UNIVERSITY OF ALBERTA

BEDLOAD WAVES IN A SMALL EPHEMERAL SAND-BED CHANNEL

BY

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

FALL 1991

ISBN 0-315-70060-2

UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: FRANCISCA C.M. NIEKUS

TITLE OF THESIS: BEDLOAD WAVES IN A SMALL EPHEMERAL SAND-BED CHANNEL

DEGREE: MASTER OF SCIENCE

YEAR THIS DEGREE GRANTED: 1991

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DATED October 11, 1991

You know my method. It is founded upon the observation of trifles.

Sherlock Holmes

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled BEDLOAD WAVES IN A SMALL EPHEMERAL SAND-BED CHANNEL submitted by FRANCISCA C.M. NIEKUS in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in GEOMORPHOLOGY.

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ABSTRACT

The study describes bedload transport in the ephemeral sand-bed channels of three small drainage basins (202,260 m^2, 22,830 m^2, and 336,810 m^2) in the badlands of Dinosaur Provincial Park, Alberta. Bedload transport during the sediment-laden flows in these channels was measured with Helley-Smith bedload samplers during the summers of 1982, 1983, 1984 and 1987. Scour cords measured erosion and deposition in the channels.

Transport rate patterns of sediment larger than 0.5 mm caught in the Helley-Smith samplers, typically showed periodic fluctuations or waves independent of discharge. Transport rate variation of sediment finer than 0.5 mm caught in the Helley-Smith bedload samplers, varied with discharge and suspended sediment concentration.

It is proposed that the difference in transport rate variation for different size sediment can be used to define and separate the bedload from the suspended load. This definition of bedload based on characteristics of transport rate pattern provides a consistent means to evaluate the amount of suspended sediment trapped in different type bedload samplers. It thereby improves the potential to compare bedload transport rates and patterns obtained by various samplers in different environments. Following the proposed definition, the 'real' bedload in the 1987 Helley-Smith bedload samples varied between 2% and 71%.

Only a few runof events each year are large enough to transport measurable bedload (five in 1982, four in 1983, two in 1984 and eight in 1987). Nevertheless, the flows in the channel have an overcapacity to transport bedload, as is indicated by the exhaustion of bedload type sediment after large storms and the thin (3 cm - 6 cm) alluvial cover in the channels of the study basins.

ACKNOWLEDGMENTS

The most important contributors to this thesis were the people who occasionally baby-sat my two sons. There were a great many of them: Sigried Deutschlander, Astrid Berthold, Gundula van Hasselt, Catherine Smith, Des McManon, Charlotte Smith, Jasper, Valerie Sloan, Manijah Charagozlou, Ella Slusarczyk, Rosaline Paul, Gesche and Mike Schmidt-McGibbon in Edmonton; Linda in Montreal; Ann Patterson, Martha Kashap, June Smith, Patricia Gomez, Johanna Sinnige, Amanda Asea and my mother in Saskatoon.

Dirk baby-sat in all three places, but it has been pointed out to me that in his case this is not called baby-sitting, but fathering. My mother not only baby-sat, she also supported me financially when I had run out of funding and savings, she ran my household for five weeks, and above all she put up with my awfull temper during the stressfull time when the thesis was almost finished, but not yet. Siggy did major reproductive labour, not the least one was getting rid of that horrible couch in Edmonton when even the Salvation Army did not want it and I had to quickly leave for Montreal. Joan, Fran and Diana in the Geography Office helped out - friendly and efficiently - with numerous administrative obstacles.

The thesis has greatly benefited from comments on earlier versions by Dirk de Boer, Ian Campbell and John Shaw. The most important comment on the thesis though was from Larry Gerard. Before I went into the field, I told him I would be measuring bedload with Helley-Smith samplers. He was very interested, but as always immediately recognized the crucical problem: 'How will you know that what you are measuring, is bedload?'

I greatly enjoyed the courses I took from Larry and also from

'Raj' Rajaratnam, their teaching not only brought me new knowledge in fluid mechanics and hydraulics but also encouragement and inspiration.

Finally, I thank Dirk de Boer, my husband, collegue, and handyman, for the photo-copying, the transformation of files, the bringing back home of books and articles from the library, the field assistance, the fathering, etc. and above all for enduring my sometimes fearsome temper for even longer than my mother.

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CHAPTER ONE INTRODUCTION

1.1 Introduction

Despite interest, expeditions and geomorphological research in arid lands for more than 100 years (Graf, 1988), the nature of bedload transport in the ephemeral sand-bed channels that occur in many dryland environments, has not yet been unveiled: the timing, the rates of transport, the size of material transported as bedload as well as the factors determining transport, remain subjects of speculation. In fact, information is so scarce that even the fundamental question 'Is there any difference between bedload and suspended load in these opaque, highly turbulent flows of sediment laden water? has not been answered. Yet, the bedload is of principal concern because of its influence on the development and the adjustments of fluvial channels. And in drylands, as well as in more humid environments, these channel adjustments are a key to our understanding of the landscape development.

1.2 Bedload measurement.

The dearth of information on bedload transport in ephemeral channels is attributed to the difficulties associated with the measurement of bedload transport in general, and bedload transport in arid environments in particular (Reid and Frostick, 1989).

One of the main problems is distinguishing between bedload and suspended load in sediment samples. Theoretically, the difference between bedload and suspended load is clear: all particles that are completely supported by turbulence in the main body of the flow are suspended load.

all particles that move downstream in close proximity to the bed by rolling, sliding or saltating at velocities less than the surrounding flow, are bedload.

The vertical distribution of sediment in flowing water, as measured in the Mississippi (Colby, 1963), is illustrated in Figure 1.1. The smallest particles, particularly clays and colloidal particles are nearly uniformly distributed in the water column, the larger particles are concentrated near and on the bed. The larger particles moving along the bed, are obviously bedload. However, the larger particles near the bed, may seem like suspended load at a particular moment, some portion - but how much? - consists of bedload particles in the process of saltating from one spot on the bed to another. Often, especially in gravel-bed rivers, the mode of transport is inferred from the size of the particles. In general, boulders, pebbles and gravels move downstream as bedload, whereas the smallest particles such as clay and silt are carried in suspension. In sand-bed channels however, this size-based criterion does not offer much assurance, because a large portion of the transported sediment consists of sand-sized particles in the range of 0.05 mm - 2 mm which may travel both as suspended load or as bedload, depending on flow conditions (Beschta, 1987; Reid and Frostick, 1987).

Bedload measurement devices that are most succesful in separating bedload from suspended load are pits or slots excavated in the channel bed, with slot widths exceeding saltation path lengths. When intending to study variation in transport rates during floods, the pits have to be equipped with a special monitoring device (see e.g. Leopold and Emmett, 1976; Reid et al., 1980). However, more often than not the ample time and resources necessary to install such a mechanism is unavailable. In such cases, researchers use portable bedload samplers that are less accurate.

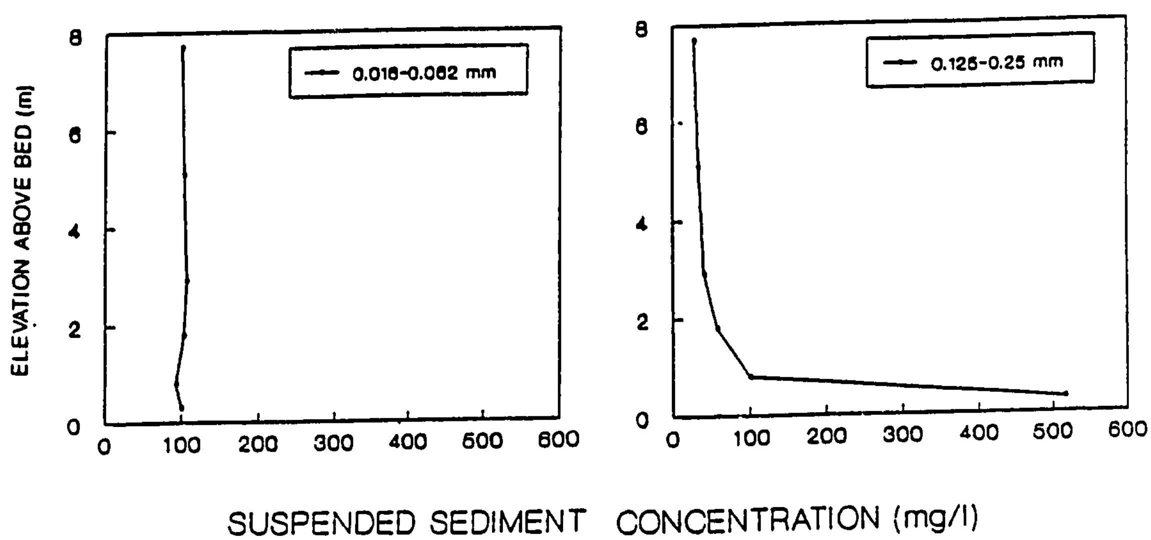


Figure 1.1 Vertical profiles of suspended sediment concentrations of two different size fractions. Mississippi River at St Louis (modified after Colby. 1963).

A - Fraction 0.016-0.082 mm.
B - Fraction 0.125-0.25 mm.

but offer a handy and available alternative. The Helley-Smith sampler (Helley and Smith, 1971), a pressure difference sampler in which diverging sides cause deposition in the sampler, is one of the most succesful of this type and is widely used (Figure 1.2). After entering through the nozzle, the sediment is trapped in a mesh bag attached to the sampler. The problem is that the nozzle of the sampler protrudes into the flow, thereby catching suspended sediment in addition to bedload. As absolute quantities of suspended sediment trapped depend on sediment concentration in the flow (Emmett, 1981), it follows that the contamination of bedload samples with suspended sediment, is especially worrisome in ephemeral sand-bed channels, where suspended sediment concentrations are generally extremely high (Reid and Frostick, 1989).

Emmett (1981) who calibrated the Helley-Smith sampler with an open slot type bedload sampler, considered the contamination problem so serious that he advised against using the Helley-Smith bedload sampler for sediment of particle sizes which can also be transported as suspended sediment. Nevertheless, for lack of better alternatives some researchers have continued the use of this sampler for fine sediments. Carey (1985) and Jackson and Beschta (1982) reacted to the problem by setting a minimum size limit for bedload, equalling the mesh size of the sampler bags. Bryan et al. (1988), who published some of the very rare data on bedload transport rates in ephemeral sandbed channels, categorized the total content of their Helley-Smith sampler bags as bedload. As their bedload samples were dominated by coarse sand, and suspended sediment concentrations of the flow were very high (between 25 and 78 g/l), a large portion of the sediment trapped in their Helley-Smith samplers probably was transported as suspended sediment. Unfortunately, it is not possible to determine how much. Lekach and Schick (1983) who did not use

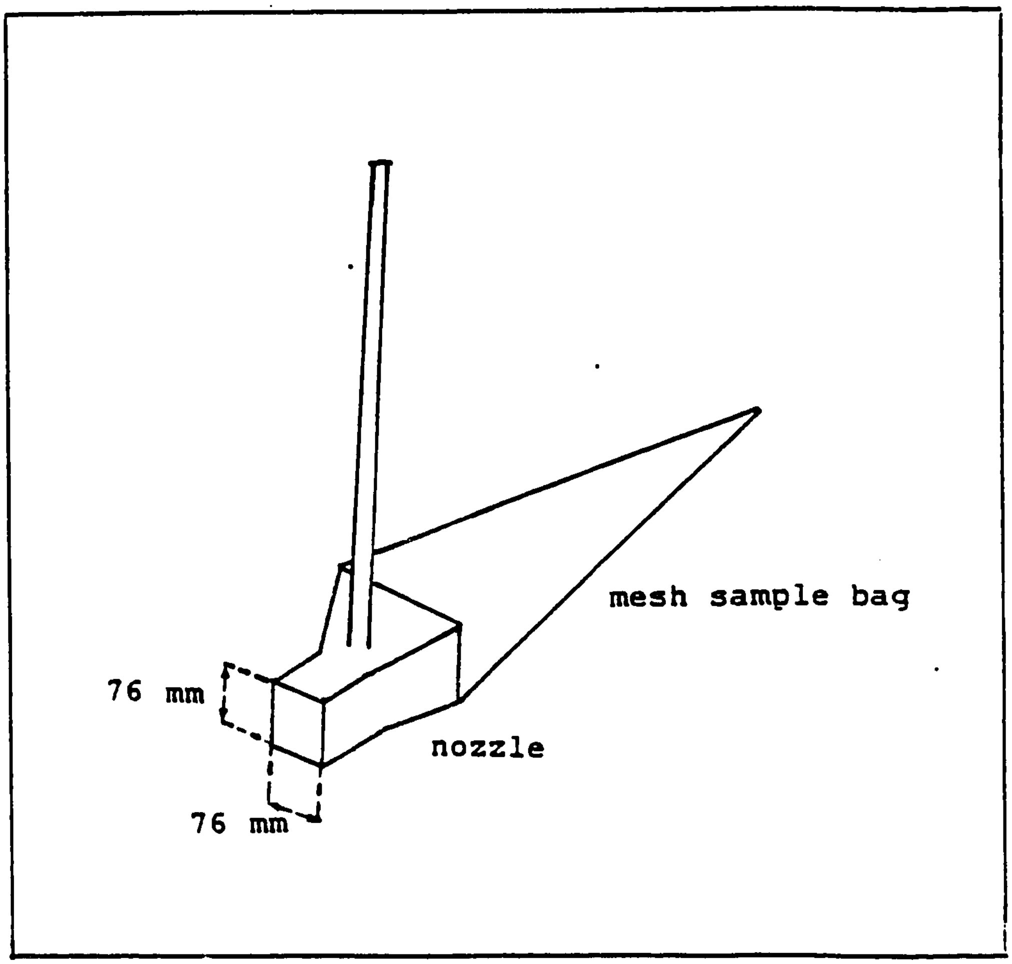


Figure 1.2 Hand held Helley-Smith bedload samplers were used in Dinosaur Provincial Park.

a Helley-Smith sampler, but obtained samples of the total sediment load of a gravel-bed desert stream by holding a container into the falling water some distance below the lip of a small waterfall, made no effort to distinguish between suspended sediment and bedload. They simply divided sediment transport into a fine (<0.063 mm) and a coarse (>0.063 mm) fraction.

1.3 Scour and deposition in ephemeral sandbed channels.

In the absence of direct bedload measurements, scour cord observations and studies of fluvial deposits are useful indicators of bedload transport in ephemeral channels. Studies of this kind indicate substantial scour, transport and subsequent deposition of bed-material in ephemeral channels (Reid and Frostick, 1989), but provide no conclusive information on how this bed-material is transported, as bedload or in suspension.

Emmett and Leopold (1963) measured up to 0.3 m scour along an ephemeral sand-bed channel, the Arroyo de los Frijoles in Mexico. The scour was matched by a more or less equal amount of deposition. In order for this amount of transport to comply with reservoir sedimentation data (Lane and Borland, 1954), Emmett and Leopold assumed that the material was transported as bedload, possibly as a slow, dense slurry along the bed. Foley (1978) attributed the 66 cm scour he observed in a Californian sandbed channel to antidune migration. He based his conclusion on estimates of antidune amplitudes and sediment transport patterns of flume tests. Brown (1983) observed 0.2 m - 0.5 m scour during light winter runoff events (peak discharges of about 6 m^3/s) in the smaller channels of a 2.5 km^2 catchment in the arid badlands near Borrego Springs.

California. During intense summer rainstorms (peak discharges of about 26.0 m^3/s) scour increased to 0.4 m - 0.9 m. A positive, deterministic relationship between scour depth and flow intensity is also indicated by Leopold et al. (1966) and Foley (1978). Leopold et al. find in their study in the Arroyo de los Frijoles in New Mexico that the mean scour depth appears to be proportional to the square root of discharge per unit width of the channel. Foley describes an increase in scour depth from 24 cm to 66 cm when bankfull flow depth increases from 23 cm to 34 cm in an ephemeral stream in California. Increases in the depth of scour however, are not necessarily an indication of an equal increase in bedload transport rates during larger storms in ephemeral sandbed channels. It is very possible that during the bigger storms a much larger portion of the bed-material is carried in suspension, leaving only the largest particles to be transported as bedload. The result could very well be a decrease in bedload transport rates at higher discharges. Reid and Frostick (1987) demonstrated that the mean particle size of the suspended load increases during larger storms in desert streams, in contrast with perennial rivers.

1.4 Bedload waves

Though direct measurements of bedload transport in the sediment-laden flows of ephemeral sand-bed channels are almost non-existent, a number of studies have taken place in laboratories and in perennial streams. These studies demonstrate the occurrence of periodic variations in bedload transport that are independent of changes in water discharge. These periodic variations have been called bedload waves or bedload pulses and have been observed in flumes (Carey, 1985; Ashmore, 1988), in perennial streams (Jackson and Beschta. 1981; Reid and Frostick. 1986) and even in an ephemeral. bedrock channel in the Negev desert (Lekach and Schick. 1983).

The pattern of periodic variation in bedload transport strongly contrasts with changes in transport of suspended sediment. Though it has been demonstrated that suspended load can also vary independently of changes in water discharge. its variations do not show the typical. wave-like pattern that has been observed in bedload transport. Rather. suspended load varies in relation to season or to storm-period. changes that have been linked to sediment-supply conditions (Walling. 1974; Carson et al.. 1973). Suspended sediment changes related to storm-period have also been related to a lag-effect. a delay in the suspended sediment pulse caused by flood waves that travel faster than stream water and the suspended sediment load (Heidel. 1956). Small pulses of sediment laden water. superimposed on the main flood wave by contribution from tributary channels. are suggested as another cause for variation in suspended load (Frostick and Reid. 1977; Campbell. 1977).

Different theories have been proposed to explain the pulsing behaviour of bedload transport. The most comprehensive explantion is the kinematic wave theory as suggested by Langbein and Leopold (1968). Langbein and Leopold theorize. and also demonstrate. that a larger flow is required to move particles which are close to one another than those that are far apart. The result is the build up of a type of 'traffic jam' centering around slow moving particles. These 'traffic jams' or bedload waves can assume different forms. They have been described from flume experiments with sandbeds as dunes (Foley. 1978; Carey. 1985). and from flume experiments with a sand/gravel mixture as areas of highly concentrated particles. no more than a couple of grains thick. with definite boundaries that move slowly down the channel (Wilcock and Kuhnle, 1987).

1.5 Spatial variation in bedload transport

Related to the spatial variation in bedload transport rates over time, is the variableness over space. Research, especially in dryland rivers, has documented periodic, lateral shifts of large amounts of sediment in fluvial networks. These rather abrupt shifts, or adjustments, occur over a wide range of spatial scales. A famous example of such a shift on a decadal to century-long basis has been documented by several generations of geomorphologists in the Henry Mountains in southern Utah, U.S.A., where the headward erosion on the tributaries that followed the drastic entrenching of the Fremont River triggered a complex series of abrupt changes in the locations of erosion and aggradation in the fluvial system (Hunt et al., 1953; Everitt, 1979; Godfrey, 1980; and Graf, 1982a).

On a smaller scale, Meade (1985) observed three sediment shifts on a one year period in the East Fork River, Wyoming, U.S.A. Each shift was related to a pulse of water discharge from melting snow packs in the mountain source area of the stream.

The abrupt nature of these adjustments is attributed to the exceedance of threshold values in the equilibrium between hydraulic force and channel morphology: at channel sections where progressive deposition occurs, the channel gradient will locally increase to a threshold inclination that induces channel incision and flushing of the sediment downstream (Graf, 1982b). The fact that these adjustments occur so prominently in dryland regions, seems related to the massive amounts of sediment involved in the channels of these areas, as well as to the radical changes in discharge to which dryland rivers are subjected (Graf, 1988).

The occurrence of sudden shifts of sediment, and the relative position to erosion and depositional sections, will strongly influence the outcome of bedload transport measurements at a specific location, especially in dryland channels. This means that knowledge of the occurrence of these sudden channel adjustments, and the spatial distribution of erosion and aggradation, is fundamental to understanding of the nature of bedload transport at a specific location at a specific time.

1.6 Object of study

This study describes and analyzes bedload transport, scour and deposition in a small, ephemeral sandbed channel in the badlands of southern Alberta. The objective is to determine the size and amounts of material that is transported as bedload, and to identify environmental factors that affect bedload transport rates in this type of channel.

During the summer of 1987 bedload transport rates were measured with a hand-held Helley-Smith bedload sampler. The spatial distribution of erosion and aggradation in the channel, as well as possible shifts in the location of these processes, were measured with scour cords installed at nine locations along the channel.

The study demonstrates differences in transport rate variation of different sediment size fractions of the Helley-Smith samples. These differences make it possible to distinguish between sediment transported as bedload and sediment transported as suspended load. Variations in transport rates of the two coarse sediment size fractions show characteristics of the typical wave pattern of bedload transport. Variations in the transport rates of the two fine fractions, mostly reflect changes in suspended sediment concentration.

Scour cord readings demonstrate that no major shifts of sediment occurred in the channel upstream from where bedload transport was measured. Typically, thin (1 cm - 3cm) deposits of sediment accumulate in the channel during small storms. During larger storms, these deposits are flushed out of the basin.

CHAPTER TWO STUDY AREA

2.1 The Badlands

Miles and miles of badlands line both sides of the deeply incised valley of the lower Red Deer River in south-eastern Alberta. The badlands expose the shales, muddy sandstones, coarse channel sandstones, thin coal seams, and resistant ironstone bands of the Upper Cretaceous Judith River Formation, deltaic and marine deposits that underly the prairies of this region. It is believed that the badland development immediately followed the incision of a giant spillway, the present Red Deer River valley, during late Wisconsin deglaciation (Bryan et al., 1987).

The study basin is located in Dinosaur Provincial Park (Figures 2.1 and 2.2), an area where the badlands have extended about 10 km from the river valley into the prairies. In the park, sandstone accounts for about 70% of the sediments (Dodson, 1971).

2.2 Climate

South-eastern Alberta typically experiences long, freezing winters, and short, though at times blistering hot summers (Table 2.1). High winds and the high summer temperatures give rise to a potential evapotranspiration of 560 - 610 mm per year (Longley, 1972). The large potential evapotranspiration combines with a low annual precipitation (usually less than 360 mm) to create the semi-arid conditions in this region.

