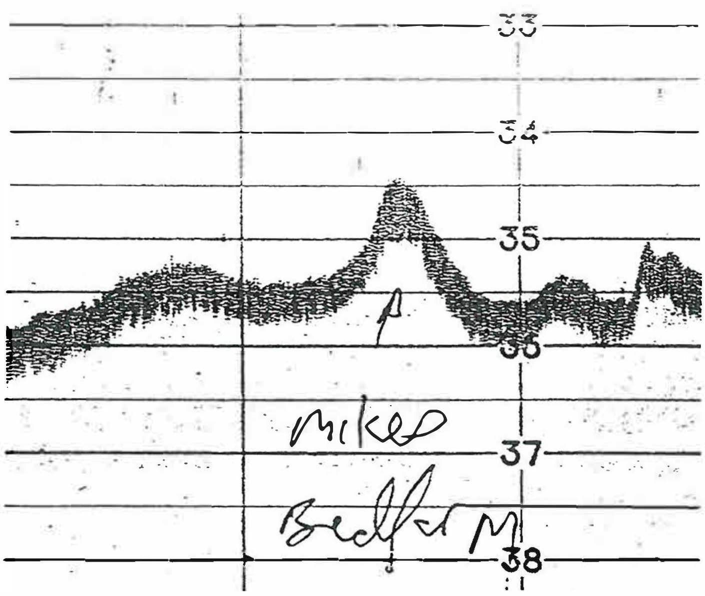
Frontispiece

Pro's and Con's of Fluvial Research,

Developing New Research Techniques



and Discovering New Features, The Imfamous "Mike Bedform" ?

SEDIMENT TRANSPORT , RIVER MORPHOLOGY AND BOTTOM SEDIMENTS OF THE LOWER WAIKATO RIVER

A thesis submitted in partial
fulfilment of the requirements for the
Degree of
Master of Science in Earth Sciences
at the
University of Waikato

by

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ABSTRACT

Sand extraction from the bed of the lower Waikato River has occurred over the past three decades, primarily to meet the demands of the Auckland construction industry. The extraction has affected bed levels over large areas of the river.

From analysis of the Waikato Catchment Board's periodic river channel cross sectional surveys degradation of river bed levels is seen to be occurring in the Puni to Huntly reach as a result sand extraction and river training, and in the Karapiro to Hamilton reach as a result of construction of the Karapiro dam. Noticeable degradation has occurred since 1964, and the rate has increased between the most recent bed level surveys, 1981 to 1987. The river level has lowered to an extent where further lowering will hinder the operation of water intake structures at the Huntly Power Station, and promote drainage of the Whangamarino wetlands.

From the interpretation of echo sounding traces, aerial photographs and field observations it is seen that sand bar, dune and ripple bedforms exist in the lower Waikato River. Two distinct dune populations exist, a short steep group with a ripple index (λ/h) of about 24 and a long flat group with a ripple index of about 40. Sand bar bedforms, which have previously been loosely referred to as 'dunes', dominate the Huntly to Mercer reach and are related to a sinuous thalweg pattern. The bars also exist in two forms, with straight or strongly curved crests. A relationship between flow discharge and the rate of bar migration exists. However, at high flows (~> 600 m^3/s) the bars become rounded and the crests undefineable. The river bed is devoid of detectable bedform ($h < 0.1$ m) immediately downstream of sand extraction sites.

Using the relationship between bedload transport and discharge determined from bar migration in the present study, and a similar relationship developed previously (Finley, 1974), an estimate of medium term (for the period 1975 - 1989) bedload transport is 180 000 m3/yr. Several bedload transport functions were applied to the lower Waikato River. Colby's Relations (1964) was found to be the most applicable mathematical approach as it provided estimates of bedload transport comparable to those estimated from bar migration. The Karapiro dam has blocked the major supply of bedload, so the bedload transport rate can be expected to drop in future.

The bottom sediments of the lower Waikato River are predominantly coarse poorly sorted pumiceous sands. There is no significant difference in textural statistics between the Mercer and Puni areas. The Puni area has a shallow pre-fluvial basal unit, thereby limiting the useful resource to 7- 9 m^3/ m^2 of river bed. No pre-fluvial unit was found in the Mercer area. A sedimentation rate of 2.8 mm/yr since the Taupo eruption was inferred from stratigraphic data.

From the results and interpretations in this study, continued sand extraction at the present rate at Mercer will promote further bed level lowering, and operations would be better concentrated in the tidally influenced areas around Puni. It is recommended that future cross sectional surveys should be conducted more regularly (2-3 yrs) and each survey should be completed over a shorter period (4-6 weeks), and regular future assessment of bedload transport should be made. A need exists for further research into the effects of sand extraction and management of the lower Waikato River.

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TABLE OF CONTENTS

CHAPTER SIX - CONCLUSIONS AND RECOMMENDATIONS

Note : All data presented in the thesis is available on disk from the Earth Science Department.

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE :

INTRODUCTION

CHAPTER 1
INTRODUCTION

1.0 NATURE OF THE PROBLEM

The bed of the lower Waikato River represents a large valuable resource to the Auckland construction industry. The management of this resource requires a careful balance between environmental needs and industrial demands. The purpose of this study is to provide an enhanced understanding of the bedload sediment transport, bed morphology and subsurface characteristics of the river. The active bed material and subsurface deposits of the lower Waikato River are composed of poorly sorted clean sands of volcanic origin. They exhibit a wide size and density range making it useful for a diverse number of tasks in the construction industry, from concrete blocks to gib board.

The value of this resource has been recognised for many decades, but large scale sand extraction has taken place only since the late 1950's. Sand extraction has occurred at several locations along the lower Waikato River, with the rate of extraction increasing from the early 1960's to a peak in the mid 1970's and then dropping and leveling somewhat in recent years in response to market forces. A summary of the extraction volumes shows that nearly 13×10^6 m^3 has been extracted from the lower Waikato River in the last 35 years (Appendix 1). The removal of such large volumes of sand from the river is likely to have a significant impact on the fluvial regime and cause problems in related areas.

A notable lowering of the mean bed level has occurred in the vicinity of active extraction sites, and for some distance upstream. A comparable lowering of the water surface profile has occurred in areas outside the tidal region (Mercer, Meremere area). In the past this lowering has to some degree been beneficial, producing a lower water table and hence improving drainage in nearby farmland. The lower profile has also facilitated flood protection, but with further lowering some problems may begin to occur. Increased bank erosion in the Mercer area, lower water levels in the Whangamarino swamp (a large undeveloped wetland and conservation area), and lowering of the bed at water intakes for the Huntly power station are the major potential problems at present. With the recognition of these problems, the rates and location of sand extraction on the river are being questioned. There is at present a lack of detailed information on sediment transport in the lower Waikato River (Dahm, 1987), and a study of the fluvial regime and geomorphic change in the Lower Waikato is long overdue.

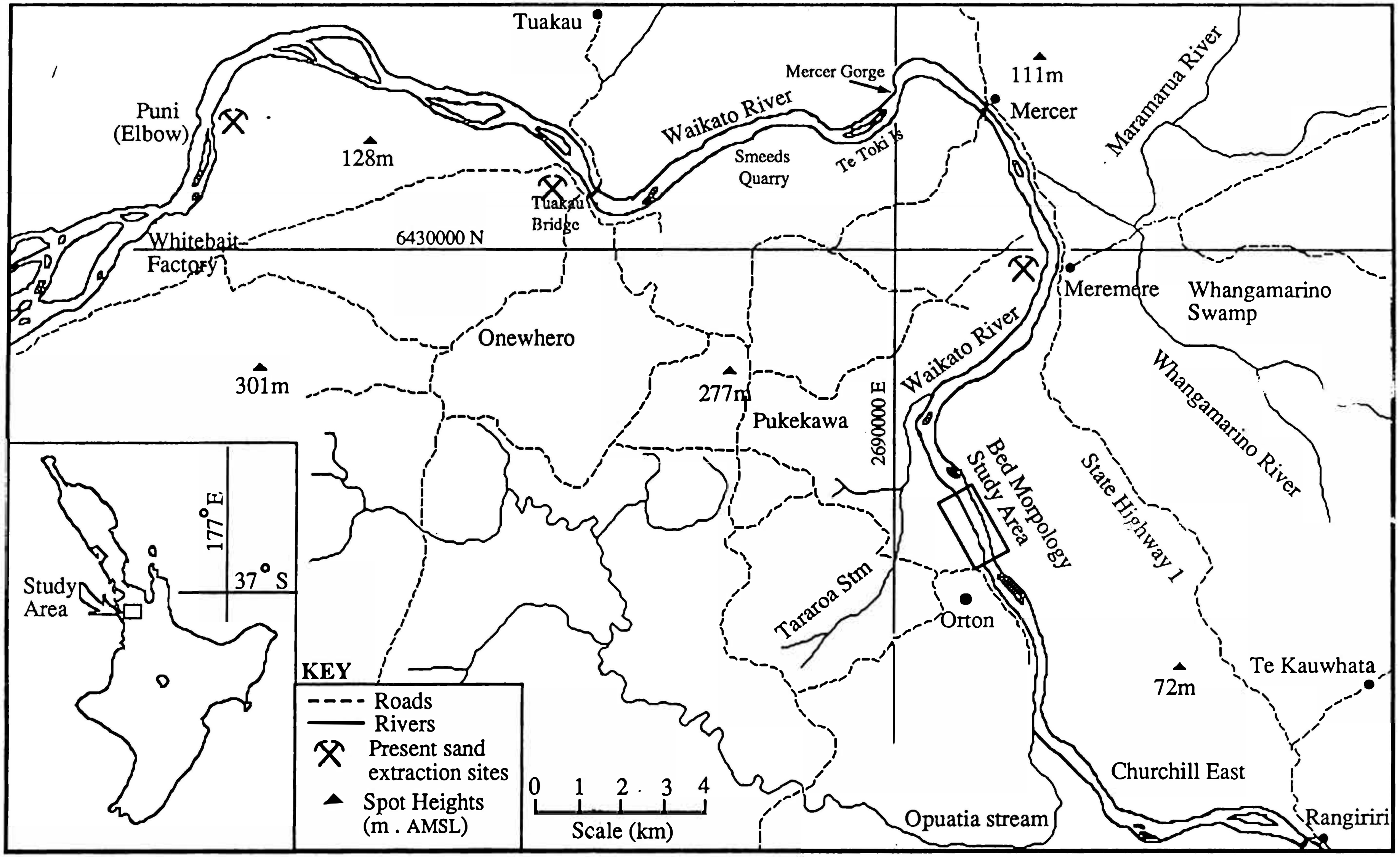

Figure 1.1 : Location map of main study area, showing important geographical features.

1.1 STUDY AREA

The lower Waikato River is generally defined as the portion downstream of the Karapiro dam. Although this reach will be considered in the broader context of the study, the majority of field work and analysis has been performed in the reach from Rangiriri downstream to just below the Elbow (Figure 1.1). This reach covers all the current extraction locations on the river and a sufficient stretch upstream in which the sediment transport regime can be studied. Smaller reaches are selected within this area for a bed morphology study (Orton) and subsurface investigation (Puni and Mercer) (see Figure 1.1).

1.2 OBJECTIVES OF STUDY

Recognition of the problems outlined above indicates that improving the general understanding of the fluvial geomorphology of the lower Waikato River is a major objective. In this study the following objectives are addressed :

(1) An estimation of the long term bedload transport rate is one of the most pertinent objectives as this defines the ability of the river to sustain continued sand extraction;
(2) A detailed investigation of changes in bed profile through time to assess the impact of extraction and other human interference;
(3) A study of bed morphology and its change with time to give a better understanding of the fluvial system;
(4) A summary of the considerable amount of data relevant to sand extraction on the river held by the Waikato Catchment Board (W.C.B), previously the Waikato Valley Authority; and
(5) Draw deductions about the likely future change to the river.

From these, specific questions such as the rates of replenishment, how long extraction can be sustained, effects of extraction and the future of the resource can be answered.

1.3 APPROACH TO THE STUDY

This study involves the integration of information from two main sources, firstly present field investigations and secondly information held by the W.C.B. The various aspects and interrelationships of the two areas are shown in Figure 1.2. It shows the aspects of field work undertaken, methods of analysis used and the resulting data bases on which interpretation was made to synthesise results for the objectives outlined in Section 1.2. In general, it is hoped to relate current field work with similar information from the W.C.B to produce a long term appraisal of the river system.

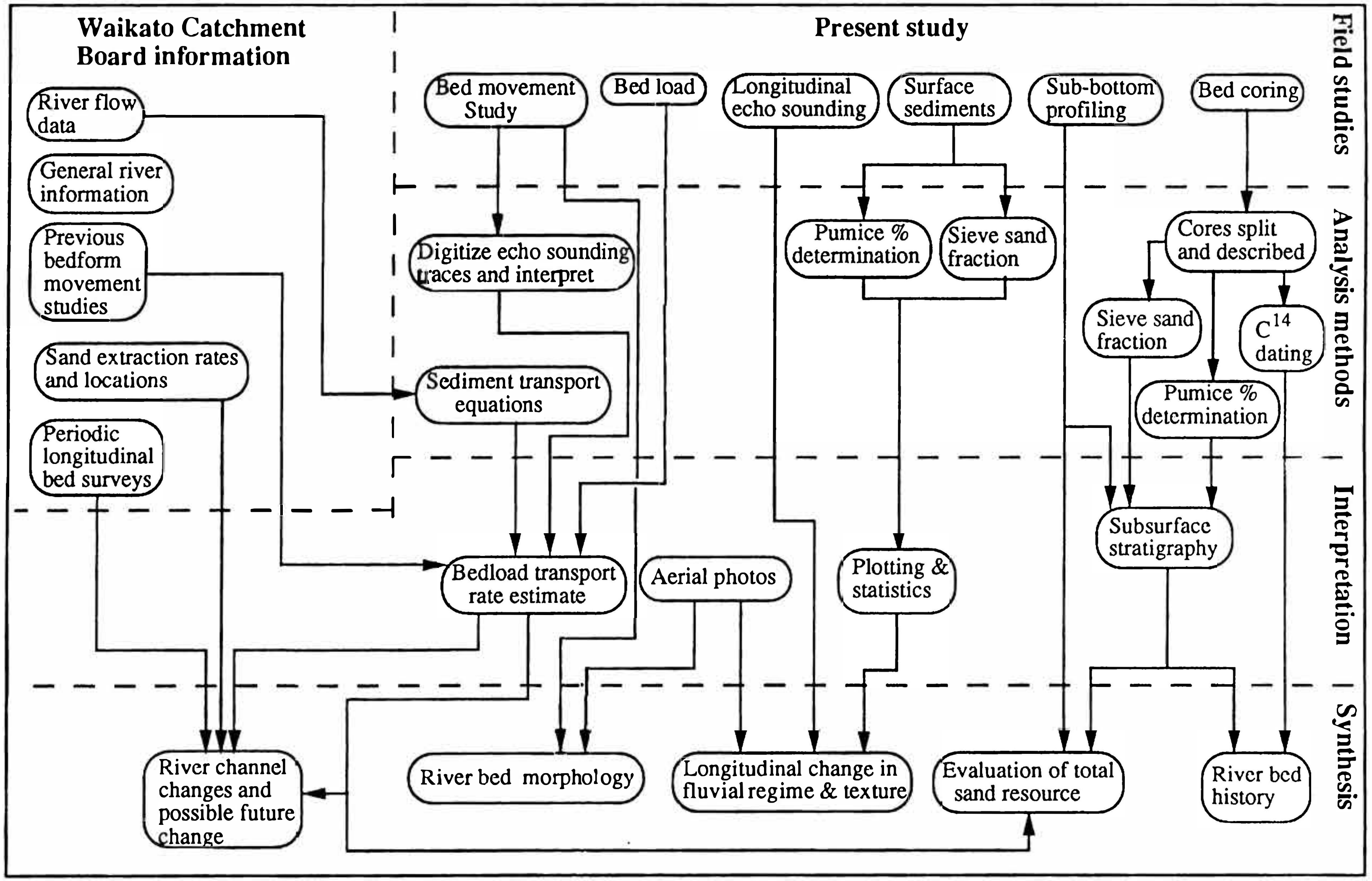

Figure 1.2 : Approach to study, showing interrelationships between present field studies and W.C.B information, and methods of achieving objectives.

An analysis and discussion of W.C.B data and river management are contained in Chapter 2. This includes a detailed analysis of the W.C.B's periodic survey data. River bed morphology and textural characteristics are discussed in Chapter 3, including a comprehensive investigation of changing bed morphology in a study area over a one year period. Bedload transport estimates are covered in Chapter 4, where three main methods of estimating sediment transport are used. These are; bedload trapping, rates of bedform movement and bedload formulae. Previous sediment transport studies on the river are also summarised in Chapter 4. Specific reaches were selected for detailed studies, including subsurface stratigraphy, where cores were taken in the Puni and Mercer licence extraction areas. The subsurface investigations performed in the two licenced extraction areas are presented in Chapter 5. This includes analysis of cores (grain size & pumice %), correlation with sub-bottom profile data and ^{14}C dates.

1.4 SCOPE OF THE STUDY

This study aims to improve the understanding of the lower Waikato River and aid in management decisions for the utilisation of a finite resource. As studies, such as the periodic surveys performed by the W.C.B continue, more data will become available to allow a better assessment of the river's changing form. As Dahm (1987) states; "Available survey data above the Horotiu Bridge is inadequate to draw any firm conclusions about the rate of downstream translation of any trend for degradation". Since the release of this report another W.C.B survey has been completed, providing further information for assessing the rate of downstream degradation. However a need exists for continued studies of the lower Waikato River if its resource potential is to be utilised correctly in the future.

1.5 RECENT HISTORY OF THE LOWER WAIKATO RIVER

The Waikato River's usefulness as a navigable waterway was first recognised by the early European settlers in the late 19th Century. River bed surveys of the lower Waikato were conducted as early as August 1862 when Captain Greaves charted channel limits, shoals and depths from Mairoa bay to the Tuakau gorge. The history of channel surveys on the river is covered comprehensively by both W.V.A (1981, Unpub) and Sledger (1987). Regular comprehensive bed surveys have been made by the Waikato Catchment Board (formerly Waikato Valley Authority) every 5-6 years since 1958. Hydroelectric dams now dominate the Waikato River from Aratiatia just downstream of Taupo to Karapiro near Cambridge. During the building of the Arapuni dam in 1928 emergency use of a partly natural spillway channel deposited about 5.4 x 10^6 m^3 of debris into the channel (Finley, 1974). This caused a large amount of aggradation of the downstream profile and some reaches are only just returning to their pre-1928 levels.

Commercial sand extraction has occurred on the river since the late 1950's until the present. During the late 1960's, bedform surveys were carried out at four reaches of the river: Huntly, Churchill East, Meremere and the Whitebait factory at the delta entrance (Ridall, 1967). In the early 1970's a Model study of the lower Waikato river was undertaken by the Hydraulics Research Station (HRS) at Wallingford, England on behalf of the Waikato Valley Authority. The study was designed to investigate ways of improving sections of the lower Waikato River to minimize the effects of flooding on surrounding farmland and communications in the region (HRS, 1971a). River training works were subsequently undertaken on the recommendation of this report. They began in 1973 just upstream of Meremere and were completed in 1985. The main aim of these works was to improve the channel efficiency by the placement of groynes which would narrow and deepen the channel. Straightening of the channel and removal of islands was also done to hasten the flow during times of flood.

1.6 PRESENT RIVER STATUS

Presently the Waikato exists largely as a regulated river due to the control imposed on it by the Lake Taupo control gates and hydroelectric dams. However, downstream of the Waipa confluence high flows are still experienced because of the uncontrolled nature of the Waipa catchment.

The major sediment supply for the lower Waikato River has been cut off with the construction of the hydroelectric dams and this is expected to cause downstream degradation of the river bed (Williams and Wolman, 1984; Dahm, 1987). This effect is seen to be occurring in the analysis of survey data (Chapter 2) and is likely to translate downstream in future. The Waipa River is the main tributary to the lower Waikato River and provides the only other potential source of bedload sediment. Some assessment of its contribution is made in Chapter 3. Other smaller tributaries contribute to suspended sediment in flood but provide little, if any, bedload sediment (Finley, 1974).

Commercial sand extraction is currently taking place at Meremere, Tuakau and Puni. Some minimal maintenance dredging also occurs periodically in the water intake forebay of the Huntly power station. The present annual extraction rate is 400 000 - 500 000 m^3/yr, with approximately half of this volume taken from the Meremere reach and the remainder at the Tuakau and Puni operations. As previously mentioned the W.C.B carries out bed surveys of the lower Waikato River every 5-6 years to monitor the effects of sand extraction and other river works. Marked degradation of the bed profile can be seen from these surveys at and upstream of the extraction sites in recent years. This aspect is examined in Chapter 2.

CHAPTER TWO :

RIVER MANAGEMENT

AND SURVEYS

CHAPTER 2

RIVER MANAGEMENT AND SURVEYS

2.0 INTRODUCTION - LOWER WAIKATO RIVER SETTING

The Waikato River has a catchment area of 14 260 km^2 and flows 425km northward through the central North Island to the Tasman sea. The lower Waikato River (Lake Karapiro to Tasman sea) can be regarded as a sub-catchment of this area (MWD, 1979), and is the area of consideration for this study (Figure 2.1). The river is largely regulated downstream of the Karapiro Dam to its main tributary, the Waipa River. The unregulated Waipa River has a catchment area of 3060 km^2 and contributes significant volumes of water to the Waikato in times of flood.

The Karapiro - Ngaruawahia reach is a deeply entrenched section with five small tributaries which drain the surrounding low lying, predominantly pastoral farmland. The surface geology in this part of the catchment consists predominantly of the Tauranga Group sediments, namely the Taupo Pumice Alluvium, Hinuera Formation and Karapiro Formation. All of these are predominantly pumiceous sands / gravel, with the latter two possessing some clay and peat lenses (Marshall and Petch, 1985). Discharge patterns in this Waikato reach are responsive to generation patterns at the Karapiro Station, with high flow during the day and low flows during the night (MWD, 1979).

The Waipa River drains similar lithologies but also has significant input from the western ranges of the Hamilton basin, whose geology is a combination of Greywacke basement, Tertiary sedimentary rocks (Waitemata & Te Kuiti Formations) and Alexandra Volcanics. The Waipa contributes large quantities of suspended sediment to the Waikato River at its confluence at Ngaruawahia.

From Ngaruawahia to the mouth, the river cuts through the Hakarimata - Taupiri Range between Taupiri and Huntly (Figure 2.1), and then flows northward through alternating low basins of peat swamps and shallow lakes and rolling hills. The gradient is low with the river falling just over 30 m in the last 88 km.A complex interplay existed with flow to and from the river and adjacent ponding basins (Ridall, 1967), but this has been modified with the construction of the Lower Waikato - Waipa Flood Control Scheme. The geology in this area is predominantly peat and alluvial deposits in the low lying areas, and Te Kuiti Group Tertiary sediment in the western ranges with an area of basaltic volcanics around Tuakau.

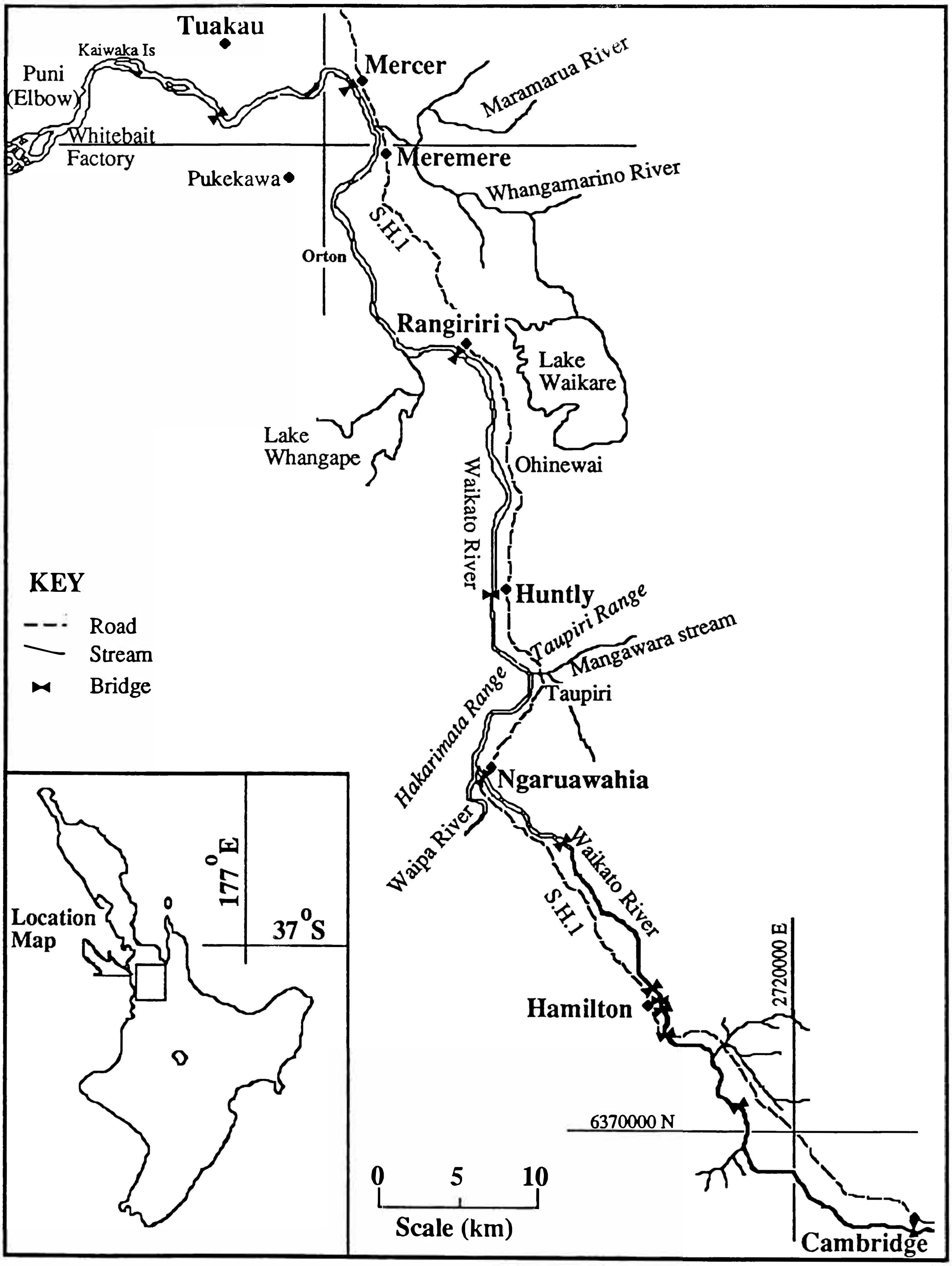

Figure 2.1 : Lower Waikato River location map, showing tributaries and townships.

2.1 RIVER MANAGEMENT AND SAND EXTRACTION

River management of the lower Waikato River has been the responsibility of the Waikato Catchment Board (W.C.B, previously Waikato Valley Authority) since its formation in 1956. Prior to this, the Public Works Department was responsible for data collection and management of the river. Areas of Catchment Board responsibility that are of interest to this study include; collection and analysis of river flow and cross section survey data, flood protection work, and monitoring and licencing of sand extraction operations on the river.

The data from regular river cross section surveys are analysed and interpreted in Section 2.2. Specific studies by the W.C.B on sediment transport are outlined in Chapter 4. Large scale flood protection works involving stopbanking and river training have been undertaken by the Catchment Board in the past three decades. Commercial sand extraction has occurred on the river since the early 1950's, and has assisted in achieving the flood protection objectives of the Catchment Board (Mullholand, 1983). It has also provided significant income for the Catchment Board in the form of royalties which has helped service the loans for flood control works.

2.1.1 Flood Protection and River Training

Lower Waikato - Waipa Flood Control Scheme

In the wake of the devastating floods of 1953, 1956 and 1958 a clear need existed for some form of flood control scheme to reduce the agricultural losses caused by such widespread flooding. The newly formed Waikato Valley Authority (W.V.A) initiated the "Lower Waikato - Waipa Flood Control Scheme". A full review of this scheme and the flood hydrology characteristics of the lower Waikato and Waipa catchments is given by Mulholland (1983). Certain aspects of the flood control scheme are of relevance to this study as they have changed the fluvial regime in parts of the river.

This HRS study investigated the effects of channel modifications on river levels, hence determining the effectiveness of the proposed scheme. This study concluded that the W.V.A design stopbank proposal provided adequate protection under, the then, existing conditions for a 63800 cusecs (cubic feet per second, 1800 cumecs) flood at Rangiriri.

Construction of the Tongariro Power Development altered the hydrology of the Waikato catchment with the implementation of the Western diversion. The diversion directs water from the Wanganui River catchment into the Waikato River and was expected to increase outflows from Lake Taupo by 26%. From flow distribution curves at Karapiro, the mean discharge

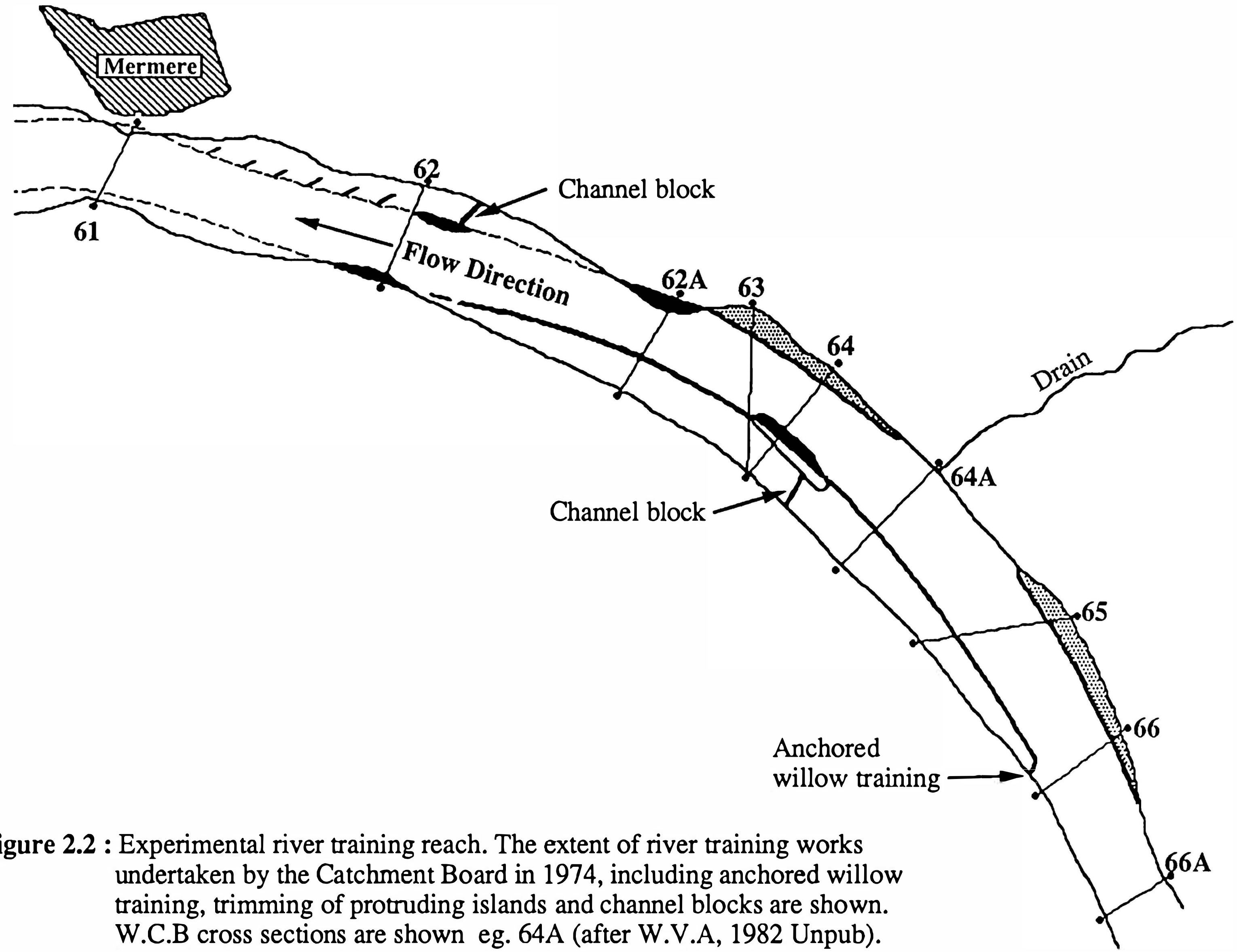

Figure 2.2 : Experimental river training reach. The extent of river training works undertaken by the Catchment Board in 1974, including anchored willow training, trimming of protruding islands and channel blocks are shown. W.C.B cross sections are shown eg. 64A (after W.V.A, 1982 Unpub).

increased by 19% or 42 cumecs (Mulholland, 1983). Considerable investigations were undertaken to determine the work required to offset the effects of the Western diversion on the Lower Waikato - Waipa Flood Control Scheme (HRS, 1971b). The HRS report proposed a number of dredging schemes to induce lowering of the bed profile. A 'major' scheme involved 7.7 x 10^6 m^3 of excavation to produce an average 30 cm lowering throughout the reach, while a 'minor' scheme proposed a 12 cm average lowering with 4.4 x 10^6 m^3 of extraction. However neither of these schemes was instituted by the W.V.A as it was felt that the lowering required could be achieved by limited river training and allowing commercial sand extractors to operate in selected areas.

River Training

An experimental river training program was undertaken by the Catchment Board over a 4km reach immediately upstream of Meremere in 1974. This involved narrowing the channel from approximately 400m to 220m (Figure 2.2), producing an initial reduction in average cross section area of 50% (Mulholland, 1983). Details of construction and maintenance are outlined in W.V.A (1982, Unpub). The extent these work can be seen in Figure 3.17 and at the top of the aerial mosaics, Figures 3.20 - 3.22. These figures show the extent of infilling behind the training works over the 1978 - 1983 period.

The object of the training was to produce a narrower, deeper and hence more hydraulically efficient channel with a lower bed profile. By 1981 pre-training cross sectional areas had been re-established as a result of natural scour (aided also by degradation caused by downstream sand extraction). This resulted in an average 0.56m lowering of the mean bed level over the 4 km reach upstream of Meremere from 1970 to 1981 (Mulholland, 1983). Further training works have been constructed between cross section (C.S).93 - cross section (C.S).96 and C.S.101 - C.S.106A in 1985 (R Sledger, WCB, pers. comm.) (the cross section locations are shown in Figure 2.4) and minor work on the left bank at C.S.61 (Figure 2.2).

2.1.2 Sand Extraction Policy and Extraction Rates

The W.C.B obtained the responsibility for controlling sand extraction on the Waikato River from the Marine Department in 1958. Initially Marine Department licences were reproduced, with a new licence form more applicable to river operations drawn up in 1959. There was however no formal policy until 1976. The policy adopted in September 1976 by the WVA gave companies until April 1979 to prepare for five year licences drawn up under the policy effective from that date. The thrust of the policy was to move operators to areas more favourable for extraction with respect to river behaviour (W.C.B, 1989 unpub). It had been hoped to move Mercer based extraction operations gradually upstream towards Rangiriri, but due to a downturn in the building industry in the mid to late 70's the incentive to move quickly

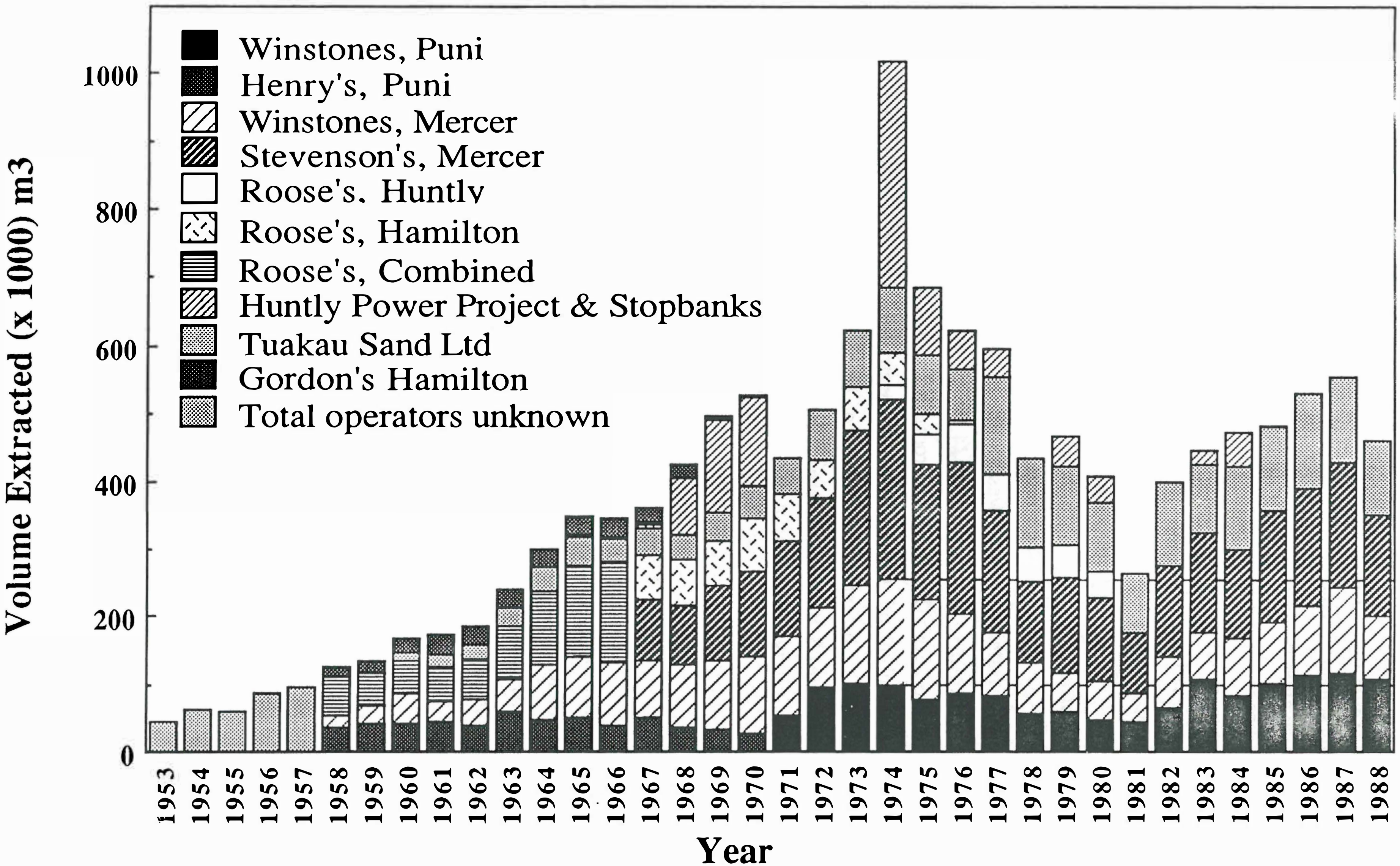

Figure 2.3 : Sand extraction volumes, operators and locations on the Lower Waikato River.
(Data Source : W.C.B files, based on out-the-gate tallies provided by companies).

upstream was reduced. As a result of this, the policy has not been adhered to as tightly as was hoped. Present policy is changing in light of the latest survey data on the river (Section 2.2), and the Catchment Board presently aims for a reduction in volumes extracted, as opposed to moving extraction sites upstream (R Sledger, WCB, pers. comm.). Future extraction is likely to be limited at Mercer to a figure just below that of bedload transport, believed to be about 170 000 m^3 (Finley, 1974), reducing yearly over the next five year licence period with the possibility of a swifter reduction if the situation deteriorates (W.C.B, 1989 Unpub). Puni operations are likely to continue as they are, with limited restriction at Tuakau.

Figure 2.3 shows the trend in sand extraction rates since 1953. Over the last decade, an average of 450 000 m^3/yr has been extracted from the river, with approximately 60% coming from the Mercer operations. Rates of extraction have been strongly controlled by market forces, and one-off projects such as the Huntly Power Project and stopbanking for the flood control scheme, which have used significant volumes of sand. Total extraction volumes recorded and operators involved are presented in Appendix 1. This indicates that a total of 13 x 10^6 m^3 has been extracted since the early 1950's

2.1.3 River Channel Surveys

Surveys of river channel cross sections have been conducted by a number of authorities since the early 1900's. The surveys provide information about changes in width, cross sectional area and mean bed levels over the river with time. They can be used to assess the natural behaviour and stability of different reaches of the lower Waikato River, and also to assess the impacts of any human manipulation of the fluvial system. The pre-1960 surveys can be summarised as follows (Sledger,1987):

1913 - 1915 : The Department of Lands and Survey undertook the first extensive survey form the river mouth to Rangiriri. Well executed and recorded and can be related to triangulated controlled surveys;

1928 - 1930 : The Public Works Department re-established most of the Lands and Survey cross sections from Kaiwaka island (upstream of the Elbow) to Rangiriri, inserting a few cross sections at Orton and extending the work upstream to Ngaruawahia. This extended work however was not related to control traverses;

1938 - 1939 : The Public Works Department re-surveyed the cross sections established in 1913 and 1928 commencing at the Tuakau bridge;

1954 : Ministry of Works re-established sections between Kaiwaka island and Huntly with fixed concrete bench marks that were tied into control traverses;

1958 : The newly formed Waikato Valley Authority re-sounded a number of selected cross sections between Kaiwaka island and Horotiu to assess the effect of the 1958 flood.

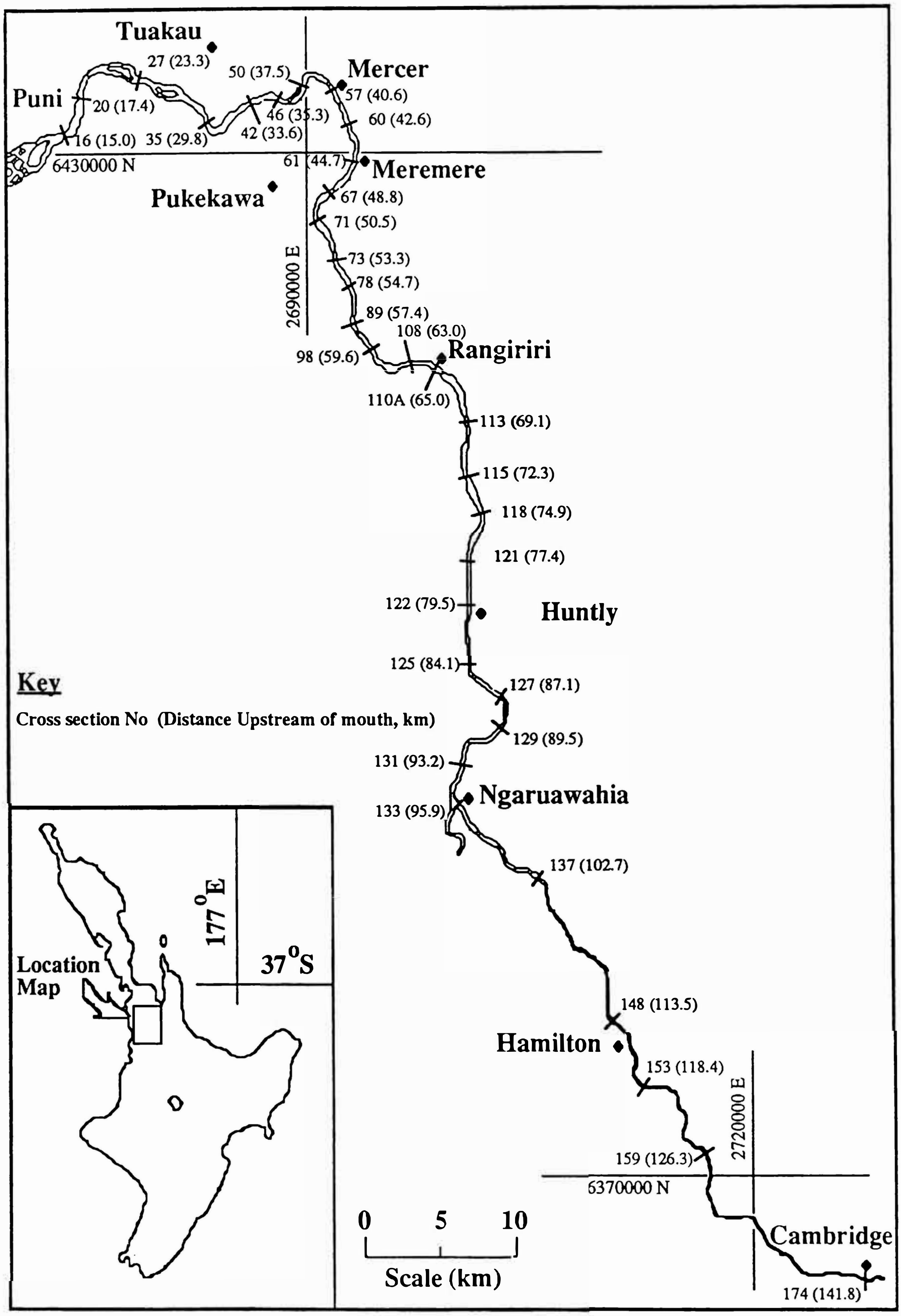

Figure 2.4 : Location and distance upstream for W.C.B cross section . Showing W.C.B number and in brackets the distance upstream of the mouth in kilometres (after W.C.B Maps).

In 1960 most of the 1913 cross sections in the delta area (below Whitebait factory) were re-instated and a large number of new sections were established in both the delta area and as far upstream as Rangiriri, in preparation for the construction of a hydraulic model of the river at the Wallingford Hydraulic Research Station in England (Sledger,1987). Since this time, the established cross sections have been surveyed at fairly regular intervals. The major sounding years that cover most of the lower Waikato river are 1964, 1970, 1975, 1981 & 1987. Figure 2.4 shows the position and distribution of the cross sections (C.S.) involved in these surveys.

2.2 DATA BASE FROM RIVER SURVEYS

A large data base of survey information has been built up throughout the years. Investigations of bed level and bed volume changes are made using this data base as it provides the only consistant long term data available . The cross sections along the river are not all surveyed over a short period of time. For example some of the cross sections in the 1964 survey where actually surveyed as early as 1962. Therefore only broad, long term trends in bed levels can be obtained from the data. However for ease of presentation and consistancy the surveys are grouped into the intervals shown. The analysis of bed survey data presented in this study concentrates on the 1964 to 1987 surveys.This approach is adopted for the following of reasons:

(1) these surveys were all electronically echo-sounded;

(2) 1964 was the first complete survey including all original cross sections and a large number of new ones;

(3) rates of sand extraction were significant from the early 1960's onwards.

Earlier survey data is however used to highlight specific points. A summary of available survey data from 1913 onwards is given in Appendix 2, showing width, cross sectional area and mean bed level of each section, at each survey.

2.2.1 Waikato Catchment Board Survey Concept & Results

The survey concept used by the W.C.B is outlined in Figure 2.5, and the survey parameters are defined as follows:

Normal Water Level (NWL) is a datum level at any given cross section. Values at cross sections are chosen so that they increase upstream. They are not necessarily related to any particular discharge or frequently occurring water level;

Cross Sectional Area below normal water level. This is a useful parameter as it takes into consideration changes in width at NWL, and is therefore a more accurate indication of bed behaviour; and

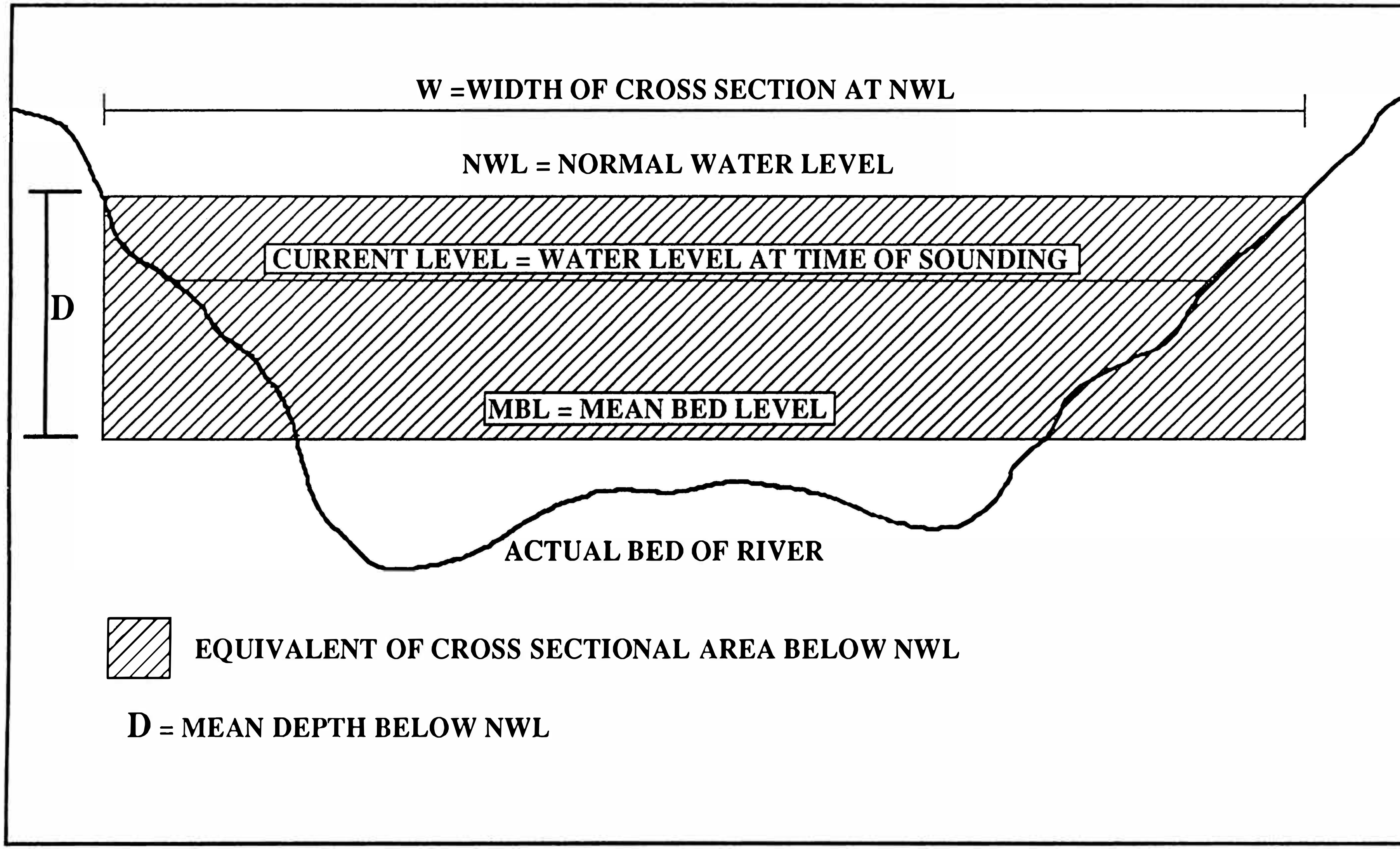

Figure 2.5 : Waikato Catchment Board survey concept of a typical cross section (after Sledger, 1987).

Mean Bed Level (MBL) is the mean reduced level (height above or below MSL) of the whole bed profile that is recorded in any particular survey of a cross section.

Trends in bed level and bed volume change above the mean sea level (MSL) datum for all of the survey data are discussed in detail by W.V.A (1981,unpub), Mulholland (1983) and Sledger (1987). The trends identified are as follows:

Whitebait Factory to Tuakau Bridge (C.S.16 - C.S.33): Bed levels appear to be stable or rising slightly since 1913, especially from 1928 -1938, but from 1962 onwards a strong degrading trend occurs, especially in sand extraction reaches at Puni and Tuakau;

Tuakau Bridge to Mercer (C.S.33 - C.S.51): A notable decrease in cross sectional area from 1928 is seen, followed by a stable period. From 1964 onwards cross sectional areas begin to show a significant increase;

Mercer Reach (C.S.51 - C.S.60) : With sand extraction occurring here since the 1940's there has been a gradual increase in cross sectional area since 1954, sharp increases from 1964. Since 1975 the rate of degradation has decreased as operators have been moved further upstream. Cross sectional areas in this reach are upward of 50% larger than in 1964. From the 1981 survey MBL's have lowered over the whole reach by an average of 1.25m since 1913, 1.50m since 1964, and 0.55m since 1972;

Meremere Reach (C.S.60 - C.S.67): Shows an aggrading trend from 1928 to 1964, with degradation occurring since. This reach has also been altered by river training which reduced the width in places from 400 to 200 m;

Meremere to Rangiriri (C.S.67 - C.S.112): A general pattern of slow aggradation up until 1964 is again followed by a trend of gradual degradation throughout the reach;

Rangiriri to Huntly (C.S.112 - C.S.123): The reach has generally been stable, but lowering of the bed levels occurred between 1970 and 1975 as a result of large scale sand removal for the Huntly Power Project;

Huntly to Hamilton (C.S.123 - C.S.151): Some aggrading in the Huntly - Waipa River reach has occurred, otherwise discharge rating curves indicate a stable situation. A lowering of the bed level at the Hamilton Traffic bridge between 1964 - 1974; and

Hamilton to Karapiro (C.S.151 - C.S.174): In 1974 a number of cross sections were established by the Ministry of Works, extending up to the Karapiro Dam. With the limited information available a stable situation is thought to have existed for some years.

Approximately 5.4 x 10^6 m^3 of pumice sand was discharged into the river in January 1928 from the erosion of the spillway diversion channel at Arapuni during the construction of the Arapuni Dam. Marked aggradation over a large stretch of the river occurred, with some areas only now returning to their pre-1928 levels. Using the concepts above and the available data, both MBL (Section 2.2.2) and cross sectional area (Section 2.2.3) changes are analysed over the period 1964 - 1987.

2.2.2 Mean Bed Level Change

Mean bed levels of surveyed cross sections are plotted against distance from a datum to produce a river bed profile. In this case Mean Bed Level (MBL) data for the period 1964 to 1987 is plotted against distance upstream of the mouth using a SAS graphics plotting procedure, PROC GPLOT.

Smoothing of River bed profiles

In this plottling procedure a cubic spline routine (I=SMxx) that minimizes a linear combination of the sum of squares of the residuals of fit, and the integral of the square of the second derivative, has been used to fit a smooth line to the profile (SAS, 1985), with a value (xx) from 01 to 99 being assigned. The higher the xx value, the smoother the curve. The effect of this value can be seen in Figure 2.6, showing straight joining of MBL data for the 1987 survey, and smoothing at xx = 70, 80 and 90. A smoothing value of 80 is used for the rest of the analysis as it does not over straighten the line as with 90, and is not excessively influenced by outliers as with 70 (top end of Figure 2.6). Interpretations at the extremities of such smoothed curves must allow for some deviation caused by the restricted number of data points available for use in the smoothing routine.

Figure 2.7 is a plot of the 1964 and 1987 survey data. This shows the bed levels (unsmoothed & smoothed) at the beginning and end of the period under consideration. From this it can be seen that the smoothing technique used provides a good indication of the broader scale bed level changes. Extreme variations do occur in the raw bed level data, but these can generally be attributed to some constriction in the river's flow path (i.e Figure 2.7, at 126km is the Narrows, 103km Horotiu Bridge, 75km C.S.118, Frost Rd Ohinewai).

River Bed Profiles, 1964 - 1987

A smoothed plot for the 1964 - 1987 data is given in Figure 2.8. From this plot several important changes and trends in river bed profile can be noted. Firstly, as already pointed out in section 2.2.1, there has been a steady decline in bed levels around the areas of extraction since 1964, with a net drop of 0.8 - 1m on the smoothed profile along the Puni to Mercer reach. The rate of decline appears to be lowest between the 1975 and 1981 surveys evidently in response to a general reduction in extraction rates during this period (Figure 2.3). Bed level change appears to be greatest between Mercer and Tuakau. This may be due to the combined effects of upstream scour from the Tuakau sand operation and downstream degradation from the Mercer operation as a result of sediment starvation. A similar trend is not seen between Tuakau and Puni. This is possibly due to the increased tidal effect and/or lower bed level gradients.

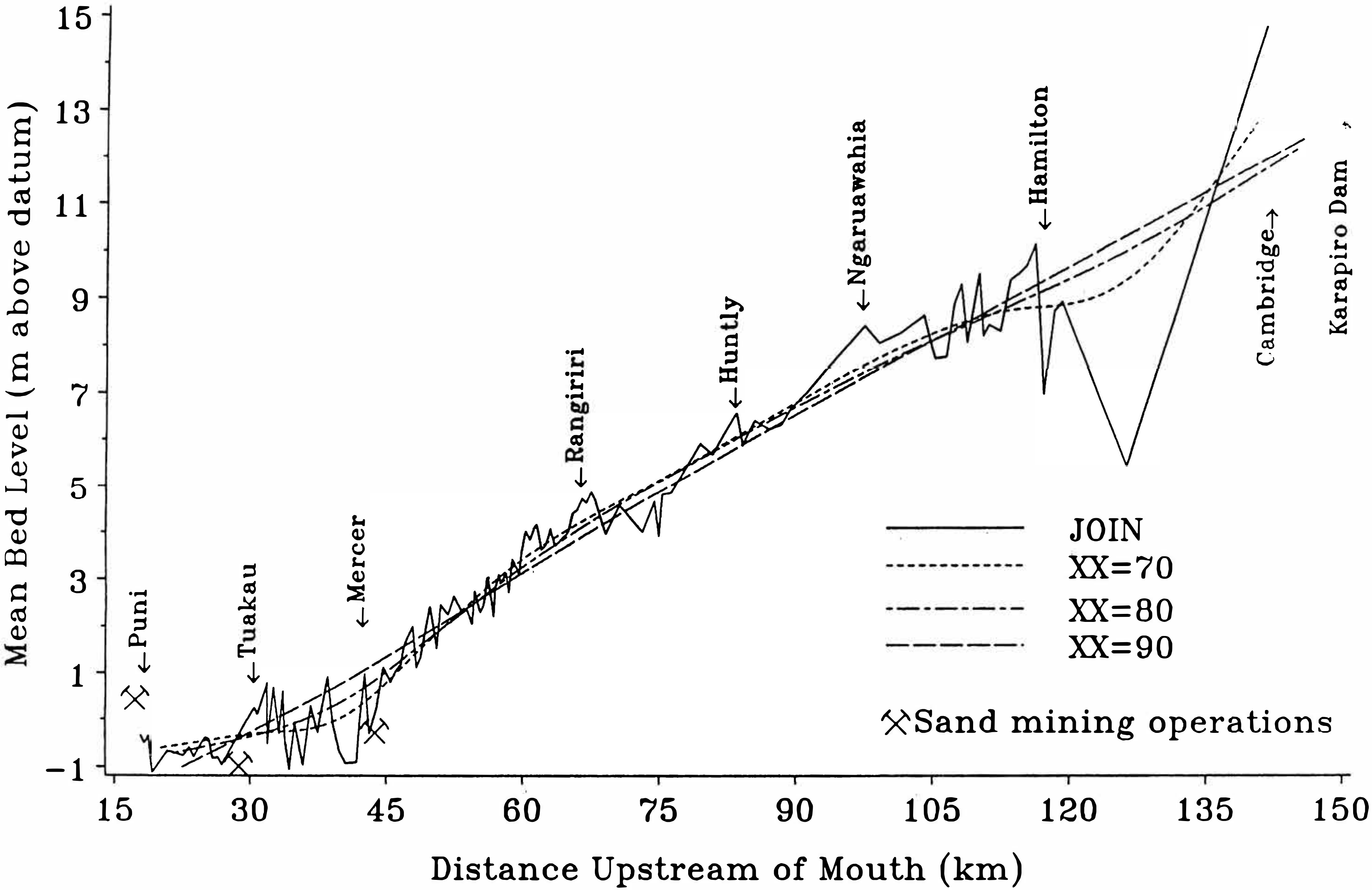

Figure 2.6 : Plot showing the effect of XX value on spline routine (I=SMXX) using the GPLOT SAS routine.

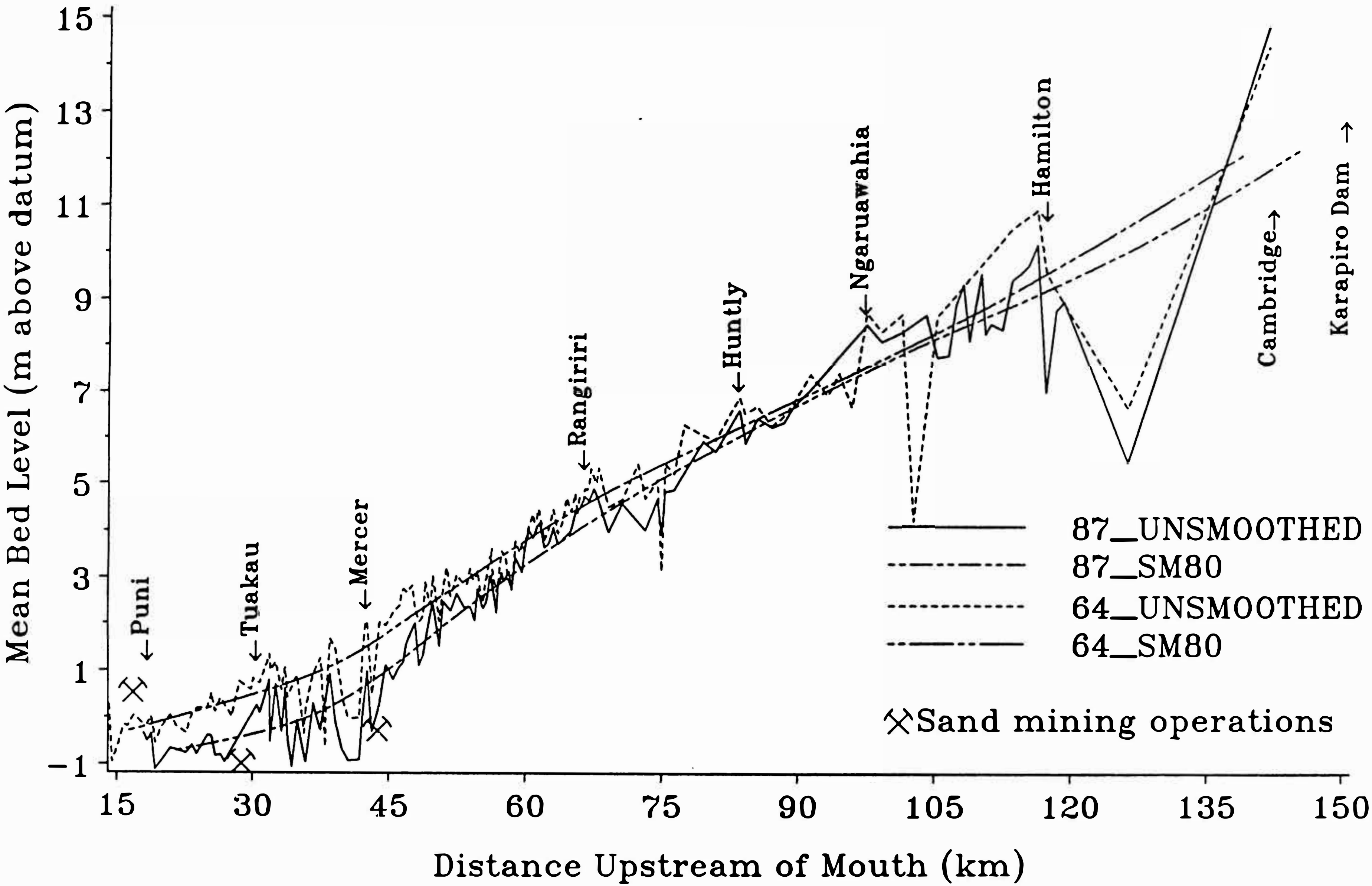

Figure 2.7 :– Waikato River Mean Bed Levels for 1964 & 1987, plotted using Join & Smooth options with GPLOT

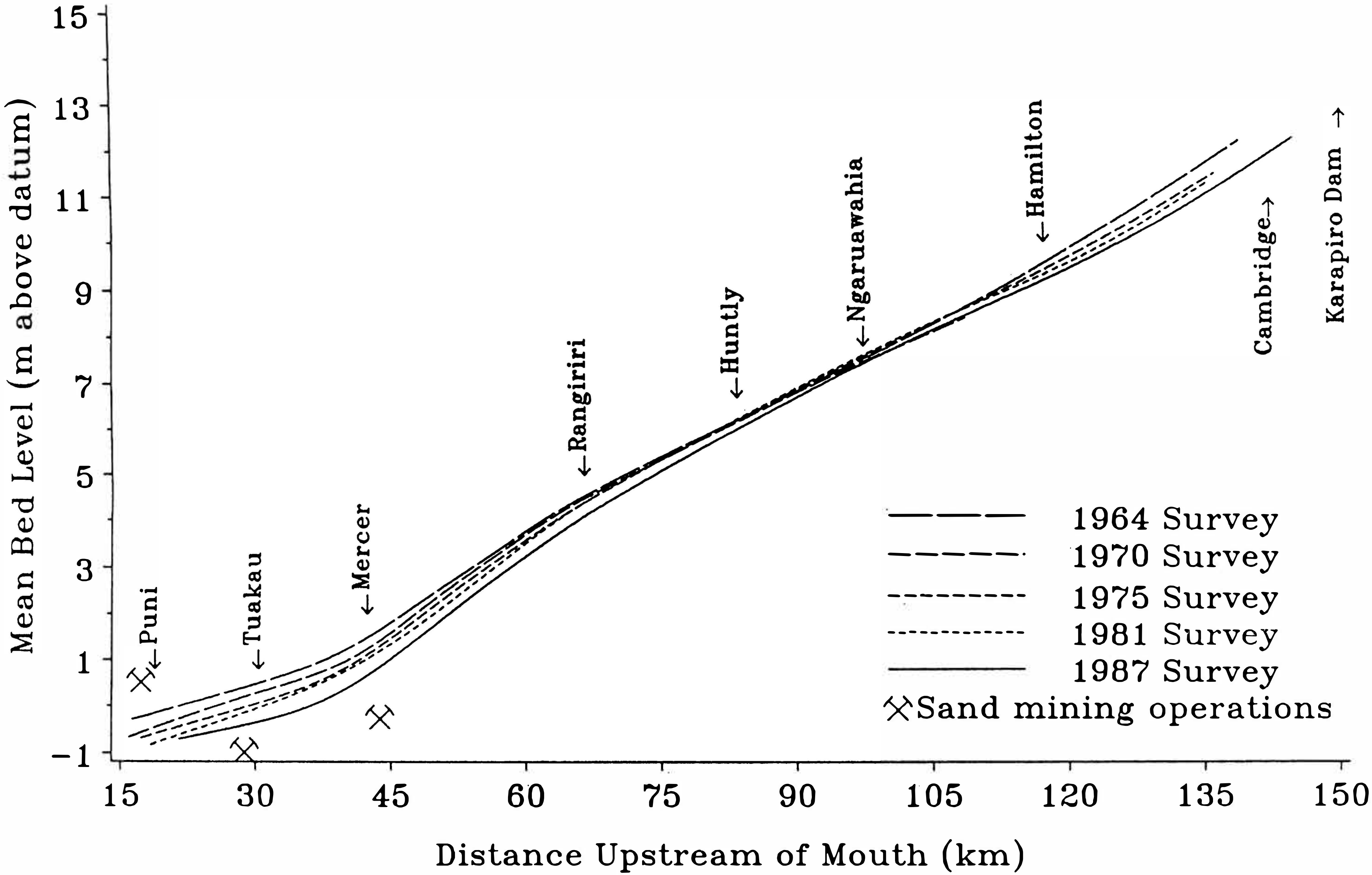

Figure 2.8 : Lower Waikato River Mean Bed Level Profiles for the surveys of 1964–1987

The Mercer - Rangiriri reach has shown a gradual trend of degradation. The upstream translation of the degrading bed levels above Mercer appears, from the first four surveys, to be hinged at some point between Rangiriri and Huntly. However, in the most recent survey this translation appears to have moved significantly upstream above Huntly with marked degradation occurring in the Mercer to Huntly reach. If this trend is valid and continues, it could result in water level lowering adjacent to the Huntly Power Station, affecting the operation of the water intake pumps (see Figure 2.7 for comparison of raw data over 1964-87 period). The Huntly to Ngaruawahia reach appears to be relatively stable with slight aggradation from 1964 to 1981, followed by degradation to just below the 1964 level in the 1987 survey.

The incised Ngaruawahia to Karapiro reach displays another interesting trend. As expected, the downstream effects of the Karapiro dam are beginning to degrade the downstream bed profile. The degradation is caused primarily by the clear water discharge from the base of a dam, which entrains bed material to re-establish its bedload transport regime. Williams & Wolman (1984), Petts (1984) and Richards (1987) discuss the numerous downstream effects of dams . The bed profile immediately downstream of the dam will degrade until such time as the bed becomes armoured or bedrock is struck. From isolated surface samples taken between Cambridge and Hamilton, both bedrock base control and armouring appear to occur, with hard clay samples being dredged in the immediate Cambridge area and coarse gravel in the downstream reach. The extent of this effect based on the limited data available to 1981 was discussed by Dahm (1987), but the most recent survey (1987) provides further useful information on the amplitude of this process. From the survey data progressive degradation appears to have occurred in the Hamilton to Karapiro reach since 1964, with the 1987 survey showing a leveling out of the profile from Karapiro to about 10km downstream of Cambridge at about 0.7 - 0.8m below the 1964 level. This degradation is likely to continue its downstream progression in future years with a new equilibrium profile being established as armouring occurs, or some solid base level control is reached. Such a downstream progression can take many decades and affect a river for 10's, even 100's of kilometres downstream as is the case with the Colorado River, USA (Williams and Wolman, 1984).

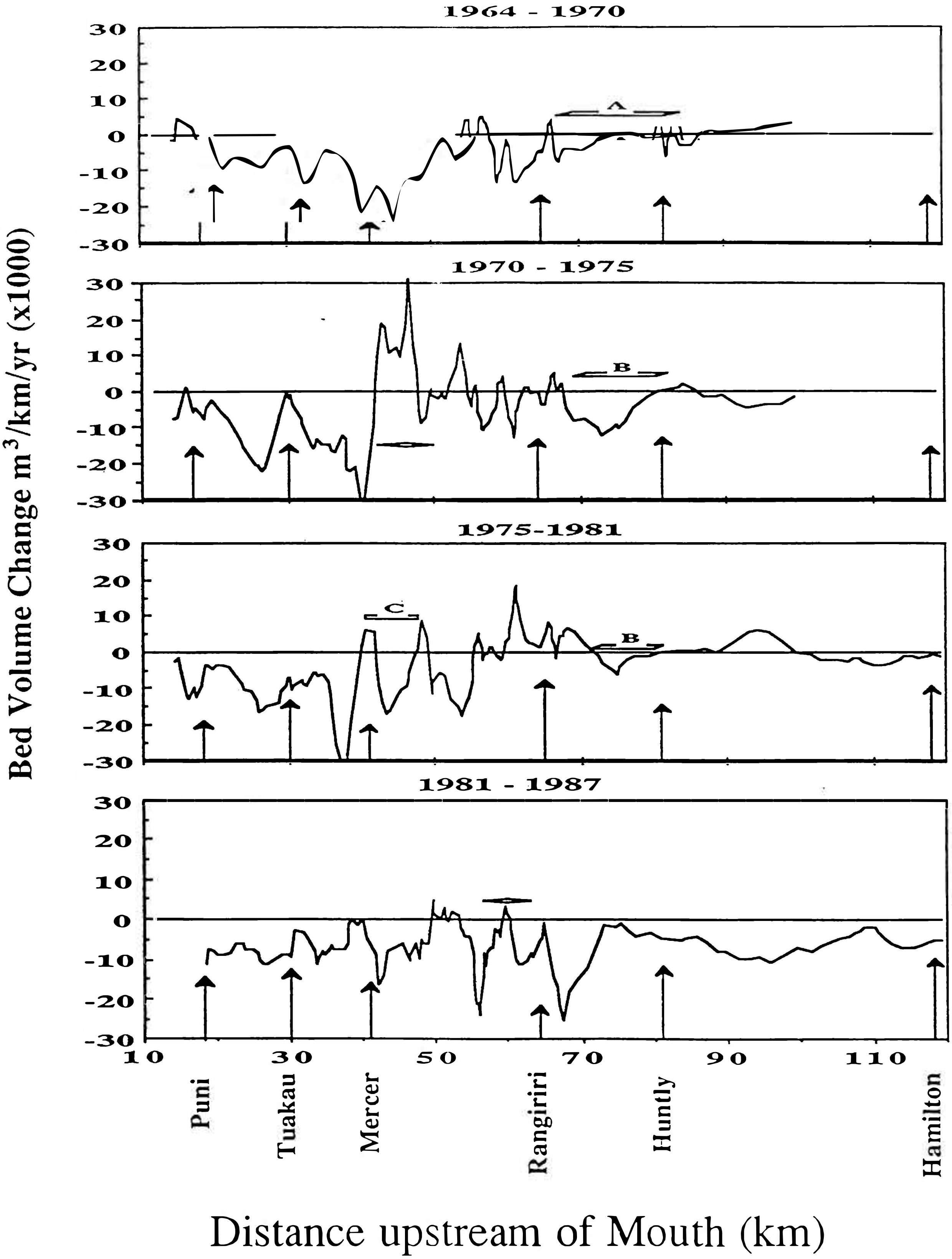

Figure 2.9 Rates of bed volume change between consecutive surveys, from 1964 to 1987. The plots represent a running mean of five values (2 up and 2 downstream of each cross section) **A** is an area where sand was extracted for stop bank ballasting, **B** is extraction for Huntly Power Project, **C** is bed loss due to river training works, <> are areas of bed volume gain due to river training works.

2.2.3 Bed Volume Change

An analysis of changes in cross sectional area between adjacent cross sections can provide bed volume change data. Previously the W.C.B used an approach of dividing the river into short reaches and calculating the mean cross sectional area over that reach for each survey. This approach takes into account large day to day fluctuations in mean bed level (MBL) that can occur because of the large bedforms and very mobile nature of the low density sand and gravel that makes up the bed material (W.V.A, 1981 unpub).

Calculation of Bed Volume Change

For the analysis used here, bed volume change is used instead of simple cross sectional area. The bed volume change between two cross sections (eg. C.S.1 and C.S.2) over the period between two surveys is calculated by ;

$$\Delta V = \left(\frac{A_1^a + A_2^a}{2} - \frac{A_1^b + A_2^b}{2} \right) \times \Delta d \ \ (m^3)$$

Where:

ΔV = volume change between two cross section between two surveys, **a** and **b** (m^3)

A_1^a = cross sectional area at cross section 1 during survey **a** (m^2)

A_2^a = cross sectional area at cross section 2 during survey **a** (m^2)

A_1^b = cross sectional area at cross section 1 during survey **b** (m^2)

A_2^b = cross sectional area at cross section 2 during survey **b** (m^2)

Δd = distance between cross sections 1 and 2 (m)

Division of the resulting value by the distance between the two cross sections (km) and the number of years between surveys produces a rate of change in m3/km/yr, where a negative result represents bed volume loss and a positive value indicates bed volume gain. When this is applied to the survey data for 1964 - 1987, four rates of bed volume change can be obtained between each set of cross sections. The *raw* bed volume change data shows rapid variations in bed volume change and some form of smoothing is needed to isolate notable trends and variations. In production of the plots (Figure 2.9 and 2.10) running mean data are used, where five immediate cross section values are meaned (2 upstream, 2 downstream and the value a the cross section distance plotted are used). This method overcomes variability from MBL fluctuations discussed in W.V.A(1981, unpub).

