability. This paper examines available data relevant to the sediment regime of the Darling River and its expression in channel form and stability.

The Darling River catchment is second only to the Murray River catchment in size, covering an area of 650,000 km^2 in New South Wales and Queensland (Fig. 1). The eastern tributaries originate in the northern tablelands of N.S.W. at elevations up to 1,600 m and in the Darling Downs Region in southeast Queensland. The average annual run-off varies from 30 mm for the Gwydir River to 9.5 mm for the Moonie River. The northern tributaries rise on or near the Great Dividing Range in south-central Queensland. Here the average annual run-off varies from 6.0 mm for the Warrego River to 3.7 mm for the Paroo River. The long-term average annual discharge of the Darling at Menindee is 102 m^{3}s^{-1}representing an average annual run-off of 5.6 mm. The run-off has two main peaks. In summer, rainfalls associated with wandering tropical cyclones in the north of the catchment increase run-off and flooding. In winter, discharge may increase due to rainfall associated with upper-atmospheric convergences.

Large amounts of montmorillonitic clays are derived from basalt and labile sediments in the upper catchment. These cohesive clays play an important role in channel morphology and in sedimentation within the channel and on the flood-plain. Downstream of Goondiwindi the stream traverses flat, low-gradient plains formed primarily of very fine-grained cohesive sediments. The channel gradient decreases progressively to Walgett (some 2,500 km from the Southern Ocean) and then remains fairly constant at about 5 x 10^{-5}.

Large numbers of distributaries, anabranches and palaeochannels divert flow from the main channel during floods. Flood peaks are slowed by storage effects due to this system of channels and general overbank storage. The travel time for flood peaks from Walgett to Wentworth ranges from 60 to 120 days. Normally floods rise very slowly and may last for up to four months. The river has ceased to flow 48 times at Menindee since 1881 for periods of up to 362 days.

METHODS OF INVESTIGATION

Bank and bed sediments were sampled to a depth of 5-7 cm on cross-sections near the gauging stations indicated in Table 1 (for locations see Fig. 1). At the time of sampling the river had ceased to flow. Fourteen sediment samples — four from each bank and six from the bed — were collected at approximately equal distances along the channel perimeter. The samples from each bank and the bed were bulked and subsampled. The percentage of sediment finer than 72 μm and organic matter in these sub-samples was determined. The channel silt-clay percentage was calculated using the weighting method of Schumm (1960).