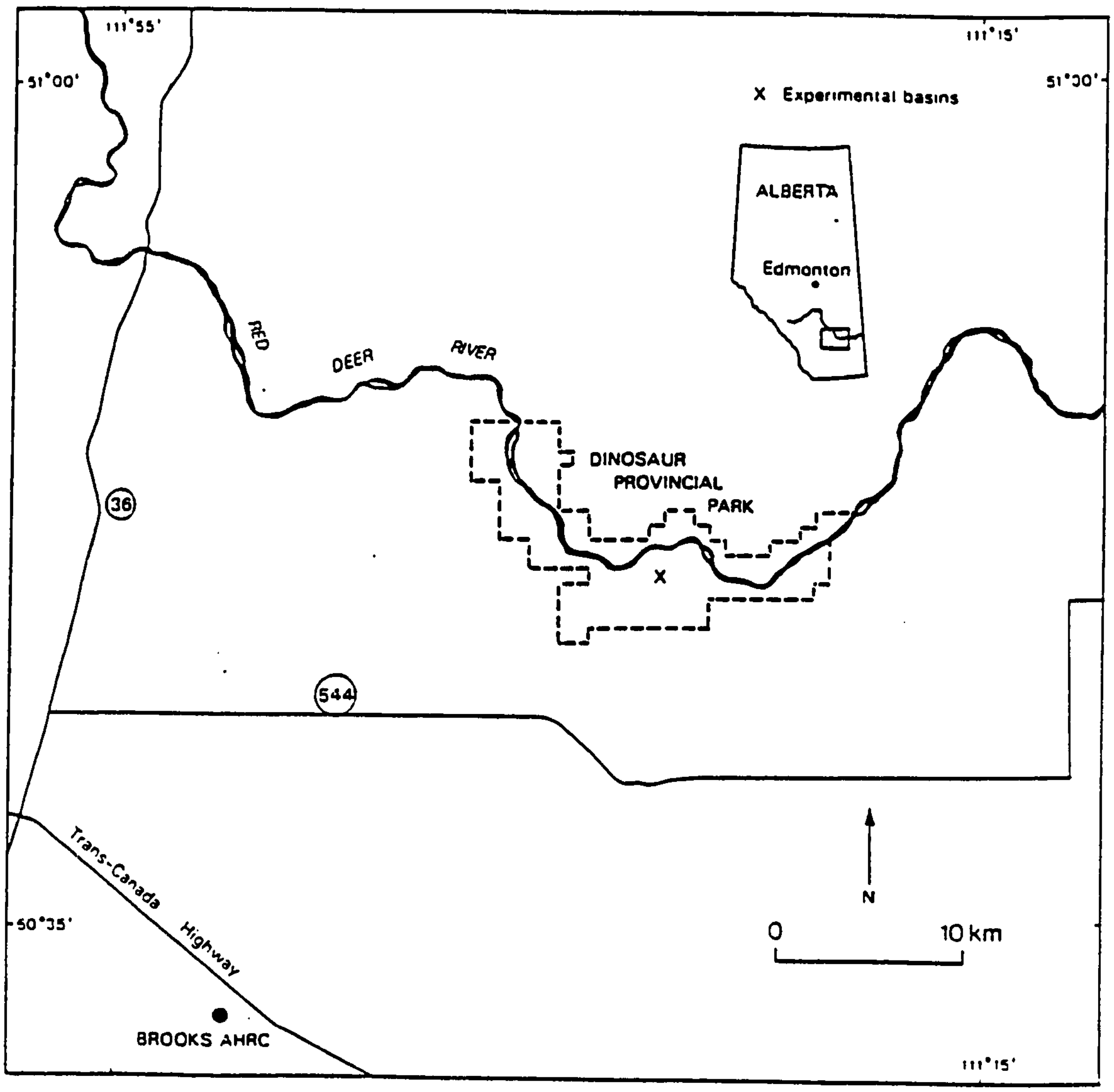


Figure 2.1 Location of Dinosaur Provincial Park, Alberta. Also shown are the locations of the study basin, and of the Alberta Horticultural Research Centre (after de Boer, 1990).

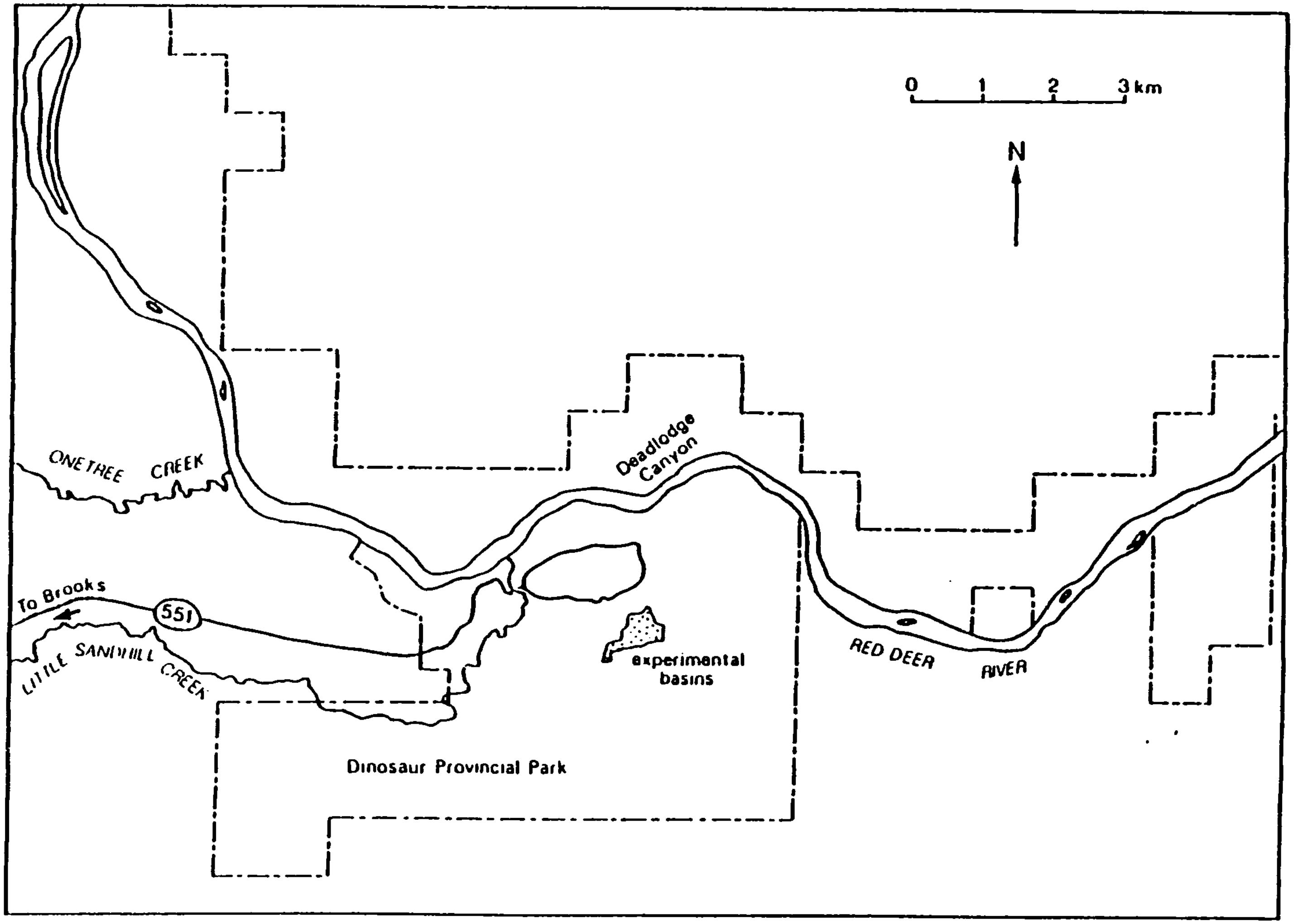


Figure 2.2 Map of Dinosaur Provincial Park, showing the location of the study basin (after de Boer, 1990).

Table 2.1 Long-term precipitation and temperature records for Brooks, Alberta Horticultural Research Centre.

	J	F	M	A	M	J	J	A	S	O	N	D	year
Daily maximum temperature	-8.6	-3.8	1.7	11.3	18.4	22.5	26.2	24.9	19.2	13.6	2.9	-3.7	10.4
Daily minimum temperature	-19.6	-15.1	-9.8	-2.2	3.8	8.6	11.0	9.7	4.4	-1.0	-9.1	-15.1	-2.9
Daily temperature	-14.2	-9.5	-4.1	4.6	11.1	15.6	18.6	17.3	11.9	6.3	-3.1	-9.4	3.8
Rainfall	0.9	0.8	2.5	14.8	37.4	65.7	32.2	40.1	32.8	8.3	2.4	1.0	238.9
Snowfall	20.9	13.6	13.5	11.3	0.9	0.0	0.0	0.0	1.0	5.1	12.5	18.1	96.9
Total precipitation	21.9	14.4	16.0	26.0	38.3	65.7	32.2	40.1	33.8	13.4	14.9	18.7	335.4

Temperatures in °C, precipitation in mm.
Source: Atmospheric Environment Service, 1982.

In spring and early summer, frontal systems generally induce precipitation of wide extent, but low intensity. During midsummer, in contrast, convectional rainstorms caused by the high surface temperatures are mostly localised and highly intensive (Longley, 1972).

2.3 Badland morphology and vegetation

The badland morphology features straight, densely-rilled sandstone slopes, and somewhat gentler, convex shale slopes (Figure 2.3). The shale slopes have dense crusts, non-coherent surfaces characterised by a dense network of fine desiccation cracks. The ironstone-bands of the formation stand out as prominent ledges in the topography, with debris of the weathered ironstone, angular, typically red and grey gravels, covering incidental segments of the slope below. Large pediments, gently sloping planation surfaces, form the foot of the badland slopes, with the transition from slope to pediment marked by a sharp break in gradient. The pediments have developed in bedrock, but are veneered with a thinly laminated deposit of sheetwash derived silts and sands of varying thickness (De Boer, 1990). Low-lying aeolian deposits and alluvial plains embody the central parts of most badland drainage basins (Figure 2.4). Channels of the badlands are ephemeral; they carry water only during, and shortly after, large and medium size storms.

Though much of the slope and pediment area is bare, different species of grasses, as well as prickley pear cactus (Opuntia polycantha) and barrel cactus (Mammillaria vivipara) and sagebrush (Artemisia spp.) and greasewood (Sarcobatus vermiculatus) grow on the central aeolian and alluvial plains.

Figure 2.3 Typical badland morphology, featuring rilled sandstone slopes, somewhat gentler, convex shale slopes, ironstone ledges, pediments and vegetated alluvial surfaces. Relief here is of the order of 80 m.

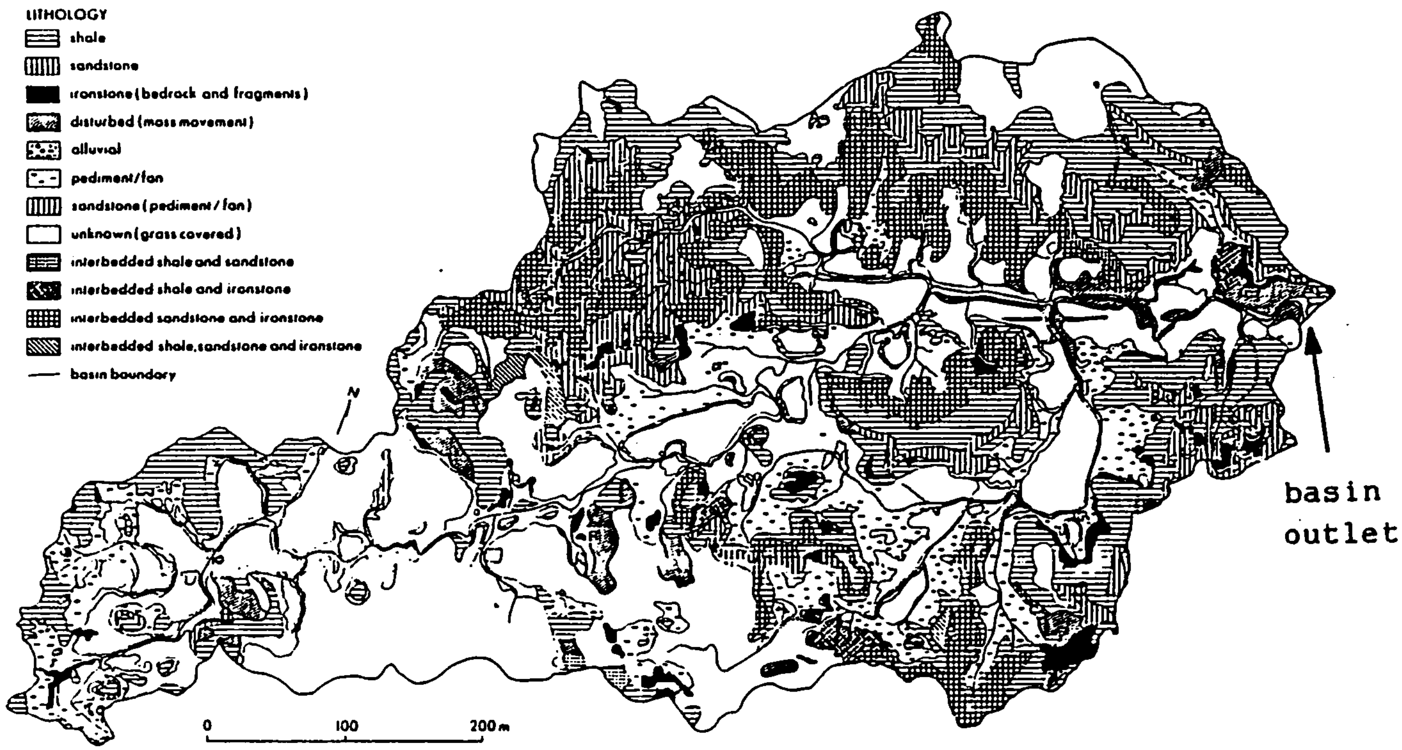


Figure 2.4 Surface units of the Aquatot Basin (modified after Bryan and Campbell, 1986).

2.4 Research in the study basin

The study basin, located in the restricted area of Dinosaur Provincial Park, is easily accessible for research at a ten minutes walking distance from a park road. Geomorphological processes in this basin have been studied since the beginning of the 1980's (cf. Campbell, 1982; Hodges and Bryan, 1982; Bryan et al., 1984; De Boer, 1990). In 1981, flumes were installed at the outlets of the Aquatot and the Rimco Basin (Figure 2.5 and Table 2.2). The New Flume was added in 1986.

2.5 Channels of the study basin

Main channels of both the Rimco Basin and the New Basin meander along the gently sloping plains of the central part of their respective basins (Figure 2.6), before they cut through a major iron-cemented ironstone band, that underlies both basins, and join into the channel leading to the Aquatot Flume. Upstream from the iron-cemented sandstone band, the channels are small and relatively shallow. Channel widths vary between 0.9 m and 2.4 m, depending on local sediment input, the presence of bank stabilizing vegetation, type of perimeter sediment and water discharge. Depth of the channels varies between 0.10 m and 0.28 m. Channel gradients range from 0.001 to 0.07. Only a shallow veneer of alluvium, 2 cm to 6 cm thick, is present in the channels. Bed characteristics vary from small sand ripples to flat bed surfaces adorned with current lineations. Scour holes and riffles of small angular ironstone gravel occur at irregular intervals.

Where they cut through the sandstone band, both channels have generated falls that cause an accumulation of boulders and gravel in the

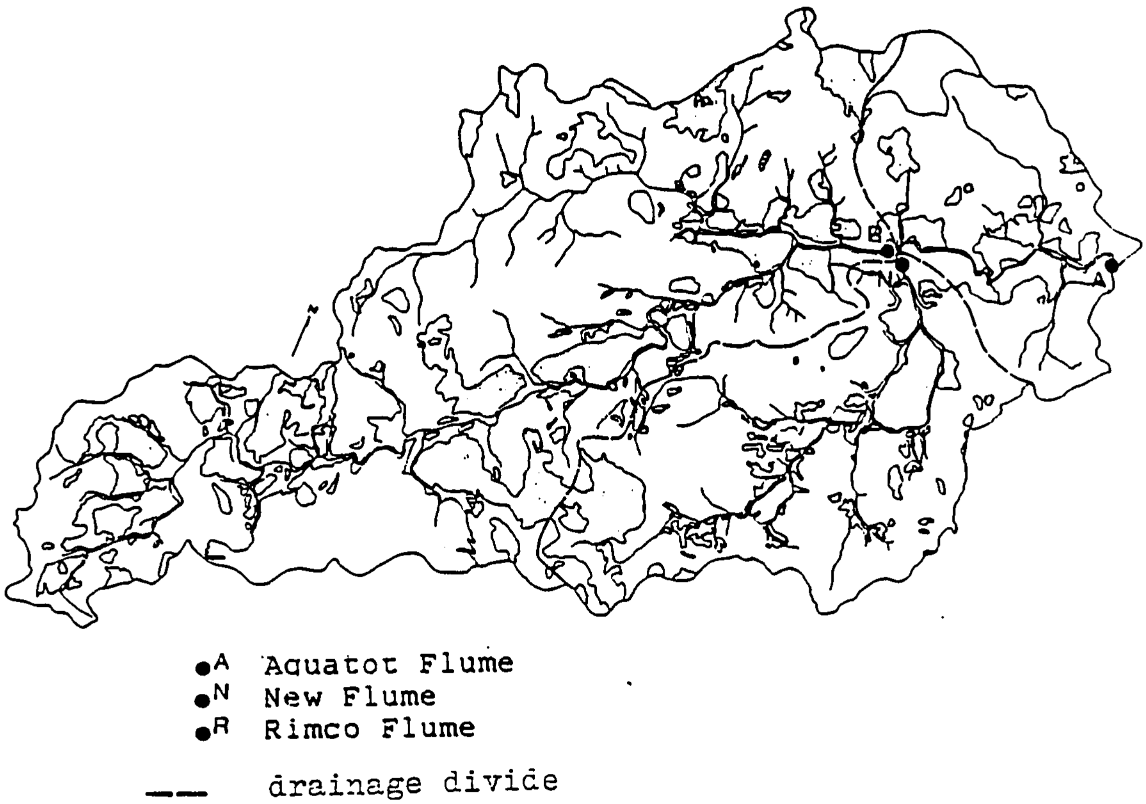


Figure 2.5 Map of the study basin, showing the location of the Aquatot Flume, Rimco Flume and New Flume.

Table 2.2 Morphometric characteristics of the study basins (modified after de Boer and Campbell, 1989).

Basin	Elongation ratio*	Relief ratio*	Drainage area m^2
New Basin	0.67	0.069	202,260
Rimco Basin	0.55	0.041	79,230
Aquatot Basin	0.59	0.036	336,810

* after Gardiner (1981)

Figure 2.6   The main channel of the New Basin meanders along the gently sloping plains of the central part of the basin.

channel bed (Figure 2.7). Flumes of the New Basin and the Rimco Basin were installed about 25 m downstream from these falls, and about 5 m upstream from where the two third order channels join the main, fourth order Aquatot channel. The well-defined Aquatot channel is incised about one meter into a grassed alluvial plain where it leaves the basin.

This fourth order channel, at the section just upstream from the Aquatot Flume, is characterised by an alluvial deposit of about 40 cm thickness, that consists of sand alternated with gravel stringers. Deposition of this material has started quite recently, after the installation of the Aquatot Flume in 1981. The reason for the aggradation of this stream section is unclear. Initially, it was attributed to the installation of the flume, but this explanation appears to be incorrect because the aggradation is so massive and consistent. Perhaps the aggradation is part of a lateral shift in sediment storage in the fluvial system, that is caused by the exceedance of a threshold value in the force-resistance balance between hydraulic force and channel resistance.

2.6 Hydrology and sediment output of the study basin

Runoff characteristics of the basin strongly depend upon the type of rainstorm. The highly intensive convectional rainstorms tend to generate hydrographs of the typical desert bore: a steep rise, a high, narrow peak, and a sharp decline. The less intensive but longer lasting rainstorms, associated with the passage of frontal disturbances, are reflected in the hydrograph by a slow, gradual rise, a flat rounded peak and a gradual fall (Bryan and Campbell, 1982).

Suspended sediment concentrations are invariably high, occurring in the 20 to 50 g/l range (De Boer, 1990). Bedload transport data of the

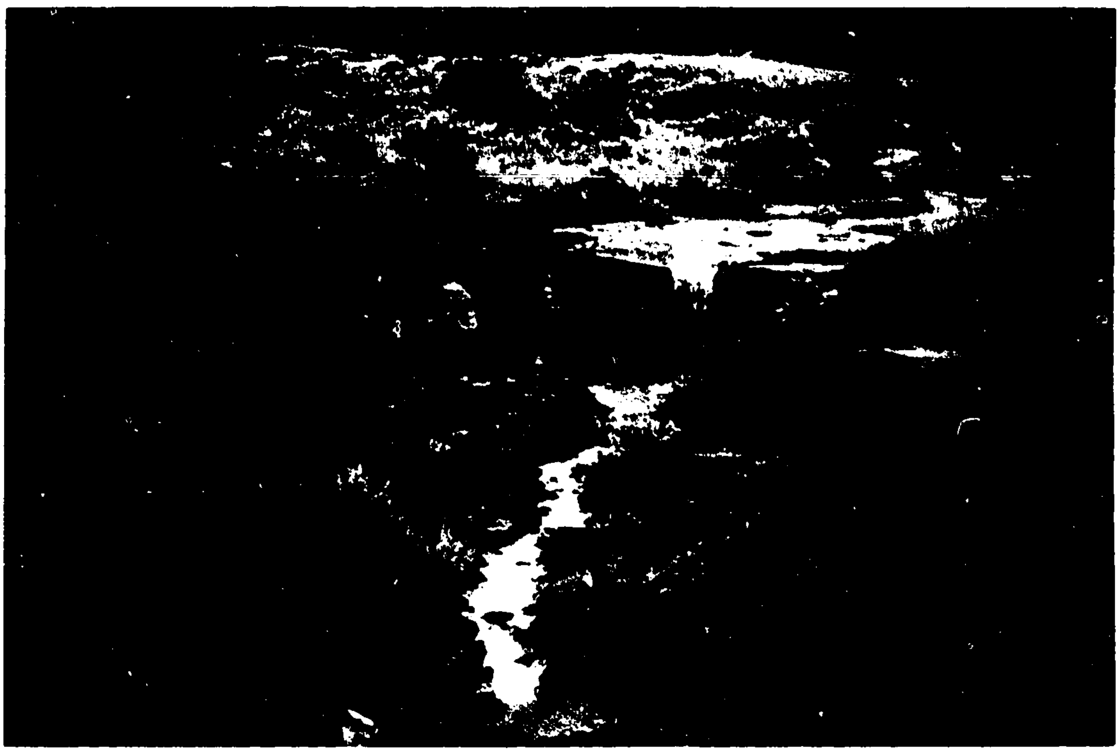


Figure 2.7 A fall has been created where the main channel of the New Basin cuts through a thick iron-cemented sandstone band.

basin are sporadic. Bryan et al. (1988) record a bedload yield of 972 kg for the Rimco Basin after 4.6 mm precipitation during a 1983 storm. They calculate that the contribution of bedload to the total sediment output (bedload, suspended load and solutes) during that particular storm, was only 0.82%. These bedload data are based on sediment samples collected with Helley-Smith bedload samplers, meaning that an unknown portion of the sampled sediment consisted of suspended sediment.

CHAPTER THREE BEDLOAD TRANSPORT IN 1987

3.1 Experimental design

Bedload transport was measured at the upstream end of the Rimco Flume, and of the New Flume, using hand-held Helley-Smith bedload samplers with a 76 mm square entrance nozzle (Figure 1.2). Standard sample bags with a bag area of 2190 cm^2 and 0.2 mm mesh openings were used. Sampling time was two minutes. The sampler rested on the aluminium bottom of the flume, which provided a good contact and ensured that lowering or rising of the sampler did not scoop additional bed material. Flume widths were 0.46 and 0.37 m, for the New Flume and the Rimco Flume respectively.