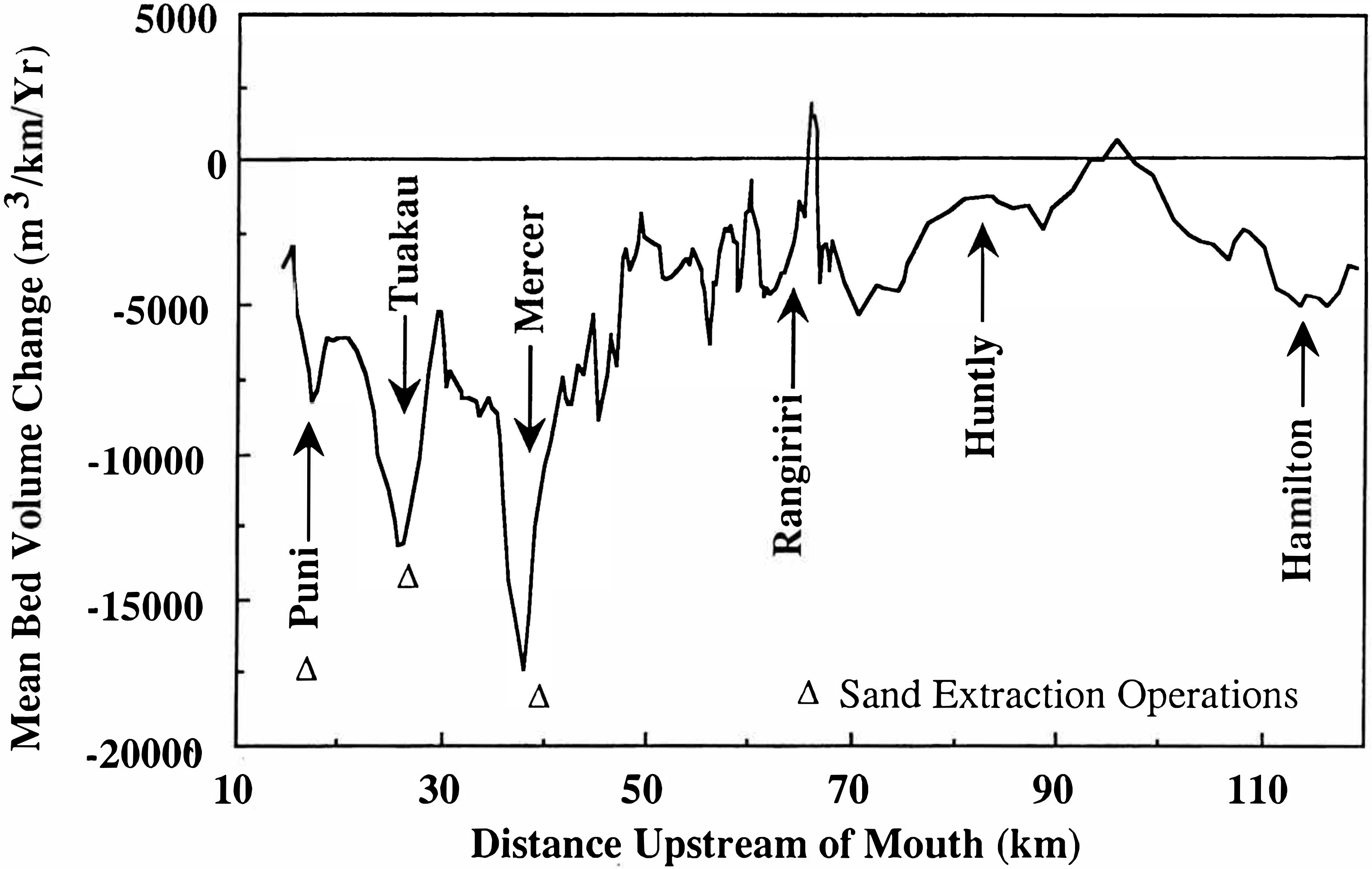

Figure 2.10 : Mean rate of bed volume change in lower Waikato River over 1964 to 1987 period. Plotted values are a running mean of the 5 closest cross sections.

Trends in Bed Volume Change

Figure 2.9 shows plots of bed volume changes between each survey. From these plots a number of developing trends can be seen. The degradation rate in areas of active sand extraction appears to parallel the extraction rate trend (Figure 2.3). Bed volume loss from 1970 - 1975 at Mercer and Tuakau decreases somewhat to the 1981 - 1987 period in response to a lowering of extraction rates from around 1977 to 1983 (some response delay will occur between extraction rate and bed volume loss). Marked on figure 2.9 are areas of the river affected by the river training works (Section 2.1.1) carried out by the W.C.B (<>, 1974 - 1976, 1985). This training produces large scale bed volume gain, which is very noticeable in 1970-1975 but minimal in 1980-1987. Such training works cause the river to scour out a deeper channel, producing degradation of the bed profile and apparent bed volume loss (see C on Figure 2.9). The other interesting trend is in the area upstream of Huntly, where the river bed appears to be stable up until 1981, after which bed volume loss has occurred over a large area of the reach. This is reflected by a lowering of MBL over the same area (Figure 2.8). There is considerable variation in the plots, and it is difficult to determine the cause of all the changes. Appendix 3 contains the raw bed volume change and mean data, which shows the extent of individual cross section variation.

Figure 2.10 is a plot of mean volume change against distance upstream of the mouth for the entire survey period 1964-1987. From this diagram it is evident that degradation is occurring along most of the lower Waikato River. Generally the trends seen in the MBL plot (Figure 2.8) are also shown in Figure 2.10, but areas of marked change can clearly be identified. These areas include Puni, Tuakau and Mercer where large scale bed volume loss over a short reach has occurred as a result of continued sand extraction. Bed volume loss in the Rangiriri to Huntly reach has also occurred and is the result of local sand extraction for the Huntly Power Project and stopbank ballasting. Extensive bed volume loss has also occurred in the Hamilton area and upstream, presumably as a result of downstream degradation from the Karapiro dam.

2.2.4 Extent and Implications of River Profile Changes

Analysis of the bed survey data clearly shows that degradation of bed levels and bed volume loss have occurred over most of the lower Waikato River, and have accelerated recently within areas and immediately upstream of active sand extraction. What then, are the implications for future sand extraction and river levels, and how significant are the lower bed levels shown in Figure 2.8. The river training works that were undertaken by the W.C.B were aimed at lowering the river bed level and improving its hydraulic efficiency, which in turn would enhance the flood protection of the low lying areas. This aim has now been met and commercial sand extraction has played a major role in achieving this objective by aiding in a lowering of the river bed profile.

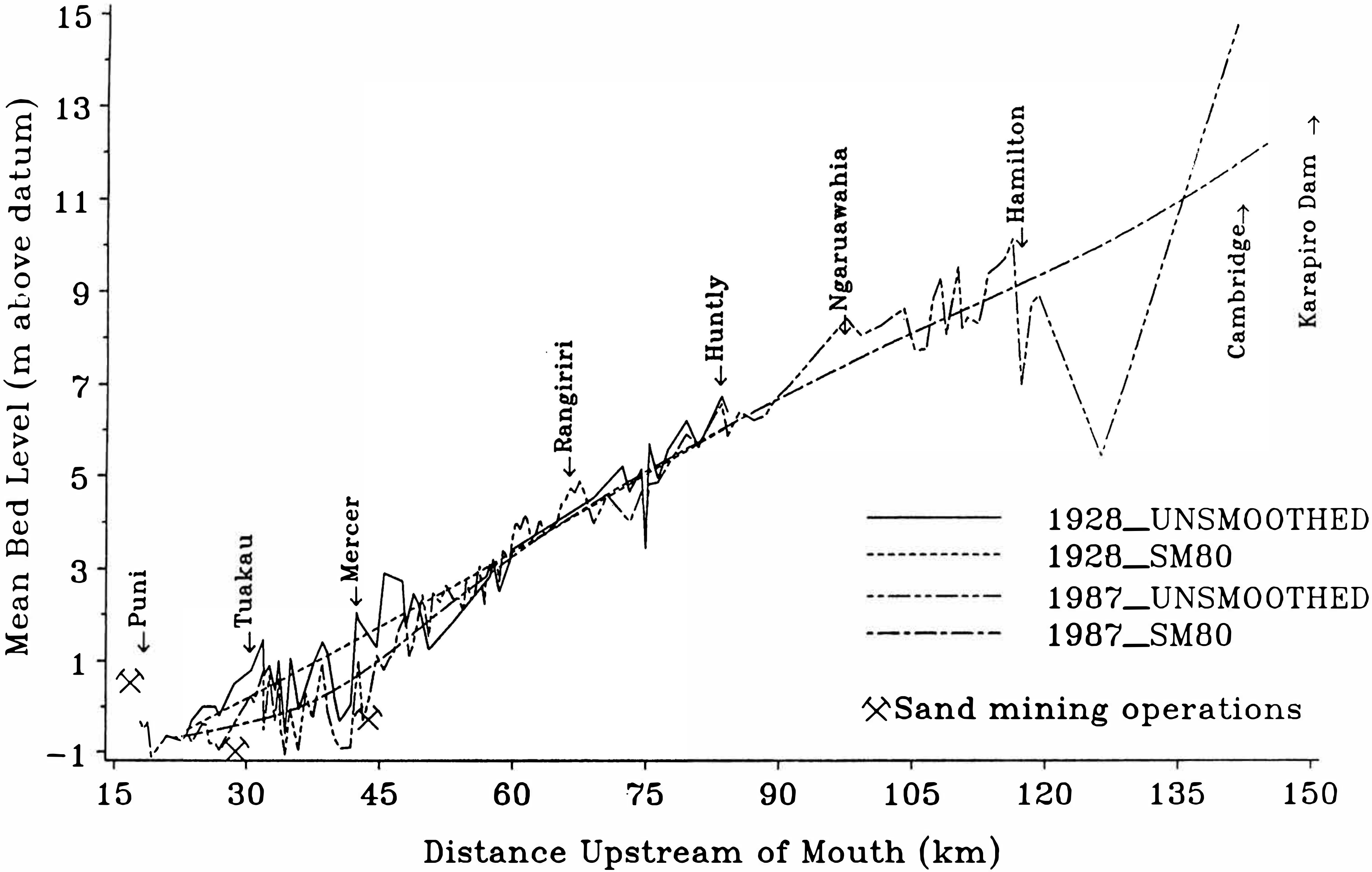

Figure 2.11 : Comparison of 1928 & 1987 Mean Bed Level Profiles

As a result of the erosion of the spillway channel at the Arapuni dam during its construction large scale aggradation occurred along reaches of the lower Waikato River. Approximately 5.3 x 10^6 m3 of loose sediment was lost into the river (Mulholland, 1983). Although the bed levels appear to have dropped markedly over the 1964 - 87, period it should be noted that the levels in the Rangiriri to Huntly reach are only now returning to the pre - 1928 levels (Figure 2.11). The net change between 1964 and 1987 bed levels may appear significant, but in effect the bed levels are just returning to a level of pre-human interference.

Future Changes in Bed Profile

If one considers that the future bed profile will reach some form of dynamic equilibrium, and accepts that the present (1987) profile is out of equilibrium because of river training and sand extraction activities, then three possible scenarios for future bed level change exist. These are schematically displayed in Figure 2.12, and described below with **A** and **C** being opposite extremes;

Situation A shows an equilibrium profile that would be established if extraction continued at much the same rate and in the same areas. Such a profile would take some time to come to equilibrium and sediment transport rates would diminish with time as the effects of the dam continue to move downstream, and a limited sediment supply in the bed is used up. This option however could potentially produce and exacerbate a number of problems:

(i) further drainage of the neighbouring wetlands;
(ii) difficulties in the operation of water intake structures at both Meremere and Huntly power stations; and
(iii) it is feared by the W.C.B that a marked lowering of water levels could produce instability and reduce the design safety factor for seepage under the stopbank system as a result of an underlying porous layer, presently protected by silt (W.C.B, 1989 Unpub). There is, however, no direct evidence for this.

Situation B shows an equilibrium profile that would be established if extraction rates in the Mercer area were restricted to approximately the bedload transport rate. This would essentially remove the hump in the 1987 profile between Meremere and Ngaruawahia as it is transported downstream to Meremere as bedload. However, the rate of bedload transport may well deminish with time.

Situation C shows an equilibrium profile that would be established if sand extraction was stopped at Mercer and stopped or restricted at Tuakau. As for **B**, the hump in the profile would be removed, but in this case it would gradually become deposited into a depression in the profile between the Meremere to Tuakau area. The resulting equilibrium profile would however

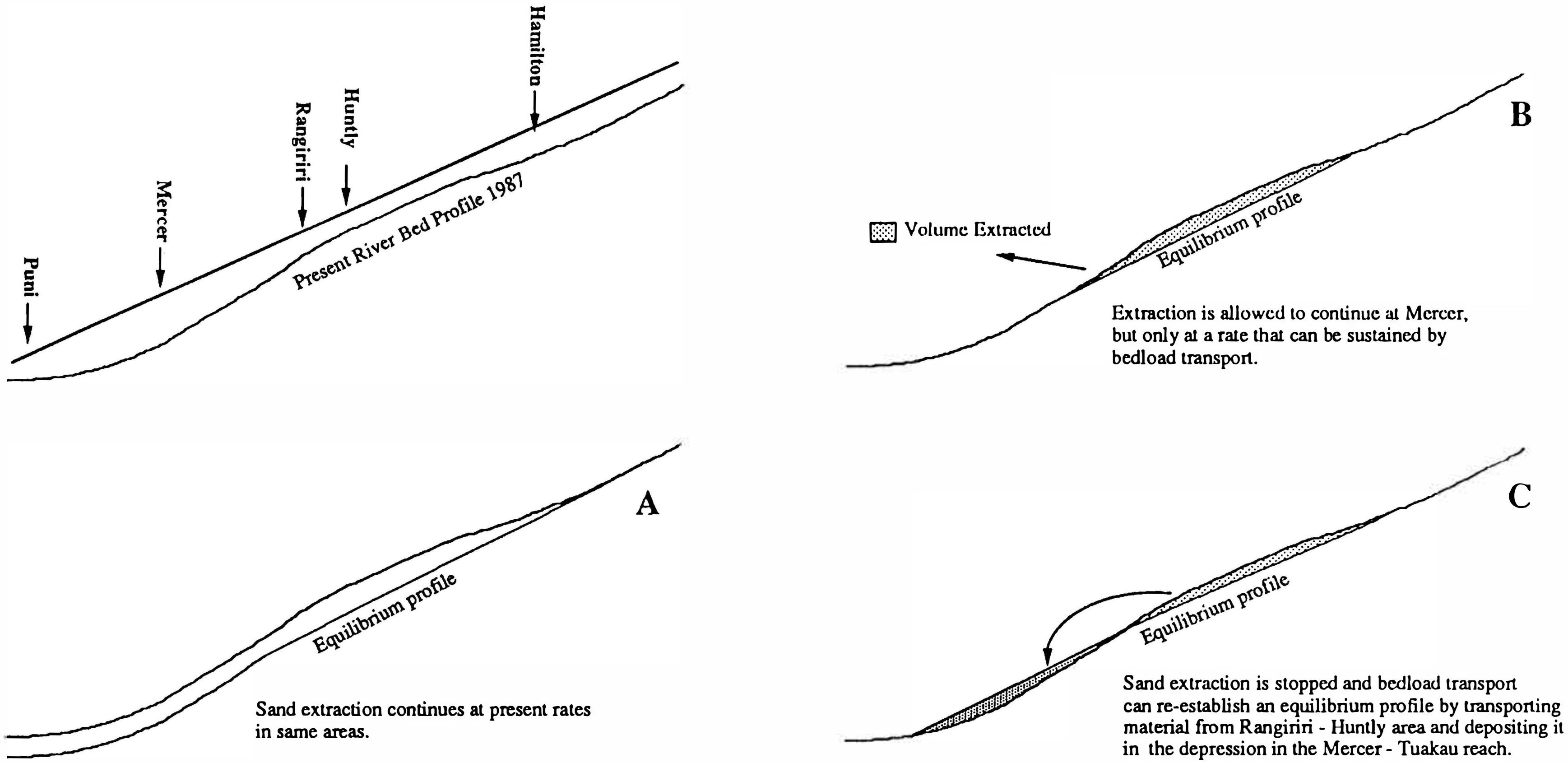

Figure 2.12 : Future changes in Mean Bed Level profile, depending on extraction rates and location of sand extraction operations.

N.B Diagram is a schematic representation and is not to scale.

be higher than that achieved in Situation **B** because of the base control effect of the material deposited into the depression. The resulting rise in levels around the Mercer reach may require some future dredging to maintain flood protection.

Now that the bed level has been lowered significantly and the W.C.B objective essentially achieved, the future of commercial sand extraction on the river is under review. The exact nature of any future extraction will depend on the governing authorities and their long term objectives and management plans. The three scenarios outlined above are simplistic, as the complexity of fluvial dynamics makes prediction of any future change in the river difficult. Monitoring and controlling an approach like Situation **B** has practical difficulties, specifically determining when the hump has been removed. Whereas Situation **C** is the safer management option

CHAPTER THREE :

RIVER MORPHOLOGY

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RIVER MORPHOLOGY

3.0 INTRODUCTION

Morphologically, the alluvial transport of sand creates forms ranging from the size of small ripples only a few centremetres high to meander belts many kilometres wide and 40 to 50 m or more thick (Pettijohn et al., 1972). This statement typifies the recent history of the lower Waikato River, having produced the extensive Hinuera Formation that blankets the Waikato Basin. The present river is incised into the basin and displays a variety of bedforms.

The aim of this chapter is to characterise several aspects of the lower Waikato River's morphology. General bedform terminology is reviewed, the types of bedforms observed in the lower Waikato River are characterised, and longitudinal changes in bedforms and sediment texture are assessed. The large sand bars that dominate the reach between Huntly and Mercer are intensively studied over a year to determine their physical characteristics, mechanisms of formation and migration, relationship to discharge, and implication for sediment transport.

3.1 BEDFORM TERMINOLOGY AND FLOW REGIME

Sediment movement is accompanied by the organisation of grains into morphological elements know as **bedforms** (Leeder, 1982). The geometry of these bedforms depends on various flow parameters. In turn, the various flow parameters are influenced by the bedforms. In the study of bedforms there is a need for unambiguous terms and clear definitions. This, however, has not been achieved so it is necessary to define the terminology used in this study. Definitions and terminology for bedform characterisation have been presented by a number of authors, for example, Simons et al.(1965), Allen (1968a, 1976a), Pettijohn et al.(1972) and Miall (1979). Reference to these and others will be made when defining general bed morphology and more specifically the bedforms in the lower Waikato River.

Bedform phase diagrams are commonly used to display the relationships between stream power (shear stress x mean velocity), grain size and the resulting bedform. Figure 3.1A shows a simple example of a phase diagram based on laboratory experiments. Bedform phase diagrams can also be presented as depth-velocity-grain size diagrams, giving three dimensional fields (Figure 3.1B). Starting from a plane bed of sand, as stream power is increased sediment movement begins and ripples form (Figure 3.2A), only in medium to fine sands (Allen, 1970). With increasing stream power dunes begin to form with ripples superimposed (Figure 3.2B) and then fully developed dune bedforms occur (Figure 3.2C). These bedforms are

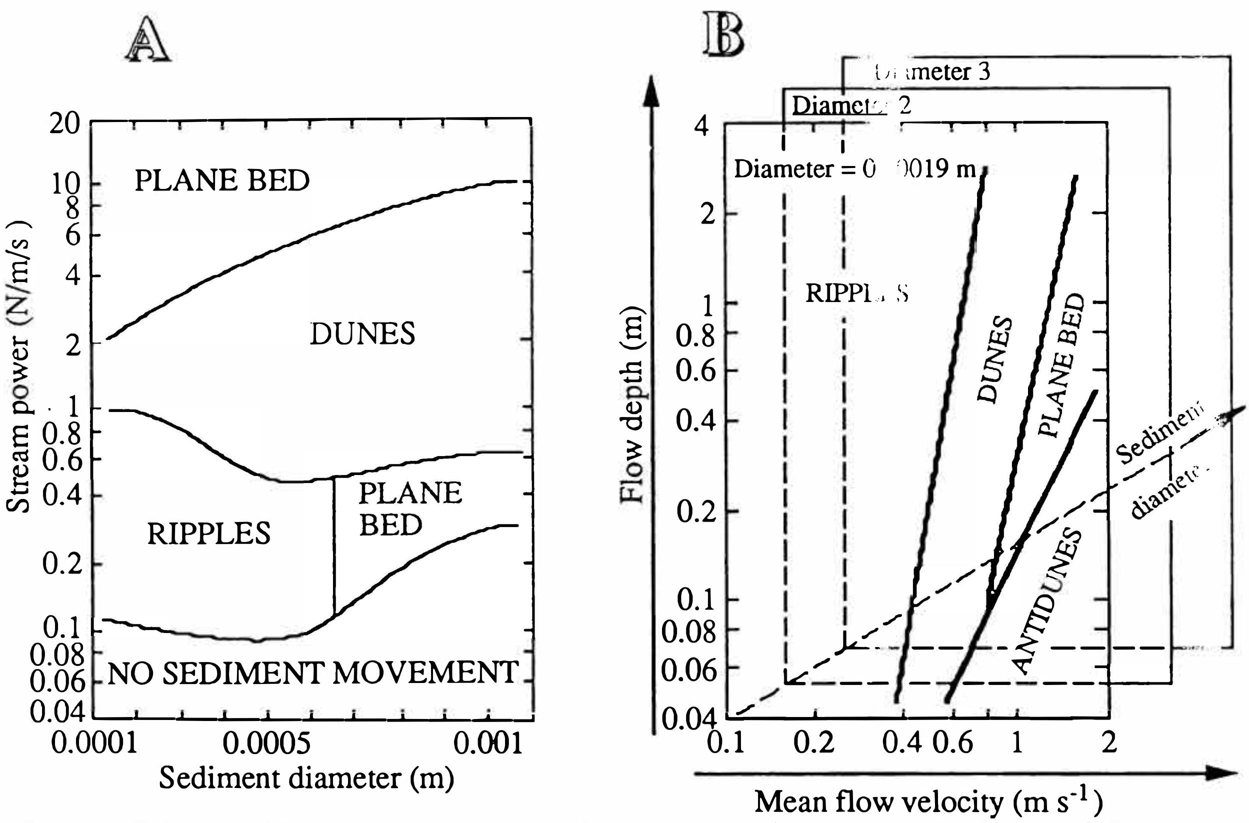


Figure 3.1 : Bedform states in relation to flow states, from laboratory experiments representing the simplest achievable conditions of steady-state equilibrium. (A) fields in the stream power - grain size plane. (B) General form of depth - velocity - size diagram for bedforms (after Allen, 1976a).

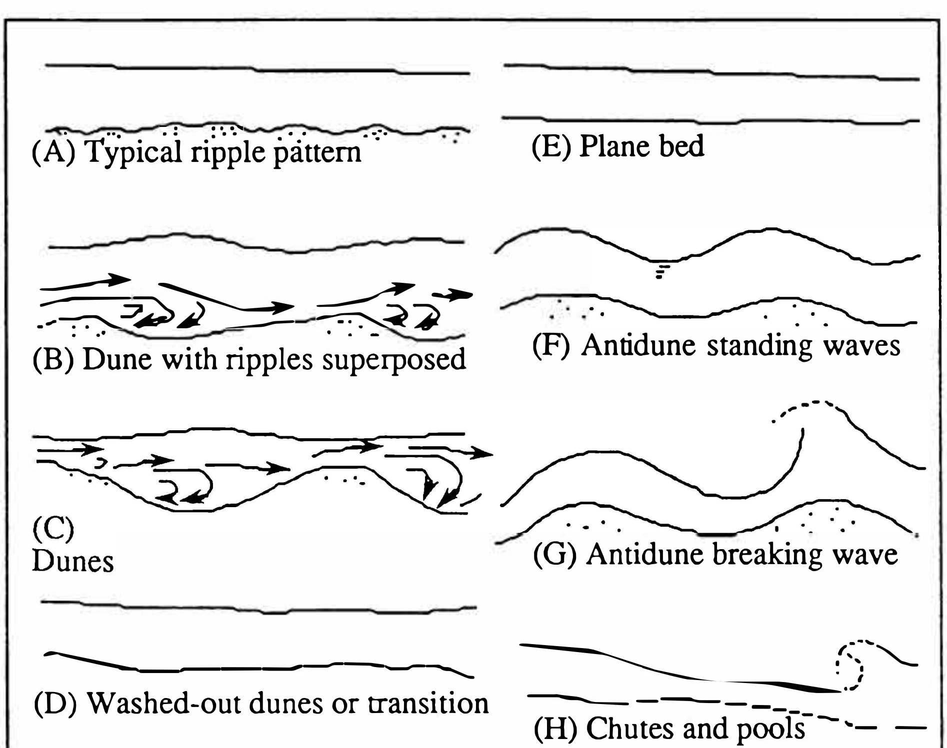


Figure 3.2 : Sequences of bedforms in loose grains as flow intensity increases. (after Vanoni, 1975)

representative of what is termed the lower flow regime, when Froude number < 1 (Table 3.1). Further increase in stream power produces a transitional zone where dunes are washed out (Figure 3.2D). Where F >1, termed upper flow regime (Table 3.1) a plane bed, antidunes and chutes and pools are produced consecutively (Figure 3.2E-H) as stream power is increases.

Flow regime	Bed form	Remarks
Lower	Ripples Ripples on dunes Dunes	F<1. Grains move in discrete steps and form roughness predominates. Water and bed surface are out of phase. Bedforms move downcurrent.
Transition	Washed out dunes	F=1. Both grain and form roughness occur
Upper	Plane bed Antidunes Chutes and pools	F>1. Grains move continuously and grain roughness predominates. Water and bed surfaces are in phase. Antidunes move upcurrent, remain stationary, or go downcurrent.

Table 3.1: Flow regime and bedforms (after Pettijohn et al, 1972).

Allen (1968) noted from experimental and naturally occurring bedforms that bedform height, h, and wavelength, λ, were bimodally distributed, and proposed that there are two distinct, but slightly overlapping, populations of transverse bedforms; ripples and dunes (dunes are also termed megaripples). Ripples are defined as having, height (h) < 0.04 m and wave length (λ) < 0.6 m, while dunes have h > 0.04 m and λ > 0.6 m (Allen, 1976a). The definition of dunes can therefore cover a vast size range of bedforms ranging from the lower limit up to features that are 10 or more metres in height and hundreds of metres in length (Leeder, 1982). The term sand wave is used by some authors to describe such large scale structures in the marine and fluvial environments, or large fluvial 'dunes' that have smaller dunes superimposed on the stoss sides (Leeder, 1982).

One bedform not normally linked to flow regime, and probably reflecting more than any other bedform the three diamensionality of natural streams, is the bar (Graf, 1971). Bars are large depositional features and have a length of the same order as channel width or longer. They are generally linked with meanders and four morphological types are distinguished: point, alternating, transverse and tributary bars (Vanoni, 1975). Ripples and dunes may occur on the upstream slopes of these features.

In many natural channels roughness, and hence resistance to flow are related to the dunes and ripples which form the bed rather than to the size of the discrete particles that make up the bed (Leopold & Wolman, 1957). Bedforms can exert significant upstream drag forces on the flow, the geometry and thus hydraulic roughness of the bed configuration depend upon, among other factors, the depth and velocity of flow (Vanoni, 1975).

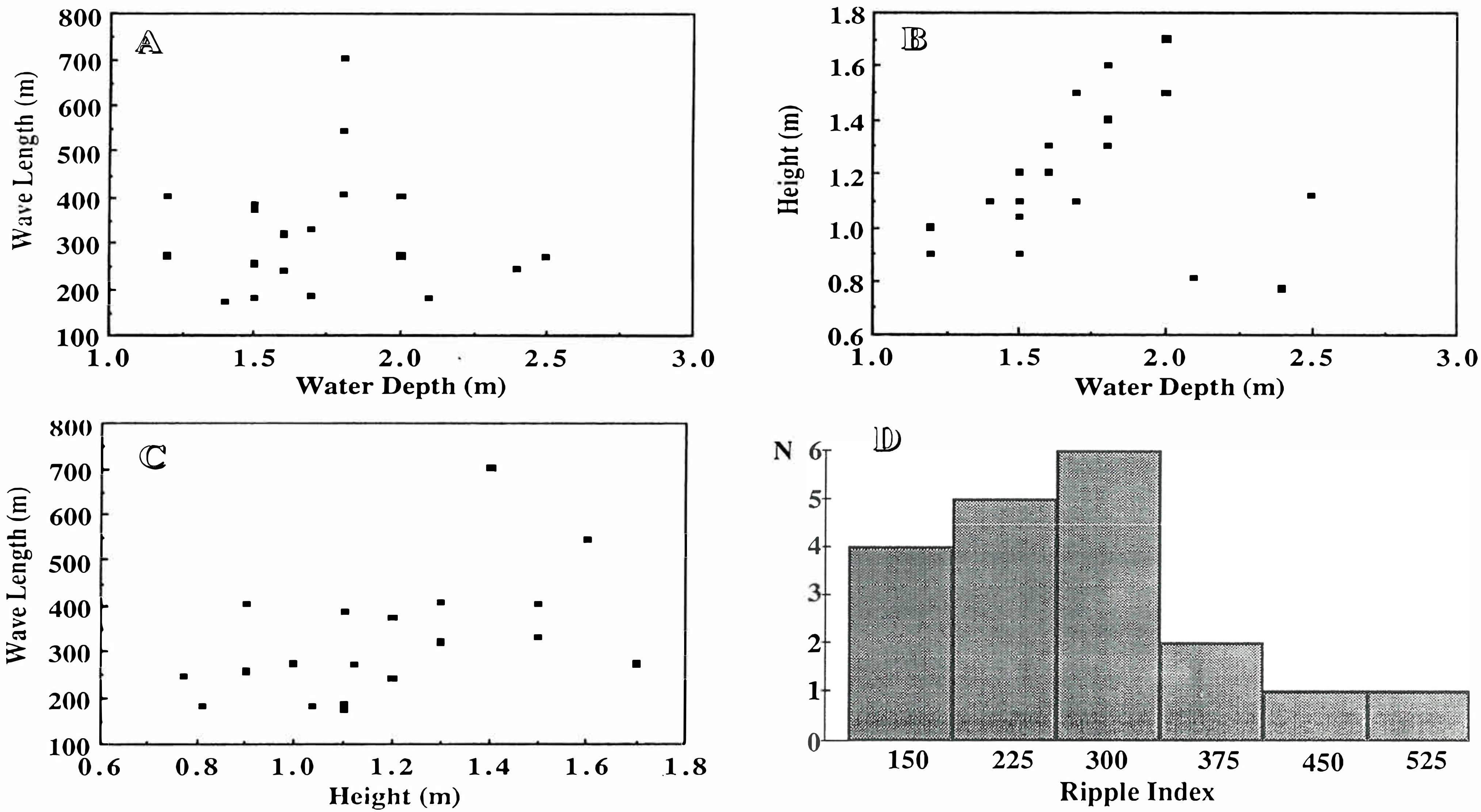


Figure 3.3 : Height, wavelength and water depth relationships of sand bar bedforms in the lower Waikato River(A - C).
Ripple index (wavelength/height) of sand bars (D).

3.2 BEDFORMS IN THE LOWER WAIKATO RIVER

The lower Waikato River flow exists in the lower regime and shows a full variety of bedforms, from the large sand bars down to ripples. Bedforms along the reach from Hamilton to Puni (termed the study area in this section) are investigated from echo sounding traces using a *RAYTHEON DE-719B FATHOMETER* precision survey depth recorder. The hierachic nature of bedforms proposed by Allen (1968) is clearly seen in the river morphology, with dunes and ripples occurring on the back of sand bars, and ripples on the backs of dunes. The types of bedforms seen in the study area will now be discussed.

3.2.1 Sand Bars

Classification

The large bedforms that dominate the morphology in the Huntly to Mercer reach have in the past been loosely referred to as dunes (Finley, 1974). Dunes in the Mississippi River have been reported as up to 3.2 km in length and as much as 10 m in height (Leopold et al., 1964). However there are two main reasons why these large bedforms in the lower Waikato River do not fit into the dune classification. They are:

(1) dunes commonly show a correlation of wavelength, λ and height, h with flow depth, y. From experimental and field measurments for the range $0.1 \text{ m} < y < 100 \text{ m}$,

$$\lambda = 1.16y^{1.55} \quad \text{and} \quad h = 0.086y^{1.19} \quad \text{(Allen, 1968a).}$$

However, the large bedforms on the lower Waikato River show no such correlation, with a plot of wavelength as a function of depth showing a wide scatter of points (Figure 3.3A). Wave height appears to show a correlation (Figure 3.3B), but all the data points with the exception of the three lower right points were obtained from echo sounding traces collected during summer low flows. The three outlying points suggest that more data from throughout the year would show no correlation; and

(2) dune height should vary between one-eigth and one-sixth of the flow depth (Allen, 1976a). This is not seen from the data (Figure 3.3).

The dominant bedforms in the study area however, show characteristics that are associated with sand bars which are related to meandering river flow within the channel:

(1) sand bars show straight crests and leeside avalanche induced migration and lack the leeside scour hollows that are associated with dunes (Leeder, 1982). From visual observation and sediment sampling the bars are found to lack a lee side scour hollow;

(2) bars do not show any strong correlation of wavelength or height with water depth (Leeder, 1982), Figures 3.3A and B;

(3) bars display a great variation in wavelength (Costello, 1974); and

(4) bar length is comparable to channel width and height is comparable to mean flow depth (Vanoni, 1975).

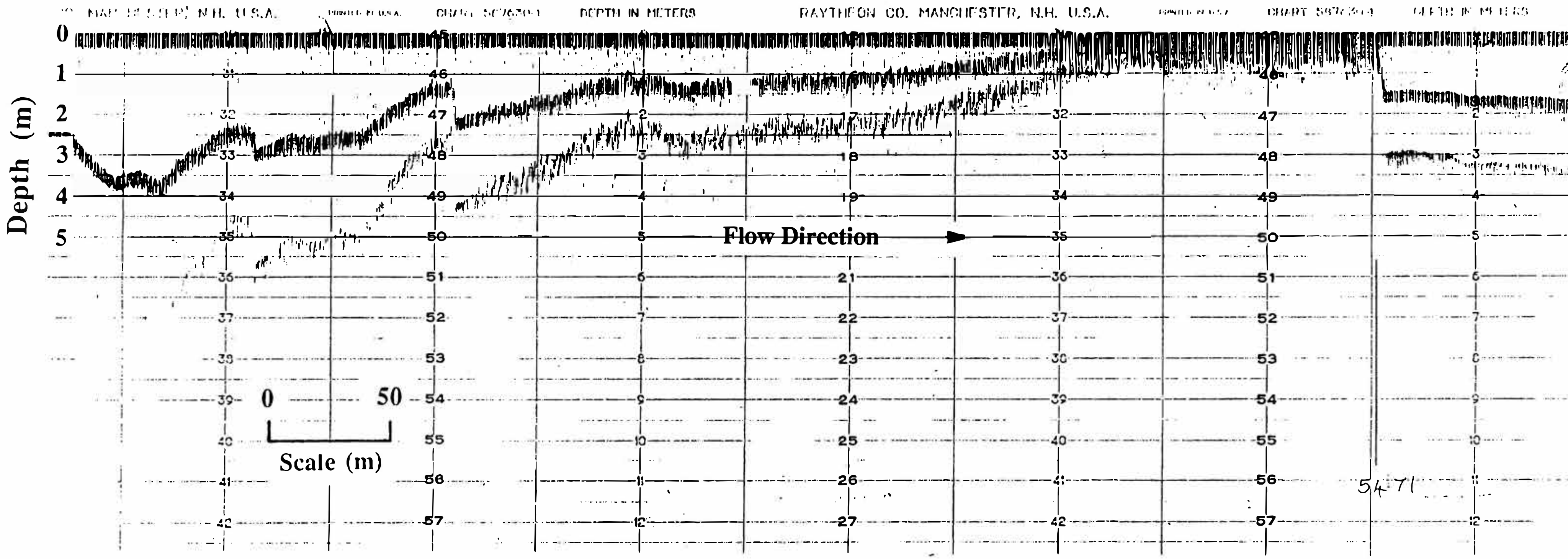


Figure 3.4 : Echo sounding trace of a sand bar bedform in the lower Waikato River with small dunes superimposed on the stoss face. The trace was obtained using a RAYTHEON DE-719B FATHOMETER from the University of Waikato research jet boat while travelling approximately down the centre of the river channel.

λ	h	R.I
36	0.9	40
38	0.63	61

R.I small dunes

Bars represent areas of net sediment accumulation. There is a great deal of confusion in the literature about what exactly constitutes a bar, with over 30 terms being used to name bars with specific shapes, orientation and position within a channel (Smith, 1978). Miall (1982) provides a convenient definition of a bar as being a bedform of a size comparable in magnitude to that of the channel in which it occurs. Further, Miall (1982) classifies bars into three broad groups; planar or massive bedded bars, simple foreset bars and compound bars. Such a classification may be acceptable for geologists working with limited vertical exposure, but for the fluvial geomorphologist who wishes to recognise the complex variations in sediment response and flow patterns it is limiting. The problems obscuring effective nomenclature of bars are defined by Smith (1978) as:

(1) the word 'bar' itself is vague and has been used to designate a great variety of unrelated bedforms in rivers;
(2) hydraulic origins of bars have been little investigated and remain poorly understood. No classification scheme can yet have a genetic basis comparable to the common small-scale bedforms (ripples, dunes etc); and
(3) bars range from relatively simple depositional features to complex forms resulting from multiple depositional and erosional events.

Smith (1978) suggests eliminating the word bar from freely migrating periodic forms so commonly seen in shallow sand bed rivers, such as those in the lower Waikato River, and substituting the common terms for large periodic forms such as dune, meggaripple or sandwave. The author however, feels that such an approach will only hinder the development of effective nomenclature for these forms, as they are distinctly different from 'dunes', while megaripples and sandwaves are terms developed and predominantly used to describe bedforms in marine and estuarine environments. The bedforms under consideration here are large, periodic, freely migrating forms that are genetically related to thalweg meandering in the river channel, and are therefore characteristically different to those in the prementioned environments.

Harms et al. (1975) state that most problems connected with bedforms in rivers centre around the relationship between large scale features. Dunes and bars are observed in both small and large rivers, but observational knowledge is still insufficient to draw definite conclusions about relations between these forms. It is hoped that observations and results from this study contribute to the understanding of such forms in the fluvial environment.

Presence in the lower Waikato River

The bar bedforms are dominant in the study area. Ranging in wavelength from 150 - 500 m, the height of these bedforms is typically controlled by water depth during low flows (Figure 3.3B) with the crests rising to within 20 - 30 cm of the surface (Figure 3.4). The bars are often exposed if a rapid fall in stage occurs. The majority of points on Figure 3.3 were taken from

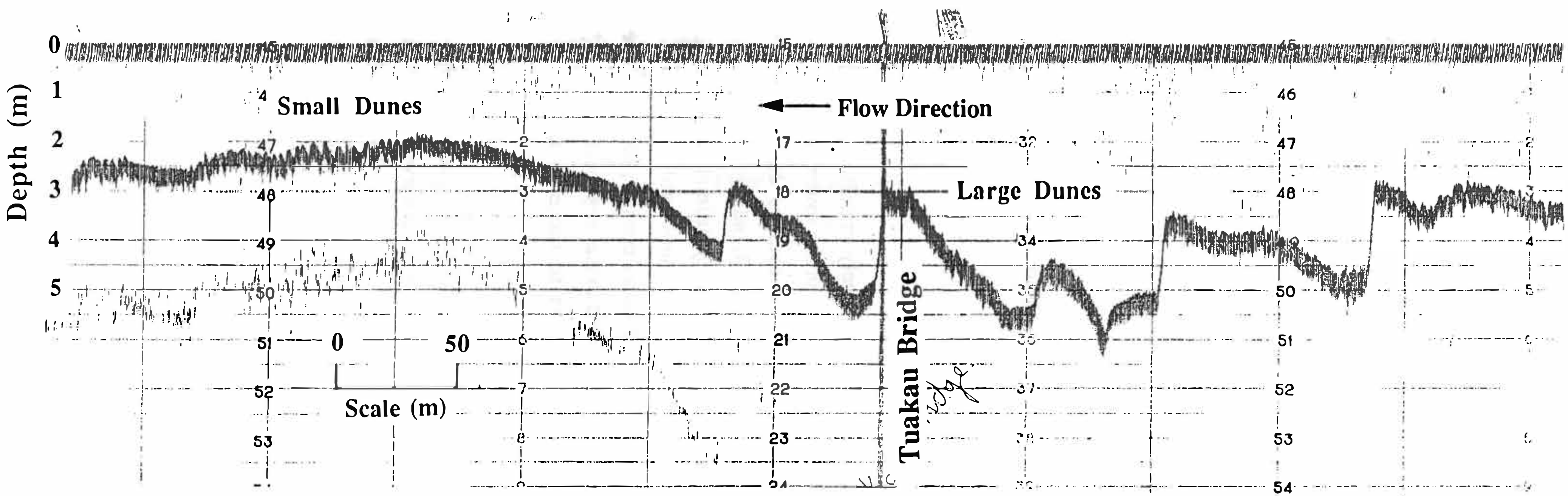


Figure 3.5 : Echo sounding trace of dune bedforms in the lower Waikato River at the Tuakau bridge. Large dunes form on the outside of a bend in the area of the Tuakau bridge , while smaller dunes occur a short distance downstream . Ripple index suggests that the two dune types are physically different, implying different flow regimes. The trace was obtained using a RAYTHEON DE-719B FATHOMETER from the University of Waikato research jet boat while travelling approximately down the centre of the river channel.

Small Dunes			Large Dunes		
λ	h	R.I	λ	h	R.I
5.0	0.20	25	49	1.2	41
4.5	0.22	21	59	1.8	33
4.2	0.22	19	31	1.0	31
4.7	0.26	18	76	1.7	45

echo sounding traces obtained during summer low flows and hence a correlation between height and water depth occurs, with the outlying points arising from traces taken at higher flows.

3.2.2 Dunes

Dunes occur over large sections of the lower Waikato. Figure 3.5 is an example of the long flat dunes that occur in areas of the river ($\lambda \cong$ 50 m, h $\cong$ 1.5 m). In this case it is on the outside of a bend past the Tuakau bridge, where the tractive forces are sufficient to produce large dune bedforms (Figure 3.1A). A short distance downstream of the Tuakau bridge dunes of a different scale ($\lambda \cong$ 4.5 m, h $\cong$ 0.22 m) occur, indicating a change in local stream power between these two sites (Figure 3.5), or possibly a significant change in grain size. This example shows that dunes can occur in a variety of sizes in the river. The difference in the ripple index (wavelength/height) between the two groups indicates that they are distinctly different groups (Figure 3.5).

Figure 3.4 is an example of superimposition of dune bedforms on the stoss face of a large bar bedform. This phenomenon occurs throughout the study area, and Figure 3.6 shows a smaller dune high up on the stoss face of a sand bar. From visual field observations large areas of the stoss face of bar bedforms can be covered with small dunes ($\lambda \cong$ 0.5 - 2 m, h $\cong$ 0.04 - 0.16 m). Visually, pumice appears to concentrate in the lee of dune bedform (Figures 3.6 - 3.8), but on inspection a significant percentage of the sand on the lee face of the dunes appears to be made up of rock fragments and quartz. The appearance of this concentration is probably due to the presence of larger physical grain size of the pumice which appear to allow the smaller material to slip below the surface.

3.2.3 Ripples

Ripples are the smallest bedforms that occur and are difficult to accurately isolate on the echo sounding traces. From visual observations they are seen over large areas of the stoss face of sand bars and are likely to cover large areas of the bed, especially during the summer low flows when stream power is at a minimum.

Figures 3.6, 3.7 and 3.8 are examples of ripple bedforms on the stoss face of a sand bar. Ripples can occur superimposed on small dunes, which in turn are superimposed on the bars (Figures 3.6 and 3.7), or they may occur directly on sand bars (Figure 3.8). The ripples tend to be poorly defined, presumably because of the coarse nature of the bed sediment. The dimensions of the ripples are, $\lambda \cong$ 0.3 - 0.5 m, h $\cong$ 0.01 - 0.02 m in the areas of dunes where superimposition occurs, while in the flatter region where only ripples exist (Figure 3.8) the dimensions are smaller, $\lambda \cong$ 0.1 - 0.3 m, h $\cong$ 0.005 - 0.01 m. Pumice also concentrates in the lee of the ripples.

Figure 3.6 : Dunes and ripples moving across the stoss face of a sand bar, note how dunes can exist on the backs of bigger dunes (right), and where the water is deeper, hence velocities lower, only ripples exist (left). Flow is from right to left. Black knife handle is 10 cm long.

Figure 3.7 : Dune bedforms on the stoss face of a sand bar, with smaller ripples superimposed on them. Note how the pumice collects preferentially on the lee face of the bedforms. Flow is from right to left. Black knife handle is 10 cm long.

Figure 3.8 : Ripple bedforms on the stoss face of a sand bar. Flow is from right to left. Black knife handle is 10 cm long.

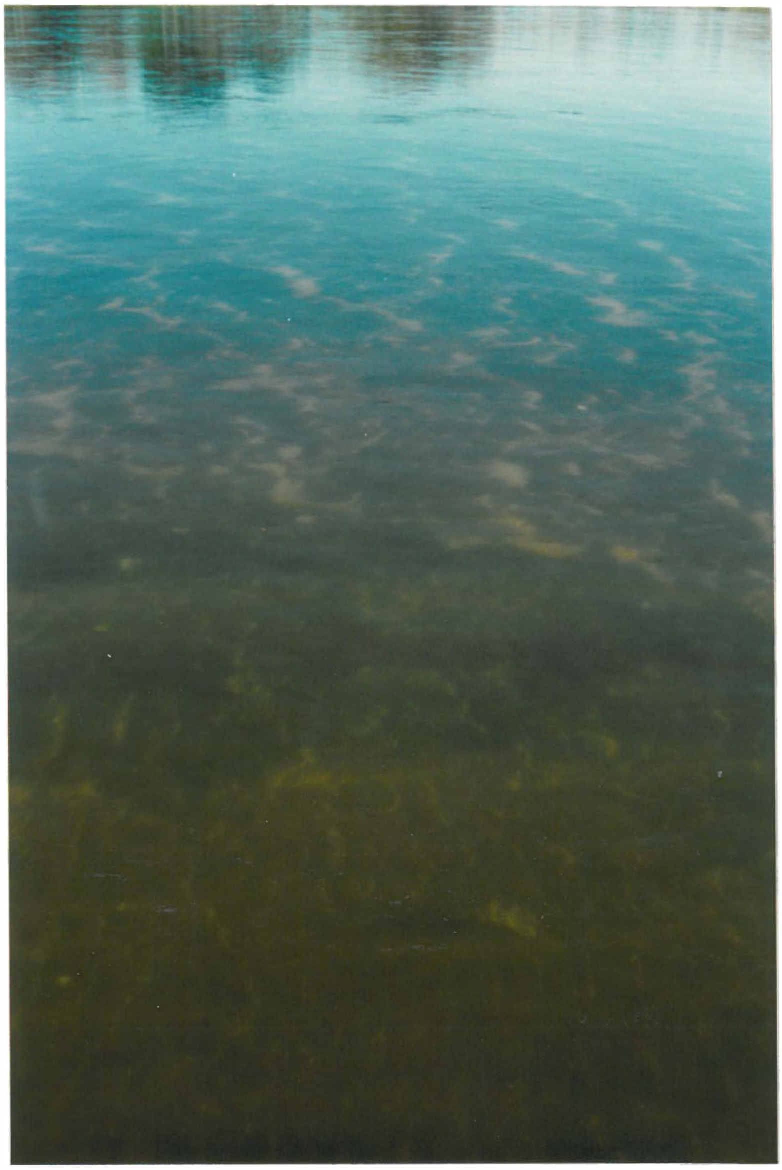


Figure 3.9 : Bedforms on the stoss face of a sand bar. Note the abrupt change between ripple bedforms in the foreground and dunes in the back ground. Flow is from right to left.

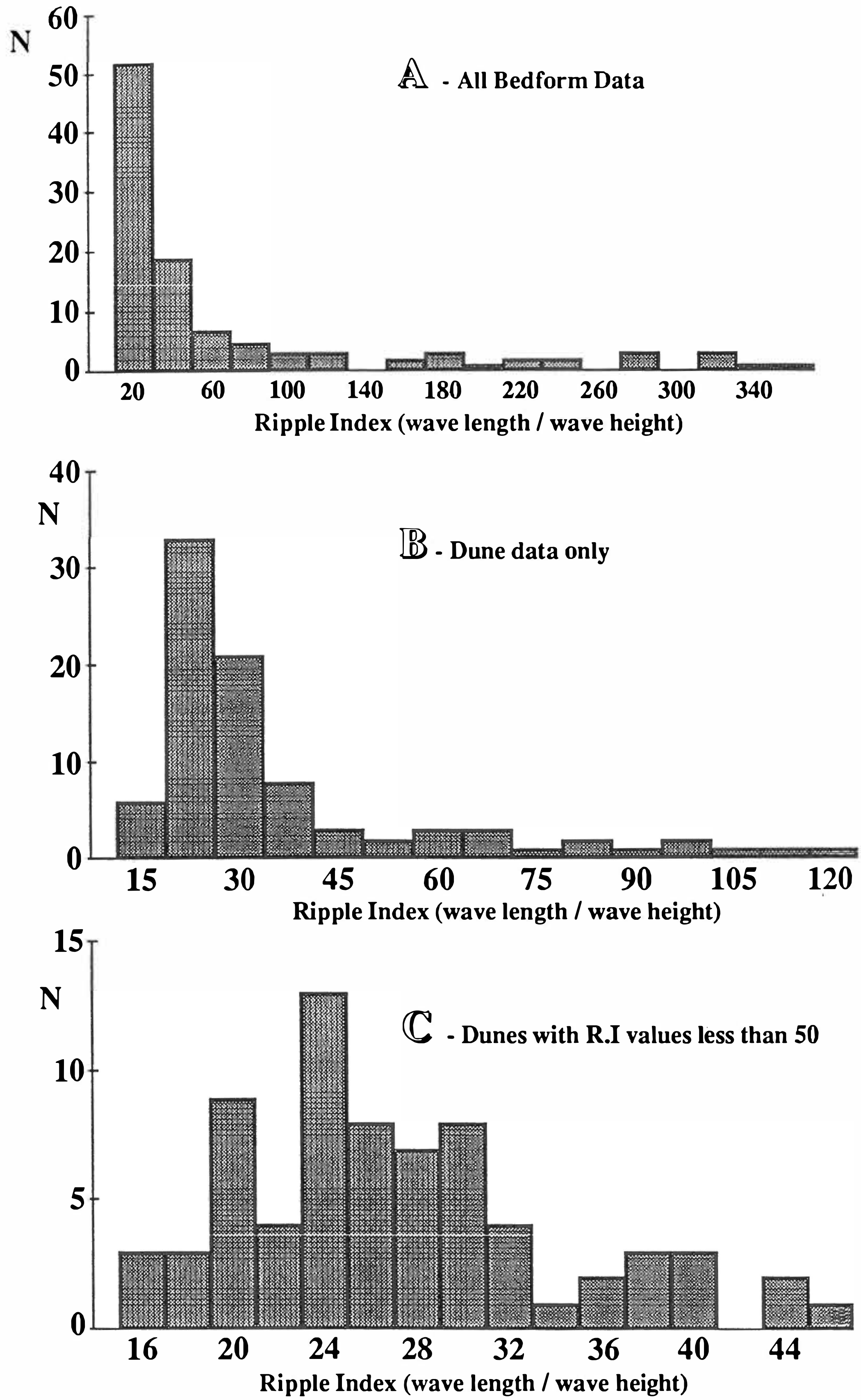


Figure 3.10 : Histograms of Ripple Index data for bedforms in the lower Waikato River, based on measurements from echo sounding traces taken from Hamilton to Puni.

Transition from one bedform to another can occur rapidly. Figure 3.9 shows the change over a short distance from dunes with ripples superimposed (in background, as in Figure 3.7) to a flat bed with only small ripples (foreground, as in Figure 3.8).

3.2.4 Ripple Index

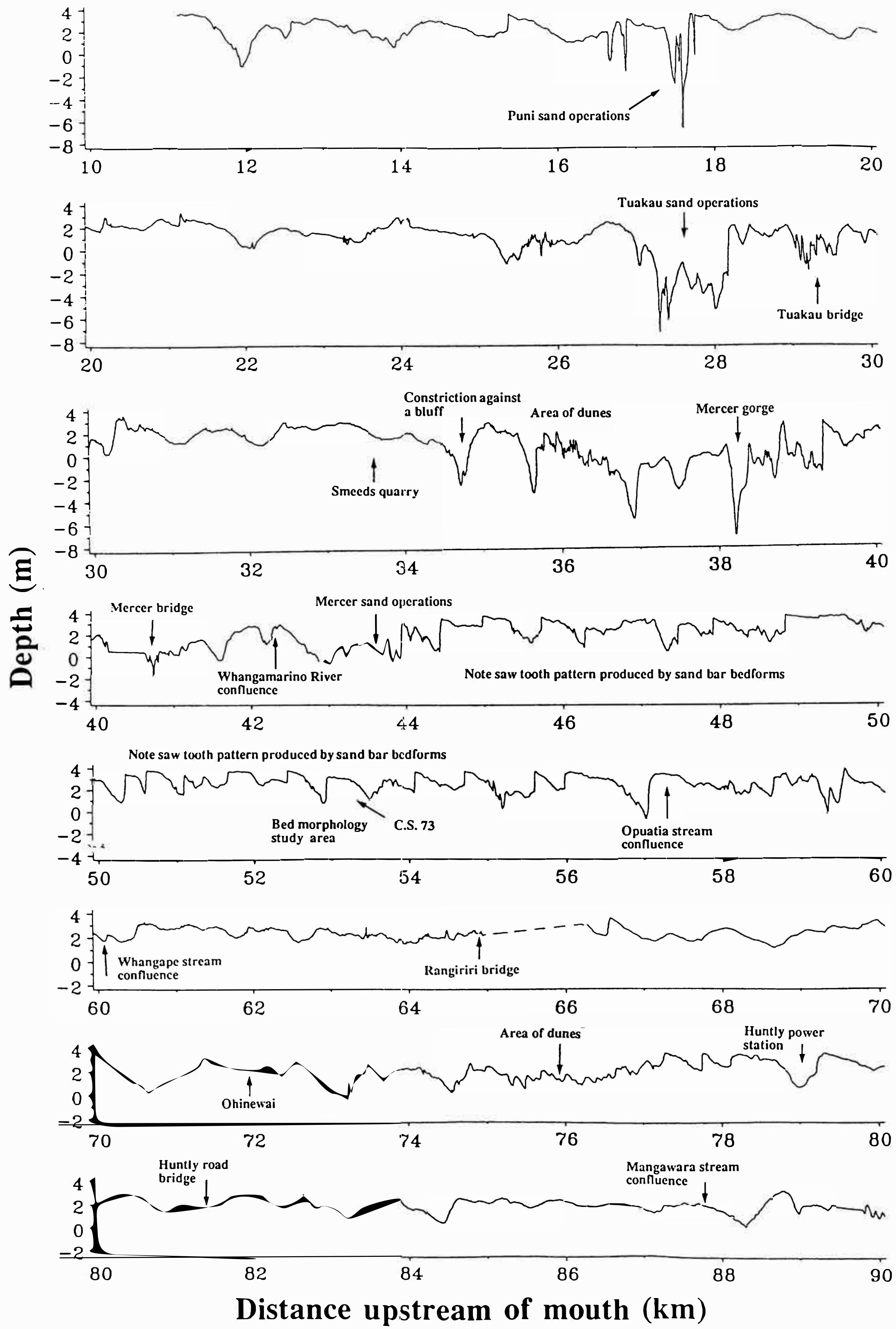
The ripple index (R.I), defined as the ratio of wave length to wave height, can be used to distinguish between different bedform groups (Costello, 1974). Figure 3.5 is an example of two possible different dune groups based on ripple index. The lower Waikato River bars have high R.I values (>150)(Figure 3.3), and are widely distributed when compared with dunes (Figure 3.10A). Dunes are far more common bedforms, hence more data are available, and R.I values for dunes concentrate around the 20 - 50 region (Figure 3.10A and B). From Figure 3.5 there is evidence of two dune populations. Figure 3.10C is an expanded histogram of R.I values less than 50, which again displays a possible bimodal distribution, with modes at approximately 24 and 40. This supports the suggestion for the existance of a population of short steep dunes (R.I $\cong$ 24) and a separate population of longer flatter dunes (R.I $\cong$ 40). Allen (1976b) investigated the effects of discharge patterns on dune population structure, and presents evidence that bimodality can occur in λ and h of dune bedforms, which he attributes to the persistance of large dunes created at high stage into receeding stages. It is therefore feasible that the bimodal dune populations in the Waikato River represent different flow stages or regimes created by differing bed geometry along the river's length.

3.3 LONGITUDINAL CHANGES IN THE RIVER'S CHARACTERISTICS

Physical and hydraulic characteristics of rivers show longitudinal changes. Generally width, depth, stream power, discharge and velocity increase, while slope and bed material size decrease in the downstream direction, according to Knighton (1987). This section investigates variations in bedforms and texture along the lower Waikato River.

3.3.1 Bedforms

Changes in bedforms along the Waikato River from Hamilton to Puni are based on echo sounding traces taken with a *RAYTHEON FATHOMETER*, while travelling approximately down the centre of the channel. However, resolution of the traces only allows the accurate detection and measurement of bedforms greater than 0.1 m in height hence ripples can not be considered in this study. The following trends are observed from the traces (Figure 3.11):



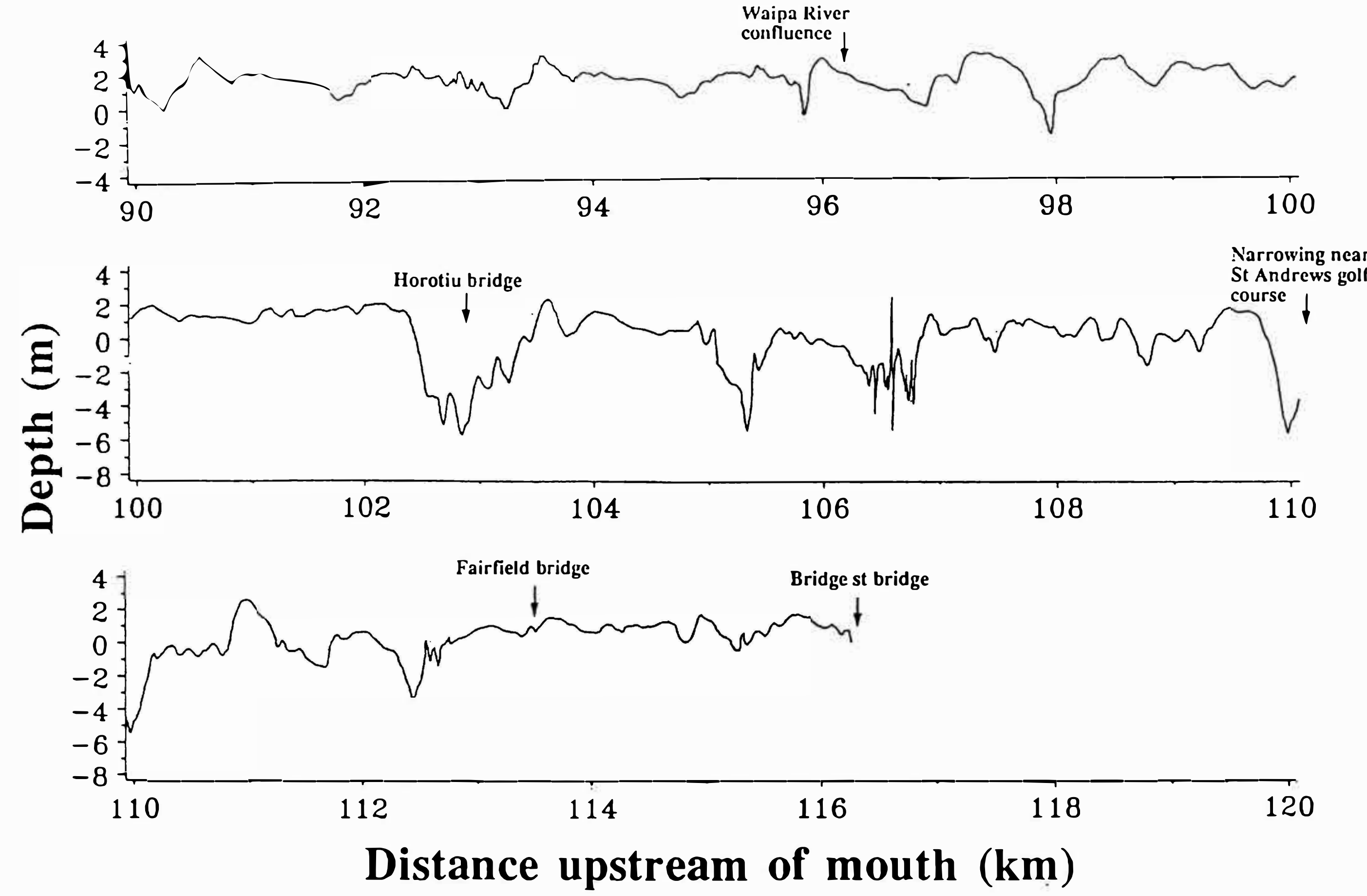


Figure 3.11 :Echo sounding profile of the lower Waikato River from Hamilton to Puni. It shows the variations in bedforms and marked fluctuations in the river bed. The original traces was obtained using a RAYTHEON DE-719B FATHOMETER from the University of Waikato research jet boat while travelling approximately down the centre of the river channel. Four metres depth represents the water surface along the profile.

(1) Hamilton to Horotiu Bridge - isolated areas of small dunes are seen, and ripples are expected to occur over most of the bed . Extreme variations in the bed level are due to channel restriction;

(2) Horotiu Bridge to Ngaruawahia (Waipa River confluence) - the bed is flatter with large areas of dunes (h = 0.15 - 0.25 m);

(3) Ngaruawahia to Huntly - small dunes (h = 0.15 - 0.3 m) dominate the flat areas, while larger dunes occur at 90 km mark due to narrowing of the channel;

(4) Huntly to Rangiriri - large dunes (h = 0.4 - 1.1 m) are seen at the 75 - 77 km zone, however the rest of the bed is devoid of significant bedforms;

(5) Rangiriri to Mercer - the large sand bar bedforms give the echo sounding trace a saw tooth pattern. Small dunes are common over large areas of the bed, while larger dunes can be seen superimposed on the stoss face of bars ;

(6) Mercer to Tuakau - the large bar bedforms do not exist beyond the extraction site. Downstream of Mercer large drops in the bed profile can be attributed to geological restrictions at Mercer gorge, along the outside bend of Te Toki Island and against a bluff of volcanic rock. An area of large dunes occurs in the region of Te Toki Island. From Smeeds Quarry to the Tuakau Bridge the bed is flat and is covered predominantly by small dunes;

(7) Tuakau to Puni - large dunes near Tuakau Bridge (Figure 3.5) are followed by an area of small dunes prior to the Tuakau sand extraction operations. No bedforms appear immediately downstream of the extraction operations. From the 24 km mark downstream to the Puni sand extraction site small dunes cover large areas of the bed.

Generally it is seen that small dunes occur in areas where the bed is relatively flat and wide. A plot of the two different dune types on a bedform phase diagram shows that they occur at opposite sides of the dune field (Figure 3.12). The dunes in the Tuakau region are larger but flatter as they are nearing the transitional zone into the upper plane bed, while the common small dunes that occur over large areas of the river and in this case around Smeeds Quarry occur in the lower part of the dune field. The major fluctuations in bed level can be attributed to channel restrictions (eg. Mercer Gorge, Horotiu Bridge) or sand extraction operations. Immediately downstream of all the sand extraction operations the bed is devoid of detectable bedforms for some distance downstream. This may be due to the impediment of sediment transport in the deep holes formed by the extraction operations.

The ripple index (R.I) shows no correlation with distance upstream (Figure 3.13). The index is however below 100 over most of the river, and increases form both ends of the river to a central zone around 45 - 75 km upstream which contains the bar bedforms with high R.I values (>150).

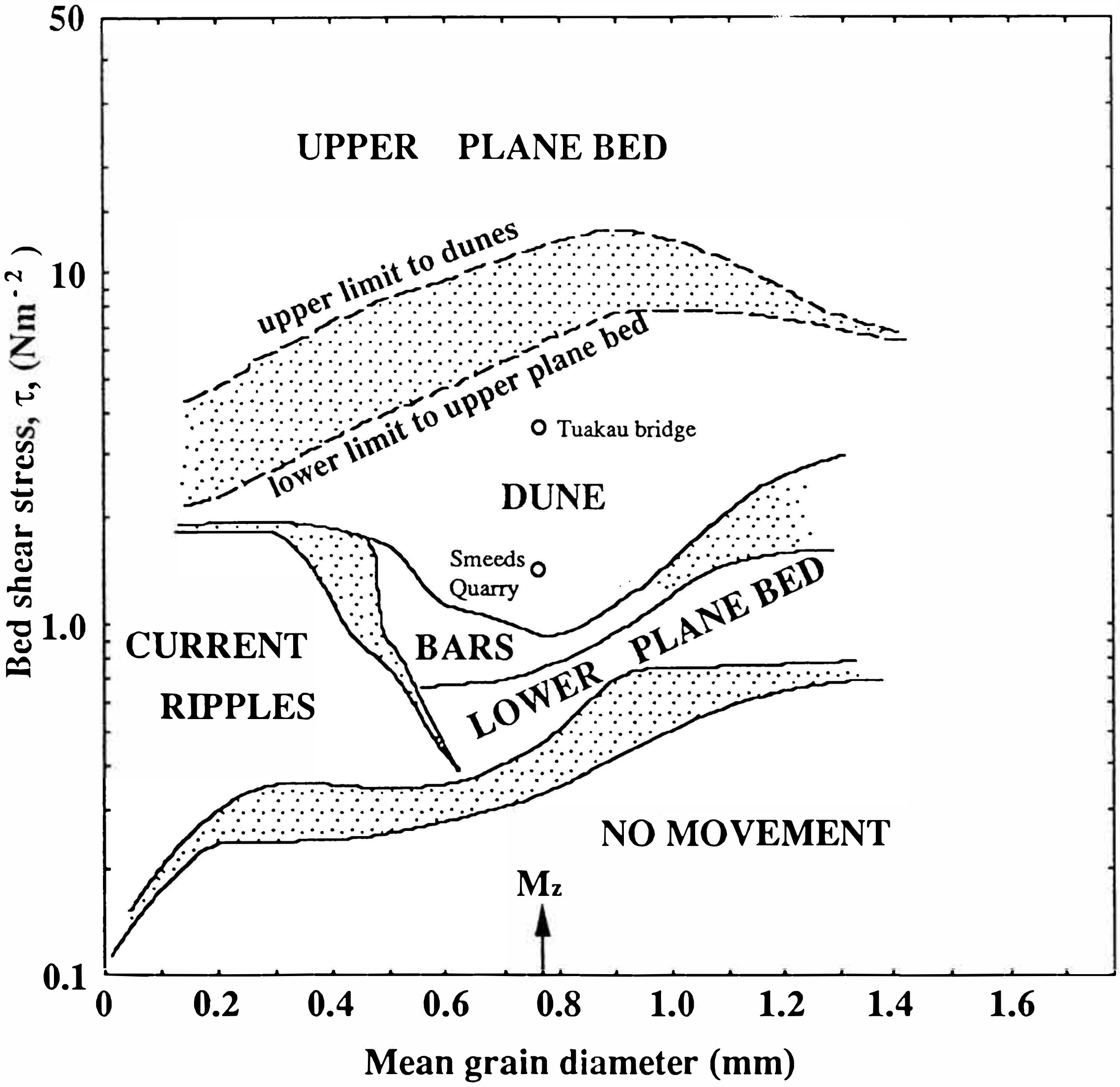


Figure 3.12 : Bedform phase diagram, showing the stability fields of various subaqueous bedforms assumed to be developed by uniform steady flow. The bed shear stress at Tuakau bridge (longer flat dunes) and Smeeds quarry (short steeper dunes) are plotted. The medium grain size (Mz) was assumed to be 0.78 mm at both sites(after, Leeder 1982).

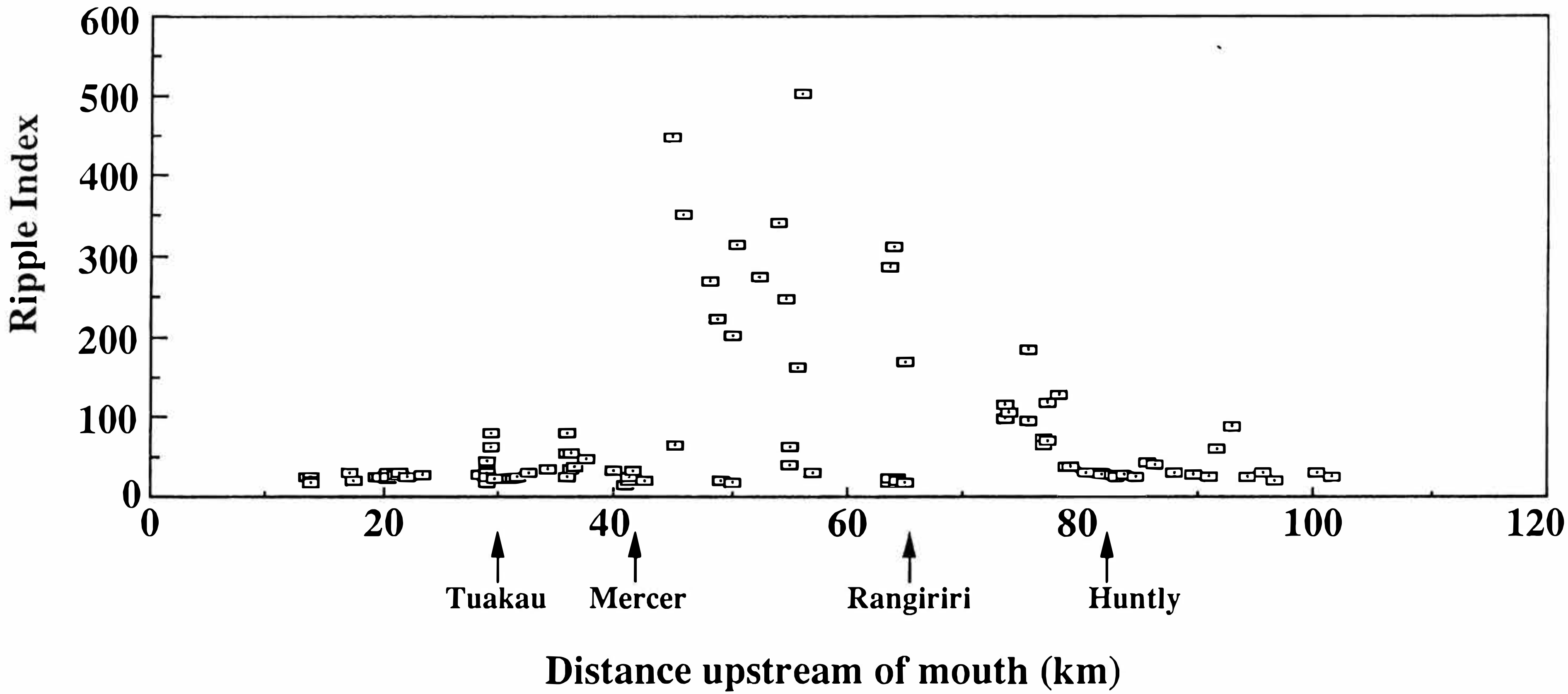


Figure 3.13 : Longitudinal variation in ripple index along the lower Waikato River. The ripple index (wavelength / height) is generally below 100 with a region of high R.I. occurring between Mercer and Rangiriri, where large sand bars are a common feature.

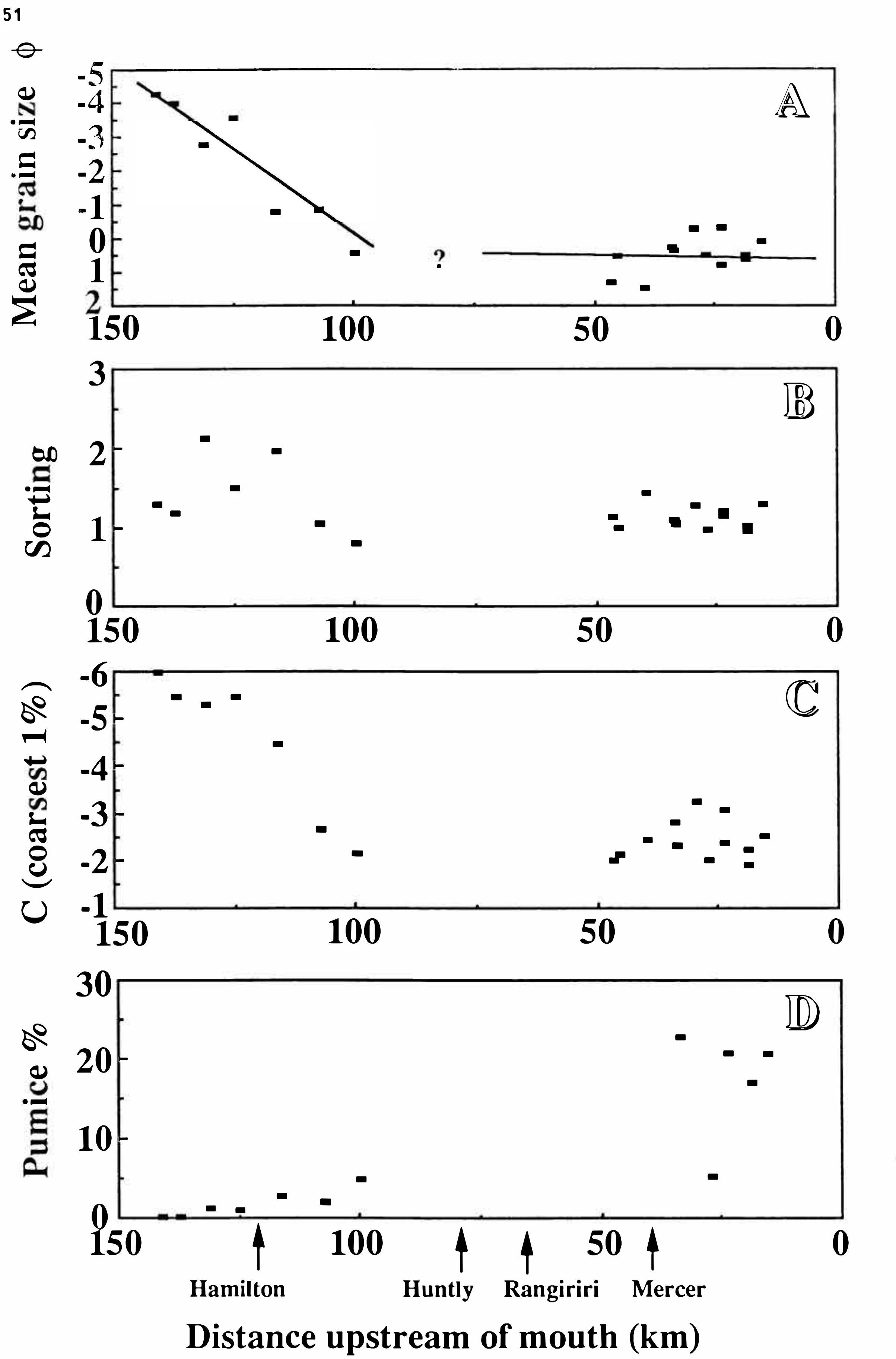


Figure 3.14 : Longitudinal changes in textural parameters in the lower Waikato River.

3.3.2 Textural Variations

The size of bed material may increase or decrease in the downstream direction or remain constant, depending on the geological nature of the drainage basin (Hack, 1957). Generally, however, a reduction in size of the bed material in the downstream direction is common for most alluvial streams. The two sets of processes that are largely responsible for this change in sediment size are abrasion and sorting (Knighton, 1980).

A limited number of bed material samples were taken and analysed to obtain some broad indications about the textural patterns in the lower Waikato River. The samples were analysed for pumice percentage and hand sieved. The grain size statistical parameters were determined using GSIZE (Appendix 6.7). Data from these samples are in Appendix 6 and are plotted in Figure 3.14.

Mean grain size decreases rapidly from the Cambridge area (~ -4Ø, 140 km upstream) towards Taupiri (~ 0Ø, 115 km upstream) (Figure 3.14A). From this point downstream to the Mercer area where the remaining samples were taken it is difficult to see a trend and it is reasonable to assume that a slight decrease in grainsize would occur (Knighton, 1987). The trend observed in mean grain size is supported by the Passega C statistic (defined as the coarsest 1% of the sample), Figure 3.14C. With a sufficiently large data base of textural information it should be possible to accurately define two regimes of changing grainsize with distance, one representing the change in grain size brought about by the downstream effect of the Karapiro dam and the other representing the normal decrease in grainsize associated with the river (Figure 3.14A). The intersection point of the two regimes may then represent the front of downstream degradation resulting from the dam. Williams and Wolman (1984) show a similar trend for the Colorado River downstream of the Hoover dam (Figure 16), in which progressive coarsening of bed material occurs with time.

The degree of sorting increases slightly in the downstream direction (Figure 3.14B), in line with that generally seen in rivers (Knighton, 1980). This is a result of the cumulative effects of local sorting and changes in competence along the river.

Figure 3.14D indicates that pumice percentage increases significantly in the downstream direction. This again can be attributed to the downstream degradation effect caused by the Karapiro dam as pumice, due to its lower density, is preferentially removed from the bed as the armouring process occurs. Coring information presented in Section 5.4 indicates that there has been no significant trend in pumice percentage of bed material for the last 6 m of bed aggradation so the trend seen in Figure 3.14D is a recent feature. However, even under normal river conditions one would expect some enrichment of pumice downstream, as it is likely to be transported preferentially from upstream.