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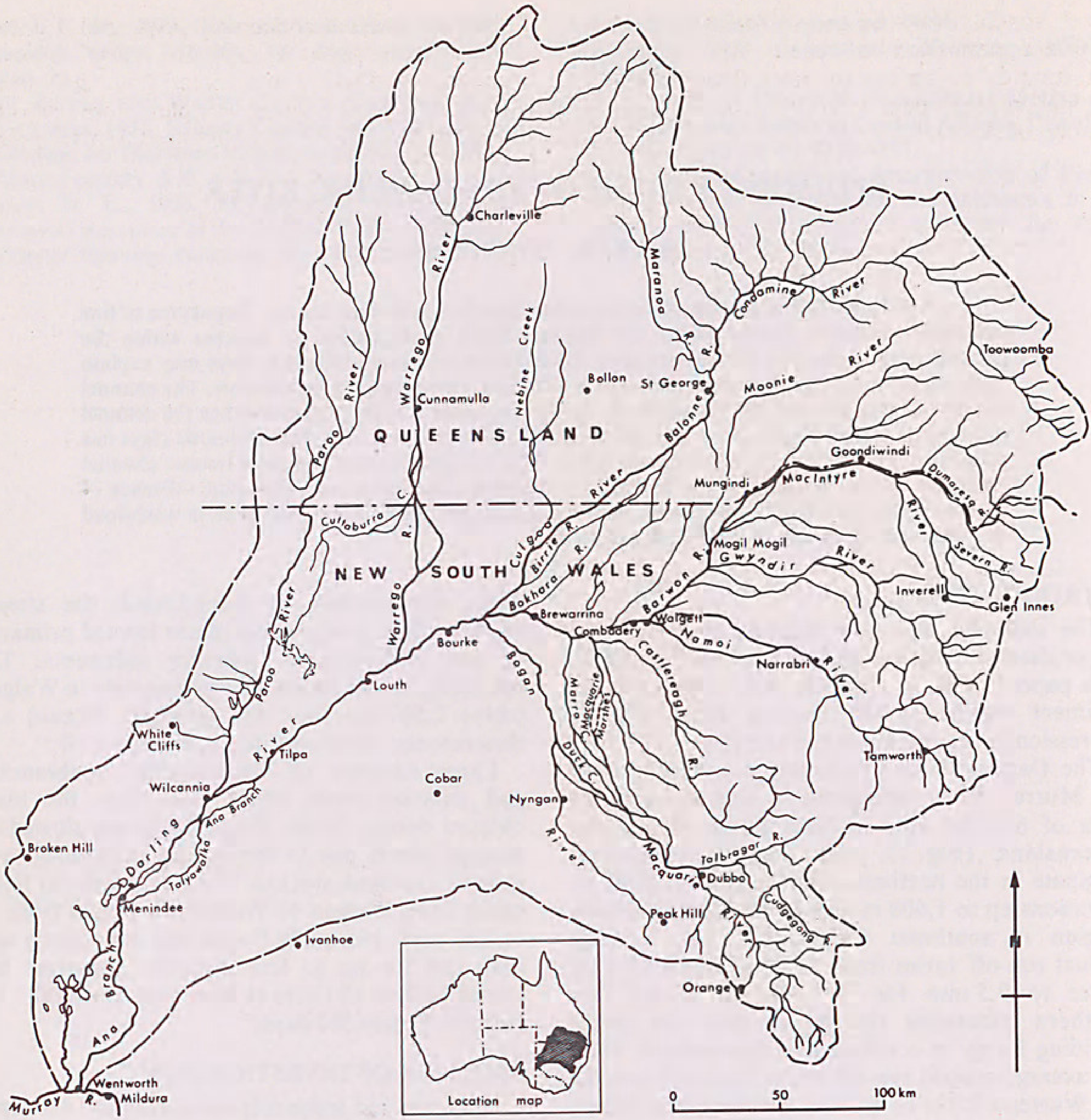

FIG. 1. — The Darling River catchment and location of the gaugings sites referred to in the text.

The channel cross-sections at these sampling sites were surveyed. The width of the channel was measured from the edge of the lower bank to the opposite bank. The depth of the channel was taken from this lower bank to the deepest part of the channel.

Sinuosity is the ratio of channel length to valley length. Sinuosities were determined between the gauging stations in Table 1 using maps at a scale of 1:250,000. The spacing of the sites varies from 102 to 280 km. By using these long reaches, local variations in sinuosities were averaged out. Sinuosities determined in this way are conservative when compared with values obtained by Schumm (1968) for the Murrumbidgee using 8-km reaches. For example, between Walgett and Brewarrina the sinuosity for the 280-km reach is 2.2 (Table 1). This compares with a sinuosity of 2.3 for a 30-km reach downstream from Walgett.

Measurements of rates of deposition of sediment on benches (Woodyer 1968), within the channel, were made using 8.5 mm diameter steel pegs about 15 cm long as surface markers. These were driven flush with the existing surface level at equal spacing (61-305 cm). The thickness of sediment deposited on these steel pegs was measured following one or more floods (Table 2). Wooden marker pegs were used to facilitate relocation of the steel pegs.

Water samples containing suspended sediment were collected using a 'U.S. D-49 depth-integrating suspended-sediment sampler' (Guy & Norman 1970). Point integrated samples were collected using a U.S. D-49 sampler modified to permit

TABLE 1
CHANNEL DIMENSIONS, SINUOSITIES AND SILT-CLAY PERCENTAGES

Location	Distance from source (km)	Width (m)	Depth (m)	Width-depth ratio	Sinuosity	Silt-clay (%) Bank	Bed	Channel
Mungindi	557	29.6	4.7	6.3		62.3	4.9	18
					1.9			
Mogil Mogil	659	40.5	5.2	7.6		54.3	11.4	21
					1.8			
Walgett	829	59.4	6.6	9.0		61.7	14.5	24
					2.2			
Brewarrina	1109	72.8	10.1	7.2		81.2	24.1	34
					2.1			
Bourke	1315	94.8	9.6	9.9		75.9	-	-
					1.7			
Louth	1507	85.3	9.7	8.8		72.4	1.0	19
					1.9			
Tilpa	1668	92.7	11.3	8.2		81.1	15.3	27