Bedload samples were air dried, weighed and sieved to determine dry incremental grain-size amounts of sediment greater than 1 mm, 0.71 mm, 0.5 mm, 0.425 mm, 0.297 mm, 0.250 mm, 0.180 mm, 0.125 mm, 0.090 mm, 0.075 mm, 0.063 mm and less than 0.063 mm. In order to calculate sediment transport per second, weight of the sediment loads trapped during the two minute sampling interval was divided by 120. No allowance was made for any bedload that passed the Helley-Smith sampler on either side of the nozzle.

3.2 Results

3.2.1 Runoff events in 1987

Of the twenty runoff events that occurred during the 1987 field season, only eight were large enough to produce appreciable bedload transport (Table 3.1). Bedload transport was measured during three of these events, two storms on June 19, and one storm the following day on June 20.

In the early afternoon of June 19, a small runoff event occurred. Rain started at 12.18 hrs, and continued until 12.44 hrs with a fairly constant intensity of about 10.8 mm/hr. At the Rimco Flume, discharge began at 12.45 hrs, after the rain had stopped, and lasted until 14.30 hrs. The maximum discharge of 24 l/s occurred at 12.53 hrs, seven minutes after onset of the flow.

Later that same afternoon, a much larger storm took place. Rainfall started at 17.13 hrs, and continued until 18.25 hrs with an intensity of about 6.5 mm/hr, and again from 18.50 hrs until 20.29 hrs with an intensity of about 2.5 mm/hr. At the Rimco Flume, runoff began at 18.40 hrs with the maximum flow (260 l/s) reaching the flume after only ten minutes (Figure 3.1). Smaller peak flows occurred at 19.55 hrs (67 l/s) and 20.29 hrs (110 l/s). At the New Flume, maximum flow (139 l/s) occurred at 18.55 hrs, a smaller discharge peak passed the flume at 20.22 hrs (Figure 3.2).

This large storm was followed the next day, on June 20, by a smaller runoff event (Figure 3.3). Rain started at 17.17 hrs with an intensity of 1.44 mm/hr until 17.30 hrs, when intensity dropped to 0.9 mm/hr.

3.2.2 Hydrographs and sediment transport rates in 1987

Transport rate variation of the coarse and fine sediment size fractions trapped in the Helley-Smith sampler bags, are compared with changes in suspended sediment concentration in order to illustrate

Table 3.1 Overview of precipitation and runoff data, 1987, including dates and location of bedload sampling.

date	average rainfall (mm)#	Rimco Flume peak discharge (l/s)#	bedload transport	New Flume peak discharge (l/s)#	bedload transport
May 26 (I)	6.0	34	**	13	**
May 26 (II)	4.5	29	**	19	**
May 27	2.5	56	**	32	**
June 16	3.0	0	-	0	-
June 19 (I)	4.2	24	***	1	*
June 19 (II)	12.6	260	***	139	***
June 20	3.9	96	***	94	**
June 30	2.0	0	-	0	-
July 3-4	3.9	R	*	R	*
July 5	2.6	6	*	1	*
July 6-7	1.0	0	-	0	-
July 16	2.0	0	-	0	-
July 18-19	10.2	21	*	23	*
July 25	3.5	R	*	R	*
July 28	1.3	0	-	0	-
August 4	2.1	R	*	R	*
August 10	4.6	17	*	19	*
August 13	0.5	-	-	0	-
August 14	17.6	64	**	61	**
August 18-19	6.3	R	**	R	**

\# data from De Boer, 1990.

- \- no runoff, no bedload transport
- *** bedload samples collected
- ** bedload transport probably occurred, but no bedload samples were collected
- * bedload transport negligible
- R Runoff occurred, but no data were collected

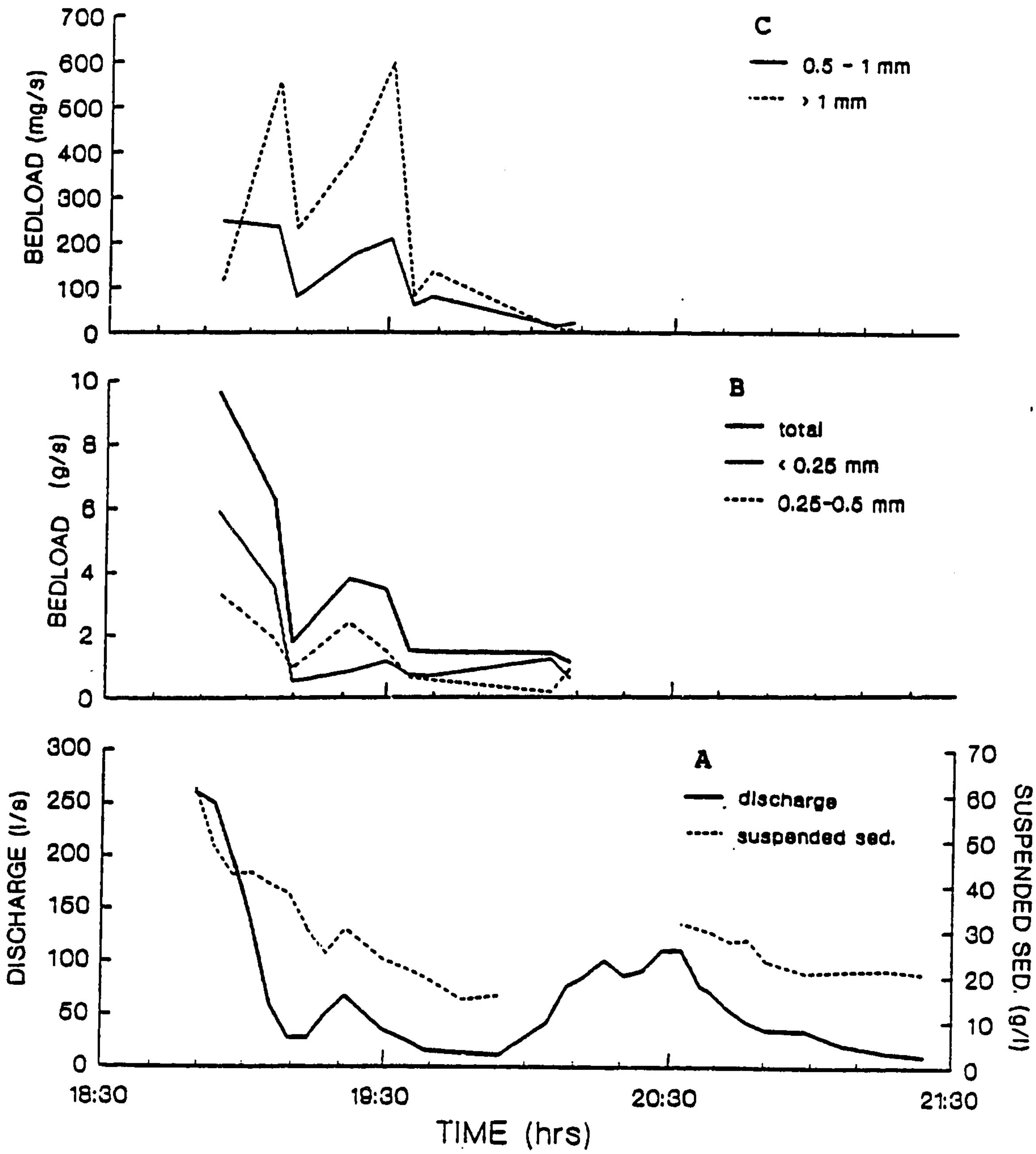


Figure 3.1 June 19, 1987. Rimco Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport, bedload fine fraction (< 0.25 mm), and bedload medium fine fraction (0.25 - 0.5 mm).
C - Bedload medium coarse fraction (0.5 - 1 mm), and bedload coarse fraction (> 1 mm).

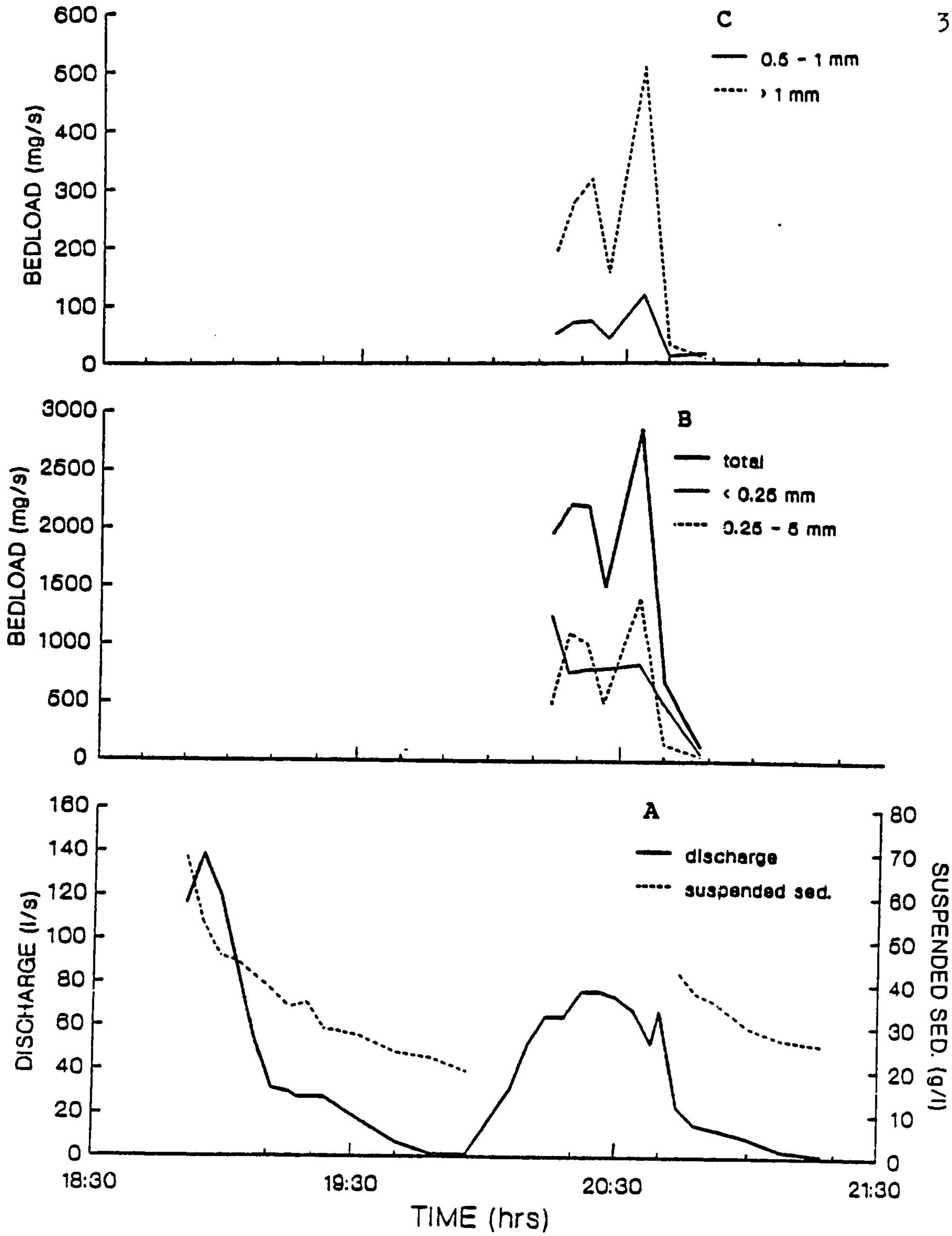


Figure 3.2 June 19, 1987, New Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport, bedload fine fraction (< 0.25 mm), and bedload medium fine fraction (0.25 - 0.5 mm).
C - Bedload medium coarse fraction (0.5 - 1 mm), and bedload coarse fraction (> 1 mm).

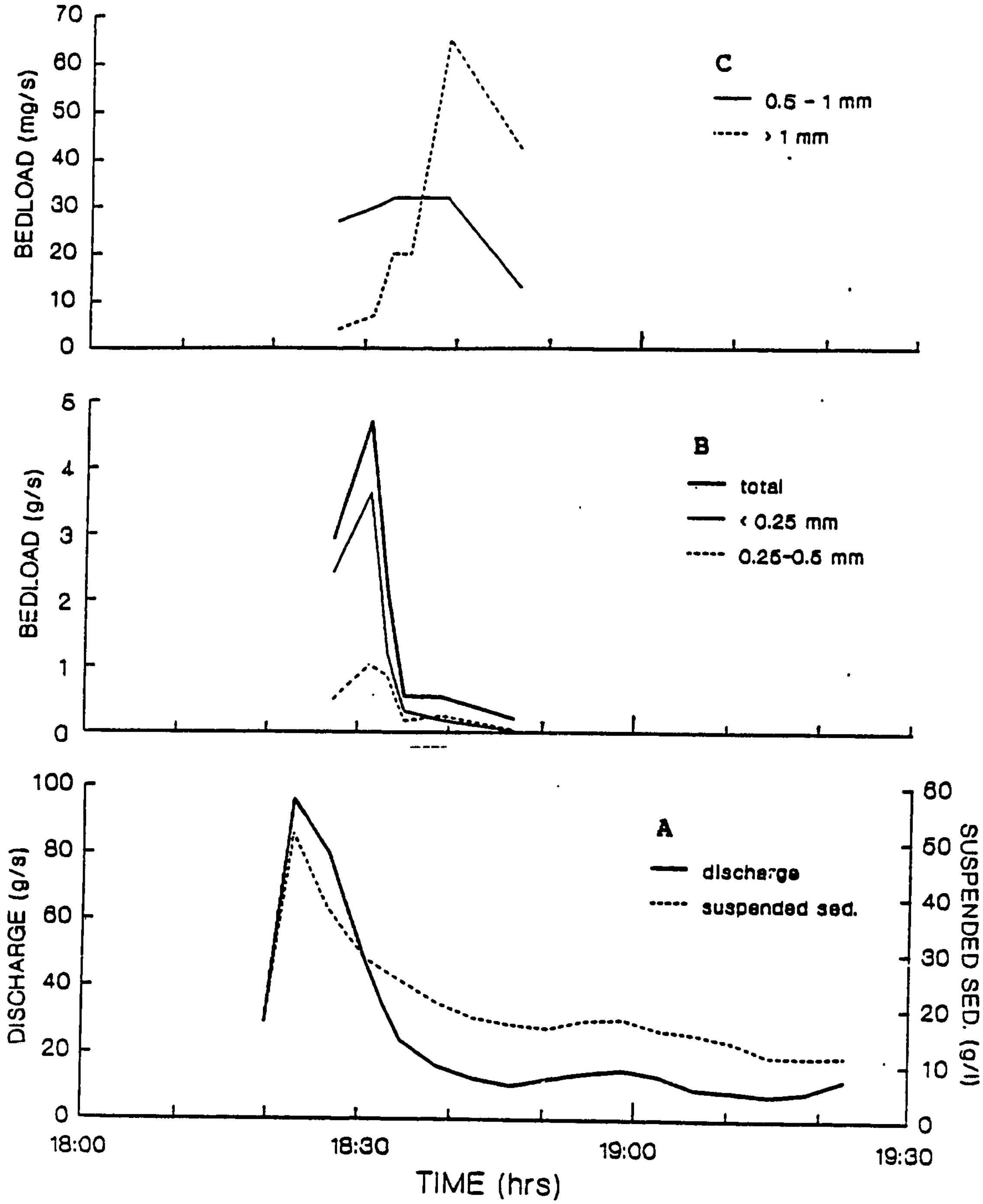


Figure 3.3 June 20, 1987, Rimco Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport, bedload fine fraction (< 0.25 mm), and bedload medium fine fraction (0.25 - 0.5 mm).
C - Bedload medium coarse fraction (0.5 - 1 mm), and bedload coarse fraction (> 1 mm).

differences and similarities in pattern. The suspended data were adopted from De Boer (1990). Suspended sediment was sampled at the same site as the bedload, by dipping a plastic bottle in the flow.

Rimco Flume June 19, 1987, storm 1.

Maximum measured bedload transport rate is 142 mg/s. Bedload transport decreases to less than measurable when discharge drops below 11.3 l/s.

Rimco Flume June 19, 1987, storm 2

The very fine and medium fine bedload fractions vary in conformity with changes in discharge, and so does the suspended sediment concentration. Contrariwise, the transport rates of the medium coarse and coarse bedload fractions vary distinctly differently. Though they echo the two peaks in the hydrograph, the peaks in these bedload transport rates, do not coincide with the peaks in discharge, they occur with respectively sixteen and six minutes delay. A third, small peak occurs in the transport rates, of the medium coarse and coarse sediment bedload size fractions, this third peak is absent in the hydrograph.

New Flume June 19, 1987, storm 2

Only the very fine bedload fraction follows the variation in discharge. The medium fine, the medium coarse and coarse bedload fractions each show two peaks in transport rates that are unrelated to changes in discharge.

Rimco Flume June 20, 1987

The very fine bedload fraction peaks eight minutes after the hydrograph, the coarse fraction peaks sixteen minutes after the hydrograph. The medium coarse fraction shows a very vague peak at the same time as the coarse fraction. The medium fine fraction peaks twice, the first time in concurrence with the very fine fraction, the second time in concurrence with the coarse fraction. The suspended sediment concentration varies in keeping with the hydrograph. When discharge falls below 11 l/s, bedload transport becomes unmeasurably small.

3.2.3 Bedload/discharge relationship

Bedload/discharge relationships (Figures 3.4 and 3.5) also reveal differences between the coarse and the fine bedload fractions. First, the graphs suggest a direct relationship between discharge and transport rates of the two fine fractions, but not for the medium coarse and coarse fractions. Second, for the two fine fractions, there is no distinct difference between the bedload/discharge relationship from June 19 and June 20, 1987. For the two coarse fractions on the other hand, the relationship displays a clockwise hysteresis, indicating a distinct decrease in transport rates during the latter part of the large storm on June 19, and the following small storm on June 20.

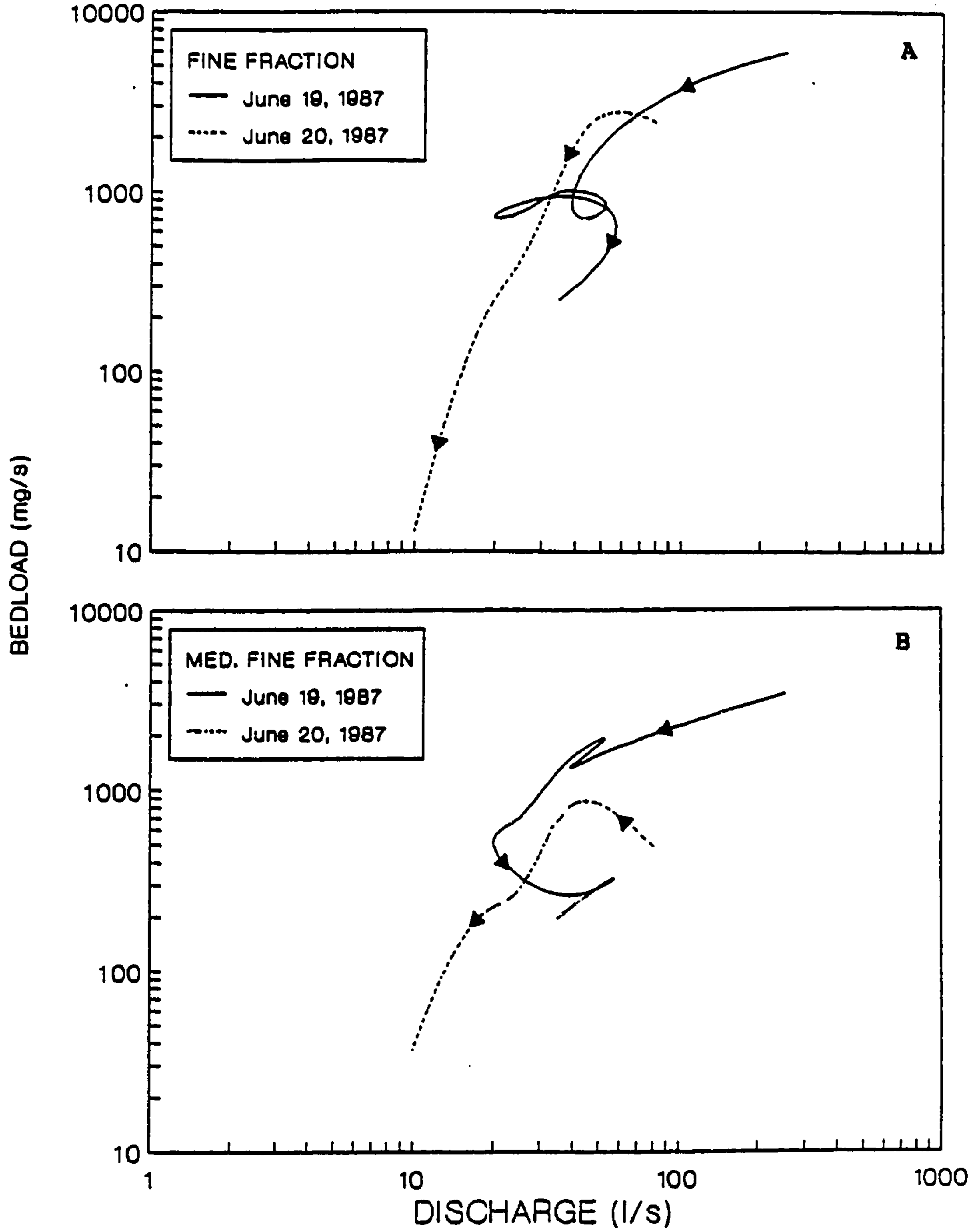


Figure 3.4 Bedload transport as a function of discharge for the Rimco Basin on June 19, 1987 (storm II) and June 20, 1987.

A - Fine fraction (< 0.25 mm).
B - Medium fine fraction (0.25 - 0.5 mm).