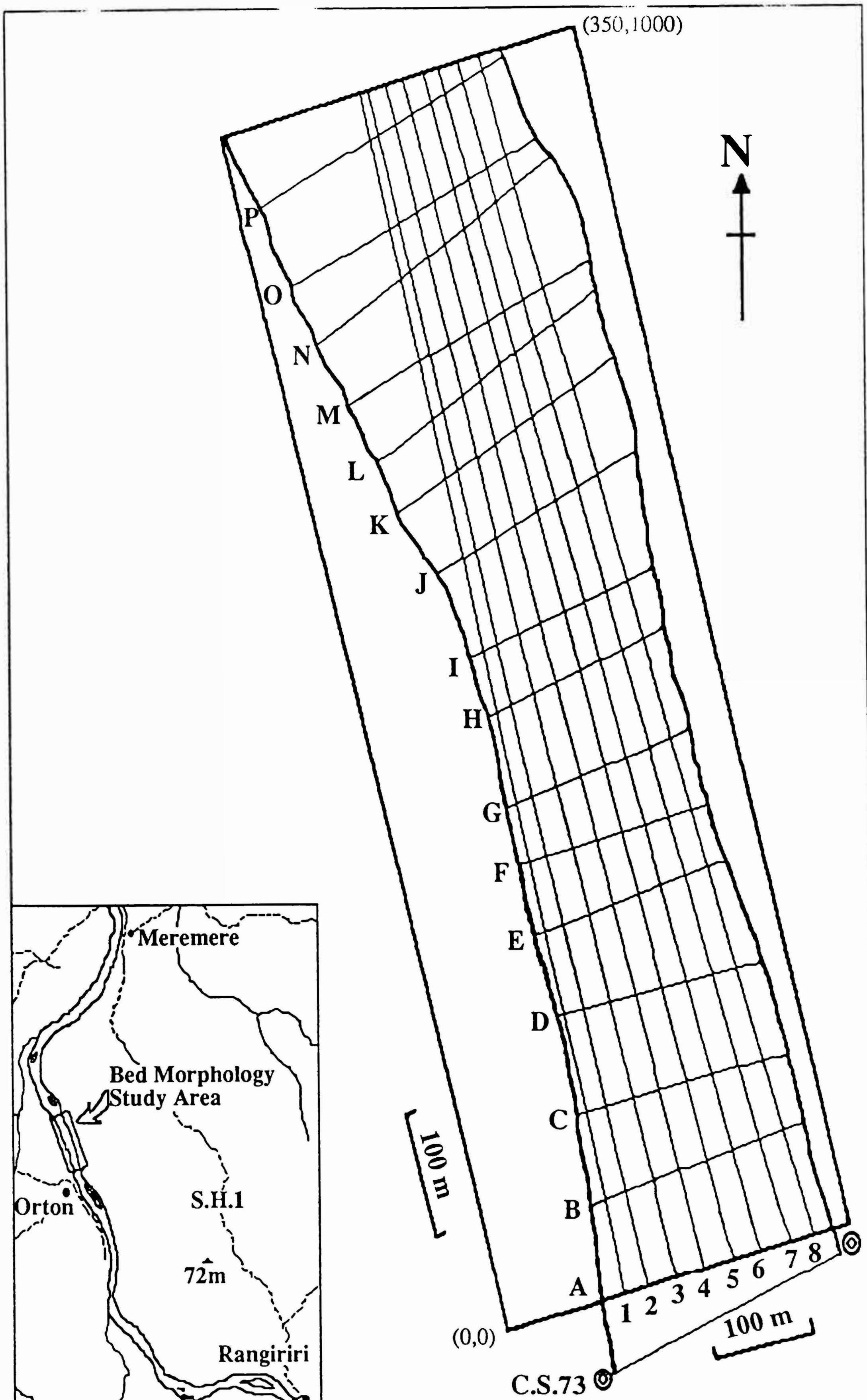


Figure 3.15 : Bed morphology study area. The locations of cross sectional (A-P) and longitudinal (1-8) transects used for surveying are shown. The bordering box represents the grid area used for plotting the three dimensional and contour diagrams.

3.4 SAND BARS IN THE LOWER WAIKATO RIVER

Sand bars dominate the lower Waikato River from Huntly to Mercer and hence strongly influence the morphology, sediment transport and navigability of the river. The sand bars have previously been studied in the lower Waiakto River by Finley (1974), Dahm (1987) and Dahm and Hume (1989). Similar bedforms have been studied by Leopold (1982) on the Colorado River in Arizona, California.

In this section the results of a year long study at Orton are evaluated, with quantification of the size, rate of movement and distribution of sand bars made. Aspects of their formation and behaviour with varying stage are also investigated, and comparisons and contrasts are made with other studies.

3.4.1 Bed Morphology Study Area and Method

A reach of the lower Waikato River was used to study bed morphology over a period of one year. The aim of this study was two fold. Firstly the study was established to monitor the size and rate of sand bar movement over time, in order to gain an estimate of current bedload transport in the lower Waikato River using a similar approach to Finley (1974). Secondly, by displaying the echo sounding data in three dimensions for each survey it was hoped to gain some insight into the changes in bed morphology which occur with the changing flow conditions throughout the year.

The study reach stretches downstream from C.S. 73, for 1000 m (Figure 3.15). The study area was initially surveyed along the left bank, and pegs were placed at known intervals to fix the position and angles of cross sectional transects through the study area (A - P, Figure 3.15). The eight longitudinal cross sections were fixed by placing a nylon rope across the river at C.S.73 and fastening eight brightly coloured buoys to this at 30 m intervals (Figure 3.15). These buoys were lined up with appropriate fixed objects in the distance during the survey to ensure reproducability during separate echo sounding runs. The study area was visited at monthly intervals from February 1988 to January 1989 (except for May 1988, due to equipment failure) to echo sound both the cross sectional and longitudinal transects using a *RAYTHEON FATHOMETER* on the University of Waikato research jet boat.

The monthly surveys are presented as three dimensional diagrams and contour plots. This requires a number of steps in which the echo sounding traces are manipulated into a form acceptable for computer plotting. The steps are as follows:

(1) Echo sounding traces are digitised using a program written for this purpose, DIGIT.PAS (Appendix 6.1). This produces coordinates where depth is standardised to a W.C.B survey datum using a temporary stage board at C.S.73's survey peg on the left bank;

Figure 3.16 : An aerial view of the lower Waikato River at Meremere, showing the sand extraction operations and the size of the sand bar bedforms that occur in this part of the river (photo by T.R.Healy).

Figure 3.17 : The crest of a sand bar. The flow over the crest leaves a distinctive signature on the waters surface. Note how the crest is steeply angled upstream.

(2) Coordinates for the cross sectional and longitudinal traces are corrected to fit the grid of the study area (Figure 3.15, 0,0 bottom left, 350,1000 top right) using the programs SCOORDS.PAS (Appendix 6.3) and LCOORDS.PAS (Appendix 6.2) respectively. These programs produce three dimensional coordinates from the two dimensional traces given the X and Y coordinates at the ends of the cross section and longitudinal transects;

(3) Longitudinal data, and data for the left and right banks are used by the program BEDFORM.PAS (Appendix 6.4) to produce two extra data points between each transect and the bank at approximately 10 metre intervals downstream. These extra points are calculated using simple linear interpolation and are required to produce an accurate plot as it results in an approximate gridational spread of data points;

(4) Data points between the banks and transects are manually corrected using the cross sectional transect data. This is neccesary as the linear interpolation produces an artificial smooth slope between the much higher banks and the adjacent echo sounded transects; and

(5) The resulting data files for each monthly survey are then plotted as a three dimensional diagram and contour plot using SAS GRAPH plotting programs, Appendix 6.5 and 6.6 respectively.

3.4.2 Sand Bar Morphology

Shape and Location

Characteristically bars are highly variable in wavelength, height, width and channel morphology (Costello, 1974). In the lower Waikato River sand bars show a wide range of wavelength, 150 - 500m and height, 0.8-1.8m (Figure 3.3B). Aerial photographs clearly show this variation. At the base of Figure 3.20 the two smaller bars cover about half a channel width at the crest and are resonably symmetrical, while further downstream the next two bars are significantly wider, being about 2/3 channel width at the crest and are unsymmetrical with the crest tapering strongly upstream away from the bank. At the extreme bars can almost occupy the entire channel, reaching within a few tens of meters of each bank (Figure 3.16).

The spacing of bars tends to be fairly regular along straight reaches (Figure 3.20), indicating that their formation and movement are related to some regular process, such as a meandering thalweg. On the larger scale however the spacing is less regular when the effects of bends and islands influence the flow (Figure 3.11, 44-56 km).

The crests of the bars are formed by an advancing slip face of sand. Flow over the crest forms a narrow turbulent zone at the surface, which makes the isolation of bars and estimation of their size easy in the field (Figure 3.17). Sand deposited on this steep face is loosely packed and unstable, with the upstream slope of the bar unable to support any appreciable weight for ten's of metres back from the crest. The crests form a variety of shapes from gently curved symmetrical to steeply angled upstream unsymmetrical. The main crest can be comprised of overlapping 'sub-crests'. These 'sub-crests' occur with height differences of 0.25 - 0.5 m, the shallower crest appears to advances over the, slower moving, deeper crest.

A complex hierachy of bedforms can exist on the upstream face of the bar, with superimposition of dune bedforms across large areas (Figures 3.6 and 3.7) on top of which smaller ripples can be superimposed.

Aerial Photographs - An Alternate View of Sand Bars

Aerial photographs provide a perspective of bar bedforms that is difficult to appreciate at river level. In this section aerial photographs are presented for the position of river from cross section (C.S.) 73 downstream to the top end of the river training reach, including the bed morphology study area (Figure 3.15), for three different periods :

April 1942	Figure 3.18
May 1979	Figure 3.19
February 1983	Figure 3.20

The three photographs were all taken during the summer to autumn period when river flows are relatively low. Several other sets of photographs from different times of the year were looked at, but in medium to high flows the sand bars can not be seen. Figure 3.19 was taken during May 1979, at medium flow, and the clarity of bedforms is low, with only the larger bedforms showing through.

The alternating bar sequence seen in these figures (especailly Figure 3.20) compares closely to that studied by Leopold (1982) in the Colorado River, California (Figure 3.21).

In Figure 3.20 muddy flow on the right side of the channel in the vicinity of C.S.73 shows how the flow is deflected around the sand bar, producing a lense of clear water to the right of the bar. A meandering thalweg is seen along the channel (darker zone), and a large bar occurs near the right bank just upstream of island A (Figure 3.18). This same thalweg pattern can be seen in all the aerial photographs (Figures 3.19 and 3.20).

Bars are often seen to occur in the same parts of the river, and for this reason they are often considered to be semi-permanent features. This is not unexpected for point bar features, which are related to bends in the river, and can be seen to occur downstream of island B (Figures 3.18 and 3.20). However the meandering thalweg pattern seen in the straight reach downstream of C.S. 73 does appear to alter, with the bar sequence immediately upstream of island A in Figure 3.20 being out of phase with the pattern seen in Figures 3.18 and 3.19. It can be envisaged that as the bars migrate, the bar immediately upstream of island A in Figure 3.20 will pass along the island, and the rest of the sand bar pattern will again be in phase with the other photographs.

Figure 3.18 : Aerial photograph mosaic, April 1942, lower Waikato River, Orton area. This reach of river includes the bed morphology study area and shows the size, spacing and location of the sand bar bedforms.

Figure 3.19 : Aerial photograph mosaic, May 1979, lower Waikato River, Orton area.

Figure 3.20 : Aerial photograph mosaic, February 1983, lower Waikato River, Orton area.

Figure 3.18

Figure 3.19

Figure 3.20

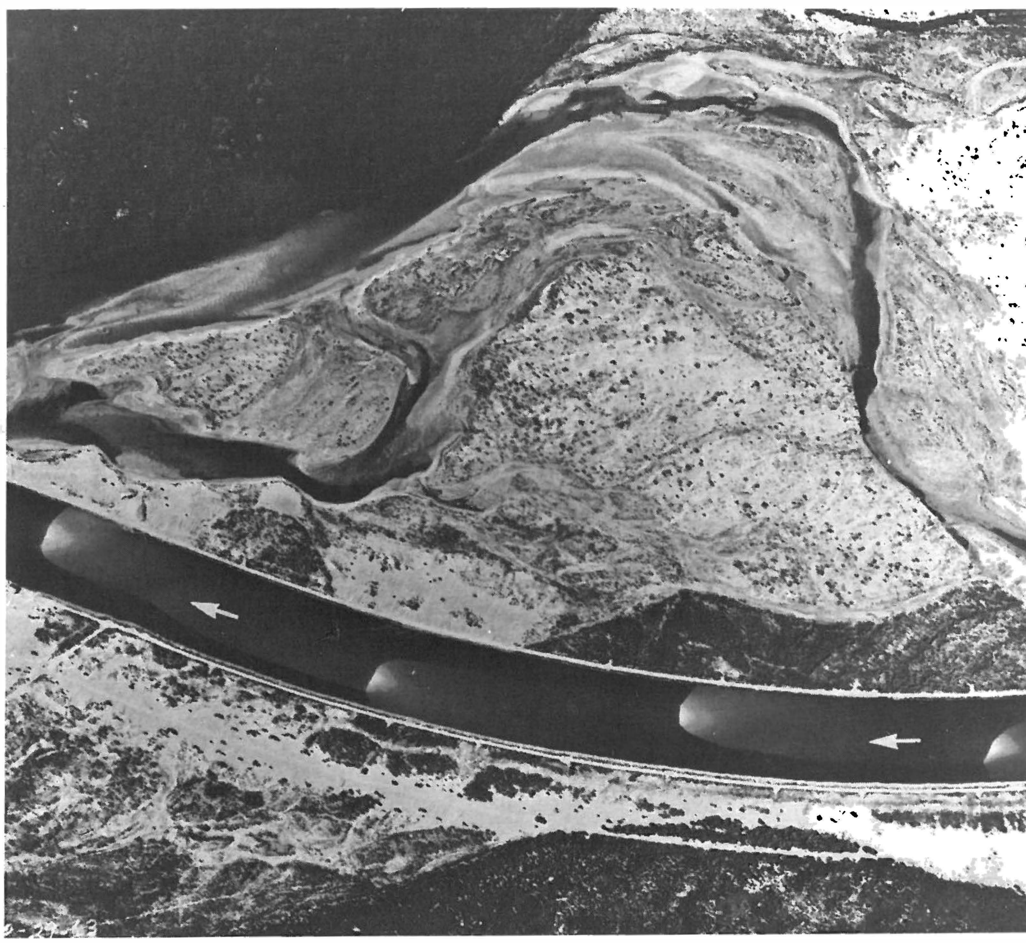


Figure 3.21 : Aerial photograph of alternate bar pattern in the Colorado River, California (after Leopold, 1982).

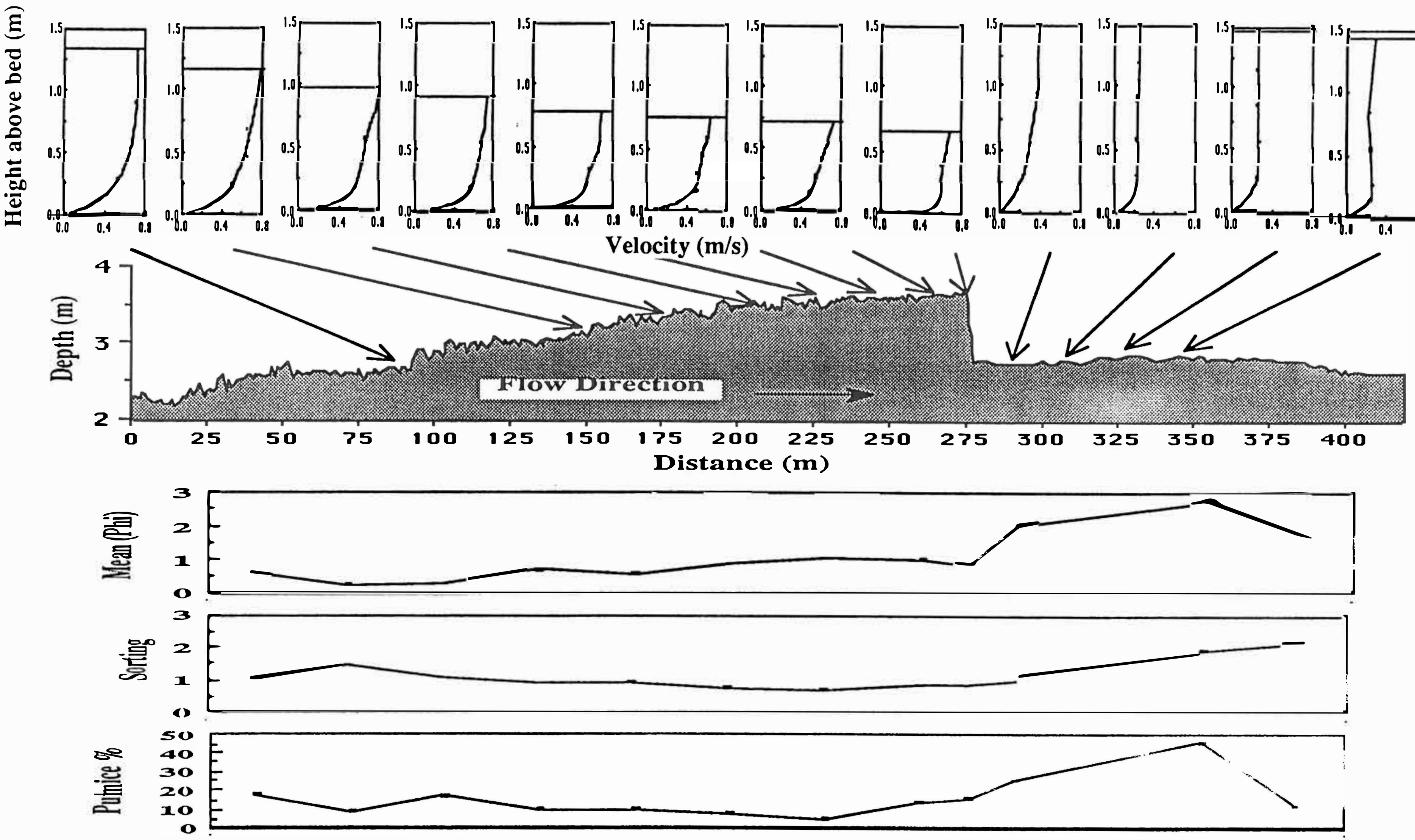


Figure 3.22 : Textural variation and flow characteristics across a sand bar. Velocity profiles were measured and sediment samples taken at approximately 20 m intervals across a sand bar. Textural analyses of the sediment indicate subtle variations in mean grain size, sorting and pumice percentage. The velocity gradient above the bed increases towards the crest, but drops away rapidly downstream of the crest.

Meanders in the thalweg measured from the aerial photographs produce a wavelength of 1100 to 1400 m, which is considerably shorter than that found by Dahm (1987) of 2800 to 3000 m in the Huntly reach.

The effects of river training works that were undertaken by the Waikato Catchment Board (Section 2.1.1) can be seen at the top of these aerial photographs with a marked reduction in channel width and sediment infilling behind the training works. Figure 3.17 also shows the river training works and their effect on channel width. This aerial photograph also displays the extent of the sand bars.

Texture Variation

Variations in texture on, and in the vicinity of bar bedforms will occur with changing stage. Results from sampling at a summer low stage are presented in Figure 3.22. From this only subtle variations in mean grain size and sorting are seen along the upstream side of the bar. Notable changes in the textural parameters occur downstream of the crest. Visual observations of several bars at this flow showed that in all cases the bed immediately downstream of the crest is covered with 2-3 cm of soft mud material. The mud lense extended for some distance downstream with the sample at 350 m (75 m downstream of crest) being 19% mud.

These textural variations are evidently controlled by the flow velocities across the bar. A series of velocity profiles across the bar (Figure 3.22) show that the velocity gradient near the bed increases towards the crest, reaching a maximum at the crest. Downstream of the crest the velocity gradient near the bed is markedly lower. The near surface velocities drop away quickly, from about 0.7 m/s on the upstream face of the bar, to 0.4 m/s immediately downstream of the crest. The velocity profile becomes more uniform downstream as the effect of the high velocity over the crest reduces. This high velocity zone is probably responsible for transport of finer sands and pumice past the crest. In Figure 3.22 poorer sorting downstream of the crest is due to the mixing of underlying sand with the muds during sampling. The presence of silt and mud at the front of the bar implies a closed system with respect to sand transport by the bar, i.e sand transport stops at the crest face, this therefore means that rate of bar movement along the bed can be used to estimate rates of bedload transport (Chapter 4).

The diversity in localised flow patterns across the sand bars is reflected in the complexity of bedforms that appear superimposed on the upstream faces. Figure 3.9 is an example of how over a short distance the flow can change sufficiently to give rise to two different types of bedforms side by side.

3.4.3 Formation and Migration of Sand Bars

From monthly surveys of the study area outlined in Figure 3.15, the progress, formation and morphological changes in the bar bedforms with varying discharge can be studied. As outlined in Section 3.4.1 each survey is plotted as a three dimensional and contour diagram. These are presented in Figures 3.23A to K, and are the basis of the following discussion.

Relationship Between Sand Bar Dynamics and Sinuous Flow Patterns within the channel

Two main bed morphology configurations were observed in the bed morphology study area (Figure 3.24). The first configuration occurred during the period February - July 1988, when only one definable bar bedform was present in the study area. This bar moved out of the study area between April and June, however the position of its crest was tracked until July 1988. The main flow line was from right to left moving downstream. No bar bedforms were present in the study area during the period August - October 1988. The second configuration was observed from November 1988 - January 1989, when two bars were seen in the area and the main flow line was from left to right moving downstream.

The alternating bar bedforms are be related to the presence of meandering flow along the river channel. The lines of maximum flow in Figure 3.24 are determined from cross section traces as the deepest point of flow (Figure 3.25A). Where the meandering flow crosses over the channel the cross section trace is broad and flat making it difficult to isolate a zone of maximum flow (Figure 3.25B). As the flow crosses over the channel it appears that a large portion of the flow spreads out across the channel and flows up across the back of the bar bedform immediately downstream. This is depicted by the arrows in Figure 3.24. This flow produces the mechanisim for the advancement of the bar, as it is sufficient to transport sediment across the stoss face of the bar and deposit it at the slip face marked by the crest. The flow is seen in the field to radiate across the bar bedforms and locally the flow across a crest can be angled slightly away from the direction of the channel towards the bank. Leopold (1982, Figure 13.3) shows streamlines of flow to meander around the bars, with stream lines also tending to spread out and flow up and across the bars, similar to that proposed for the study area. The flow passes over the crest and joins the main flow either in the region of the crossover or flows off to one side of a bar and joins the channel of flow that tends to occur past one or two sides of the bar (Figures 3.25A and C).

The morphological and flow pattern changes observed during the study are as follows:

(1) in February 1988 a straight crested bar was positioned in the bottom half of the study area. It was asymmetrical in shape with the bulk of its volume occurring near the right bank. During the next three months this bar moved towards the bottom end of the study area,

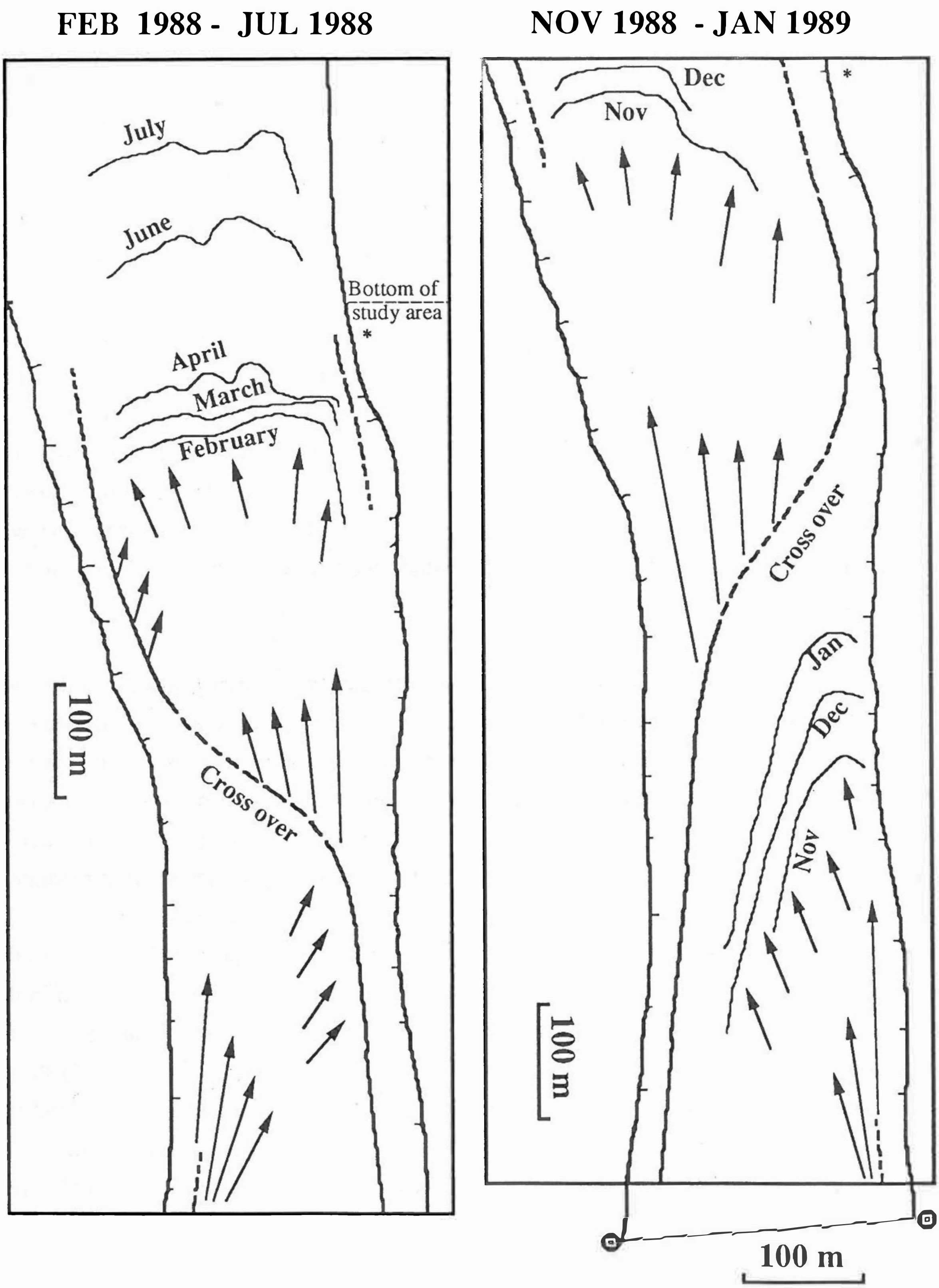
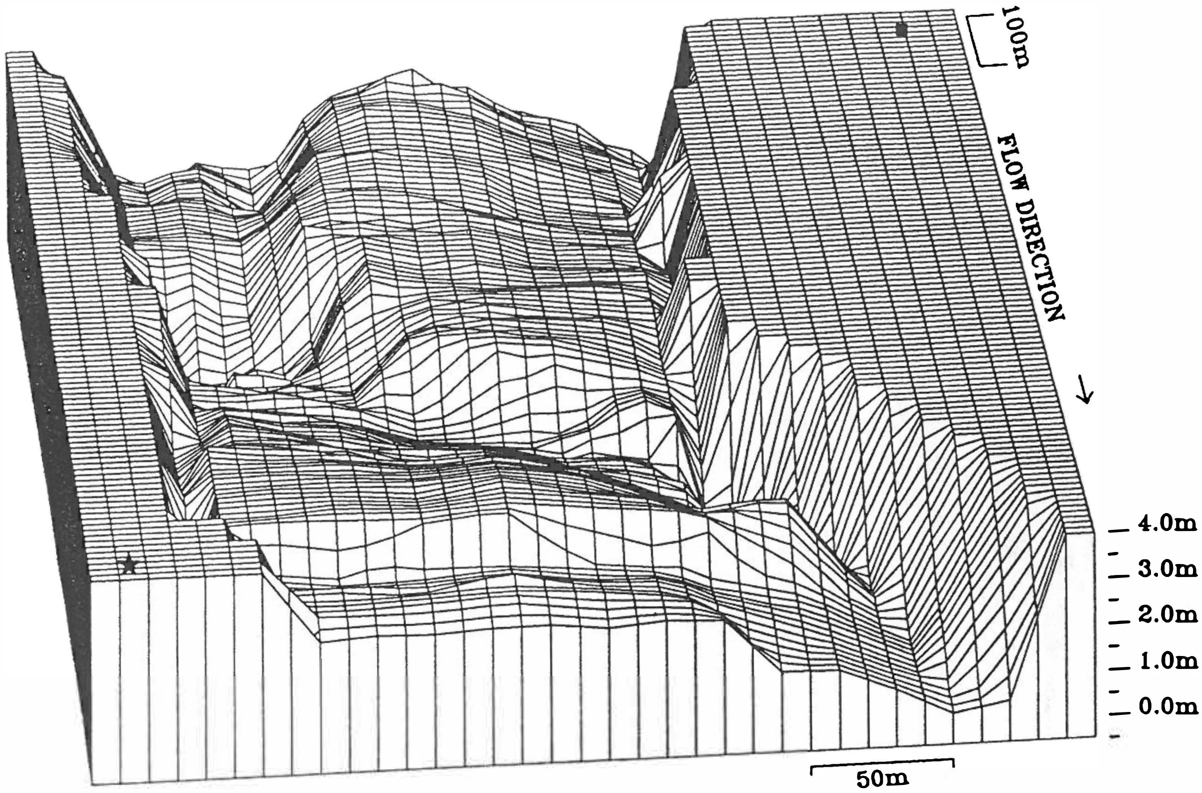


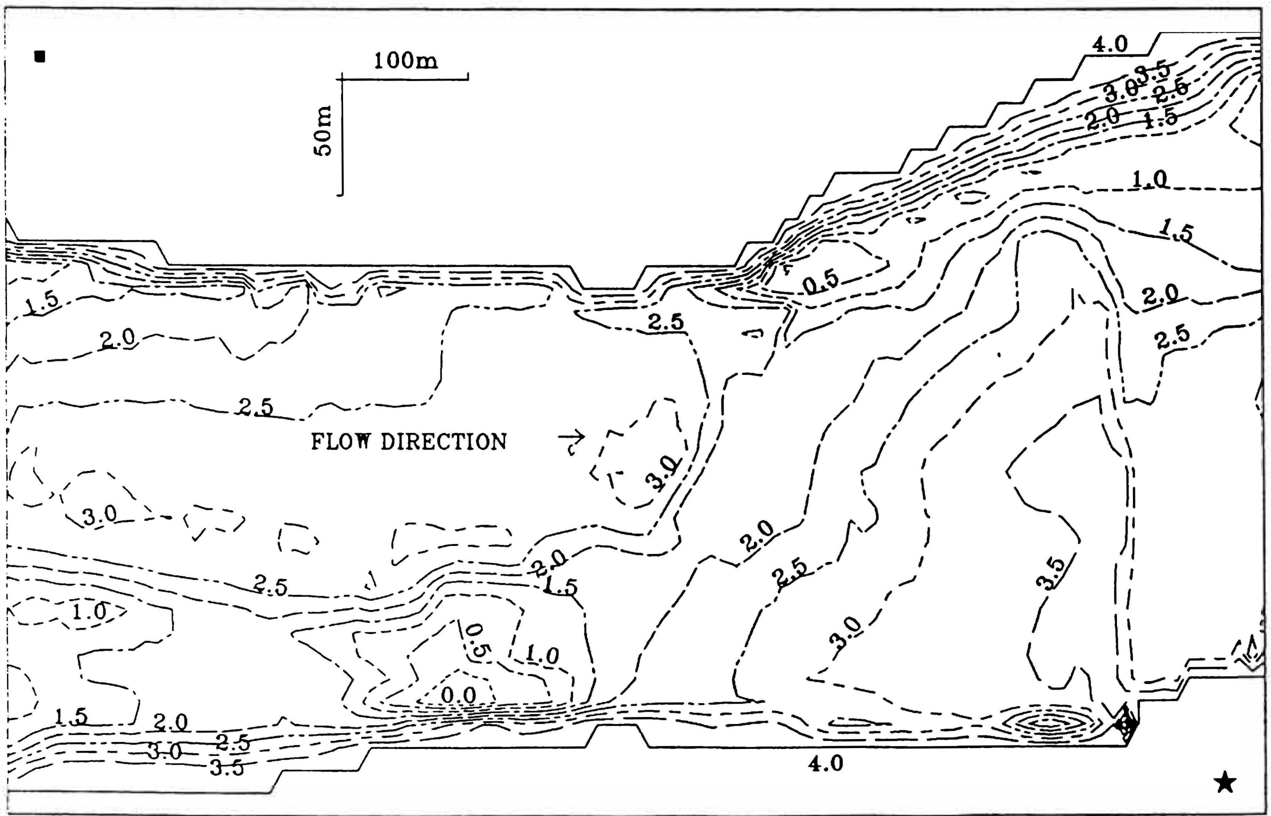
Figure 3.24 : Crest positions of sand bars during surveys, and inferred major flow patterns. Arrows indicate patterns of flow to and from areas of inferred main flow. * indicates relative positions on both diagrams.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 25/2/88



CONTOUR DIAGRAM OF STUDY AREA ON 25/2/88

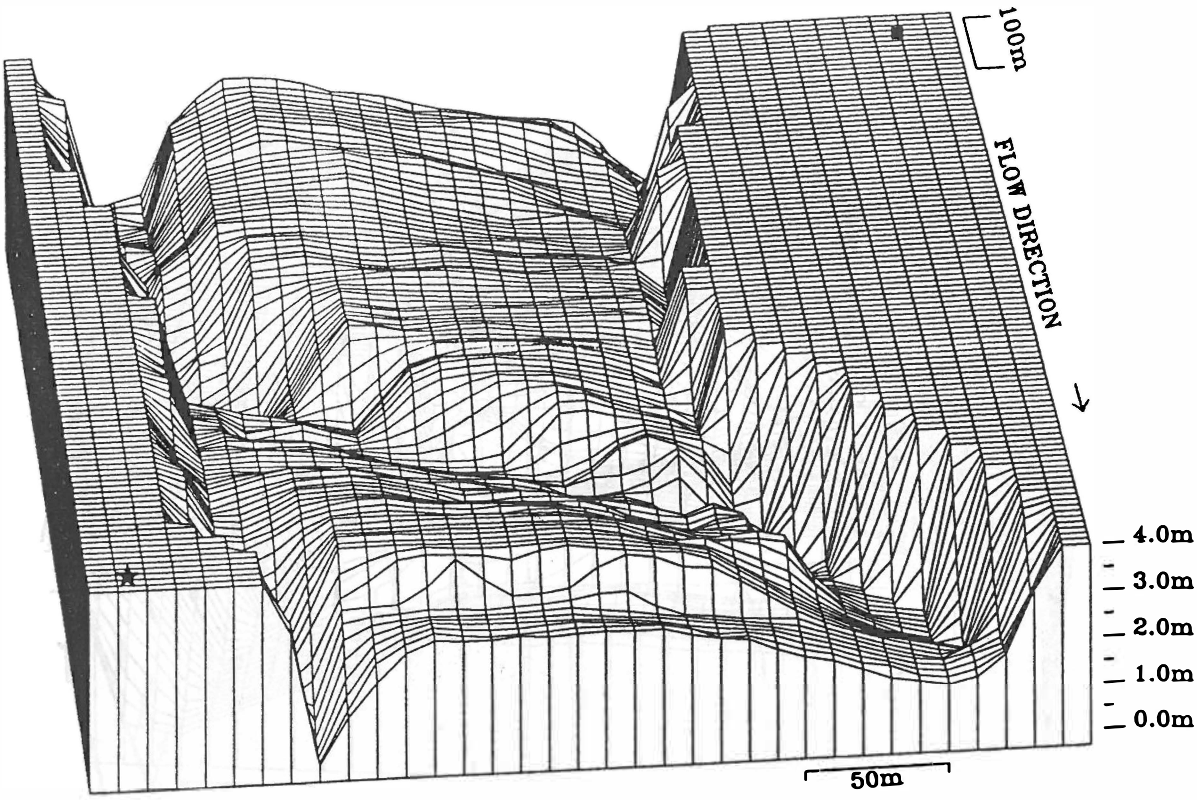


Contours at 0.5m intervals above W.C.B survey datum.

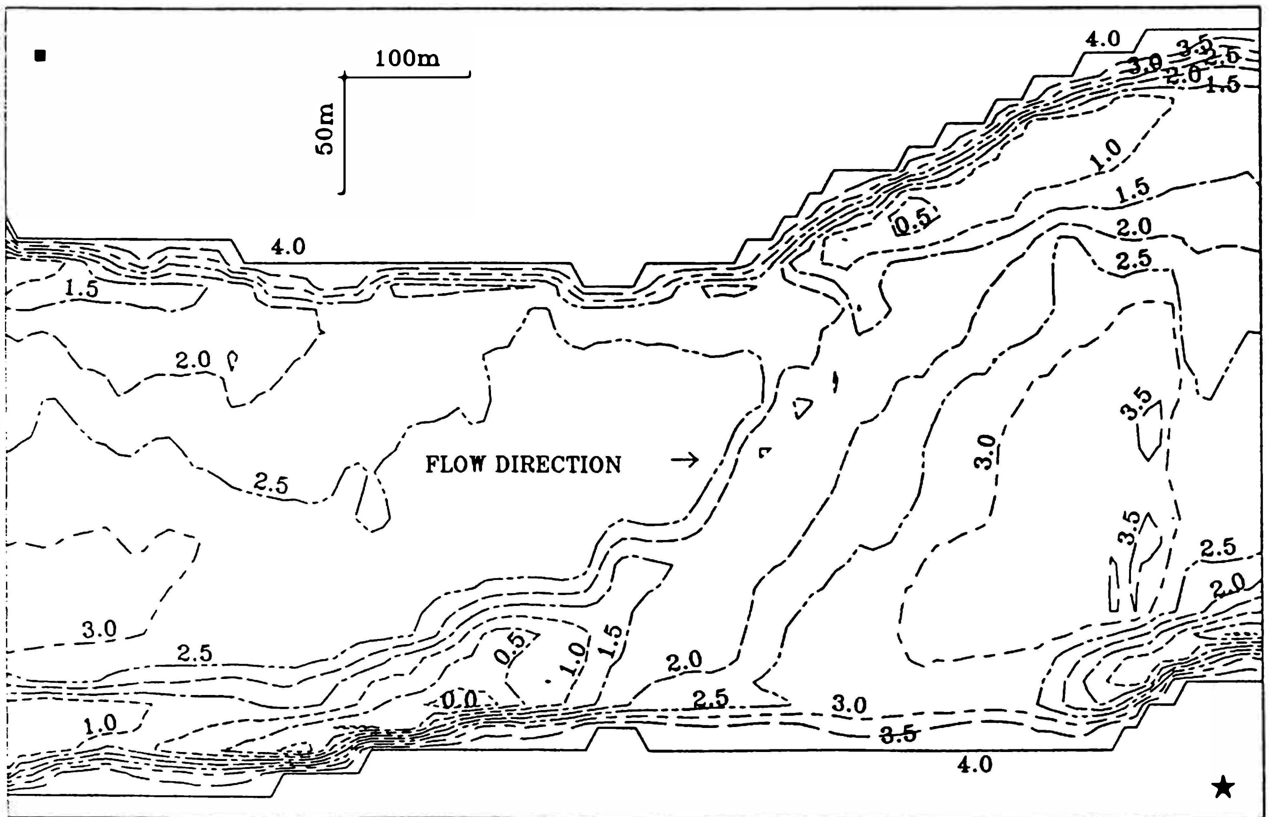
Figure 3.23A : Three dimensional and contour plots of the bed morphology study area, 25th February 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 17/3/88



CONTOUR DIAGRAM OF STUDY AREA ON 17/3/88

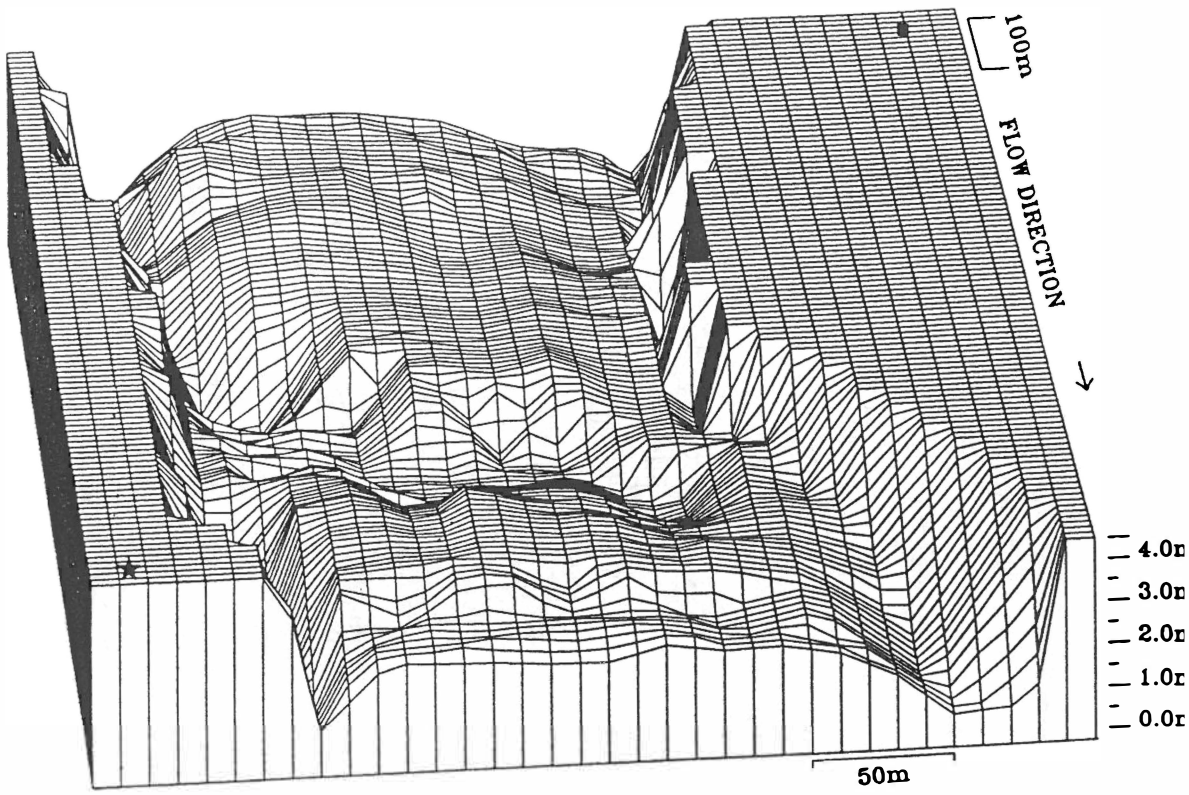


Contours at 0.5m intervals above W.C.B survey datum.

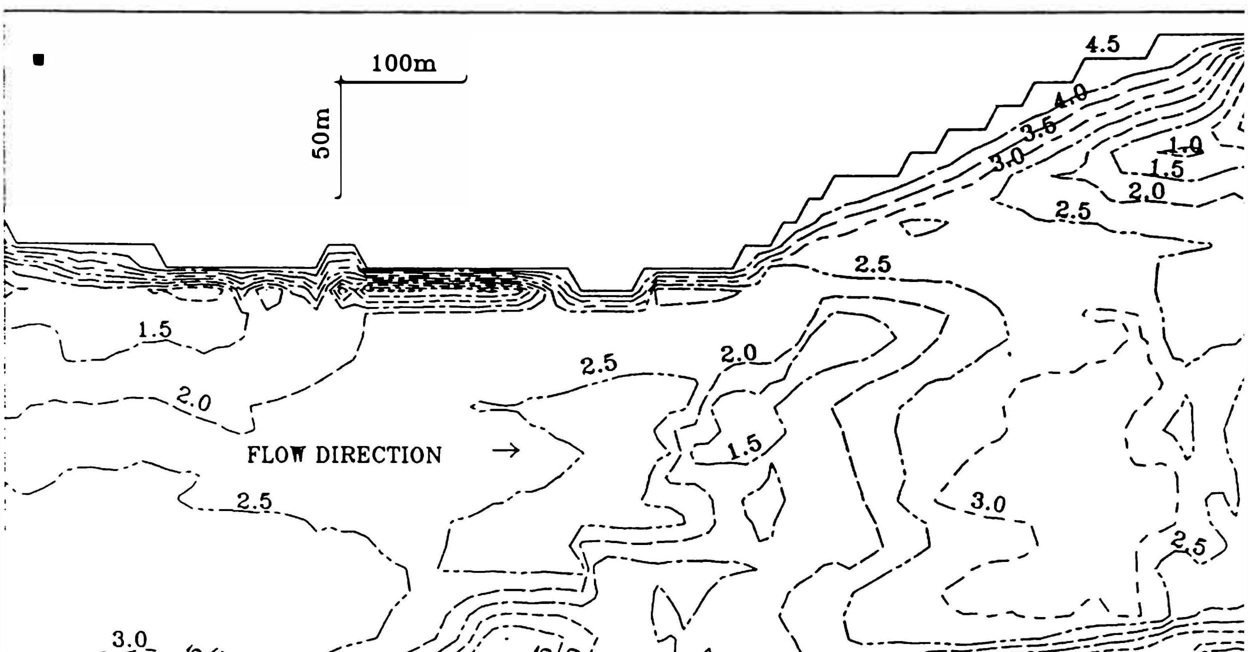
Figure 3.23B : Three dimensional and contour plots of the bed morphology study area, 17th March 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 14/4/88



CONTOUR DIAGRAM OF STUDY AREA ON 14/4/88

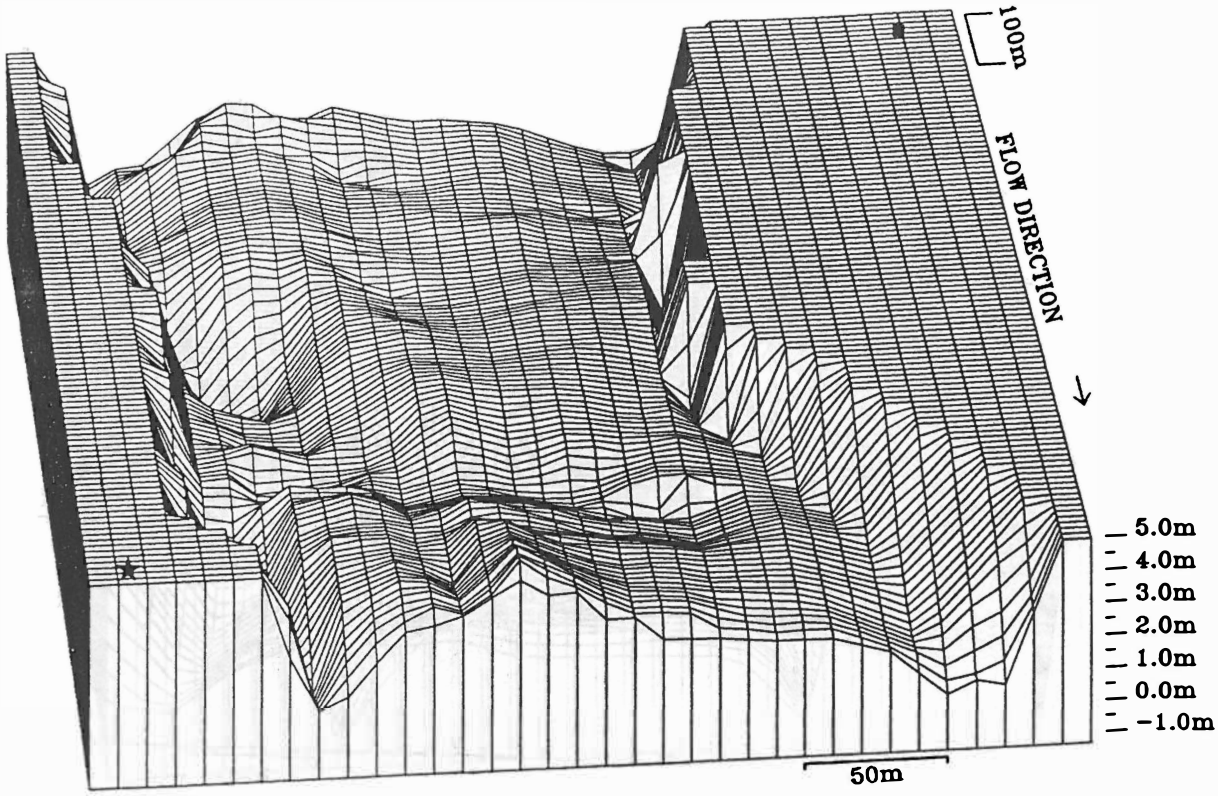


Contours in meters above W.C.B survey datum.

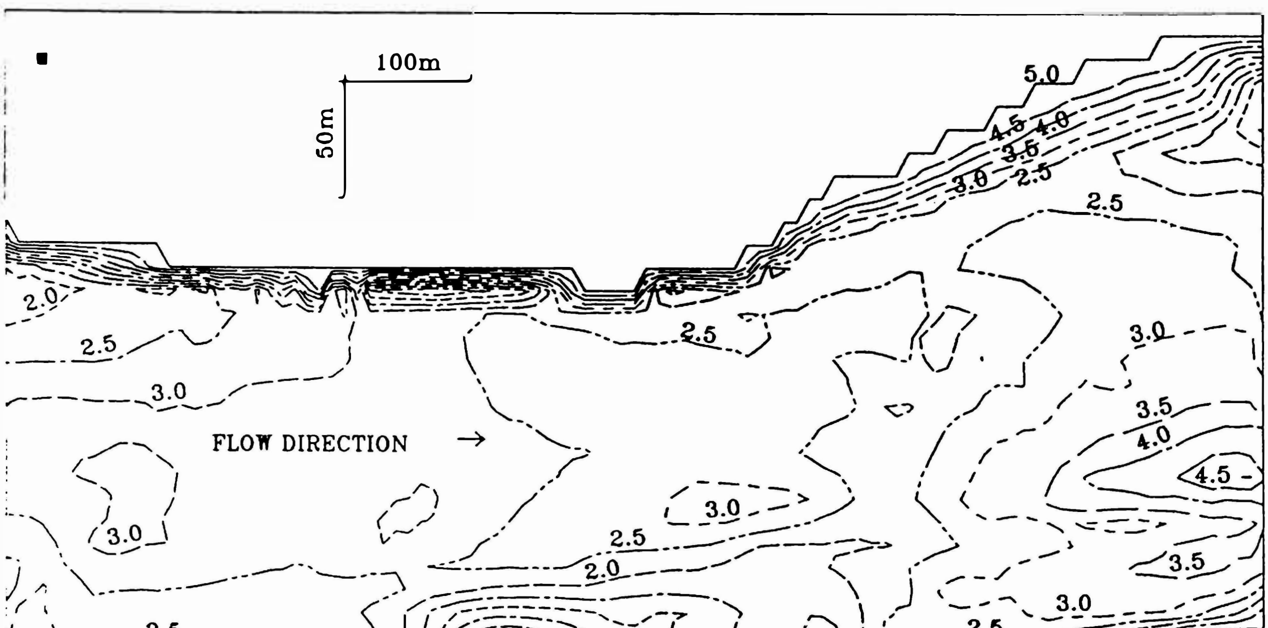
Figure 3.23C : Three dimensional and contour plots of the bed morphology study area, 14th April 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 13/6/88



CONTOUR DIAGRAM OF STUDY AREA ON 13/6/88

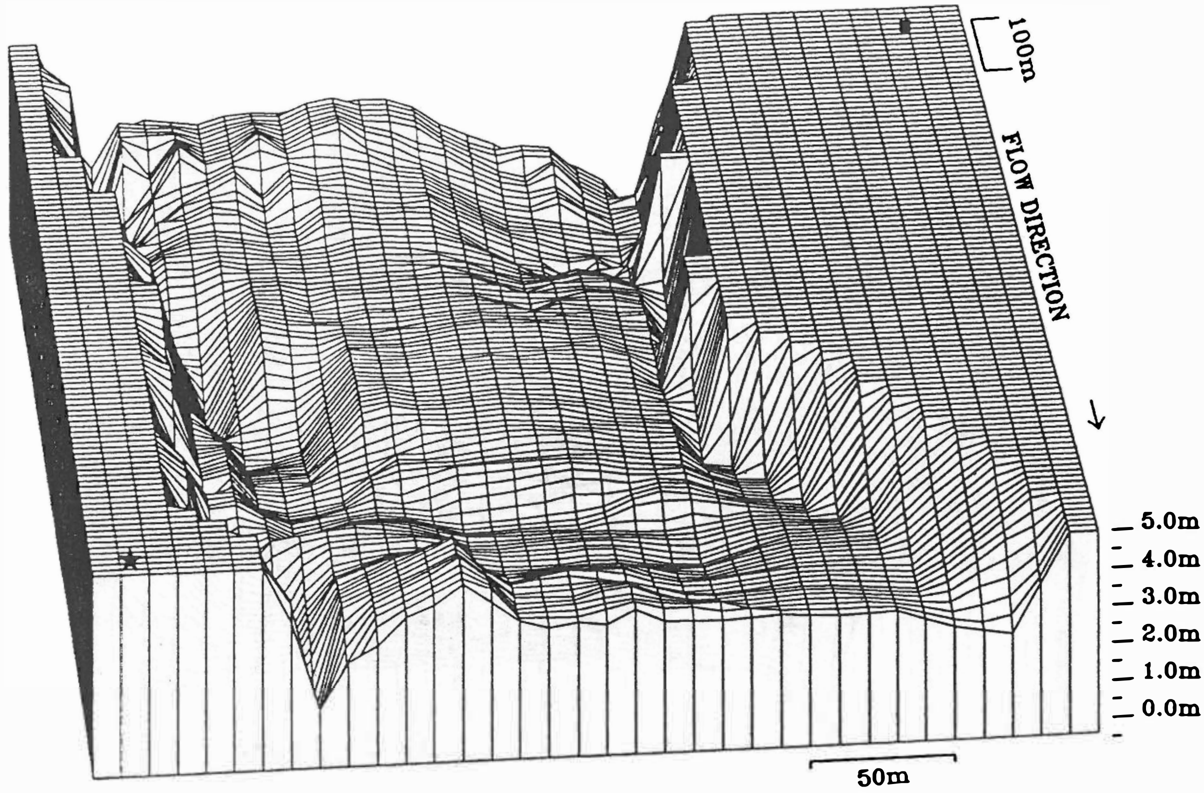


Contours at 0.5m intervals above W.C.B survey datum.

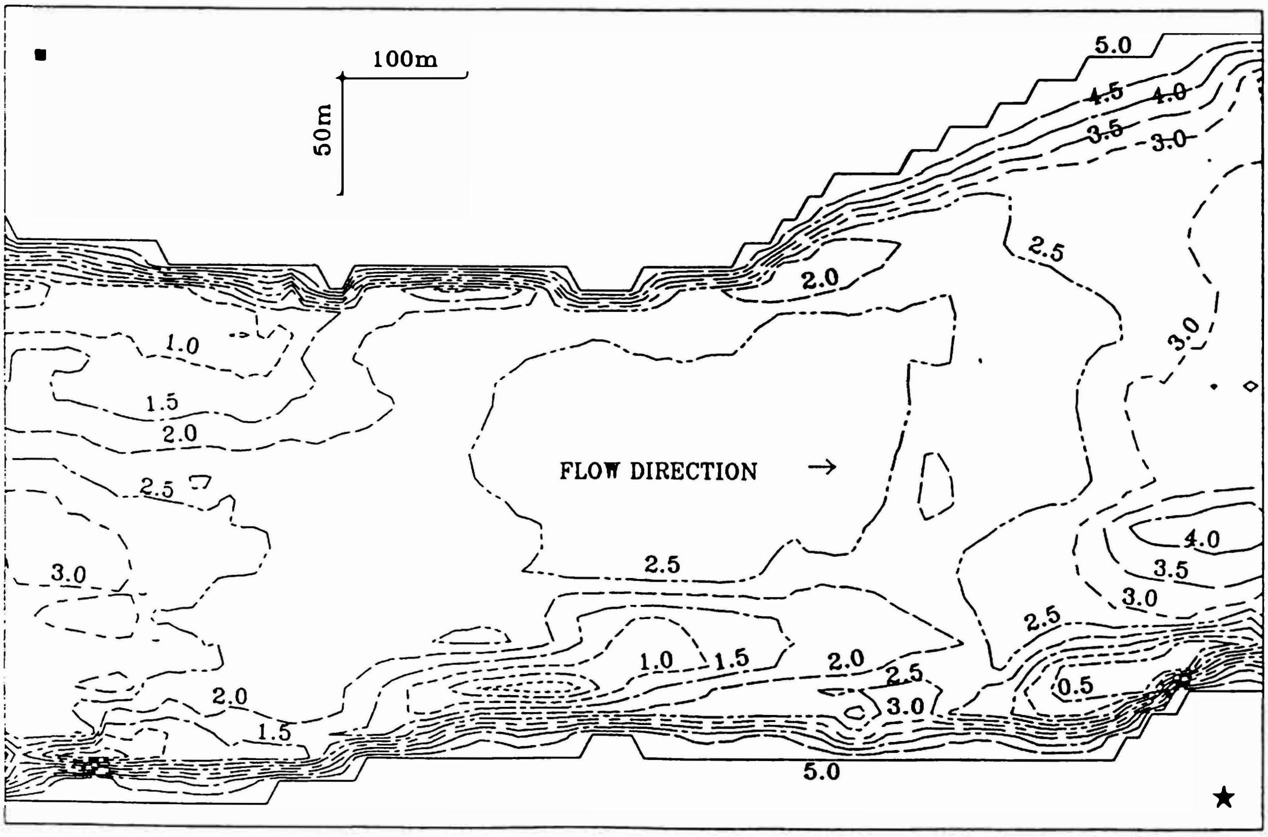
Figure 3.23D : Three dimensional and contour plots of the bed morphology study area, 13th June 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 6/7/88



CONTOUR DIAGRAM OF STUDY AREA ON 6/7/88

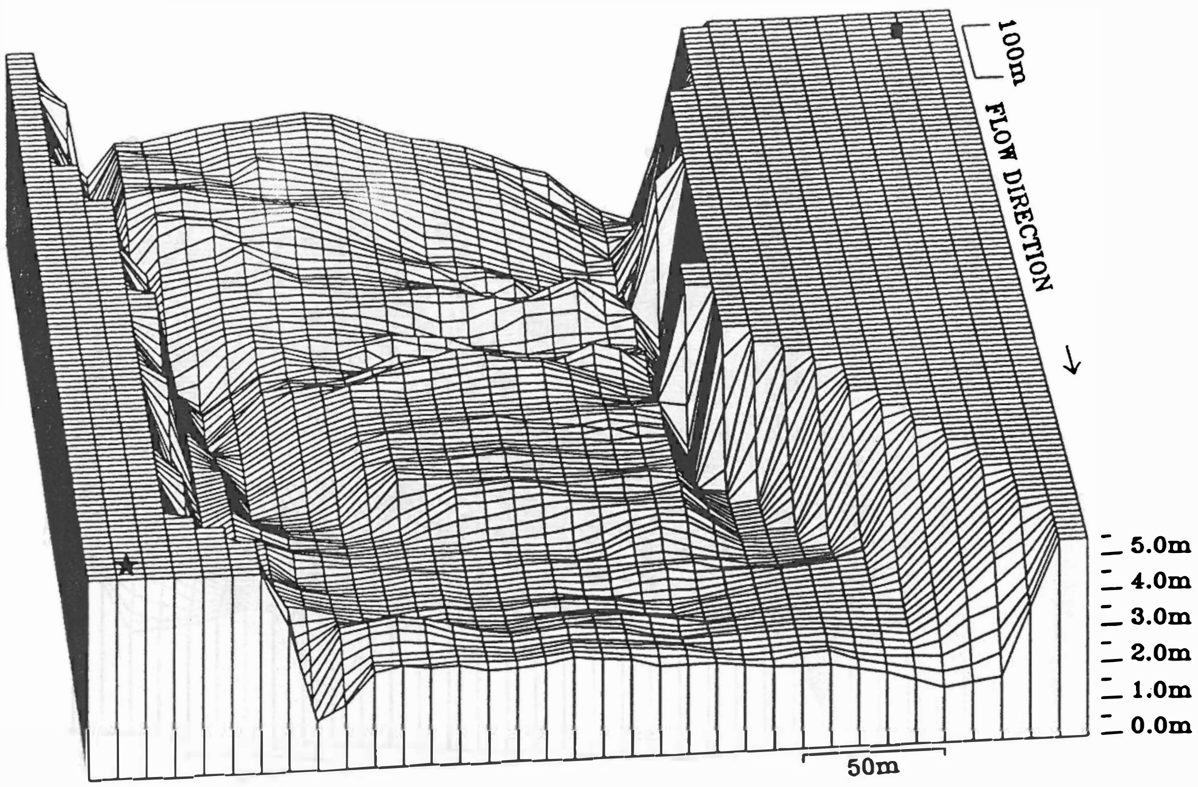


Contours at 0.5m intervals above W.C.B survey datum.

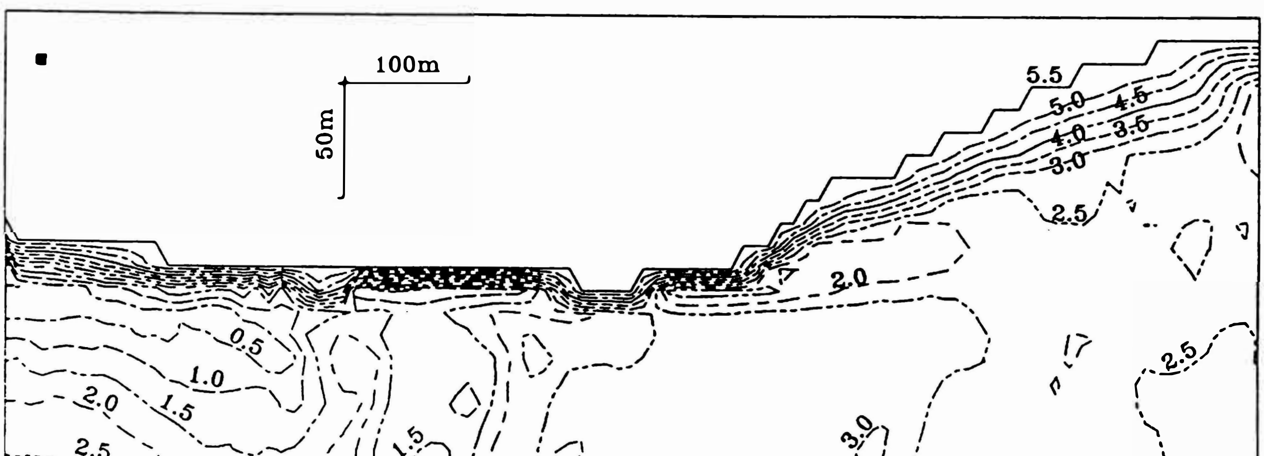
Figure 3.23E : Three dimensional and contour plots of the bed morphology study area, 6th July 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 2/8/88



CONTOUR DIAGRAM OF STUDY AREA ON 2/8/88

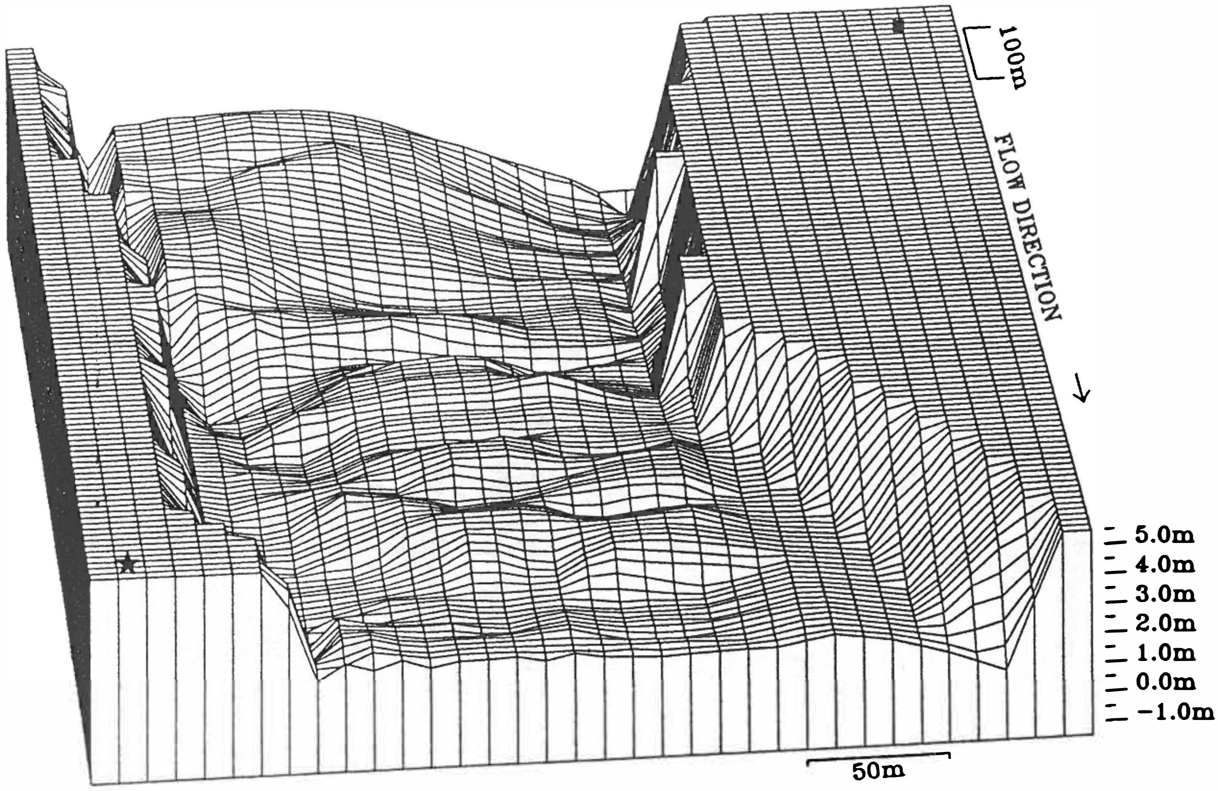


Contours at 0.5m intervals above W.C.B survey datum.

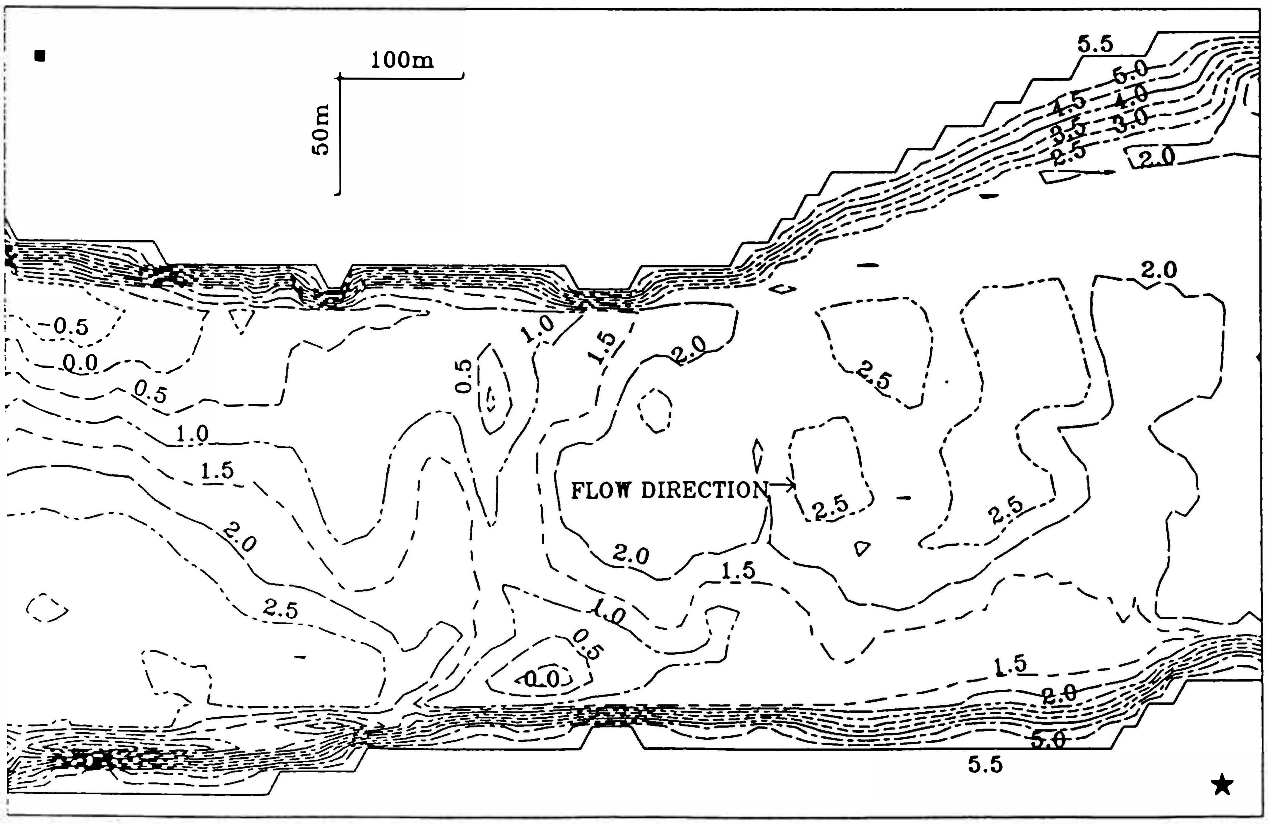
Figure 3.23F : Three dimensional and contour plots of the bed morphology study area, 2nd August 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 1/9/88



CONTOUR DIAGRAM OF STUDY AREA ON 1/9/88

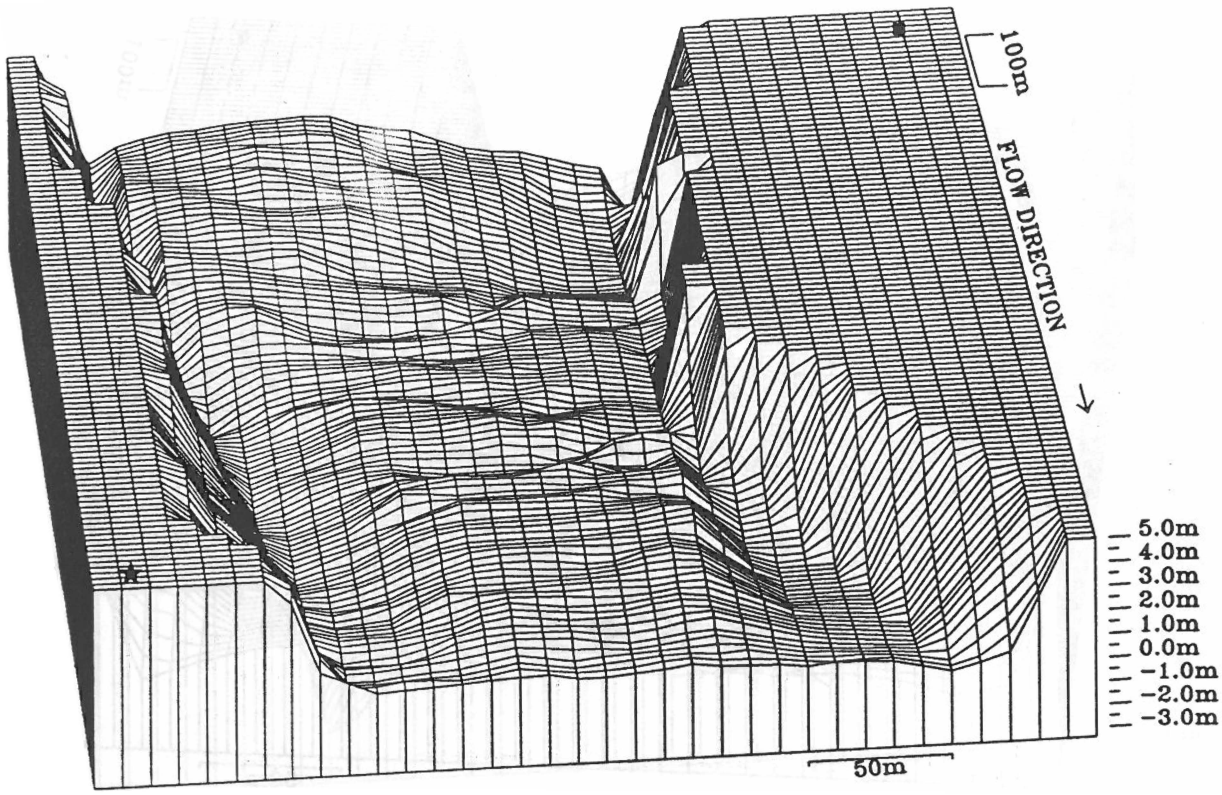


Contours at 0.5m intervals above W.C.B survey datum.

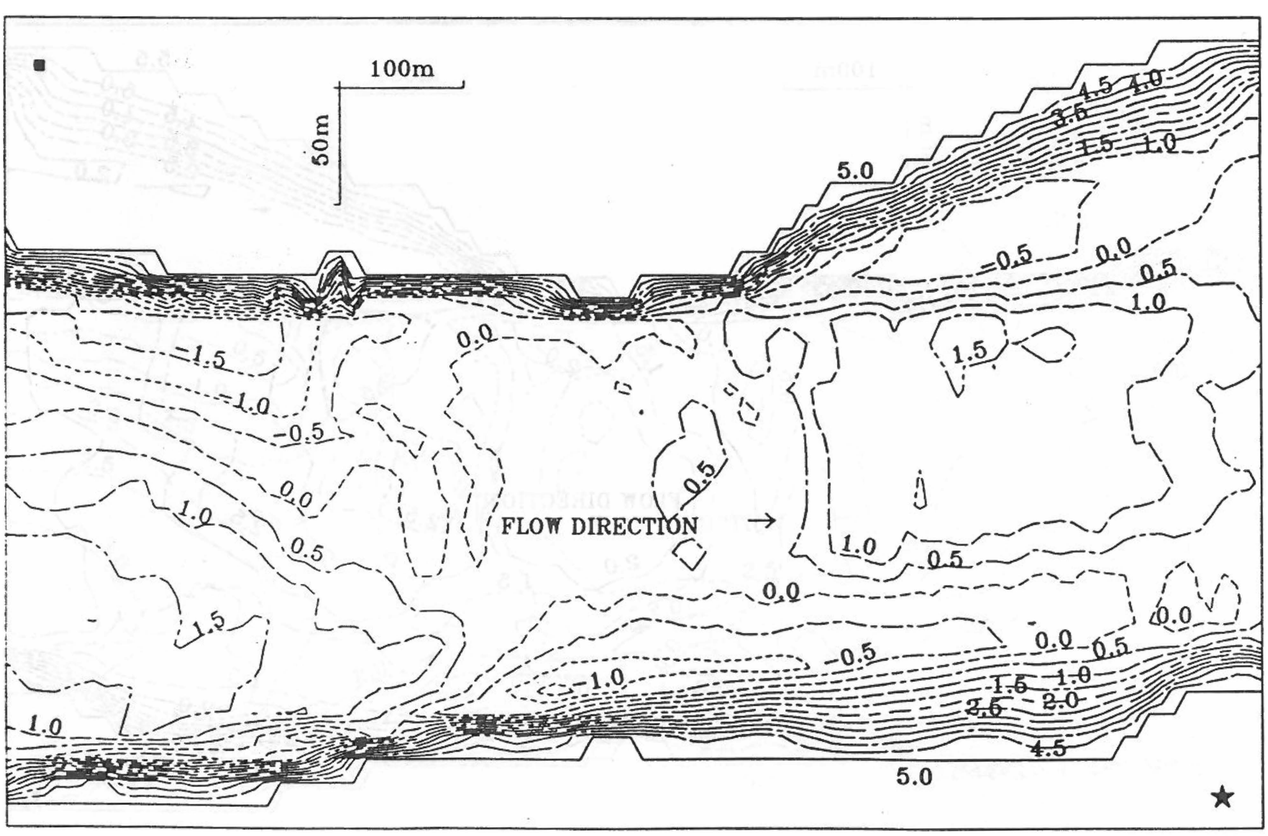
Figure 3.23G : Three dimensional and contour plots of the bed morphology study area, 1st September 1988.