TABLE 2
RATES OF DEPOSITION ON BENCHES

Sampling site*	Period	No. pegs read	Mean thickness per peg (mm)	Mean rate of deposition per year (mm)	Number of inundations	Mean rate of deposition per flood (mm)	Height above thalweg (m)
240 m upstream from station No. 422001 on left bank	May 1971 to Feb. 1974	8	23.7	8.7	3	7.9	6.2
670 m downstream from station No. 422001, on left bank	Dec. 1970 to Feb. 1974	6	85.0	26.2	4	21.3	5.9
Hairpin bend 1.7 km downstream from station No. 422008, on right bank	Oct. 1970 to Feb. 1974	8	57.8	16.9	6	9.6	5.8

*Sampling sites identified by distance from gauging stations (Aust. Water Res. Council 1974).

exclusion of water by air pressure until the required depth for sampling was reached. The concentration of suspended sediment and the particle size distribution were determined using the methods described by Walker *et al.* (1974).

DATA

Channel Dimensions and Sediments

Table 1 gives channel dimensions, width-depth ratios, sinuosities and percentages of silt-clay in banks, bed and the whole channel perimeter, near gauging stations, along the Darling River. These data plot adjacent to equivalent data for the Murrumbidgee River (Schumm 1968, Figs. 24-26) and approximate the regression lines Schumm derived for the Great Plains rivers in the U.S.A. These regression lines are for sinuosities versus width-depth ratios, sinuosities versus channel silt-clay percentages and width-depth ratios versus channel silt-clay percentages.

Fig. 2 compares the values in Table 1 with the values obtained by Schumm (1968) for the