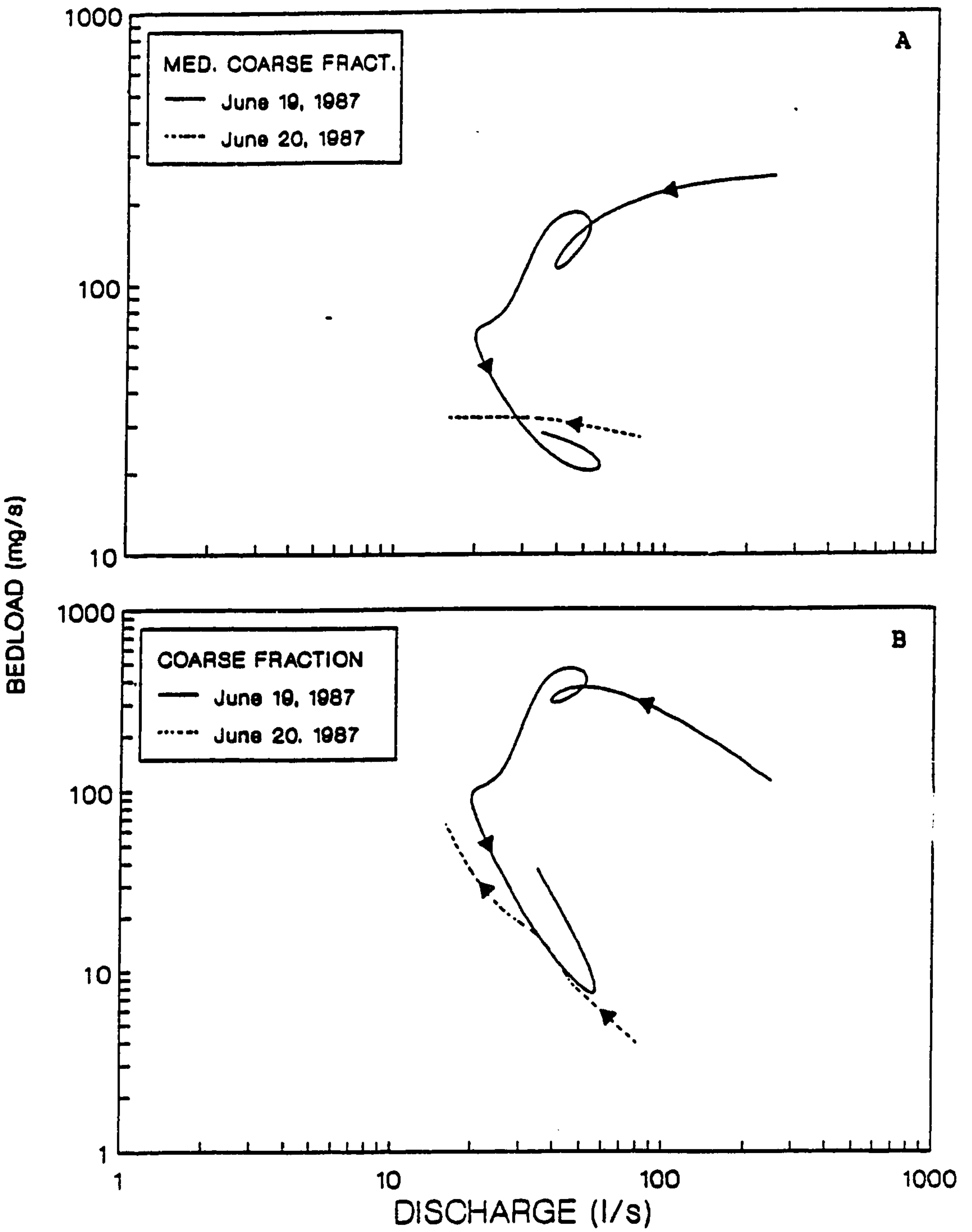


Figure 3.5 Bedload transport as a function of discharge for the Rimco Basin on June 19, 1987 (storm II) and June 20, 1987.

A - Medium coarse fraction (0.5 - 1 mm).
B - Coarse fraction (> 1 mm).

3.3 Analysis of bedload transport data

3.3.1 Bedload versus suspended sediment

Fundamental differences are demonstrated between transport rate dynamics of coarse and fine sediment collected with Helley-Smith bedload samplers (Table 3.2). While the transport rates of the very fine fraction follow a pattern that is almost identical to the discharge and to the suspended sediment concentration, peaks in transport rates of the two coarse fractions take place several minutes after the occurrence of peaks in the hydrograph. As well, the coarse fractions show peaks in transport rates when no peaks in discharge occur. In addition, while bedload rating curves indicate a considerable decrease in transport of coarse sediment during the latter part of the June 19 storm, and during the following storm on June 20, no such decrease is noticed in the transport of fine and very fine sediment.

These differences in transport rate variation indicate that in the opaque, highly turbulent, sediment laden flows of this small ephemeral sand-bed channel, two sediment (sand) fractions respond differently to the same sediment supply and transport conditions. The peaks observed in the transport rates of the coarse fraction resemble the waves that are symptomatic of bedload transport. Because the size of the two coarse fractions (0.5 mm - 1 mm, and > 1 mm) also agrees with affirmed bedload sediment sizes, it seems acceptable to categorize the two coarse fractions as bedload. Because the very fine fraction follows a pattern of transport rate variation similar to the suspended load, this fraction (sediment <0.025 mm) can be considered as part of the suspended load.

The medium fine fraction follows a pattern similar to the very fine fraction during storm 2 on June 19, at the Rimco Flume. Later during the same storm, at the New Flume, this fraction varies in conformity with the

Table 3.2 Bedload transport data 1987.

No.	Peak discharge l/s	Bedload transport mg/s	Transport rates for individual size fractions: Very fine < 0.25 mm	Medium fine 0.25-0.50 mm	Medium coarse 0.50-1.0 mm	Very coarse > 1.0 mm
			RIMCO FLUME 19-6-1987 STORM I			
1	24	150	28	70	13	38
			RIMCO FLUME 19-6-1987 STORM II			
1	250	9628	5908	3359	248	112
2	59	6273	3575	1907	235	557
3	28	1787	532	947	80	232
4	67	3792	833	2387	173	400
5	35	3433	1150	1482	208	597
6	26	1493	722	628	62	82
7	16	1443	675	555	80	135
8	42	1400	1213	165	15	8
9	76	1118	612	482	22	5
10	35	513	253	197	28	37
			NEW FLUME 19-6-1987 STORM II			
1	64	1977	1260	475	52	190
2	64	2228	770	1107	72	280
3	76	2208	797	1018	73	320
4	76	1513	803	512	43	157
5	67	2872	842	1402	118	510
6	67	690	497	150	13	32
7	15	135	70	43	17	8
			RIMCO FLUME 20-6-1987			
1	80	2940	2427	485	27	4
2	48	4688	3623	1028	30	7
3	35	2123	1207	867	32	20
4	24	548	322	177	32	20
5	16	538	188	255	32	65

coarse fractions. On June 20, at the Rimco Flume, the transport rate pattern is intermediate between the very fine, and the two coarse fractions. This suggests that the medium fine fraction was transported as suspended load at the beginning of the June 19 storm, at the Rimco Flume. During later and lesser discharges of that storm, and during the smaller storm on June 20, this fraction likely moved largely as bedload. The bedload/discharge relationship of the medium fine fraction is most similar to the bedload/discharge relationship of the very fine sediments, though it does suggest a small decrease in transport of this fraction on June 20. This indicates that the very fine and the fine sediment size fractions do not have the same sediment source as the two coarse fractions (see also section 3.2.3).

3.2.3 Exhaustion of bedload type sediment

Exhaustion of the bedload type sediment supply appears as the most likely cause for the distinct decrease in transport of the medium coarse and coarse sediment size fractions during the latter part of the major storm on June 19, and the following storm on June 20. Because the low transport figures already commence during the falling stage of the June 19 storm, it is unlikely that the decrease in transport is caused by the inability of the small June 20 storm to cross the threshold of incipient motion for larger particles. A possible creation of large bedforms during the rising stage, increasing bedform resistance and thereby decreasing the transport capacity of the flow, does not appear to be an acceptable explanation either because such an increase in bedform size was not observed after the flood in the channel.

3.4 Discussion

In an ephemeral sand-bed channel in the badlands of southern-Alberta, fluvial transport of particles larger than 0.5 mm (during smaller discharges particles larger than 0.25 mm) displays characteristics that are typical of bedload waves. The same sediment size fraction demonstrates a clockwise hysteresis in the bedload/discharge relationship during a large and subsequent smaller storm. The hysteresis is attributed to an exhaustion of this type sediment in the channel bed. Transport rates of the smaller size fractions, also trapped in the Helley-Smith bedload samplers, display neither waves nor hysteresis.

It is proposed that these differences in transport rate variation can be used to define, and separate the bedload from the suspended load in this stream. Following this definition, the 'real' bedload in the 1987 Helley-Smith bedload samples of this study, varies between 2% and 71% (Table 3.3). It then becomes clear how large the amounts of suspended sediment are that get trapped in Helley-Smith bedload samplers during the sediment-laden flows of ephemeral sand-bed channels.

The storms of June 19 (Figure 3.1) and June 20 (Figure 3.2) also demonstrate, that the pattern of transport rate variation of the total Helley-Smith samples, can be fundamentally different from the 'real' bedload transport rate pattern. These differences in transport rate variation between the total bedload samples and the 'real' bedload, illustrate how the inability to make a proper distinction between bedload and suspended load, not only seriously hampers our capacity to obtain accurate data on the rates of bedload transport, but also obscures the research and discussion on the mechanism of bedload transport and its determining factors. For if the pattern of the total load were adopted as

Table 3.3 Percentage 'real' bedload in the Helley-Smith samples, 1987.

Date collection	No.	Bedload transport g/s (1)	'Real' bedload transport g/s (2)	Percentage 'real' bedload transport
Rimco Flume 19-6-87 Storm I	1	150	51	34
Rimco Flume 19-6-87 Storm II	1	9627	360	4
	2	6273	792	13
	3	1787	311	17
	4	3792	573	15
	5	3433	805	23
	6	1493	143	10
	7	1443	215	15
	8	1400	23	2
	9	1118	27	2
	10	513	65	
New Flume 19-6-87	1	1977	717	36
	2	2228	1458	65
	3	2208	1412	64
	4	1513	712	47
	5	2872	2030	71
	6	690	195	28
	7	135	68	50
Rimco Flume 20-6-87	1	2940	31	1
	2	4688	37	1
	3	2123	52	2
	4	548	52	9
	5	538	97	18

(1) Calculated using total content of the Helley-Smith bedload samples.
(2) Calculated using only the size fractions of the Helley-Smith bedload samples that demonstrate sediment waves independent of discharge during each individual storm.

the pattern of bedload transport rate variation. this could lead to incorrect conclusions about the timing and relationship to environmental conditions of bedload transport in this stream.

The bedload waves probably resemble the flat bed transport pulses that are described by Wilcock and Kuhnle (1987). Evidence of such flat bed pulses is found in the form of 1 to 2 m long, and about 4 cm wide stringers of coarse material, that are aligned in the direction of the flow in the dry channel beds after the floods. It is unlikely that the observed sediment pulses are caused by the passing of dunes such as described by Foley (1987) and Carey (1985). In the dry channel beds, immediately upstream from the flumes, no dunes were observed at any time during the 1987 field season. Small dunes and ripples do appear in the channel at other locations. Their occurrence seems related to the presence of large concentrations of sand on the channel bed, which the flows are unable to carry away. For instance, ripples are prominent downstream from the junction of the channels of the Rimco Basin and the New Basin in the rapidly aggrading section leading to the Aquatot Flume. Ripples are also found over short distances downstream from sites where heavy sediment-laden tributaries enter the main channel.

Generation of the sediment waves does not appear to be dependent on the presence of equally spaced gravel bars as previously assumed (Langbein and Leopold, 1968; Beschta, 1987). Though rather irregularly spaced gravel bars do exist in the upstream channels, the presence of the falls, with the large concentrations of very coarse boulders and gravels, seems sufficient to perturb small-scale transport patterns generated upstream. The falls would also destroy a bedload pulse pattern triggered by intrinsic characteristics of watershed dynamics such as discontinuities in downchannel increase in drainage area, an explanation forwarded by Lekach and Schick (1983).

It appears then that the bedload waves are generated within the 25 m distance from the falls to the flumes, and therefore are inherent to the mechanism of bedload transport in these streams. This conclusion is supported by the fact that bedload waves have also been observed in flume experiments (Carey 1985) where neither equally spaced gravel bars, nor watershed dynamics exert any influence on the bedload transport.

Finally, when evaluating the effectiveness of the Helley-Smith bedload sampler in these streams, it appears that the problem of separating suspended sediment from bedload can be adequately solved. The problem remains that particles larger than 1 mm are rarely caught in the Helley-Smith samplers, while their transport as bedload is indicated by the occurrence of ironstone gravels in lag deposits in the flumes. This problem has also been noted by Bryan and Campbell (1986). Emmett (1980) however, while calibrating the Helley-Smith sampler in a perennial river with much lower suspended sediment concentrations, found a near perfect sediment trapping efficiency for sediment particle sizes between 0.5 and 16 mm. This suggests that the presence of the many fine suspended particles clogging up the mesh of the sampler bags might be the source of the problem. A solution, therefore could be to use a minimum of two Helley-Smith samplers, one with a fine mesh sampler bag to catch the finer bedload, and 40another with a much coarser mesh to catch the coarser bedload. It is likely that the efficiency of the Helley-Smith sampler to catch fine sediments will also decrease when the mesh of the sampler bags gets clogged. It seems therefore best to keep sampling intervals short (no longer than 30 seconds). Also, Beschta (1981) found that a three-fold increase in bag surface from the standard surface area

(1950 cm^2), greatly helped to improve sampling effiency in streams with high sand and organic matter transport.

Given the inefficiency of the Helley-Smith sampler to catch coarser bedload, it is obvious that the bedload data presented here underestimate the real amount of bedload transport. Also, the nozzle opening of the samplers is only 76 mm, whereas the widths of the Rimco Flume and the New Flume are 0.61 m and 0.46 m respectively. This implies that some of the bedload transport could pass the sampler on both sides without being caught. It is believed however, that this amount is quite small. When holding the sampler in the cross-sectional center of the flume, a strong drag was felt to be exerted on the sampler. Along the edges, the amount of drag was much smaller. When operating the Helley-Smith samplers one got a feeling for the amount of drag, induced by a certain velocity, that was needed to sustain bedload transport. Flow velocity on the edges of the flume did not 'feel' strong enough. However, the floods occurring during 1987 were relatively small, when compared to those of previous years. It therefore must be pointed out that the 'missing' amount could be significantly more during larger storms when the same measuring method is applied.

CHAPTER FOUR BEDLOAD TRANSPORT DATA FROM 1982, 1983 AND 1984.

4.1 Introduction and experimental design

Bedload measurements from 1982, 1983, and 1984 illustrate how bedload transport in the badlands greatly varies from year to year. The data also show how different shapes of hydrographs, different size storms, and different sediment concentrations influence bedload transport.

The data from 1982 to 1984 were collected as part of the long-term process studies in the Rimco Basin and the Aquatot Basin (Bryan and Campbell, 1986). During these years, bedload was measured with Helley-Smith bedload samplers as described in section 3.1. Sampling time varied (Table 4.1 and Table 4.2) and sampling took place at the Aquatot Flume and the Rimco Flume. Unfortunately, only samples collected during the 1983 field season were sieved to determine dry incremental grain size amounts.

4.2 Bedload transport data

4.2.1 1982

Six storms were sampled for bedload transport at the Rimco Flume, and five at the Aquatot Flume.

The storm on May 26 was small, with a maximum discharge of 62 l/s at the Rimco Flume, and 90 l/s at the Aquatot Flume. Patterns of bedload

Table 4.1 Overview of Helley-Smith bedload sampling at the Aquatot Flume.

AQUATOT FLUME				
Date	Sampling time	Number of samples	Peak discharge l/s	Peak bedload g/s
16-5-1981	-	1	-	-
07-6-1981	-	1	-	-
10-6-1981	-	2	-	-
13-6-1981	-	4	-	-
23-6-1981	-	1	-	-
27 6-1981	-	1	-	-
01 7-1981	-	2	-	-
13-7-1981	-	1	-	-
26-5-1982	-	6	90	795
05-6-1982	-	3	280	8.525
27-6-1982	-	7	840	19.483
01-7-1982	-	4	808	19.567
09-7-1982	-	3	958	68.900
18-5-1983	30 s	3	47	5.840
03-7-1983	20 s	4	629	20.085
12-7-1983	30 s	4	299	46.253
31-7-1984 I	60 s	11	123	783
31-7-1984 II	60 s	11	216	35.500

- data are unavailable

Table 4.2 Overview of Helley-Smith bedload sampling at the Rimco Flume and the New Flume.

Date	Sampling time	Number of samples	Peak discharge l/s	Peak bedload g/s
RIMCO FLUME				
16-5-1981	-	1	-	-
07-6-1981	-	1	-	-
10-6-1981	-	1	-	-
13-6-1981	-	2	-	-
28-6-1981	-	1	-	-
01-7-1981	-	1	-	-
13-7-1981	-	1	-	-
26-5-1982	-	12	62	1.360
05-6-1982	-	3	280	5.608
27-6-1982	-	6	280	11.617
01-7-1982	-	4	410	22.085
09-7-1982	-	5	680	6.088
25-7-1982	-	1		
02-7-1983	30 s	10	540	93.007
03-7-1983	30 s	6	360	27.220
31-7-1984 I	60 s	5	3	1.761
19-6-1987 I	120 s	1		
19-6-1987 II	120 s	10		9.617
20-6-1987	120 s	5	80	4.683
NEW FLUME				
19-6-1987 II	120 s	7		2.867

- data are unavailable

transport, suspended sediment concentration, and discharge are quite similar at both flumes, even though the two peaks in bedload transport at the Rimco Flume occurred a little later than the two peaks in discharge (Figure 4.1). At the Aquatot Flume a rather small peak in bedload transport occurred about 12 minutes earlier than the peak discharge (Figure 4.2). The similarity in pattern between bedload and suspended sediment concentration suggests that the Helley-Smith samples contain a large percentage of suspended sediment, likely because the storm runoff was too small to generate significant bedload transport.

On July 1, two peaks in discharge were recorded at the Aquatot Flume, for a medium size storm (Figure 4.3). Twenty nine minutes after the second, and largest (808 l/s) peak, a very large bedload wave passed the flume.

Another large storm took place on July 9. Again, the graph of bedload transport shows a very large bedload wave (Figure 4.4). Unfortunately, the large sampling interval of about 30 minutes, prevents a clear picture of this wave. The fluctuations in suspended sediment concentration for this storms are very remarkable. These fluctuations mostly coincide with changes in discharge, though one peak in suspended sediment concentration lags behind the discharge, and another occurs without a corresponding peak in the hydrograph.

During other storms in 1982, bedload samples were either too few, or the sampling interval was too large for any analysis of bedload transport rate variation during storms.

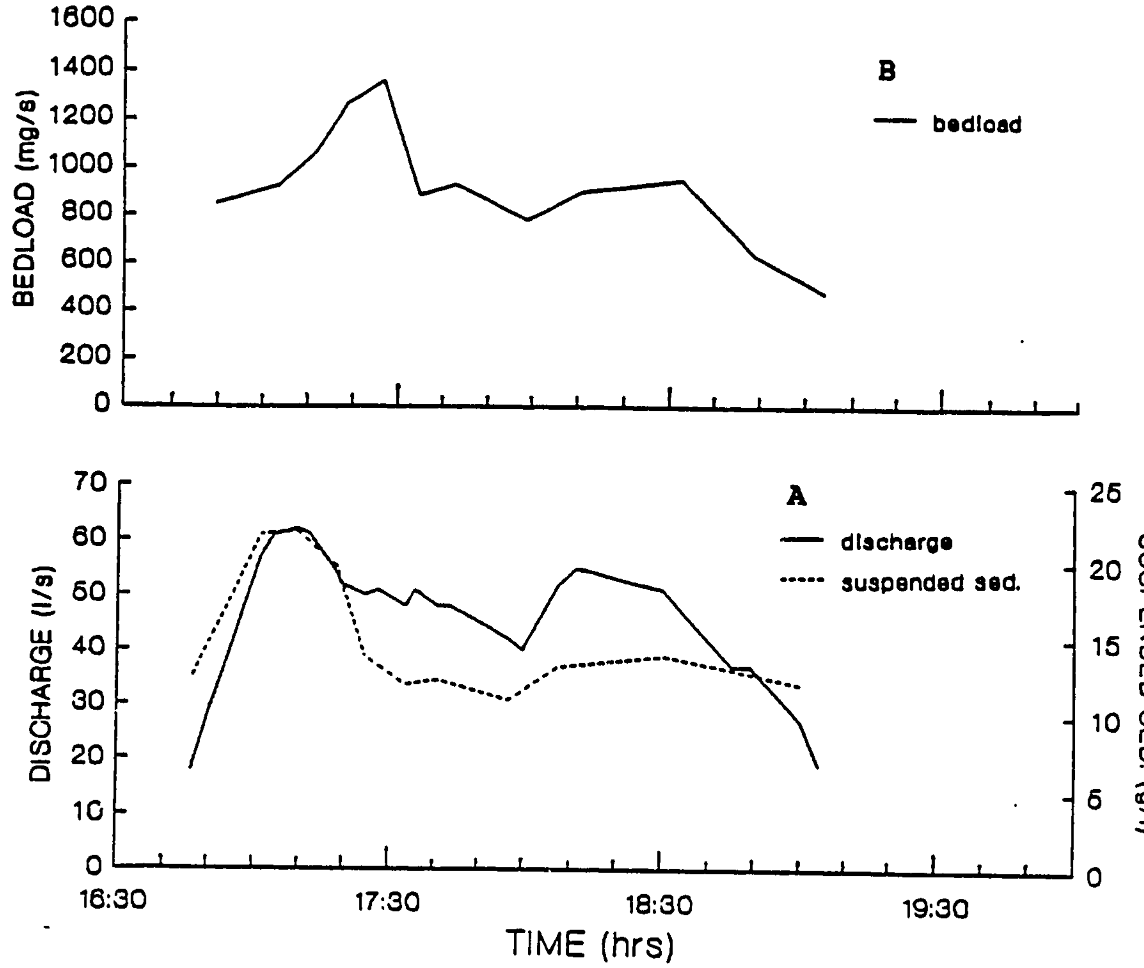


Figure 4.1 May 26, 1982. Rimco Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport.

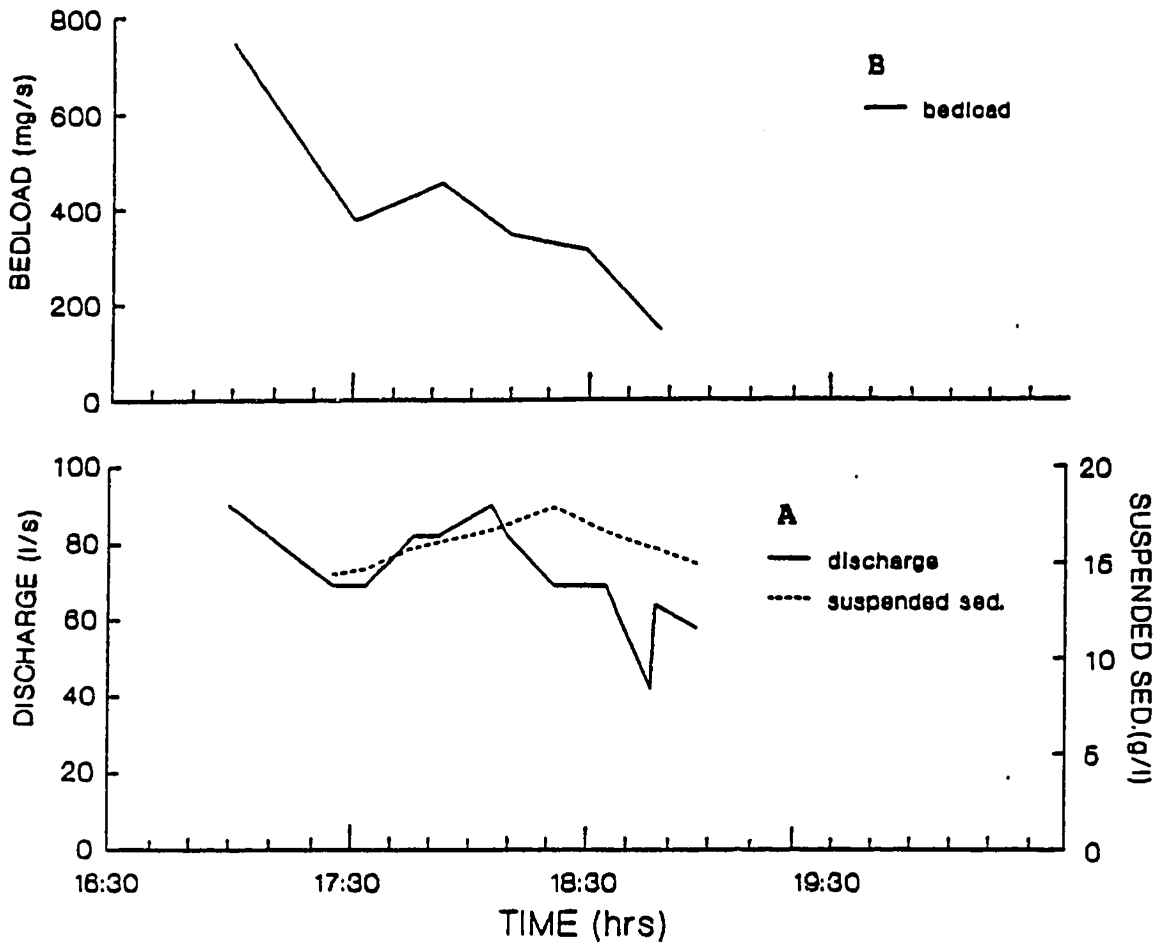


Figure 4.2 May 26, 1982, Aquatot Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport.