BED M RPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 12/10/88



CONTOUR DIAGRAM OF STUDY AREA ON 12/10/88

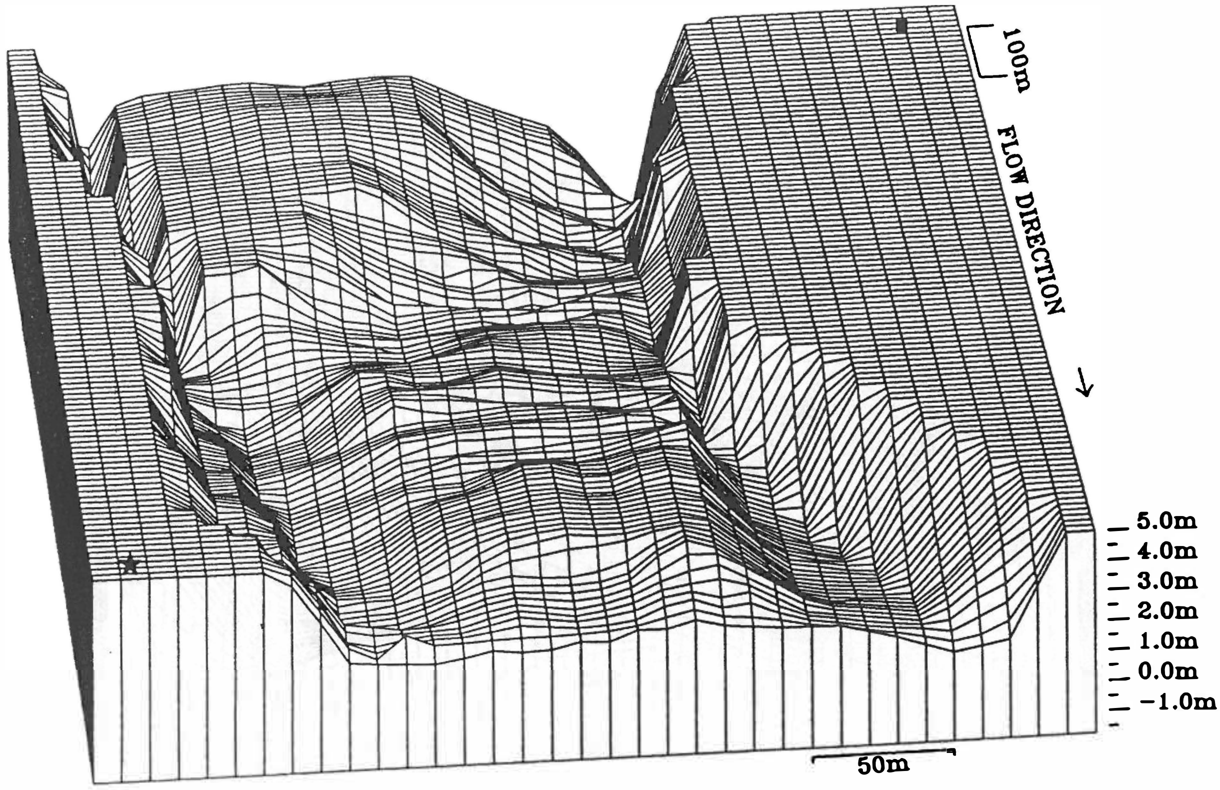


Contours at 0.5m intervals above W.C.B survey datum.

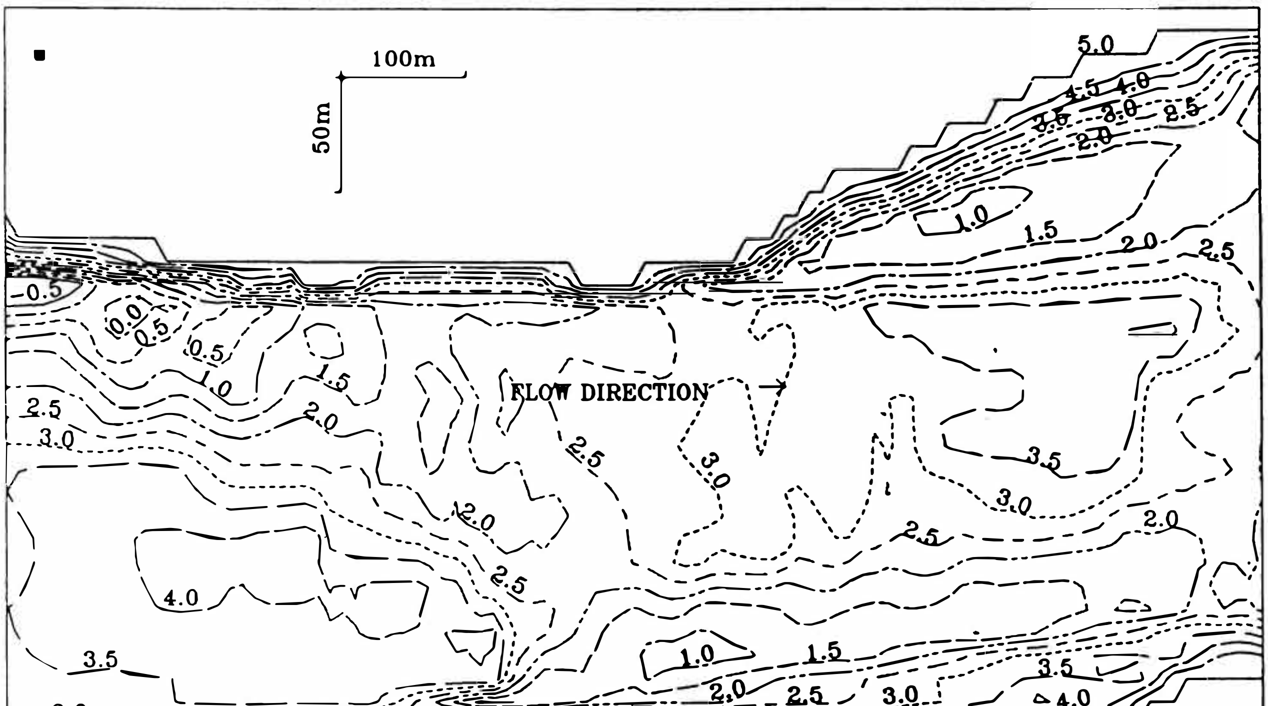
Figure 3.23H : Three dimensional and contour plots of the bed morphology study area, 12th October 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 10/11/88



CONTOUR DIAGRAM OF STUDY AREA ON 10/11/88

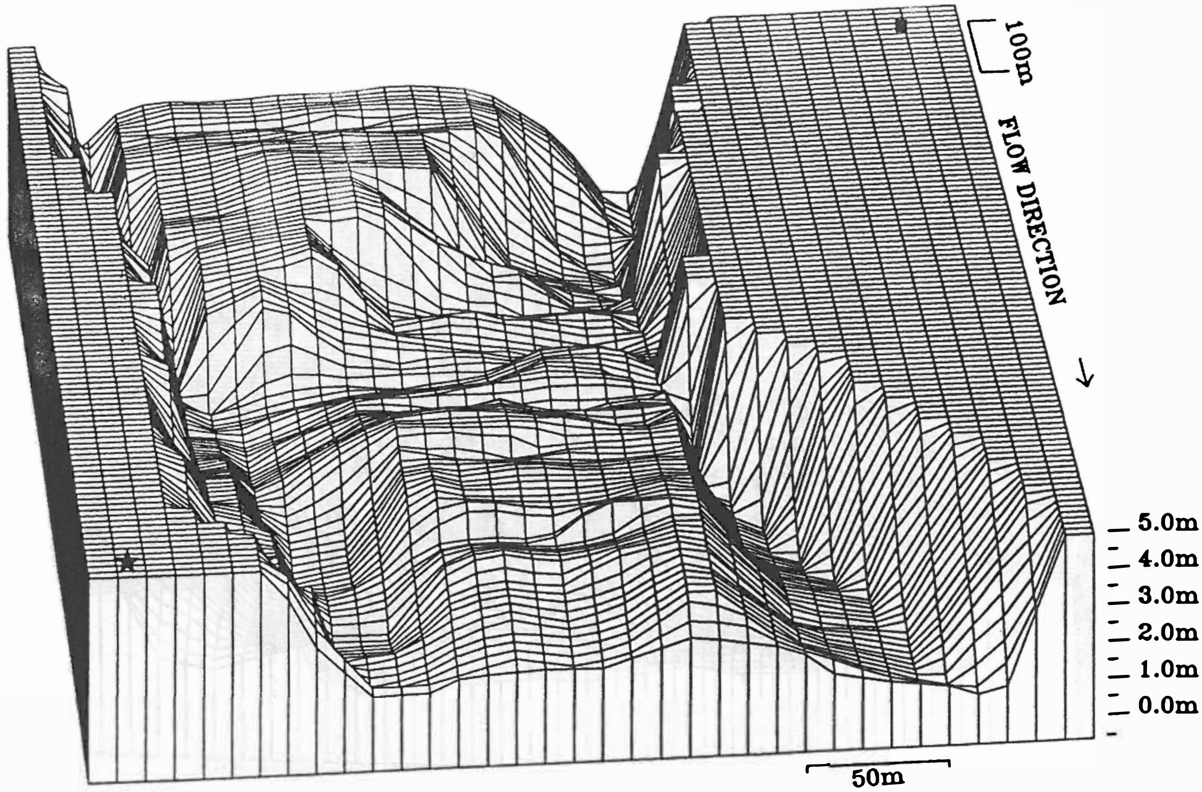


Contours at 0.5m intervals above W.C.B survey datum.

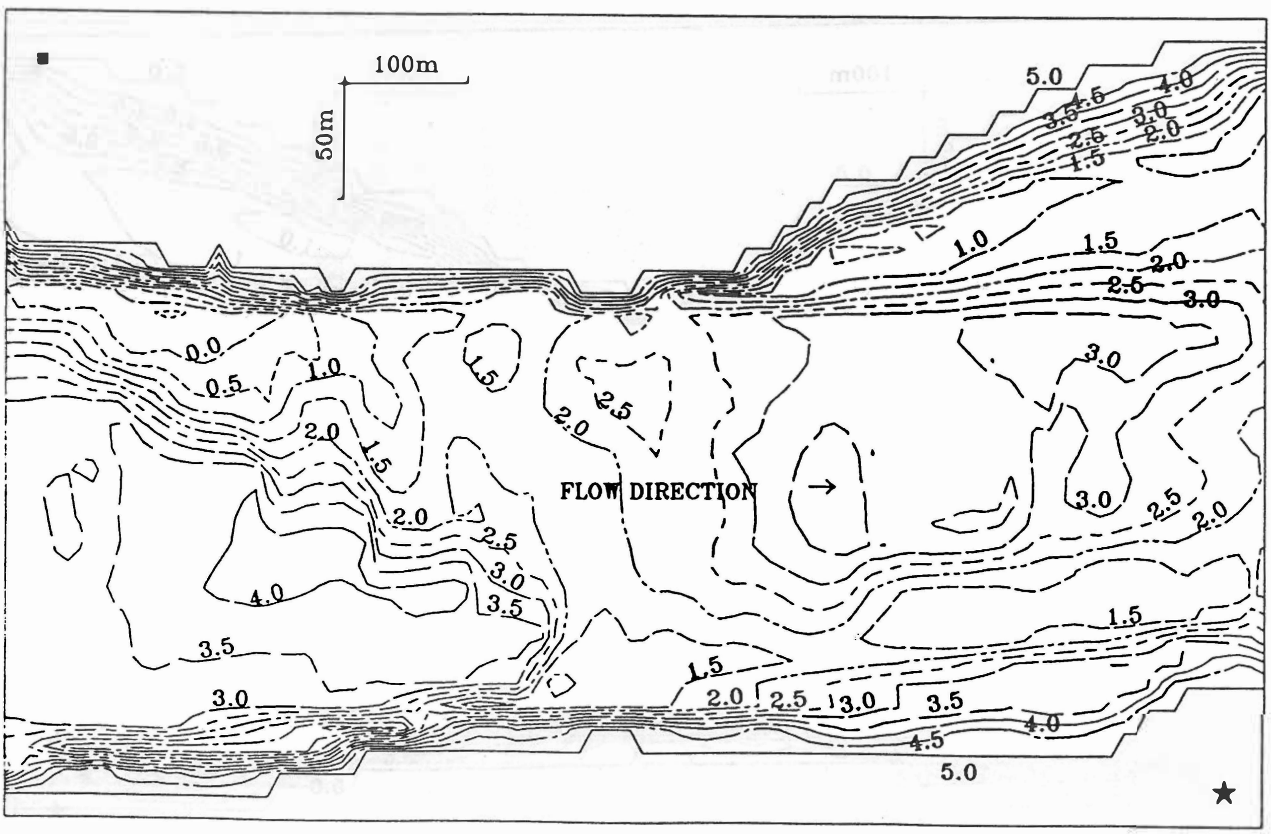
Figure 3.23I : Three dimensional and contour plots of the bed morphology study area, 10th November 1988.

BEL MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 8/12/88



CONTOUR DIAGRAM OF STUDY AREA ON 8/12/88

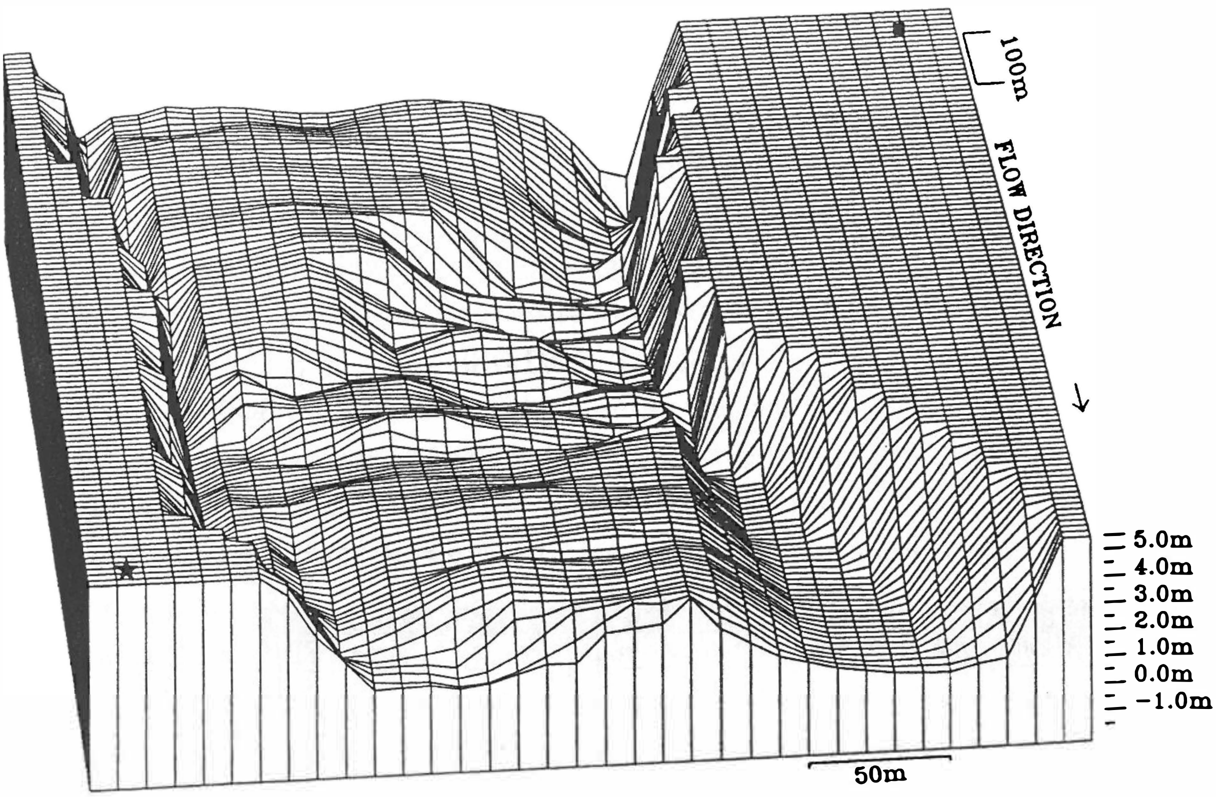


Contours at 0.5m intervals above W.C.B survey datum.

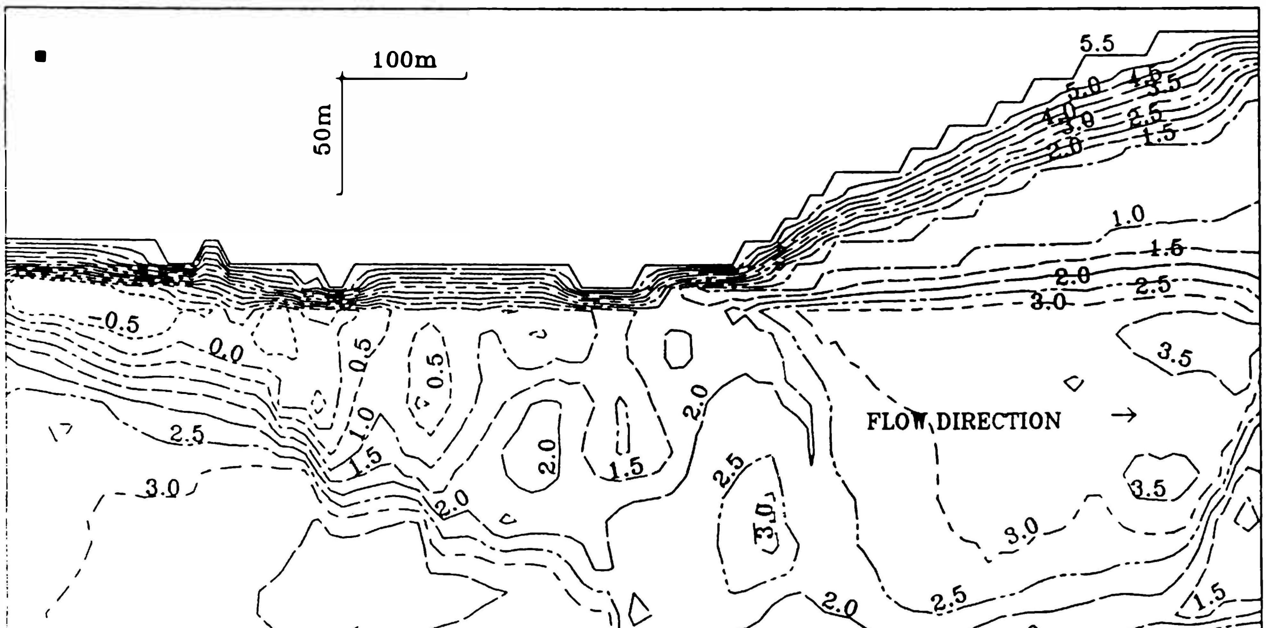
Figure 3.23J : Three dimensional and contour plots of the bed morphology study area, 8th December 1988.

BED MORPHOLOGY STUDY

3D DIAGRAM OF STUDY AREA ON 24/01/89



CONTOUR DIAGRAM OF STUDY AREA ON 24/01/89



Contours at 0.5m intervals above W.C.B survey datum.

Figure 3.23K : Three dimensional and contour plots of the bed morphology study area, 24th January 1989.

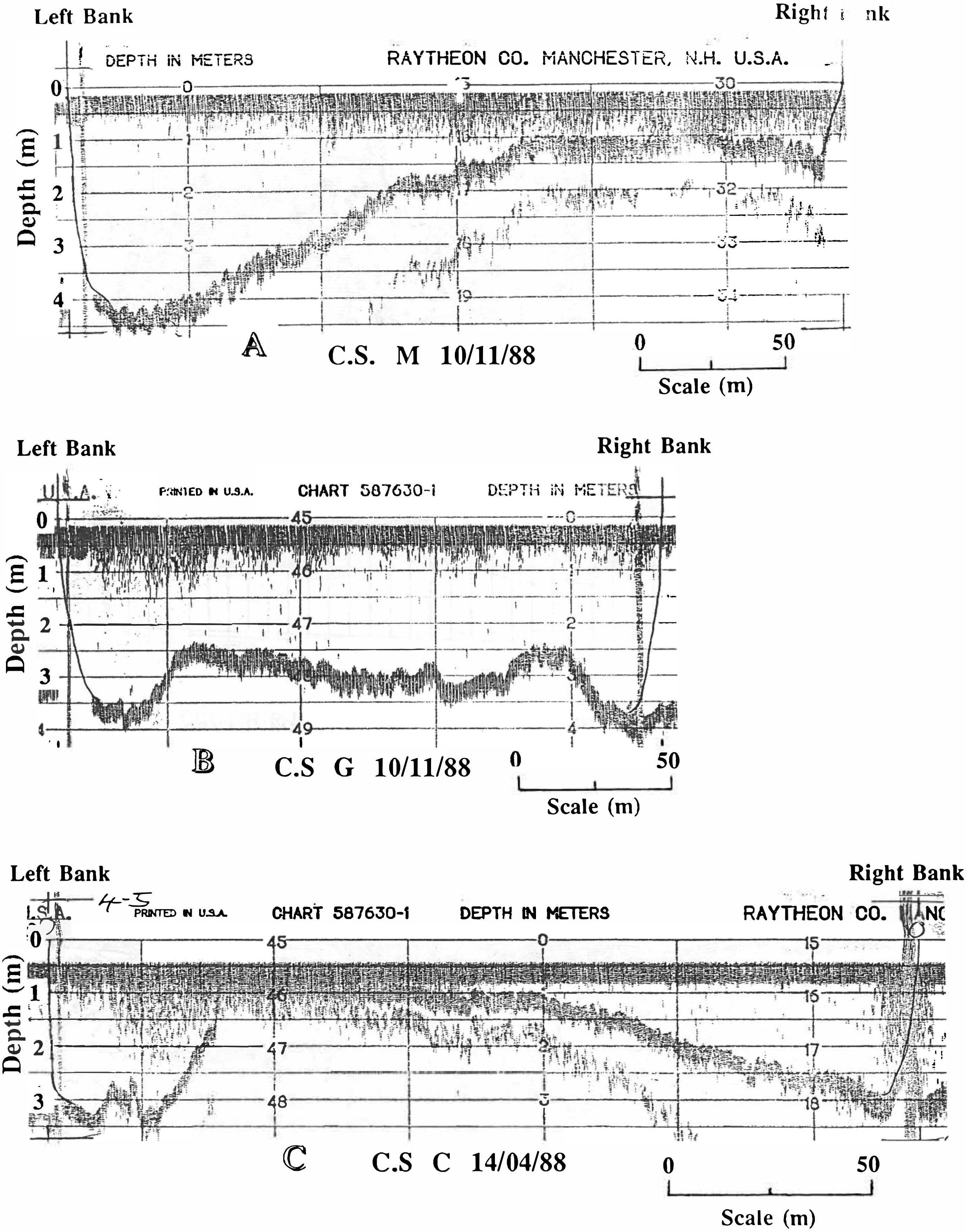


Figure 3.25 : Selected echo sounding traces from the bed morphology study area, A cross section M 10/11/88, B cross section G 10/11/88, and C cross section C 14/04/88.

maintaining its shape (Figure 3.23A-C). During June and July only the back part of this bar remained in the area with the crest downstream of the study area (Figure 3.24);

(2) a large raised section of the bed existed in the upper left half of the study area during February. This area has enlarged by the March survey, extending downstream slightly but also expanding across the channel to occupy two thirds of its width. Only minor growth of this feature occurs between the March and April surveys. In these three surveys a deep zone existed at the upper left corner of the study area. From this observation it can be inferred that significant flow must originate from the top left of the area and spread out across the channel in order to produce the expansion seen in this bed feature;

(3) during the period between February and September the main flow follows the right bank crossing over to the left bank in the central to lower part of the study area. As expected the meander flow pattern is observed to move in the downstream direction with the advancement of the bar bedforms. The flow is presumed to radiate from the upper left corner of the study area towards the path of maximum flow causing the expansion of the raised area of bed in this region. Figure 3.25C shows the channel that existed near the left bank at cross section C during the April survey, this tapers away in the downstream direction (Figure 3.23C). This reduction in area must cause the flow to move across the bed towards the right bank and the main flow (right to left in Figure 3.25C);

(4) over the period June to October 1988 (Figure 3.23D-H), no bar bedforms were present in the study area. During this period the raised feature continues to persist at the top end of the area, but the deep area in the left corner appears to grow progressively between surveys, in both size and depth. By September this deep channel has developed to a point where it has split the raised area leaving raised areas of the bed in the upper right and bottom central parts of the study area. In high flow the relatively low bed relief makes the distinction of main flow paths difficult. At this time of the year the cross over, seen previously, appears to have all but moved out of the area, and an opposite cross over pattern can be seen moving in the top of the study area. This change in flow pattern conforms with that expected from an advancing meander flow pattern;

(5) in the November survey the advancing meander flow pattern was confirmed with the development of two bar bedforms and a definable main flow path with a cross over region, as the raised areas of the bed appear to have developed into bar bedforms producing definable crests in the upper right and lower central regions of the study area (Figure 3.23I). These two bars are followed over the period November 1988 to January 1989 (Figure 3.23I-K). The bar in the lower part of the study area has a straight to wavy crest across the channel and its upstream face slopes upwards from right to left, with the bar having a steep edge near the left bank. The bar in the upper right part of the study area has a crest that angles strongly upstream from the right bank, and its upstream face slopes upwards from right to left towards the crest; and

(6) the main flow pattern is opposite to that seen during the summer with it flowing from the left bank and crossing over to the right bank in the middle of the area. This is presumed to be evidence for the advancement of the meandering flow pattern in the downstream direction.

A schematic summary of the study is presented in Figure 3.26, in which the main flow paths, flow directions and bar crest locations are shown. It can be concluded that the main flow path was from right to left over the February to September period. During this time the flow cross over and sand bars are observed to advance downstream in unison. The sandbars, however, become poorly defined and disappear at high flows. By November the meander flow pattern has advanced downstream and consequently the main flow in the morphology study area is from left to right moving downstream. New bar bedforms appear to form on existing bathymetric highs in the bed when the flow decreases. These bars are again seen to advance downstream with the advancing meander flow pattern.

Mechanisms of Bar Formation and Migration

"It is typical of a large number of straight reaches studied for the thalweg or line of maximum depth to wander back and forth from positions near one bank and then the other" (Leopold and Wolman, 1957). This is the situation in the study area where a meandering flow pattern is clearly visible (Figure 3.26).

Bar bedforms of some type are normally associated with meandering. Leopold et al. (1964) outline the basic formation of bars as:
"A local perturbation which would tend to increase temporarily the linear concentration would also make particles there slow up, and this lears to a cessation of movement of grains, building up a mound of grains on the bed. But the growth of the bar shallows water over it, probably resulting in an increased slope of the water surface. These changes probably increase the gradient of velocity near the bed. The net result, apparently, is to increase locally the transporting power, and there is established an equilibrium between factors enhancing transport and the tendency for local deposition."

The specific mechanisms which are involved in the formation and movement of alternating bar bedforms are presented by Leopold (1982) in a study on alternate bars in the Colorado River near Needles, California (Figure 3.21). In this study dye experiments provided information about surface and bed flow patterns. In short Leopold notes:

"The convergence of near surface streamlines towards a zone adjacent to the sand bar suggests the near bed water must be deflected toward the sand bar. This would result in 'herding' or shepherding of sand toward the bar leaving a deep hole adjacent to and on the side of the channel opposite the bar. This is supported by dye experiments on the surface and bed of the

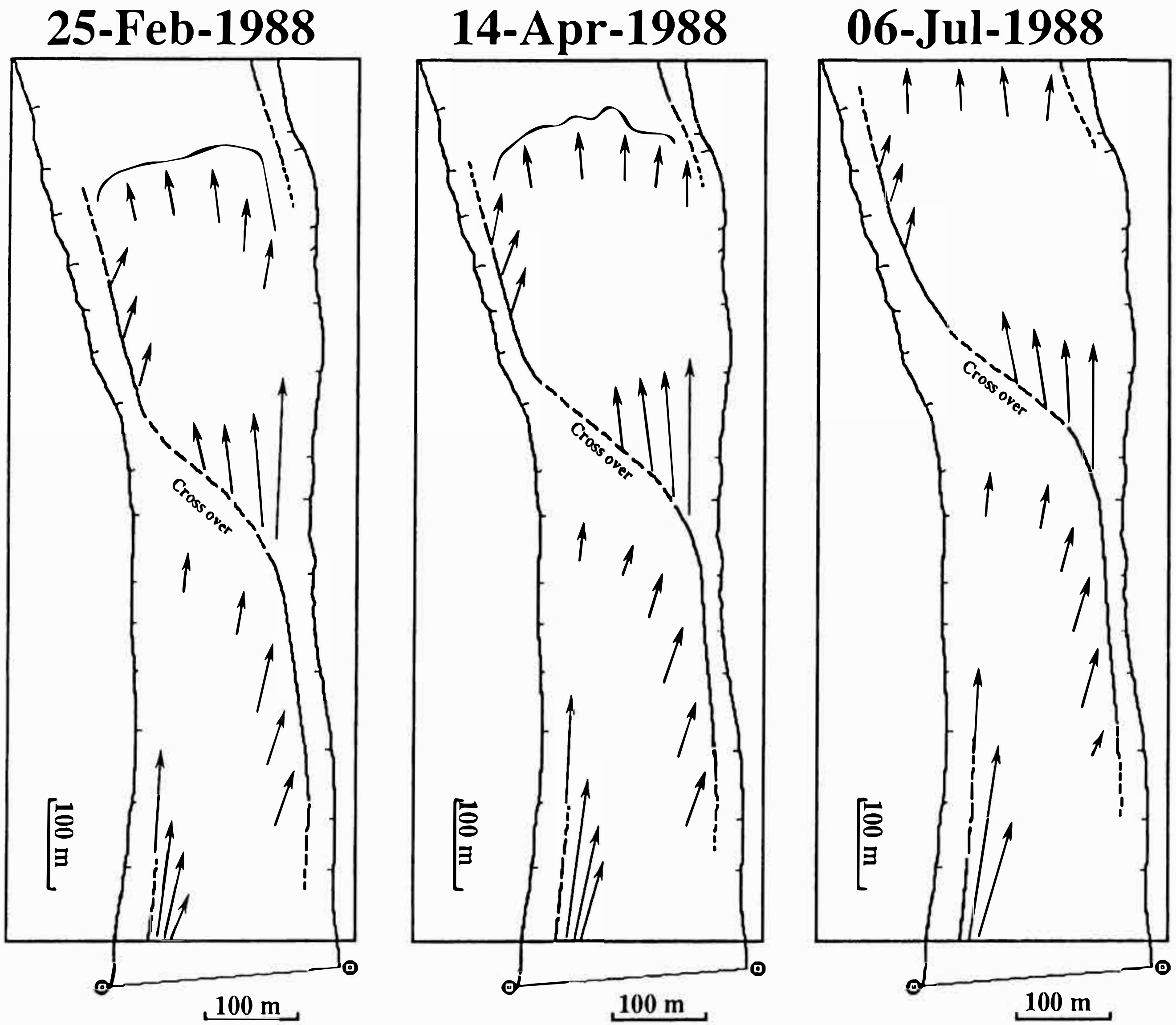
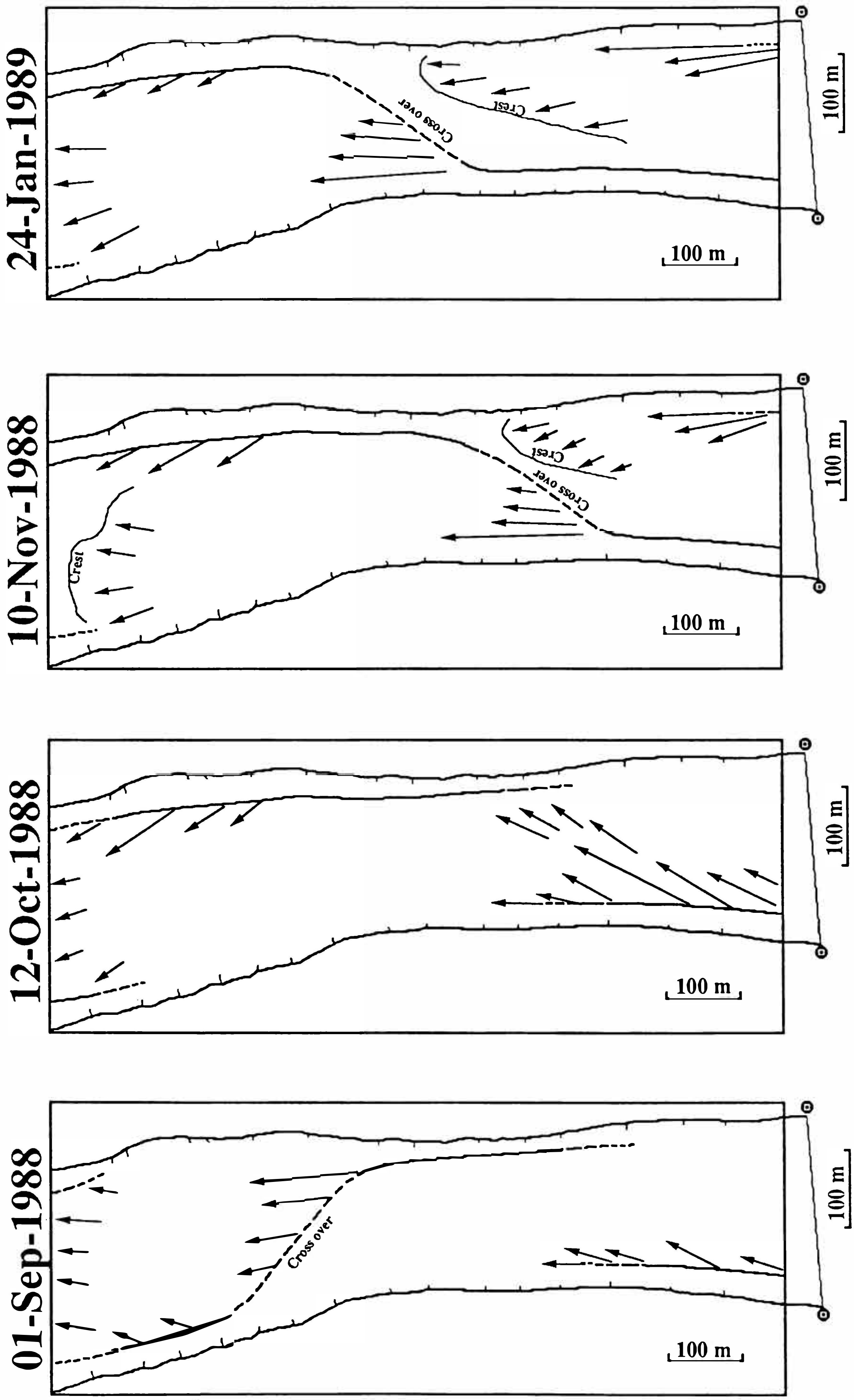


Figure 3.26 : Changes in flow patterns in the bed morphology study area during a year long study. Lines of inferred major flow shown, with arrows indicating flow pattern of water to and from the zones [illegible] maximum flow.


24-Jan-1989
Crest
Cross over
100 m
100 m
10-Nov-1988
Crest
Crest
Cross over
100 m
100 m
12-Oct-1988
100 m
100 m
01-Sep-1988
Cross over
100 m
100 m

stream. The bed directions are all with one exception toward the bar relative to the water surface, implying that sand is herded toward the bars by a near bed, cross channel component."

This mechanism is presumed to be in effect in the study area. It is not unexpected that with meandering flow there would exist water surface highs on the outside of the meander, inducing back flow towards the bar across the bed. However a significant mechanism in the formation and advancement of the bars must be the flow emitted off the edge of the meander (prior to cross over) as it is seen in the surveys that secondary channels do exist (Figure 3.25C) for this flow, which then taper out along the bar causing the flow to spread out across the bar.

Maddock (1969) refers to the Colorado example (Figure 3.21) and a similar alternating pattern in the Rio Grande River near Vinton, stating that bars that create meandering flow are formed at high discharges with low sediment loads, and low flows simply erode the bars and redistribute the sediment locally. From the photograph this appears the case in the Rio Grande (Maddock, 1969, Figure 51). However the Colorado River appears to be very similar in appearance to the lower Waikato River morphology. Similarly Harms et al. (1975) state in large rivers sandwaves (bars) are predominant features during high stage flow, the sandwaves (bars) tend to become larger during rising stage and smaller during falling stage. Bar dynamics in the lower Waikato River are found to be opposite to that described by Maddock (1969) and Harms et al (1975), with the bars present and dominating the channel in the low to medium flows, while at high discharges the bars are all but absent.

From the aerial photographs the wavelength of the meandering flow in the morphology study area is about 1100 to 1400 m, which compares with a wavelength represented by flow around the bar bedforms in the Huntly reach of about 1000 m (Dahm and Hume, 1989, Figure 3.11). It therefore appears from these comparisions that the wavelength for the meander flow pattern that is related to the alternate bar bedforms is 1100 - 1400 m. There is also some evidence for a larger fixed meander thalweg pattern as Dahm (1987) finds the stable thalweg pattern in the Huntly reach to have a wavelength of 2500 - 3000 m. In the morphology study area there are consistent deep areas in the top left and bottom right of the area, which would equate to a wavelength of about 2000 m. This large wavelength pattern appears to be controlled by channel shape and margins, with the Huntly pattern held in position by the location of islands and bends at either end of the reach (J. Dahm, Works Consultancy, pers comm. 1989).

Changes in Bedforms With Varying Stage

During the bed morphology study there was considerable variation in stage on the river. Figure 3.27 shows the changes in stage with time at Rangiriri during the study period. Also shown on this figure are the dates when bed surveys were conducted.

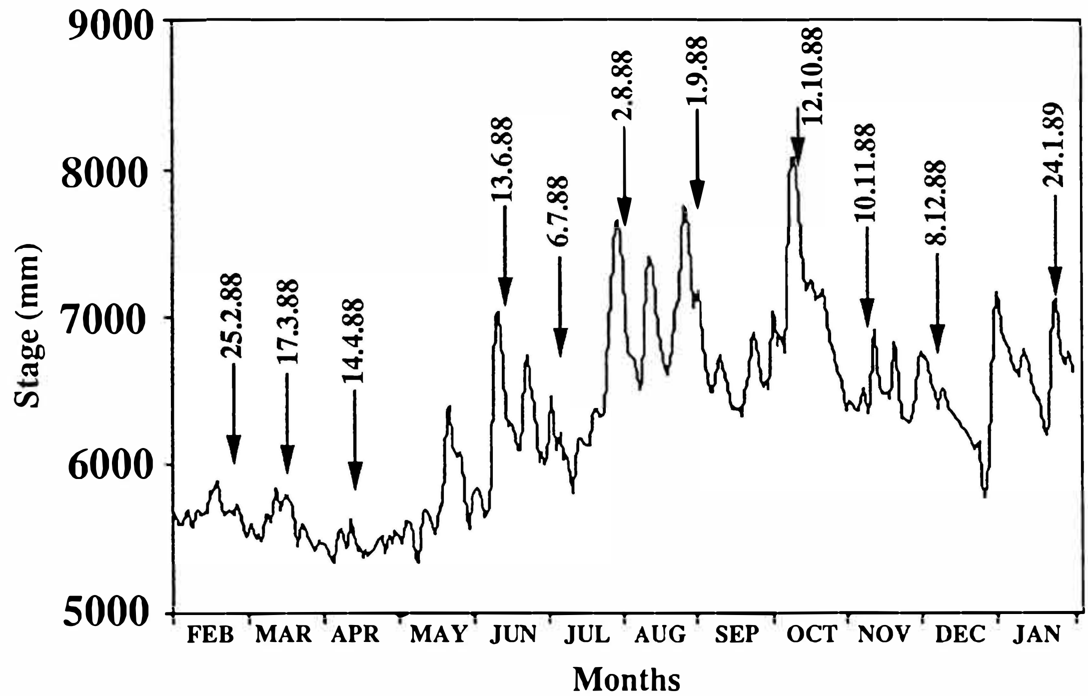


Figure 3.27 : Stage variations at the Rangiriri gauging station during February 1988 to January 1989 (data is daily mean values from W.C.B, TIDEDA Site 43420).

The bar bedforms are thought to be semi perminent features (Dahm 1987), existing in the channel throughout the year but being absent from visual observation during medium to high flows. The graphic results of this study shows that considerable variation in bed morphology occurs between summer low flow (Figure 3.23A-C), where bar bedforms are seen to exist and migrate downstream with time, and winter high flows (Figure 3.23G-H) in which the bed relief is at a minimum with no definable bedforms present.

The rounding of bed relief and disappearance of large scale bedforms is not an isolated occurance. A comparison of echo sounding traces taken on 22nd February 1988 (summer low flow) and 12th October 1988 (winter high flow) over a 5 km stretch of river (including the bed morphology area) shows that while a number bar bedforms occurred during the low flows in this area, at higher flows the bed is more rounded and appears to lack the large bar bedforms (Figure 3.28).

The disappearance or absence of bar bedforms at high flows seen in the bed morphology study area is a contradiction to the bar behaviour stated by Maddock (1969) and Harms et al (1975). However, by using approximations of slope from the limited data available, the two flow extremes during the study can be plotted on a phase diagram (Figure 3.29). This shows that during March (low flow) bed conditions are near the bar section of the phase diagram, while in October (high flow) the bed conditions are significantly different being high up in the transition between dunes and upper plane bed. The phase diagram is based on flume studies so fields on the diagram may not fully represent conditions in the field.

With the increased bed shear stress at higher discharges the bed is seen to become more rounded, and consequently the type of bedload transport changes. At low flows the transport is predominantly controlled by transport up the bars with deposition at the slip faces. As discharge increases and the bed flattens, a point is reached when transport past the crest occurs. This marks the limit for utilising bar movement for sediment transport estimates (Section 4.2). Beyond this limit transport is predominantly over dunes and upper plane beds.

The flow patterns through the study area (Figure 3.27) are well defined during the summer low flows, but during the higher winter flow the area of maximum flow is difficult to define and covers a wider area of the channel.

Rates of Bar Migration

Rates of crest movement during the study are not constant with time (Table 3.2), ranging from 0.6 - 3.1 m/day. Results presented by Dahm and Hume (1989) are comparable at 0.9 - 1.4 m/day, while in the Colorado River rates of 2.5 m/day at 165 m^3/s occur (Leopold, 1982).

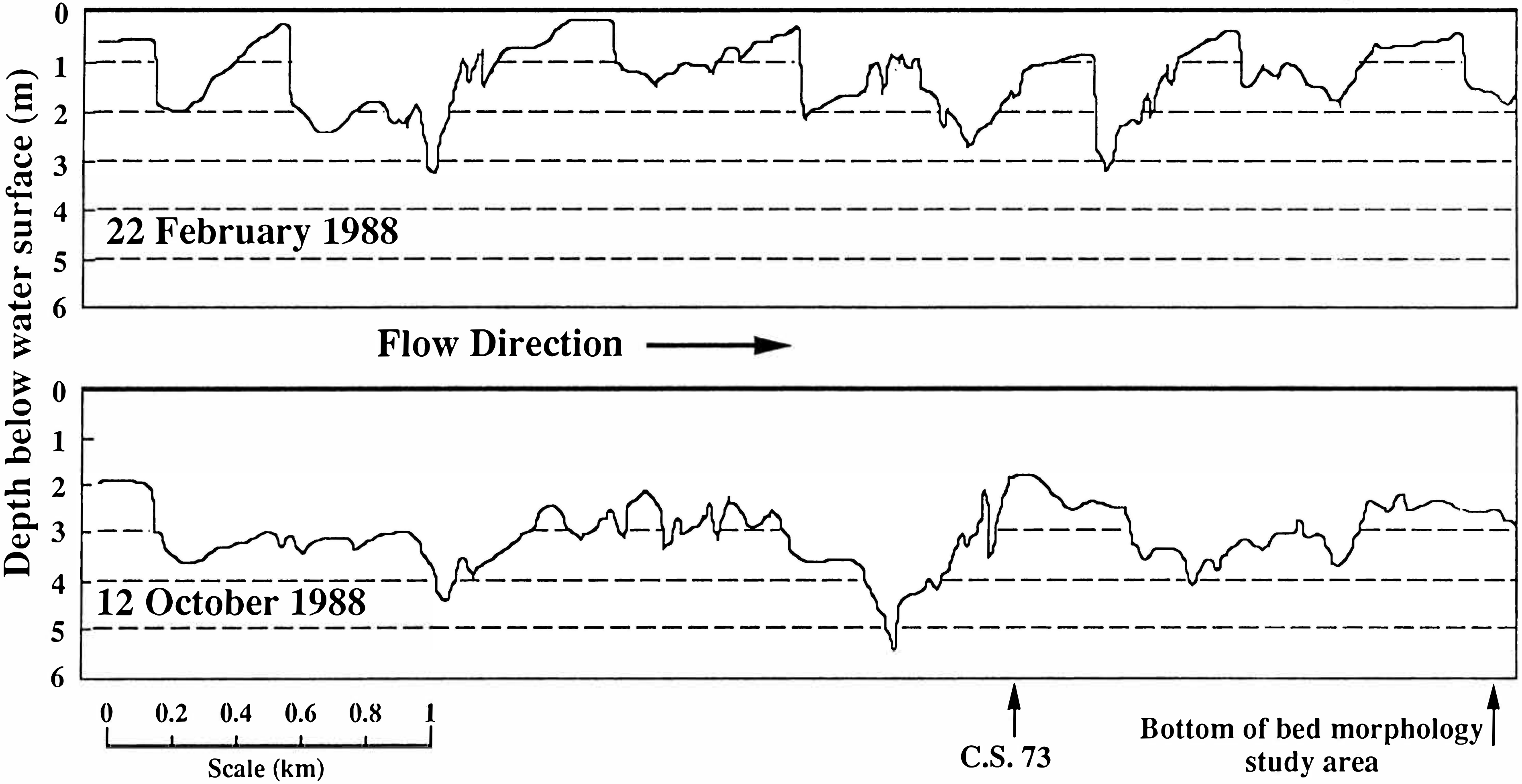


Figure 3.28 : Comparison of river bed profile between summer low flow (February) and winter high flows (October) over a 4.5 km reach upstream of the bed morphology study area. Profiles are obtained from echo sounding traces taken along the centre of the river channel.

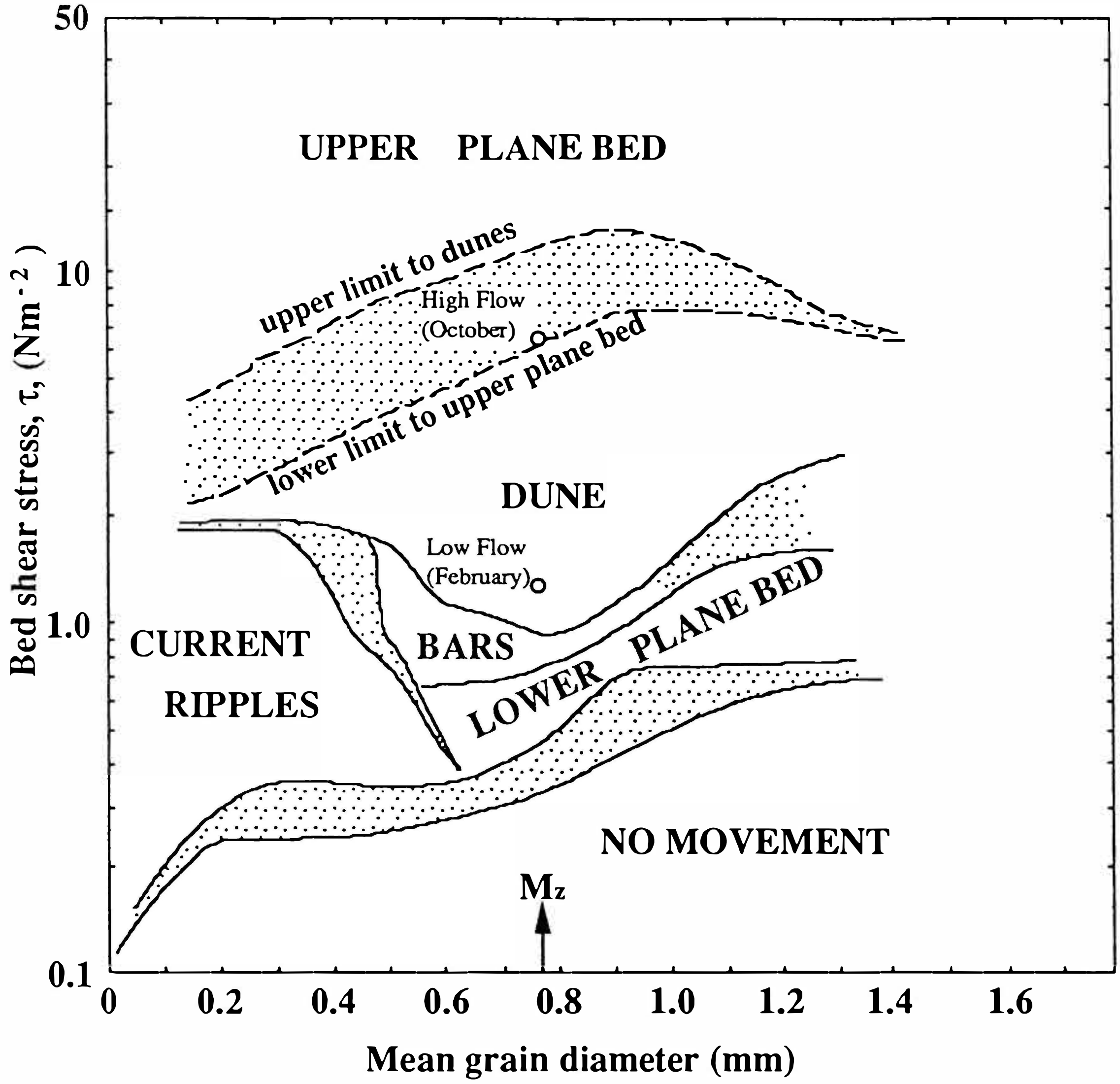


Figure 3.29 : Bedform phase diagram, showing the stability fields of various subaqueous bedforms developed by uniform steady flow. Plotted is the bed shear stress during low flow (March, R= 2.1, S ~ 0.00008) and high flow (October, R=4.5, S~ 0.00014). Note that during low flow conditions are near the dune-bar boundary while at high flow, conditions are close to upper plane bed. (after, Leeder 1982).

Period	Crest rate (m/day)	Discharge (m^3/s)	Mean bar height (m)	Volume Transport (m^3/day/m width)
25 FEB - 17 MAR	1.07	266	1.08	1.14
17 MAR - 14 APR	0.64	221	0.93	0.59
14 APR - 13 JUN	2.56	281	0.79	2.02
13 JUN - 6 JUL	3.07	400	0.95	2.90
10 NOV - 8 DEC	2.02	472	1.67	3.37
8 DEC - 24 JAN	1.54	459	2.02	3.08

Table 3.2 : Sand bar movement rate and related discharge.

Some trend is seen between the rate of bar movement and discharge, however taking into account the height of the bar crest a good crrelation exists between bedload volume transported over the crest (crest movement x height = m3/day/m width) and discharge (Figure 3.30). There is however an upper limit to this relationship, as the bars alter at higher discharge making isolation of the crest location impractical. A similar tentative relationship is presented by Dahm and Hume (1989, Figure 3.20) based on Finley's (1974) results, which is of a similar order to that presented in Figure 3.28.

3.5 CONCLUSIONS

The lower Waikato River consists of straight to gently sinuous channels with bifurcation of flow by a number of islands below Ngaruawahia. The channel exhibits a variety of bedforms ranging in size from ripples to large scale sand bars. Complex relationships exist between the bedforms, with superimposition of smaller forms on larger forms being a common feature.

The large scale bedforms that occur in the lower Waiakto River have in the past have been loosely refered to as 'dunes'. They are however, more characteristic of bars, specifically alternate bars that are related to sinuous flow patterns along straight reaches.

Dunes and ripples are present throughout most of the lower Waikato River, while the larger bar bedforms only occur over the reach between Huntly and Meremere. It is likely that upstream of Ngaruawahia the channel is too incised and narrow for meander flow patterns of a suitable size to develop and cause the formation of alternate bars. Also, the section between Ngaruawahia and Huntly is probably too sinuous for the formation of a meander pattern and alternate bars. It is surprising however that such bedforms do not occur downstream of Meremere, as the channel is relatively straight towards the Mercer gorge. Their absence is probably the result of sand extraction in the area. Extraction has caused a marked decrease in water slope, and a channel with an artificially high cross sectional area. Also there is likely to be a sediment deficit downstream of the extraction site as transport is halted in the deep hole created by extraction in which the velocities are very low. These factors when combined, appear to create conditions of insufficient sediment and flow development to create the large

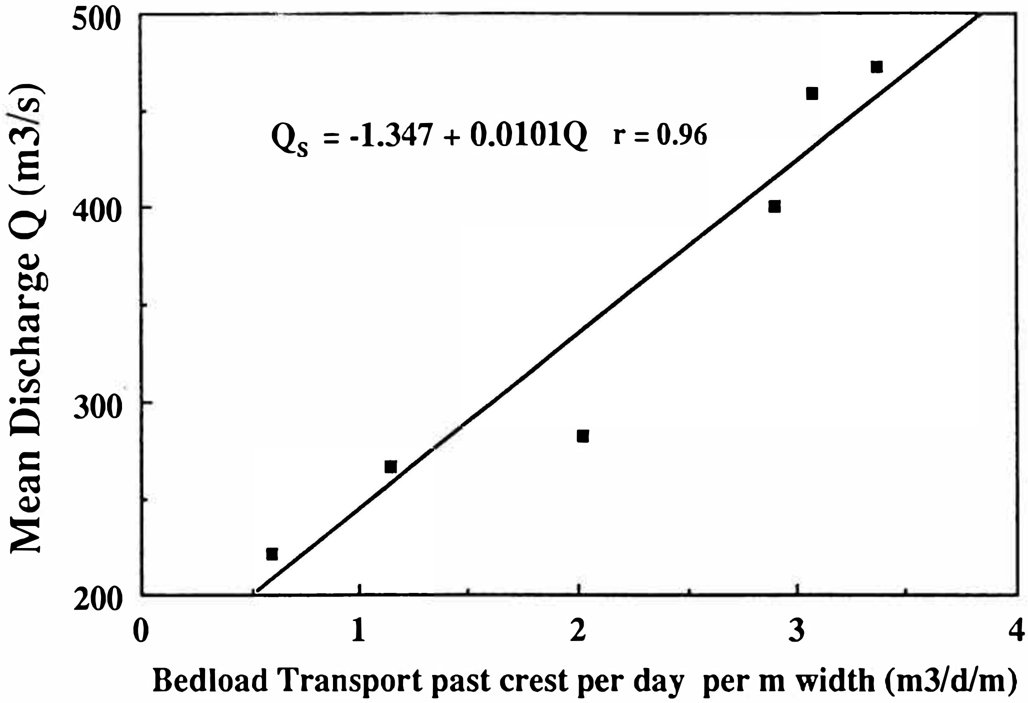


Figure 3.30 : Relationship between volume of bedload transport past the bar crest and mean discharge for the period between the surveys. This relationship has a cut off point as at high discharge the bars deform and the crest disappears making measurement of its advancement impossible. The relationship is a line of best fit to the data determined by least squares regression.

scale bedforms seen upstream. Immediately downstream of all extraction sites the bed is devoid of detectable bedforms for one kilometre or more.

There is evidence from ripple index data for dunes for the existance of two distinct populations of dunes in the river - a short steep group assumed to form in areas of lower bed shear stress, and long flatter dunes assumed to form in areas of higher bed shear stress.

Texturally there is a rapid decrease in grain size immediately downstream of the Karapiro dam, as the degrees of sediment starvation and bed armouring decrease downstream. This continues to a point where the size change then occurs at a rate controlled by natural sorting and abrasion caused by the river. The hinge point between these two different processes marks the ever advancing downstream effects of the dam.

Alternate sand bars are of particular interest as they influence the morphology and sediment transport in the reach from Huntly to Meremere. They therefore having specific implications for the Huntly Power Station and sand extraction operations. From a year long bed morphology study a number of conclusions can be derived concerning flow patterns, movement and formation of the sand bar bedforms. They are as follows:

(1) the bars appear to alternate from side to side down the relatively straight reaches of the lower Waikato River. They are clearly related to the sinuosity of the thalweg or line of maximum flow;

(2) the bars exist in two main forms, either with a relatively straight crest and located slightly to one side of the channel centre, or with a strongly curved crest and attached or very close to one bank (Figure 3.31). The form is controlled by the flow pattern up the back of the bar (ie. faster flow near a bank is assumed to form a strongly curved bar as this area will migrate faster) and the existance of a secondary channel. This secondary channel seems to spread the flow out across the back of bars from the region of the main flow cross over in one instance , or accumulates the flow after it passes over the crest of the bars;

(3) the bars are not static features, and are observed to move downstream at a rate of 1-3 m/day. The pattern of sinuous main flow appears to advance in unison with the bar bedforms. The mechanism for this advancement is thought to be flowdispersing from the main flow path as it crosses over the channel and flowing up over the bars, thus transporting sand to the crest. Generally the flow patterns and related sediment transport are thought to be primarily the same as described by Leopold (1982);

(4) only subtle variations in mean grain size and sorting occur along the upstream face of the bars. However during low to medium flows it appears that a layer of mud exists over the bed immediately downstream of the crest, and for some distance downstream. This has important implications for sediment transport as it implies that the bar is a closed system,

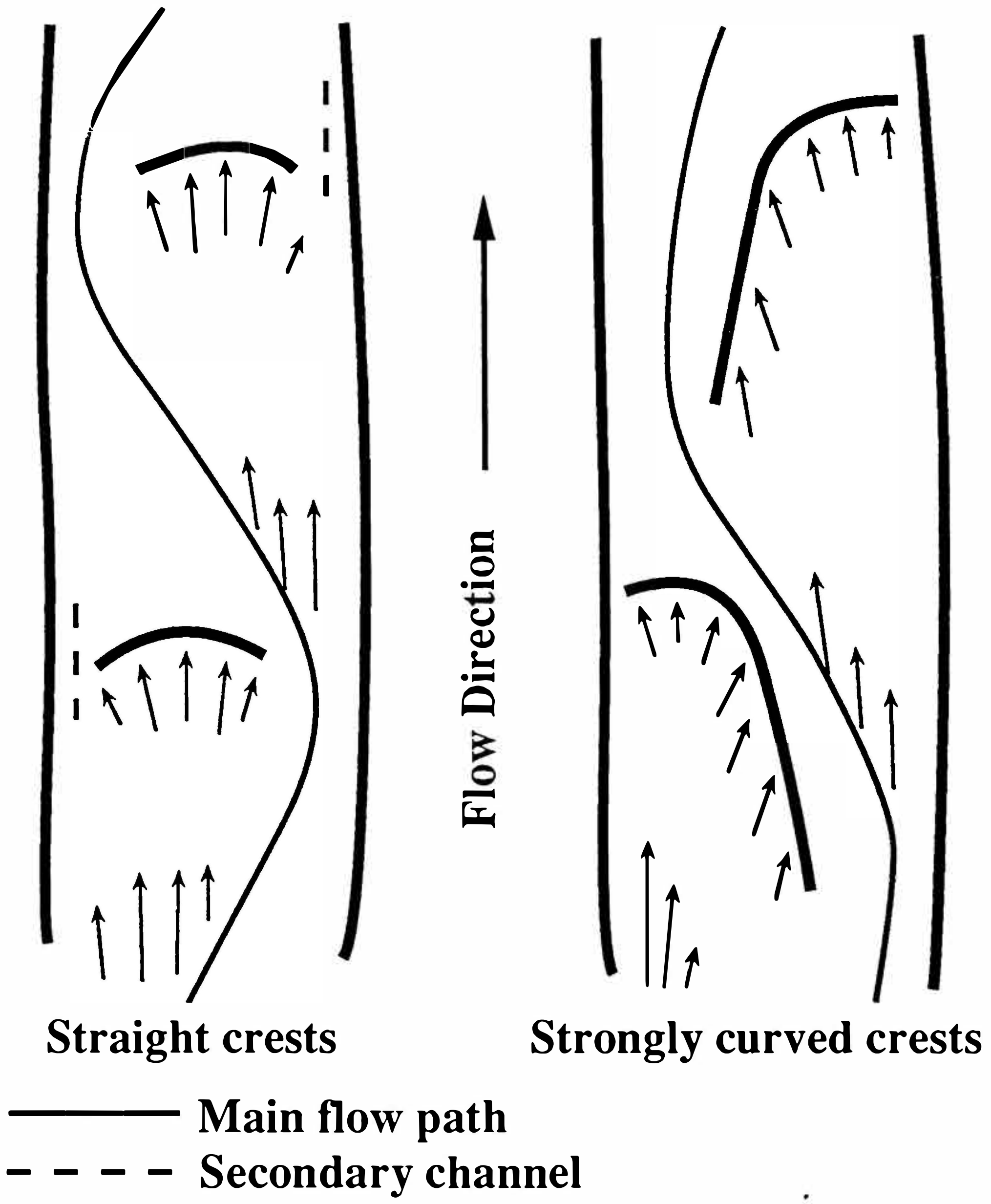


Figure 3.31 : Two types of sand bar bedfoms are seen to occur in the lower Waikato River.

Straight crested bars, that appear to alternate along the channel with the major flow, evidence for the existance of a 2° channel on the opposite side of the bar from the main channel.

Strongly curved crested bars, that are in close proximity or attached to one bank with the crest curving strongly awayfrom the bank.

and therefore the migration rate of the bars is an accurate indication of the river's bedload transport rate;

(5) the sand bars have in the past been regarded as semi-perminent features. However, they are observed to flatten and become more rounded with increasing flow to a point where they are undefinable. During these high flows delineation of the main flow pattern is difficult. When flow recedes the bars are seen to reform in areas that were bathymetric highs during the high flows. This disappearance during high flow appears to be contadictory to the literature as bars are often considered as high flow features that are reworked during lower flows; and

(6) a strong relationship exists between the volume of bedload transport past the bar crest and mean flow discharge. This has important implications for estimating bedload transport rates in the river, and is applied in Chapter 4.

CHAPTER FOUR :

SEDIMENT TRANSPORT

CHAPTER 4

SEDIMENT TRANSPORT

4.0 INTRODUCTION

A sound knowledge of the sediment transport characterisitics of the lower Waikato River provides a better understanding of the river's behaviour, and thus aids in the optimum modelling, management and utilization of the river as a resource.

The aim of this chapter is to calculate the bedload transport rate of the lower Waikato River. Previous sediment transport studies on the lower Waikato River are summarised. Results from additional bedload transport experiments for the current study are presented, and broad bedload transport relationships are developed for both the Rangiriri and Mercer river sections. The limitations and values of the different methods are discussed, and an updated estimate of annual bedload transport in the lower Waikato River is made. Trends in the bedload transport rate over the past 20 years are also investigated.

Although some suspended sediment transport estimates have been given in previous studies, no measurements are undertaken in this study.

4.1 PREVIOUS SEDIMENT TRANSPORT STUDIES

In the past a number of sediment transport studies have been performed on the Waikato River. Most notable work was done by the W.C.B. (then the Waikato Valley Authority) in 1966-1967, in which four research reaches at Huntly, Churchill East, Meremere and the Whitebait factory at the entrance to the delta were investigated (Ridall, 1967). The aim was to obtain information for use in modelling and monitoring the effects of river works on lowering bed levels as part of the flood protection scheme (Section 2.1.1). From this work a number of internal reports were written and a paper was published by Finley (1974). Most of the available written information concentrates on the study at Churchill East (C.S. 92-93). Major findings of the Finley study are summarised below.

4.1.1 Bedload Sediment Parameters

Particle size parameters for bed material were determined as, d_{15} = 0.38 mm (15% finer than 0.38 mm), d_{50} = 0.78 mm and d_{85} = 2.09 mm from a number of samples collected in 1971. In the previous studies sediments collected near the crest of a bar (d_{50} = 0.76 mm) were coarser than those collected further upstream on the back of the bar were d_{50} = 0.48 mm (W.V.A, 1971b). This trend was also seen in the present study (Figure 3.19). Finley (1974) also showed that mean particle size of bed material varies along the river, being 1.2 mm at Huntly, 0.92 mm at Mercer, 0.77 mm at the Elbow, and 0.65 mm at Port Waikato. This supports the trend inferred in Figure 3.14a.

The bulk density of the moving sand in water was estimated at 960 kg/m3, with an on-land dry bulk density of about 1120 kg/m3 (W.V.A, 1971a). The mean specific gravitiy of the sand was 2.25 in 1966, and 2.38 in 1971 (W.V.A, 1971b).

4.1.2 Suspended Sediment

The suspended sediment load for the lower Waikato River was estimated at 377 900 tonnes for 1966 at Mercer (Finley, 1974). Suspended sediment loads show a marked increase downstream of Cambridge (Table 4.1), indicating as expected that most of the lower Waikato suspended sediment is derived from tributaries downstream of the Karapiro Dam.

Site and Distance from Karapiro		Estimated Discharge (m^3/s)	Suspended Sediment Discharge (tonnes/day)
Cambridge	8 km	310	18.3
Hamilton	32 km	330	42.7
Ngaruawahia	53 km	323	153.4

Table 4.1 : Suspended sediment loads along the lower Waikato River (Finley, 1974).

A comparison of suspended sediment loads in the Waikato River and Waipa River during a flood showed that the Waipa reaches a peak sediment discharge before the Waikato River and has a greater total suspended sediment discharge (Table 4.2). The total sediment load for these two rivers upstream of their confluence is of a similar order to the lower Waikato River at C.S.92 (W.V.A, 1971d).

	3 rd SEPT 1971		8th SEPT 1971	
	Q (m^3/s)	Q_s (tonnes/day)	Q (m^3/s)	Q_s (tonnes/day)
Waikato	365	630	436	1168
Waipa	266	1494	365	1361
Total	631	2123	800	2530

Table 4.2 : Comparison of suspended sediment loads in the Waikato River and Waipa River during a flood (W.V.A, 1971d)

For a mean discharge of 416 m3/s at Mercer the suspended load was 782 tonnes/day or 22ppm in 1966 (Finley, 1974). This is low when compared with other New Zealand rivers where suspended loads over 1 million tonnes/day are frequently observed. A rating curve for suspended sediment was produced based on these results (Figure 4.1).

4.1.3 Bedload Transport

The bedload transport rate was estimated by Finely (1974) using two methods: bedload trapping, and sand bar migration. The volume of sand transported over the bar crest provides an estimate of bedload discharge for the width of the river channel occupied by the bar. Bedload trapping results are used to estimate the bedload transport rate in the flat bed regions that can occur on either side of the bars. Through using both these methods a mean bedload transport estimate can be made for the full width of the channel.

Bedload trapping was conducted by the W.V.A using a sampler developed by the Ministry of Works and Development that was 25 cm wide and weighed 22.5 kg when empty. The trap was estimated to be 60% efficient and became more inefficient when more than 4.5 kg of sand had been collected (1/4 - 1/2 full). However without any laboratory or other calibration it would be unwise to base any prediction of absolute bed load discharge on the results obtained from the sampler (W.V.A, 1971b). The rates of bedload transport measured by the W.V.A using the trap are much less than that estimated by movement of bars alone and there is considerable variation in results, which change from 0 to 1.4 kg/min over a period of 12 minutes (Finley, 1974). A summary of the W.V.A bedload trapping results are presented in Table 4.3. Attempts at bedload trapping were made in the Waipa River at 266 m3/s, but resulted in only trace or no bedload (W.V.A, 1971d).

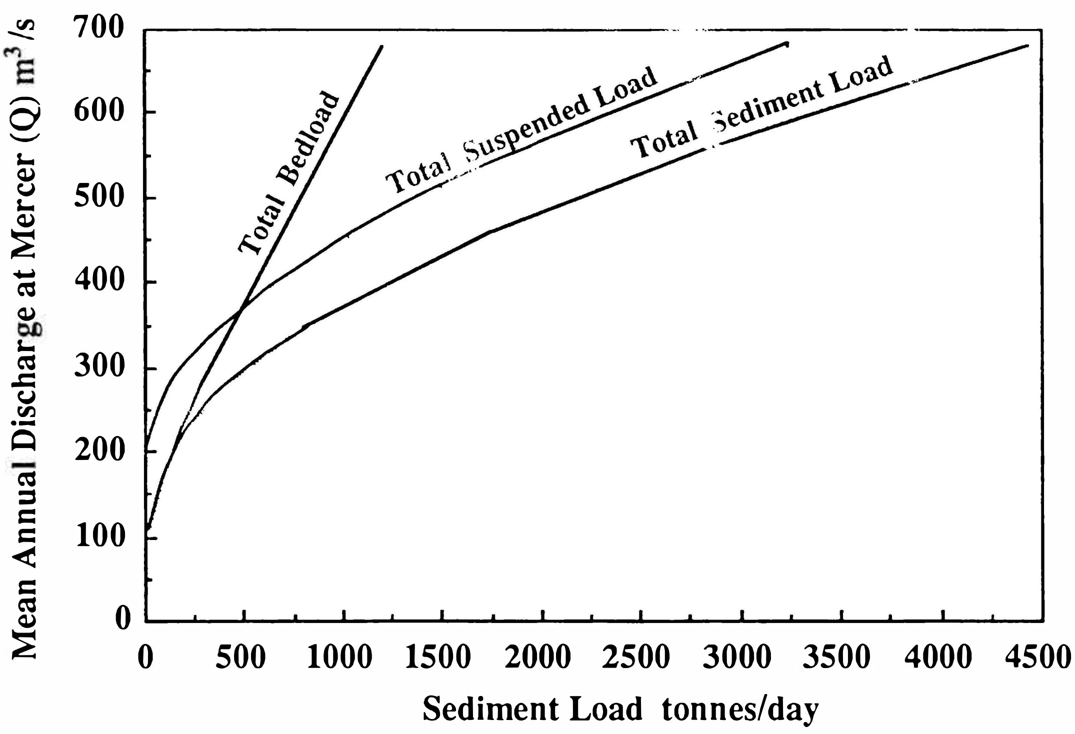


Figure 4.1 : Bedload, Suspended and total sediment load discharge curves for the lower Waikato River, 1966 (after Finley, 1974).

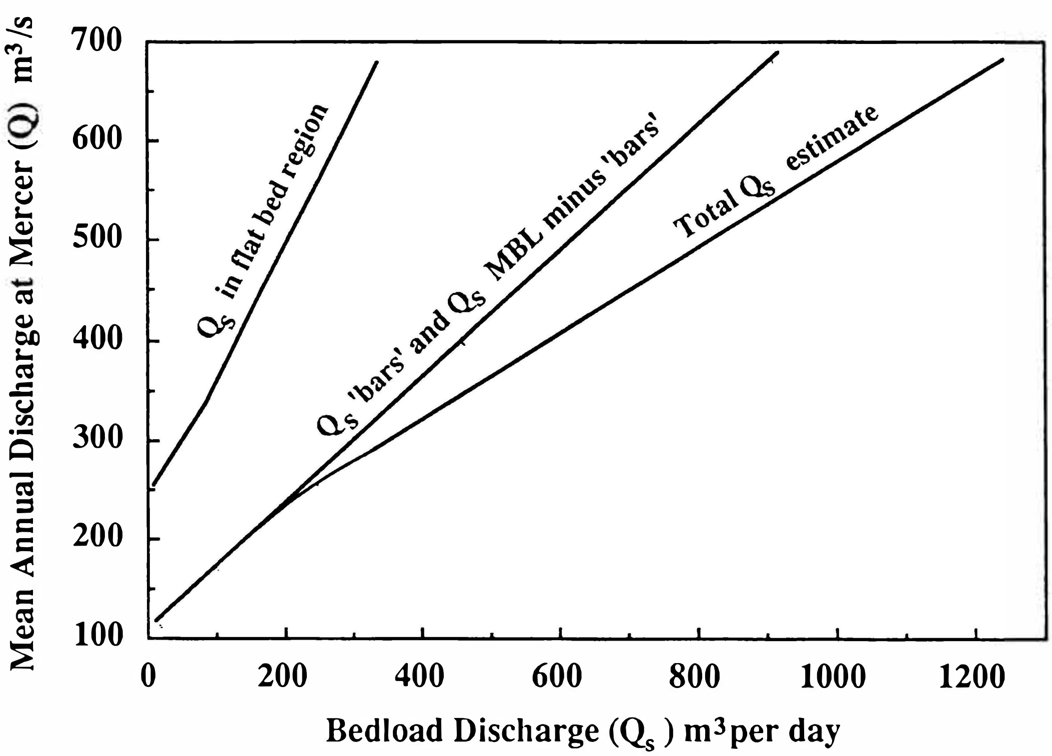


Figure 4.2 : Bedload rating curve for the lower Waikato River, 1966. Bedload discharge (Qs) curves are shown for the flat bed region of the channel that is determined by bedload trapping, 'bars' determined by measurement of bar migration rates, and mean bed level (MBL) minus bar which accounts for changes in MBL. These are summed to gice the total transport curve (after Finley, 1974).

Date (1970)	6th Aug		20th Aug		24th Aug		10th Nov	
Q (m^3/s)	488		570		510		570	
	Bedload (kg/s/m)							
Long Section No	N		N		N		N	
580	14	0.00376	18	0.00361	22	0.00184	22	0.00131
500							22	0.00205
380							15	0.00245
340					24	0.00195		
180			4	0.00038	5	0.00005		

Table 4.3 : W.V.A 1970 bedload trapping results (W.V.A, 1971b).
N is the number of samples trapped for that estimate.

Finley's (1974) study of bar movement between C.S 92 and 93 included 34 sounding intervals that were performed in 1966. The study takes into account the effects of changing mean bed level and makes some allowance for the flat bed region of the reach in determining total bedload. In monitoring sand bar movement the bedload discharge per unit width (g_s) is defined as:

$$g_s = \frac{(\bar{h} \times \Delta d)}{t} \quad m^3/day/m \qquad (4.1)$$

Where:

$\bar{h}$ = mean bar face height (m)

Δd = distance moved downstream (m)

t = time between observations (days)

Finley's results for the flat bed region, bar movement, mean bed level change and total bedload discharge are given in Figure 4.2. In the bar monitoring it appears that for discharges greater than 560 m^3/s the apparent g_s decreases markedly caused by the almost complete disappearance of measurable bars during these flows (Finley, 1974). A similar change was noted during the present study. The total annual bedload discharge for 1966 was estimated as 227 600 m^3 or 218 500 tonnes (W.V.A, 1971a), or 623 m^3/day at a mean water discharge of 416 cumecs (W.V.A, 1971b).

The total load for 1966 was estimated as 596 400 tonnes or 45 ppm, which is comparatively low (Finley, 1974). Finley (1974) also noted that construction of stopbanks and ponding control in recent years has eliminated much of the overland flow to lakes and swamps and consequently increased the sediment transport power of the river. However, as a result of dam construction the sediment transport rate may have dropped from a pre-dam rate in the order of 2 x 10^6 m^3/yr (Dahm and Hume, 1989), to the present estimate used by the Waikato Catchment Board of 1.7 x 10^5 m^3/yr which is based on Finley's work.

4.2 BEDLOAD TRAPPING

Bedload samplers of the direct measuring type are the simplest and most widely used (Emmett, 1980). Hubbell (1964) describes many of the problems encountered with measurement of bedload and provides a state-of-the-art report on apparatus and techniques for measuring bedload. Since this report the Helley-Smith bedload sampler has been developed and is presently in wide use. The Helley-Smith sampler was used for the present study.

The calibration, or determination of the sampling efficiency of the sampler is required if absolute measurements are required. Emmett (1980) undertook field calibration of the Helley-Smith sampler, and concluded the following:

(1) the sampler should not be used for particles smaller than 0.25 mm;

(2) the sampler should not be used for measuring bedload transport rates of sediments with particle sizes which are also transported in suspension;

(3) a trap efficiency for sediments of size 0.25 - 0.5 mm was no able to be determined; and

(4) a trap efficiency of 100% is assumed when there is no suspended sediment transport and the grain size range is 0.5 - 16 mm. This efficiency is not dependent upon sediment transport rate.

In the present study bedload trapping was performed using a 152.4 mm wide Helley - Smith sampler. The sampler was lowered either from a bridge using a crane or over the side of the boat by hand (Figure 4.3). Result from the Helley - Smith sampler can be applied directly to the Waikato River, with its bed material consisting primarily of coarse sand (d_{50} = 0.78 mm). However at higher flows significant portions of the lighter pumice material may be transported as suspended load.

Sampling attempts were made from both the Rangiriri and Mercer bridges during summer flows. It was found, though, at these flows that the sampling efficiency of the trap was severely reduced by clogging of the mesh by algae (Figure 4.4), and volumes of sediment collected were very low and thought to be non-representative of the prevailing conditions. Two productive trappings where conducted at cross section 73 during September and October of 1988, and the results are presented in Table 4.4. This table shows the extreme variablility in trapping results, and an increase in mean sediment discharge with a decrease in flow. This implies that a large number of bedload trappings would be required to encompass the variablility and fluctuation in bedload transport on the river. Hubbell et al. (1985) concluded from a continuous bedload measuring system that bedload discharge varies throughout a wide range in a cyclic manner in phase with dune movement. Such cyclic patterns are also likely to occur in the lower Waikato River. The pumice content of the bedload shows considerable variation (Table 4.4). It is assumed at higher discharges, that the lighter pumice contributes more to the suspended load and hence, the bedload has a lower pumice content.

A

B

Figure 4.3 : Deployment of bedload traps. A - using a gauging crane off a bridge , B - by hand from the side of the boat.

Figure 4.4 : Algae clogged mesh in the bedload trap. During summer low flow algae severly limited the efficency of the traps.