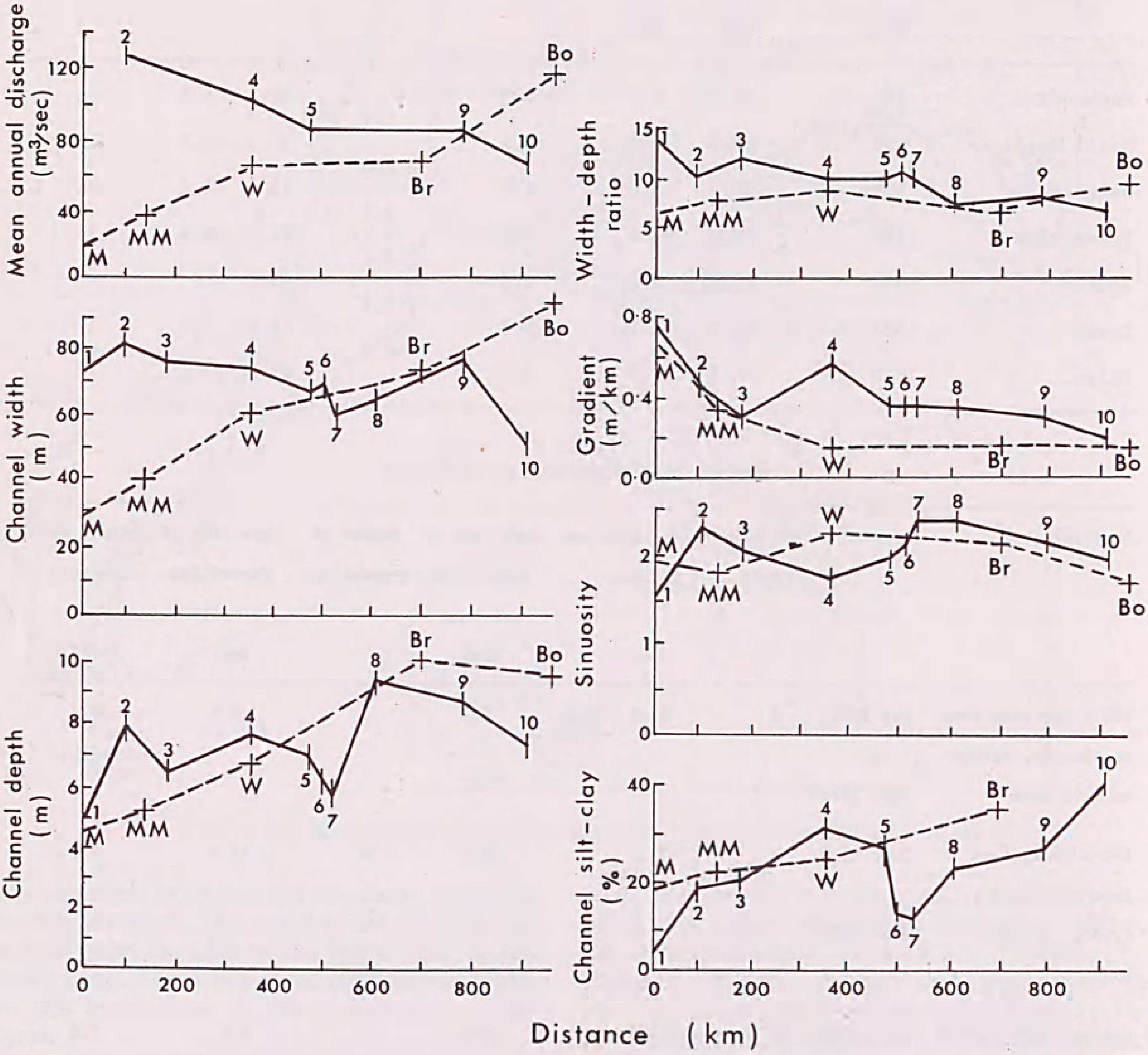

FIG. 2. — Downstream changes in channel character, silt-clay percentage and discharge for Darling and Murrumbidgee (after Schumm 1968) Rivers. Murrumbidgee cross-sections (unbroken line): 1, Wantabadgery; 2, Wagga Wagga; 3, Currawarna; 4, Narranderra; 5, Darlington Point; 6, Yarrada Lagoon; 7, Bringagee; 8, Carrathool; 9, Hay; 10, Maude. Darling cross-sections (broken line): M, Mungindi; MM, Mogil Mogil; W, Walgett; Br, Brewarrina; Bo, Bourke; L, Louth.

Murrumbidgee River. It includes data for the Darling River downstream to Bourke only to give a similar overall channel distance for both rivers. Mean annual discharges are included in Fig. 2 to complete the comparison. The Murrumbidgee differs from the Darling River and most other rivers in that its mean annual discharge decreases downstream. The differences in behaviour of channel width and width-depth ratio downstream in the two rivers reflects the different trends in discharge. Despite this difference there are marked similarities in the general downstream trends for channel depth, gradient, sinuosity and channel silt-clay percentage. The Murrumbidgee channel from about Hay downstream resembles the Darling channel fairly closely.

Pl. 12 shows (above) the channel at the sampling site downstream of Bourke with its steep cohesive banks and sandy bed (see also Woodyer 1968). However, even the sandy bed sediments and particularly the sediments which accumulate by bed-load movement on the points of bends contain montmorillonitic clays, which tend to immobilise them. This, combined with the low energy gradients (1×10^{-4}), results in a very stable channel.

Sediment Transport

Taylor (1976) estimates the total sediment load at Walgett as 420,000 tons per year, of which a maximum of 5% is transported as bed-load. An independent estimate of the percentage of the sediment load which moves as bed-load is 2.5%. This estimate was derived from data presented by Schumm (1968, Fig. 27) and the mean channel silt-clay percentage for all the Darling River sites (Table 1).