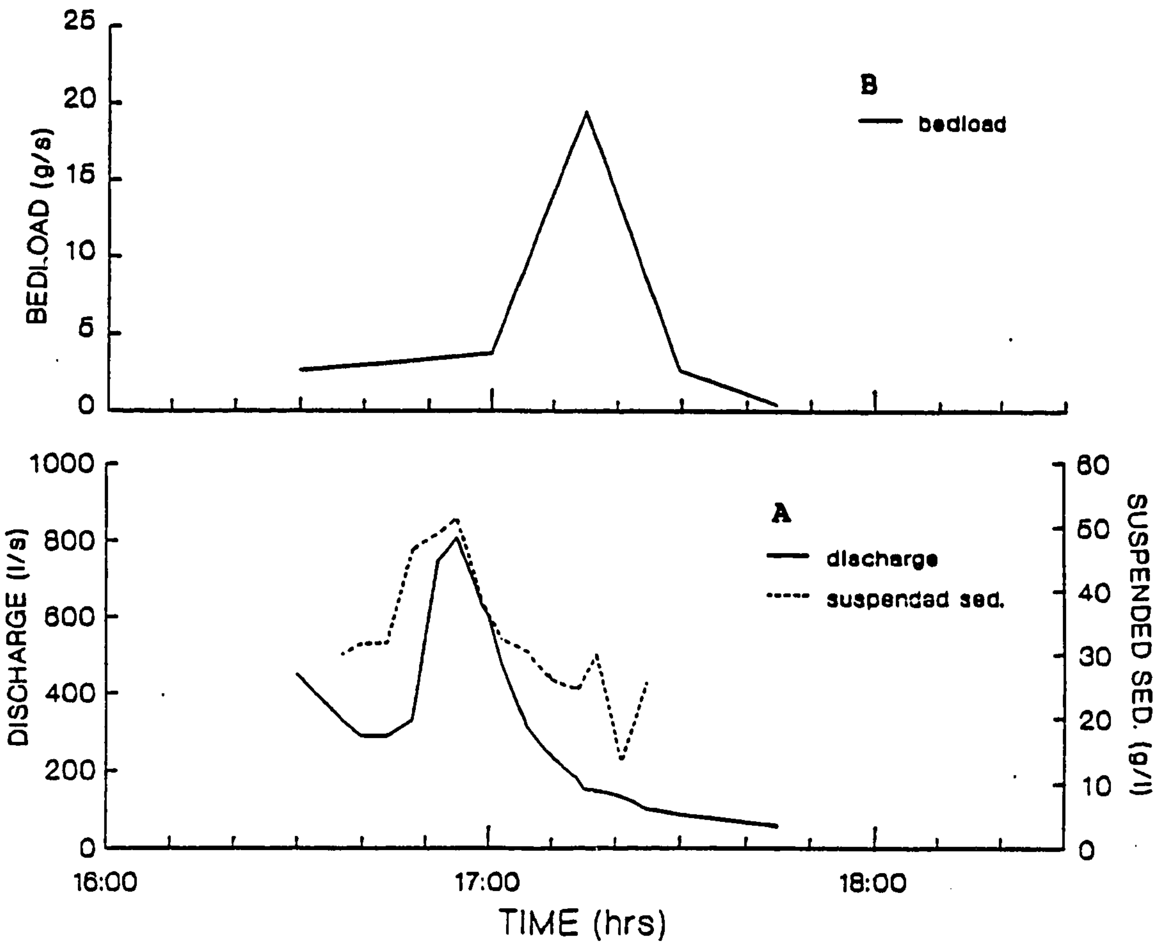


Figure 4.3 July 1, 1982, Aquatot Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport.

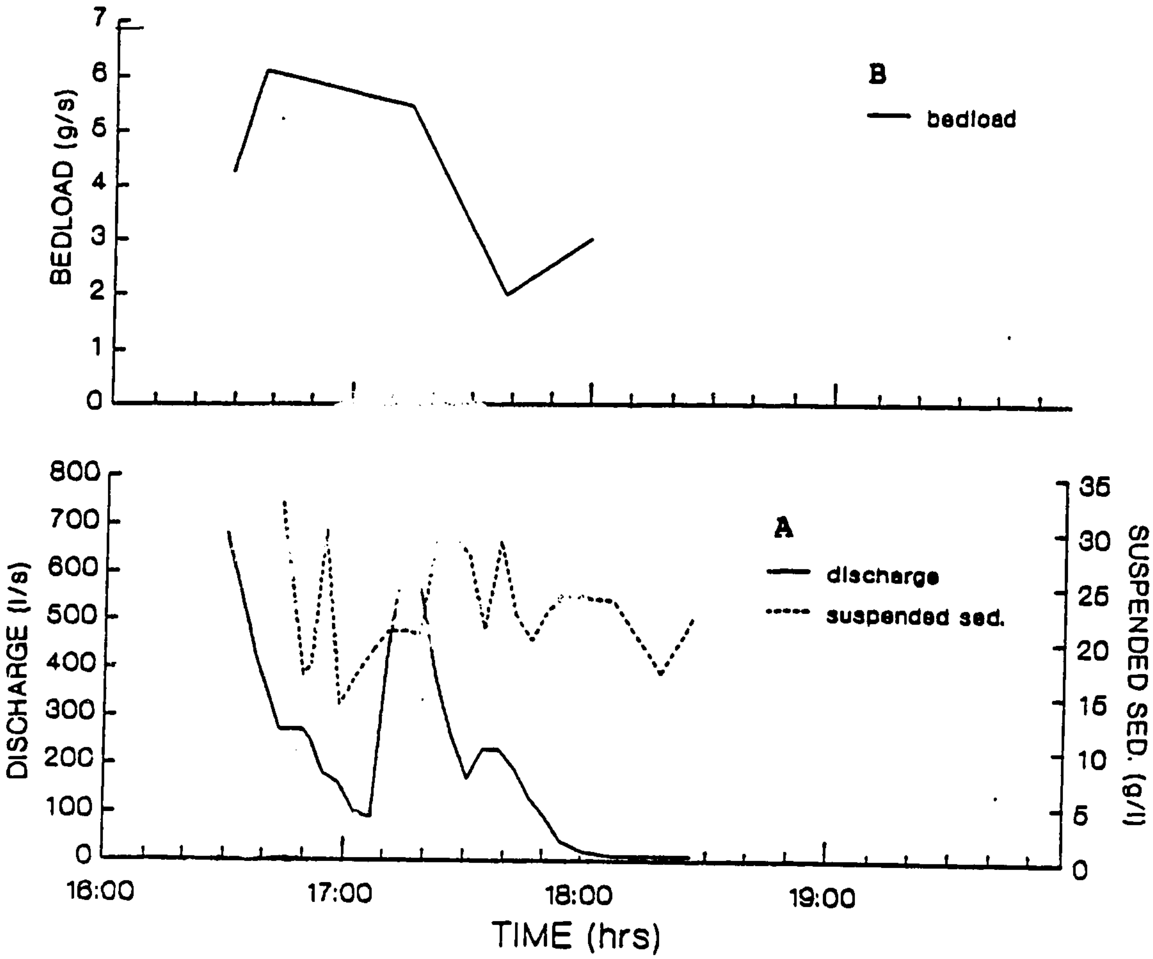


Figure 4.4 July 9, 1982, Rimco Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport.

4.2.2 1983

For 1983, data on bedload transport are available for two storms at the Rimco Flume, and three at the Aquatot Flume. During other storms bedload transport was negligible. Sediment size distribution was determined for sediment larger than 1 mm only, all sediment smaller than 1 mm was grouped into one category (Table 4.3).

The storms of July 2 and July 3 were large and simple, each with only one discharge peak followed by a fairly smooth, descending limb. Graphs of bedload transport on July 2 (Figure 4.5) and July 3 (Figure 4.6) at the Rimco Flume, and of July 3 at the Aquatot Flume (Figure 4.7) show fine sediment waves, occurring with intervals of 22 and 20 minutes respectively on July 2 at the Rimco Flume, and of 20 minutes on July 3. At the Aquatot Flume on July 3, the interval between waves is 29 minutes.

Though the waves show in transport patterns of all size fractions, a difference in transport patterns between the different size categories occurs at the onset of the July 2 storm at the Rimco Flume, when the fine fraction (<1 mm) starts with a very distinct decrease after an initial high. All larger fractions either remain somewhat the same (fraction <1mm), or show a large, initial accelleration of transport (fractions > 2 mm). The suspended sediment concentration and the total bedload transport, like the < 1 mm fraction, show an initial decrease of transport rates, suggesting that not only the fine fraction, but also the total Helley-Smith bedload samples at that time are dominated by suspended sediment. The extremely high suspended sediment concentration (53 g/l) at the onset of flow is probably the cause of this. Later during the flow, when suspended sediment concentration is smaller, all sediment size fractions show a typical bedload wave pattern, with very

Table 4.3 Helley-Smith bedload transport data, 1983.

No.	Peak discharge l/s	Bedload transport mg/s*	Transport rates for individual size fractions, mg/s < 1 mm	1-2 mm	2-8mm	> 8 mm
			RIMCO FLUME 2-7-1983			
1	235	35.333	26.933	4.137	4.260	0
2	540	20.500	4.340	4.082	11.018	1.065
3	410	1.490	570	156	439	327
4	290	960	343	84	150	382
5	235	5.910	3.848	452	897	713
6	167	1.060	58	77	790	134
7	217	93.007	3.640	3.765	58.498	27.102
8	187	36.310	3.490	4.535	25.440	2.843
9	137	6.903	4.297	565	1.610	432
10	137	18.187	2.960	1.827	12.173	1.223
			RIMCO FLUME 3-7-1983			
1	187	13.843	8.763	2.437	2.502	140
2	315	27.220	10.706	3.950	7.467	5.097
3	290	4.630	917	250	578	2.883
4	235	11.793	3.190	1.960	5.835	808
5	177	3.723	980	660	1.612	472
6	86	2.942	-	-	-	-
			AQUATOT FLUME 3-7-1983			
1	419	24.085	4.000	4.970	13.925	1.190
2	569	35.966	20.620	5.335	8.480	1.545
3	659	2.295	955	655	685	0
4	359	14.355	6.115	4.490	3.585	165

AQUATOT FLUME 12-7-1983

No.	Peak discharge l/s	Bedload transport mg/s*	transport rates for individual size fractions, mg/s < 0.5 mm	0.5-2 mm	2-4 mm	> 4 mm
1	156	25.117	1.513	9.260	8.987	5.357
2	186	20.293	4.700	4.480	5.033	6.080
3	275	46.253	11.477	10.883	7.210	16.683
4	180	23.117	6.717	3.247	1.937	11.217

- data unavailable

* bedload transport based on total weight of Helley-Smith bedload samples.

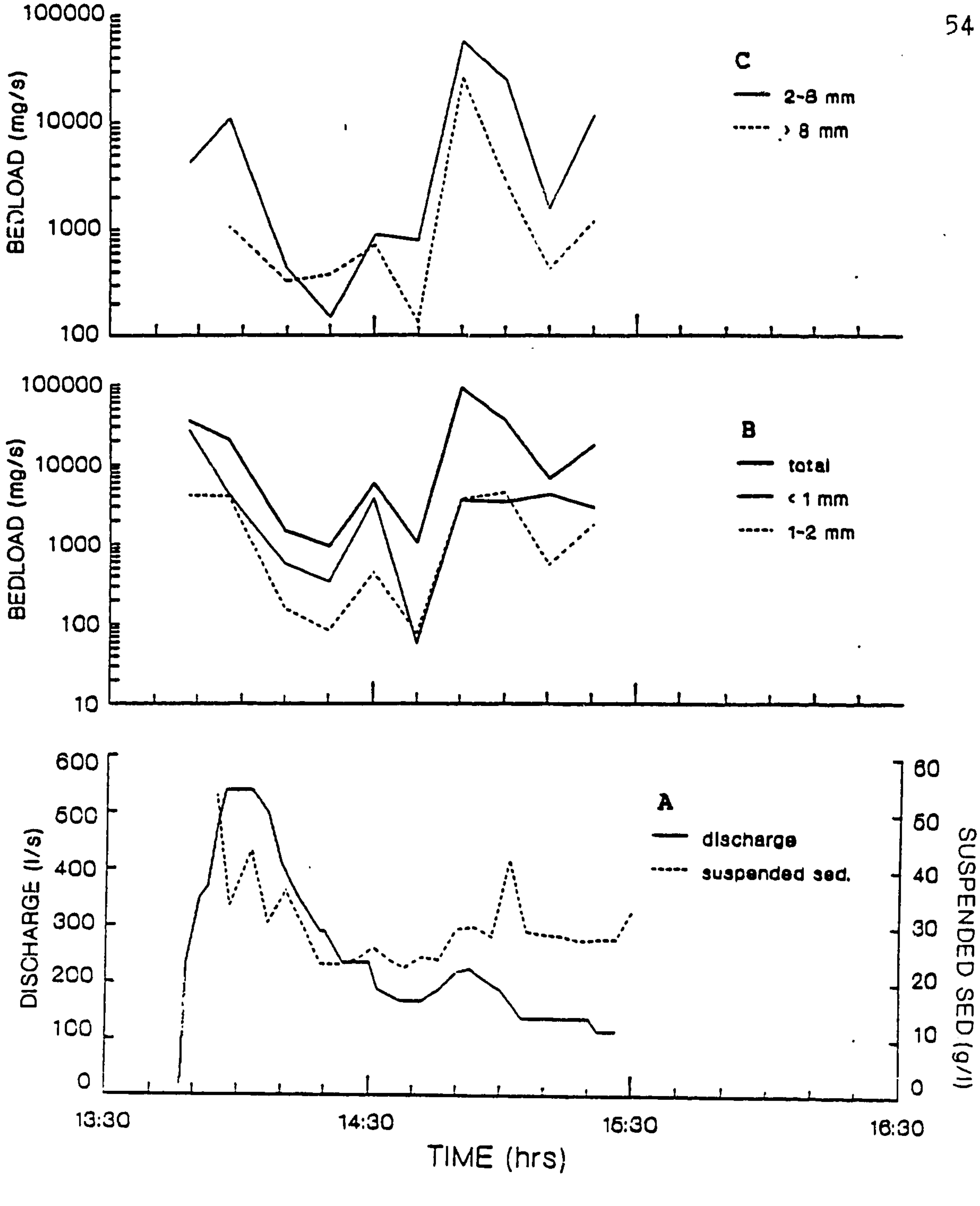


Figure 4.5 July 2, 1983, Rimco Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport, bedload fraction (< 1 mm), and bedload fraction (1 - 2 mm).
C - Bedload fraction (2 - 8 mm) and bedload fraction (> 8 mm).

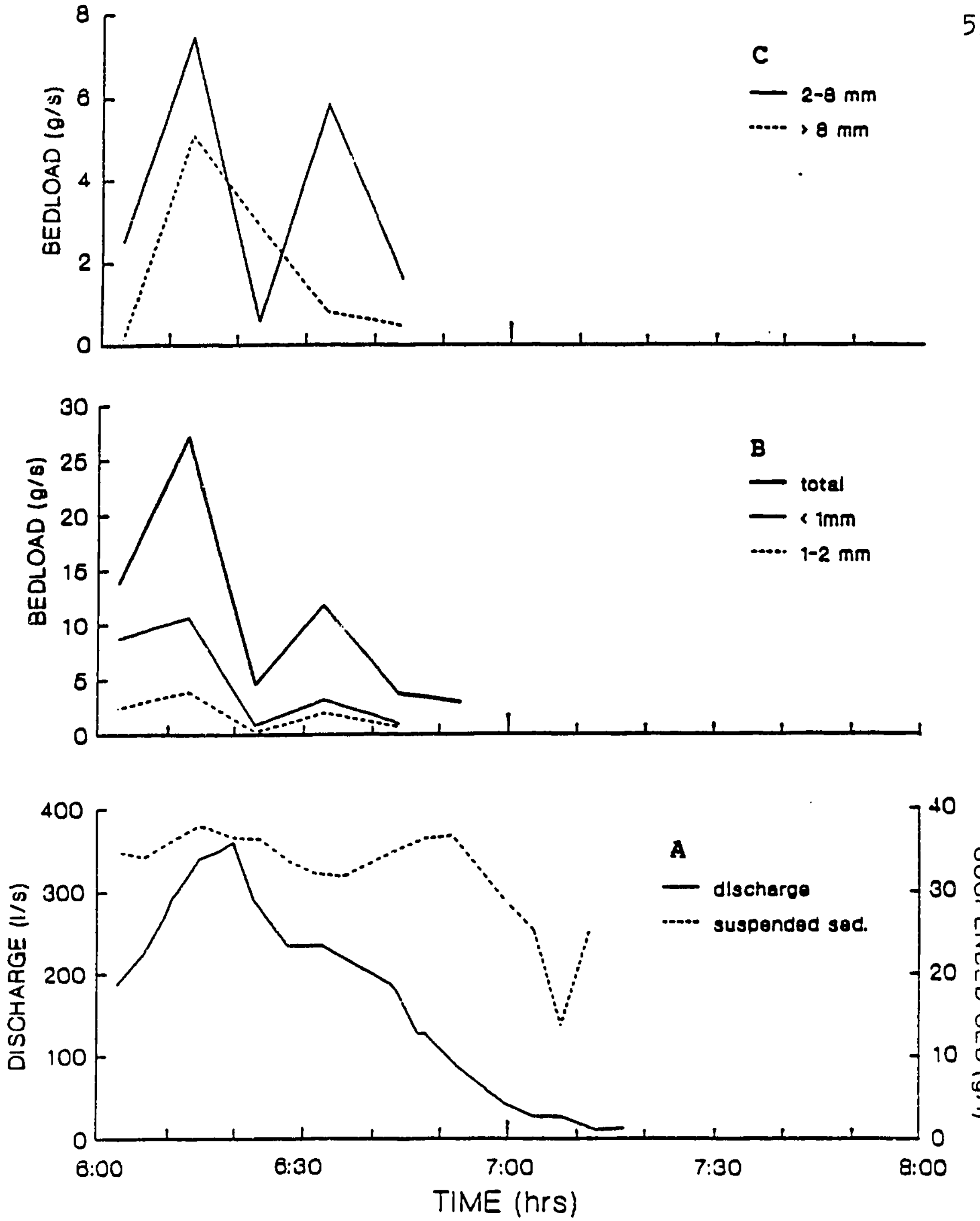


Figure 4.6 July 3, 1983, Rimco Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport, bedload fraction (< 1 mm), and bedload fraction (1 - 2 mm).
C - Bedload fraction (2 - 8 mm) and bedload fraction (> 8 mm).

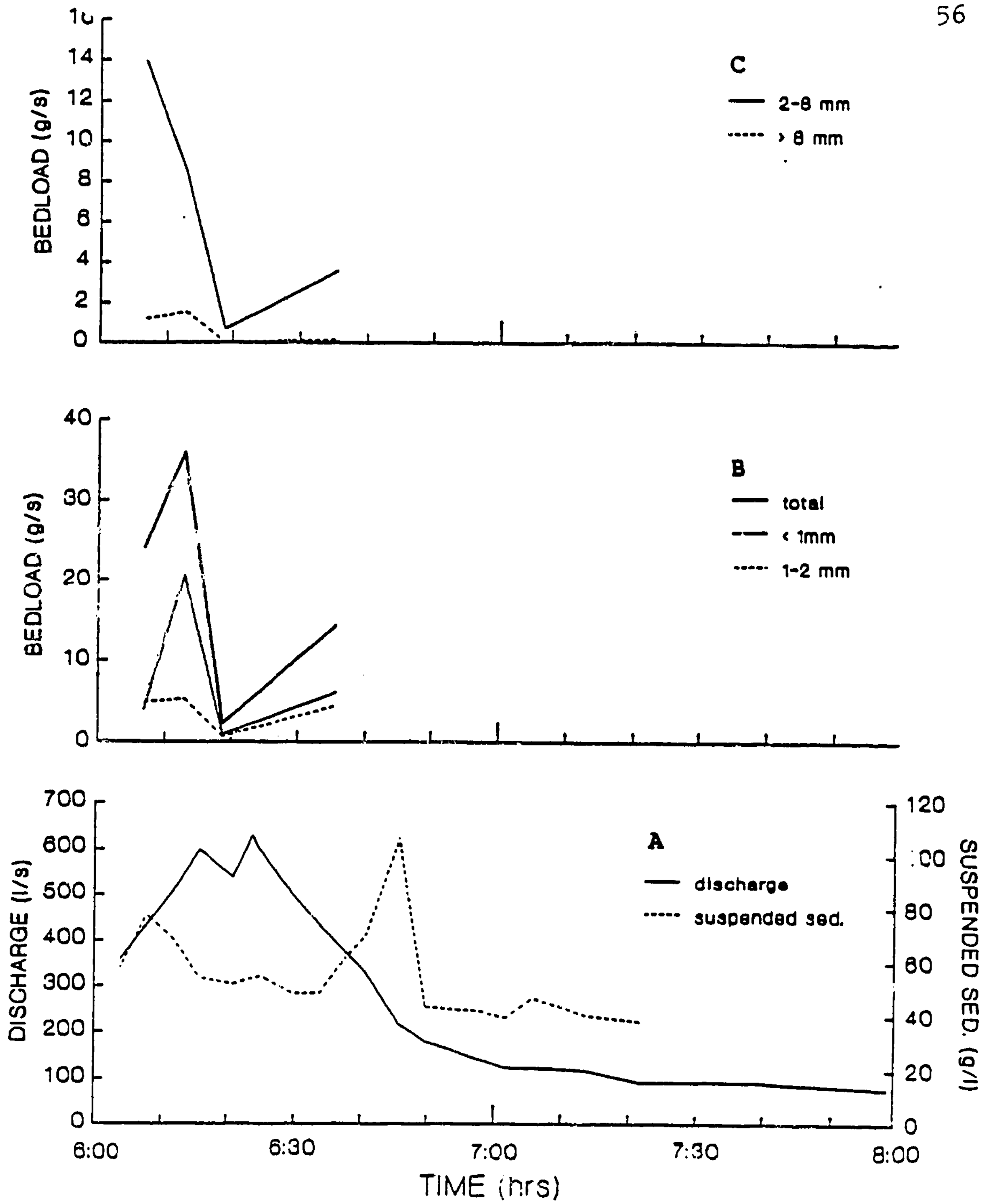


Figure 4.7 July ?. 1983. Aquatot Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport. bedload fraction (< 1 mm). and bedload fraction (1 - 2 mm).
C - Bedload fraction (2 - 8 mm) and bedload fraction (> 8 mm).

large amplitudes, indicating the domination of bedload in all size fractions at this stage of the flood.