Date	L.S. No	Height (m)	Length (m)	Crest location
25-Feb-88	1	1.15	114	880
	2	1.15	136	883
	3	1.20	158	884
	4	1.10	157	890
	5	1.10	157	901
	6	1.10	179	902
	7	1.05	208	900
	8	0.95	277	830
	Mean	1.10	173	883
17-Mar-88	1	1.10	106	900
	2	1.10	117	900
	3	1.00	160	898
	4	1.00	161	903
	5	1.10	174	909
	6	1.05	202	911
	7	1.00	260	912
	8	0.95	257	916
	Mean	1.04	180	906
14-Apr-88	1	1.05	168	927
	2	0.90	157	924
	3	0.80	174	939
	4	0.80	179	932
	5	0.80	202	947
	6	0.75	172	920
	7	0.65	180	895
	8	0.75	227	913
	Mean	0.81	182	924
1-May-88	NO RESULTS Equipment failure			

Date	L.S No	Height (m)	Length (m)	Crest location
13-Jun-88	1	0.55	194	1056
	2	0.70	233	1060
	3	0.80	214	1049
	4	0.75	288	1073
	5	0.95	286	1075
	6	0.80	258	1067
	7	0.85	238	1055
	Mean	0.77	244	1062
6-Jul-88	1	1.05	260	1122
	2	1.10	281	1143
	3	1.10	260	1133
	4	1.10	262	1133
	5	1.20	292	1137
	6	1.10	288	1152
	7	1.20	252	1130
	Mean	1.12	271	1136
2-Aug-88	NO RESULTS High flow - no sand bars			
1-Sep-88	NO RESULTS High flow - no sand bars			
12-Oct-88	NO RESULTS High flow - no sand bars			
10-Nov-88	1	0.90	269	970
	2	0.80	240	955
	3	0.90	209	905
	4	1.10	213	922
	Mean	0.93	233	938

Date	L.S. No	Height (m)	Length (m)	Crest location
10-Nov-88	5	1.00	222	223
	6	1.50	300	324
	7	1.35	350	366
	8	1.50	380	380
	Mean	1.34	313	323
8-Dec-88	1	0.80	339	1000
	2			
	3	0.85	234	837
	Mean	0.83	287	919
	3	0.80		101
	4	1.90		215
	5	2.00	230	296
	6	1.40	270	358
	7	2.10	300	435
	8	2.50	300	436
	Mean	2.00	275	307
24-Jan-89	2	1.7	365	1020
	3	1.8	340	1010
	4	1.7	350	995
	5	2	365	988
	Mean	1.8	355	1003
	4	2.5	400	260
	5	1.6	360	347
	6			
	7	1.7	500	475
	8	2.3		438
	Mean	2.025	420	380

Table 4.5 : Sand bar heights, wavelengths and crest locations (m downstream of C.S 73) for monthly surveys. L.S. No is the longitudinal transect number for the bed morphology study area (Figure 3.15). During the period Nov-88 to Jan-89 two sand bars where present in the study area, hence two mean values are given.

Long Section Number	01 Sept 1988 Dry Weight (kg)	q_s (kg/s/m)	Pumice %	12 Oct 1988 Dry Weight (kg)	q_s (kg/s/m)
1	0.846	0.0093	49	0.391	0.0043
2	1.446	0.0159	17	0.499	0.0055
3	1.198	0.0131	27	0.506	0.0055
4	2.151	0.0236	11	0.521	0.0057
5	2.255	0.0247	26	0.693	0.0076
6	0.079	0.0009			
7	0.179	0.0020		0.545	0.0060
8	0.941	0.0103	16	0.598	0.0066
		X = 0.0125			X = 0.0059
		σ = 0.0083			σ = 0.0009
Discharge (m^3/s)		666			1009

Table 4.4 : Bedload trapping results from C.S. 73, lower Waikato River. Bedload transport mean (x) and standard deviation (σ). The flow discharge is the daily mean value. Pumice percentages determined for September samples only. Each sample was trapped over a period of 10 minutes.

4.3 BEDLOAD TRANSPORT ESTIMATE FROM SAND BAR MIGRATION

Rates of bar migration and bar dimensions obtained from the bed morphology study are summarised in Table 4.5. These results can be used to calculate bar volume and net downstream bedload transport (Q_s). The bedload transport rate is calculated using equation 4.1, where mean bar face height and distance moved downstream are taken as the mean values across the bar between consecutive surveys (Table 4.5). The volume of bedload transport past the bar crest is seen to increase with increasing discharge (Figure 4.5). The linear regression equation for this relationship can be applied to mean daily discharge data (Q) for the duration of the morphology study, to provide a plot of sediment discharge (Q_s) with time (Figure 4.6). From this plot, the mean bedload transport by sand bars during the study period was 2.58 m^3/day/m width. Hence an estimate of bedload transport is derived from the rate of sand bar migration. Assuming a channel width of 220 m (mean width in bed morphology study area) then the annual bedload transport rate for the study period was 207 000 m^3/yr.

This method provides a reliable estimate of bedload transport assuming the bar is a closed system, i.e no transport occurs beyond the crest. However this method of calculating bedload transport fails at higher discharges when the bed becomes more rounded and the crest becomes undefinable. It should be noted however, that the relationship obsevered (Figure 4.5) characterises the bedload transport across the stoss face of the sand bars, it is logical therefore that it may be extraporlated beyond the discharge at which the bars disappear, to provide an

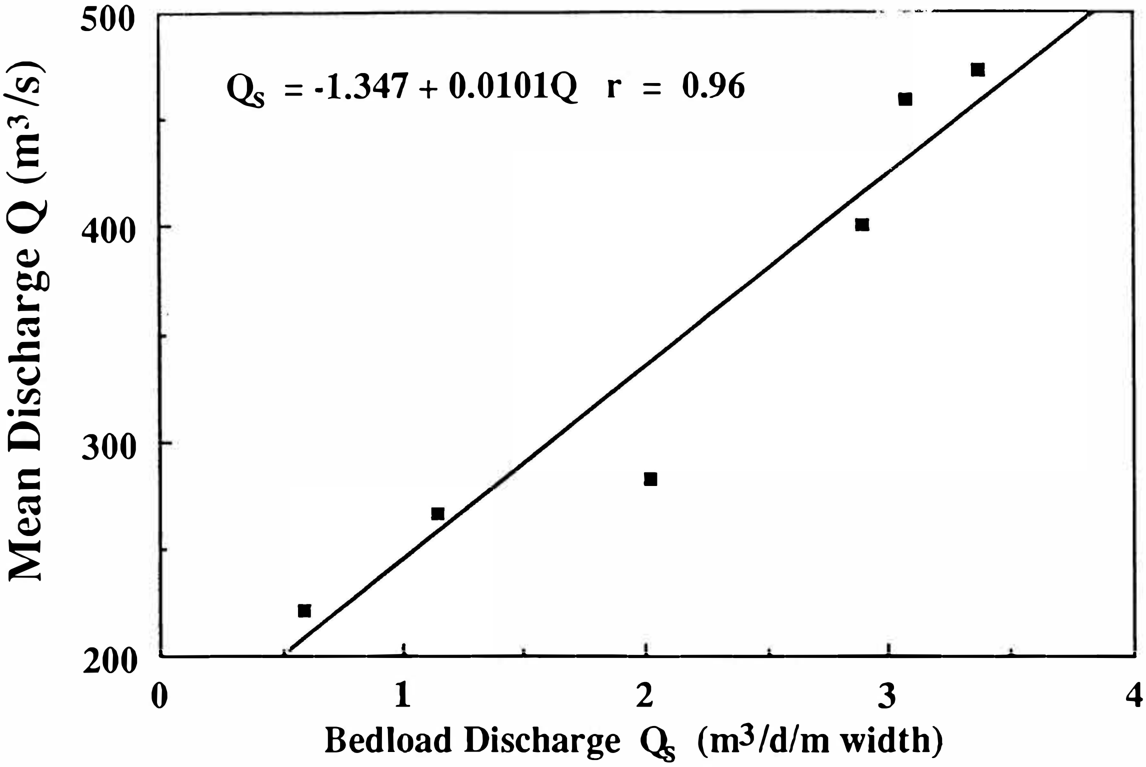


Figure 4.5 : Bedload discharge (Qs) past bar crest relationship with flow discharge (Q), based on data in Table 4.5. The line is fitted by least squares regression, the resulting equation and correlation coefficent are given. Q is the mean flow discharge at Rangiriri for the period between surveys.

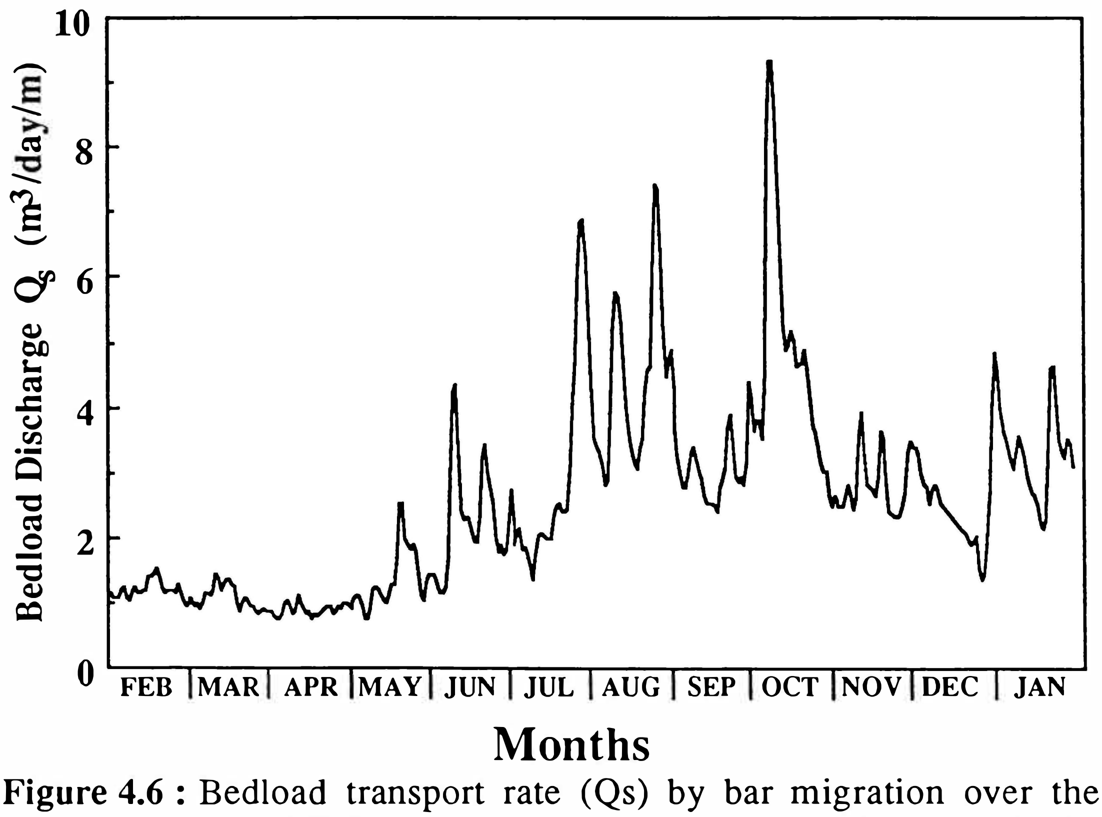


Figure 4.6 : Bedload transport rate (Qs) by bar migration over the period February 1988 to January 1989. The curve is the result of intergating the equation from Figure 4.5 on daily mean flow data for Rangiriri. Mean Qs for the year long period is 2.58 m /day/m width of bar.

estimate of bedload transport at higher discharges. In the present study no account has been taken for bedload transport in the flat bed region along the sides of the bars, as it is assumed to be minimal when compared to bar movement for the following reasons:

(1) during the morphology study the bars monitored dominated the width of the channel, with channels of only 20 - 30 m down each side;

(2) flow evidence presented by Leopold (1982) shows that sand in the main flow channels is 'shepherded' towards the bar, thereby reducing the actual transport rate in the main channels past the bar crest; and

(3) bedload transport rates per unit width in the flat bed region are significanlty lower than that transported across the bars.

Further discussion on the results of the present bar migration study when compared to other methods of determining bedload transport is presented in Section 4.5.

4.4 APPRAISAL OF BEDLOAD FORMULAE

There are numerous theories for predicting sediment transport. There does not exist a set of universal equations which completely describe river and sediment behaviour and there probably never will be, because of the complex nature and diversity of river systems. There are essentially three slightly different approaches to the bedload problem (Graf, 1971):

(1) *duBoys-type* equations, which considers a shear stress relationship;

(2) *Schoklitsch-type* equations, which considers a discharge relationship; and

(3) *Einstein-type* equations, which are based upon statistical considerations of the lift forces.

In this section several established bedload formulae are applied to the the lower Waikato River at a range of discharges. The development procedure and limitations for each formula are outlined.

4.4.1 Bedload and Hydraulic Variables

Prior to the application of bedload formulae to a specific setting, a number of parameter values must be determined, either by calculation or direct measurement. They are:

ρ_s	sediment density (kg/m^3);	d_{50}	medium grain size (m);
V	velocity (m/s);	R	hydraulic radius (m);
S	slope;	D	depth (m).

Fixed variables used in the calculations are:

ρ	water density, taken as 999.1 kg/m^3 at 15.5 °C (60°F);
g	gravitational accelaration, 9.81 m/s^2.

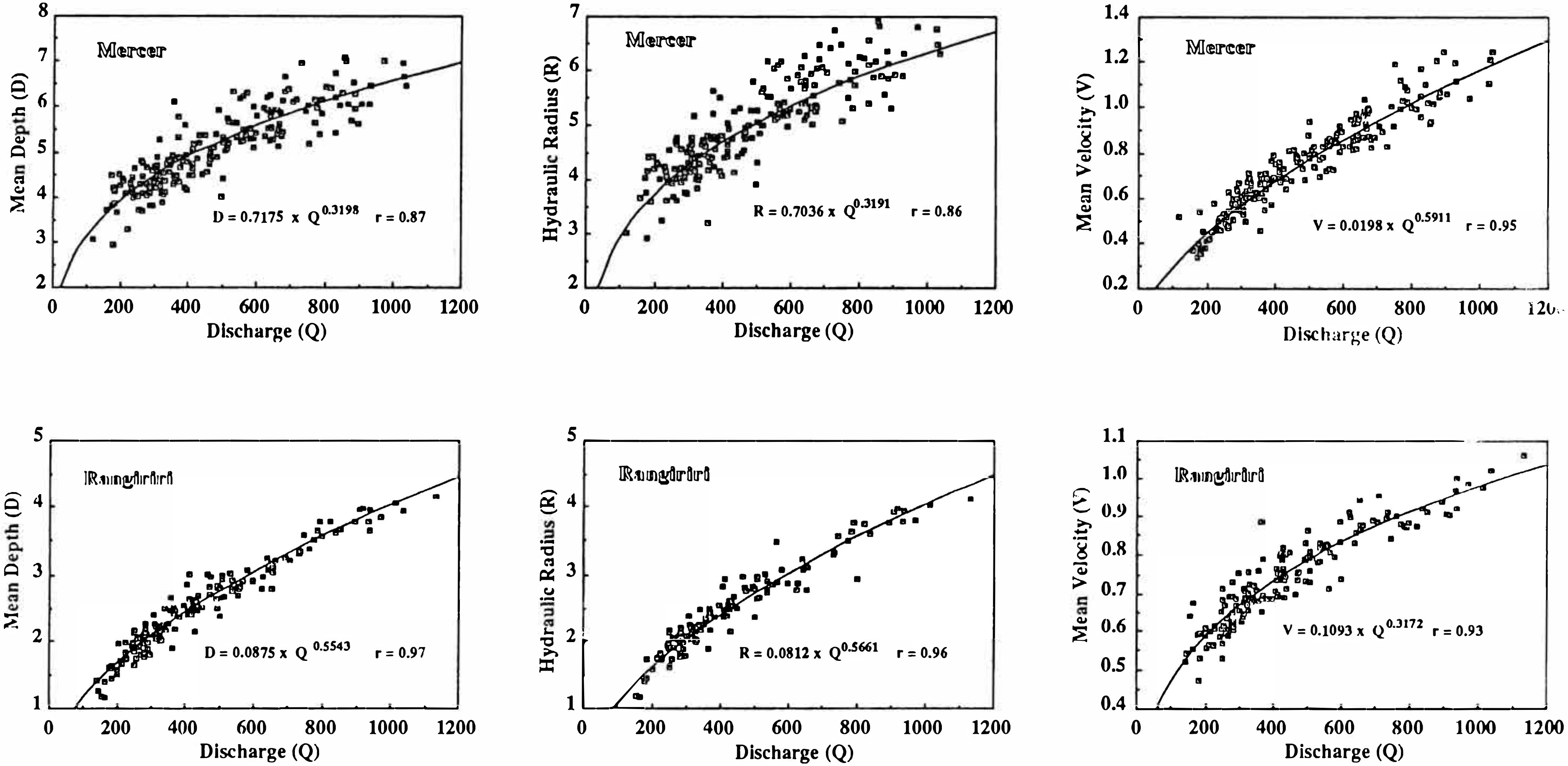


Figure 4.7 : Mean depth (D), hydraulic radius (R) and mean velocity (V) rating curves and equations for Mercer and Rangiriri. Based on Catchment Board gauging data from the Mercer and Rangiriri bridges. The curves for each relationship are fitted using a best fit logrithmic equation (see separate graphs for equations and correlation coefficients, r).

Velocity, Depth and Hydraulic Radius

Waikato Catchment Board flow gauging data for the Mercer and Rangiriri sites are used to create rating curves for velocity, depth and hydraulic radius (Figure 4.7). The equations for these curves are used to produce values of V, D and R at different discharges for use in the bedload equations.

Slope

Only limited slope data are available over a small range of discharges for the lower Waikato River. Regular slope profiles are conducted by the Waikato Catchment Board at a discharge of about 350 m^3/s. In this study synthesised slope data are used above and below the 350 m^3/s stage. This data is produced by a method of back calculation using a Mannings 'n' value, as outlined in Henderson (1966). The resulting slope discharge relationships for Mercer and Rangiriri are shown in Figure 4.8.

Grain Size and Sediment Density

The medium grain size (d_{50}) for the bedload transport calculations is taken as the average d_{50} of all the surface sediment samples analysed from the study area (Appendix 6.10). A value of 0.78 mm is obtained.

Sediment density is an important parameter in sediment transport studies and an average value is required to insert in bedload formulae. Material from bedload trapping is used to determine sediment density, as it represents what is being transported. To determine sediment density each oven dry sample (OD) was lightly ground and put in a stoppered density bottle. The bottle was filled with water and weighed (W_s), then washed out, fillled with water and reweighed (W_w). Particle density is then calculated as;

$$\rho_s = \frac{OD}{W_w - (W_s - OD)} \quad \text{kg/m}^3 \qquad (4.2)$$

The result of analysis on a number of bedload samples are presented in Table 4.6.

OD (g)	W_s (g)	W_w (g)	Density kg/m^3
5.21	80.01	77.04	2321.8
9.47	81.69	75.95	2538.0
7.94	74.97	70.22	2488.9
6.66	77.51	73.53	2482.6
7.36	80.01	75.48	2598.1
5.47	80.22	77.13	2294.4

Mean density = 2454 kg/m^3
Standard deviation = 120.7 kg/m^3

Table 4.6 : Bedload density calculations, from samples trapped at C.S. 73.

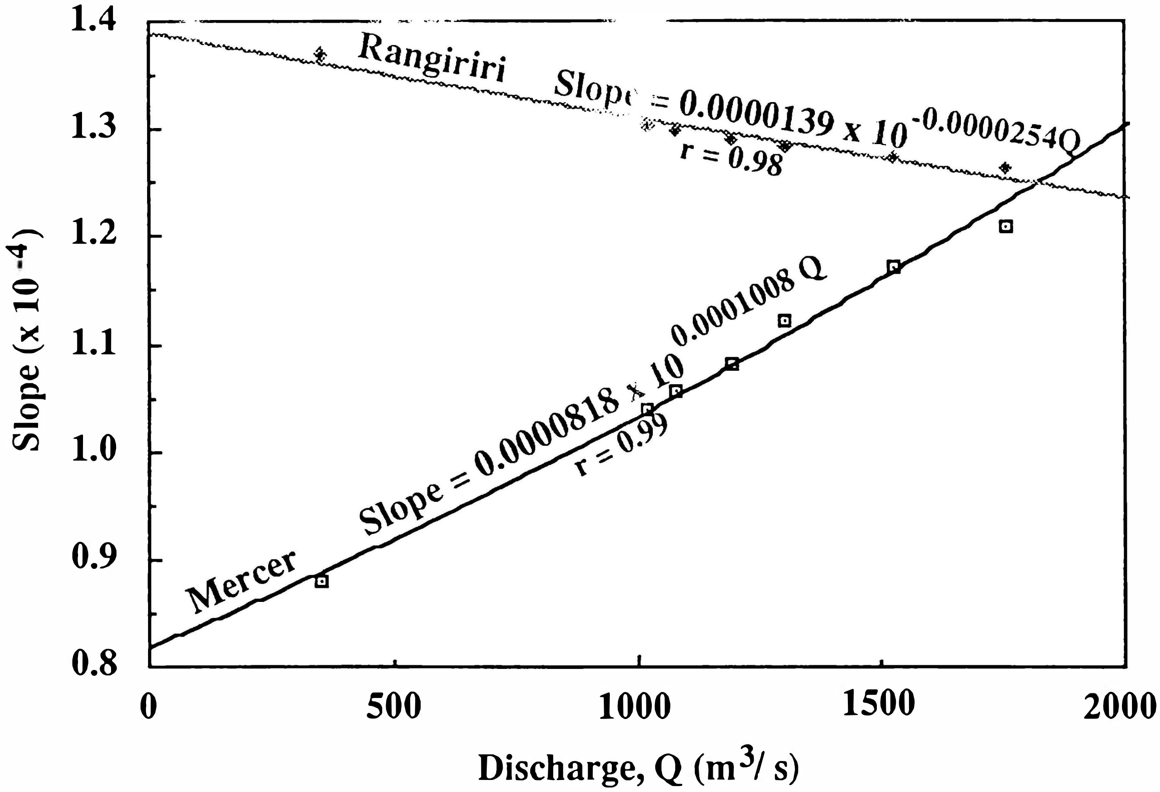


Figure 4.8 : Slope discharge relationships for Mercer and Rangiriri. Best fit exponential curves are fitted to data, resulting correlation coefficients (r) are given. Slope data is calculate in a computer model by the W.C.B, which given a Manning's 'n' value back calculates the rivers slope using an equation given by Henderson (1966).

4.4.2 Meyer-Peter and Muller (1948)

Meyer-Peter and Muller (1948) developed an empirical bedload equation based on, and corrected to, experimental results from flumes ranging in width from 15 cm - 2 m, with slopes varying from 0.0004 - 0.02, and water depths 1 cm - 120 cm. Sediments used range from coal with a specific gravity (γ_s/γ) of 1.25, to river sediments, to barite with a specific gravity of greater than 4.0. Most of the data on which the formula is based were obtained in flow with little or no suspended sediment. The formula may therefore be invalid for flows with appreciable suspended loads. The equation assumes that the energy gradient of a channel is used for the conveyance of both water and sediment, and that similar controls both initiate and maintain sediment motion. Thus in this model bedload transport is related to discharge. The advantage of this formula over the older Meyer-Peter formula is that it can be used for graded sediments under flow conditions that give rise to dunes and other bedforms.

The formula is given as:

$$\left(\frac{k_r}{k_r'}\right)^{\frac{3}{2}} \gamma RS = 0.047(\gamma_s - \gamma)d_{50} + 0.25\left(\frac{\gamma}{g}\right)^{\frac{1}{3}}\left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{\frac{2}{3}} g_s^{\frac{2}{3}} \qquad (4.3)$$

where:

γ is the specific weight of the fluid (ρg);

γ_s is the specific weight of sediment;

g_s is the sediment mass transport rate per unit width (kg/s/m);

k_r is an empirical coefficent related to sediment particle roughness; and

k_r' is the total roughness obtained from the flow data.

The expression (k_r/k_r') defines the effective shear on particle grains (Richards, 1983), and usually varies between 0.5 and 1.0 depending on bed configuration, a ratio of 1.0 represents plane beds and 0.5 represents strong bedforms (Graf, 1971). For this study a ratio of 0.55 is used at water discharge of 200 m^3/s, when bar bedforms are dominant, increasing linearly to 1.0 at 900 m^3/s, beyond which a plane bed is assumed to exist. The equation is dimensionally homogeneous.

4.4.3 Engelund-Hansen (1967)

The Engelund-Hansen formula is only valid for dune covered beds for which the boundary Reynolds No ($U_* d_{50}/\nu$) exceeds 12. This condition applies for the study sites (Appendix 4). The formula is not recommended for cases where the d_{50} gain size is less than 0.15 mm. The equation is dimensionally homogeneous, and is based heavily on data from four sets of experiments in a large 2.4 m wide, 46 m long flume. Sediments used had mean fall diameters of 0.19, 0.27, 0.45, and 0.93 mm.

The Engelund-Hansen (1967) formula is:

$$g_s = 0.05\gamma_s V^2 \sqrt{\frac{d_{50}}{g\left(\frac{\gamma_s}{\gamma} - 1\right)}} \left[\frac{\tau_o}{(\gamma_s - \gamma)d_{50}}\right]^{\frac{3}{2}} \qquad (4.4)$$

where τ_o is the boudary shear stress (ρgRS) (Nm^{-2})

4.4.4 Einstein Bedload Function (1950)

The contribution of Einstein (1950) is probably the most complete and integrated discussion of the overall process of sediment transport. His work represents a departure from the *duBoys-type* and *Schoklitsch-type* equations. The two basic considerations that break with earlier work are:

(1) that the definition of a *critical* value for the initiation of sediment motion is a difficult if not impossible proposition. Therefore such a criterion was avoided; and

(2) that the bedload transport is related to fluctuations in flow velocity rather than to an average value of velocity. The beginning and end of the particle motion are expressed using the concept of probability, relating instantaneous hydrodynamic lift forces to the particle weight.

The method computes sediment discharge for individual size fractions of the bed material. Einstein developed a function for the intensity of bedload transport

$$\Phi = \frac{g_s}{\gamma_s} \sqrt{\frac{\rho}{\rho_s - \rho} \frac{1}{g d_{50}^3}} \qquad (4.6a)$$

where Φ is the intensity of bedload transport, and g_s is the rate of bedload transport in mass p unit width.

Einstein then introduced a flow function

$$\Psi = \frac{\rho_s - \rho}{\rho} \frac{d_{50}}{SR} \qquad (4.6b)$$

where Ψ is the flow function.

The two functions are related by

$$\Phi = fn(\Psi) \qquad (4.6c)$$

given by Figure 10 of Einstein's paper (1950). The figure is based on data from uniform bed material, and is applicable for material from 0.7 - 28 mm. In this study Ψ is calculated, and a value of Φ obtained from Einstein's Figure 10. Rearrangement of equation 4.6a yeilds a sediment discharge per unit.

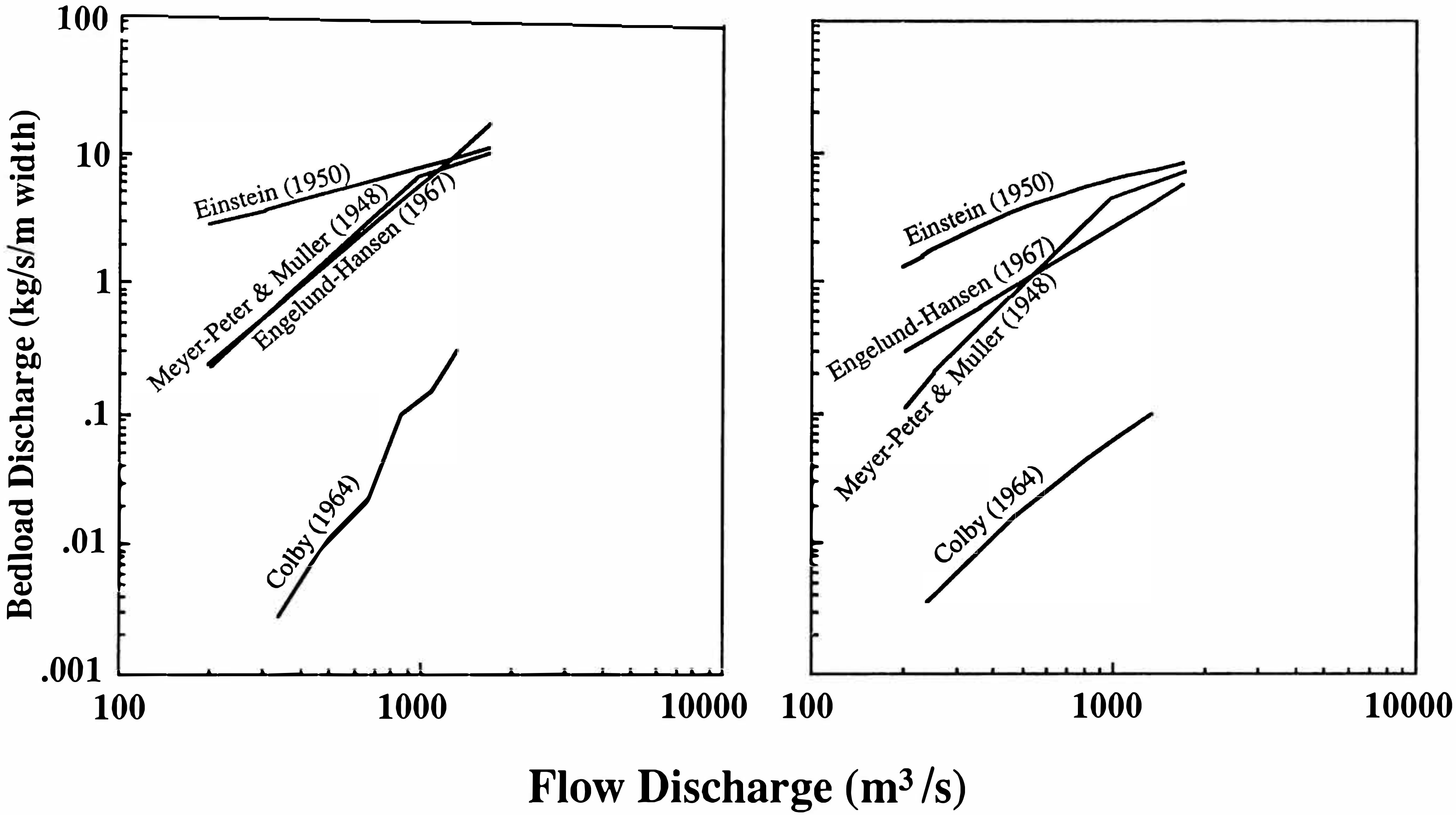


Figure 4.9 : Comparison of bedload rating curves based on bedload formulae for both Mercer and Rangiriri. Bedload formulae used are outlined in sections 4.4.2 - 4.4.6. Determination of parameters outlined in Section 4.4.1.Data in Appendix 4.

4.4.5 Colby Relations (1964)

Colby's relations for sediment discharge that apply only for sand are presented in four graphs. An uncorrected value of bedload discharge is obtained from one set of graphs. This value is then corrected using equation 4.7, for temperature, grain size and suspended sediment to provide a value of bedload discharge in tonnes per day per unit width.

$$g_s = [1 + (k_1 k_2 - 1)0.01\, k_3]\, g_{s1} \qquad (4.7)$$

where:

$k_1 = 1$ when temperature is 60° F ;

$k_2 = 1$ when concentration of suspended sediment is negligible; and

$k_3 = 100$ when d_{50} lies between 0.2 and 0.3 mm.

If conditions are different from these, k values are determined from the appropriate graph and applied to equation 4.7. In this study the lower Waikato River is assumed to be at 60°F and suspended sediment is negligible, however, with a d_{50} of 0.78 mm the k_3 variable has a value of 30.

In arriving at his curves Colby (1964) was guided by the Einstein bedload function and an immense amount of data from streams and flumes.

4.4.6 Formulae Calculations and Conclusions

The values of unit bedload discharge (g_s) are calculated for the above equations, with the exception of Colby (1964), at 20 m^3/s increments of discharge from 200 m^3/s to 1700 m^3/s. The results of these calculations are summarised in Appendix 4. Values of bedload discharge from Colby's relations are taken from the graphs in increments of velocity of about 0.5 ft/s, as the graphs are in imperial units.

There appears to be no significant difference in bedload transport relationships between the Rangiriri and Mercer sites (Figure 4.9). The Meyer-Peter and Muller (1948) and Engeland-Hansen (1967) bedload transport curves plot closely together, generally with a slightly lower unit bedload transport rate (g_s) than Einstein's function (1950), but with a steeper gradient. The kink in the Meyer-Peter and Muller curves is due to the assumption that k_r/k_r' is 1 above 900 m^3/s. The Colby Relations are applicable to sand streams only, and were based on a large amount of data from both streams and flumes. They are therefore likely to be more representative of the lower Waikato River, than the other formulae that are based only on flume data over a much wider range of grain size.

Medium grain size (d_{50}) and sediment density (ρs) values are utilised in most bedload formulae. Accurate determination of these two parameters is therefore important as variation in either can strongly influence the bedload transport rate determined by bedload formulae,

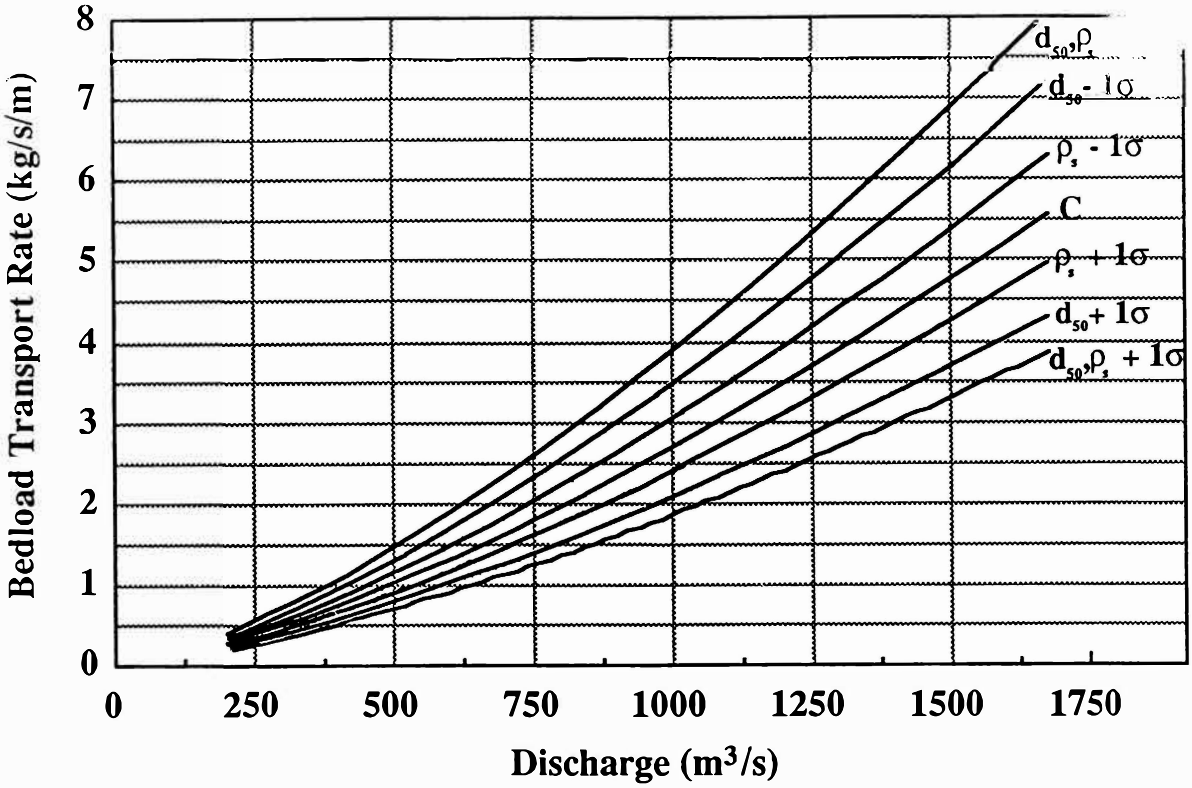


Figure 4.10 : Sensitivity of the Engelund-Hansen bedload equation to changes in grain size (d_{50}) and sediment density (ρ). C is the control where d_{50} is 0.78 mm and ρ is 2454 kg/m^3 . Variations show in the graph are $\pm$ one standard deviation of the medium grain size ($d_{50} \pm 1\sigma$), sediment density ($\rho_s \pm 1\sigma$), and a cumulative change in both size and density ($d_{50}, \rho_s \pm 1\sigma$).

Where: $d_{50} + 1\sigma$ = 1.01 mm, $d_{50} - 1\sigma = 0.604$ mm; and

$\rho_s + 1\sigma$ = 2575 kg/m^3 , $\rho_s - 1\sigma$ = 2333 kg/m^3 .

especially at higher water discharges (Figure 4.10). The bed sediments of the lower Waikato River are variable in both size and density. The average sediment density of the active bedload is dependant on its pumice content, and this content appears to decrease at higher discharges (Eynon-Richards, 1988), with lighter pumice tending to become suspended load. The medium grain size is also variable, with physically larger pumice grains behaving hydrodynamically similar to lithic and quartz grains. This would make the true mean hydrodynamic grain size finer than 0.78 mm, producing a higher sediment transport rate (Figure 4.10).

At the present level of development it is clear that sediment discharge formulae, at best can be expected to give only estimates (Vanoni, 1975).

4.5 SUMMARY AND DISCUSSION OF BEDLOAD TRANSPORT ESTIMATES

The presently accepted estimate of bedload transport for the lower Waikato River is 170 000 m^3/yr at Mercer. This figure is based on Finley's (1974) bedload transport rating curve (Figure 4.2), assuming a yearly mean water discharge of 350 m^3/s at Mercer. However, during the period of this study (February 1988 to January 1989) the mean water discharge was 419 m^3/s, this represents a bedload transport rate of 240 000 m^3/yr based on Finley's curve (Figure 4.2). The mean discharge from the Mercer flow duration curve for the period October 1979 to February 1982 is 380 m^3/s (Mulholland, 1983), this equates to a bedload transport rate of 195 000 m^3/yr from Finley's bedload transport curve (Figure 4.2).

The mean annual bedload transport rate from bar migration in the present study is 2.58 m^3/day/m width, assuming the average width of the morphology study area is 220 m,which equates to a bedload transport over the study period of 207 000 m^3/yr. This value compares favourably with the estimate from Finley's curve over the same period (240 000 m^3/yr).

It is clear that there can be considerable variation in the bedload transport estimates from year to year depending on the mean annual water discharge. Therefore, to determine a best estimate of bedload transport from the above bar migration relationships, it is necessary to apply them to the past flow records. Mean monthly flows for both the Mercer and Rangiriri section of the river show considerable variation with time (Figure 4.11), however, most of the cyclic pattern is due to seasonal variation. There does appear to be a noticable drop in mean flow discharge at Mercer, with a slight decreasing trend at Rangiriri.

Application of these flow curves (Figure 4.11) to the bedload transport relationships obtained in the present study provides an indication of longterm bedload discharge with time (Figure 4.12). This plot provides evidence of a decrease in bedload discharge with time. Also there is

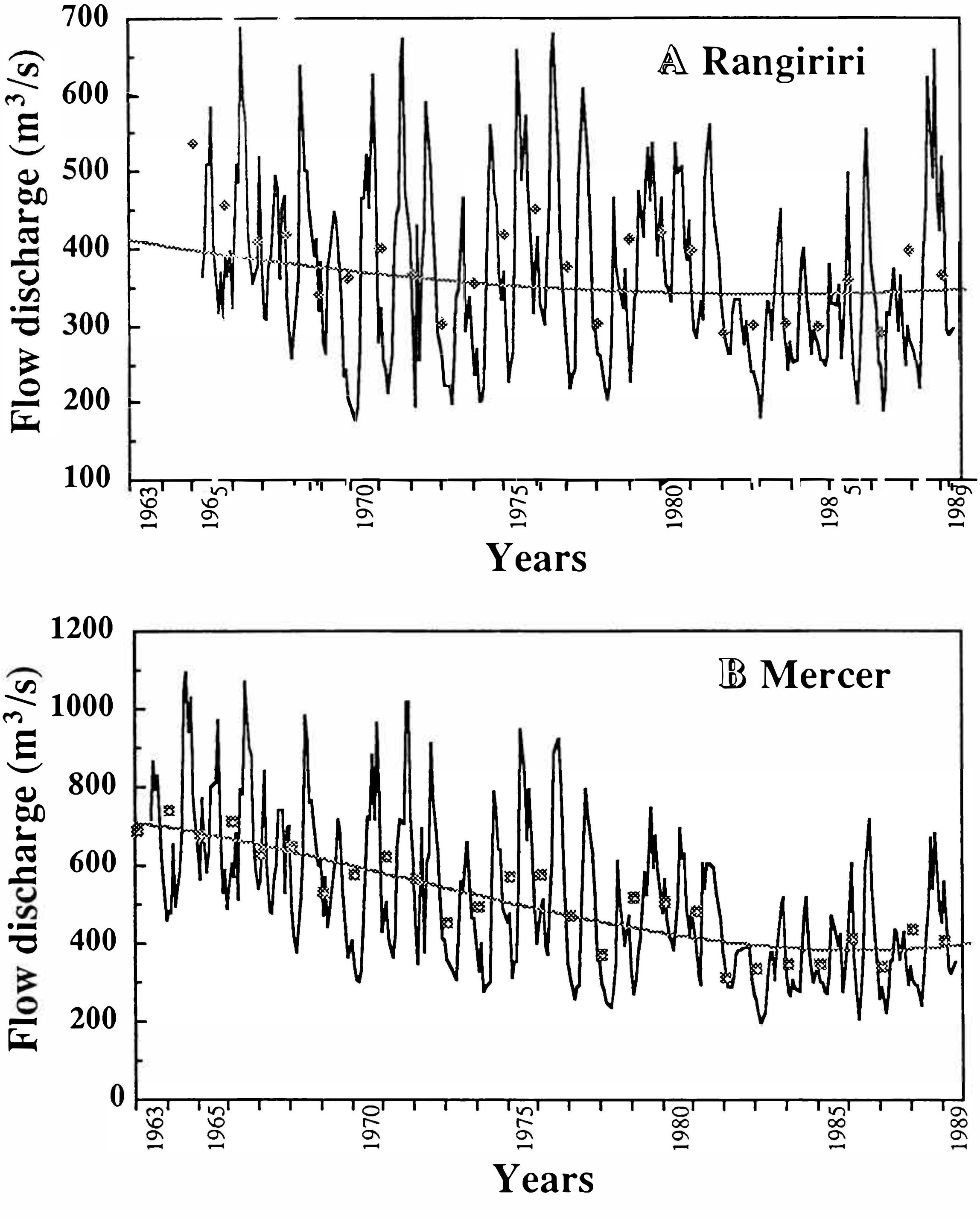


Figure 4.11 : Plots of flow discharge at Rangiriri and Mercer since 1963. Solid lines are monthly mean discharge values, Shaded dots are yearly mean discharge values, and shaded line is a best fit third order polynomial curve to provide an indication of the trend in mean yearly values.

initially a significant difference between the two areas. Application of Finley's (1974) bedload transport relationship yeilds a very similar curve to Figure 4.12. Table 4.7 is a statistical summary of the bedload transport rates for both the Mercer and Rangiriri sites, using both the present bedload transport relationship and Finley's with monthly mean flow data from 1963 to 1989. The mean and standard deviations were determined for all the data, pre-1975 data, and post-1975 data. It is clear that there is a considerable difference between the Mercer and Rangiriri sites.

Annual Bedload Transport (m^3/s)					
		Mercer		Rangiriri	
		Present study	Finley (1974)	Present Study	Finley (1974)
All Data	X	306040	309928	190598	195180
	σ	101607	101811	43021	42892
Pre-1975	X	384777	388774	205136	209675
	σ	70114	69903	36206	36097
Post-1975	X	232927	236715	179175	183792
	σ	64449	65050	45708	45570

Table 4.7 : Annual bedload transport estimates (m^3/yr) for the period 1963 to 1989. Mean (X) and standard deviation (σ) values are shown for all data, pre-1975 data, and post-1975 data derived from using both the present bedload transport relationship and Finley (1974) curve.

The author considers that application of both the bedload transport relationships to the Mercer site has a number of limitations. They are:

(1) the bars bedfoms on which both relationships are based are not present in the Mercer area and bedload transport may therefore be controlled by different mechanisms;

(2) the channel in the Mercer area may be considered out of equilibrium as a result of local sand extraction, resulting in large cross sectional areas, and hence, lower velocities;

(3) the marked drop in flow discharge seen at Mercer, is not so apparent at Rangiriri and the discrepency may be due to the changing stage discharge relationship in the Mercer area as a result of sand extraction; and

(4) the channel is considerabley marrower at Mercer (~156 m) than that in the bed morphology study area (~ 220 m) where the bedload relationship was developed, while at Rangiriri the width is comparable (~ 250 m).

The bedload transport estimates at Rangiriri are therefore considered more representative. Both bedload relationships show a drop in the annual bedload transport at Rangiriri (Table 4.7), from about 205 000 m^3/yr to 180 000 m^3/yr.

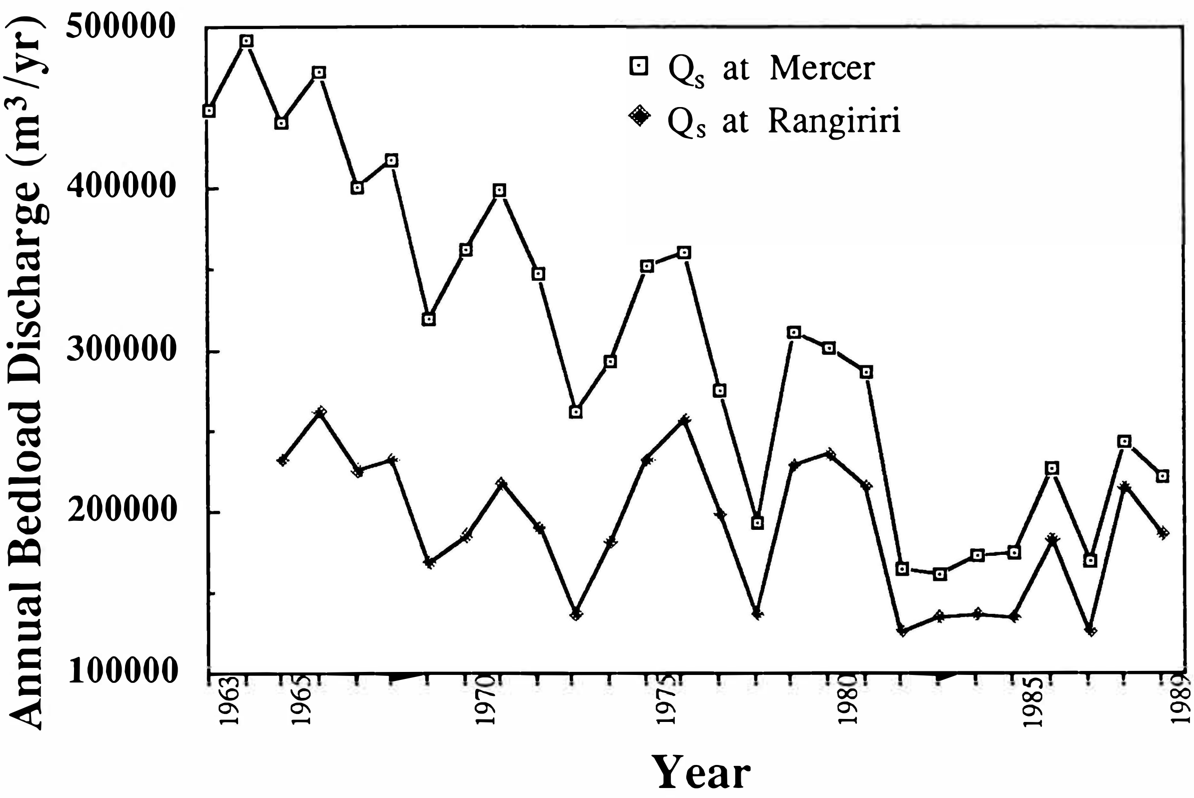


Figure 4.12 : Annual bedload discharge at Mercer and Rangiriri from 1963 to 1989. Values are based on mean yearly flow values for each site (Figure 4.11) applied to the bar migration bedload transport relationship (Figure 4.5).

Presently, the most reliable estimate of medium term bedload transport in the lower Waikato River is 180 000 m^3/yr. There is however, a need for future monitoring and reassessment of this bedload transport figure. As long as the bar bedforms persist in the Huntly to Mercer reach they provide an accurate means of assessing the bedload transport flow discharge relationship of the lower Waikato River. A major advantage of a bar migration study for estimating bedload transport rate is that an estimate of wet bulk density of *insitu* bed material in not required, eliminating a difficult to define parameter that is required for other methods such as bedload formulae to obtain a volume transport, as opposed to a weight transport. Trends in mean annual flow discharge must also be monitored to assess the extent of bedload transport change with time. The need for future monitoring will become more inportant as the effects of sediment starvation caused by the Karapiro dam progress downstream.

All the bedload transport data presented in this chapter is summarised in Figure 4.13. It can be seen that the bedload transport relationship from bar migration observed in this study (Figure 4.5) compares well with Finley's (1974) results for the lower Waikato River. A correlation also appears to exist between the W.V.A bedload trapping data and trapping results from this study. The Colby relations (1964) appears to be the formulae that is most representative of the lower Waikato River, producing bedload transport values that lie between those obained from bar migration, and those from bedload trapping. The remaining formulae are an order of magnitude or more greater than that obtain from bar migration.

A general bedload transport model can be inferred for the lower Waikato River based on the present study (Figure 4.14). Bedload transport due to bar migration increases with increasing flow discharge (Figure 4.5), similarly bedload transport in the flat bed region in assumed to increase with increasing flow discharge. The bedload transport relationship due to bar migration will decreasing rapidly away from the Finley (1974) total bedload curve as discharge exceed about 600 - 700 m^3/s due to the bars flattening and disappearing. At the same time bedload transport in the flat bed region of the channel increase rapidly as the bar disappear to a point where total bedload transport is represented by the flat bed region (joining an extrapolated Finley curve).

The contribution of bedload to the lower Waikato River from its major tributaries appears to be minimal, and can be considered insignificant when compared to the volume transported by the lower Waikato River. Evidence for this is seen in Figure 5.18, which shows the beds of the Waipa River and Mangawara Stream to be markedly lower than the Waikato River's bed, which has aggraded significantly in recent times. If transport rates had been significant in these tributaries their bed should have risen to some extent with the Waikato Rivers. The Tributaries are likely to contribute bedload only during high flood flows

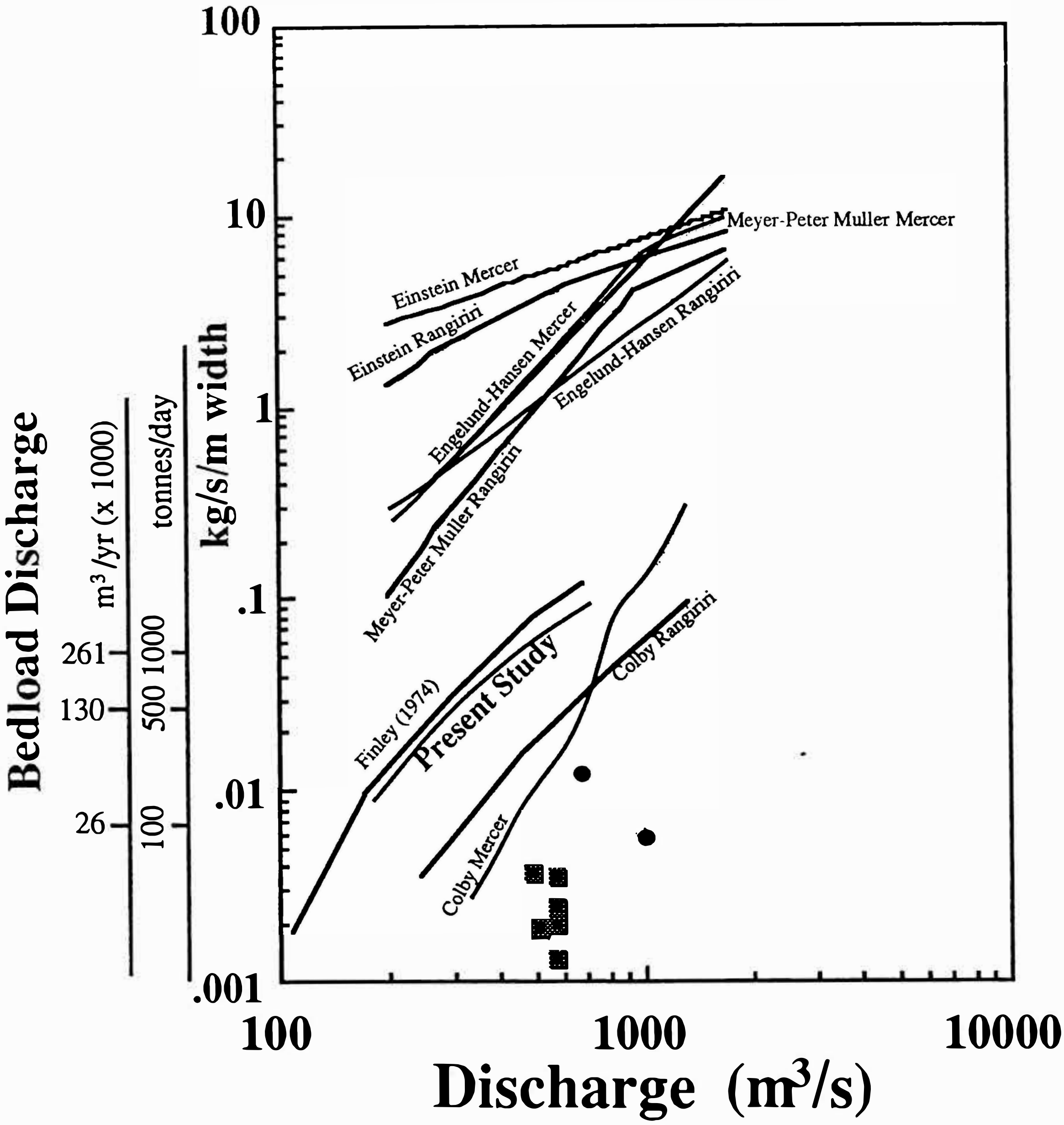


Figure 4.13 : Summary of bedload transport measurements and calculations presented in Chapter 4. Transport rates in m^3 /yr and tonnes per day are calculated with the assumption that channel width is 220 m and wet bulk density of the sand is 1400 kg/m³ .

■ Bedload trapping samples conducted by the W.C.B

● Bedload trapping results from the present study.

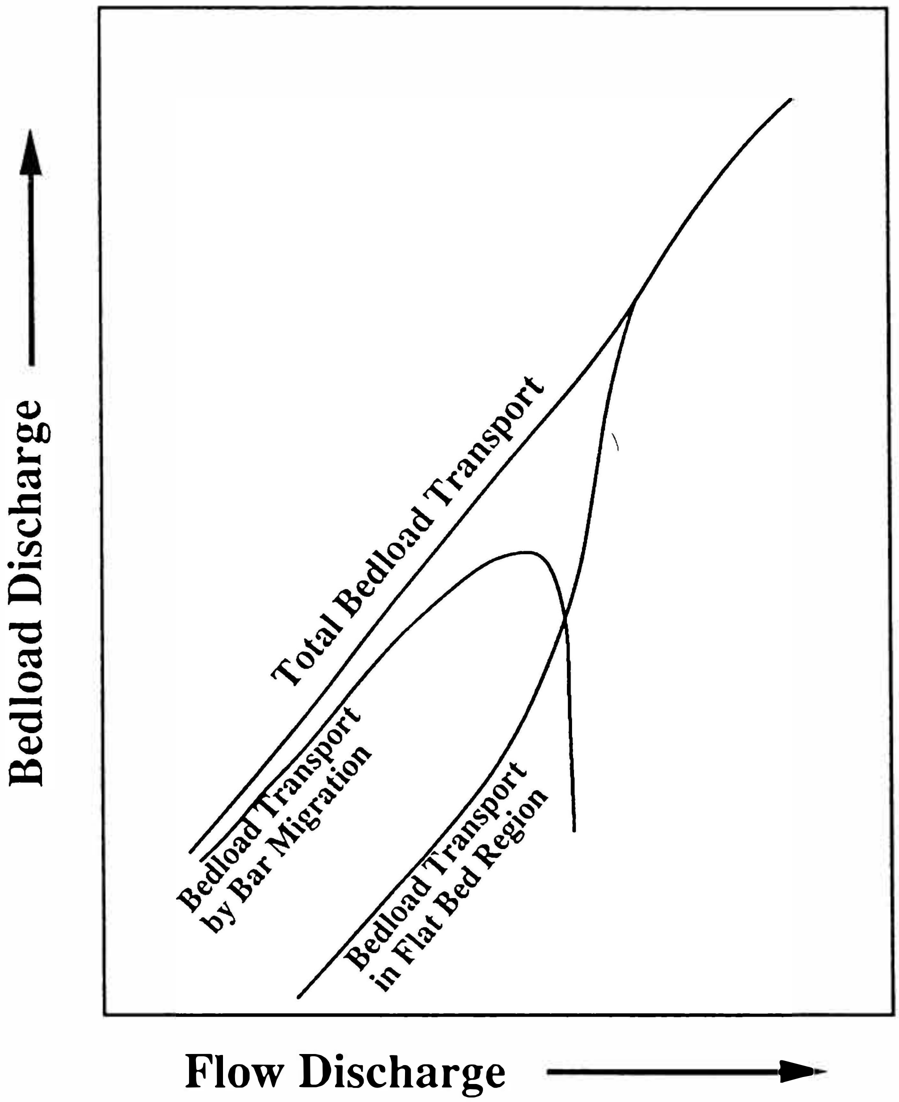


Figure 4.14 : Schematic representation of the general bedload transport relationship that is assumed to exist in the lower Waikato River. The total bedload transport is the summation of transport in the flat bed region and transport by bar migration. As flow discharge increases the bars begin to deform and the main mode of transport rapidly change to the flat bed region. When the bars disappear, total transport is due to sediment movement over a flat bed.

CHAPTER FIVE :

SUBSURFACE STRATIGRAPHY

CHAPTER 5
SUBSURFACE STRATIGRAPHY

5.0 INTRODUCTION

Cores were taken over selected areas of the lower Waikato River, specifically in the Mercer and Puni sand extraction licence areas. The cores were analysed for textural parameters and pumice percentage. These results are used to characterise the deposits and to draw conclusions about hydrodynamic processes in the river. Sub-bottom profiling of parts of the study area provide an increased understanding of subsurface stratigraphy. Some inferences are made about the recent sedimentation history of the lower Waikato River using stratigraphic information and radiocarbon dates on woody material obtained from coring.

5.1 CORING METHODS AND LOCATIONS

Methods

Two methods of coring were used. Firstly, a method of 'vibracoring' where a 6 m long, 100 mm diameter PVC pipe was driven into the bed with a concrete vibrator attached to the top. Although used overseas in well sorted beach sands (Lanesky et al., 1979), the method was not very successful in the coarse pumiceous sands and gravels of the Waikato River bed. The vibrating pipe could be driven only 2 - 3 m into the bed before the vibrating appeared to cause the sediment to firmly hold the pipe, and halt penetration. The vibrating also caused about 0.5 - 1 m of compaction of the material within the core. In retrieving the core from the bed, large portions, or in some cases all of the sediment was lost from the bottom of the core because of the very poor cohesion of the loosely packed, unsupported clean pumice sands and gravels across the wide tube. Consequently, this method of coring was abandoned. Smith (1984) provides specific information on improving penetration and recovery in fluvial and deltaic sediments, but also found that penetration was limited in the coarser sands.

The second coring method used was a modified Livingstone piston corer developed at the University of Waikato by Dr J.D. Green. This method involves using 6 m long, 50 mm diameter PVC pipes. An aluminum tube with a brass flange is attached firmly to one end of the PVC tube with a bolt. A rubber stopper attachment (piston) is placed in the bottom of the tube, and fixed to a cable running up the centre of the core (Figure 5.1). The tube is then set in position and the cable is anchored to a fixed point above the opening in the brass flange. Once

Figure 5.1 : Rubber stopper that is placed in the bottom of the Livingstone corer.

Figure 5.2 : Driving the core tubing into the river bed.

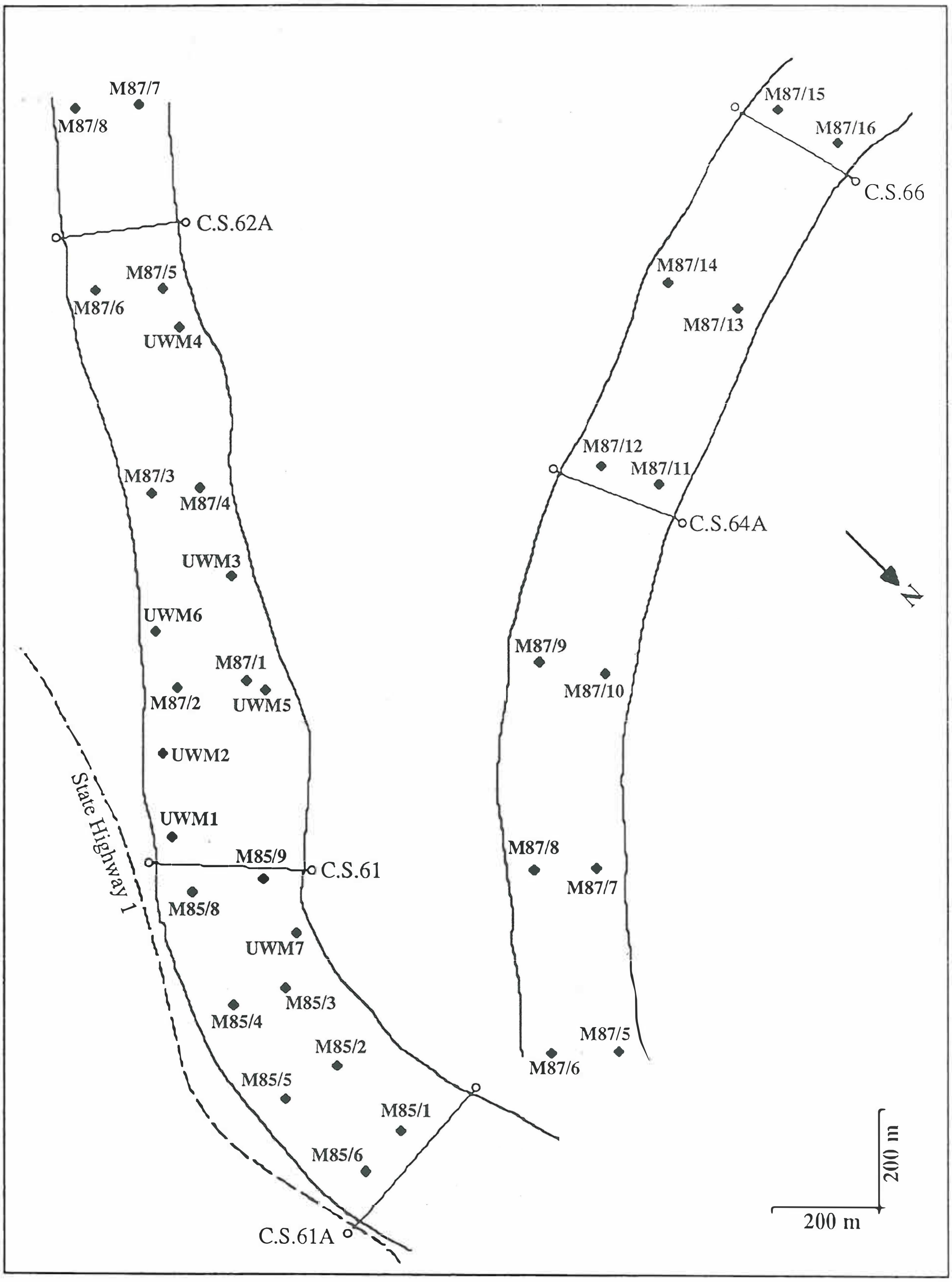


Figure 5.3 : Coring sites in the Mercer licence area. UWM = Universtiy of Waikato core numbers. M85 and M87 = Cores taken by Winstones (N.Z.) Ltd in 1985 and 1987 respectively.

in position the tubing is driven into the river bed using a post rammer over the aluminum tube attachment (Figure 5.2). Further sections of aluminum tubing are added to the top as the core is driven in. The rubber stopper stays fixed relative to the river bed as the tubing is driven in, and prevents the sediment slipping out the bottom of the tube during recovery from the bed. Good penetration was obtained (5-6 m) with only minimal loss out the base of the core during recovery. The degree of recovery depended inpart on the nature of the basal unit in the core.

Locations

A total of 17 cores were taken, 7 in the Mercer licence area and 10 in the Puni area (Figures 5.3 and 5.4). The sites for coring were chosen to compliment existing core data obtained by Winstones (NZ) Ltd. However, difficulties were encountered in obtaining access to all areas designated for coring (especially upstream of UWM4) because low flows at the time of coring produced difficulties with movement of the barge. Hence, cores were taken nearer the banks in deeper water, as there was a need to be at least 6 m above the river bed to begin driving the core in. These problems were encountered mainly in the Mercer licence area, with greater flexibility in the selection of sites available in the Puni licence area.

5.2 ANALYSIS OF CORE DATA

In the laboratory the cores were split in half and one half was wrapped and stored. The other half was described, photographed, and sampled for determining pumice percentage and textural analysis. The cores were divided into units wherever a change in colour, texture, or lithology was significant. Divisions are therefore fairly broad. It should be noted that this study does not emphasise stratigraphy, rather the coring was undertaken mainly to assess the gross textural character and pumiceous nature of the river bed. Textural samples for each unit were sieved using a 'Fritsch' sieve shaker for 3-5 minutes at 0.5 Phi (Ø) intervals using a set of Walcotts 8-inch diameter brass sieves. Shaking times were kept to a minimum to avoid excessive abrasion of the soft pumice, which comprised up to 80% some samples. Samples containing a significant size fraction finer than 4Ø were wet sieved and only the sand portion used in textural analysis. These samples are noted in core descriptions with an asterisk (*), and a sand percentage is given. Textural parameters for each unit are calculated using a pascal program, GSIZE. This program produces a number of selected grain size parameters. These parameter and the methods used to determine them are outlined in Appendix 6.7.

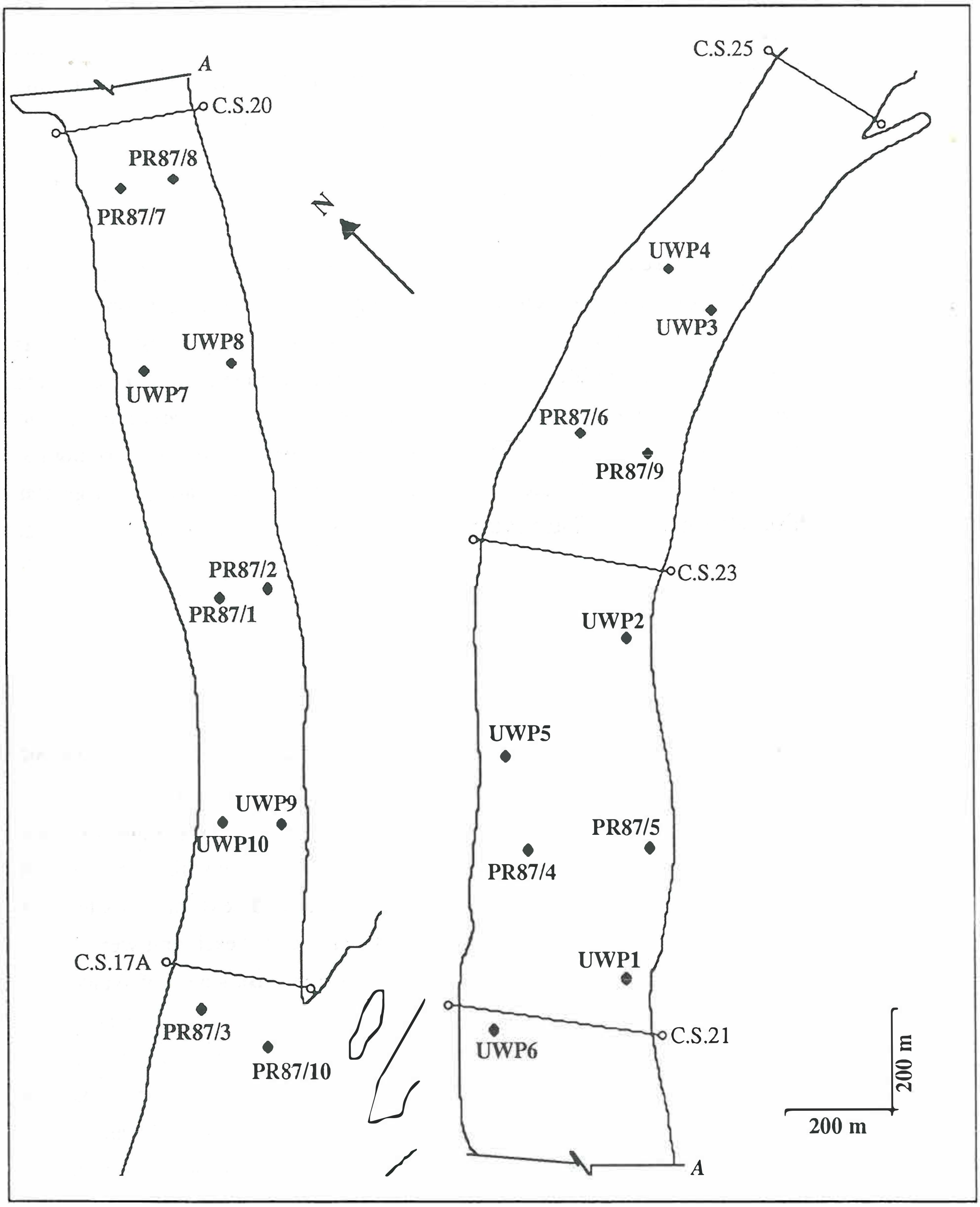


Figure 5.4 : Coring sites in the Puni licence area. UWP = University of Waikato Puni core numbers. PR87 = Puni cores taken in 1987 by Winstones (N.Z) Ltd.

Determination of Pumice Percentages

Pumice percentage determination was performed using the NZS 3111 Standard method for determining light aggregate (S.G. < 1950 kg.m-3). This method involves immersing an oven-dry sample in a beaker of $ZnCl_2$ solution (S.G. 1950 ± 20 kg.m-3), stirring vigorously (Figure 5.5A), and then letting it stand for 20 minutes. The light aggregate (predominantly pumice) floats to the top of the dense $ZnCl_2$ solution (Figure 5.5B); this can then be decanted off. The beaker is refilled, stirred vigorously, and left to settle for another 20 minutes before decanting again. The separated light aggregate is thoroughly washed and oven dried before re-weighing to produce a pumice percentage for the sample.

Stratigraphy

Full descriptions of the cores are given in Appendix 5. Figures 5.6, 5.7 and 5.8 are photographs of some of the cores and show stratigraphic and colour contrasts. The distinction between what has been classed as pumiceous (pale) and lithic (dark) sand can clearly be seen by colour difference. Note that 'lithic' is used in the description of units to mean sand that is predominantly made up of rock fragments and quartz, while pumiceous sands are those that visually appear to be dominated by pumice sand (on analysis pumice is > 30% by weight).

The cores show a number of common stratigraphic feature, which may be consider characteristic of these deposits. They are:

(1) poorly defined interbedded coarse lithic and pumiceous sands (Figure 5.6A, at depths of 0.5-0.85 m);

(2) consistent directional bedding (Figure 5.6A, at depths of 3.0-3.75 m and Figure 5.7B, at depths of 2.75 - 4.3 m). This stratigraphy could represent that formed at the lee face of a large sand bar or dune feature with changes in composition brought about by variations in flow velocity and hence entrainment of sediment;

(3) abrupt changes in lithology and texture (Figure 5.6A, at a depth of 2.85m, Figure 5.6B at depths of 1.3 - 1.55 m, Figure 5.8A and Figure 5.8C). These rapid changes represent marked changes in hydraulic regime and/or sediment supply;

(4) isolated pumice cobbles and pebbles (Figure 5.6A and Figure 5.8D). The large pumice cobbles and pebbles found in cores are seen in the modern river bed environment rolling slowly along the bed on the stoss of the sand bars. These cobbles are probably released from bank deposits and float and roll downstream until they are fully saturated and become incorporated into bed deposits;

(5) basal estuarine deposits (Figure 5.6B). This unit of interbedded dark grey fine lithic sand and grey brown mud represents the basal estuarine deposits in the Puni area;

(6) gradational nature (Figure 5.7A). This gradual change in texture and lithology makes division into discrete units difficult;

Figure 5.5A : Stirring sand sample vigourously into the $ZnCl_2$ solution.

Figure 5.5B : Pumice (light aggregate) settles at the surface after standing for 20 minutes.

Figure 5.6A : Puni site 5 core, shows poorly defined interbedding of coarse lithic and pumiceous sand (0.5-0.85 m). Also consistent directional bedding (3.0-3.75 m) of lithic sand into more pumiceous sand is seen. The rapid change in lithology that occurs in a number of the cores can be seen at 2.85 m. Isolated pumice pebbles that appear throughout this core is a common feature in the lower Waikato Rivers bed deposits.

Figure 5.6B : Puni site 10 core, shows the interbedded dark grey fine lithic sand and grey brown mud unit that represents the basal estuarine deposits in the Puni area. This core also provides a good example of the extreme variability in lithology and grain size that occurs in these sediment, with the stratigraphy varying from a coarse lithic sand to very coarse pumice sand then to a fine pumiceous silty sand within the space of 25 cm (1.3 - 1.55 m).

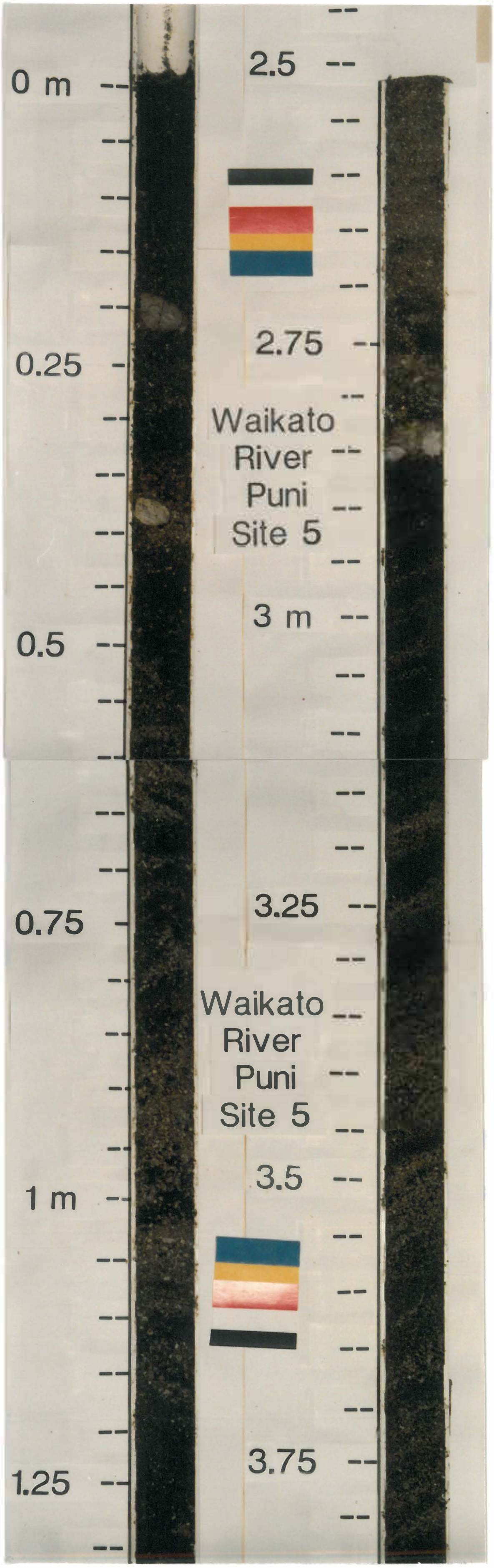


Figure 5.6A

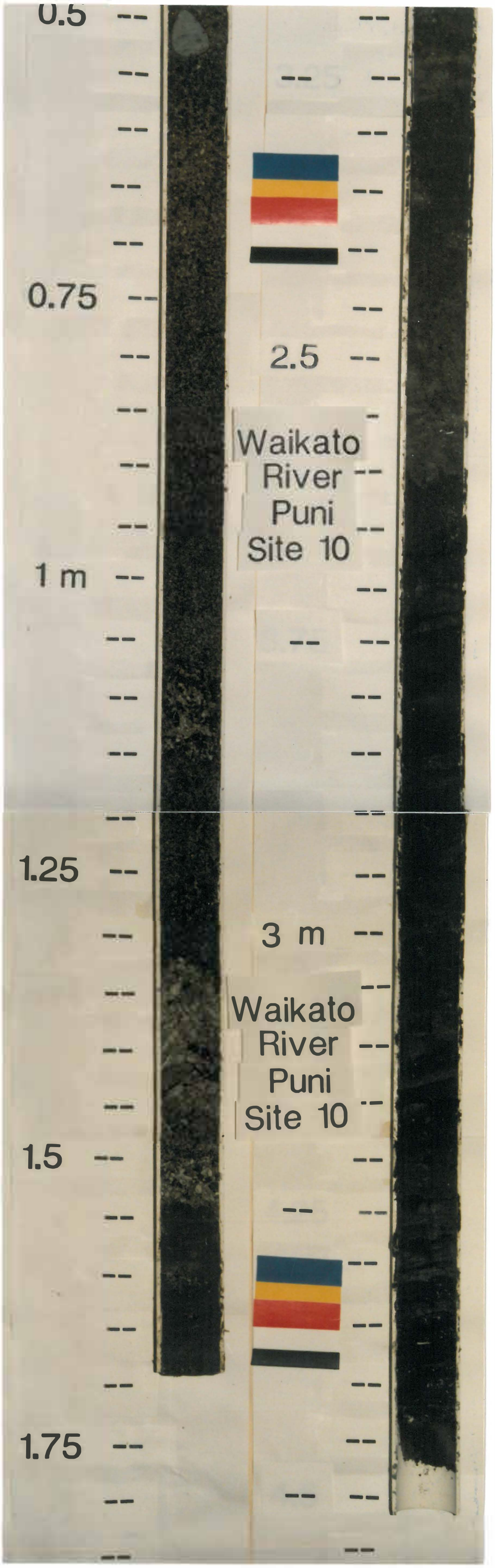


Figure 5.6B

Figure 5.7A : Mercer site 1 core, this is an example of the complex interbedded gradational nature of the river bed deposits. The section from 0.9 to 3.45 m consists of poorly defined interbedding of coarse lithic sand and very coarse pumiceous sand, with an increase in the pumice percentage down the unit. Iron staining is also predominant around the lithic sands, inferring oxidizing conditions must occur deeply into the river bed in some areas. Such oxidation conditions could be produced by the passage of fresh groundwater.