At least 95% of the sediment transported by the Darling is fine suspended sediment. Concentrations are generally low: the highest recorded to date is 1,800 p.p.m. Despite the low concentrations the water is turbid. This turbidity is due to the fineness of the suspended sediment. Some 80 suspended-sediment samples were collected near the hairpin bend 1,730 m downstream of Combadery gauging station (station number 422008) (Australian Water Resources Council 1974). Some 80-95% of the suspended sediment (when dispersed for analysis) was finer than 2 μm. These samples were collected during two near bankfull flood-waves in 1969 and 1970. During the 1969 flood a close grid of points was used for sampling in two adjacent cross-sections (Pl. 12, below). The concentration of suspended sediment was uniform throughout these cross-sections. No sediment particles coarser than 37 μm were captured. Numerous laminae containing fine to medium sands occur in the point-bench sediments deposited from suspension (Woodyer *et al.* in press). Either the suspended-sediment sampler failed to capture sand-sized particles or suspension of sand is very intermittent in time and space. This suspension may be related to turbulence associated with sand dunes and bend sharpness (Woodyer *et al.* in press).

An exceptional flood occurred during January 1974 in the Walgett area. Intense local rains caused the most rapid rate of rise of river levels during the 92 years of record (namely 4.34 m in two days). The turbulence associated with this rapid rise brought the sandy bed-material into suspension. When the flood subsided sand was observed in the crevices of the bark of trees to just below maximum flood level. However, apart from these infrequent events, the suspended sediment in the Darling is dominantly wash-load (Einstein *et al.* 1940) with some local suspension and deposition of fine to medium sands derived from the bed-material.

In contrast the tributary streams, at least in the highlands and slopes, carry a great deal more sediment as bed-load. In the steeper more turbulent reaches the suspended-load is dominantly suspended bed-material. As these streams enter the western plains most of the bed-material is dumped and it is mainly the finer suspended load that continues downstream. Examples are the sand deposited by the Castlereagh River north of Coonamble and by the Gwydir River west of Moree. In these reaches and upstream natural levees occur, downstream no levees are present.

The bed-material of the Darling River is highly variable in size distribution over short distances. An example of this is provided by detailed sampling of the bed-material at and near the hairpin bend downstream of Combadery gauging station. Bed-material was collected at 3 m intervals across the entrance to the bend, across the straight reach downstream of this bend and at two sites opposite the point of the bend (Pl. 12, below). In the straight reach the coarsest sediment sample (sample 1, Fig. 3) contained 95% by weight coarser than 62 m and only 2% finer than 2 μm. Samples 2 and 3 (Fig. 3) show the size-distribution range across the channel at the bend entrance. Sample 4 is for bed sediments opposite the point of the bend in the deepest water. This fine sediment is deposited during periods when flow has ceased and water pools in the bend. Apparently it resists subsequent erosion due to the cohesive nature of the clay. Sample 5 is for sediment opposite the point (and adjacent to sample 4) but where the greatest flow velocity occurs at high stage. Sample 5 is similar to

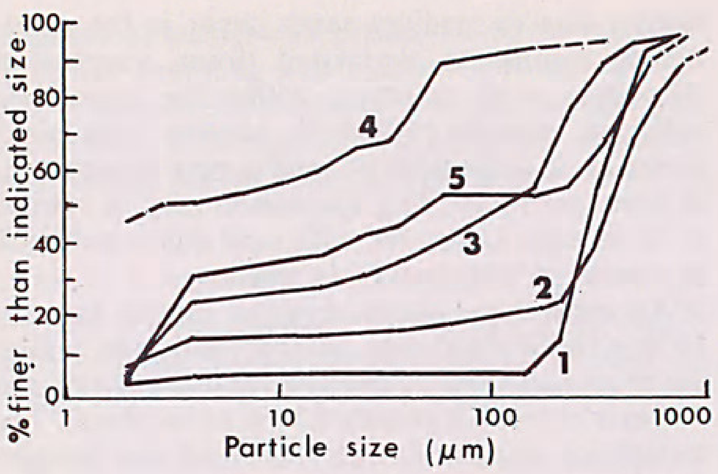

FIG. 3. — Size distribution of sediment samples taken from bed of Darling-Barwon River 1.7 km downstream of Combadery gauging station. Sample 1 from straight reach downstream of hairpin bend and 39.3 m from left bank. Samples 2 and 3 from entrance to hairpin bend 29.3 m and 49.4 m respectively from right bank. Sample 4 from central deep of hairpin bend. Sample 5 adjacent to sample 4 but below filament of maximum velocity (see Pl. 12, below).

sample 4 in respect of the fine fractions, but is comparable with samples 2 and 3 in respect of the coarse fractions. Apparently the higher velocities, where sample 5 was collected, have removed some of the finer fractions. The variability of the bed sediments, particularly adjacent to the banks, is increased by slumping of the fine bank sediments following floods.