The transport pattern of the sediment fraction larger than 8 mm deviates from others in two spots at the Rimco Flume, once on July 2, and again on July 3. No conclusion about an unlike transport mechanism should e attached to this, because the presence of only one piece of gravel can strongly influence the measured transport pattern in this size category. Whether or not a piece of gravel will enter the sampler during sampling time is largely a matter of chance.

Remarkable about the July 2 storm are again the small fluctuations in the suspended sediment concentration. These are not explicitly connected to changes in discharge.

Because sediment waves with large amplitudes dominate bedload transport in 1983, bedload tranport varies almost randomly with discharge (Figure 4.8 and 4.9). The plots show no evidence of hysteresis.

4.2.3 1984

Two storms each, both occurring on July 31, were sampled at the Rimco Flume and the Aquatot Flume. Sampling interval was 10 minutes. Measured bedload at the Rimco Flume varied only between 17 and 170 mg/s, which means that no significance can be attached to the observed transport patterns. The Helley-Smith samplers are simply too inaccurate at these low transport levels. At the Aquatot Flume, discharge was large, and sediment transport as high as 36 g/s was recorded. At the beginning of the storm, when discharge was at its highest, a sediment wave passed. Later on during that storm, when discharge was lower, measured bedload transport was smooth (Figure 4.10).

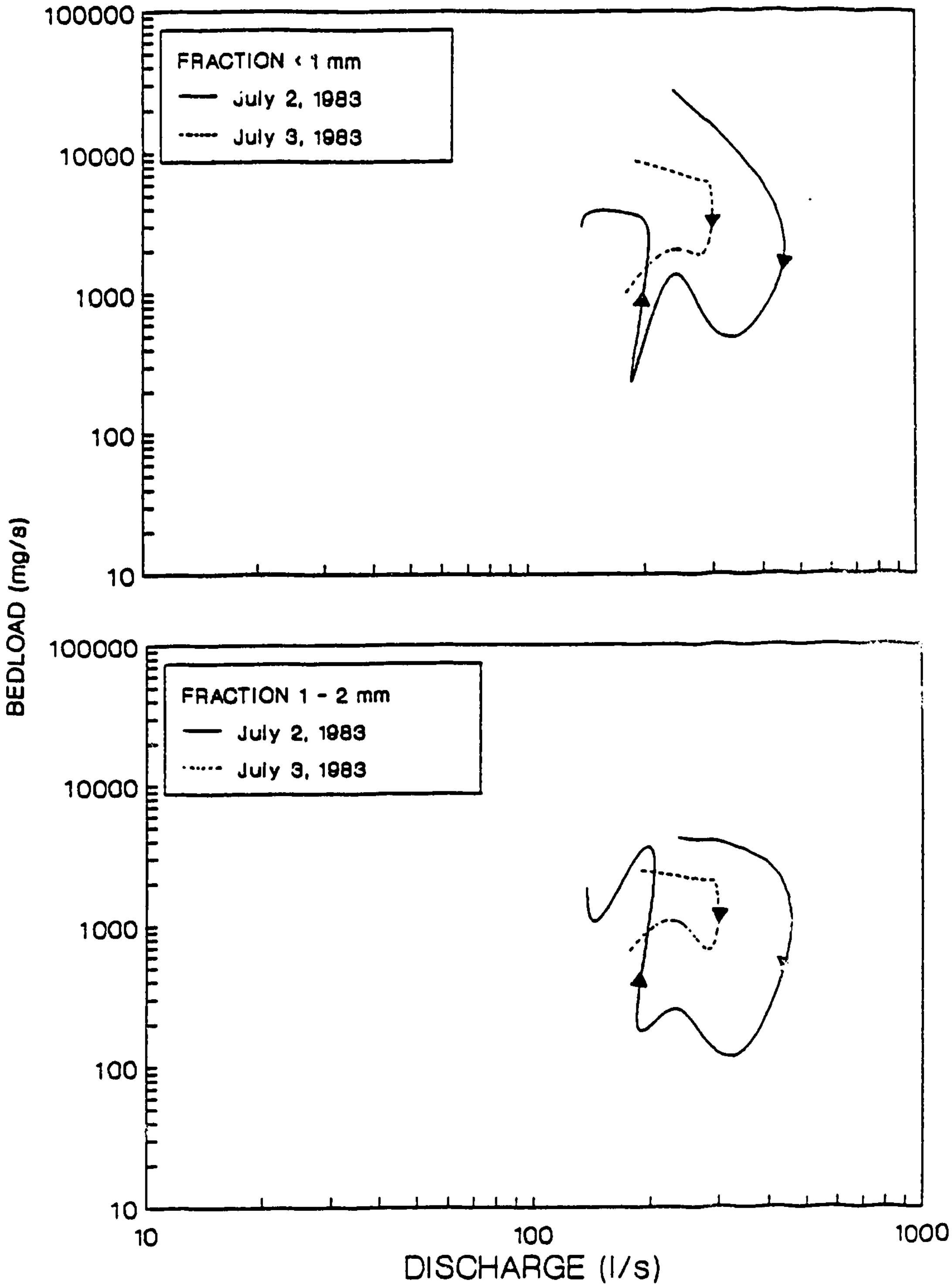


Figure 4.8 Bedload transport as a function of discharge for the Rimco Basin on July 2, 1983 and July 3, 1983.

A - Fraction < 1 mm.
B - Fraction 1 - 2 mm.

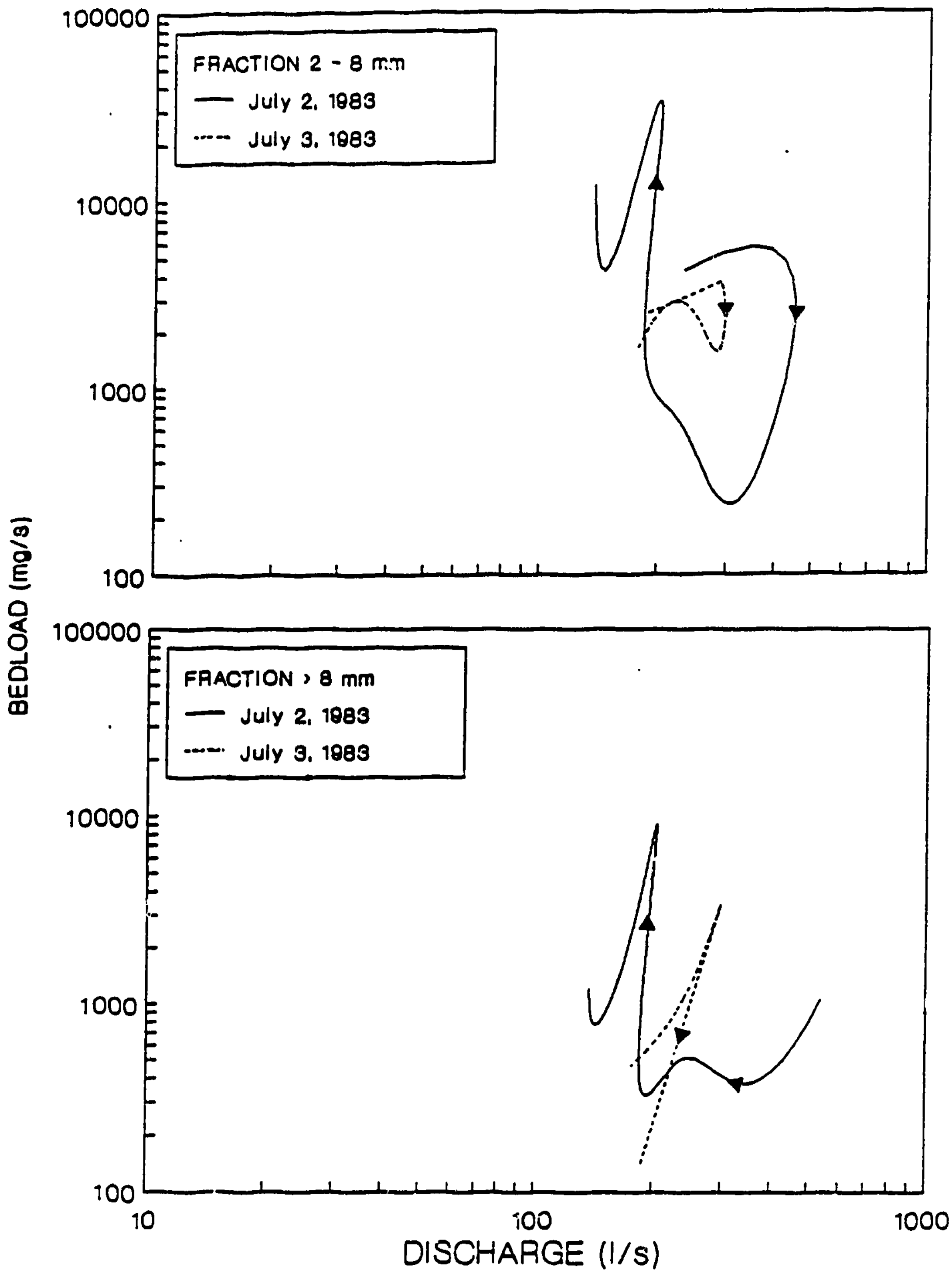


Figure 4.9 Bedload transport as a function of discharge for the Rimco Basin on July 2, 1983 and July 3, 1983.

A - Fraction 2 - 8 mm.
B - Fraction > 8 mm.

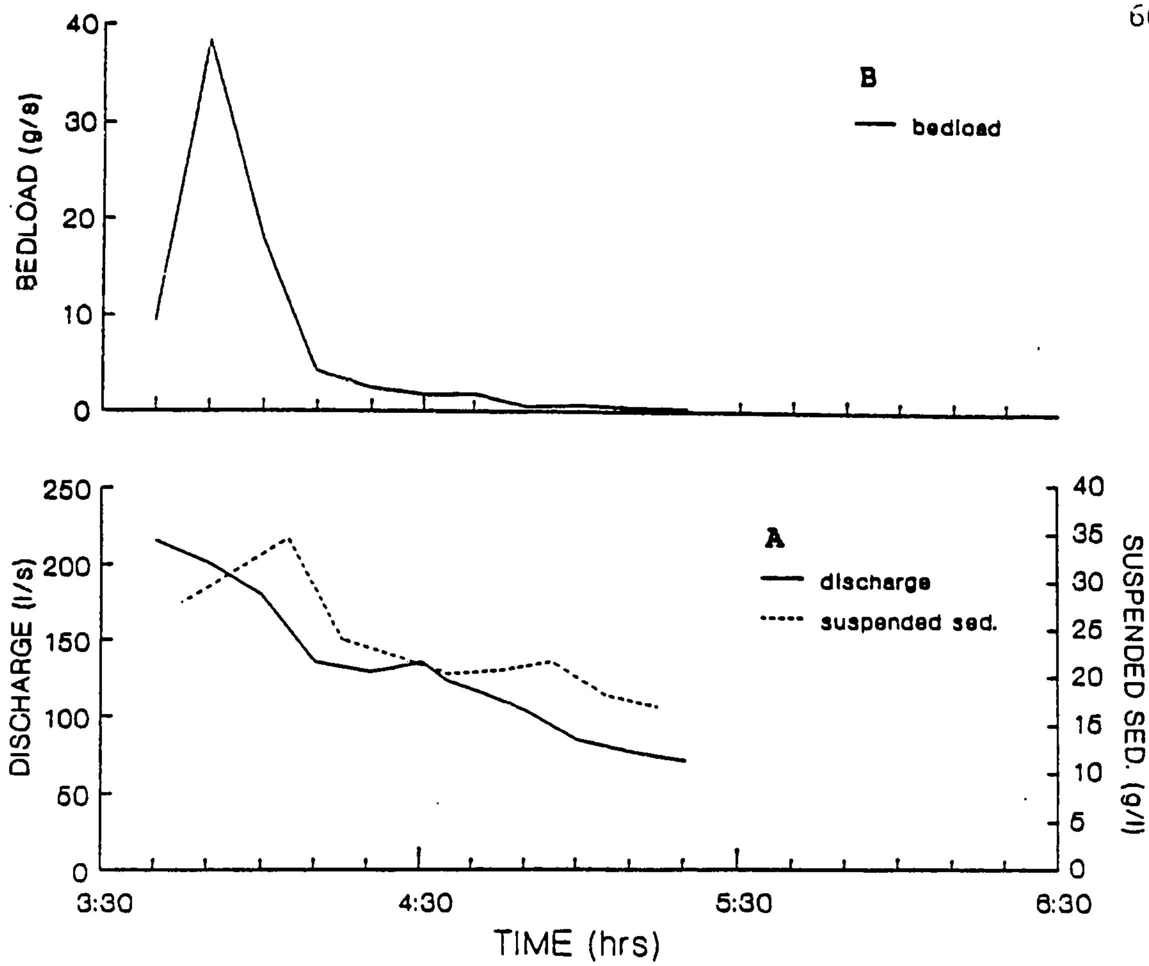


Figure 4.10 July 31, 1984, Aquatot Flume. Variation over time of:

A - Water discharge and suspended sediment concentration.
B - Total bedload transport.

4.3 Discussion

The observations in 1982, 1983 and 1984 of clearly defined bedload waves that coincide with smooth descending limbs of the hydrographs, corroborates the conclusions from 1987 bedload transport data: sediment waves totally independent of changes in discharge occur in this ephemeral, sand-bed channel. The recorded wave intervals of 25 minutes on average, are similar to some of the wave intervals that have been reported for perennial streams (Table 4.4). Wave amplitudes vary, bedload transport rates during the peaks of the waves are anywhere between 2 and 37 times larger than transport rates during troughs, which does nothing to distinguish this channel from perennial streams in terms of bedload transport.

The proportion of large particles strongly fluctuates in the bedload samples. For instance in 1983, the relative amount of particles larger than 1 mm, varies between 24% and 95%. The peaks in the sediment waves often have the highest percentages of coarse particles (Table 4.5). This has also been observed during flume experiments (Einstein, 1937), and in a desert, rock/gravel bed channel (Lekach and Schick, 1983). This, and the relatively small amplitudes of the smaller size fractions (<1 mm, and 1 mm - 2 mm), an expression of the same phenomenon, might be explained by the presence of a significant amount of suspended sediment in the samples that moderates troughs in the transport pattern of the small size fraction. However, a difference in transport mechanism between the smaller (<2 mm) and the larger bedload particles, more saltating, higher jumps for the smaller particles, and exclusively rolling, and sliding for the larger particles, might provide a better or at least additional explanation. Particles that exclusively roll and slide will

Table 4.4 Bedload pulse interval and flow type reported for natural rivers (mnodified after Reid et al., 1985).

Reference	River	Flow type	Bedload pulse interval (h)
Reid, Frostick and Layman, 1985	Turkey Brook, England	perennial	1.4-2
Ehrenberger, 1931	Danube, Austria	perennial	0.3
Muhlhofer, 1933	Inn, Austria	perennial	0.1
Einstein, 1937	Rhine, Switzerland	perennial	20
Solov'yev, 1967	Mzymta and Ugam, USSR	perennial	0.2
Emmett, 1975	Slate cr., Idaho	perennial	0.1-0.7
Lekach and Schick, 1983	Nahal Yael, Negev, Israel	ephemeral	0.3-1
Niekus (this study) 1991	Dinosaur Park badlands,	ephemeral	0.3

Table 4.5 Distribution of coarse particles in Helley-Smith bedload transport data, 1983.

No.	Peak discharge l/s	Bedload transport mg/s*	Distribution of coarse particles in the 1983 bedload samples (%) > 1 mm	> 2 mm
			RIMCO FLUME 2-7-1983	
1	235	35,333	24	12
2	540	20,500	79	59
3	410	1,490	62	51
4	290	960	64	55
5	235	5,910	35	27
6	167	1,060	95	87
7	217	93,007	96	92
8	187	36,310	98	78
9	137	6,903	38	30
10	137	18,187	84	74
			RIMCO FLUME 3-7-1983	
1	187	13,843	37	19
2	315	27,220	61	46
3	290	4,630	80	75
4	235	11,793	73	56
5	177	3,723	74	56
6	86	2,942	-	-
			AQUATOT FLUME 3-7-1983	
1	419	24,085	83	63
2	569	35,966	43	28
3	659	2,295	58	39
4	359	14,355	57	26

- data unavailable

* bedload transport based on total weight of Helley-Smith bedload samples.

clearly experience more interference from other particles, and therefore, (Langbein and Leopold, 1968), have a stronger tendency to move in waves.

During small storms, measured bedload transport rates tend to vary more or less in concurrence with discharge and suspended sediment, suggesting that the Helley-Smith samples of these smaller storms are dominated by suspended sediment. During storms with peak discharges larger than 200 l/s however, contamination of the Helley-Smith bedload samples with suspended sediment appears minor, because even transport rates of the smallest fraction (<1 mm) of such storms display distinct wave patterns. An exception occurs during the very high suspended sediment concentration of 53 g/l (July 2, 1983 at the Rimco Flume), when the total weight of the Helley-Smith samples appears dominated by suspended sediment, notwithstanding the respectable discharge of 540 l/s.

Because the samples from the largest storms appear relatively free from suspended sediment, samples from these storms give a reasonable estimate for bedload transport in this basin. The samples suggest that despite the apparently large amplitudes in bedload transport, bedload transport rates of this basin vary between a meagre 0.01 % and an almost equally meagre 1.4% of the combined suspended and bedload transport rates. This is in striking contrast to the Nahal Yael basin in the Negev desert where bedload is estimated to contribute 60% to the total sediment output of the basin (Schick et al., 1987). The small percentage of bedload transport in the total sediment output of the study basin in Dinosaurpark is probably related to the limited supply of coarse sediment . The badlands in this area are dominated by shales, muddy sandstones and coarse channel sandstones (see also section 2.1). Exhaustion of bedload type sediment after a medium size storm observed in 1987, indicates that the amount of coarse particles, bedload type sediment, in the basin is very limited. The thin alluvial deposit in the channel (see also section 5.4) also suggests that sediment supply is a major limiting factor in bedload transport rates.

The combination of large amplitude bedload waves, and the short, flashy nature of the storms in the badlands, makes it impossible to establish a rating curve of bedload transport and discharge. Bedload transport data indicate that differences in bedload transport between storms can not be attributed to differences in discharge. For instance, bedload transport rates of 93 g/s and 36 g/s were measured at the Rimco Flume on July 2, 1983, after discharge had dropped to 290 l/s. The next day, a maximum bedload transport rate of only 27 g/s was measured even though discharge during that storm reached up to 315 l/s. Exhaustion of bedload sediment supply in the channels of the study basin seems the most likely explanation for these differences in bedload transport between storms. The storm on June 2, 1983 probably flushed most of the bedload type sediment present in the channels out of the Rimco Basin and the New Basin, and deposited it downstream in one of the larger channels of the badlands. The aggradation occuring upstream from the Aquatot Flume indicates that substantial amounts of sediment that are transported out of the two smaller upstream basins is deposited in this section of the fluvial system in the badlands.

The Helley-Smith samples record that the minimum amount of discharge necessary to initiate a measurable bedload transport ranges between 42 l/s (18-5-1983, Rimco Flume) to 119 l/s (17-6-1982, Rimco Flume). On one occasion (July 12, 1983, Rimco Flume) even a discharge of 96 l/s did not generate bedload transport. Minimum discharge necessary to sustain bedload transport was recorded as 27 l/s (26-5-1982). It must be emphasized however, that bedload movement may have started a little earlier, and at a much lower discharge than was actually measured because of sample intervals of 10 minutes and larger, and the flashy nature of the badland storms. Also, it is uncertain at these low discharges how much of the sediment trapped in the Helley-Smith samplers actually consists of bedload. Operators of the Helley-Smith samplers record that in 1982 only five storms were large enough to transport measurable amounts of bedload, four in 1983, and two in 1984.

The fluctuations in suspended sediment concentration in some of the 1982 and 1983 storms are very remarkable. They are quite distinct from the waves in bedload transport, in that they occur with much shorter intervals and with much smaller amplitudes. They have not been noted in any of the 1987 storms, possibly because all 1987 storms were relatively small. Such fluctations in suspended sediment concentration have also been described for the Red Deer River (Campbell 1977). Campbell attributes the abrupt variations in suspended sediment concentration to 'slugs' of wash load with minimal discharges from tributaries, and to local bank collapses. On the basis of an examination of a single flood deposit in an ephemeral stream, Frostick and Reid (1977) also suggest the occurrence of small pulses of high sediment concentrations, superimposed on the main flood wave by contribution from tributary channels. Such pulses or 'slugs' could easily cause the recorded fluctuations in suspended sediment concentration in this badland channel.

CHAPTER FIVE SCOUR AND DEPOSITION

5.1 Experimental design

Scour cords were buried vertically in the dry stream bed. At the lower end they were attached to a nail driven in the bedrock, their upper ends were cut off flush with the bed surface. During floods, scour exposes part of the cord, and causes the exposed part to fall over. The length of cord lying horizontal after a flood indicates the depth of scour at that location. The thickness of sediment deposited on top of the horizontal part of the cord is a measure of deposition (Figure 5.1).

Crest gages were installed near the scour cords to measure the maximum stage of flow. The crest gages consisted of perforated, plastic pipes that were coated on the inside with charcoal powder. The pipes were taped to a large iron pin that was driven into the bedrock. The maximum water level of a flood is indicated by the height in the crest gages to which the charcoal has been washed.

Scour cords and crest gages were installed at nine locations upstream from the nickpoint in the main channel of the New Basin (Figure 5.2). Table 5.1 describes the channel cross-sections at these sites. Three scour cords were installed midstream at each site, with a spacing of 2 cm in a downstream direction. This was done in order to make it possible to average the readings and thereby, as much as possible, eliminate the effect of local bedforms such as ripples on the results.