Figure 5.7B : Mercer site 2 core, shows the poorly defined chaotic type interbedding of coarse pumiceous and lithic sand that occurs in these bed deposits (0.4 - 1.1 m). More defined interbedding of medium lithic sand with coarse pumice sand is seen within the same core (2.75 - 4.3 m) indicating the variability of deposition environment during the aggradation of these deposits.

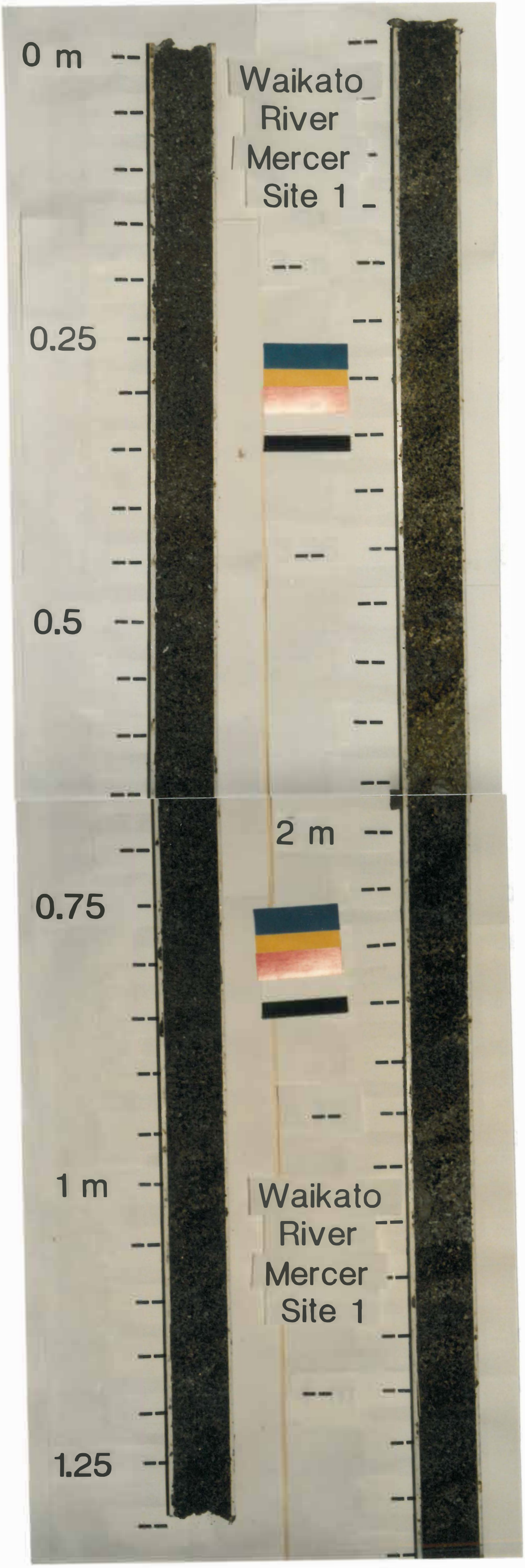


Figure 5.7A

Figure 5.7B

Figure 5.8A : Mercer site 3 core, shows a number of interesting stratigraphic features. It is an example of very coarse lithic sand (above 4.05 m), note that it appears to be made up mostly of rock fragments and quartz grains. This then grades quickly into a very coarse pumiceous sand gravel (59% pumice).

Figure 5.8B : Puni site 1 core, displays the extreme diversity that can occur in these bed sediments. Rapidly changing from a lithic gravel (2.95 - 3.1 m) into a chaotic unit of mainly poorly sorted pumiceous gravel with zones of muddy material (3.25 m) and finer lithic sand on the right side of the core above a large wood fragment (3.15 m).

Figure 5.8C : Mercer site 5 core, shows clearly how rapid a change in lithology can occur, above 1.7 m is a coarse lithic sand (2% pumice) while below is a coarse to very coarse pumice sand (68% pumice). The common feature of isolated pumice pebbles can be seen in this figure.

Figure 5.8D : Puni site 2 core, shows the large pumice cobbles that also occur in the deposits (2.1 m), also a rapid change from coarse lithic to very coarse pumiceous sand. Large massive units are also seen in the bed deposits (4.5 - 5 m). This is a good example of this showing no bedding throughout a very coarse pumiceous sand (85% pumice). Note also the presence of charcoal fragments scattered throughout this unit and down as far as 5 m.

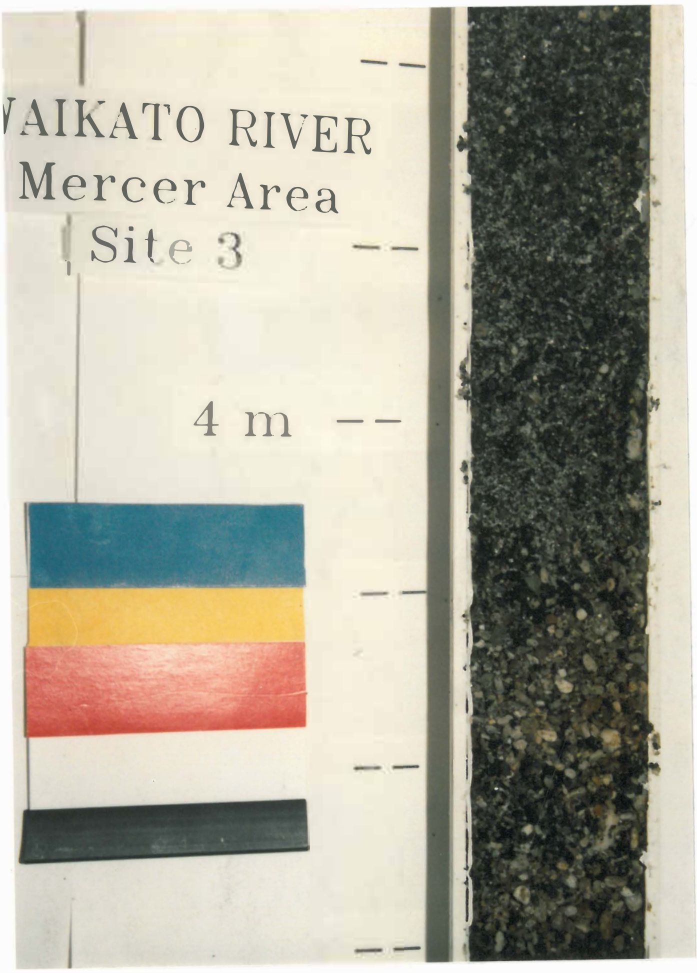


Figure 5.8A

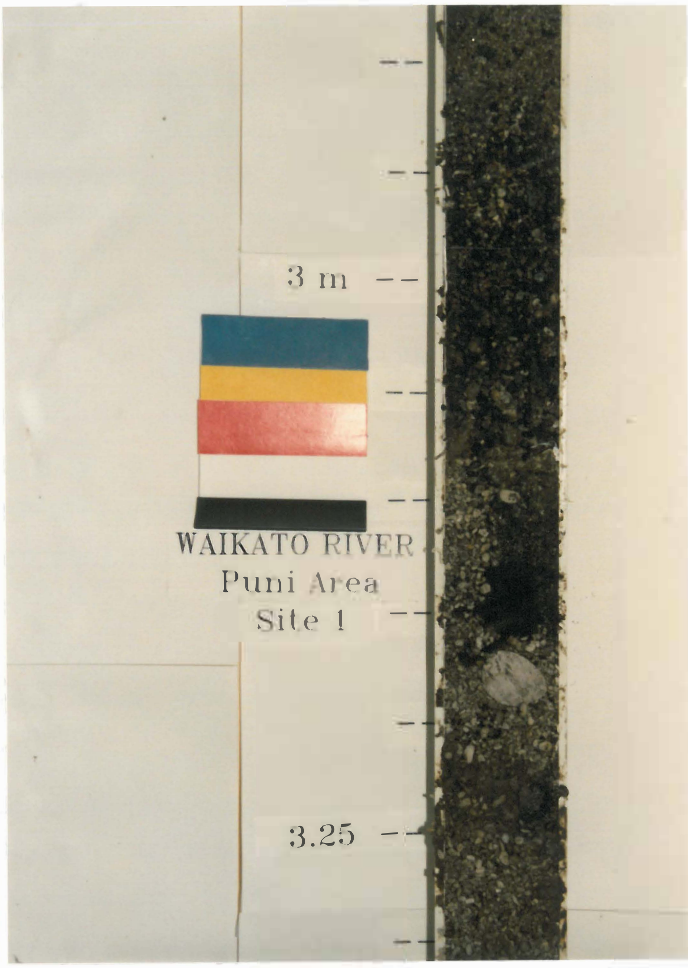


Figure 5.8B

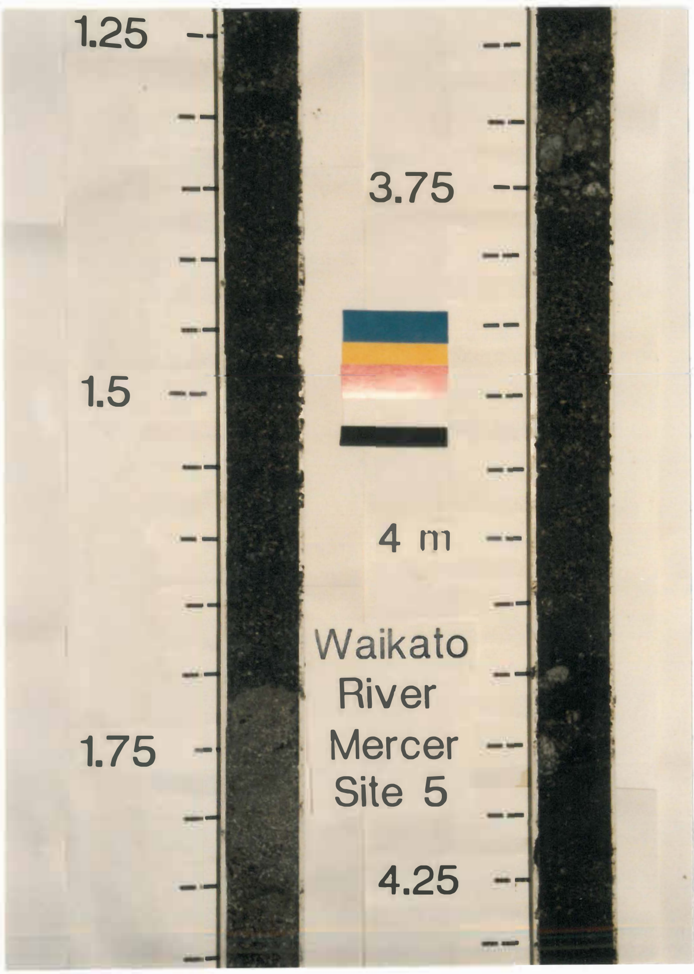


Figure 5.8C

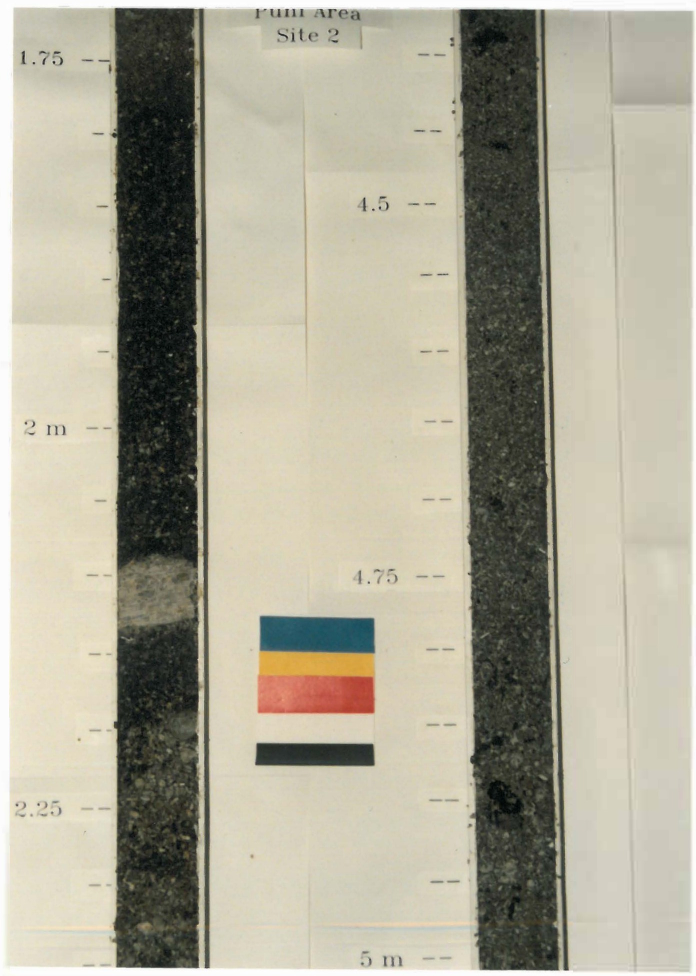
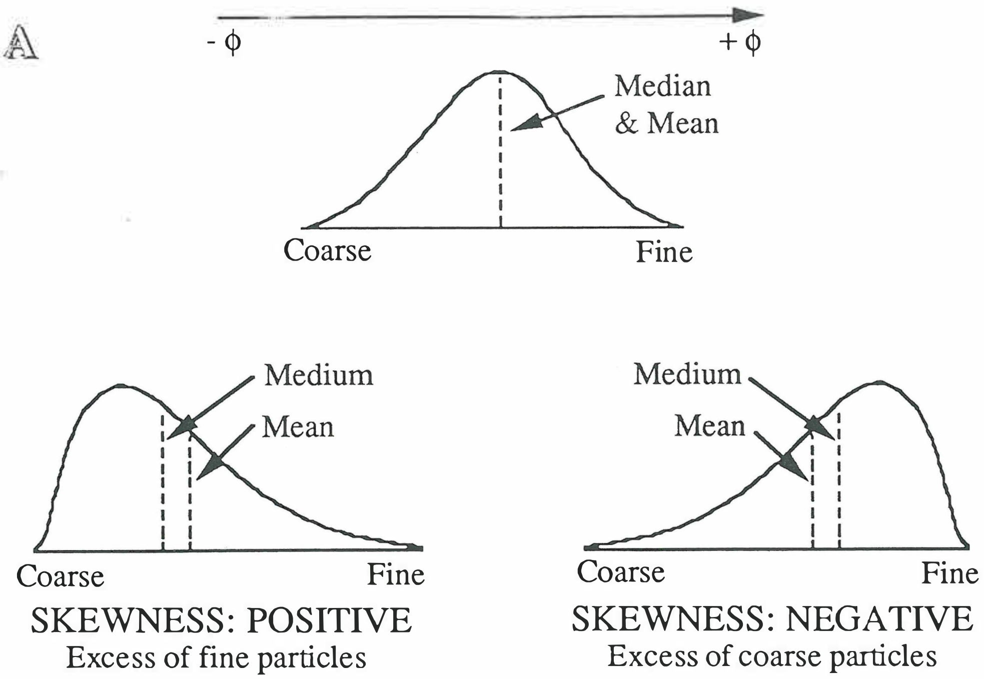
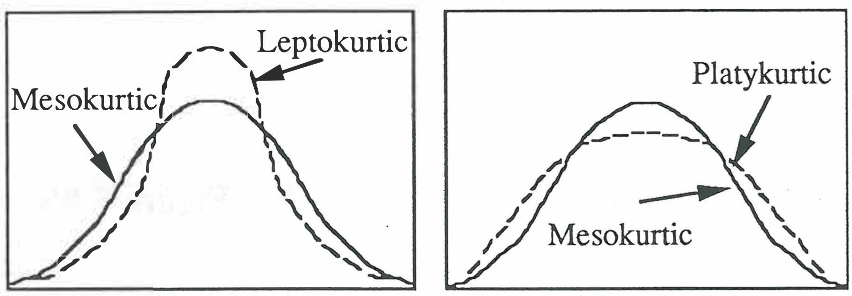


Figure 5.8D

A



B



C

	Millimeters	Phi (ϕ) units	Wentworth size class
GRAVEL	4	-2	
			Granule
	2	-1.0	
SAND			Very coarse sand
	1	0.0	
			Coarse sand
	0.5	1.0	
			Medium sand
	0.25	2.0	
			Fine sand
	0.125	3.0	
			Very fine sand
	0.0625	4.0	
MUD			Coarse silt

Figure 5. 9 : Textural terminology, A - Skewness definition, B - Kurtosis definition C - Class intervals for grade scales. (after Pettijohn, 1972).

(7) iorn staining (Figure 5.7A), predominants around the lithic sands, implying that oxidizing conditions must occur deeply into the river bed in some areas. Such oxidation conditions could be produced by the passage of fresh groundwater;

(8) chaotic sediments (Figure 5.7B, at depths of 0.4 - 1.1 m, and Figure 5.8B at depths of 2.95 - 3.1 m); and

(9) large massive units (Figure 5.8D at depths of 4.5 - 5 m).

In summary, the stratigraphy of the Waikato River bed sediments is complex and highly variable. The variation in lithology and grain size can be very marked, representing changes in flow characteristics and morphology. The presence of coarse lithic sand represents a high flow situation as may be found in the thalweg on the outside of a bend. The poorly defined interbedded lithic and pumiceous sand units could be produced by the downstream movement of bedforms partially reworking the deposit, and by fresh deposition occurring in a different flow setting. The deposits of coarse to very coarse, almost pure pumice that occur at the base of cores from Puni sites 2 and 7 indicate a temporary change in the type of sediment supply, presumably as a result of some form of catastrophic geomorphological event upstream, because under the present quasi-equilibrium conditions the bedload is made up of significant amounts of lithic sand (75-80%).

5.2.1 Textural Results

The GSIZE program produces a full range of textural parameters, including both graphical and moment method statistics. An advantage of the moment method is that it uses the entire distribution in computing the statistics, while the graphical method employs only parts of the distribution (Carver, 1971). Interpretation in this section will therefore be made using the moment statistics. Figure 5.9 defines some of the textural terminology. Mean grain size, sorting and pumice percentage results are presented with the core descriptions in Appendix 5. Complete textural results are given in Appendicies 6.8 (Mercer) and 6.9 (Puni).

Mean Grain Size (M_z)

Mean grain size is a function of the size range of available material and the amount of energy imparted to the sediment, which depends on the current velocity or turbulence of the transporting medium (Folk, 1968).

The mean grain size of the core samples ranges from -1.0Ø (very coarse sand) to 2.8Ø (fine sand), with most values occurring in the coarse sand size range (0.0 to 1.0Ø) (Figure 5.10A). There is no significant difference between the Puni and Mercer sites as can be seen from the statistics in Table 5.1. The extreme values of 2.4-2.8Ø are due to isolated estuarine samples that occurred at the base of some Puni cores.

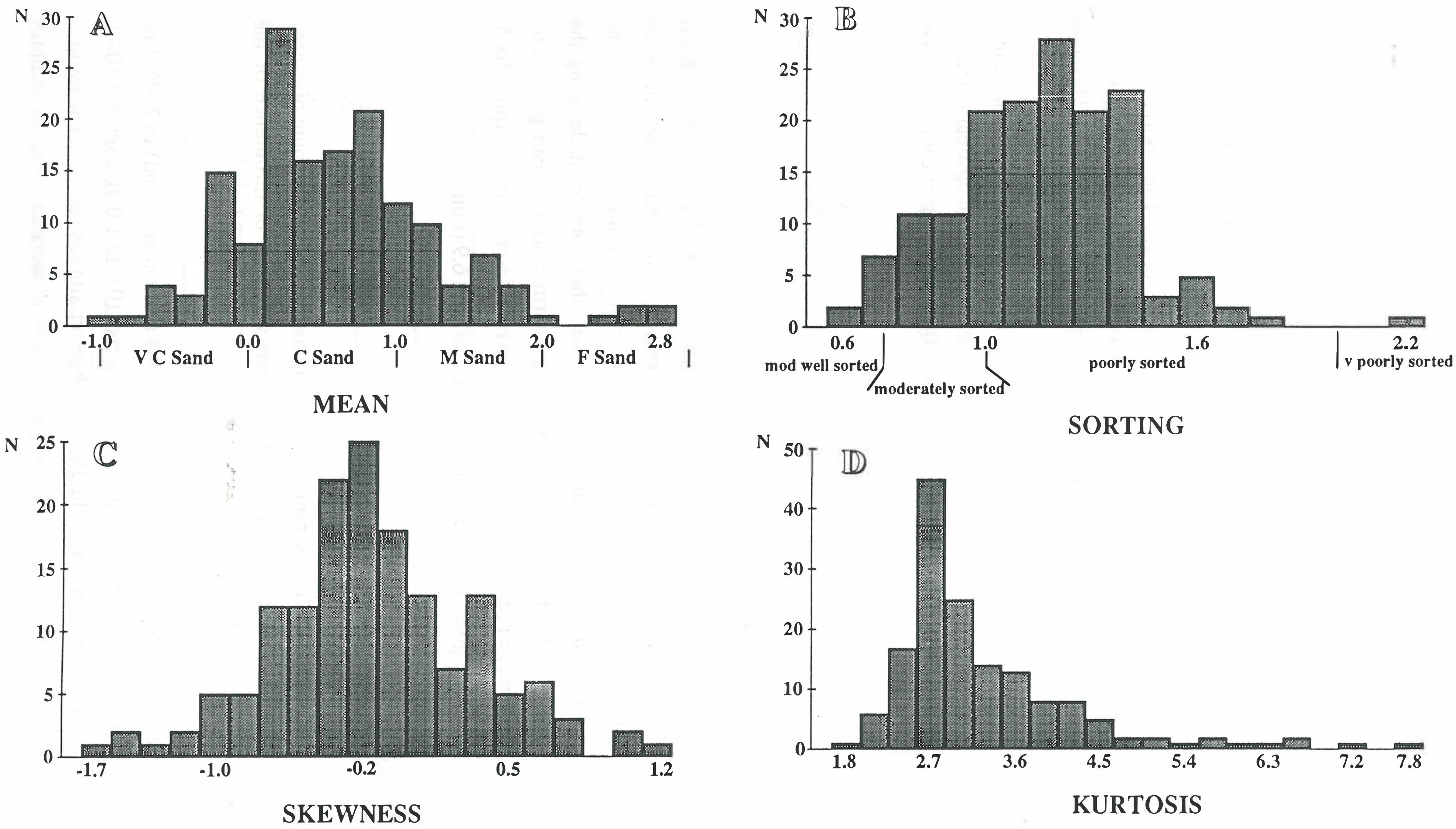


Figure 5. 10 : Histograms of grain size statistical parameters for the Mercer and Puni core samples, plotted as a function of frequency (Data in Appendices 6.8 and 6.9). Note : Verbal descriptions for graphical classes are after Folk (1968). Mean grain size in Phi (Ø) units.

Modal Grain Size

Modal grain size is the most frequently occurring grain size and is defined as the steepest gradient (point of inflection) on the cumulative curve (arithmetic frequency scale)(Folk, 1968). The Puni and Mercer samples appear to be unimodal, implying that all the sediment has originated from the same source. From this the inference can be made that either no significant input of bed material from other sources such as the Waipa River is made, or that other sediment sources are of a similar nature to Waikato River sediments and therefore undefinable by this method.

Sorting

The degree of sorting in a sedimentary environment is dependent on four main factors (Folk, 1968):

(1) Size range of material supplied to the environment;
(2) Types of depositional processes active;
(3) Current characteristics (strength, continuity, turbulence); and
(4) Time (sediment supply rate vs time available to sort sediment).

Most of the core samples are poorly sorted, but they range from moderately well to very poorly sorted (Figure 5.10B). The mean sorting value is 1.15 (poorly sorted) with no significant difference occurring between the two areas cored (Table 5.1).

It is probable that in every environment, sorting is strongly dependent on grain size (Folk, 1968). A correlation between sorting and mean grain size is apparent (Figure 5.11A), with fining grain sizes relating to improved sorting, as expected for sand of fluvial origin.

Area		Mean (M_Z) Ø		Sorting		Skewness		Kurtosis	
	N	$\overline{X}$	Std Dev	$\overline{X}$	Std Dev	$\overline{X}$	Std Dev	$\overline{X}$	Std Dev
Puni	88	0.53	0.64	1.16	0.27	-0.21	0.56	3.31	1.08
Mercer	67	0.59	0.60	1.16	0.22	-0.30	0.43	3.24	0.97

Table 5.1 : Statistical comparison of textural parameters for the Puni and Mercer areas (N = number of samples).

Skewness

Skewness and kurtosis are measures of non-normality of the sediment distribution. Skewness defines the asymmetry of the distribution. The core samples are generally coarsely skewed (Figure 5.10C), implying an excess of coarse particles (in this case pumice, see section

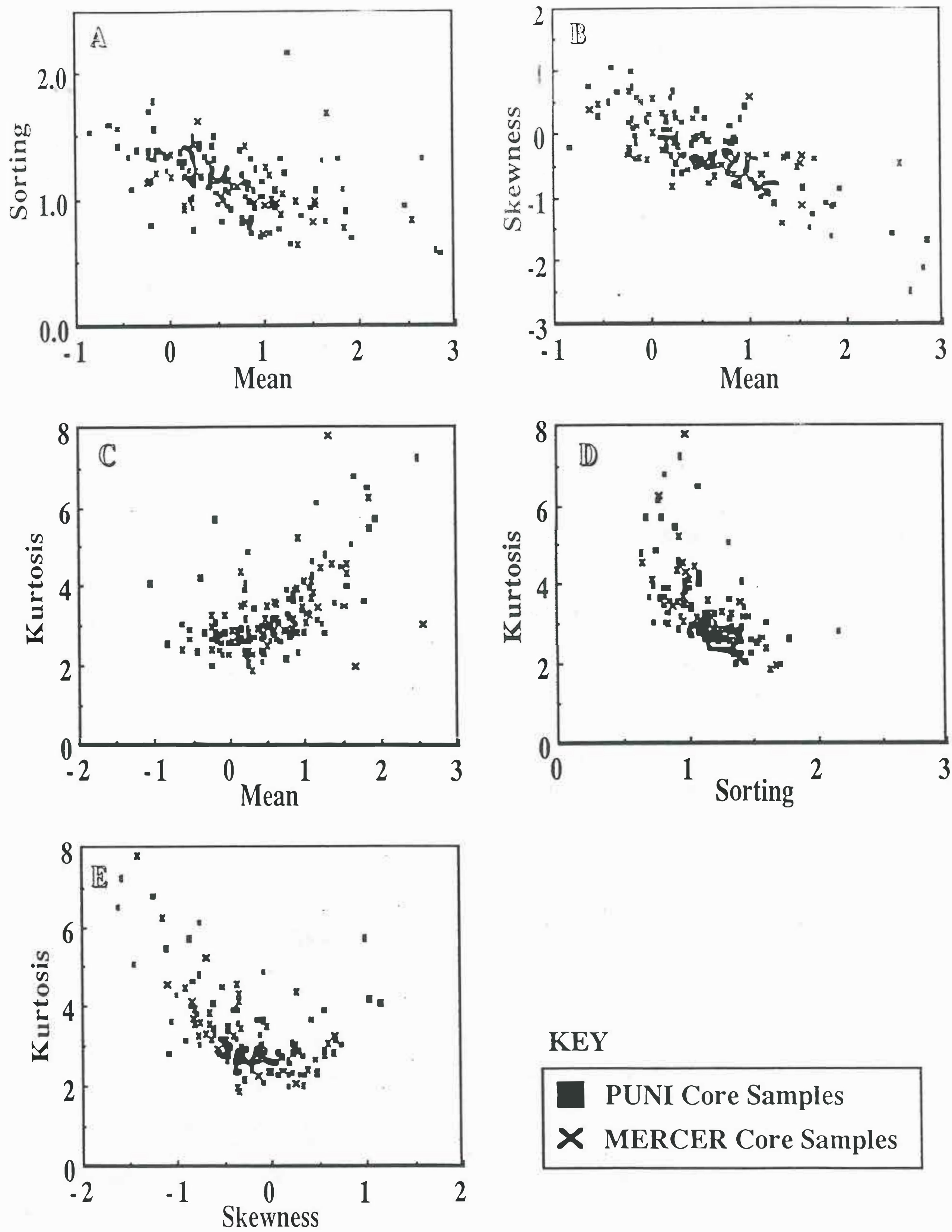


Figure 5.11 : Textural scattergrams of selected grain size statistical parameters for Puni and Mercer core samples (Data in Appendices 6.8 and 6.9).

5.2.2) in the distribution (Friedman & Sanders, 1978). No significant difference in skewness occurs between samples from the two areas cored (Table 5.1).

Kurtosis

Kurtosis is a measure of peakedness for grain size distributions. Extreme values of skewness and kurtosis are exhibited by bimodal sediments (Folk, 1968). In this case extreme values can be attributed to samples with a significant percentage of finer than 4Ø material, since they were wet sieved and only the sand fraction was used in the textural analysis, leaving an open ended distribution. Table 5.1 shows no significant difference in kurtosis between the two areas, with most samples being very leptokurtic to extremely leptokurtic (Figure 5.10D).

5.2.2 Textural Character and Comparison of River Bed Deposits

The fluvial nature and origin of the river bed deposits cored is obvious. Therefore there is no need to apply the approaches of Friedman (1979), Folk & Ward (1957), Folk (1968), and Passega (1957), for example, to determine possible depositional environments. Scatter plots of selected textural parameters can, however, provide insight into specific attributes of the deposit and establish base data that is characteristic of fluvial deposits.

Skewness

Skewness plotted as a function of mean grain size (Figure 5.11B) shows a trend towards positive skewness with increasing grain size, which is opposite to a rough trend described by Hume et al. (1975) in the Hinuera Formation sediments, where rapid deposition has prevented removal of the fines. This trend (Figure 5.11B) can be explained by the presence of pumice and its hydrodynamic behaviour. Negative skewness indicates an excess of coarse particles in the distribution. In the core sediments these coarse particles tend to be pumice, which, because of their lower density, behave hydrodynamically similar to the smaller denser particles which make up the bulk of the size distribution. Therefore, as the mean grain size increases, there becomes a limit to the availability of pumice particles for transport that are hydrodynamically equivalent to the bulk of the distribution. The excess of coarse particles therefore decreases, and skewness becomes more positive. Figure 5.12C supports this interpretation, showing a trend towards positive skewness with increasing pumice percentage. The discrepancy with the findings of Hume et al. (1975) is probably due to the lower Waikato River deposits being reworked material of the Hinuera Formation and Taupo Pumice Alluvium and has been deposited slowly compared to the rapidly deposited Hinuera Formation.

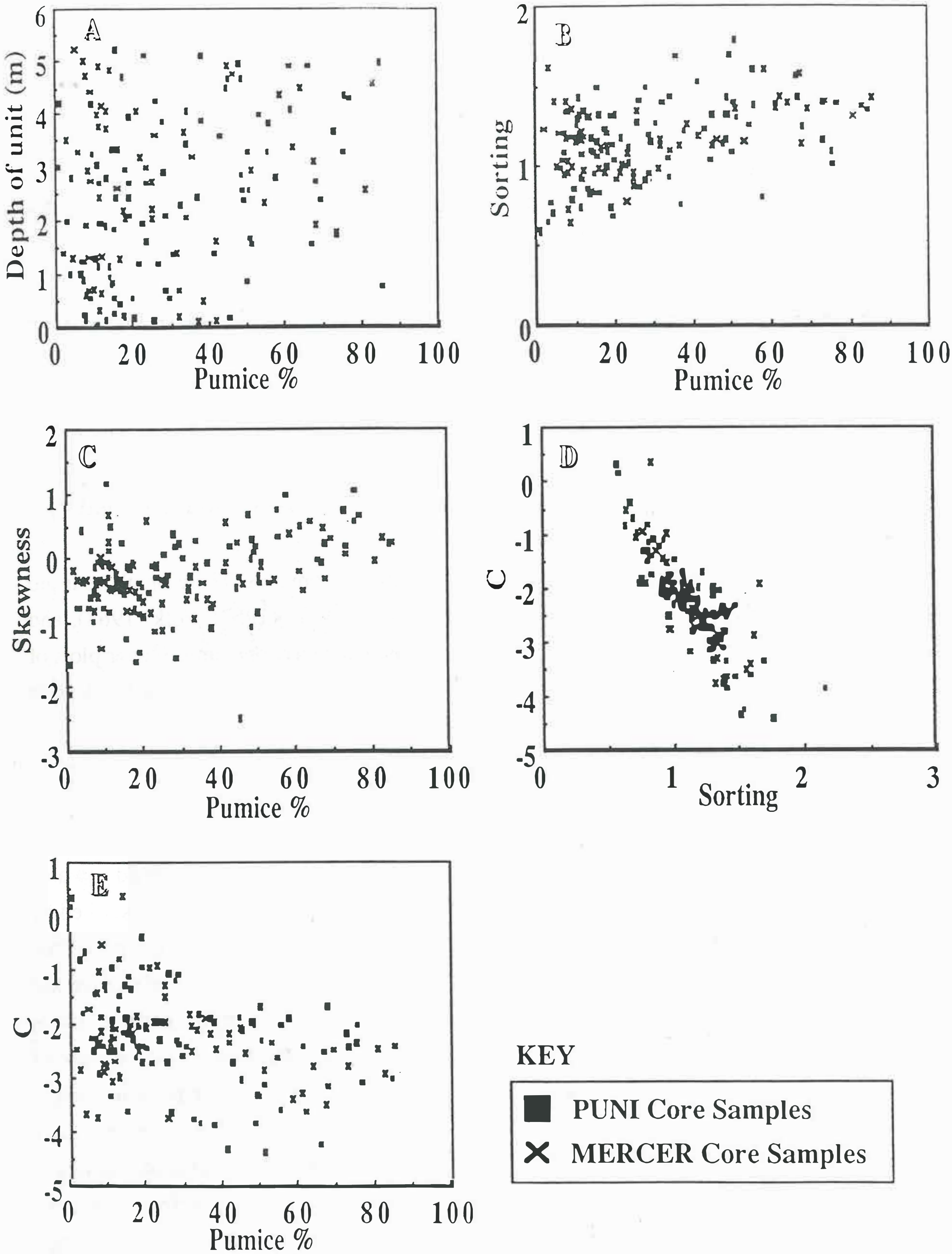


Figure 5.12 : Scattergrams of selected grain size statistical parameters showing the influence of pumice in Puni and Mercer core samples.
(Data in Appendices 5, 6.8 and 6.9).

Kurtosis

Kurtosis, although not environmentally diagnostic, has important relationships with other grain size parameters. When plotted as a function of mean grain size (Figure 5.11C) kurtosis shows a trend towards leptokurtic with decreasing grain size. Kurtosis also shows a trend with sorting (Figure 5.11D) and skewness (Figure 5.11E). However these trends are different to those seen by Sherwood (1972) in the polymodal Hinuera Formation. Improved sorting tends to lead to more leptokurtic distributions. Negatively skewed sediments have platykurtic distributions because of finer sand making up the bulk of the distribution is offset by the coarser end member of coarse pumiceous sand. The trends in these plots appear to confirm the homogeneity of these fluvial sediments.

Hydrodynamics of pumice

Deposits containing pumice have textural characteristics influenced by its hydrodynamic behaviour. Figure 5.12A shows that during the period over which the deposits were laid down there has been no consistent change in the pumice percentage of the bedload material. The effects of pumice on sorting and C (coarsest 1%) are displayed in Figures 5.12B, D, and E. The degree of sorting tends to decrease, and C size increase, as pumice percentage increases. Hence, pumice is hydrodynamically similar to more dense lithic sand of a smaller grain size. Thus, the total grain size distribution curve is wider and flatter. Sorting and C are strongly related (Figure 5.12D).

5.3 CORRELATION OF SUBSURFACE STRATIGRAPHY WITH SUB-BOTTOM PROFILES

The geophysical method of sub-bottom profiling is commonly used in sedimentary research to define and interpret the internal structure of sedimentary deposits. From limited stratigraphic information obtained by coring, results from sub-bottom profiling can generally be used to extrapolate between the areas of known information. The reach from Meremere to Puni was sounded with a Geopulse sub-bottom profiler, with double passes made in the extraction licence areas. This data is then compared with core data to allow assessment of the extent and variation in subsurface stratigraphy.

In a fluvial environment the results from sub-bottom profiling are restricted. The profilers work better in the deeper water of the marine environment and interference is often incurred as the towing vessel drags on the bottom in shallow water. Interpretation of the traces is complicated because much of the time was spent near the bank while following the thalweg. Consequently some of the return signal represented on the traces may in fact represent reflection from material within the bank region.

In the lower Waikato River bed sediments the most common textural feature is a transitional boundary from coarse to medium sand. Consequently, application of data from coring to the traces yields few definable bedding surfaces. With the extreme variation between cores the sub-bottom profiles could only be combined with coring information if the transect passed directly over the core site.

Results From the Sub-bottom Profiles

Interesting structural features are seen in some areas. Figure 5.13 is the trace from the upper Mercer licence area and shows bedding surfaces within the fluvial sediments. These surfaces show a tendency to dip steeply in the downstream direction. Figure 5.14 shows similar bedding surfaces in the Puni licence area with overlapping of surfaces more evident. The low gradient surfaces terminating in a steeper slope in the downstream direction are interpreted as buried dune or bar features, that are a common bedform features in the present river system. Figure 5.15 displays similar paleo-bedform surfaces, however because of the sand extraction in this area it is feasible that such steep dipping bedding surfaces could be produced during the infilling of extraction holes. The boundary between fluvial and estuarine sediments is evident in Figure 5.15, being located at UWP10 in the region shown. However, extrapolation of this boundary away from this core is limited, with the same fine sand boundary appearing at 3.5 m in UWP9 and 8 m in PR87/1 (Figure 5.17).

Correlation of Subsurface Stratigraphy

Correlation of the available core data into a fence diagram has limitations. Figures 5.16 and 5.17 display all the available coring data in the Mercer and Puni licence areas respectively. It is immediately clear that conventional correlation between sedimentary units is not viable because of large local variations. This is not surprising considering the dynamic 'cut & fill' nature of most fluvial systems.

Generally in the Mercer area the sub-surface stratigraphy comprises coarse sand of variable lithology, with zones of medium sand and isolated bands of silt. No pre-fluvial units were found in the licence area at this depth of coring. The Puni area data indicates that there is a limited supply of fluvial sand in the river bed as the estuarine sand occurs in the lower end and mud (tuffs) appear in the upper part. This limits the volume of sand that is available for current commercial extraction requirements. The predominant unit is also coarse sand of variable lithology, with medium sand being very common and fine sand occuring at the base of cores in the lower end of the area.

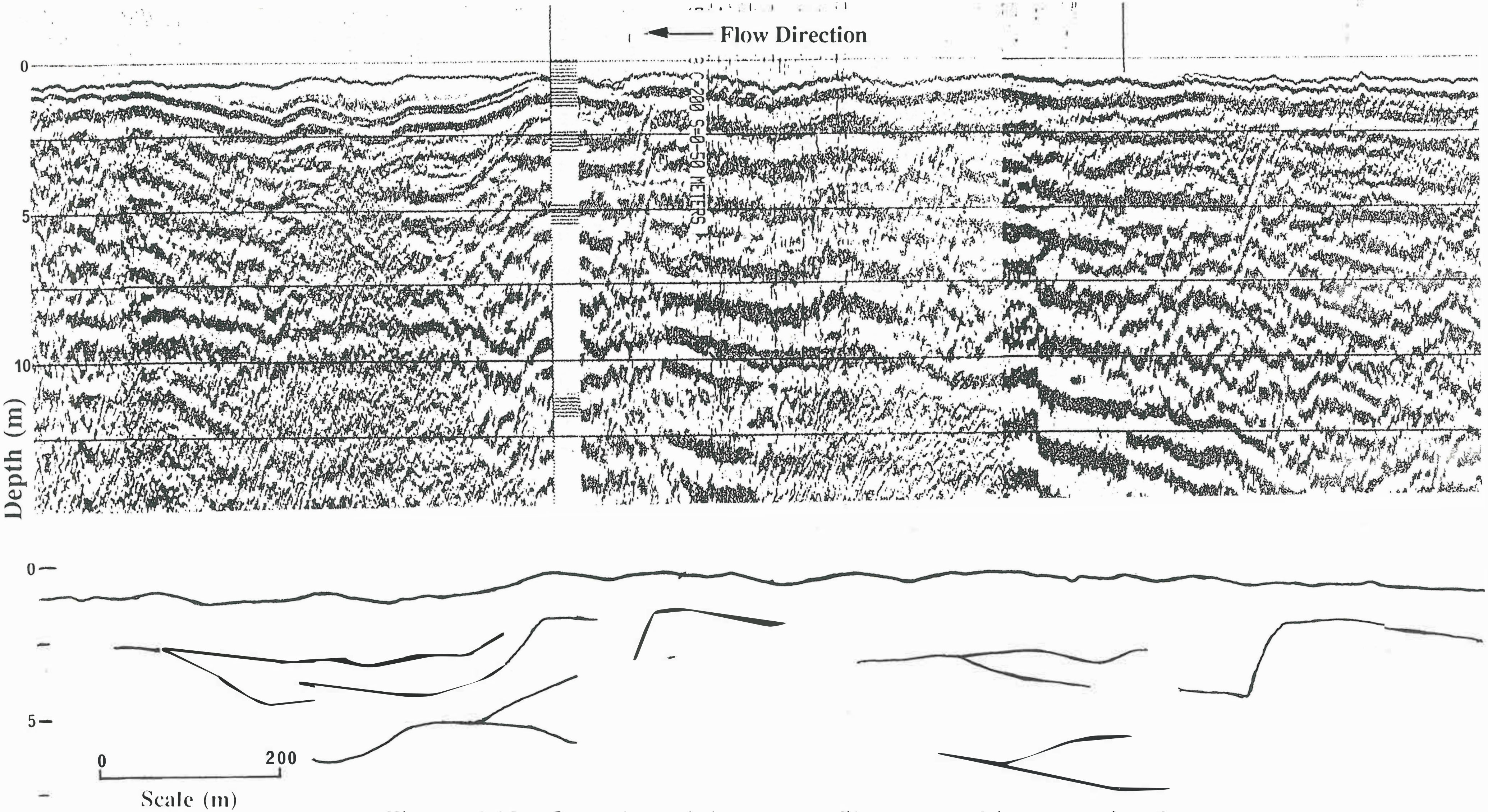


Figure 5.13 : Geopulse sub-bottom profile trace and interpretation from the upper end of the Mercer licence area. Profile trace taken along the thalweg of river (against right bank).

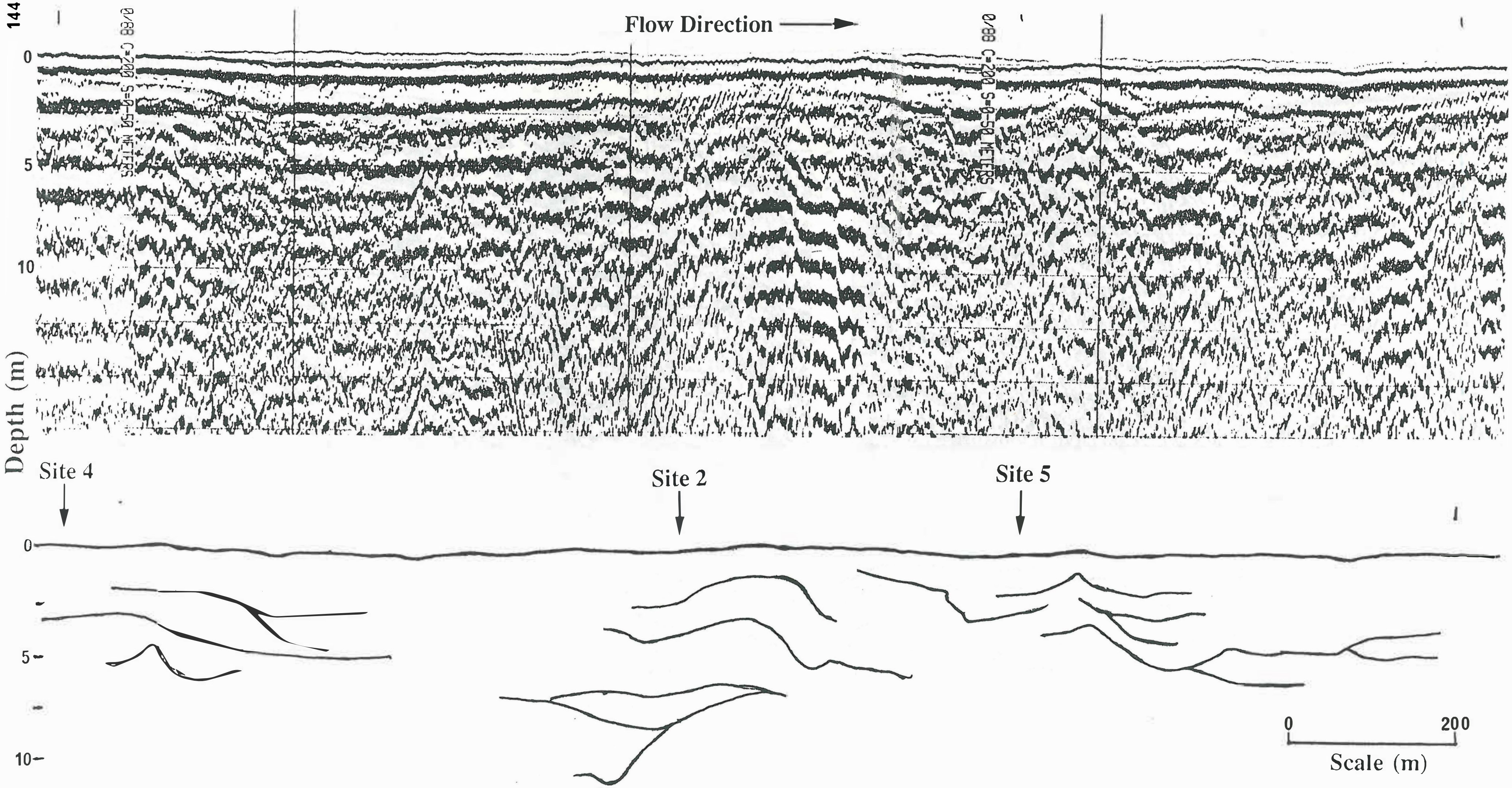


Figure 5.14 : Geopulse sub-bottom profile trace and interpretation from the upper end of the Puni licence area. Profile trace taken along the thalweg of the river (against left bank).

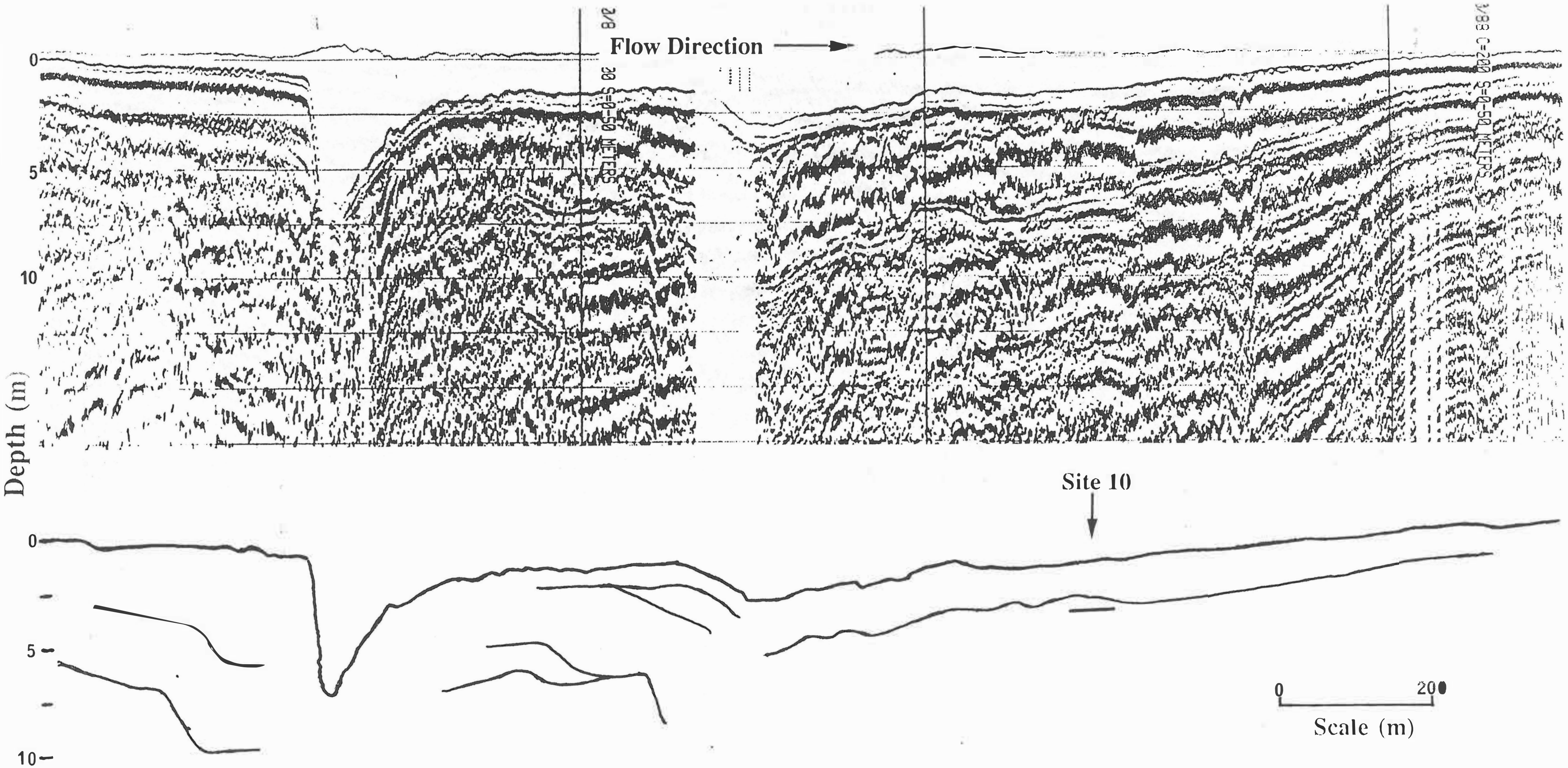


Figure 5.15 : Geopulse sub-bottom profile trace and interpretation from the lower end of the Puni licence area. Profile trace taken along the thalweg of the river (against left bank).

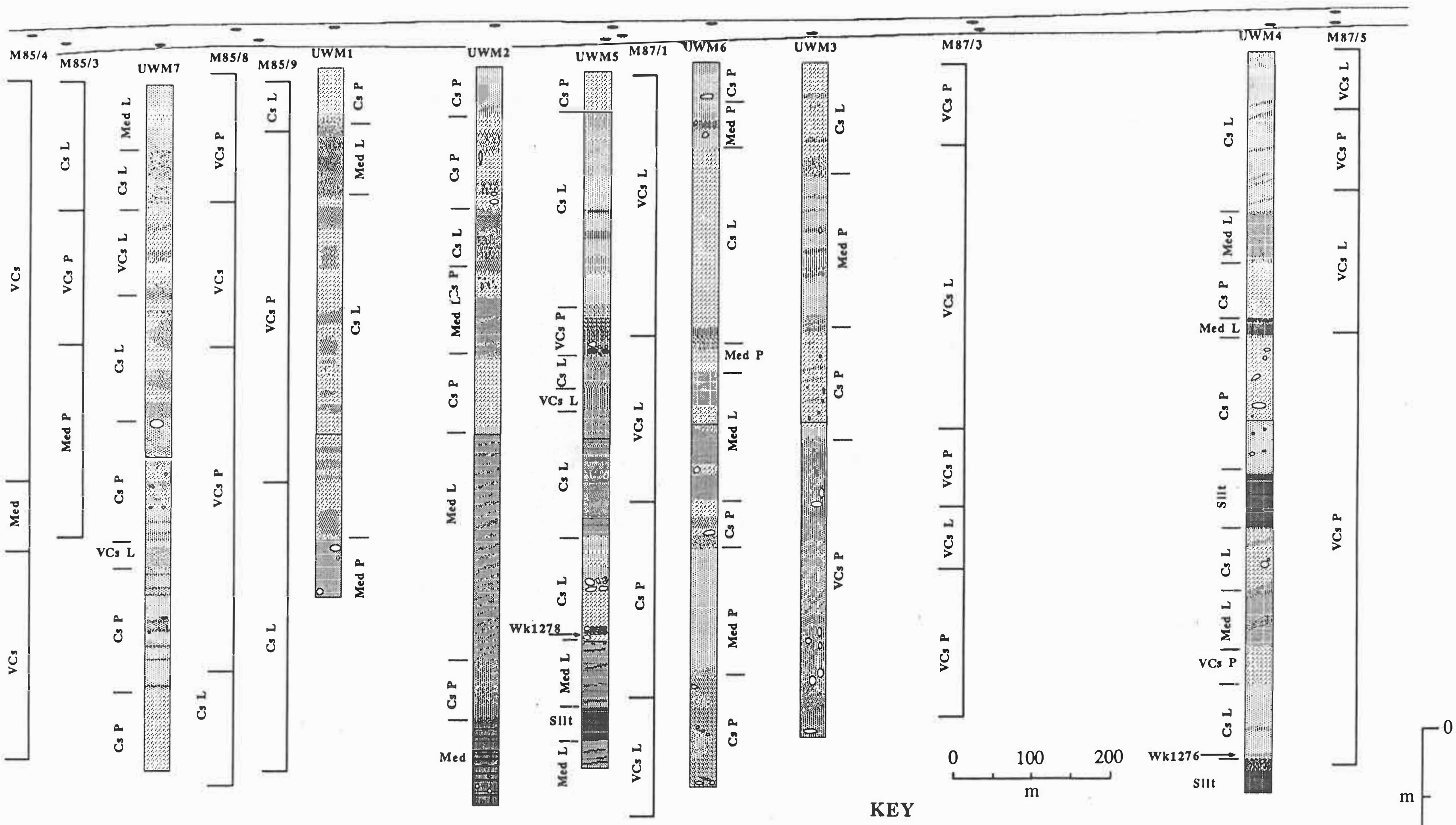
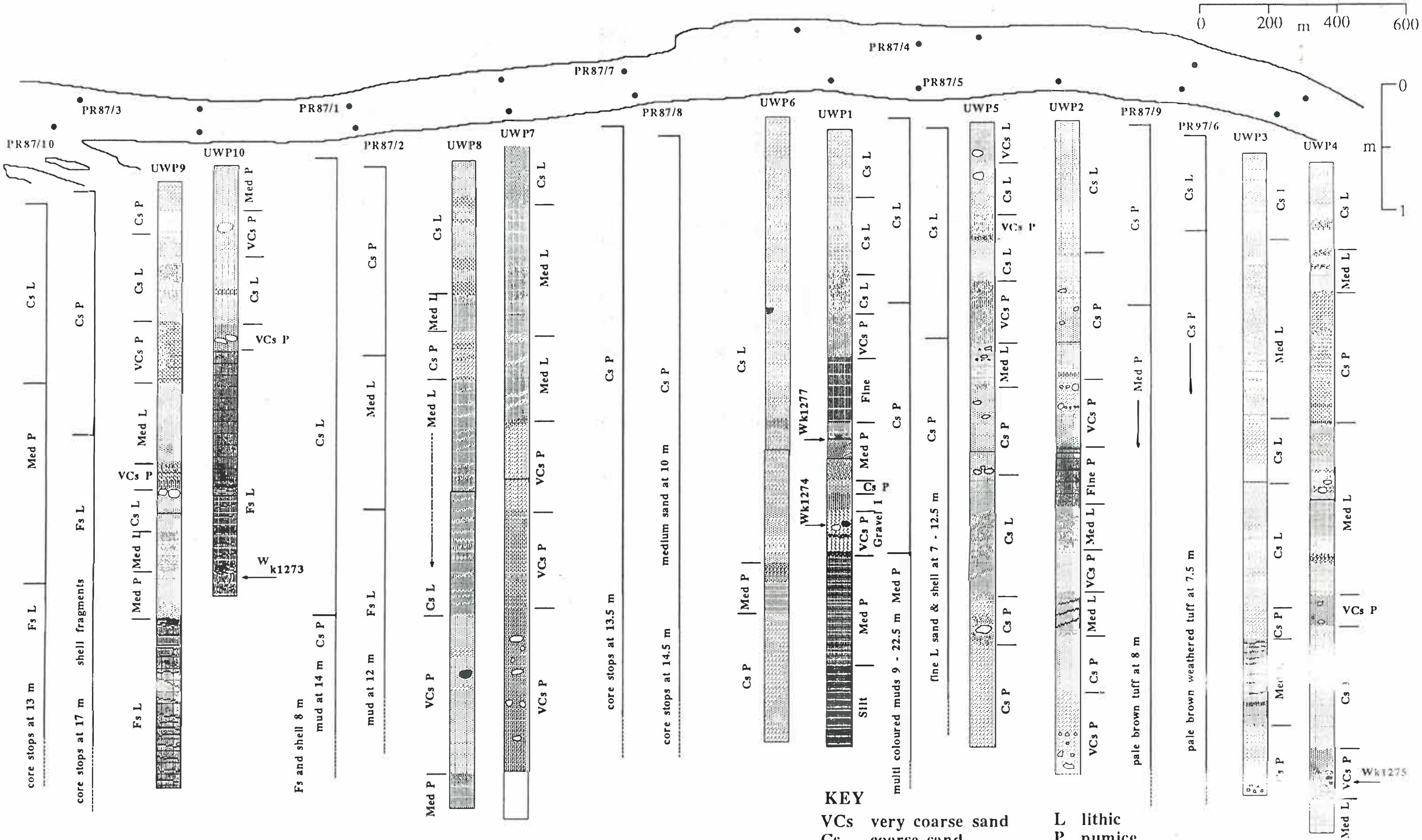


Figure 5.16 : "Fence" Diagram of Mercer licence area.

KEY

VCs	very coarse sand	L	lithic
Cs	coarse sand	P	pumice
Med	medium sand	Wk	University of Waikato radiocarbon dating number



KEY

VCs	very coarse sand	L	lithic
Cs	coarse sand	P	pumice
Med	medium sand	Wk	University of Waikato radiocarbon dating numbers
Fs	fine sand		

Figure 5.17 : "Fence" Diagram of Puni licence area.

5.4 RIVER BED HISTORY

The history of recent sedimentation in the lower Waikato River presented by Schofield (1967) was based on a study of drill holes taken between the Waikato River and Lake Waikere. Schofield (1967) concluded that aggradation of 6 - 9 m has occurred in the Huntly - Ngaruawahia area, while 4.5 - 6 m has occurred between Ohinewai and Rangiriri since about 130 A.D (deposition of Taupo Pumice Alluvium).

Six wood and shell samples from the cores in the present study (Figure 5.16 and 5.17) were radiocarbon dated at the University of Waikato to try and enhance the understanding of the areas sedimentation history. There are, however, numerous difficulties involved in developing a chronology of fluvial history using ^{14}C dating. For instance, wood of some species may remain intact on the surface for decades or centuries before becoming entrained during a fluvial event (Butler & Stein, 1988). This may be particularly pertinent in New Zealand with its generally long-living indigenous trees. The problem is compounded further if fluvial activity entrains previously buried or long-dead wood (Dunnell & Readhead, 1988). These and other aspects of fluvial chronology are discussed fully by Blong & Gillespie (1978), Kochel & Baker (1982), and Schiffer (1986).

The ages obtained (based on the old halflife) are presented in Table 5.2. No correlation appears to exist between age and depth of sample. The only shell sample, Wk 1273, was taken from estuarine sands and provides a "reservoir-corrected" (330 years is subtracted from estuarine carbonate ages for New Zealand) age of 4540 ± 220 yrs (BP). The overlying fluvial pumiceous sediments in the vicinity of this site must therefore be younger in age. However, considering that the Waikato River has probably been flowing in the vicinity of its present course for the past 20 000 years (Schofield, 1965), the river channel must have meandered across the Tuakau swamp - delta area. The remaining Puni samples provide no reliable information about sedimentation rates, with Wk1275 being twice the age of the base control (Wk1273, estuarine sands). This highlights the problems involved in fluvial studies with reworking and 'old wood'. Wk1274 and Wk1277, although taken from the same core, are not significantly different (Gupta & Polach, 1985). Only two samples were analysed from the Mercer licence area (Wk1276, Wk1278) and provide similar ages. However, insufficient sample material was available in the Mercer area for further dates.

A valid study of sedimentation history in this area would require a large scale coring program both in the river and on the flood plains to provide sufficient samples to meet the requirements for paleofluvial ^{14}C dating e.g.,(Kochel & Baker, 1982). A wide lateral area would need to be studied to encompass any paleo-meanders of the river over the past 15 000 - 20 000 yrs.

Schofield (1967) makes reference to different rates of aggradation of the Waikato River and its main tributaries, the Waipa River and Mangawara Stream. These differences are confirmed by echo sounding through the confluences and upstream into the tributaries (Figure 5.18). The resulting traces show that aggradation of the Waikato River bed has been considerably higher than its tributaries in recent times. At the Waipa River confluence the Waikato River bed is approximately 4 m higher than the Waipa River bed, only 30 - 40 m away. The Waipa bed then only rises gradually upstream and averages 5 m depth at 4 km upstream of the confluence. The Mangawara trace shows the bed dropping off more gradually to be 3 m lower 80 m upstream and remaining at a fairly constant elevation as far upstream as it was possible to measure in the boat due to obstructions across the channel. This state may change in the future as a result of downstream effects of the Karapiro dam (Section 2.2.2). This difference in bed levels between the lower Waikato River and its major tributaries has significant implications for bedload transport rates in the tributaries (Section 4.5).

Wk No	Type of Material	Sample Site	Conv Age (yrs BP)	Dilution %
1273	shell	Puni site 10, 3.25 m	4730 ± 210*	13
1274	wood	Puni site 1, 3.15 m	580 ± 65	32
1275	wood	Puni site 4, 4.9 m	9850 ± 300	14
1276	wood/leaf	Mercer site 4, 5.25 m	4050 ± 330	6
1277	peat/leaf	Puni site 1, 2.5 m	780 ± 210	8
1278	peat/leaf	Mercer site 5, 4.1 m	3900 ± 110	31

Table 5.2 : Radiocarbon Dating Results. Wk No refers to the University of Waikato radiocarbon dating laboratory number. Dilution % indicates the propotion of sample carbon to dead (dilutent) carbon. * not corrected for 'reservoir' effect, see text.

The presence of charcoal in the bed sediments of the Waikato River suggests that the material has been deposited since the Taupo eruption (AD214, Froggatt and Lowe, 1989), because the Hinuera Formation is devoid of charcoal (Hume et al., 1975). From the cores, charcoal appears at 5 m depth in UWP4, 4.8 m in UWP2, 4.2 m in UWP8 and 2.5 m in UWM3. Therefore most of the stratigraphy cored has been deposited in the past 2000 - 3000 years, which would be in approximate agreement with the Wk1273 basal date of 4500 years. Assuming the lower limit of Taupo Pumice Alluvium as a source material, to be 5 m, an average approximation of aggradation since AD214 is 2.8 mm/yr.

The New Zealand regional sea level curve records a post glacial marine transgression from about -33.5 ± 2.5 m below present sea level at 10 000 years ago, culminating at the present sea level at 6 500 ± 100 years ago, with fluctuations of a few decimeters over the last 6 500 years (Gibbs, 1986). Information from deeper cores presented in Figure 5.17 shows that the base control of the river in its present course is a brown mud material. The depths presented

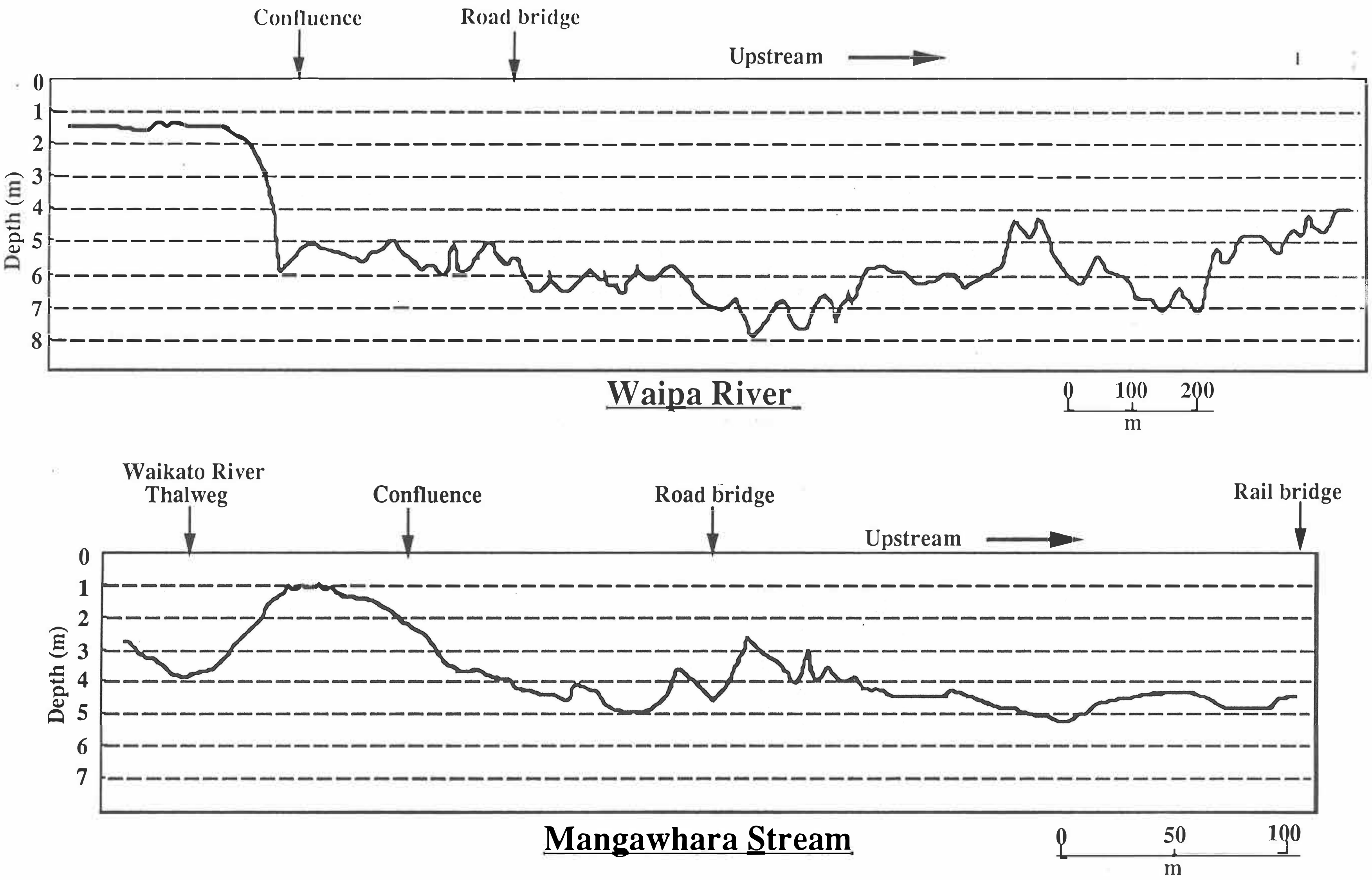


Figure 5.18 : Bed aggradation at the confluences of the Waipa River and Mangawhara Stream with the lower Waikato River. Aggradation of the lower Waikato River has occurred at a rate higher than these two main tributaries, leaving their beds significantly lower.

indicated that 7 - 9 m of aggradation has occurred over this mud in the upper part of the Puni licence area. Gibbs (1986) evidence, however, implies that a much deeper paleochannel must exist through the flood plain far below the 9 m level found in the present channel.

5.5 SUMMARY OF SUBSURFACE STRATIGRAPHY

The bottom sediments in the study area are primarily coarse, poorly sorted sand, composed of varying percentages of pumice, rock fragments and quartz. Stratigraphically the river deposits cored show considerable variation in lithology and texture, even over short distances, both vertically and laterally (Figures 5.16 and 5.17). Consistent directional bedding is seen in some cores (Figure 5.6A), while others show no bedding through large sections of the core (Figure 5.8D). Large pumice pebbles and cobbles are common in the deposits, as are abrupt changes in texture and lithology (Figure 5.6B and 5.8C). In the Puni licence area the base of the fluvial sediments was identified. It consists of dark fine lithic estuarine sands and mud (Figure 5.6B) at the downstream end of the licence area and brown to multicoloured mud in the upper part (Figure 5.17). No pre-fluvial basal unit was found in the Mercer licence area.

Textural analysis of the cored units yields no significant difference between the two licence areas. The sediments are unimodally distributed, implying that there has only been one sediment source during deposition. The presence of pumice in the bed sediments appears to effect sorting and the C statistic, presumably as a result of its different hydrodynamic behaviour. No significant change in pumice percentage with time was evident in the deposits.

Sub-bottom profiling of the licence areas shows up interesting structural features in the bed, but extensive lateral extrapolation of core stratigraphy from the profiles is of limited value. This is primarily as a result of the complex nature of the deposits (Figures 5.16 and 5.17), hence the correlation of units in a conventional fence diagram to gain quantitative estimates of a unit(s) was not feasible.

A 'reservoir' corrected age of 4540 ± 220 yrs BP is obtained from ^{14}C dating of shell from the basal estuarine unit. In the past the channel must have cut deeper into the bed, as the regional sea level was 31 m lower than that of the present level 10 000 years ago (Gibbs, 1986) and the river is thought to have flowed through this area for the past 20 000 yrs (Schofield, 1965). Charcoal is found as deep as 5 m in some cores, indicating that this degree of aggradation has occurred since the Taupo eruption (AD 214), because charcoal is absent from the Hinuera Formation which is the other major source of sediment. Considering that the cores do not exceed 5.4 m in length, and the unimodality of the sediments, it appears that the fluvial deposits are primarily composed of sediments related to Taupo Pumice Alluvium. A detailed mineralogical study would be needed to test this hypothesis.

CHAPTER SIX :

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

A brief summary of conclusions concerning the objectives outlined in the introduction is given. On the basis of these conclusions, implications are made regarding future changes in bed levels and the future role of sand extraction on the river. Finally, recommendations are made about future research and management plans for the lower Waikato River.

6.1 CROSS SECTIONAL RIVER BED SURVEYS AND DATA ANALYSIS

Periodic river bed level surveys have been conducted by the Waikato Catchment Board every five to six years. Analysis of the river bed level data from 1964 to 1987 shows that progressive degradation has occurred in the areas of sand extraction, from Puni to Mercer. In the surveys up until 1981 the upstream translation of the degrading effect caused by sand extraction appears to have been hinged near Rangiriri, but the most recent survey indicates that the hinge point appears to have moved upstream past Huntly, with marked degradation evident in the Mercer to Huntly reach (approximately a 0.3 m drop in smoothed bed level profile at Rangiriri between 1981 and 1987, Figure 2.8). The Karapiro to Hamilton reach also shows a degrading trend in river bed levels (approximately a 0.7 m drop in smoothed bed level profile at Cambride between 1964 and 1987, Figure 2.8). This is the result of the dam construction at Karapiro, causing the river to scour sediment from the bed downstream. This degrading effect is likely to continue until the bed armours or bedrock is struck, progressing downstream with time.

The trends observed in bed level change along the river are supported by analysis of bed volume change along the river. Bed volume analysis isolates areas of marked changes in bed volume that are caused by sand extraction, river training works, stopbank ballasting, and bed degradation caused by the Karapiro dam (Figure 2.10).

The data from these surveys provide a basis for assessing the extent and direction of bed changes in the lower Waikato River. The surveys also provide the only long term database for determining river stability. However, considering the extent of bed level change between the 1981 and 1987 surveys, and that the levels are approaching what the W.C.B consider to be acceptable in terms of flood protection and bank stability, the periodicity of the surveys may need reviewing.

6.2 MORPHOLOGY OF THE LOWER WAIKATO RIVER

Textually a rapid decrease in mean grain size occurs immediately downstream of the Karapiro dam, to a point where the size change then occurs at a rate controlled by sorting and abrasion, as opposed to bed armouring as a result sediment starvation due to the dam.

The large scale bedforms that occur in the lower Waikato River between Huntly and Mercer have in the past have been loosely referred to as 'dunes'. They are however, more characteristic of bars, specifically alternate bars that are related to sinuous flow patterns along straight reaches. Their isolation to this reach of the Waikato River is thought to be because of differences in channel sinuousity and width, which appear to be controlled by the degree of channel incision. Immediately downstream of all sand extraction sites the bed is devoid of detectable bedforms ($h < 0.1$ m) for 1 km or more, which is the result of a sediment deficit and/or higher cross sectional areas and hence lower velocities.

These alternate sand bars strongly influence the morphology and sediment transport in the reach from Huntly to Mercer. The following can be concluded about the morphology of the sand bars:

(1) the bars appear to alternate from side to side down the relatively straight reaches of the lower Waikato River. It is seen from aerial photographs and field observations that they are clearly related to the sinuosity of the thalweg or line of maximum flow;

(2) the bars exist in two main forms, either with a relatively straight crest and located slightly to one side of the channel centre, or with a strongly curved crest and attached or very close to one bank;

(3) the bars are not static. Results from this study show that they move downstream at a rate of 1-3 m/day. The mechanism for this advancement is thought to be flow radiating off the main flow path as it crosses over the channel and flowing up over the bars transporting sand to the crest. Generally the flow and sediment transport patterns are the same as those described by Leopold (1982) (Section 3.4.3, p81);

(4) Textually, only subtle variations in mean grain size and sorting occur along the upstream face of the bars. At low to medium flows a layer of mud exists over the bed immediately downstream of the crest. This has important implications for sediment transport as it indicates that the bars are a closed system during low to medium flows, and therefore the migration rate of the bars is an accurate indication of the river's bedload transport rate across the width of channel they occupy;

(5) the sand bars have in the past been thought of as semi-permanent features. However, they are observed to flatten and become more rounded to a point where the crests are undefinable and only raised areas of the bed remain during winter high flows. When flow recedes the bars are seen to reform in areas that were bathymetric highs during the high flows; and

(6) a strong relationship exists between the volume of bedload transport past the bar crest and mean flow discharge. This has important applications for estimating bedload transport rates in the river.

The conclusions on bar morphology have important implications for understanding and determining bedload transport in the lower Waikato River.

6.3 BEDLOAD TRANSPORT IN THE LOWER WAIKATO RIVER

The bedload transport relationship from bar migration observed in this study compares well with Finley's (1974) results for the lower Waikato River. The presently accepted estimate of bedload transport for the lower Waikato River is 170 000 m^3/yr. This figure is based on Finley's (1974) bedload transport rating curve, assuming a yearly mean water discharge at Mercer of 350 m^3/s. The mean annual bedload transport rate from bar migration in the present study is 2.58 m^3/day/m width, assuming the average width of the morphology study area is 220 m, the bedload transport over the study period was 207 000 m^3/yr, and the mean discharge at Rangiriri during the present study was 419 m^3/s.

There is evidence of a decrease in bedload discharge with time. Considerable variation in the bedload transport estimates can, however, occur from year to year depending on the mean annual water discharge used in the bedload transport relationships as defined in this study and by Finley (1974). To determine a best estimate of bedload transport from the bar migration relationships, it is necessary to apply these relationships to the past flow records.