SEDIMENT DEPOSITION

Woodyer *et al.* (in press) determined mean rates of accretion on benches (other than concave-bank benches) near Walgett. In one case the mean rate was 28 mm per year over an estimated period of 116 years. In the other case the mean rate was 27-57 mm per year for a period that could have been 8-17 years. Subsequently data have been collected (Table 2) by measuring the depth of sediment deposited on steel pegs driven flush with the surface. These rates vary from 9 to 26 mm per year (Table 2). In view of these additional measurements and the uncertainty about the period of deposition (8-17 years), the upper rate of 57 mm per year should be discounted. Therefore rates of deposition of 9-28 mm per year for these benches seem more appropriate. These rates compare with mean rates of 48-64 mm per year for the concave-bank benches.

DISCUSSION

It is apparent that the Darling River is a suspended-load stream. Moreover, the suspended sediment is dominantly wash-load consisting of silts and clays with 80-95% finer than 2 μm. In view of this, it is surprising that deposition occurs at high rates (9-64 mm per year) within the channel. Obviously some form of coagulation of the individual particles is necessary to permit deposition.

Partheniades (1971) found that, below a critical shear force, floccules of fine cohesive clays are not disrupted and so deposit. This concept appears to fit the deposition of muds in the Darling system. For example, rapid deposition (48-64 mm per year) of mud occurs on concave-bank benches (Woodyer 1975). Some 46-60% of the deposited sediment, when dispersed, is finer than 2 m and 85-90% is finer than 62 μm. This deposition occurs in gentle reverse flow, where the shear forces are low. The high proportion of clay (dominantly montmorillonite with minor amounts of kaolinite and illite) also suggest the likelihood of flocculation. Norrish and Quirk (1954) and Blackmore and Miller (1961) showed that calcium montmorillonite exists in 'packets' of 3-9 clay platelets. Shainberg and Otoh (1968) found that the introduction of sodium did not cause the breakdown of these packets until the sodium fraction reached 10-15% of the exchange capacity of an originally pure calcium montmorillonite. In four samples of sediment from the concave-bank bench exchangeable sodium plus potassium comprises only 4.8% of the total cations. On this basis it seems likely that deposition of mud, in quiet backwaters, is due to flocculation. This would not be 'salt water flocculation' (Partheniades 1971) since the concentration of solubles is less than 200 p.p.m. during these high flows in the Darling River. The dominant interparticle bonding is probably electrostatic attraction between the negatively charged faces and the positively charged edges of particles.

The deposition of montmorillonitic clays stabilises the channel. Woodyer *et al.* (in press) found that the channel had not shifted significantly since 1880 in a 30-km reach downstream of Walgett. Riley (1975) showed similar data for a number of sites on the Namoi, Gwydir and Barwon Rivers plotted in the 'straight' field of an Ackers and Charlton (1970) plot of stream slope versus discharge. Because these streams are 'meandering' and not straight Riley claimed that either the Ackers and Charlton line is not generally applicable or the Namoi-Gwydir streams are not in a 'live-bedded' condition. Taylor and Woodyer (in press) concluded that, although much of the channel of the Barwon-Darling River has a 'live bed', it has become fixed in a sinuous form, which

PLATE 12

(Above) The Darling River channel downstream of Bourke where the cross-section was surveyed and where the channel sediments were sampled. The picture was taken looking upstream and shows low amplitude sand dunes on the bed.

(Below) Aerial view of hairpin bend in the Darling-Barwon River 1.7 km downstream of Combadery gauging station showing locations of cross-sections where suspended sediment samples and bed-material samples were collected in 1969. The locations where samples 4 and 5 were collected are also indicated.

reflects its past history when it was a typical meandering channel. It appears that a channel has to have 'live banks' as well as a 'live bed' to fit the Ackers-Charlton classification. The deposition of montmorillonitic clays on the banks effectively stabilises them under the present flow regime.