Scour cords were also installed at the three following locations: a few metres upstream from the Rimco Flume (Site I), a few metres upstream from the New Flume (Site II), and about 20 m upstream from the Aquatot Flume (Site III). At these three sites, the channels are larger, and the

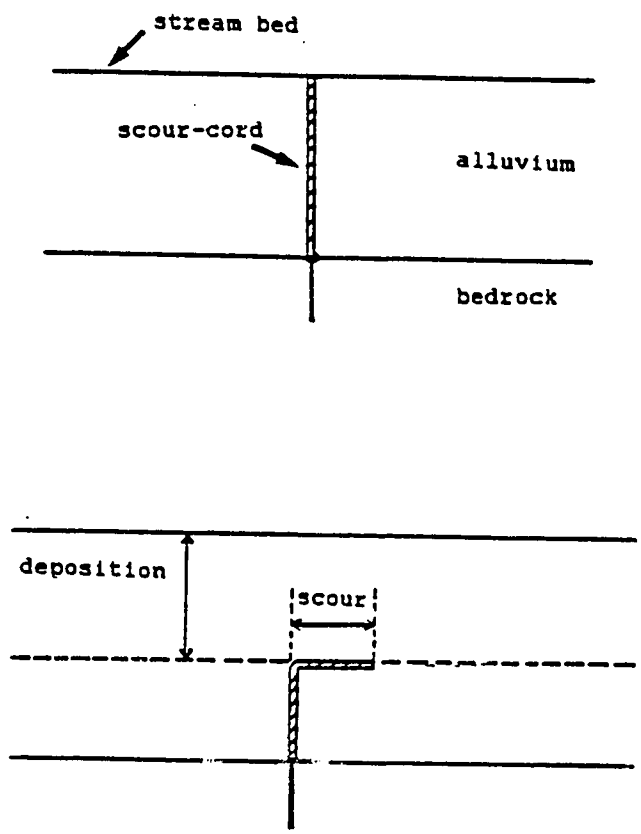
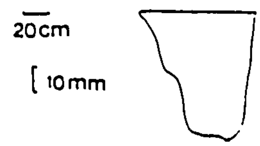
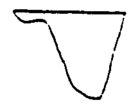
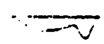
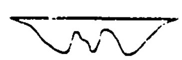
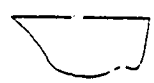
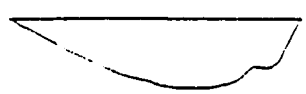
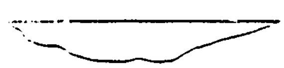
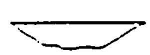


Figure 5.1 Scour cords measure erosion and deposition.

Site 1

Figure 5.2 Location of scour cords along the main channel of the New Basin.

Table 5.1 Description of scour cord sites along the main channel of the New Basin.

Thickness No.	Description bedsurface	Channel alluvium mm	dimensions	W = width, D = depth, W/D = width depth ratio
1	flat/clay/sand/ gravel (in gully)	40		W = 0.9 m D = 516 mm W/D = 1.7
2	flat/[illegible]d/ grave[illegible]	10		W = 0.9 m D = 354 mm W/D = 2.5
3	ripples, sand	40		W = 0.8 m D = 69 mm W/D = 11.7
4	ripples, sand	25		W = 0.7 m D = 60 mm W/D = 11.7
5	ripples, sand	25		W = 1.40 m D = 154 mm W/D = 9.1
6	flat, gravel (riffle)	30		W = 1.10 m D = 238 mm W/D = 4.6
7	ripples, sand	60		W = 2.30 m D = 283 mm W/D = 8.1
8	ripples, sand	40		W = 2.10 m D = 169 mm W/D = 12.4
9	ripples, sand (in gully)	20		W = 1.10 m D = 102 mm W/D = 10.8

bed surface is rather heterogeneous, containing well-developed thalwegs, sometimes boulders and gravels, and ripples, all in one cross-section. In order to get readings representative for the entire cross-section, nine scour cords were installed at each of these three locations (Figure 5.3). At site III, immediately upstream from the Aquatot Flume, the channel section was clearly aggrading, the thickness of the alluvium was between 1 and 25 cm. The Aquatot Flume itself had been filled with a sandy deposit of about 20 cm from 1984 to 1987. As opposed to this, the sections upstream from the Rimco Flume and the New Flume, seemed rather stable, there was no thick alluvium deposit and the channel bed was indurated.

Scour cords and crest gages were read and newly installed after each flood whenever possible.

5.2 Scour and deposition in the New Basin

Scour cord data from the channel upstream from the nickpoint in the main channel of the New Basin are shown in Figure 5.4 and Figure 5.5. On June 19, 1987, an average erosion of about 2 cm was recorded along the channel (Figure 5.4). At site 3, the channel had eroded down to the bedrock. Deposition varied between 1 and 5 cm. Four sites had experienced net deposition, four net erosion. Crest gages in the channels recorded maximum water levels varying between 4 and 14 cm.

On July 3-4, 1987, after a small storm, hardly any erosion had occurred. Deposition was very limited. The maximum deposition was 2 cm, it had occurred at site 9. Recorded maximum water levels varied between 1 and 3 cm.

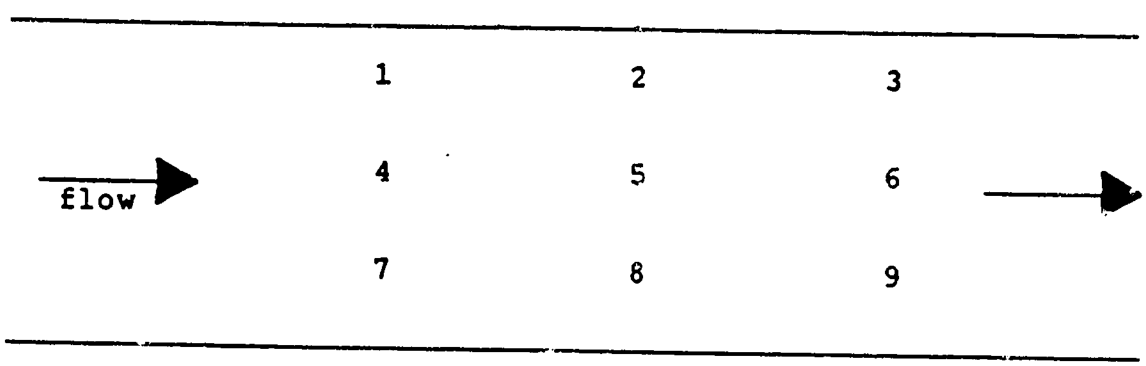


Figure 5.3 Schematic representation of scour cord distribution at sites immediately upstream from the Rimco Flume, New Flume and Aquatot Flume.

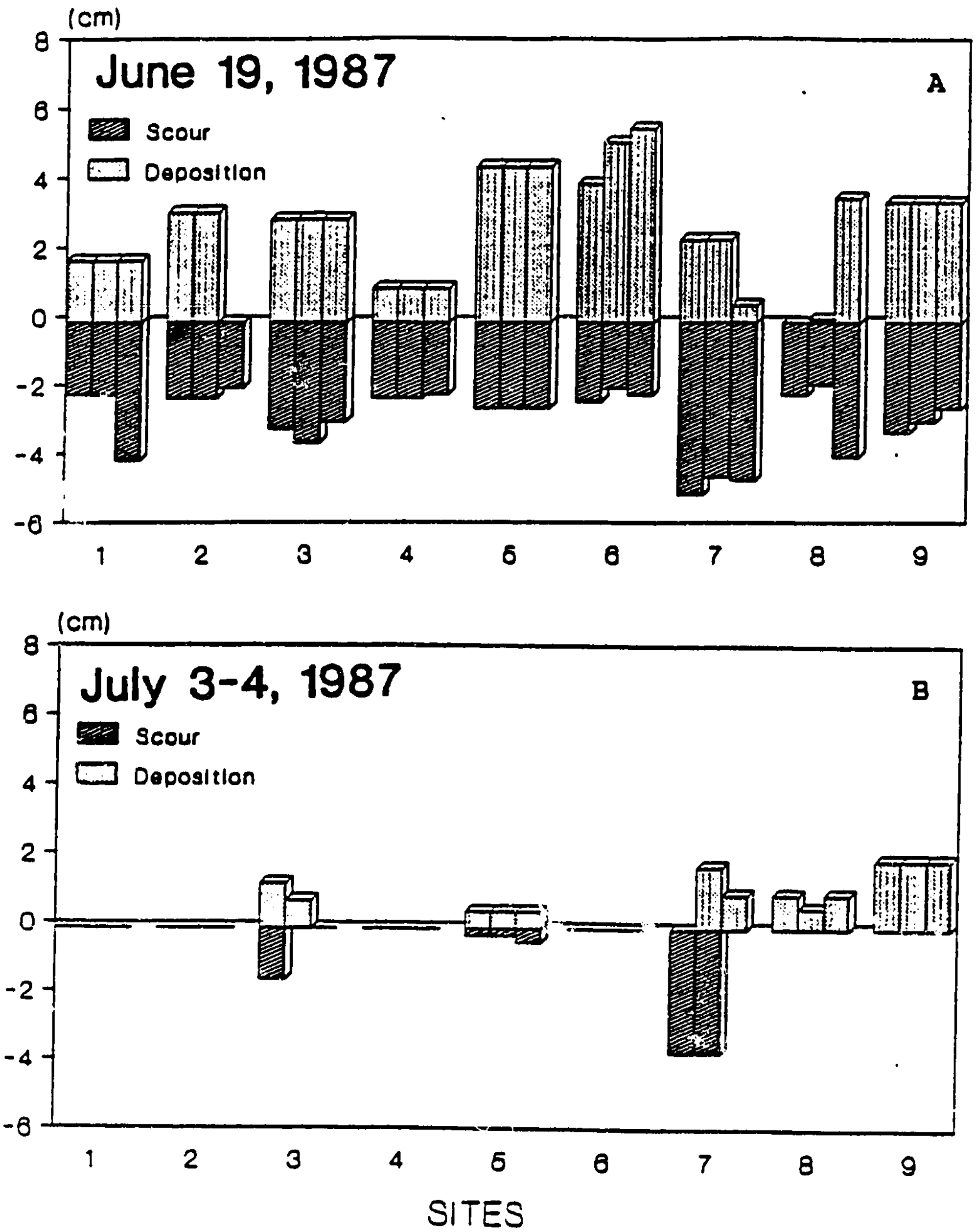


Figure 5.4 Variation in scour and deposition along the main channel of the New Basin.

A - June 19, 1987.
B - July 5, 1987.

On July 18-19, 1987, erosion averaged about 1.5 cm. Deposition measured about 3 cm, with a local maximum of 5 cm at site 7. Six sites had experienced a net deposition, two sites a net erosion (Figure 5.6). Recorded maximum water levels varied between 1 and 10 cm.

On July 25, 1987, erosion averaged about 1.5 cm, and deposition about 2.0 cm (Figure 5.5). Seven sites recorded a net deposition, two sites a net erosion (Figure 5.6). Maximum water levels varied between 2 and 12 cm.

5.4 Analysis of scour and deposition in the New Basin

In general, depth of erosion seems related to the magnitude of the storm. Maximum recorded erosion for the season was 5 cm (Figure 5.4). This was measured at site 7 on June 19, 1987, after a flood with maximum water levels in the channel of up to 14 cm. On average, erosion after this flood measured about 2 cm. A small storm on July 3-4, 1987 , with maximum water levels up to 3 cm, produced flows that were virtually unable to erode the channel bed. Two medium sized storms, on July 18-19 and July 25, recorded waterlevels up to 10 cm and 12 cm. They caused erosion averaging a little over 1 cm.

Deposition of sediment dominated during the three smallest floods, while erosion slightly dominated over deposition during the largest flood.

Over the field season, deposition dominated. Five sites experienced a cumulative net deposition, only three a cumulative net erosion (Figure 5.7). The dominance of deposition over erosion appears related to the small size of the 1987 storms later in the season. Overland flow and

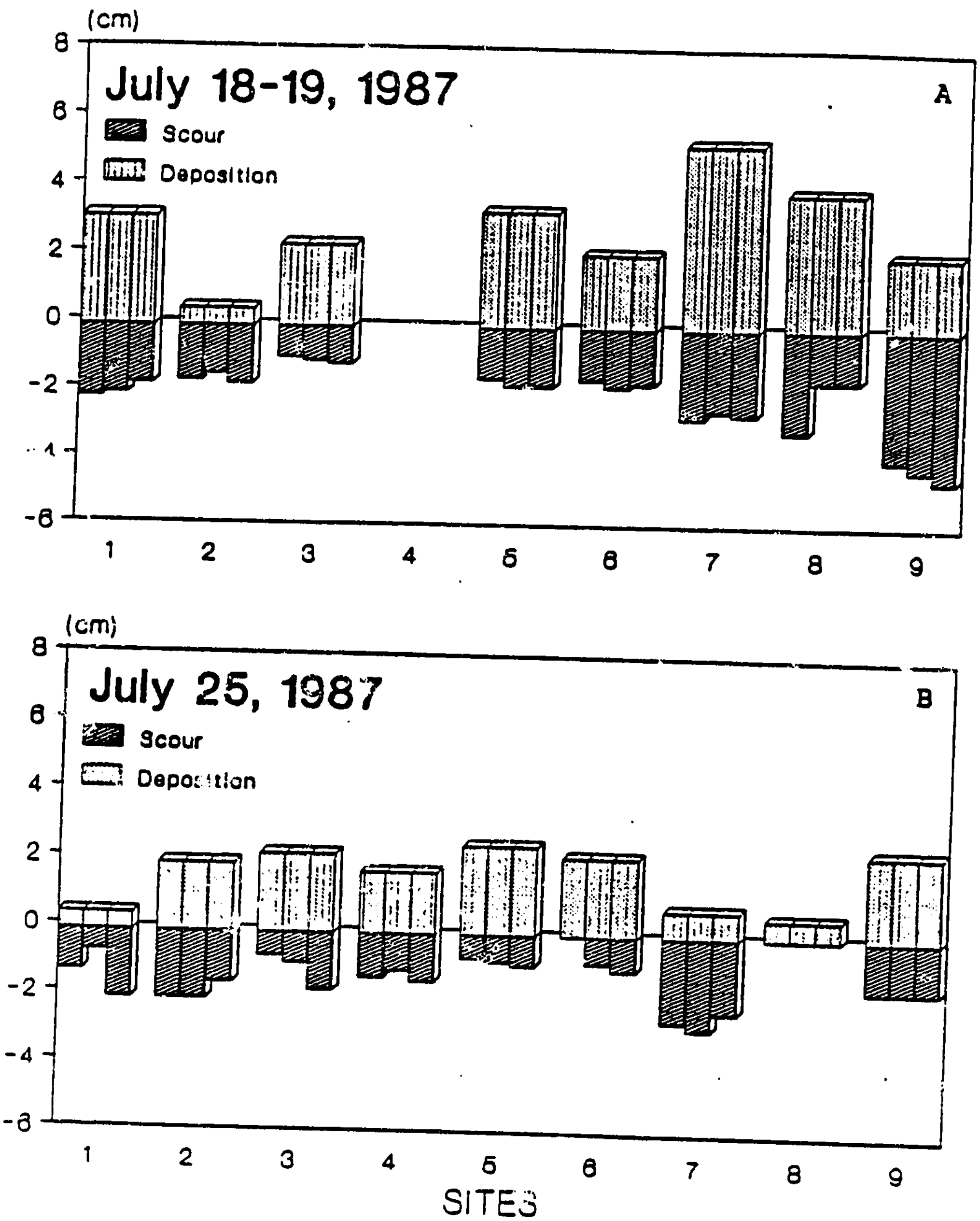


Figure 5.5 Variation in scour and deposition along the main channel of the New Basin.

A - July 18-19, 1987.
B - July 25, 1987.

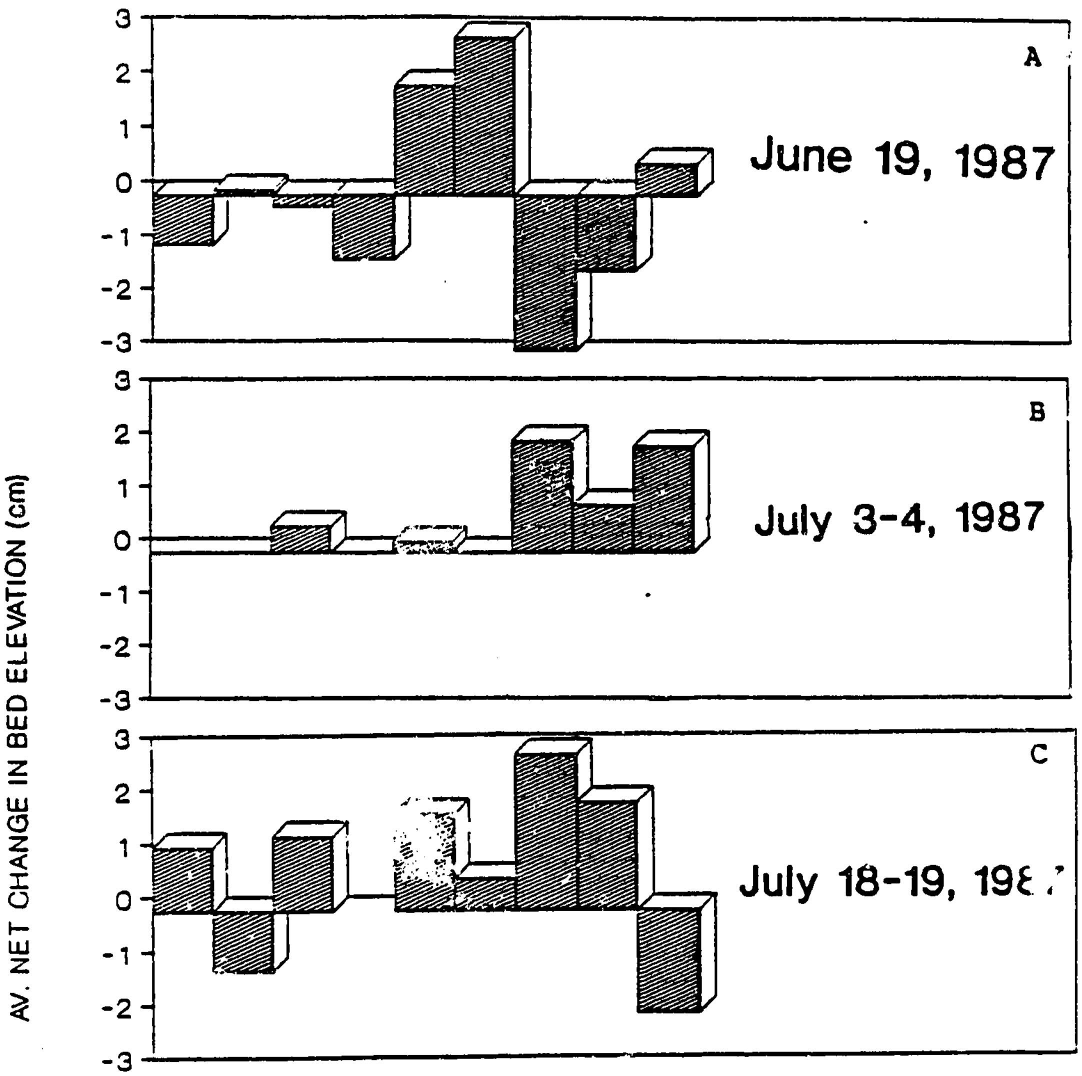


Figure 5.6 Average change in bed elevation along the main channel of the New Basin.

A - June 19, 1987.
B - July 5, 1987.
C - July 18-19, 1987.

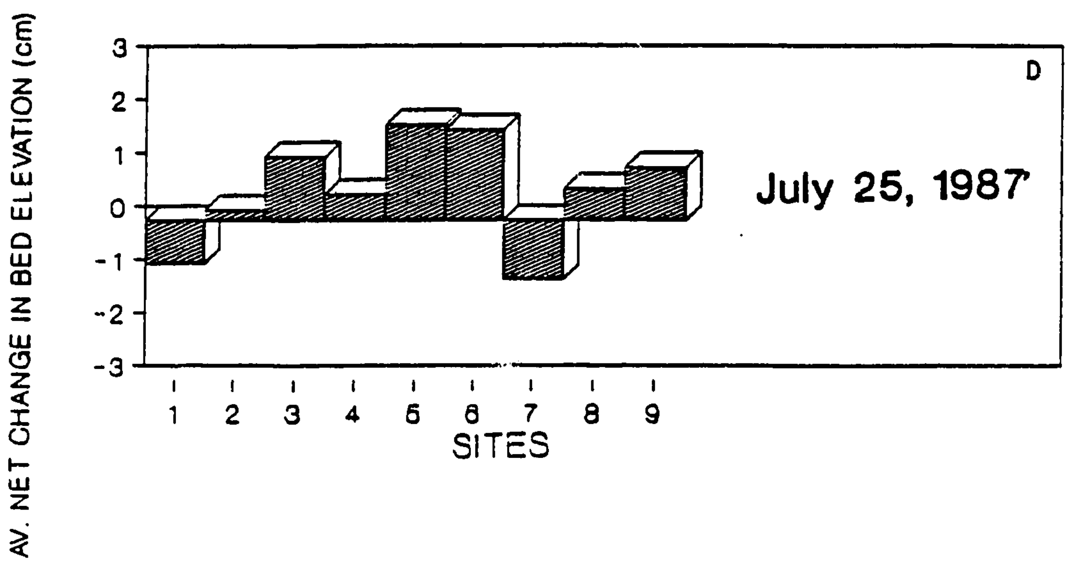


Figure 5.6 Average change in bed elevation along the main channel of the New Basin.

D - July 25, 1987.

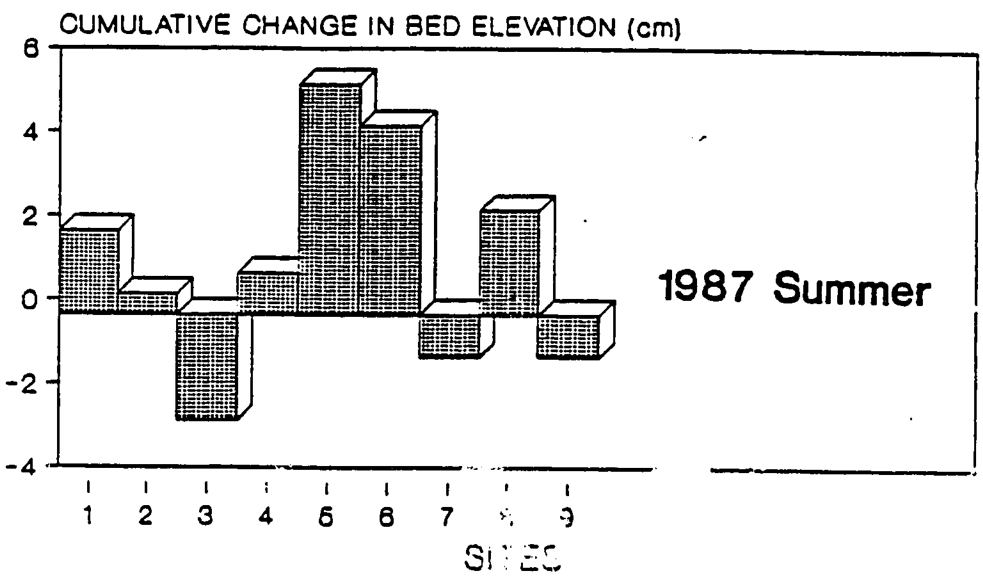


Figure 5.7 Cumulative change in bed elevation along the main channel of the New Basin over the 1987 summer season.

sediment laden tributaries deposit sediment in the main channel during floods. Small floods do not have the capacity to transport all of this sediment further, so it accumulates in the channel until it is eroded and transported out of the basin during a larger flood. The thin alluvial cover of the bedrock in the channel suggests that there is no tendency for a long-term sediment build-up.

Over the season, different sites experienced different depths of erosion during one storm, different sites also experienced different maximum water levels. When comparing depth of erosion with maximum water levels however, there appears to be no relationship between the two (Figure 5.8). Added over the season, sites also differed: sites 1,2,4,5,6, and 8 had a cumulative net deposition, sites 3, 7 and 9 a cumulative net erosion. These differences in bed level change between the sites are too small, and too inconsistent to warrant any conclusion that certain channel reaches experience significantly more deposition or erosion than others. One has to take into account that in this study, scour cords had a margin of error of about 2 cm, where ripples adorned the channel bed. Maximum ripple height was 2.5 cm.