A considerable difference exists bewteen bedload estimates calculated using the bar migration transport relationships for the Mercer and Rangiriri sites. The author considers that application of both Finley's (1974) and the present bedload transport relationship to the Mercer site has a number of limitations. They are:

(1) the bar bedforms on which both relationships are based are not present in the Mercer area and bedload transport may therefore be controlled by different mechanisms;

(2) the channel in the Mercer area may be considered out of equilibrium as a result of local sand extraction, resulting in large cross sectional areas, and hence, lower velocities;

(3) the marked drop in flow discharge seen at Mercer is not as apparent at Rangiriri and the discrepancy may be due to the changing stage-discharge relation in the Mercer area as a result of sand extraction; and

(4) the channel is considerably narrower at Mercer (~156 m) than that in the bed morphology study area (~ 220 m) where the bedload relationship was developed, while at Rangiriri the width is comparable (~ 250 m).

Both bedload relationships show a drop in the annual bedload transport at Rangiriri (Table 4.7), from about 205 000 m^3/yr to 180 000 m^3/yr. It appears that the most reliable estimate of medium term bedload transport in the lower Waikato River based on the comparison of Finley's (1974) and the present bedload transport relationship is 180 000 m^3/yr based on the mean annual flow at Rangiriri since 1975.

From the mathematical methods used in this study to determine bedload transport the Colby Relations (1964) method is most representative of the lower Waikato River. This method provides bedload transport values that lie between those obtained from bar migration, and those from bedload trapping.

The contribution of bedload to the lower Waikato from its major tributaries is thought to be minimal, and any input of bedload probably occurs only during high flood flows.

6.4 BOTTOM SEDIMENTS OF THE LOWER WAIKATO RIVER

The bottom sediments in the study area are primarily coarse, poorly sorted sand, comprised of varying percentages of pumice, rock fragments and quartz. The river deposits show considerable variation in lithology and texture, even over short distances, both vertically and laterally. In the Puni licence area the base of the fluvial sediments was identified. It consists of dark fine lithic estuarine sands and mud at the downstream end of the licence area and brown to multicoloured mud in the upper end of the area. No pre-fluvial basal unit was identified in the Mercer licence area.

Textural analyses of the cored units yielded no significant difference between the two licence areas. The sediments are unimodally distributed, implying that there has only been one sediment source during deposition. The presence of pumice in the bed sediments appears to affect sorting and the C statistic, presumably as a result of its different hydrodynamic behaviour. No significant change in pumice percentage was evident in the deposits.

The presence of a basal unit in the Puni licence area implies that the volume of extractable coarse poorly sorted pumiceous sand is limited to about 7-9 m^3 per m^2 of channel bed. Expansion of the potential resource in this area would require operations to move into the delta area or onto the flat areas adjacent to the river channel.

The Mercer licence area appears to have no pre-fluvial base at the depths cored (5-6 m), so there appears to be a larger sand resource in this area. However, the degree of extraction in this reach is likely to be limited by lowering bed level considerations.

6.5 IMPLICATIONS FOR FUTURE CHANGES IN THE LOWER WAIKATO RIVER

River Bed Levels

If sand extraction continues at the current rates in the current locations, then bed levels are likely to continue falling in future years. The degrading trend is likely to affect further upstream of Huntly in future and the rate of degradation in the Huntly to Rangiriri reach will increase. The degrading trend currently occurring in the Karapiro to Hamilton reach caused by the Karapiro dam is certain to progress downstream with time. The cumulative effect of these two converging trends on river bed level is difficult to quantify. Hence, a need exists for ongoing research and frequent monitoring of river bed levels, textural trends and sediment transport.

Presently the river bed in the Rangiriri to Tuakau area has reached levels that were targeted by the Waikato Catchment Board as part of the Flood Control Scheme. However, further lowering of levels is feared to be detrimental as it may impede the operation of water intake structures at the Huntly and Meremere Power Stations, further promote drainage of the Whangamarino Wetlands, and possibly produce instability of the stopbanks. It therefore appears, that in future, some restrictions on sand extraction in the lower Waikato River will be necessary. The exact nature and reasons for any restrictions should be based on sound scientific data and analysis, and should be in line with a long term management plan for the lower Waikato River.

Sand Extraction

When considering the future of sand extraction the operation at Mercer which affect the reach immediately upstream must be considered separately from the Puni operations and to some extent the Tuakau operations whose river water levels are controlled by tidal influence.

In the Mercer area three simplistic senarios can be used to define the options for future sand extraction:

(1) continue at the current extraction rate in the same areas. Bed levels will continue to degrade and problems associated with lower river bed levels will be exacerbated;

(2) continue sand extraction at a rate at or slightly below that of annual bedload transport. Bed levels are likely to stabilise in the immediate area, while upstream they can be expected to further degrade but at a slower rate until the bed re-equilibrates. This would require continued monitoring of the bedload transport rate and adjacent river bed levels; and

(3) quickly phase out extraction operations. This would allow bedload transport to fill in the lowered bed profile caused by continued sand extraction, and hence stop bed level degradation as a result of sand extraction. Bed levels in the Mercer reach are likely to rise and this might require some dredging to maintain the flood protection. The extent and rate of any bed level rise can only be determined by continuous monitoring of bed levels.

The bedload transport discharge of the river is an important parameter as it dictates the river's ability to sustain continued sand extraction. The present bedload transport estimate of 180 000 m3/yr implies that significant extraction may be sustained in the Mercer reach by bedload transport alone. However, it should be noted that as a result of the Karapiro dam closure the bedload supply in the river is finite, and bedload transport rates in the river are likely to decrease in future. Another possible option is to operate roving dredges upstream of the Mercer sand processing plants. This however, is still likely to promote degradation of the bed levels bewteen Huntly and Mercer.

In the tidally influenced areas around Puni, and to a lesser extent Tuakau, the water level is not strongly controlled by changes in river bed levels as is the case upstream. Extraction may therefore continue in these tidal areas in the future, with the limited volume of useable sand in the channel bed being the limiting factor for the resource. Other options in this area include moving into the delta area downstream or creating embayments into the sand deposits on land adjacent to the present river channel.

6.6 RECOMMENDATIONS FOR FUTURE RESEARCH AND MANAGEMENT

From the conclusions of this study a number of recommendations for future research and management of the river can be made:

(1) because of the extent bed level change between the 1981 and 1987 surveys, and the fact the levels are approaching what the W.C.B consider to be acceptable in terms of flood protection and bank stability, it is recommended that the time between surveys should be reduced from the present 5-6 year spacing to about 2-3 years. This would allow for tighter management and control of factors affecting bed level change. Each survey of cross sections should be conducted over as shorter period as logistically possible (a month to six week) so that more accurate comparisons can be made between surveys in localised areas;

(2) future detailed evaluation of textural trends in the lower Waikato River should be made as this would be a useful tool for determining and monitoring the extent of the downstream effects of the Karapiro dam when used in conjunction with bed survey data;

(3) there is a need for future monitoring and reassessment of the presentlt accepted bedload transport rate. The continued presence of bar bedforms in the Huntly to Mercer reach provides an easy method for assessing the bedload transport relationship of the lower Waikato River;

(4) future demands for sand extraction are likely to be transferred from the Mercer area to the Puni reach of the river. Although water levels are not noticeably affected in this area by sand extraction some future detailed investigation may be required to investigate the effects of sand extraction on delta stability. This research could also investigate why no detecable bedforms are seen on echo sounding traces for some distance downstream of the extraction operations;

(5) with the expected increase in pressure on the sand resource at Puni, attention is likely to be directed at the sand contained in the low lying areas adjacent to the river channel. Utilisation of this resource would require considerable research to establish the extent and character of the deposits. This would be best obtained from a extensive coring program across the area, from which textural parameters could be obtained and with the aid of radicarbon dating an evolutionary history of the area could be developed;

(6) if bed levels continue to fall as a result of both sand extraction and the downstream effects of the Karapiro dam, then some study of the likely impacts on the lower Waikato River's tributaries is needed to assess the likely implications such as tributary entrenchment;

(7) the bar bedforms that dominate the Huntly to Mercer reach still require further research to charaterise morphology, occurrence, migration, affect on resistance to flow and numerous other fluvial aspects.

Finally, the future for the river as a resource is likely to be a demanding one. Demands will be placed on the areas of conservation, recreation and utilisation, and thus correct management of this resource is essential.

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APPENDICES

APPENDIX 1

Sand Extraction Volumes From the Lower Waikato River

VOLUMES OF SAND EXTRACTION IN THE LOWER WAIKATO RIVER, 1953 - 1988
Extraction volumes for specific operators are shown, and where possible quarterly data is given.
(Data source : Waikato Catchment Board files, based on out the gate tallies of operators.)

YEARS	Winstones Ltd				Stevensons		Rooses				Tuakau Sand Ltd		Power station / Stop banks #	Smeeds Quarry	Gordons & Waikato Sands
/Quarters	Puni	m3	Mercer	m3	Mercer	m3	Combined	m3	Hamilton	m3	Tuakau	m3			
1953							Mercer & Hamilton						Totals only	44913	
1954							Operation figures						specific operators	63306	
1955													unknown	60402	
1956														86130	
1957														94849	
1958		36821		18057				54887							14977
/1	Henry's		6888												
/2	Operaters 1958-1970		4817												
/3			1737				13591								
/4			4615				14034								
1959		40504		28489				46875							19827
/1			3028				12231								
/2			9141				11890								
/3			6443				11587								
/4			9877				11167								
1960		42961		43946				48434				11374		330	20990
/1			7196				12432				1357				
/2			12864				13913				3041				
/3			13808				9870				3769				
/4			10078				12219				3207				
1961		44108		32217				49037				19934		50	28015
/1			7328				11149				3573				
/2			8279				13502				4149				
/3			8052				12414				5746				
/4			8558				11972				6466				
1962		38470		40463				59932				18704		167	27989
/1			7740				9847				4898				
/2			10714				15979				4839				
/3			11931				16965				3502				
/4			10078				17141				5465				
1963		61387		47816				76010				27347		922	27268
/1			13257				12420				8176				
/2			14373				17757				4749				
/3			18417				20961				6653				
/4			1769				24872				7769				
1964		47886		81032				107029				36417		1151	26154
/1			18303				22008				9358				
/2			20446				28370				10303				
/3			22539				26393				7487				
/4			19744				30258				9269				
1965		51463		89391				133580				43258		1553	27388
/1			18120				30909				11081				
/2			24833				37995				11478				
/3			25716				31281				11414				
/4			20722				33395 *				9285				
1966		38147		93238				150139				33695		3793	25633
/1			18852				37535 *				8308			477	
/2			23829				40338				8263			1320	
/3			28621				36585				8085			833	
/4			21936		19481			671036	16200		9039			1163	
1967		49553		85757		87999	Changed to			68868		37348	5775 #	3441	21558
/1			16695		17851		Stevensons at		15852		8555			836	
/2			21637		24309		Mercer		21049		12146			900	
/3			27035		23940				16189		8569			994	
/4			20390		21899				15778		8078			711	
1968		35917		92188		89008				68053		34169	84975 #	1300	20243
/1			15578		23441				17501		8776			600	
/2			24212		20077				17970		9056			97	
/3			32178		21858				18537		8036			325	
/4			20220		23632				14045		8301			278	
1969		32834		100749		112497				64250		43425	137325 #	1285	5931
/1			19477		24254				13384		9736			205	
/2			23319		26445				16269		12698			191	
/3			30169		29457				16639		10392			718	
/4			27784		32341				17958		10599			171	
1970		27770		114576		125514				75557		48268	134325 #	1578	
/1	Changed		26766		28777				14911		9851			1235	Changed
/2	to	>Winstone	24845		30684				18023		12684			343	to
/3	13591		31495		30328				20449		12730			Changed to	Winstones
/4	14179		31470		35725				22174		13003			Wintones	
1971		53167		117417		139970				69665		53262			
/1	12844		27148		30643				17519		13394				
/2	11391		28577		37496				17609		13463				
/3	16088		34513		34998				19320		14771				
/4	12844		27179		36833				15217		11634				
1972		94763		117582		162640				56979		73956			
/1	24654		14695		33488				14738		15196				
/2	22164		31860		40997				15152		16984				
/3	22726		37529		43158				12274		21910				
/4	25219		33498		44997				14815		19866				
1973		101261		145290		229988				62503		83756			
/1	24710		30190		50250		Rooses operation at		15527		18793				
/2	21423		34936		49596 *		HUNTLY		15175		23085				
/3	29813		43842		61819				15474		20939 *				
/4	25315 *		36322 *		68323				16327		20939 *				
1974		97723		156710		265920		21945		47835		95080	335000 1		
/1	23204		32773		63655				15558		23788				
/2	25291		43262		69540		0		16768		28673				
/3	26509		37496		73590		1852		7052		23770 *				
/4	22719		43179		59135		9215		8457		18849				
1975		79298		144969		200593	10878	44916		30351		86872	100000 #		
/1	18470		30436		46342				6772		19448				
/2	20340		37566		51100		9635		9558		22879				
/3	17590		38347		50610		10371		7042		23199				
/4	22898		38620		52541		11250		6979		21346				

Sand Extraction Volumes From the Lower Waikato River

YEARS /Quarters	Winstones Ltd Puni	m3	Mercer	m3	Stevensons Mercer	m3	Rooses Combined	m3	Hamilton	m3	Tuakau sand Ltd Tuakau	m3	Power station ! Stop banks #	Smeeds Quarry	Gordons &
1976		87458		117502		222525	13660	57480		5852		74882	59000 !		
/1	19103		27905		28274				3903		3223				
/2	24689		31223		72697		7290		1949		34315				
/3	21694		28074		61223		16333		0						
/4	21972		30300		60331		18352		0		37344				
1977		82793		94448		178300	15505	55233				143128	44000 !		
/1	28389		24128		52005						48559				
/2	19570		26237		48555		13802				37706				
/3	18080		21826		39970		12970				29067				
/4	16754		22257		37770		14908				27796				
1978		56737		75481		119510	13553	51870				130466			
/1	11951		18416		27900						33058				
/2	15406		18371		34740		11126				36781				
/3	13955		20194		24294		13431				28610				
/4	15425		18500		32576		12024				32017				
1979		59615		58140		141443	15289	45344				118378	45000 !		
/1	14698		13551		40566						32962				
/2	16121		14739		32423		9719				29069				
/3	11748		14433		31455		13627				26532				
/4	17048		15417		36999		10745				29815				
1980		48637		56102		123848	11253	36706				103762	38000 !		
/1	9963		13284		29230						24143				
/2	14213		11335		35048		9990				25237				
/3	10885		13854		26393		10790				25525				
/4	13576		17629		33177		8955				28857				
1981		44030		44019		87727	6971	128				88309			
/1	13415		8665		44412						27580				
/2	13710		15911		4489		128				28446				
/3							0								
/4	16905		19443		38826		0				32283				
1982		65220		75246		135179	0					123331			
/1	10858		11386		37256						30266				
/2	17944		26239		33389						36136				
/3	15208		21710		33545						29864				
/4	21210		15911		30989						27065				
1983		107915		69321		146931						101301	21000 !		
/1	20273		14535		39826						21167				
/2	22721		14466		31002						24570				
/3	33088		20280		43288						27353				
/4	31833		20040		32815						28211				
1984		82907		85901		129778						124052	50000 !		
/1	21729		20304		31753						27578				
/2	18539		19641		32593						33423				
/3	20578		23150		42217						30790				
/4	22061		22806		23215						32261				
1985		102251		88255		165095						127896			
/1	22907		21852		40457						31974 *				
/2	22948		24748		40049						31183				
/3	28391		23131		45254						35350				
/4	28005		18524		39335						29389				
1986		113838		102255		173261						142487			
/1	29196		22083		39058						25412				
/2	31758		25960		50793						26773				
/3	25534		27498		43861						45924				
/4	27350		26714		39549						44378				
1987		118074		125317		184189						127288			
/1	27471		25531		48246						30010				
/2	30371		28863		46618						30486				
/3	29860		25385		48304						33510				
/4	30372		20153		41021						33282				
1988		108411		91740		113533						82532			
/1	27542		22091		42246						29178				
/2	28419		25679								28599				
/3	23642		22376		35665										
/4	28808		21594		35622						24755				
	TOTAL=	1986699	TOTAL=	2558368	TOTAL=	3670966	TOTAL=	313622	TOTAL=	885431	TOTAL=	2234677	TOTAL= 1054400	TOTAL= 15570	TOTAL= 265973
					GRAND TOTAL=	12985706									

N.B

* One month missing in quarterly data, hence a mean value used from other 2 months.

\# Volumes extracted for stopbank ballasting.

! Volumes extracted for Huntly Power Project.

APPENDIX 2

W.C.B Bed Survey Data 1913 - 1987

WAIKATO CATCHMENT BOARD PERIODIC SURVEYS OF THE LOWER WAIKATO RIVER, 1913 TO 1987

Cross Section Number	Distance Upstream (km)	1913 Survey Area (m2)	1913 Survey Width (m)	1913 Survey MBL (m)	1928 Survey Area (m2)	1928 Survey Width (m)	1928 Survey MBL (m)	1929 Survey Area (m2)	1929 Survey Width (m)	1929 Survey MBL (m)	1938 Survey Area (m2)	1938 Survey Width (m)	1938 Survey MBL (m)	1954 Survey Area (m2)	1954 Survey Width (m)	1954 Survey MBL (m)
14	14.16	1006	730	-0.43												
15	14.47															
16	14.96															
17	15.25	729	426	-0.68												
17A	15.72															
18	16.21	725	500	-0.35												
19	16.86	563	441	-0.15												
20	17.42	630	287	-1.01												
21	17.94	765	381	-0.76												
22	18.33	614	362	-0.41												
23	18.81	666	373	-0.44												
24	19.24	567	255	-0.82												
25	19.80	691	387	-0.32												
26	20.90	696	434	0.04												
26A	21.57															
27A	22.66															
27	23.32	638	325	-0.10	721	297	-0.57	793	297	-0.81				535	296	0.05
28	23.85	506	234	-0.24	581	262	-0.30	479	262	-0.07				567	261	-0.26
29	25.02	497	293	0.34	714	347	0.00	678	347	0.10				473	362	0.75
29A	25.46															
30A	25.87															
30	26.47	557	291	0.28	681	303	0.00	615	303	0.20				622	312	0.24
31	26.92	511	244	0.16	779	312	-0.20	671	312	0.06				598	309	0.36
31A	27.70															
32	28.56	666	391	0.74	743	388	0.50	734	387	0.53				668	380	0.66
33	29.11	607	145	-1.71	669	168	-1.52	631	168	-1.30	564	164	-0.95	555	166	-0.87
34	29.47	898	432	0.43							801	427	0.63			
35	29.84	647	285	0.28	662	357	0.70	638	357	0.77	525	331	0.97	538	352	1.03
36	30.09	596	348	0.88							618	392	1.01			
37	30.49	1173	497	0.29	718	387	0.79	659	387	0.95	766	380	0.63	751	392	0.73
37A	30.81															
38	31.87	701	437	1.17	598	455	1.46	799	455	1.02	742	438	1.07	733	446	1.12
39	31.97	659	296	0.60	694	323	0.68	622	323	0.91	683	316	0.67	567	324	1.08
40	32.57	771	403	0.99	748	372	0.90	460	372	1.67	722	363	0.92	543	363	1.41
41	33.22	648	226	0.08	613	238	0.37	543	238	0.67	558	230	0.52	578	239	0.54
42	33.63	721	338	0.87	746	369	1.00	509	369	1.64	758	367	0.91	607	334	1.19
43	33.87	686	222	-0.05	635	241	0.41	548	241	0.78	643	221	0.13	594	223	0.37
44	34.39	694	185	-0.63	688	184	-0.60	556	184	0.12	617	147	-1.08	795	216	-0.55
45	34.92	593	296	1.19	646	302	1.06	644	302	1.06	554	247	0.95	508	253	0.88
46	35.32	663	133	-1.72							524	117	-1.24	517	120	-1.07
47	35.69	690	163	-0.94							534	152	-0.29			
48	35.89	795	234	-0.08	748	222	-0.05	585	222	0.07	640	211	0.28	634	212	0.33
49	36.67	708	294	1.00							648	275	1.05	944	302	0.29
50	37.51	512	261	1.55	855	332	0.94	516	216	1.97	671	316	1.45	662	326	1.49
51	38.04	432	80	-1.64							512	111	-1.04	444	111	-0.40
52	38.12	742	293	1.07							886	251	0.07			
53	38.54	921	419	1.46	854	381	1.41	1142	381	0.66	763	356	1.51	756	383	1.68
55	39.11	588	259	1.49	759	294	1.18	615	294	1.67	788	283	0.98	615	-9	1.66
56	39.93	535	154	0.45	664	184	0.22	480	184	1.22	[illegible]	186	0.41	587	187	0.68
57	40.56	633	163	0.01	678	160	-0.32	524	160	0.64	595	151	-0.03	676	168	-0.15
58	41.75	618	157	0.05	647	165	0.06	551	165	0.64	555	162	0.45	546	158	0.53
58A	42.09															
59	42.38	700	381	2.21	936	469	2.05	844	469	2.25	819	427	2.13	925	433	1.94
60	42.61	1030	537	2.14	792	365	1.89	862	365	1.67	749	361	1.99	785	353	1.84
60A	43.17															
61A	43.98															
61	44.68	955	362	1.59	766	262	1.31	499	262	1.68	711	264	1.53	545	271	2.22
62	45.45	688	286	1.87	379	274	2.91	591	274	2.14	679	272	1.96	703	295	1.91
62A	46.19															
63	46.40	761	384	2.38							880	481	2.53			
64	46.61	851	495	2.66							714	393	2.56	613	397	2.84
64A	47.00															
65	47.56	922	409	2.19	683	402	2.74	707	402	2.69	676	417	2.82	723	423	2.73
66	47.87	671	290	2.17	783	285	1.75	590	285	2.42	669	278	2.08	611	284	2.34
66A	48.31															
67	48.77	884	362	2.12	757	361	2.47	792	361	2.38	812	314	1.98	682	314	2.40
68	48.99	765	388	2.61							835	448	2.71			
69	49.42	721	357	2.58	793	332	2.21	770	332	2.28	748	333	2.35	715	337	2.48
69A	49.63															
70	49.81	732	390	2.76							775	392	2.66	670	400	2.97
71	50.53	639	199	1.45	651	191	1.27	505	191	2.04	512	186	1.92	579	197	1.73
71A	51.00															
72	51.34	802	397	2.76							682	399	3.07	717	406	3.02
72A	51.78															
73A	52.43															
73	53.25	652	266	2.46	798	275	1.85	673	275	2.49	491	263	3.04	544	263	2.87
74	53.56	882	325	2.24							756	302	2.46	618	306	2.95
75	53.91										587	311	3.09	545	317	3.26
76	54.18										610	281	2.86	519	299	2.74
77	54.44										534	251	2.90			
78	54.73	577	280	2.99							635	294	2.90	576	296	3.12
79	55.09	750	246	2.01							672	235	2.20	536	235	2.79
80	55.35										571	228	2.59	561	228	2.64
81	55.57										520	218	2.74	542	221	2.68
82	55.86										571	262	2.95	515	269	3.23
83	56.07										553	285	3.22			
84	56.19	887	371	2.78							541	342	3.59	551	363	3.66
85	56.31										639	374	3.48	639	382	3.65
86	56.50										520	288	3.42	575	291	3.25
87	56.79										557	204	2.51	495	207	2.87
88	56.99										542	204	2.60	518	206	2.75
89	57.38	779	339	2.99	949	386	2.84	884	393	3.05	638	314	3.27	558	324	3.58
90	57.63										446	269	3.67	542	348	3.50
91	57.76	699	289	2.92	632	293	3.19	610	293	3.27	439	274	3.74	548	301	3.52
92	58.17										514	192	2.70	471	205	3.08
93	58.49	568	219	2.79	601	209	2.52	559	208	2.71	590	204	2.49	479	216	3.18
94	58.85										537	272	3.30			
95	58.87										581	301	3.50	503	294	3.71
96	58.90	593	328	3.64							671	381	3.69			
97	59.37	653	303	3.32							710	308	3.18			

MBL in metres above Moturiki Datum

W.C.B Bed Survey Data 1913 - 1987

Cross Section Number	Distance Upstream (km)	1913 Survey			1928 Survey			1929 Survey			1938 Survey			1954 Survey		
		Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)
98	59.60										539	266	3.47	483	202	3.11
99	59.85										539	266	3.49			
100	60.11	632	334	3.65	614	290	3.43	555	296	3.67	724	390	3.73	650	383	3.85
101	60.33										561	363	4.09	542	366	4.08
102	60.78	727	425	3.87							830	427	3.64	575	432	4.26
103	60.98										509	322	4.03	548	320	3.89
104	61.23										513	342	4.13	500	344	4.18
105	61.33										516	348	4.16	494	351	4.24
106	61.50	1130	594	3.76							546	436	4.41	477	389	4.44
106A	62.01															
107	62.50	712	319	3.52							503	276	3.93	521	299	4.02
108	63.05	560	387	4.32							579	365	4.20	481	363	4.46
108A	63.54															
109A	64.13															
109	64.52	541	418	4.69							420	364	4.83	460	324	4.56
110A	64.95															
110	65.45										513	324	4.60	524	357	4.72
110C	65.68															
110D	65.91															
110E	66.11															
110F	66.34															
111	66.48													465	372	5.08
111A	66.74															
111B	66.95															
111C	67.18															
111D	67.48															
111E	67.64															
111F	67.80															
112	68.01													498	374	5.20
113	69.10				516	241	4.54	473	241	4.72				461	232	4.70
114	70.63													500	296	5.22
115	72.34				534	285	5.22	472	275	5.38				492	288	5.39
116	73.16				539	208	4.67	418	210	5.26				433	177	4.87
117	74.48				569	253	5.16	496	255	5.45				508	250	5.37
118	74.95				596	148	3.44	445	148	4.46				374	100	3.72
119	75.34				444	244	5.71							491	240	5.47
120	76.32				563	208	4.96	461	210	5.47				490	208	5.31
121	77.41				690	308	5.59	517	311	6.17				595	306	5.78
122	79.49				550	290	6.21	562	284	6.13				529	258	6.40
123	80.85				610	230	5.64	448	230	6.34				501	237	6.17
124	83.48				590	303	6.75	649	329	6.61				529	319	6.87
125	84.13				590	253	6.41	497	255	6.80				526	196	6.06
126	85.46													558	229	6.44
127	87.09													473	188	6.57
128	88.40													430	159	6.57
129	89.45													477	188	6.88
130	91.29													370	199	7.81
131	93.23													427	143	6.94
132	94.45													367	141	7.51
133	95.88													288	90	7.12
134	97.54													405	208	8.60
135	99.15													340	135	8.28
136	101.36													335	134	8.61
137	102.66													227	41	5.66
138	104.03															
139	105.24															
140	106.51															
141	107.28															
142	108.12															
143	108.76															
144	110.11															
145	110.53															
146	111.17															
147	112.43															
148	113.52															
149	114.31															
150	115.34															
151	116.27															
152	117.26															
153	118.37													337	111	11.27
154	119.21															
159	126.33															
174	141.77															

W.C.B Bed Survey Data 1913 - 1987

WAIKATO CATCHMENT BOARD PERIODIC SURVEYS OF THE LOWER WAIKATO RIVER, 1913 TO 1987

Cross Section Number	1958 Survey			1964 Survey			1970 Survey			1975 Survey			1981 Survey			1987 Survey		
	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)	Area (m2)	Width (m)	MBL (m)
14				518	756	0.26	729	470	-0.61	813	481	-0.74	783	470	-0.73			
15				633	329	-0.95	661	329	-1.04	607	330	-0.86	712	327	-1.21			
16				638	251	-1.56	493	254	-0.94	822	255	-2.22	631	257	-1.46			
17				678	443	-0.49	896	439	-1.01	731	442	-0.68	886	436	-1.00			
17A						-0.17	633	285	-1.16	644	286	-1.19	649	283	-1.23			
18						-0.19	613	219	-1.71	647	220	-1.85	626	221	-1.74			
19						0.04	617	281	-1.07	521	280	-0.73	798	280	-1.72			
20				782	287	-1.53	605	246	-1.28	665	250	-1.47	748	247	-1.84	1054	241	-3.18
21				537	383	-0.16	503	384	-0.06	632	386	-0.39	556	386	-0.19	614	387	-0.34
22				518	363	-0.15	568	374	-0.24	580	363	-0.32	646	365	-0.49	661	371	-0.50
23				509	379	0.01	592	382	-0.21	588	379	-0.24	658	383	-0.38	647	383	-0.35
24				498	257	-0.54	569	260	-0.79	580	260	-0.83	577	262	-0.80	666	265	-1.11
25				537	362	-0.25	577	263	-0.82	613	275	-0.77	645	261	-1.01	711	261	-1.27
26				689	414	0.04	717	402	0.15	713	400	-0.03			-0.46	777	344	-0.66
26A				522	319	-0.19	590	274	0.19	619	316	-0.54	656	320	-0.63	686	322	-0.69
27A				568	270	-0.33	575	259	-0.45	627	262	-0.62	649	256	-0.73	669	264	-0.76
27				520	294	0.09	536	298	0.06	575	293	-0.10	648	293	-0.36	711	291	-0.59
28	562	264	-0.21	451	259	0.18	553	260	-0.21	671	259	-0.67	638	257	-0.56	705	260	-0.79
29				640	347	0.20	675	333	0.09	728	350	-0.40	869	344	-0.48	830	342	-0.39
29A				512	299	0.51	565	284	0.26	694	337	0.16	759	294	-0.08	860	296	-0.40
30A				588	283	0.12	650	276	-0.12	688	282	-0.17	803	273	-0.41	835	255	-0.82
30	568	312	0.41	553	309	0.40	588	297	0.21	796	308	-0.39	806	306	-0.44	877	293	-0.80
31				611	308	0.27	661	306	0.09	711	307	-0.07	882	307	-0.62	997	312	-0.95
31A				596	255	0.01	586	248	-0.01	703	249	-0.49	830	246	-1.03			
32				628	375	0.76	585	375	0.88	729	381	0.53	780	375	0.36			
33	601	168	-1.12	638	167	-1.33	719	165	-1.86	706	165	-1.77	750	171	-1.89	742	164	-2.02
34				693	370	0.64	741	333	0.28	651	277	0.16						
35				621	316	0.59	610	314	0.61	676	316	0.41	752	324	0.23	802	319	0.04
36				606	344	0.83	678	354	0.67	687	332	0.25						
37	688	392	0.89	735	385	0.74	760	381	0.66	763	373	0.27	806	389	0.58	917	381	0.25
37A				533	272	0.73	635	263	0.29	694	244	-0.12	676	248	0.02	690	267	0.10
38				621	437	1.35	797	417	0.85	710	432	1.16	830	439	0.88	868	438	0.79
39	609	324	0.95	593	322	0.99	639	306	0.95	668	294	0.83	777	281	0.54	721	216	-0.51
40				626	365	1.18	643	341	1.01	796	365	0.73	777	366	0.78	807	366	0.69
41				557	234	0.58	613	234	0.34	692	240	0.07	720	240	-0.05	763	235	-0.30
42				636	327	1.07	658	347	1.11	680	342	1.02	751	317	0.64	826	345	0.61
43	655	224	0.13	587	223	0.42	617	220	0.24	715	224	-0.14	759	223	-0.36	796	256	-0.48
44				753	149	-1.90	713	149	-1.66	788	142	-2.42	786	179	-1.27	936	224	-1.05
45				574	249	0.89	664	248	0.60	740	249	0.22	812	247	-0.10	833	257	-0.06
46	560	120	-1.40	555	120	-1.36	598	121	-1.67	652	121	-2.13	669	119	-2.36	633	121	-1.97
47				557	153	-0.34	597	154	-0.58	675	154	-1.08	714	154	-1.33	781	154	-1.77
48	631	212	0.34	657	211	0.21	647	210	0.26	738	212	-0.16	804	211	-0.49	892	209	-0.95
49				697	282	0.94	738	276	0.74	807	285	0.58	911	281	0.16	915	293	0.29
50				726	324	1.27	754	280	0.83	847	298	0.41	1002	339	0.03	1120	295	-0.27
51				443	105	-0.63	583	111	-1.68	701	110	-2.78	967	118	-4.62	904	126	-3.60
52				803	254	0.44	867	257	0.22	891	251	0.05	1200	254	-1.33	1287	259	-1.37
53	822	383	1.51	750	379	1.68	852	383	1.42	781	370	1.55	1028	396	1.05	1090	399	0.92
55				666	293	1.49	842	293	0.88	1112	291	-0.06	1148	288	-0.23	1086	285	-0.04
56				619	181	0.40	772	186	-0.33	1087	184	-2.09	936	185	-1.24	843	187	-0.69
57	617	168	0.21	663	169	-0.02	828	166	-1.08	737	166	-0.53	751	167	-0.57	806	167	-0.92
58				625	156	-0.01	564	156	0.37	758	156	-0.86	697	156	-0.49	763	156	-0.90
58A				604	219	1.25	585	217	1.33	809	214	0.23	802	200	0.00	815	202	-0.01
59	859	434	2.07	894	428	1.96	1100	415	1.09	1009	432	1.62						
60				721	357	2.04	981	363	1.36	672	364	22.20	854	346	1.59	1109	359	0.98
60A				669	184	0.48	753	181	-0.05	648	181	0.53	748	181	-0.02	804	182	-0.30
61A				729	338	2.02	875	342	1.62	755	337	1.94	871	339	1.61	907	234	0.30
61				576	254	1.96	647	262	1.76	735	262	1.42	783	271	1.37	760	244	1.12
62	720	289	1.80	601	292	2.23	515	192	1.61	604	200	1.27	699	203	0.84	689	198	0.81
62A				543	280	2.40	638	280	2.06	521	238	1.95	575	218	1.70	653	201	1.09
63				810	482	2.68	998	486	2.31									
64				641	393	2.75	733	375	2.41	558	224	1.89	555	224	1.90	712	223	1.19
64A				698	403	2.68	739	397	2.55	545	233	2.07	641	236	1.69	658	235	1.61
65				684	424	2.83	711	422	2.76									
66	624	281	2.63	622	288	2.33	656	288	2.23	687	291	2.13	645	291	2.27	646	258	2.00
66A				480	193	2.04	536	197	1.82	676	197	1.10	614	206	1.55	699	206	1.12
67				750	313	2.17	726	312	2.21	743	312	2.16	713	313	2.26	801	249	1.35
68				759	454	2.91	865	455	2.67	892	455	2.62						
69				732	334	2.41	717	335	2.46	670	331	2.58	759	333	2.32			
69A				565	270	2.53	532	269	2.64	588	270	2.41	636	285	2.12			
70				638	399	3.04	603	396	3.12	576	395	3.18	682	397	2.97	556	253	2.44
71				512	194	2.04	565	194	1.76	561	194	1.78	642	238	1.95	611	195	1.53
71A				587	308	2.84	653	301	2.56	659	304	2.57	640	300	2.59	651	290	2.48
72	576	405	3.36	682	405	3.22	655	405	3.16	692	405	3.07	656	403	3.15	763	403	2.85
72A				543	243	2.59	617	242	2.26	640	244	2.20	678	273	2.33	622	245	2.28
73A				516	286	3.07	632	286	2.66	575	286	2.86	716	287	2.38	625	281	2.65
73	578	262	2.73	526	261	2.85	459	261	3.17	537	260	2.87	602	263	2.61	675	261	2.35
74				638	303	2.86	655	307	2.65	602	256	2.61	729	302	2.55			
75				561	314	3.19	594	317	2.83	495	239	2.91	560	229	2.54	603	230	2.36
76				574	282	2.98	648	297	2.83	528	229	2.70	570	219	2.14	619	221	2.21
77				518	251	2.97	552	261	2.93	431	208	2.97	646	207	1.92	615	206	2.07
78	555	296	3.18	533	280	3.15	493	282	3.30	555	281	2.97	646	207	1.92	673	292	2.75
79				552	224	2.61	477	230	2.99	581	230	2.54	575	219	2.45			
80				604	227	2.44	516	231	2.86	547	230	2.72	590	229	2.53	623	225	2.33
81				490	219	2.89	511	218	2.79	527	218	2.72	525	217	2.71	596	219	2.41
82				520	262	3.16	604	272	2.92	518	269	3.22	511	270	3.26	677	269	2.64
83				505	294	3.45	565	312	3.35	558	310	3.36	499	305	3.53	659	310	3.03
84				593	344	3.45	663	357	3.32	640	356	3.38						
85				598	382	3.62	585	381	3.65	676	383	3.43	633	378	3.51	812	379	3.05
86	583	292	3.23	545	292	3.36	458	293	3.65	574	291	3.25	579	292	3.24	632	285	3.00
87				525	205	2.69	510	203	2.74	517	203	2.72	541	202	2.58	611	203	2.24
88				493	210	2.92	461	208	3.05	506	210	2.86	578	206	2.46	484	200	2.85
89				554	322	3.57	567	322	3.54	595	323	3.46	546	325	3.61	706	323	3.10
90				515	272	3.44	476	270	3.56	539	270	3.34	519	270	3.40	649	271	2.93
91	545	302	3.54	546	289	3.45	478	300	3.75	575	299	3.41	542	293	3.49			
92				473	193	2.92	522	202	2.79	514	202	2.83	544	200	2.65	451	201	3.13
93	480	198	2.96	511	194	2.75	462	214	3.23	483	213	3.14	488	198	2.93	528	199	2.74
94				427	242	3.64	559	265	3.30	559	264	3.41	554	215	2.82	574	218	2.76
95				499	305	3.78	517	290	3.64	539	289	3.56	535	285	3.56	579	291	3.43
96				669	386	3.71	609	389	3.88	669	389	3.73	706	370	3.54	748	389	3.53
97				597	306	3.53	786	312	2.96	688	311	3.26						

W.C.B Bed Survey Data 1913 - 1987

Cross Section Number	1958 Survey Area (m2)	1958 Survey Width (m)	1958 Survey MBL (m)	1964 Survey Area (m2)	1964 Survey Width (m)	1964 Survey MBL (m)	1970 Survey Area (m2)	1970 Survey Width (m)	1970 Survey MBL (m)	1975 Survey Area (m2)	1975 Survey Width (m)	1975 Survey MBL (m)	1981 Survey Area (m2)	1981 Survey Width (m)	1981 Survey MBL (m)	1987 Survey Area (m2)	1987 Survey Width (m)	1987 Survey MBL (m)
98	546	198	2.75	379	216	3.74	548	205	3.05	464	203	3.20	534	204	2.88	486	204	3.12
99				485	253	3.60	509	268	3.61	580	258	3.27	569	266	3.37	513	261	3.54
100				643	406	3.96	623	379	3.90	588	365	3.93	567	422	4.20			
101	553	368	4.06	537	366	4.09	495	366	4.20	535	367	4.10	487	365	4.23	559	365	4.02
102				518	421	4.36	497	426	4.42	634	430	4.11	587	336	3.84	584	335	3.85
103				462	323	4.17	541	312	3.86	512	310	3.95			3.16			
104	517	340	4.12	478	343	4.24	549	344	4.04	602	341	3.87	483	341	4.21	524	342	4.10
105				433	362	4.46	519	360	4.21	621	375	3.96	457	372	4.43	578	379	4.12
106				463	373	4.42	575	374	4.12	639	375	3.96	457	372	4.43	556	373	4.17
106A				451	234	3.79	476	234	3.68	446	235	3.81	487	235	3.63	475	231	3.65
107				431	252	4.05	525	286	3.93	457	285	4.16	506	281	3.96	573	284	3.74
108	518	363	4.37	476	360	4.46	574	356	4.18	639	364	4.04	542	356	4.27	618	360	4.08
108A				417	221	3.95	461	221	3.78	432	226	3.94	435	232	3.98	508	240	3.73
109A				444	263	4.25	453	263	4.21	467	271	4.21	434	256	4.20	544	262	3.84
109				458	360	4.71	500	312	4.38	520	287	4.14	501	288	4.24			
110A				389	231	4.41	448	220	4.07	398	229	4.36	477	226	3.99	369	175	4.00
110	515	361	4.76	500	363	4.80	531	323	4.55	557	325	4.47	519	303	4.47	560	315	4.41
110C				489	261	4.35	480	261	4.38	536	260	4.16	472	146	4.30			
110D				561	365	4.72	578	360	4.64	628	344	4.43	551	359	4.70	597	337	4.48
110E				492	315	4.69	575	304	4.39	577	288	4.27	461	297	4.72			
110F				747	444	4.63	637	434	4.84	484	431	5.19	515	478	5.23			
111				525	362	4.89	475	367	5.04	414	330	5.07	515	361	4.90	589	368	4.73
111A				468	313	4.87	443	317	4.97	512	317	4.76	488	305	4.77			
111B				465	319	4.94	456	317	4.96	472	317	4.91	424	313	5.05	584	317	4.65
111C				452	407	5.31	502	391	5.15	498	389	5.15	503	380	5.10			
111D				475	360	5.13	552	350	4.89	517	342	4.95	518	350	4.98	596	380	4.89
111E				454	323	5.04	566	308	4.64	535	309	4.75	487	311	4.92			
111F				549	364	5.00	530	349	4.99	548	342	4.89	480	338	5.08			
112	521	380	5.17	469	390	5.33	495	382	5.24	500	383	5.22	484	360	5.19	718	385	4.66
113				501	230	4.51	533	228	4.35	520	228	4.42	492	227	4.52	614	277	3.98
114				538	239	4.67	555	234	4.53	570	236	4.88	569	234	4.48	610	263	4.59
115	487	282	5.37	476	284	5.42	494	283	5.35	716	308	4.78	597	285	5.01			
116				452	177	4.69	552	174	4.08	482	172	4.45	542	168	4.02	550	170	4.02
117	550	249	5.20	578	249	5.08	501	248	5.38	572	250	5.11	643	252	4.84	681	249	4.67
118	495	94	2.21	393	91	3.15	392	89	3.04	449	122	3.79	514	120	3.17	437	123	3.93
119	485	245	5.54	499	241	5.43	478	245	5.32	529	241	5.32	550	234	5.16	654	244	4.83
120				482	197	5.21	500	207	5.25	586	202	4.75	586	226	5.06	532	190	4.87
121				467	305	6.28	534	281	5.90	544	276	5.84	537	296	6.00			
122				511	252	6.06	466	256	6.26	498	254	6.13	511	250	6.05	556	256	5.92
123				617	263	5.95	555	238	5.96	541	239	6.01	544	230	5.92	566	219	5.70
124				527	317	6.87	562	323	6.78	522	306	6.83	559	302	6.68	608	313	6.59
125				411	185	6.52	473	179	6.11	494	172	5.87	467	172	6.03	443	155	5.89
126	530	238	6.66	524	237	6.68	538	255	6.69	533	257	6.82	499	239	6.80	565	231	6.41
127				485	171	6.26	480	176	6.40	482	176	6.35	480	163	6.41	503	176	6.23
128	459	155	6.32	428	153	6.48	448	155	6.39	426	156	6.54	443	155	6.41	463	158	6.33
129				477	179	6.76	429	187	7.14	450	187	7.02	471	172	6.69	503	183	6.68
130	447	204	7.48	461	201	7.37	423	206	7.63	493	199	7.19	476	202	7.32	538	206	7.05
131				409	137	6.92	489	140	6.43	437	137	6.73	444	152	7.00			
132	428	152	7.30	450	167	7.40	417	150	7.33	443	153	7.22	334	152	7.91			
133	271	94	7.43	321	88	6.66	340	89	6.51				303	105	7.45			
134				370	201	8.71	309	205	9.04	376	206	8.73	361	201	8.75	432	206	8.45
135				329	133	8.30	314	132	8.41	318	132	8.32	316	127	8.29	361	133	8.08
136				315	133	8.68	319	132	8.67	305	131	8.76	319	129	8.61	369	132	8.29
137	265	42	4.98	282	40	4.20	264	41	4.87	265	42	4.93	256	42	5.17			
138										325	131	9.11	334	122	8.86	351	123	8.67
139				261	84	8.64				255	78	8.54	282	74	7.98	321	80	7.74
140										324	88	8.34	354	98	8.41	362	86	7.78
141										319	108	9.21	309	118	9.53	351	110	8.91
142										349	132	966.00	371	130	9.46	381	129	9.32
143										332	90	8.74	332	82	8.36	349	82	8.10
144										357	122	9.71	349	124	9.83	367	119	9.55
145										200	39	7.51	268	42	6.39	251	39	8.24
146										314	76	8.65	325	78	8.66	345	79	8.47
147										312	80	9.16	361	87	8.88	399	85	8.34
148	311	111	10.44							385	108	9.67	377	108	9.76	433	113	9.42
149										382	115	10.08	391	107	9.74	440	114	9.54
150													310	83	9.88	347	89	9.73
151	257	87	10.87	251	86	10.91				278	86	10.62	286	101	11.01	315	86	10.17
152				232	52	9.57				354	55	7.56	352	50	7.06	385	52	7.00
153	333	113	11.35										482	89	8.90	542	98	8.77
154										380	63	8.49	345	70	9.54	358	85	8.96
159	217	28	8.31	273	29	6.62				257	29	7.16	274	29	6.75	296	28	5.46
174	225	54	14.76	243	54	14.37				238	55	14.59	219	51	14.53	227	54	14.82

APPENDIX 3

Bed Volume Change Data 1964 - 1987

C.Section Number	Distance U/S (km)	Dist btwn C.S's (m)	C.S Area 1964	Rate of Vol change 64-70	Rate of Vol change Run Mean	C.S Area 1970	Rate of Vol change 70-75	Rate of Vol change Run Mean	C.S Area 1975	Rate of Vol change 75-81	Rate of Vol change Run Mean	C.S Area 1981	Rate of Vol change 81-87	Rate of Vol change Run Mean	C.S Area 1987	Rate of Vol change 64-87	Rate of Vol change Run Mean
14	14.16	310	518	-19917		729	-3000		813	-6250		783				-9971	
15	14.47	490	633	9750	-1679	661	-27500	-7875	607	7167	-2354	712				-2087	-3685
16	14.96	290	638	-6083	-1679	493	-16400	-7200	822	3000	-1617	631				-5826	-3201
17	15.25	470	678	9533	4400	896	15400	-5360	731	-13333	-4633	886				3142	-2893
17 A	15.72	490				633	-4500	860	644	1333	-12067	649				-1261	-5293
18	16.21	650				613	6200	360	647	-21333	-12783	626				-8435	-5645
19	16.86	560				617	3600	-5540	521	-30000	-9950	798				-14087	-7230
20	17.42	520	782	17583	1722	605	-18900	-4800	665	-583	-12483	748	-30333		1054	-7587	-8200
21	17.94	390	537	-1333	-1917	503	-14100	-6180	632	833	-9333	556	-6083		614	-4783	-7843
22	18.33	480	518	-11083	-3383	568	-800	-7840	580	-11333	-3817	646	-333	-11233	661	-6109	-6513
23	18.81	430	509	-12833	-8033	592	-700	-4700	588	-5583	-3772	658	-6500	-7639	647	-6652	-6094
24	19.24	560	498	-9250	-9367	569	-4700	-2380	580	-2417	-4924	577	-12917	-8028	666	-7435	-6190
25	19.80	1100	537	-5667	-8400	577	-3200	-3840	613	-361	-3319	645	-12361	-8986	711	-5493	-6120
26	20.90	670	689	-8000	-6217	717	-2500	-5520	713		-3903			-9090	777	-5261	-6059
26 A	21.57	1090	522	-6250	-6333	590	-8100	-7720	619	-4917	-4132	656	-4167	-8569	686	-5761	-6507
27 A	22.66	660	568	-1917	-7483	575	-9100	-10500	627	-7917	-6292	649	-6917	-6063	669	-6348	-7339
27	23.32	530	520	-9833	-7350	536	-15700	-13640	575	-3333	-8467	648	-10833	-5883	711	-9674	-8626
28	23.85	1170	451	-11417	-8017	553	-17100	-15360	671	-9000	-10483	638	-2333	-7267	705	-9652	-10061
29	25.02	440	640	-7333	-9250	675	-18200	-18460	728	-17167	-10983	869	-5167	-7600	830	-11696	-11274
29 A	25.46	410	512	-9583	-8700	565	-16700	-20480	694	-15000	-13333	759	-11083	-8533	860	-12935	-12426
30 A	25.87	600	588	-8083	-7083	650	-24600	-20400	688	-10417	-16500	803	-8583	-10033	835	-12413	-13204
30	26.47	450	553	-7083	-4733	588	-25800	-21980	796	-15083	-16033	806	-15500	-11250	877	-15435	-13103
31	26.92	780	611	-3333	-3450	661	-16700	-21260	711	-24833	-14617	882	-9833	-11306	997	-13543	-12046
31 A	27.70	860	596	4417	-3983	586	-26100	-14280	703	-14833	-14133	830				-11188	-10277
32	28.56	550	628	-3167	-3183	585	-13100	-8640	729	-7917	-13896	780				-7652	-7303
33	29.11	360	638	-10750	-3533	719	10300	-6800	706	-8000	-10618	750	-3500	-8917	742	-3565	-6497
34	29.47	370	693	-3083	-6033	741	2400	-1820	651		-9213					-565	-5207
35	29.84	250	621	-5083	-7517	610	-7500	-440	676	-11722	-7269	752	-13417	-9111	802	-9514	-5151
36	30.09	400	606	-8083	-10000	678	-1200	-1940	687		-7435			-9389		-4739	-6194
37	30.49	320	735	-10583	-13083	760	-6200	-1260	763	-2083	-10347	806	-10417	-6667	917	-7370	-7712
37 A	30.81	1060	533	-23167	-13117	635	2800	-3400	694	-8500	-9292	676	-4333	-2771	690	-8783	-7152
38	31.87	100	621	-18500	-12717	797	5800	-7800	710	-19083	-7583	830	1500	-3433	868	-8152	-7887
39	31.97	600	593	-5250	-11900	639	-18200	-8580	668	-7500	-8817	777	2167	-3317	721	-6717	-8135
40	32.57	650	626	-6083	-8133	643	-23200	-11540	796	-750	-9033	777	-6083	-4317	807	-8413	-8113
41	33.22	410	557	-6500	-4267	613	-10100	-16160	692	-8250	-5917	720	-9833	-7733	763	-8609	-8187
42	33.63	240	636	-4333	-4050	658	-12000	-15540	680	-9583	-5583	751	-9333	-11017	826	-8674	-8765
43	33.87	520	587	833	-5050	617	-17300	-13500	715	-3500	-6917	759	-15583	-9550	796	-8522	-8548
44	34.39	530	753	-4167	-5133	713	-15100	-14120	788	-5833	-6200	786	-14250	-8100	936	-9609	-8139
45	34.92	400	574	-11083	-4767	664	-13000	-15100	740	-7417	-6033	812	1250	-8817	833	-7326	-8400
46	35.32	370	555	-6917	-5450	598	-13200	-14840	652	-4667	-8167	669	-2583	-7233	633	-6565	-8665
47	35.69	200	557	-2500	-5767	597	-16900	-15060	675	-8750	-11317	714	-12917	-6417	781	-9978	-9404
48	35.89	780	657	-2583	-6350	647	-16000	-16680	738	-14167	-16850	804	-7667	-7583	892	-9848	-11657
49	36.67	840	697	-5750	-8367	738	-16200	-16880	807	-21583	-25500	911	-10167	-7467	915	-13304	-14452
50	37.51	530	726	-14000	-10633	754	-21100	-12560	847	-35083	-33017	1002	-4583	-7367	1120	-18587	-16039
51	38.04	80	443	-17000	-14750	583	-14200	-13340	701	-47917	-34900	967	-2000	-5833	904	-20543	-17374
52	38.12	420	803	-13833	-19083	867	4700	-21800	891	-46333	-28667	1200	-12417	-1217	1287	-17913	-17513
53	38.54	570	750	-23167	-21583	852	-19900	-22060	781	-23583	-19367	1028	0	333	1090	-16522	-15391
55	39.11	820	666	-27417	-19917	842	-58500	-21280	1112	9583	-9000	1148	12917	-1283	1086	-14000	-12504
56	39.93	630	619	-26500	-15817	772	-22400	-30580	1087	11417	1400	936	3167	-117	843	-7978	-10439
57	40.56	1190	663	-8667	-14300	828	-10300	-29260	737	3917	6183	751	-10083	-4583	806	-6109	-9674
58	41.75	340	625	6667	-16583	564	-41800	-9560	758	5667	5333	697	-6583	-8958	763	-7587	-7448
58 A	42.09	290	604	-15583	-17017	585	-13300	3200	809	333	-3396	802	-22333	-16229	815	-12696	-8126
59	42.38	230	894	-38833	-19117	1100	40000	9760	1009		-8875			-15625		-2870	-8265
60	42.61	560	721	-28667	-24067	981	41400	18760	672	-23500	-13708	854	-25917	-14250	1109	-11370	-8322
60 A	43.17	810	669	-19167	-20700	753	22500	17880	648	-18000	-16771	748	-7667	-7979	804	-6804	-6965
61 A	43.98	700	729	-18083	-13083	875	3200	10440	755	-13667	-15900	871	-1083	-7517	907	-7870	-7252
61	44.68	770	576	1250	-12067	647	-17700	12167	735	-11917	-12050	783	2750	-6250	760	-5913	-5277
62	45.45	740	601	-750	-12900	515	2800	9583	604	-12417	-10563	699	-5667	-5896	689	-4304	-8785
62 A	46.19	210	543	-23583	-11500	638	50033	18008	521	-4250	-9083	575	-19583	-9250	653	-1493	-7346
63	46.40	210	810	-23333	-12883	998		26733			-7229			-10313		-24348	-6025
64	46.61	390	641	-11083	-13750	733	36900	34711	558	-7750	-5500	555	-14500	-8896	712	-674	-6225
64 A	47.00	560	698	-5667	-10533	739	17200	12333	545	-4500	-1194	641	-1500	-5792	658	696	-6983
65	47.56	310	684	-5083	-6400	711		5325			1021			-9396		-5304	-3287
66	47.87	440	622	-7500	-5550	656	-17100	-5000	687	8667	5542	645	-7167	-4979	646	-5283	-2996
66 A	48.31	460	480	-2667	-5933	536	-15700	-8800	676	7667	8889	614	-14417	-6139	699	-5870	-3752
67	48.77	220	750	-6833	-4117	726	-4400	-7220	743	10333	3813	713	3167	-6139	801	783	-3259
68	48.99	430	759	-7583	-1483	865	2000	-4380	892		-1563					-3087	-2870
69	49.42	210	732	4000	-1250	717	-900	-620	670	-11417	-7375	759				-2841	-1770
69 A	49.63	180	565	5667	-1867	532	-2900	220	588	-12833	-11250	636		4917		-3333	-2635
70	49.81	720	638	-1500	-1000	603	3100	-1040	576	-15583	-8083	682	13083	1639	556	-370	-2648
71	50.53	470	512	-9917	-2583	565	-200	-2060	561	-5167	-5833	642	1667	222	611	-3543	-2775
71 A	51.00	340	587	-3250	-6883	653	-4300	-800	659	4583	-6250	640	-9833	2583	651	-3152	-2926
72	51.34	440	682	-3917	-7400	655	-6000	-1840	692	-167	-6567	656	-4250	267	3.15	-3478	-3974
72 A	51.78	650	543	-15833	-4583	617	3400	-2300	640	-14917	-8733	678	12250	-356	622	-4087	-4067
73 A	52.43	820	516	-4083	-4767	632	-2100	1600	575	-17167	-12850	716	1500	2014	625	-5609	-3958
73	53.25	310	526	4167	-5767	459	-2500	7180	537	-16000	-14600	602	-1445	1160	675	-4007	-3641
74	53.56	350	638	-4167	-4400	655	15200	11320	602	-16000	-15900	729		-2278		-2609	-3441
75	53.91	270	561	-8917	-3483	594	21900	12920	495	-8917	-17567	560	-7667	-2569	603	-1891	-3349
76	54.18	260	574	-9000	-2400	648	24100	10100	528	-21417	-15783	570	-1500	-4056	619	-3087	-3525
77	54.44	290	518	500	1150	552	5900	4360	431	-25500	-13200	646	333	-4056	615	-5152	-3055
78	54.73	360	533	9583	4050	493	-16600	-960	555	-7083	-12100	646	-7389	-4306	673	-4884	-3220
79	55.09	260	552	13583	4100	477	-13500	-4380	581	-3083	-7667	575		-8868		-261	-3746
80	55.35	220	604	5583	1600	516	-4700	-3700	547	-3417	-1467	590	-8667	-15743	623	-2717	-4068
81	55.57	290	490	-8750	-2483	511	7000	220	527	750	1906	525	-19750	-20958	596	-5717	-4490
82	55.86	210	520	-12000	-6150	604	9300	1560	518	5500	3153	511	-27167	-20958	677	-6761	-5525
83	56.07	120	505	-10833	-5600	565	3000	-1640	558	9778	4799	499	-28250	-23625	659	-6993	-6290
84	56.19	120	593	-4750	-2150	663	-6800	-5500	640		4007			-21250		-5435	-5899
85	56.31	190	598	8333	1033	585	-20700	-8400	676	3167	632	633	-19333	-13958	812	-6543	-4881
86	56.50	290	545	8500	3517	458	-12300	-10460	574	-2417	-2292	579	-10250	-8271	632	-3761	-4104
87	56.79	200	525	3917	4900	510	-5200	-10920	517	-8000	-683	541	2000	-11450	611	-1674	-4261
88	56.99	390	493	1583	5017	461	-7300	-9980	506	-1917	-433	578	-5500	-8083	484	-3109	-3083
89	57.38	250	554	2167	3633	567	-9100	-9300	595	5750	100	546	-24167	-7542	706	-6217	-2719
90	57.63	130	515	8917	2850	476	-16000	-8520	539	4417	1117	519	-2500	-6938	649	-652	-2362
91	57.76	410	546	1583	1150	478	-8900	-7480	575	250	1500	542		-6813		-1942	-2454
92	58.17	320	473	0	-1783	522	-1300	-6100	514	-2917	500	544	4417	-2104	451	109	-2197
93	58.49	360	511	-6917	-2867	462	-2100	-4540	483	0	-933	488	-5000	-3271	528	-3565	-2758
94	58.85	20	427	-12500	-5333	559	-2200	-2000	559	750	-1417	554	-5333	-2517	574	-4935	-2852
95	58.87	30	499	3500	-11300	517	-8200	1900	539	-2750	-1042	535	-7167	-4250	579	-3457	-4404
96	58.90	470	669	-10750	-13133	609	3800	2580	669	-2167	-2271	706	500	-833	748	-2413	-4278
97	59.37	230	597	-29833	-10700	786	18200	2300	688		-1792			859		-7652	-3251
98	59.60	250	379	-16083	-10367	548	1300	3840	464	-4917	333	534	8667	3534	486	-2935	-1829
99	59.85	260	485	-333	-7167	509	-3600	-460	580	2667	2854	569	1436	1451	513	201	-1729
100	60.11	220	643	5167	-2167	623	-500	-6260	588	5750	3872	567		296		3652	-671
101	60.33	450	537	5250	-1450	495	-17700	-7000	535	7917	6069	487	-5750	-2494	559	-1913	-1598
102	60.78	200	518	-4833	-4000	497	-10800	-9380	634	7945	11299	587	-3167	-7472	584	-2362	-2468
103	60.98	250	462	-12500	-8333	541	-2400	-12600	512		17069			-10188		-7565	-4233
104	61.23	100	478	-13083	-11667	549	-15500	-9740	602	23583	18028	483	-13500	-10563	524	-4152	-4359
105	61.33	170	433	-16500	-12683	519	-16600	-5620	621	28833	14167	457	-18333	-10917	578	-5174	-4609

Bed Volume Change Data 1964 - 1987

C.Section Number	Distance U/S (km)	Dist btwn C.S's (m)	C.S Area 1964	Rate of Vol change 64-70	Run Mean	C.S Area 1970	Rate of Vol change 70-75	Run Mean	C.S Area 1975	Rate of Vol change 75-81	Run Mean	C.S Area 1981	Rate of Vol change 81-87	Run Mean	C.S Area 1987	Rate of Vol change 64-87	Run Mean
106	61.50	510	463	-11417	13383	575	-3400	-5080	639	11750	12133	457	-7250	-11117	556	-2543	4330
106 A	62.01	490	451	-9917	-13133	476	9800	-2700	446	-7500	8983	487	-4583	-10900	475	-3609	4513
107	62.50	550	431	-16000	-10717	525	300	920	457	4000	3717	506	-11917	-10283	573	-6174	-4309
108	63.05	490	476	-11833	-9283	574	-3600	920	639	7833	2233	542	-12417	-8361	618	-5065	3820
108 A	63.54	590	417	-4417	-8983	461	1500	-440	432	2500	2733	435	-15250	-9306	508	-4152	-3858
109 A	64.13	390	444	-4250	-7283	453	-3400	-20	467	4333	1250	434	2361	-4931	544	-101	2797
109	64.52	430	458	-8417	-5283	500	3000	-940	520	-5000	1383	501		-4514		-3797	-2354
110 A	64.95	500	389	-7500	-4533	448	2400	-3360	398	-3417	3233	477	5583	-935	369	-870	-1367
110	65.45	230	500	-1833	-5350	531	-8200	-3720	557	8500	5583	519	-10750	-6306	560	-2848	-1885
110 C	65.68	230	489	-667	-3217	480	-10600	-1300	536	11750	8000	472				783	399
110 D	65.91	200	561	-8333	950	578	-5200	2500	628	16083	6483	551	-13750	-14324	597	-2696	1975
110 E	66.11	230	492	2250	2567	575	15100	3980	577	7083	3500	461				7623	1538
110 F	66.34	140	747	13333	3267	637	21400	4400	484	-11000	2350	515				7014	1503
111	66.48	260	525	6250	4250	475	-800	5200	414	-6417	-150	515	-18472	-16759	589	-5036	1057
111 A	66.74	210	468	2833	1683	443	-8500	2960	512	6000	-1667	488				609	1013
111 B	66.95	230	465	-3417	-4133	456	-1200	0	472	3583	1317	424	-18056	-21329	584	-4927	4179
111 C	67.18	300	452	-10583	-6933	502	3900	420	498	-500	4533	503				-2725	2963
111 D	67.48	160	475	-15750	-7617	552	6600	1660	517	3917	4733	518	-27458	-25060	596	-8815	2850
111 E	67.64	160	454	-7750	-7900	566	1300	2060	535	9667	4750	487				1043	3438
111F	67.80	210	549	-583	-6600	530	-2300	1240	548	7000	5333	480				1174	3698
112	68.01	1090	469	-4833	-4033	495	800	-4820	500	3667	6550	484	-29667	-18122	718	-7870	2688
113	69.10	1530	501	-4083	-4450	533	-200	-8120	520	2417	5600	492	-13583	-15009	614	-4022	-4120
114	70.63	1710	538	-2917	-4717	555	-23700	-7680	570	10000	2017	569	-1778	-12215	610	-3768	5229
115	72.34	820	476	-9833	-2450	494	-15200	-10400	716	4917	-983	597		-3986		-6116	-4294
116	73.16	1320	452	-1917	-1267	552	-100	-12520	482	-10917	-2900	542	-3833	-1153	550	-4370	4355
117	74.48	470	578	6500	-633	501	-12800	-10520	572	-11333	-5250	643	3250	-1750	681	-3196	-4493
118	74.95	390	393	1833	-83	392	-10800	-9400	449	-7167	-6117	514	-2250	-1378	437	-4326	-4020
119	75.34	980	499	250	-67	478	-13700	-10220	529	-1750	-4033	550	-4167	-764	654	-4457	-3552
120	76.32	1090	482	-7083	417	500	-9600	-8020	586	583	-2033	586	111	-2972	532	-3754	-2887
121	77.41	2080	467	-1833	500	534	-4200	-4780	544	-500	-1267	537		-3889		-2029	-2152
122	79.49	1360	511	8917	-1167	466	-1800	-1660	498	-1333	-1083	511	-5583	-3368	556	130	-1752
123	80.85	2630	617	2250	-1017	555	5400	-60	541	-3333	-183	544	-5917	-4271	566	-652	-1319
124	83.48	650	527	-8083	-800	562	1900	840	522	-833	517	559	-2083	-4900	608	-2457	-1170
125	84.13	1330	411	-6333	-2833	473	-1600	1600	494	5083	533	467	-3500	-4500	443	-1587	-1426
126	85.46	1630	524	-750	-2817	538	300	540	533	3000	567	499	-7417	-4183	565	-1283	-1561
127	87.09	1310	485	-1250	233	480	2000	-1660	482	-1250	667	480	-3583	-5333	503	-1152	-1517
128	88.40	1050	428	2333	800	448	100	-1700	426	-3167	-183	443	-4333	-8013	463	-1326	-2299
129	89.45	1840	477	7167	167	429	-9100	-1240	450	-333	917	471	-7833	-8162	503	-2239	-1573
130	91.29	1940	461	-3500	650	423	-1800	-3807	493	833	3728	476	-16900	-9689	538	-5496	-999
131	93.23	1220	409	-3917	883	489	2600	-4783	437	8500	5451	444		-9683		2348	-3
132	94.45	1430	450	1167	717	417	-10833	-4283	443	12806	5889	334		-9330		1720	36
133	95.88	1660	321	3500	1600	340		-3583			5431	303		-10579		3652	761
134	97.54	1610	370	6333	2617	309	-7100	-3908	376	1417	3201	361	-9667	-9028	432	-2043	-108
135	99.15	2210	329	917	2979	314	1000	-1600	318	-1000	0	316	-7917	-6771	361	-1870	-452
136	101.36	1300	315	1167		319	1300		305	-417	-600	319	-9500	-7938	369	-2000	-1983
137	102.66	1370	282			264			265	0	-1833	256		-6500		0	-2478
138	104.03	1210							325	-3000	-1967	334	-4667	-5563	351	-4000	-2713
139	105.24	1270	261						255	-4750	-2083	282	-3917	-4271	321	-4522	-2870
140	106.51	770							324	-1667	-2450	354	-4167	-3867	362	-3043	-3296
141	107.28	840							319	-1000	-1717	309	-4333	-3517	351	-2783	-2730
142	108.12	640							349	-1833	-1767	371	-2250	-2750	381	-2130	-2357
143	108.76	1350							332	667	-2750	332	-2917	-1967	349	-1174	-2461
144	110.11	420							357	-5000	-3550	349	-83	-2067	367	-2652	-2930
145	110.53	640							200	-6583	-3867	268	-250	-3183	251	-3565	-3678
146	111.17	1260							314	-5000	-4017	325	-4833	-4350	345	-5130	-4365
147	112.43	1090							312	-3417	-2983	361	-7833	-5767	399	-5870	-4565
148	113.52	790							385	-83	-2083	377	-8750	-6817	433	-4609	-5000
149	114.31	1030							382	167	-958	391	-7167	-6883	440	-3652	-4565
150	115.34	930									-1187	310	-5500	-6867	347	-5739	-4652
151	116.27	990	251						278	-500	-1556	286	-5167	-6333	315	-2957	-5000
152	117.26	1110	232						354	-4333	-1111	352	-7750	-5483	385	-6304	-4417
153	118.37	840									-792	482	-6083	-4883	542	-6348	-3513
154	119.21	7120							380	1500	-889	345	-2917	-4813	358	-739	-3652
159	126.33	15440	273						257	167		274	-2500		296	-1217	
174	141.77		243						238			219			227		

N.B : CROSS SECTIONAL AREA IN SQUARE METRES

RATE OF VOLUME CHANGE IN CUBIC METRES PER KILOMETRE RIVER LENGTH PER YEAR

APPENDIX 4

Bedload Transport Formulae Results

				RANGIRIRI						RANGIRIRI			
Discharge Cumecs	Velocity (m/s)	Depth (m)	Hydraulic Radius (m)	Slope	K/K'	Meyer-Peter Muller (kg/s/m)	To (N/m2)	Engeland Hansen (kg/s/m)	Einstein Y	Einstein Ø	Einstein gs (kg/s/m)	U*	R*
200	0.587	1.650	1.630	0.0001411	0.550	0.1065	2.254	0.279	4.939	0.655	1.332	0.0475	32.47
220	0.605	1.739	1.720	0.0001404	0.562	0.1395	2.368	0.319	4.702	0.745	1.516	0.0487	33.28
240	0.622	1.825	1.807	0.0001398	0.574	0.1759	2.477	0.361	4.495	0.835	1.698	0.0498	34.03
260	0.638	1.908	1.891	0.0001393	0.586	0.2157	2.581	0.404	4.313	0.922	1.876	0.0508	34.74
280	0.653	1.988	1.972	0.0001387	0.598	0.2590	2.681	0.448	4.152	1.008	2.049	0.0518	35.42
300	0.667	2.066	2.050	0.0001383	0.610	0.3058	2.779	0.494	4.006	1.091	2.219	0.0527	36.05
320	0.681	2.141	2.127	0.0001378	0.622	0.3560	2.873	0.541	3.875	1.172	2.384	0.0536	36.66
340	0.694	2.214	2.201	0.0001374	0.634	0.4097	2.964	0.589	3.756	1.251	2.546	0.0545	37.23
360	0.707	2.285	2.273	0.0001370	0.646	0.4670	3.053	0.639	3.647	1.329	2.702	0.0553	37.79
380	0.719	2.355	2.344	0.0001366	0.658	0.5279	3.139	0.689	3.546	1.404	2.855	0.0561	38.32
400	0.731	2.423	2.413	0.0001363	0.670	0.5925	3.223	0.741	3.454	1.477	3.004	0.0568	38.83
420	0.743	2.489	2.481	0.0001359	0.682	0.6609	3.305	0.793	3.368	1.548	3.148	0.0575	39.32
440	0.754	2.554	2.547	0.0001356	0.694	0.7331	3.386	0.847	3.288	1.617	3.289	0.0582	39.79
460	0.764	2.618	2.612	0.0001353	0.706	0.8092	3.464	0.902	3.214	1.684	3.426	0.0589	40.25
480	0.775	2.681	2.676	0.0001350	0.718	0.8892	3.541	0.958	3.144	1.750	3.560	0.0595	40.70
500	0.785	2.742	2.738	0.0001348	0.730	0.9733	3.616	1.014	3.078	1.814	3.690	0.0602	41.13
520	0.795	2.802	2.800	0.0001345	0.742	1.0614	3.690	1.072	3.017	1.876	3.816	0.0608	41.55
540	0.804	2.861	2.860	0.0001342	0.754	1.1537	3.763	1.130	2.958	1.937	3.940	0.0614	41.95
560	0.813	2.920	2.919	0.0001340	0.766	1.2503	3.834	1.190	2.903	1.996	4.061	0.0619	42.35
580	0.823	2.977	2.978	0.0001338	0.778	1.3512	3.904	1.250	2.851	2.054	4.178	0.0625	42.73
600	0.831	3.033	3.036	0.0001335	0.790	1.4565	3.973	1.311	2.802	2.110	4.293	0.0631	43.11
620	0.840	3.089	3.093	0.0001333	0.802	1.5662	4.041	1.373	2.755	2.166	4.405	0.0636	43.48
640	0.849	3.144	3.149	0.0001331	0.814	1.6806	4.108	1.436	2.710	2.219	4.514	0.0641	43.83
660	0.857	3.198	3.204	0.0001329	0.826	1.7995	4.173	1.500	2.667	2.272	4.621	0.0646	44.18
680	0.865	3.251	3.259	0.0001327	0.838	1.9231	4.238	1.564	2.627	2.323	4.725	0.0651	44.52
700	0.873	3.304	3.313	0.0001325	0.850	2.0515	4.302	1.629	2.588	2.373	4.827	0.0656	44.86
720	0.881	3.356	3.366	0.0001323	0.862	2.1848	4.365	1.695	2.550	2.422	4.927	0.0661	45.19
740	0.889	3.407	3.418	0.0001321	0.874	2.3230	4.427	1.762	2.515	2.470	5.024	0.0666	45.51
760	0.896	3.458	3.470	0.0001320	0.886	2.4662	4.488	1.829	2.480	2.517	5.120	0.0670	45.82
780	0.904	3.508	3.522	0.0001318	0.898	2.6145	4.549	1.897	2.447	2.563	5.213	0.0675	46.13
800	0.911	3.558	3.573	0.0001316	0.910	2.7680	4.609	1.966	2.415	2.608	5.305	0.0679	46.43
820	0.918	3.607	3.623	0.0001315	0.922	2.9268		2.036	2.385	2.652	5.394	0.0684	46.73
840	0.925	3.655	3.673	0.0001313	0.934	3.0908	4.726	2.106	2.355	2.695	5.482	0.0688	47.02
860	0.932	3.703	3.722	0.0001311	0.946	3.2603	4.784	2.177	2.327	2.738	5.568	0.0692	47.30
880	0.939	3.751	3.771	0.0001310	0.958	3.4352	4.841	2.249	2.300	2.779	5.653	0.0696	47.59
900	0.946	3.798	3.819	0.0001308	0.970	3.6157	4.898	2.321	2.273	2.820	5.735	0.0700	47.86
920	0.952	3.844	3.867	0.0001307	0.982	3.8019	4.953	2.394	2.247	2.860	5.816	0.0704	48.13
940	0.959	3.891	3.914	0.0001306	0.994	3.9938	5.009	2.467	2.223	2.899	5.896	0.0708	48.40
960	0.965	3.936	3.961	0.0001304	1.000	4.1291	5.063	2.542	2.199	2.937	5.974	0.0712	48.67
980	0.971	3.981	4.008	0.0001303	1.000	4.2031	5.118	2.617	2.175	2.975	6.051	0.0716	48.93
1000	0.978	4.026	4.054	0.0001302	1.000	4.2769	5.171	2.692	2.153	3.012	6.126	0.0719	49.18
1020	0.984	4.071	4.099	0.0001300	1.000	4.3504	5.224	2.768	2.131	3.048	6.200	0.0723	49.43
1040	0.990	4.115	4.145	0.0001299	1.000	4.4237	5.277	2.845	2.110	3.084	6.272	0.0727	49.68
1060	0.996	4.158	4.190	0.0001298	1.000	4.4966	5.329	2.922	2.089	3.119	6.343	0.0730	49.93
1080	1.002	4.202	4.234	0.0001297	1.000	4.5693	5.381	3.000	2.069	3.153	6.414	0.0734	50.17
1100	1.008	4.245	4.278	0.0001295	1.000	4.6417	5.432	3.079	2.050	3.187	6.482	0.0737	50.41
1120	1.014	4.287	4.322	0.0001294	1.000	4.7138	5.483	3.158	2.031	3.220	6.550	0.0741	50.64
1140	1.019	4.330	4.366	0.0001293	1.000	4.7857	5.533	3.238	2.012	3.253	6.617	0.0744	50.87
1160	1.025	4.372	4.409	0.0001292	1.000	4.8573	5.583	3.318	1.994	3.285	6.682	0.0748	51.10
1180	1.030	4.413	4.452	0.0001291	1.000	4.9287	5.632	3.399	1.977	3.317	6.747	0.0751	51.33
1200	1.036	4.454	4.494	0.0001290	1.000	4.9999	5.681	3.480	1.960	3.348	6.810	0.0754	51.55
1220	1.041	4.495	4.537	0.0001289	1.000	5.0708	5.730	3.562	1.943	3.379	6.872	0.0757	51.77
1120	1.014	4.287	4.322	0.0001294	1.000	4.7138	5.483	3.158	2.031	3.220	6.550	0.0741	50.64
1140	1.019	4.330	4.366	0.0001293	1.000	4.7857	5.533	3.238	2.012	3.253	6.617	0.0744	50.87
1160	1.025	4.372	4.409	0.0001292	1.000	4.8573	5.583	3.318	1.994	3.285	6.682	0.0748	51.10
1180	1.030	4.413	4.452	0.0001291	1.000	4.9287	5.632	3.399	1.977	3.317	6.747	0.0751	51.33
1200	1.036	4.454	4.494	0.0001290	1.000	4.9999	5.681	3.480	1.960	3.348	6.810	0.0754	51.55
1220	1.041	4.495	4.537	0.0001289	1.000	5.0708	5.730	3.562	1.943	3.379	6.872	0.0757	51.77
1240	1.047	4.536	4.579	0.0001288	1.000	5.1414	5.778	3.645	1.927	3.409	6.934	0.0760	51.99
1260	1.052	4.577	4.620	0.0001287	1.000	5.2119	5.826	3.728	1.911	3.439	6.994	0.0764	52.20
1280	1.057	4.617	4.662	0.0001285	1.000	5.2821	5.874	3.811	1.895	3.468	7.054	0.0767	52.41
1300	1.063	4.657	4.703	0.0001284	1.000	5.3521	5.921	3.895	1.880	3.497	7.112	0.0770	52.62
1320	1.068	4.696	4.744	0.0001284	1.000	5.4219	5.967	3.980	1.866	3.525	7.170	0.0773	52.83
1340	1.073	4.735	4.784	0.0001283	1.000	5.4915	6.014	4.065	1.851	3.553	7.227	0.0776	53.04
1360	1.078	4.775	4.825	0.0001282	1.000	5.5608	6.060	4.151	1.837	3.580	7.283	0.0779	53.24
1380	1.083	4.813	4.865	0.0001281	1.000	5.6300	6.106	4.237	1.823	3.608	7.338	0.0782	53.44
1400	1.088	4.852	4.904	0.0001280	1.000	5.6990	6.151	4.324	1.810	3.634	7.392	0.0785	53.64
1420	1.093	4.890	4.944	0.0001279	1.000	5.7677	6.197	4.411	1.797	3.661	7.446	0.0788	53.84
1440	1.098	4.928	4.983	0.0001278	1.000	5.8363	6.241	4.499	1.784	3.687	7.499	0.0790	54.03
1460	1.102	4.966	5.022	0.0001277	1.000	5.9047	6.286	4.587	1.771	3.712	7.551	0.0793	54.22
1480	1.107	5.004	5.061	0.0001276	1.000	5.9728	6.330	4.676	1.759	3.738	7.602	0.0796	54.41
1500	1.112	5.041	5.100	0.0001275	1.000		6.374	4.765	1.746	3.762	7.653	0.0799	54.60
1520	1.117	5.078	5.138	0.0001274	1.000	6.1087	6.418	4.855	1.735	3.787	7.703	0.0801	54.79
1540	1.121	5.115	5.176	0.0001274	1.000	6.1763	6.461	4.945	1.723	3.811	7.752	0.0804	54.98
1560	1.126	5.152	5.214	0.0001273	1.000	6.2437	6.505	5.036	1.711	3.835	7.801	0.0807	55.16
1580	1.130	5.188	5.252	0.0001272	1.000	6.3110	6.547	5.127	1.700	3.859	7.849	0.0810	55.34