Deposition of sediment within the channel in association with the growth of the ti-tree (*Melaleuca linariifolia* Sm.) tends to block the channel. Woodyer *et al.* (in press) concluded that at certain places and times this blocking effect leads to the formation of anabranches. This may explain the variation in form along the present channel from straight to sinuous reaches.

Preliminary analysis of suspended sediment data supplied by the New South Wales Water Resources Commission indicates that the peaks of sediment concentration lead the flood peaks. During the March-April flood of 1971 at Menindee this lead was 34 days. Heidel (1956) reported wash-load sediment peaks progressively, lagging the flood-wave. Whatever the explanation for this difference in behaviour, it is apparent that wash-load sediment peaks are not closely associated with flood peaks. In contrast, the peak concentration for suspended bed-material is likely to remain more constantly associated with the flood peak. This statement is based on the fact that the sediment peak of suspended bed-material is related to the greatest energy gradients. These maximum energy gradients remain more constant in their association with the flood peak than does the wash-load sediment peak. Thus the peak concentration of suspended bed-material is likely to occur at higher stages (up to the flood peak) than a wash-load sediment peak. This fact, plus the high percentage of sandy sediments in suspension in streams in which bed-material suspension predominates, may be related to the formation of levees along channel margins. It may be significant that there are no natural levees along the Darling River, a wash-load stream. In contrast levees occur on tributaries upstream of where they have dumped sandy bed-load (as mentioned previously). In a wash-load stream the sediment peak occurs well below the flood peak and below bankfull level (Wolman & Leopold 1957, Fig. 65) and the percentage of sand in suspension, particularly at higher stages, is low.

CONCLUSIONS

The channel of the Darling displays similar downstream trends, in respect to depth, sinuosity and silt-clay percentage, to at least one other channel in the Murray catchment, the Murrumbidgee River. This river was selected for comparison because the data was available. The main difference is the downstream decrease in width along the Murrumbidgee with decreasing discharge, whereas width increases downstream on the Darling River with the normal downstream increase in discharge.

The Darling normally carries a very fine suspended load. Sampling during near-bankfull flows failed to capture suspended sediment coarser than 37 μm. Suspension of fine to medium sands, deposited in bench sediments, must be very intermittent. However the steeper highland tributaries carry sand in suspension to a much greater extent. Much of this sand is dumped where these tributaries enter the western plains, forming distinct levees which are absent downstream along the Darling.

The bed material varies greatly in size distribution from sand to mud. The fine sediments occur mainly in the pools at bends, where the fine wash-load deposits during periods when discharge ceases, and near the banks where slumping has occurred.

Rates of deposition are estimated as 9-26 mm per year for point benches and 48-64 mm per year for concave-bank benches. These high rates of deposition suggest that flocculation of the fine suspended sediment occurs. This flocculation is probably related to the nature of the clay minerals (dominantly montmorillonite) and the adsorbed cations. Salt-water flocculation is ruled out because of the low concentration of dissolved solids (less than 200 ppm). Deposition of the floccules occurs in quiet backwaters where bed shear forces are low. These are often zones of reverse flow.

The deposition of these montmorillonitic clays on the banks has stabilised them and the present sinuous channel form reflects the past history when the river had a typical meandering channel. Blocking of this channel by sediment deposition associated with the growth of ti-trees in the channel has led to the formation of anabranches.

The occurrence of levees along streams may be related to the behaviour of the suspended sediment peak in relation to the flood peak and the calibre of the suspended sediment. The maximum sediment concentration of wash load leads the flood peak along the Darling River. As a result the sediment peak occurs below the flood peak and probably below bankfull level. The occurrence of the sediment peak at relatively low stages and the fineness of the suspended sediment may explain the absence of levees along the Darling. In contrast, where the sediment peak consists of sandy bed-load in suspension the sediment peak occurs near the flood peak at higher overbank stages. This association of the sediment peak with the flood peak favours overbank deposition of sandy bed-material adjacent to the channel to form levees.

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