The differences in erosion and deposition are probably best explained by local differences in channel morphology. The net deposition at site 6 for instance, was the result of a small sandbar that built up in the lee of a plant just upstream from the scour cords. This sandbar certainly does not represent an overall sand build up along this channel section.

In general, the thin alluvial cover (4 to 6 cm) along the channel suggests, that this channel is quite capable of exporting all the sand that reaches the stream via tributatries and overland flow. Temporary accumulation of sediment in the channel occurs only over short reaches.

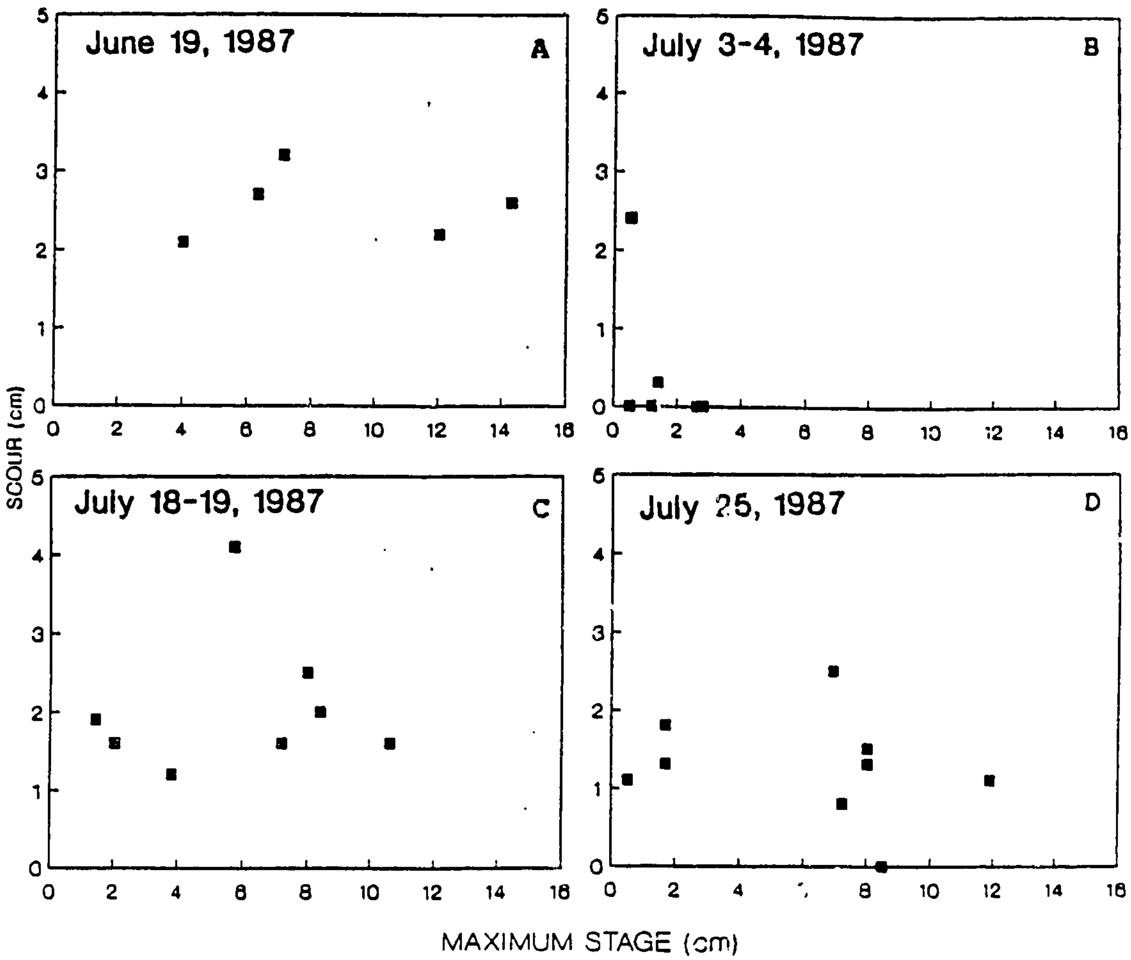


Figure 5.8 No relationship is found between spatial variation in scour, and spatial variation in maximum water level during floods in the New Basin.

A - June 19, 1987.
B - July 5, 1987.
C - July 18-19, 1987.
D - July 25 1907.

where the channel is not confined and where it widens considerably. A relatively wide and shallow channel is usually found at sites where tributaries with sediment laden water enter the stream. The widening of the channel, and its braided appearance, can be explained by the increased sediment concentration of the flow at these sites. The sudden increase in sediment load enhances the abbrasive force of the flow, causing local erosion of the channel banks. Though, wide and shallow channels have a relatively smaller capacity to transport bedload than similar size streams with a rathe deep and narrow channel (Henderson, 1966). The deposition of sediment in these sections does not appear to be an accumulation of the nature that will progressively increase until a threshold value is attained such as described by Schumm (1977). Schumm describes how sediment deposition occurs when the channel gradient is not capable of conveying increased sediment loads to the mouth of the basin. As a result, deposition continues until the gradient is locally increased to a threshold inclination that induces renewed channel incision and flushing of the sediments down valley. In this badland channel however, there is no evidence of such consistent local deposition, sediment storage remains more or less the same during the summer.

.5 Scour and deposition immediately upstream from the three flumes

On June 19, 1987, the channel at site III was eroded an average of 4 cm, deposition averaged about 6 cm. At sites I and II, just upstream from the New Flume and the Rimco Flume, erosion and deposition was very small, negligible for most of the scour cords (Figure 5.9).

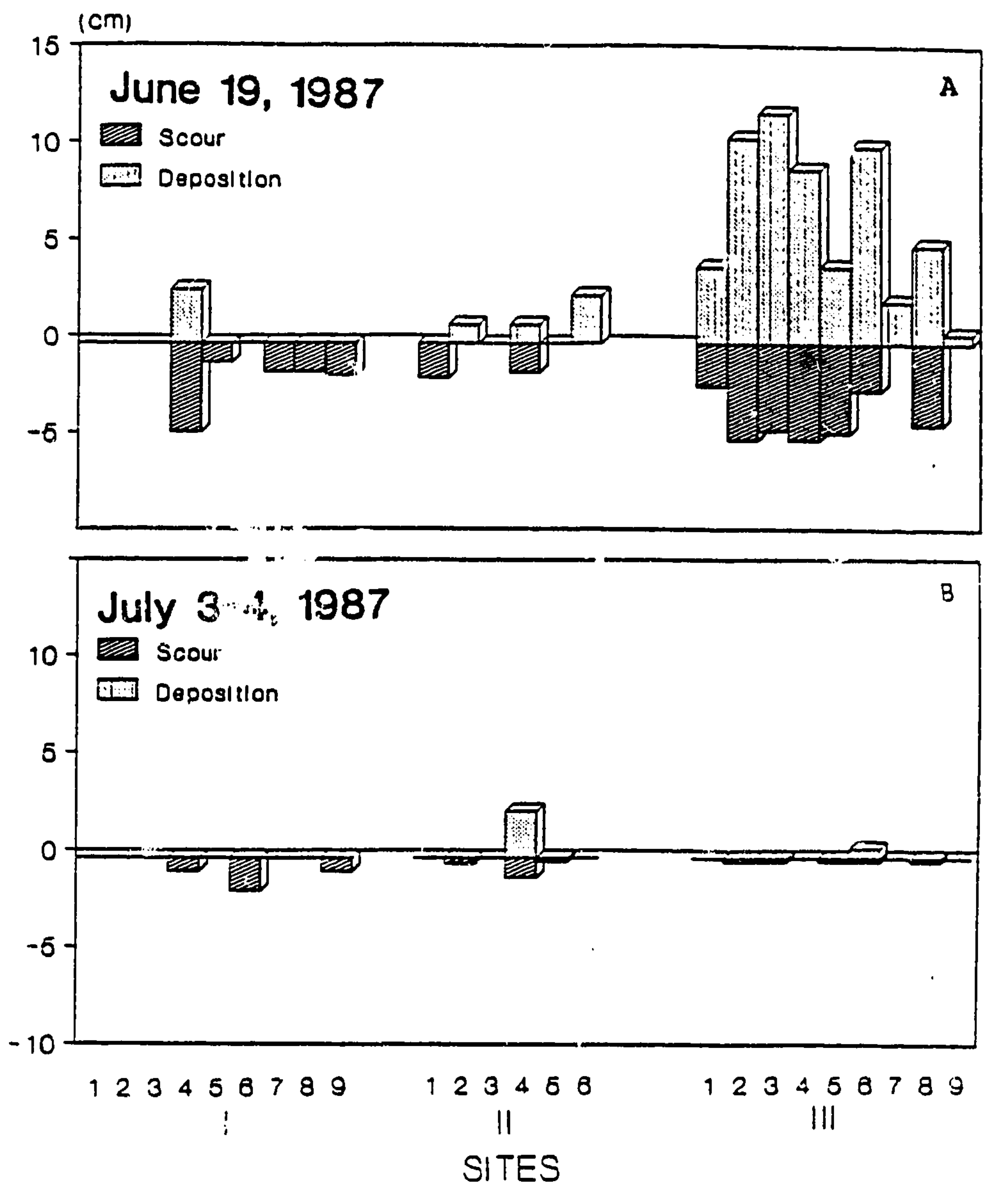


Figure 5.9 Variation in scour and deposition directly upstream from the Rimco Flume (Site I), the New Flume (Site II) and the Aquatot Flume (Site III).

A - June 19, 1987. B - July 5, 1987.

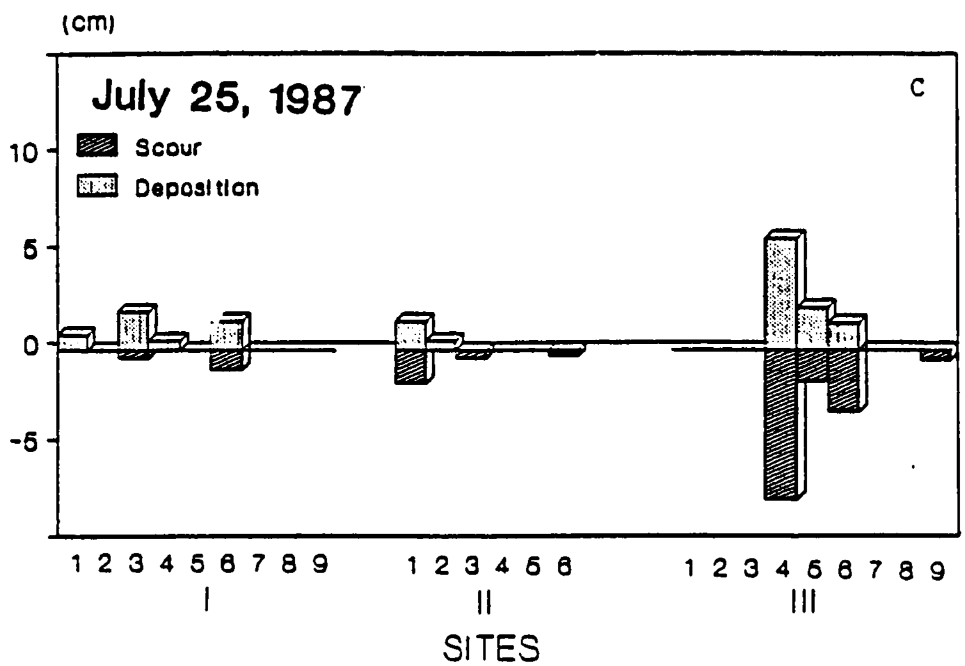


Figure 5.9 Variation in scour and deposition directly upstream from the Rimco Flume (Site I), the New Flume (Site II) and the Aquatot Flume (Site III).

C - July 18-19, 1987.

On July 3-4, 1987, erosion and deposition was negligible for all sites. The storm had been too small to have a measurable impact on the channel bed.

On July 18-19, 1987, changes in the bed at site I and II were negligible again. At site III however, scour cords in the middle of the channel experienced scour varying between 1.5 and 8 cm, and deposition between 1.5 and 6 cm. Erosion dominated over deposition during this event at site III.

5.6 Analysis of scour and deposition immediately upstream from the flumes

Sites I and II, immediately upstream from the Rimco Flume and the New Flume respectively, appear to be very stable with negligible erosion and deposition. Site III, in contrast, experiences both erosion and deposition, with deposition dominating during the largest flood, and erosion during the smallest (Figure 5.10).

These results conform to the general appearance of these channel sections. Site I and II are characterized by flat, compacted channel beds with abundant gravels at the surface. Channel gradients (0.06 and 0.07 immediately upstream from the New Flume and the Rimco Flume respectively) and therefore transport capacities at these reaches are relatively high. All sediment reaching these sections is immediately transported downstream. The compacted bed and the presence of gravel at these locations prevent further erosion during all but the very largest floods.

Site III just upstream from the Aquatot Flume has the appearance of an aggrading channel. It is characterized by a thick, alluvial deposit consisting of sand alternated with strings of gravel. The scour cords confirm the aggradation of this section (Figure 5.11).

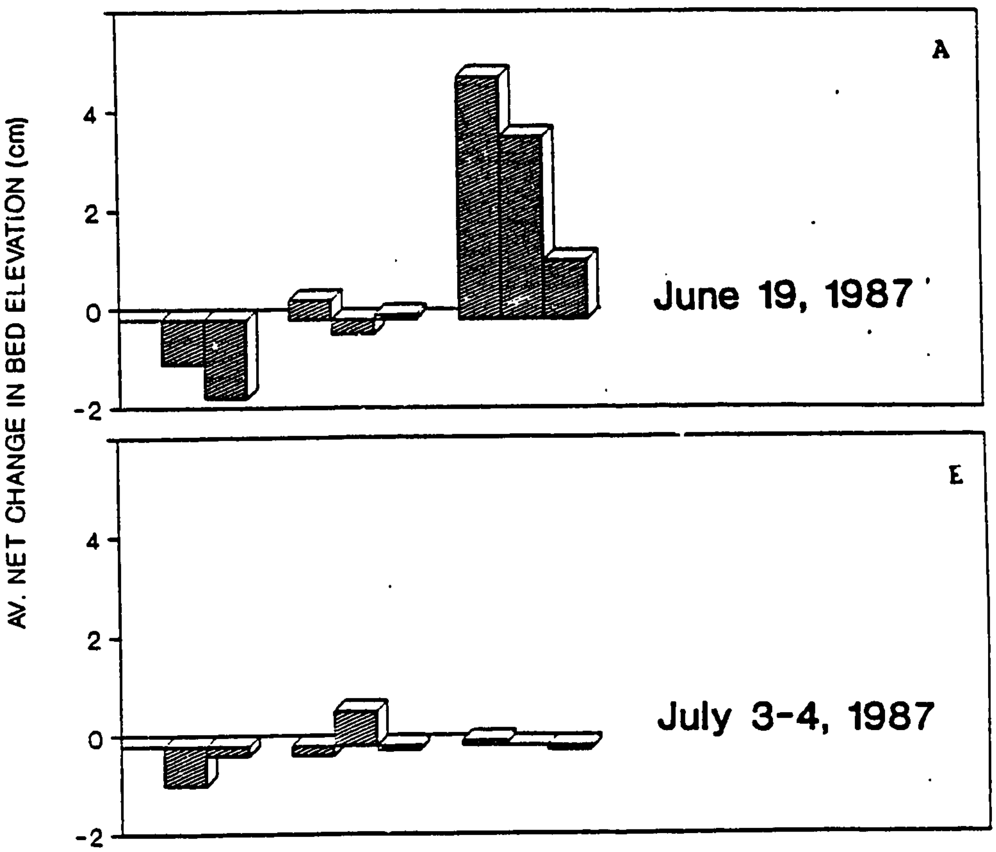


Figure 5.10 Average change in bed elevation immediately upstream from the Rimco Flume (Site I), the New Flume (Site II) and the Aquatot Flume (Site III).

A - June 19, 1987.
B - July 5, 1987.

L = Left (scour cords no. 1,2 and 3)
M = Middle (scour cords no. 4,5 and 6)
R = Right (scour cords no. 7,8 and 9)
(see Figure 5.3 for schema of scour cord distribution)

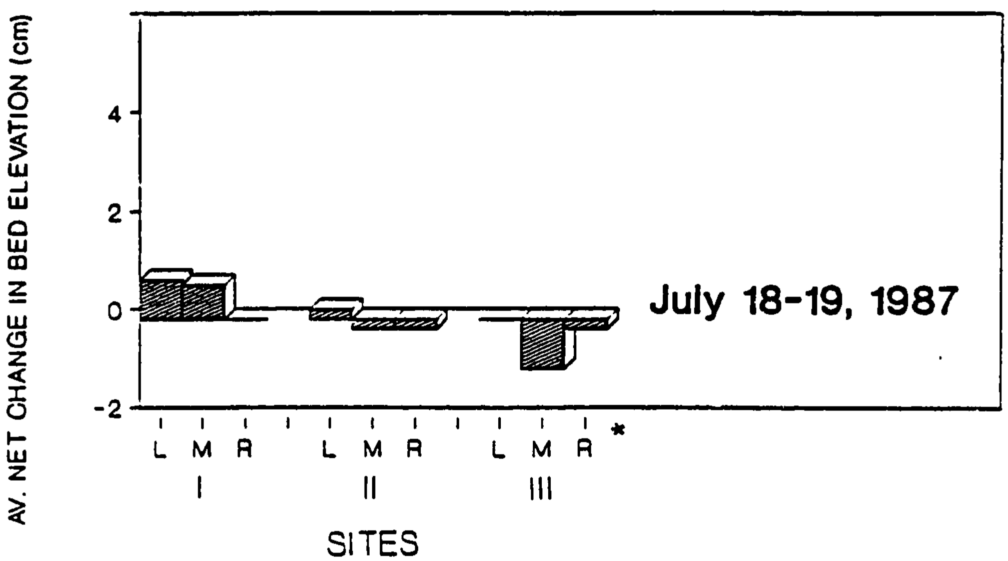


Figure 5.10 Average change in bed elevation immediately upstream from the Rimco Flume (Site I), the New Flume (Site II) and the Aquatot Flume (Site III).

A - June 19, 1987.
B - July 5, 1987.
C - July 18-19, 1987.

L = Left (scour cords no. 1,2 and 3)
M = Middle (scour cords no. 4,5 and 6)
R = Right (scour cords no. 7,8 and 9)
(see Figure 5.3 for schema of scour cord distribution)

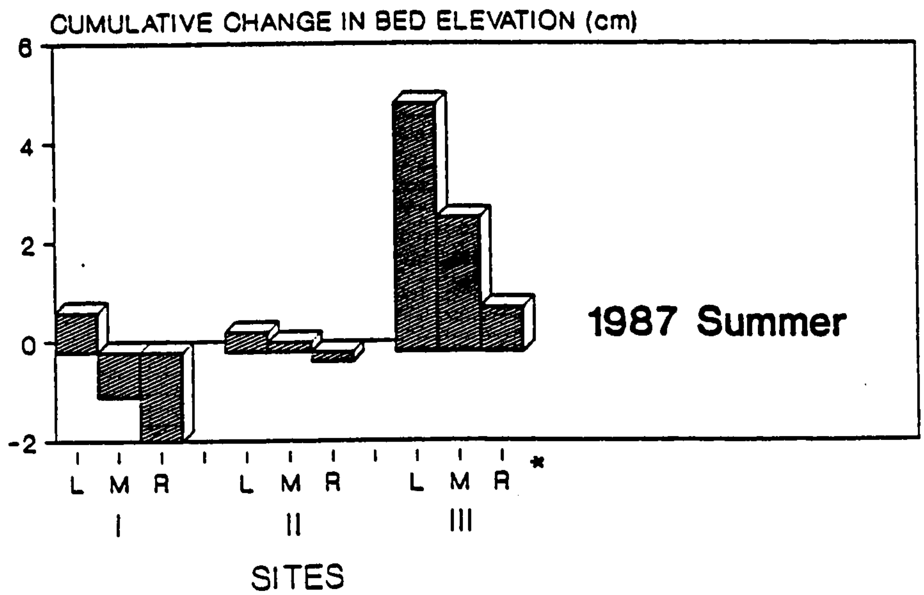


Figure 5.11 Cumulative change in bed elevation immediately upstream from the Rimco Flume (Site I), the New Flume (Site II), and the Aquatot Flume (Site III) over the 1987 summer season..

*
L = Left (scour cords no. 1,2 and 3)
M = Middle (scour cords no. 4,5 and 6)
R = Right (scour cords no. 7,8 and 9)
(see Figure 5.3 for schema of scour cord distribution)

5.7 Discussion

The relationship between storm size and channel erosion/deposition differs for the channels in the New Basin, and the larger channel downstream. The smaller channel dominantly experienced net erosion during the large June 19 storm, and net deposition during the smaller July 18-19 storm. The opposite trend occurred in the larger channel. This suggests that storm size has influence on the location of sediment deposition in the fluvial system. If the size of the storms indeed has an important influence on the location of deposition, the recent aggradation at the Aquatot Flume might be related to changes in rainfall. Annual precipitation varies greatly in the prairies; cycles of alternating wet and dry years are experienced over the years. The change in deposition might be related to such a precipitation cycle, i.e. a change in dominance of a certain size storm, rather than to the exceedance of a threshold in the force-resistance balance between hydraulic forces and channel morphology such as described by Graf (1982b). In addition to size of the storm, Bryan et al. (1988) conclude that location and orientation of the storm also have an important influence on erosion, sediment transport and location of deposition.

When the amount of scour observed in the main channel upstream from the New Flume is compared with data published by Brown (1983), who observed 0.2 m - 0.5 m scour in a similar size drainage basin, in Borrego Springs, California, the scour in this basin seems awfully small. Peak discharges in the Borrego Springs basin were about 10 times larger than in this basin though, explaining at least part of the difference. More important though, is that scour in the study basin is limited by the small thickness of alluvium deposit in the channels.

CHAPTER SIX CONCLUSIONS

This study demonstrates that it is possible to distinguish between bedload and suspended transport in the highly turbulent, sediment-laden flows of a ephemeral sand-bed channels in the badlands of Dinosaur Provincial Park, Alberta. Bedload measurements with Helley-Smith bedload samplers demonstrate that the transport pattern of a coarse fraction displays waves independent of changes in discharge. These waves are typical for bedload transport. The fine fractions vary with changes in discharge and suspended sediment concentration. It is proposed that these differences be used to identify the coarse fraction as bedload, and the fine fraction as suspended load.

Particles larger than 0.5 mm were transported as bedload during a 1987 storm that had a peak discharge of 260 l/s. At discharges in the range of 200 l/s, particles larger than 0.25 mm were transported as bedload, indicating that high discharges will cause more, and larger particles to be carried in suspension.

Bedload waves occur in general with intervals of about 25 minutes. Similar wave intervals have been reported for a desert stream in the Negev desert (Lekach and Schick, 1983) as well as for some perennial streams. It is believed that the waves are caused by the passing of a type of flat bed pulses of concentrated coarse particles. The occurrence of bedload waves in this channel appears inherent to the transport process, rather than as a result of fluctuations in sediment supply. Only a few runoff events each year are large enough to transport measurable bedload (five in 1982, four in 1983, two in 1984, and eight in 1987). The Helley-Smith samples record that the minimum amount of discharge necessary to initiate bedload transport varies between 42 l/s

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