				MERCER						MERCER			
Discharge Cumecs	Velocity (m/s)	Depth (m)	Hydraulic Radius (m)	Slope	K/K'	Meyer-Peter Muller (kg/s/m)	To (N/m2)	Engeland Hansen (kg/s/m)	Einstein Y	Einstein Ø	Einstein gs (kg/s/m)	U*	R*
200	0.454	3.906	3.816	0.0000777	0.550	0.2297	2.905	0.244	3.833	1.406	2.788	0.0539	36.86
220	0.480	4.027	3.934	0.0000791	0.562	0.2838	3.050	0.294	3.650	1.493	2.959	0.0553	37.77
240	0.505	4.140	4.044	0.0000805	0.574	0.3426	3.189	0.348	3.491	1.577	3.125	0.0565	38.62
260	0.530	4.247	4.149	0.0000817	0.586	0.4061	3.323	0.407	3.350	1.658	3.286	0.0577	39.42
280	0.554	4.349	4.248	0.0000829	0.598	0.4744	3.452	0.471	3.225	1.736	3.442	0.0588	40.18
300	0.577	4.446	4.343	0.0000840	0.610	0.5474	3.576	0.538	3.113	1.813	3.594	0.0598	40.90
320	0.599	4.539	4.433	0.0000851	0.622	0.6253	3.696	0.611	3.012	1.888	3.742	0.0608	41.58
340	0.621	4.628	4.520	0.0000861	0.634	0.7083	3.813	0.687	2.920	1.961	3.887	0.0618	42.23
360	0.642	4.713	4.603	0.0000870	0.646	0.7962	3.926	0.768	2.835	2.032	4.029	0.0627	42.85
380	0.663	4.796	4.683	0.0000879	0.658	0.8894	4.037	0.854	2.758	2.102	4.167	0.0636	43.45
400	0.684	4.875	4.760	0.0000888	0.670	0.9878	4.144	0.944	2.686	2.171	4.303	0.0644	44.03
420	0.704	4.952	4.835	0.0000897	0.682	1.0915	4.249	1.038	2.620	2.238	4.437	0.0652	44.58
440	0.723	5.026	4.907	0.0000905	0.694	1.2007	4.352	1.137	2.558	2.305	4.568	0.0660	45.12
460	0.742	5.098	4.978	0.0000913	0.706	1.3155	4.452	1.240	2.500	2.370	4.697	0.0668	45.63
480	0.761	5.168	5.046	0.0000920	0.718	1.4360	4.550	1.347	2.446	2.434	4.824	0.0675	46.14
500	0.780	5.235	5.112	0.0000927	0.730	1.5622	4.647	1.459	2.396	2.497	4.949	0.0682	46.62
520	0.798	5.302	5.176	0.0000935	0.742	1.6943	4.741	1.575	2.348	2.559	5.072	0.0689	47.09
540	0.816	5.366	5.239	0.0000941	0.754	1.8325	4.834	1.695	2.303	2.620	5.193	0.0696	47.55
560	0.834	5.429	5.300	0.0000948	0.766	1.9767	4.925	1.820	2.261	2.680	5.313	0.0702	48.00
580	0.851	5.490	5.360	0.0000955	0.778	2.1272	5.014	1.949	2.220	2.740	5.431	0.0708	48.43
600	0.869	5.550	5.418	0.0000961	0.790	2.2839	5.102	2.082	2.182	2.799	5.548	0.0715	48.85
620	0.886	5.608	5.475	0.0000967	0.802	2.4472	5.189	2.220	2.146	2.857	5.663	0.0721	49.26
500	0.780	5.235	5.112	0.0000927	0.730	1.5622	4.647	1.459	2.396	2.497	4.949	0.0682	46.62
520	0.798	5.302	5.176	0.0000935	0.742	1.6943	4.741	1.575	2.348	2.559	5.072	0.0689	47.09
540	0.816	5.366	5.239	0.0000941	0.754	1.8325	4.834	1.695	2.303	2.620	5.193	0.0696	47.55
560	0.834	5.429	5.300	0.0000948	0.766	1.9767	4.925	1.820	2.261	2.680	5.313	0.0702	48.00
580	0.851	5.490	5.360	0.0000955	0.778	2.1272	5.014	1.949	2.220	2.740	5.431	0.0708	48.43
600	0.869	5.550	5.418	0.0000961	0.790	2.2839	5.102	2.082	2.182	2.799	5.548	0.0715	48.85
620	0.886	5.608	5.475	0.0000967	0.802	2.4472	5.189	2.220	2.146	2.857	5.663	0.0721	49.26

Bedload Transport Formulae Results

Discharge Cumecs	Velocity (m/s)	Depth (m)	Hydraulic Radius (m)	MERCER Slope	K/K'	Meyer-Peter Muller (kg/s/m)	To (N/m2)	Engeland ~~Hansen~~ (kg/s/m)	Einstein Y	MERCER Einstein Ø	Einstein gs (kg/s/m)	U*	R*
640	0.902	5.666	5.531	0.0000973	0.814	2.6169	5.274	2.362	2.111	2.914	5.777	0.0727	67
660	0.919	5.722	5.585	0.0000979	0.826	2.7934	5.358	2.508	2.078	2.971	5.889	0.0732	.06
680	0.935	5.776	5.639	0.0000984	0.838	2.9766	5.440	2.658	2.046	3.027	6.000	0.0738	.45
700	0.951	5.830	5.691	0.0000990	0.850	3.1667	5.522	2.813	2.016	3.083	6.110	0.0743	0.82
720	0.967	5.883	5.742	0.0000995	0.862	3.3638	5.602	2.972	1.987	3.137	6.219	0.0749	1.19
740	0.983	5.935	5.793	0.0001001	0.874	3.5681	5.681	3.135	1.959	3.192	6.327	0.0754	51.55
760	0.999	5.986	5.842	0.0001006	0.886	3.7795	5.760	3.303	1.933	3.246	6.433	0.0759	1.90
780	1.014	6.036	5.891	0.0001011	0.898	3.9983	5.837	3.475	1.907	3.299	6.539	0.0764	2.25
800	1.030	6.085	5.939	0.0001016	0.910	4.2246	5.913	3.651	1.883	3.352	6.643	0.0769	2.59
820	1.045	6.133	5.986	0.0001021	1.000	5.4534	5.989	3.831	1.859	3.404	6.747	0.0774	2.93
840	1.060	6.180	6.032	0.0001026	1.000	5.5652	6.063	4.015	1.836	3.456	6.849	0.0779	3.25
860	1.075	6.[illegible]7	6.077	0.0001030	1.000	5.6765	6.137	4.204	1.814	3.507	6.951	0.0784	3.58
880	1.089	6.[illegible]3	6.122	0.0001035	1.000	5.7872	6.209	4.397	1.793	3.558	7.052	0.0788	53.89
900	1.104	6.318	6.166	0.0001039	1.000	5.8974	6.281	4.594	1.772	3.608	7.152	0.0793	54.20
920	1.118	6.363	6.210	0.0001044	1.000	6.0072	6.353	4.795	1.752	3.658	7.251	0.0797	54.51
940	1.133	6.407	6.252	0.0001048	1.000	6.1164	6.423	5.001	1.733	3.708	7.349	0.0802	54.81
960	1.147	6.450	6.295	0.0001052	1.000	6.2251	6.493	5.210	1.715	3.757	7.447	0.0806	55.11
980	1.161	6.493	6.336	0.0001057	1.000	6.3334	6.562	5.424	1.697	3.806	7.544	0.0810	55.40
1000	1.175	6.535	6.377	0.0001061	1.000	6.4412	6.630	5.643	1.679	3.854	7.640	0.0815	55.69
1020	1.189	6.576	6.418	0.0001065	1.000	6.5485	6.698	5.865	1.662	3.902	7.735	0.0819	55.97
1040	1.202	6.617	6.457	0.0001069	1.000	6.6555	6.765	6.091	1.646	3.950	7.830	0.0823	56.25
1060	1.216	6.658	6.497	0.0001073	1.000	6.7620	6.831	6.322	1.630	3.998	7.924	0.0827	56.53
1080	1.229	6.697	6.536	0.0001077	1.000	6.8680	6.897	6.557	1.614	4.045	8.017	0.0831	56.80
1100	1.243	6.737	6.574	0.0001081	1.000	6.9737	6.962	6.796	1.599	4.091	8.110	0.0835	57.07
1120	1.256	6.776	6.612	0.0001084	1.000	7.0789	7.027	7.039	1.584	4.138	8.202	0.0839	57.33
1140	1.269	6.814	6.649	0.0001088	1.000	7.1838	7.091	7.286	1.570	4.184	8.293	0.0842	57.59
1160	1.283	6.852	6.686	0.0001092	1.000	7.2883	7.154	7.538	1.556	4.230	8.384	0.0846	57.85
1180	1.296	6.890	6.723	0.0001095	1.000	7.3924	7.217	7.794	1.542	4.275	8.474	0.0850	58.10
1200	1.308	6.927	6.759	0.0001099	1.000	7.4961	7.280	8.054	1.529	4.321	8.564	0.0854	58.35
1220	1.321	6.964	6.795	0.0001102	1.000	7.5995	7.342	8.318	1.516	4.366	8.653	0.0857	58.60
1240	1.334	7.000	6.830	0.0001106	1.000	7.7025	7.403	8.586	1.504	4.410	8.742	0.0861	58.85
1260	1.347	7.036	6.865	0.0001109	1.000	7.8051	7.464	8.858	1.491	4.455	8.830	0.0864	59.09
1280	1.359	7.071	6.900	0.0001113	1.000	7.9074	7.525	9.134	1.479	4.499	8.917	0.0868	59.33
1300	1.372	7.107	6.934	0.0001116	1.000	8.0094	7.585	9.415	1.468	4.543	9.004	0.0871	59.56
1320	1.384	7.141	6.968	0.0001119	1.000	8.1110	7.644	9.700	1.456	4.586	9.091	0.0875	59.80
1340	1.397	7.176	7.001	0.0001123	1.000	8.2123	7.704	9.989	1.445	4.630	9.177	0.0878	60.03
1360	1.409	7.210	7.035	0.0001126	1.000	8.3133	7.762	10.282	1.434	4.673	9.263	0.0881	60.26
1380	1.421	7.244	7.067	0.0001129	1.000	8.4140	7.821	10.579	1.423	4.716	9.348	0.0885	60.48
1400	1.433	7.277	7.100	0.0001132	1.000	8.5144	7.879	10.880	1.413	4.759	9.432	0.0888	60.71
1420	1.445	7.310	7.132	0.0001135	1.000	8.6144	7.936	11.185	1.403	4.801	9.516	0.0891	60.93
1440	1.457	7.343	7.164	0.0001138	1.000	8.7142	7.993	11.495	1.393	4.843	9.600	0.0894	61.15
1460	1.469	7.375	7.196	0.0001141	1.000	8.8137	8.050	11.808	1.383	4.885	9.683	0.0898	61.36
1480	1.481	7.407	7.227	0.0001144	1.000	8.9129	8.106	12.126	1.373	4.927	9.766	0.0901	61.58
1500	1.493	7.439	7.258	0.0001147	1.000	9.0118	8.162	12.448	1.364	4.969	9.849	0.0904	61.79
1520	1.505	7.471	7.289	0.0001150	1.000	9.1104	8.218	12.774	1.355	5.010	9.931	0.0907	62.00
1540	1.516	7.502	7.319	0.0001153	1.000	9.2087	8.273	13.104	1.346	5.051	10.012	0.0910	62.21
1560	1.528	7.533	7.349	0.0001156	1.000	9.3068	8.328	13.438	1.337	5.092	10.094	0.0913	62.41

APPENDIX 5

CORE DESCRIPTIONS

Appendix 5 contains the core descriptions of the 17 cores taken from the bed of the Waikato River. Refer to Figure 5.3 and 5.4 for the location of cores. Mean grain size (M_Z) and sorting and pumice percentage are graphically displayed down the side of the core descriptions using the format shown in Figure A5.1. Note that these textural values used for M_Z and sorting are those determined by the moment method (see Appendix 6.7). The general shadings used in the core descriptions are shown in Figure A5.1.

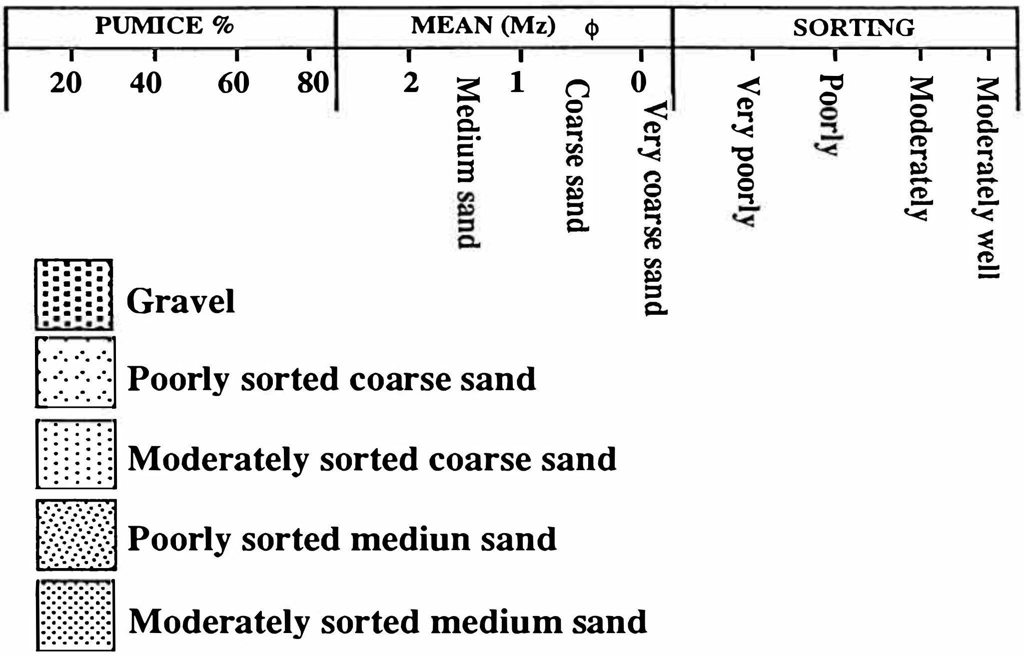


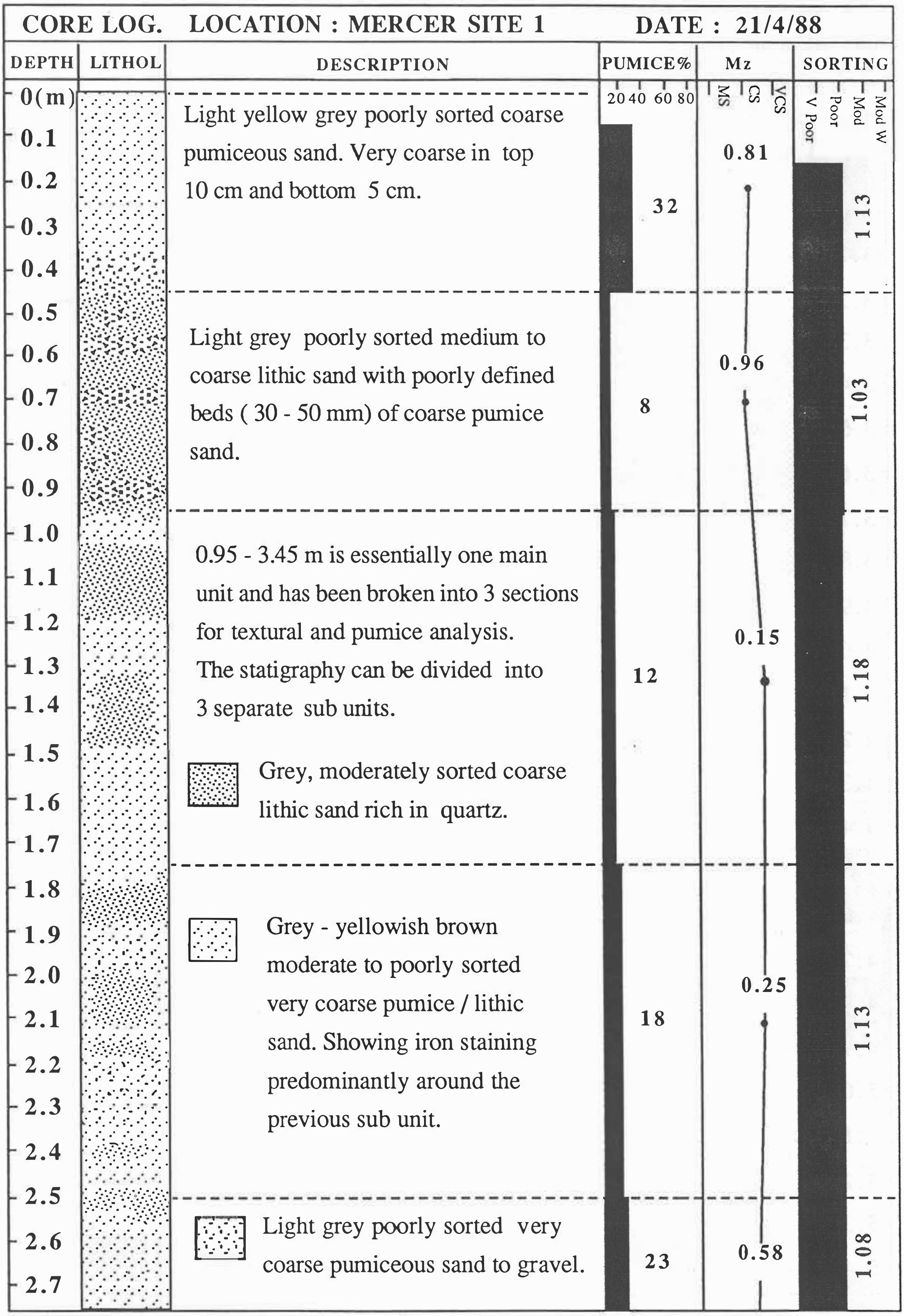
Figure A5.1 : Format of textural information in core descriptions.

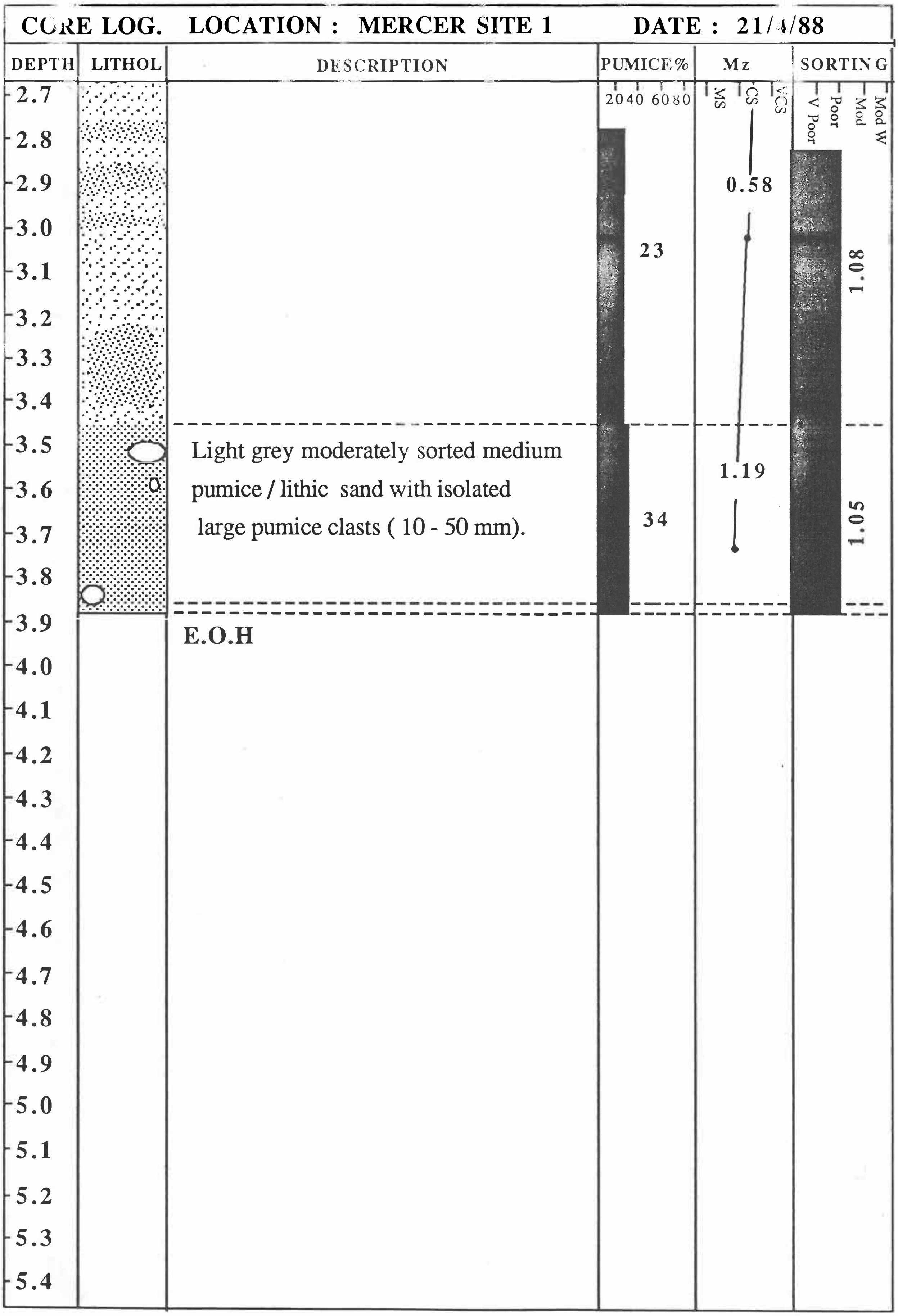
Full textural results for the cores are given in Appendix 6.8 (Mercer core sites) and Appendix 6.9 (Puni core sites). In the verbal descriptions, unit lithology is defined as either pumiceous or lithic sand. In this case lithic refers sands primarily composed of quartz, rock fragments. Pumiceous sand are those where visually, pumice dominates the lithology. ^{14}C is used to mark sample sites on cores which were ^{14}C dated.

* marks samples with a significant percentage of silt and mud, asterisk is followed by a percentage sand value.

Verbal Descriptions of Sorting (after Folk, 1968).

0.35 - 0.50, well sorted	1.0 - 2.0, poorly sorted
0.50 - 0.71, moderately well sorted	2.0 - 4.0, very poorly sorted
0.71 - 1.00, moderately sorted	


CORE LOG. LOCATION : MERCER SITE 1
DATE : 21/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Light yellow grey poorly sorted coarse pumiceous sand. Very coarse in top 10 cm and bottom 5 cm.
32
0.81
1.13
Light grey poorly sorted medium to coarse lithic sand with poorly defined beds (30 - 50 mm) of coarse pumice sand.
8
0.96
1.03
0.95 - 3.45 m is essentially one main unit and has been broken into 3 sections for textural and pumice analysis. The statigraphy can be divided into 3 separate sub units.
Grey, moderately sorted coarse lithic sand rich in quartz.
12
0.15
1.18
Grey - yellowish brown moderate to poorly sorted very coarse pumice / lithic sand. Showing iron staining predominantly around the previous sub unit.
18
0.25
1.13
Light grey poorly sorted very coarse pumiceous sand to gravel.
23
0.58
1.08


CORE LOG. LOCATION : MERCER SITE 1
DATE : 21/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE %
Mz
SORTING
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
0.58
23
1.08
Light grey moderately sorted medium pumice / lithic sand with isolated large pumice clasts (10 - 50 mm).
1.19
34
1.05
E.O.H

CORE LOG. LOCATION : MERCER SITE 2 DATE : 21/4/88

Depth scale (m): 0(m), 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7

PUMICE% scale: 20 40 60 80 — Mz scale: MS, CS, VCS — SORTING scale: V Poor, Poor, Mod, Mod W

DESCRIPTION	PUMICE%	Mz	SORTING
Yellowish grey moderately sorted coarse lithic / pumice sand.	20	0.63	0.92
Light grey poorly sorted coarse lithic / pumice sand with poorly defined beds (10 - 20mm) of coarse poorly sorted pumiceous sand. A number of pumice clast > 5mm.	32	0.47	1.16
Grey poorly sorted coarse pumice / lithic sand. Upper and lower 10cm rich in lithics with centre being pumice rich and coarser.	16	0.72	1.11
Pale yellow poorly sorted very coarse pumiceous sand with a number of large pumice clasts.	42	0.42	1.18
Grey moderately well sorted medium lithic sand with isolated beds of yellow grey coarse pumiceous sand.	8	0.98	0.73
Pale yellow poorly sorted very coarse pumiceous sand. Distinct upper and lower boundaries.	69	-0.02	1.35

CORE LOG. LOCATION : MERCER SITE 2 DATE : 21/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE %	Mz	SORTING
2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7		Grey moderately sorted medium lithic sand, interbedded with moderately well defined beds (5 - 30 mm) of light grey poorly sorted coarse pumiceous sands. Pumice beds tend to fine up through the unit.	22	1.08	1.01
3.8, 3.9, 4.0, 4.1, 4.2, 4.3		Similar to above unit, but lithic sands are finer and pumiceous beds have poorer definition.	13	1.51	0.82
4.4, 4.5, 4.6, 4.7		Light grey poorly sorted very coarse pumiceous sand and gravel . Contains two main beds that fine upwards.	83	0.11	1.38
4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4		Light grey moderately sorted medium pumiceous sand interbedded with 5 - 10 mm beds of moderately well sorted fine lithic sand. Isolated pumice clasts (10mm). **E.O.H**	23	1.84	0.78

PUMICE % scale: 20 40 60 80

Mz scale: MS, CS, VCS

SORTING scale: V Poor, Poor, Mod, Mod W

CORE LOG. LOCATION : MERCER SITE 3 DATE : 21/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE%	Mz	SORTING
		Yellowish grey poorly sorted coarse lithic / pumice sand. Poorly defined beds of very coarse pumice (20-40mm).	11	0.25	1.32
		Light grey poorly sorted medium lithic sand. Sorting improves upwards.	86	0.25	1.44
		Grey moderately sorted medium lithic sand, with poorly defined beds (10 - 30 mm) of light grey poorly sorted coarse pumiceous sand.	32	1.12	0.98
		Light grey poorly sorted coarse pumice sand. Some poorly defined beds (10 - 30 mm) of moderately sorted medium lithic sand. Isolated large pumice clasts (5-10 mm) & charcoal fragment	54	0.6	1.25

DEPTH: 0(m), 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7

PUMICE% scale: 20 40 60 80

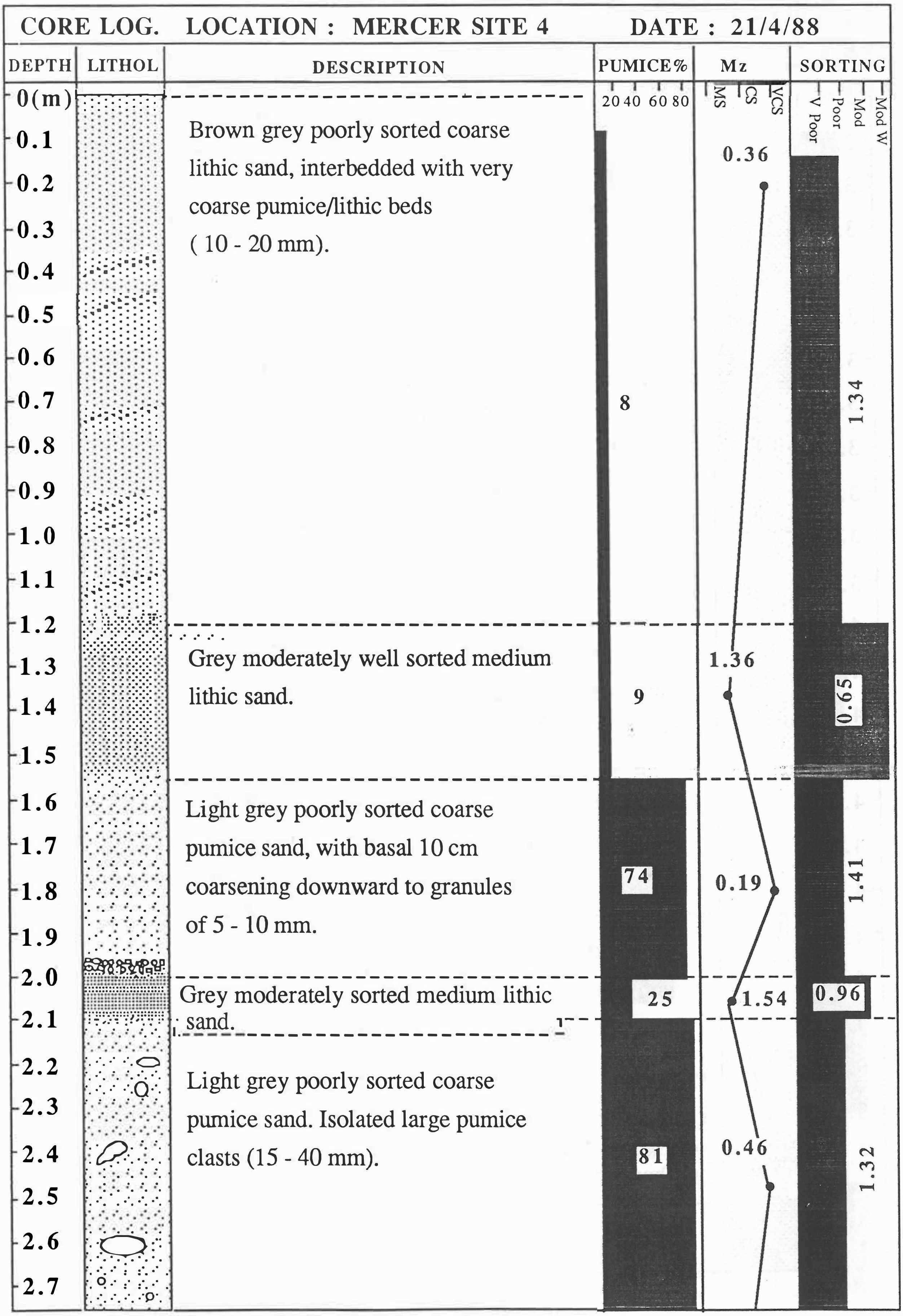
Mz scale: MS, CS, VCS

SORTING scale: V Poor, Poor, Mod, Mod W

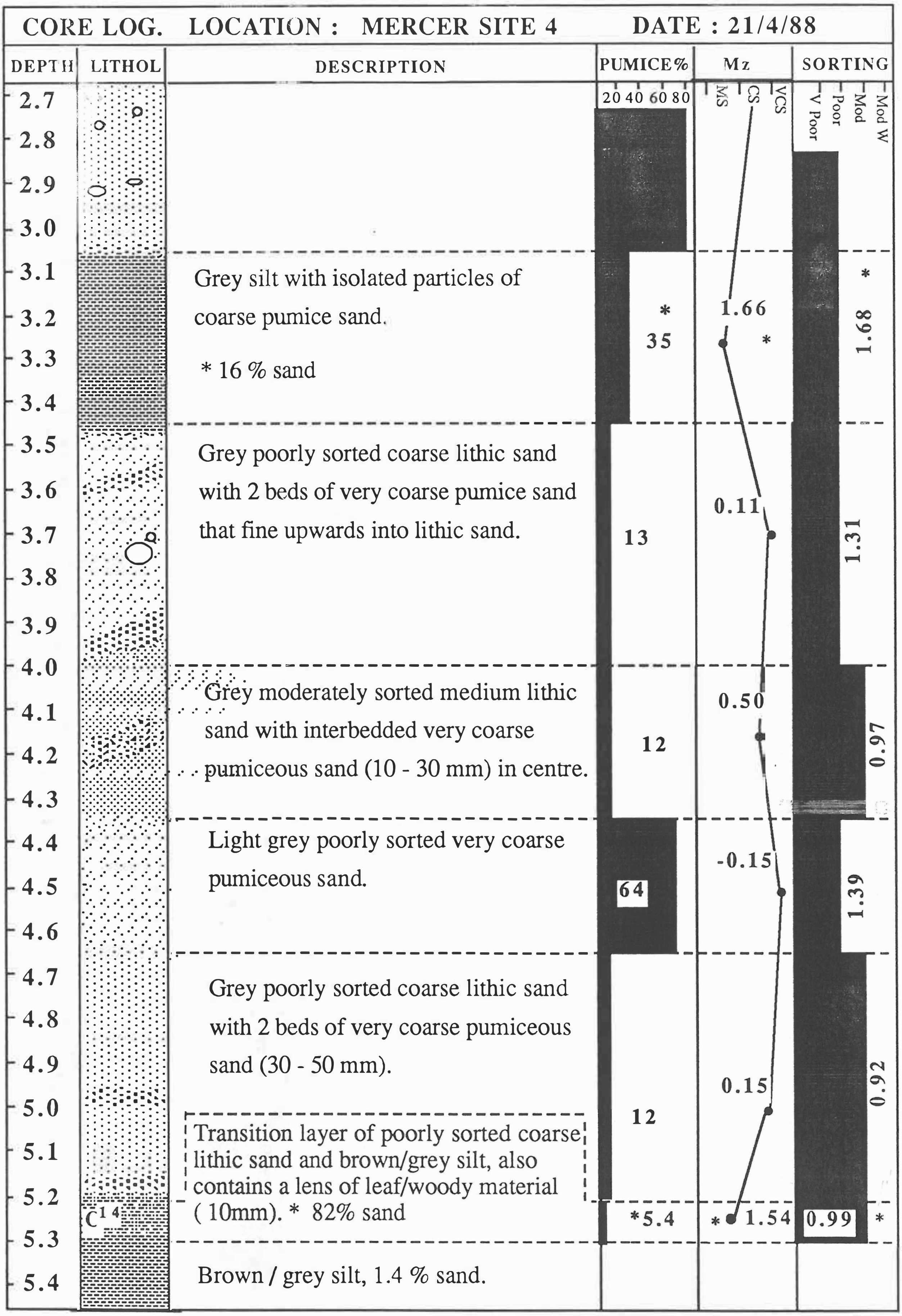
CORE LOG. LOCATION : MERCER SITE 3 DATE : 21/4/88

DEPTH: 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4

DESCRIPTION	PUMICE%	Mz	SORTING
Grey poorly sorted coarse lithic sand.	9	0.01	1.36
Light grey poorly sorted very coarse pumiceous sand to gravel, with large clast (20 - 30 mm).	67	-0.54	1.57
Grey poorly sorted very coarse lithic sand.	12	-0.15	1.21
Light grey poorly sorted very coarse pumiceous sand to gravel, with a number of large pumice clasts (20 - 30 mm).	59	-0.63	1.60
Greenish grey wedge of poorly sorted coarse lithic sand.	8	0.42	1.17
Light grey poorly sorted very coarse pumice sand to gravel. One large pumice clast (40mm).	62	-0.23	1.35
E.O.H			



CORE LOG. LOCATION : MERCER SITE 4 DATE : 21/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Brown grey poorly sorted coarse lithic sand, interbedded with very coarse pumice/lithic beds (10 - 20 mm).
8
0.36
1.34
Grey moderately well sorted medium lithic sand.
9
1.36
0.65
Light grey poorly sorted coarse pumice sand, with basal 10 cm coarsening downward to granules of 5 - 10 mm.
74
0.19
1.41
Grey moderately sorted medium lithic sand.
25
1.54
0.96
Light grey poorly sorted coarse pumice sand. Isolated large pumice clasts (15 - 40 mm).
81
0.46
1.32


CORE LOG. LOCATION : MERCER SITE 4 DATE : 21/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
Grey silt with isolated particles of coarse pumice sand.
* 16 % sand
* 35
1.66 *
* 1.68
Grey poorly sorted coarse lithic sand with 2 beds of very coarse pumice sand that fine upwards into lithic sand.
13
0.11
1.31
Grey moderately sorted medium lithic sand with interbedded very coarse pumiceous sand (10 - 30 mm) in centre.
12
0.50
0.97
Light grey poorly sorted very coarse pumiceous sand.
64
-0.15
1.39
Grey poorly sorted coarse lithic sand with 2 beds of very coarse pumiceous sand (30 - 50 mm).
12
0.15
0.92
Transition layer of poorly sorted coarse lithic sand and brown/grey silt, also contains a lens of leaf/woody material (10mm). * 82% sand
C14
*5.4
* 1.54
0.99 *
Brown / grey silt, 1.4 % sand.

CORE LOG. LOCATION : MERCER SITE 5 DATE : 21/4/88

DEPTH: 0(m), 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7

PUMICE% scale: 20 40 60 80 — Mz scale: MS, CS, VCS — SORTING scale: V Poor, Poor, Mod, Mod W

DESCRIPTION	PUMICE%	Mz	SORTING
Yellow grey poorly sorted coarse pumiceous sand, fining downwards.	37	0.84	1.13
Pale grey poorly sorted coarse lithic sand with poorly defined beds of moderately sorted very coarse pumiceous sand (10-30mm).	12	0.62	1.07
Grey poorly sorted coarse lithic sand with beds (20-50mm) of very coarse lithic sand which fine upwards. Thin layer of medium ferromagnesium mineral rich sand.	2	0.27	1.23
Light grey moderately sorted coarse pumiceous sand grading downwards to very coarse pumice sand/gravel. Base unit contains large wood fragments (20-30mm)and pumice clasts (10-20mm).	68	-0.24	1.14
Grey moderately sorted coarse to medium lithic sand.	25	0.90	0.93
Dark grey poorly sorted very coarse lithic sand.	12	-0.23	1.16

CORE LOG. LOCATION : MERCER SITE 5 DATE : 21/4/88

DEPTH: 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4

LITHOL: C14 (at 4.1)

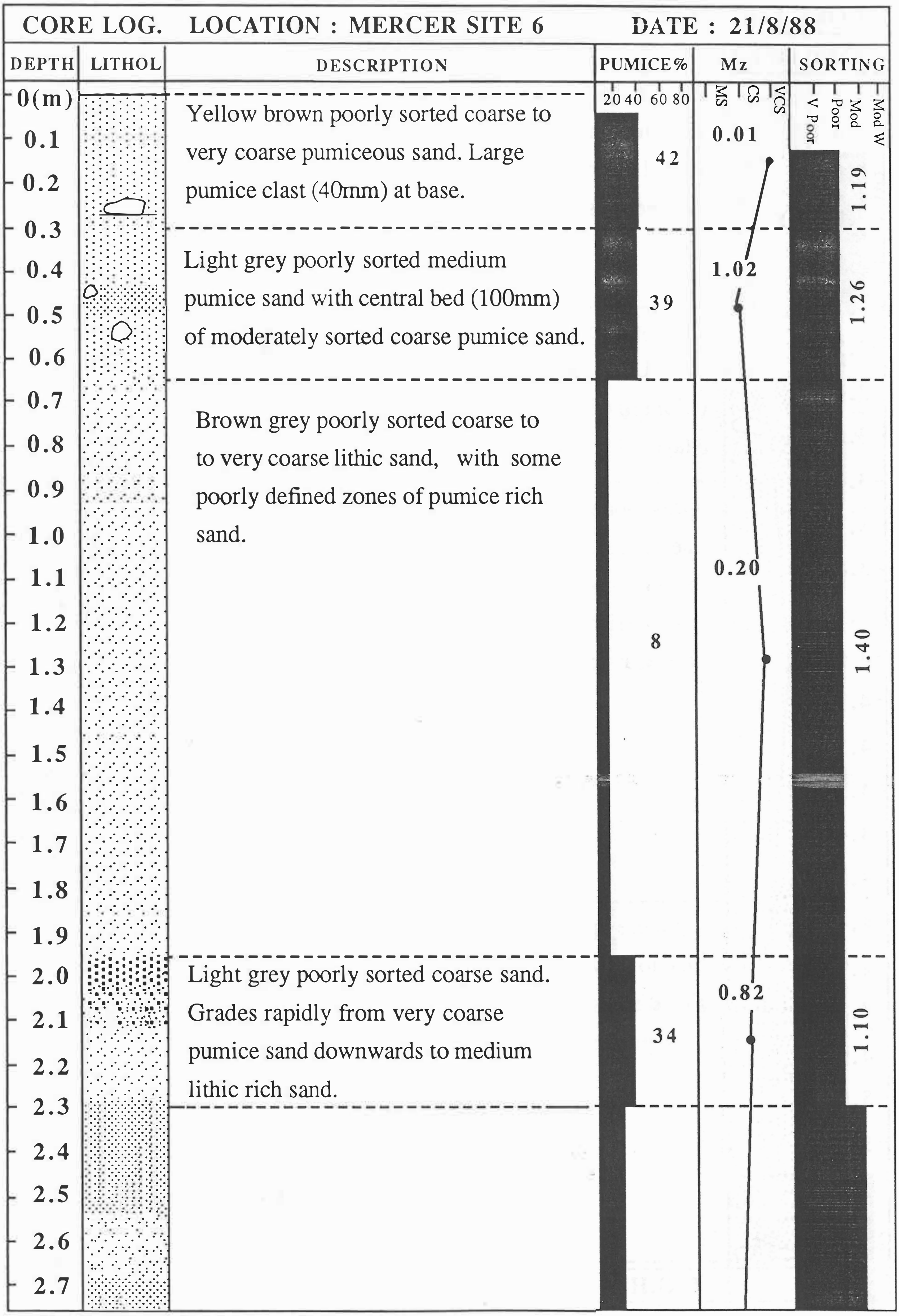
PUMICE% scale: 20 40 60 80

Mz scale: MS, CS, VCS

SORTING scale: V Poor, Poor, Mod, Mod W

DESCRIPTION	PUMICE%	Mz	SORTING
Grey moderately sorted coarse lithic sand interbedded with poorly sorted coarse to very coarse darker lithic sands.	8	0.15	0.96
Grey poorly sorted coarse lithic sand interbedded with poorly sorted very coarse pumiceous sand. Basal 70mm is poorly sorted pumiceous gravel.	26	-0.06	1.34
Grey poorly sorted coarse lithic sand, coarsens downward for first 10cm to very coarse then fines downward to a peat layer at 4.1m (~30mm thick). Basal portion is silty with pumice clasts (5-30mm).	11	0.25	1.17
Brown grey moderately sorted medium lithic sand interbedded with finer silt rich lenses.	9	1.32	0.99
Dark brown silt to fine sand, with a massive structure.* 60% sand.	14 *	2.25 *	0.84 *
Brown grey moderately sorted medium lithic sand interbedded with finer silt rich lenses (10-20mm). * 89 % sand.	7 *	1.48 *	0.94 *

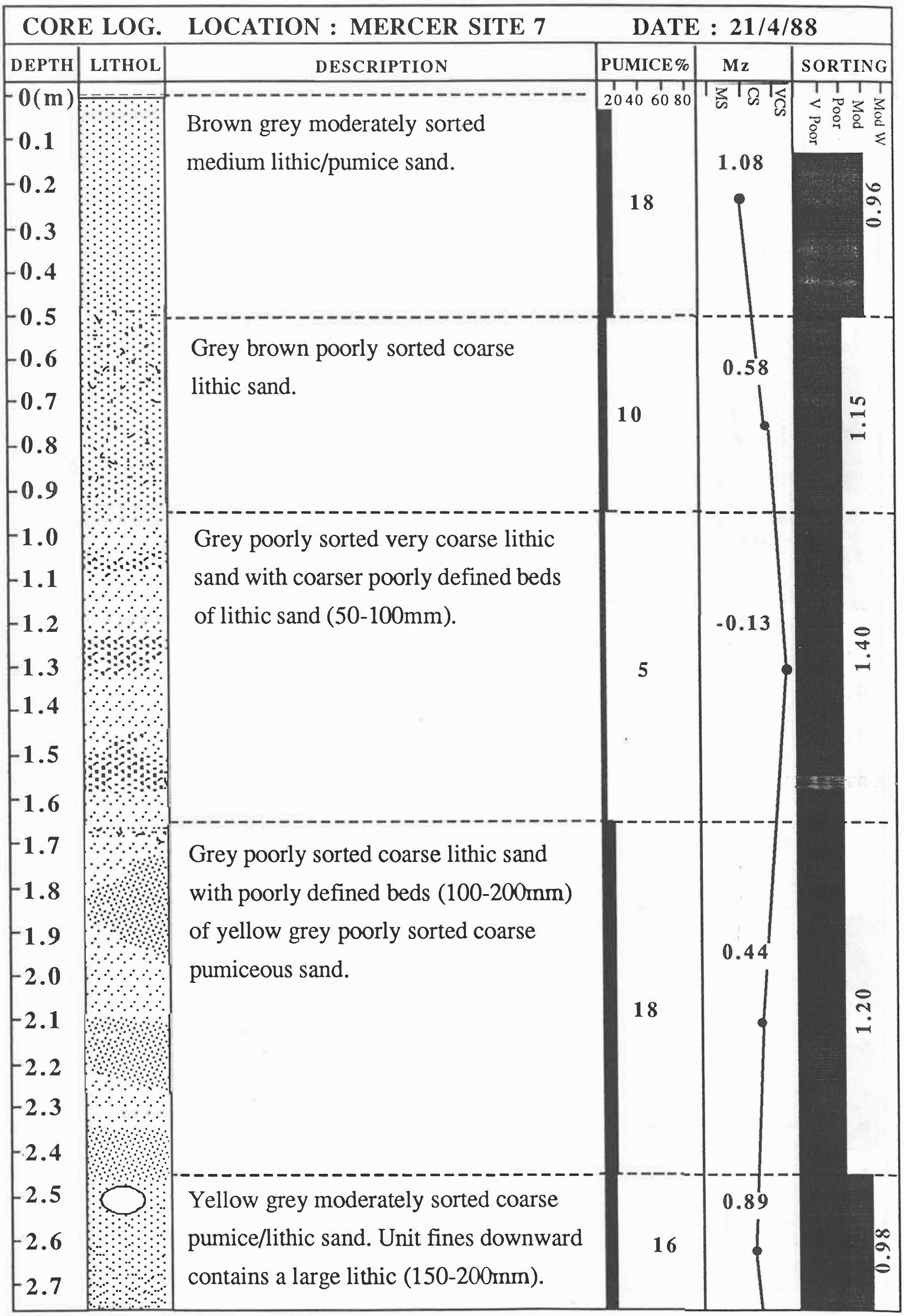
E.O.H


CORE LOG. LOCATION : MERCER SITE 6
DATE : 21/8/88
DEPTH
LITHOL
DESCRIPTION
PUMICE %
Mz
SORTING
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Yellow brown poorly sorted coarse to very coarse pumiceous sand. Large pumice clast (40mm) at base.
42
0.01
1.19
Light grey poorly sorted medium pumice sand with central bed (100mm) of moderately sorted coarse pumice sand.
39
1.02
1.26
Brown grey poorly sorted coarse to to very coarse lithic sand, with some poorly defined zones of pumice rich sand.
8
0.20
1.40
Light grey poorly sorted coarse sand. Grades rapidly from very coarse pumice sand downwards to medium lithic rich sand.
34
0.82
1.10

CORE LOG. LOCATION : MERCER SITE 6 — **DATE : 21/4/88**

DEPTH	DESCRIPTION	PUMICE% (20 40 60 80)	Mz (MS CS VCS)	SORTING (V Poor, Poor, Mod, Mod W)
2.7 – 3.2	Light to mid grey moderately sorted medium lithic sand with large beds (100-150mm) of poorly sorted coarse pumiceous sand.	25	1.17	0.88
3.2 – 3.6	Light grey poorly sorted coarse pumice sand. Unit coarsens downward to a layer (150mm) of medium lithic rich sand, then a layer of very coarse pumiceous sand.	62	0.80	1.42
3.6 – 4.55	Grey moderately sorted coarse to medium lithic sand with poorly defined beds of moderately sorted coarse pumice rich sand (10-40mm). Base of unit coarsens and grades into next unit.	21	1.01	0.96
4.55 – 5.4	Light grey poorly sorted coarse pumice sand to gravel, with zones of moderately sorted coarse lithic sand. A number of large pumice clasts (20-50mm).	45	0.42	1.13
5.4	E.O.H			

Depth scale: 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4


CORE LOG. LOCATION : MERCER SITE 7
DATE : 21/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Brown grey moderately sorted medium lithic/pumice sand.
18
1.08
0.96
Grey brown poorly sorted coarse lithic sand.
10
0.58
1.15
Grey poorly sorted very coarse lithic sand with coarser poorly defined beds of lithic sand (50-100mm).
5
-0.13
1.40
Grey poorly sorted coarse lithic sand with poorly defined beds (100-200mm) of yellow grey poorly sorted coarse pumiceous sand.
18
0.44
1.20
Yellow grey moderately sorted coarse pumice/lithic sand. Unit fines downward contains a large lithic (150-200mm).
16
0.89
0.98

CORE LOG. LOCATION : MERCER SITE 7 DATE : 21/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE%	Mz	SORTING
			20 40 60 80	MS CS VCS	V Poor Poor Mod Mod W
2.7					
2.8 – 3.1		Light grey poorly sorted coarse to very coarse sand. Unit contains poorly defined beds that fine upwards. Some large pumice clasts (10-20mm).	51	0.22	1.35
3.2 – 3.4		Grey poorly sorted medium lithic sand with poorly defined beds (5-15m) of darker lithic sands.	6	1.05	1.20
3.4 – 3.5		Deep grey poorly sorted very coarse lithic sand.	3	0.29	1.62
3.6 – 4.5		Light grey poorly sorted coarse pumice sand with beds (10-20mm) of moderately sorted medium lithic sand. Unit tends to fine upwards. Isolated pumice clasts (5-10mm).	53	0.50	1.15
4.5 – 5.1		Pale grey poorly sorted coarse pumiceous sand.	47	0.62	1.16
5.1		E.O.H			
5.2					
5.3					
5.4					

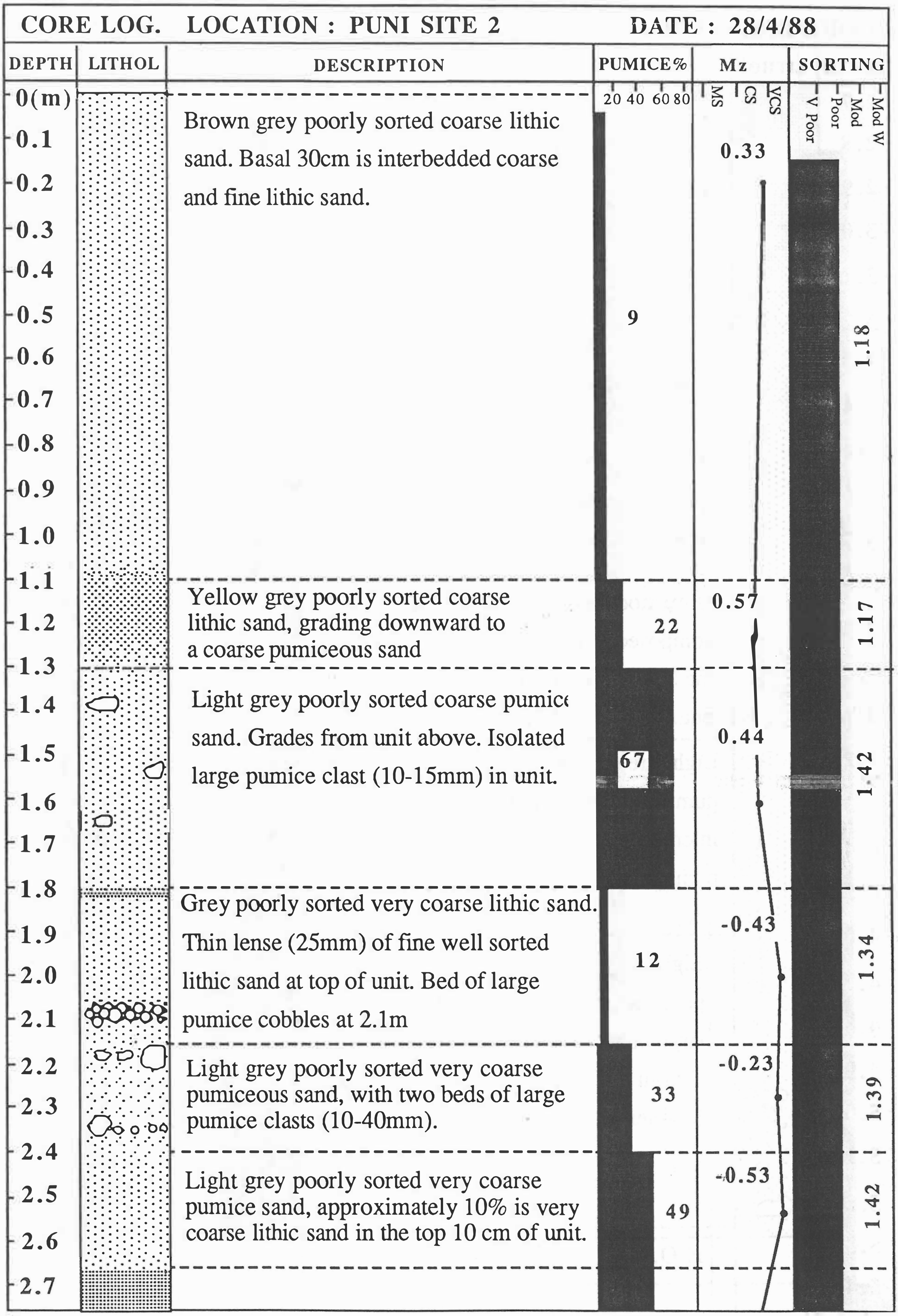
CORE LOG. LOCATION : PUNI SITE 1 DATE : 28/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE%	Mz	SORTING
			20 40 60 80	MS CS VCS	V Poor Poor Mod Mod W
0(m) 0.1 0.2 0.3 0.4 0.5		Brown grey poorly sorted coarse to very coarse lithic sand, with pumice increasing in the central to lower region.	16	0.49	1.06
0.6 0.7 0.8 0.9 1.0 1.1		Brown grey moderately sorted coarse lithic sand. Similar to overlying unit but finer in texture.	15	0.60	0.96
1.2 1.3 1.4		Grey poorly sorted coarse lithic sand.	11	0.45	1.25
1.5 1.6 1.7 1.8		Grey poorly sorted very coarse pumice sand to gravel. Notable lithics in upper part, and large pumice clasts (10-50mm) throughout.	51	-0.17	1.78
1.9 2.0 2.1 2.2		Yellow grey moderately well sorted medium to fine pumiceous sand.	20	1.93	0.69
2.3 2.4 2.5	C14	Grey brown poorly sorted medium pumice sand in top half, then a peaty lens and 25mm of muddy coarse pumice. Bottom 50mm is moderately well sorted fine pumice sand.	19	1.62	1.32
2.6 2.7		Grey poorly sorted coarse to medium pumice sand, with poorly defined beds that coarsen upwards (30-60mm).	68	0.91	1.24

CORE LOG. LOCATION : PUNI SITE 1 DATE : 28/4/88

DEPTH: 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4

LITHOL	DESCRIPTION	PUMICE% (20 40 60 80)	Mz (MS CS VCS)	SORTING (V Poor, Poor, Mod, Mod W)
	Grey poorly sorted coarse lithic/ pumice sand.	28	0.46	1.49
	Dark grey poorly sorted lithic gravel.	11	-1.06	1.42
C14	A chaotic unit of poorly sorted pumiceous gravel, large wood (25mm) & pumice (20mm) particles. 20mm muddy layer at 3.3m. Lower 50mm very coarse and fines upwards. * 74% sand.	56 *	-0.64 *	1.60 *
	Yellow grey very poorly sorted massive medium to fine pumiceous sand. Contains 20% pumice gravel scattered throughout the unit.		1.26	2.16
	Light grey silt. Fine scale bedding of lighter coloured material (1-4mm). Isolated clasts of pumice (2-3mm). Unit is sandy in the upper portion as it grades into overlying unit. * 3% sand.	45 *	2.66 *	1.32 *
	E.O.H			


CORE LOG. LOCATION : PUNI SITE 2
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Brown grey poorly sorted coarse lithic sand. Basal 30cm is interbedded coarse and fine lithic sand.
9
0.33
1.18
Yellow grey poorly sorted coarse lithic sand, grading downward to a coarse pumiceous sand
22
0.57
1.17
Light grey poorly sorted coarse pumice sand. Grades from unit above. Isolated large pumice clast (10-15mm) in unit.
67
0.44
1.42
Grey poorly sorted very coarse lithic sand. Thin lense (25mm) of fine well sorted lithic sand at top of unit. Bed of large pumice cobbles at 2.1m
12
-0.43
1.34
Light grey poorly sorted very coarse pumiceous sand, with two beds of large pumice clasts (10-40mm).
33
-0.23
1.39
Light grey poorly sorted very coarse pumice sand, approximately 10% is very coarse lithic sand in the top 10 cm of unit.
49
-0.53
1.42

CORE LOG. LOCATION : PUNI SITE 2 DATE : 28/4/88

DEPTH	DESCRIPTION	PUMICE %	Mz	SORTING
2.7 – 3.1	Light grey poorly sorted fine pumiceous sand intermixed with coarse pumice material. Unit fines towards base.	49	1.78	1.32
3.1 – 3.45	Grey moderately sorted medium lithic sand interbedded with poorly defined coarse pumice sand (10-20mm).	10	0.76	0.85
3.45 – 3.8	Light grey poorly sorted very coarse pumiceous sand, lithics become more predominant towards top of unit.	73	-0.19	1.16
3.8 – 4.15	Grey moderately sorted medium sand, composed of poorly defined interbedded medium lithic sand (15-40mm) & coarse pumice sand (10-25mm).	19	1.06	0.74
4.15 – 4.6	Light grey moderately sorted very coarse pumiceous sand. Unit grades from interbedded lithic sands into very coarse pumice.	76	0.20	1.01
4.6 – 5.3	Light grey poorly sorted very coarse pumiceous sand, with a number of large pumice clasts (5-30mm) in bottom half of unit. Wood and charcoal fragments through unit.	85	-0.06	1.36
5.3 – 5.4	E.O.H			

Pumice % scale: 20 40 60 80. Mz scale: MS, CS, VCS. Sorting scale: V Poor, Poor, Mod, Mod W.

CORE LOG. LOCATION : PUNI SITE 3 DATE : 28/4/88

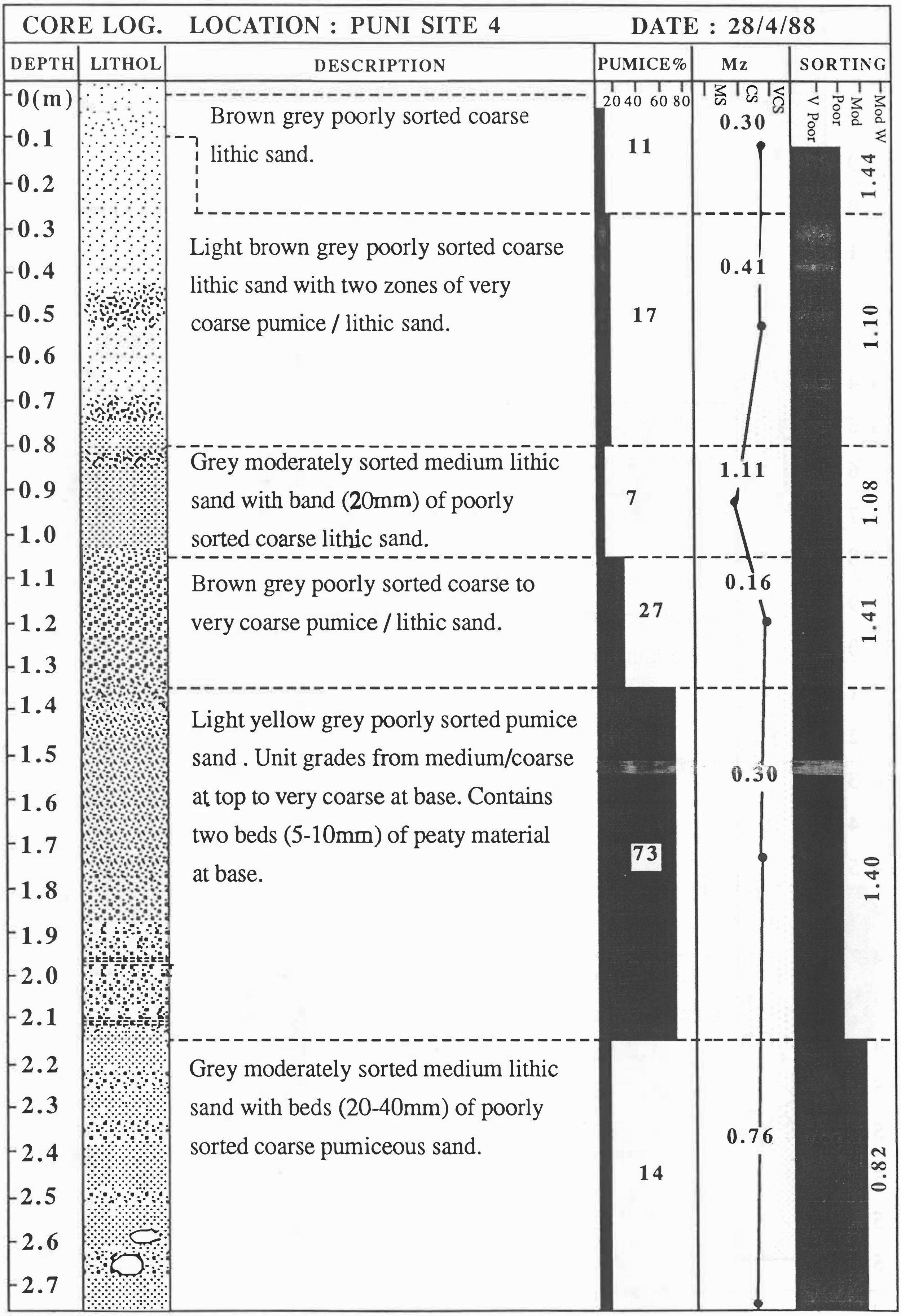
DEPTH: 0(m), 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7

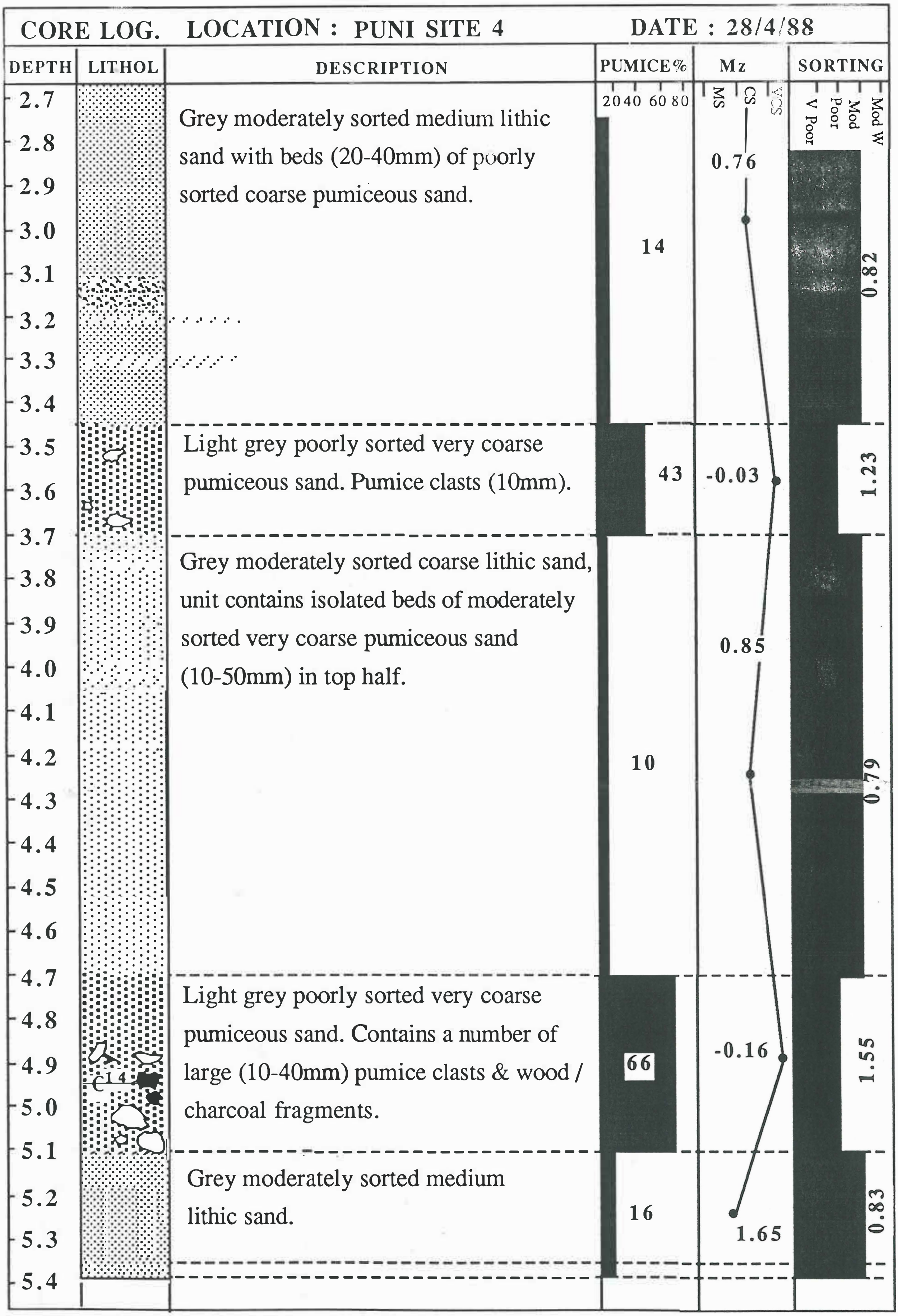
PUMICE% scale: 20 40 60 80 — Mz scale: MS, CS, VCS — SORTING scale: V Poor, Poor, Mod, Mod W

DESCRIPTION	PUMICE%	Mz	SORTING
Brown grey poorly sorted coarse lithic sand. Bottom 70mm is very coarse sand.	8	0.58	1.20
Yellow grey moderate to poorly sorted coarse pumiceous sand.	20	0.55	1.03
Light grey medium to coarse moderately sorted lithic sand, interbedded with poorly defined beds of poorly sorted coarse pumiceous sand (30-50mm).	15	0.65	1.10
Light grey moderately sorted medium lithic sand interbedded with poorly sorted coarse pumiceous sands (5-15mm).	16	0.98	1.15
Light grey moderately sorted coarse lithic sand interbedded with poorly sorted coarse pumiceous sands (15-20mm).	16	0.86	1.32

CORE LOG. LOCATION : PUNI SITE 3 DATE : 28/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE%	Mz	SORTING
			20 40 60 80	MS CS VCS	V Poor Poor Mod Mod W
2.7 2.8 2.9 3.0		Grey moderately well sorted coarse lithic sand.	5	0.96	0.71
3.1 3.2 3.3 3.4 3.5 3.6 3.7		Yellow grey moderately sorted coarse lithic sand with poorly defined beds of moderately sorted coarse to very coarse pumiceous sands (30-50mm).	15	0.55	0.83
3.8 3.9		Light grey poorly sorted coarse pumiceous sands.	56	0.24	1.37
4.0 4.1 4.2 4.3 4.4 4.5 4.6		Grey moderately sorted medium pumiceous sands interbedded with medium moderately sorted lithic sand (5-20mm). Interbedding is more predominant in top half.	27	1.39	0.87
4.7 4.8 4.9 5.0 5.1 5.2		Light grey poorly sorted coarse pumice sand with a number of pumice clasts (~10mm) at base.	48	0.22	1.14
5.3 5.4		E.O.H			


CORE LOG. LOCATION : PUNI SITE 4
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Brown grey poorly sorted coarse lithic sand.
11
0.30
1.44
Light brown grey poorly sorted coarse lithic sand with two zones of very coarse pumice / lithic sand.
17
0.41
1.10
Grey moderately sorted medium lithic sand with band (20mm) of poorly sorted coarse lithic sand.
7
1.11
1.08
Brown grey poorly sorted coarse to very coarse pumice / lithic sand.
27
0.16
1.41
Light yellow grey poorly sorted pumice sand . Unit grades from medium/coarse at top to very coarse at base. Contains two beds (5-10mm) of peaty material at base.
73
0.30
1.40
Grey moderately sorted medium lithic sand with beds (20-40mm) of poorly sorted coarse pumiceous sand.
14
0.76
0.82


CORE LOG. LOCATION : PUNI SITE 4
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Grey moderately sorted medium lithic sand with beds (20-40mm) of poorly sorted coarse pumiceous sand.
14
0.76
0.82
Light grey poorly sorted very coarse pumiceous sand. Pumice clasts (10mm).
43
-0.03
1.23
Grey moderately sorted coarse lithic sand, unit contains isolated beds of moderately sorted very coarse pumiceous sand (10-50mm) in top half.
0.85
10
0.79
Light grey poorly sorted very coarse pumiceous sand. Contains a number of large (10-40mm) pumice clasts & wood / charcoal fragments.
C14
66
-0.16
1.55
Grey moderately sorted medium lithic sand.
16
1.65
0.83

CORE LOG. LOCATION : PUNI SITE 5				DATE : 28/4/88
DEPTH	DESCRIPTION	PUMICE% (20 40 60 80)	Mz (MS CS VCS)	SORTING (V Poor, Poor, Mod, Mod W)
0(m) – 0.3	Dark grey poorly sorted very coarse lithic sand. Unit contains a large pumice clast (35mm dia)	8	-0.15	1.33
0.3 – 0.8	Brown grey poorly sorted coarse lithic sand in 40mm beds, interbedded with poorly defined poorly sorted coarse pumiceous beds (30mm).	16	0.24	1.49
0.8 – 1.0	Light yellow grey poorly sorted very coarse pumiceous sand. Contains scattered woody material at 0.95m.	50	-0.23	1.70
1.0 – 1.3	Grey poorly sorted coarse lithic sand.	11	0.76	1.20
1.3 – 1.8	Light yellow grey poorly sorted very coarse pumiceous sand to gravel.	51	0.09	1.30
1.8 – 2.15	Brown grey moderately sorted medium lithic sand with large pumice particles (10-20mm diameter) in top half.	12	1.11	0.93
2.15 – 2.7	Light yellow grey poorly sorted coarse pumiceous sand , large pumice clast (15-20mm diameter).	51	0.74	1.39

Depth scale: 0(m), 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7

CORE LOG. LOCATION : PUNI SITE 5 DATE : 28/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE% (20 40 60 80)	Mz (MS CS VCS)	SORTING (V Poor, Poor, Mod, Mod W)
2.7, 2.8					
2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8		Light grey poorly sorted pumice and lithic sands. Unit grades downward from medium to coarse, mainly lithic sand with poorly defined beds of coarse pumiceous sand (20-40mm).	17	0.80	0.83
3.9, 4.0, 4.1, 4.2		Grey poorly sorted coarse pumiceous sand. Coarse in top half of unit, fining below 4.2m to a lithic rich sand. One large pumice clast (45mm dia).	35	0.32	1.43
4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0		Pale yellow grey poorly sorted coarse pumiceous sand.	49	0.53	1.16
5.1, 5.2, 5.3, 5.4		E.O.H			

CORE LOG. LOCATION : PUNI SITE 6 DATE : 28/4/88

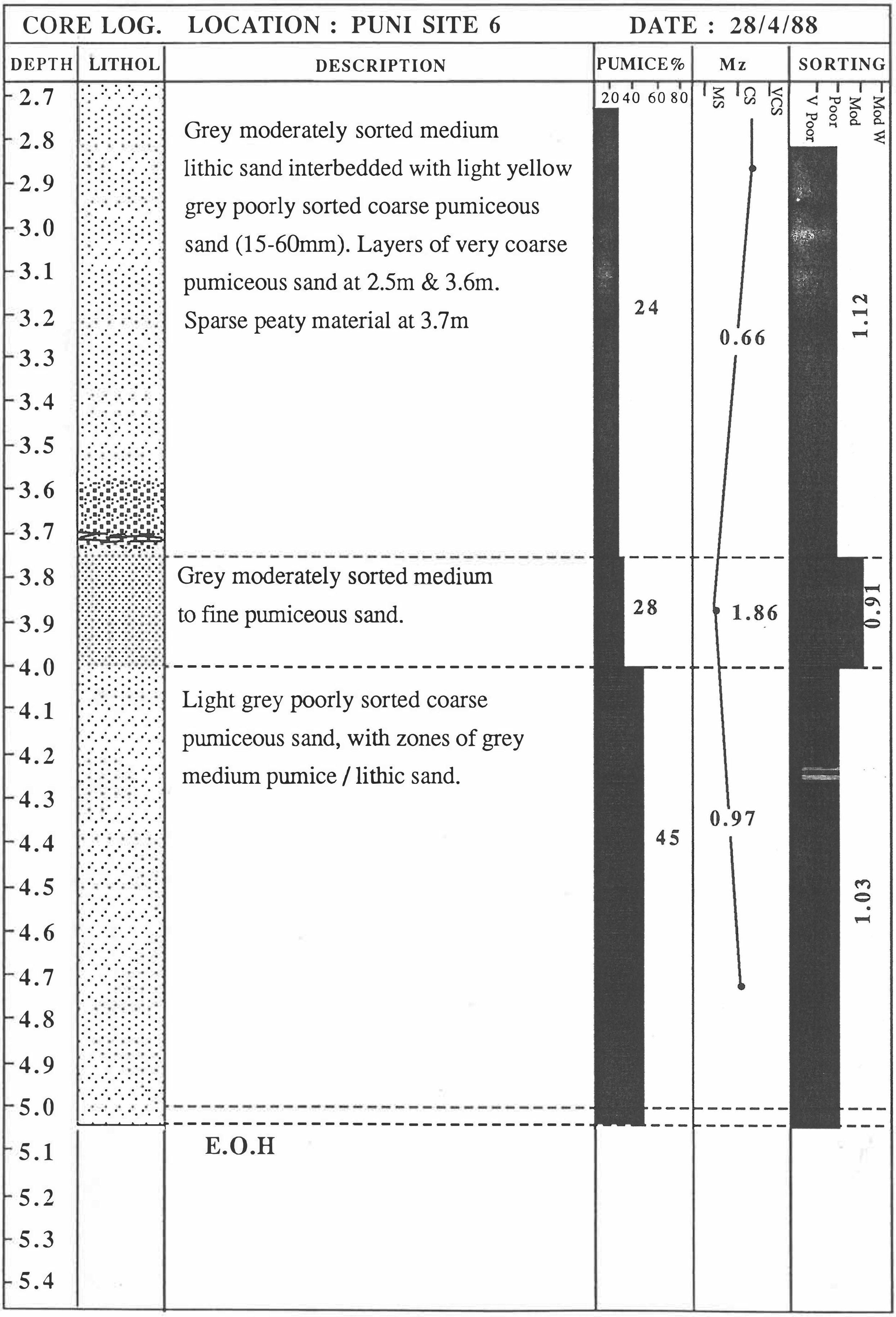
DEPTH	LITHOL	DESCRIPTION	PUMICE%	Mz	SORTING
0(m) – 0.3		Brown grey poorly sorted coarse to very coarse lithic sand.	13	0.16	1.30
0.3 – 1.65		Grey moderately sorted coarse lithic sand interbedded with poorly defined beds of poorly sorted coarse to very coarse pumice / lithic sand (20-80mm). Muddy zone at 1.6m. Iron staining is apparent on lighter coloured pumice material.	14	0.20	1.17
1.65 – 2.7		Grey moderately sorted medium lithic sand interbedded with light yellow grey poorly sorted coarse pumiceous sand (15-60mm). Layers of very coarse pumiceous sand at 2.5m & 3.6m. Sparse peaty material at 3.7m.	24	0.66	1.12

Depth scale: 0(m), 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0, 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2.0, 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7

PUMICE% scale: 20 40 60 80

Mz scale: MS, CS, VCS

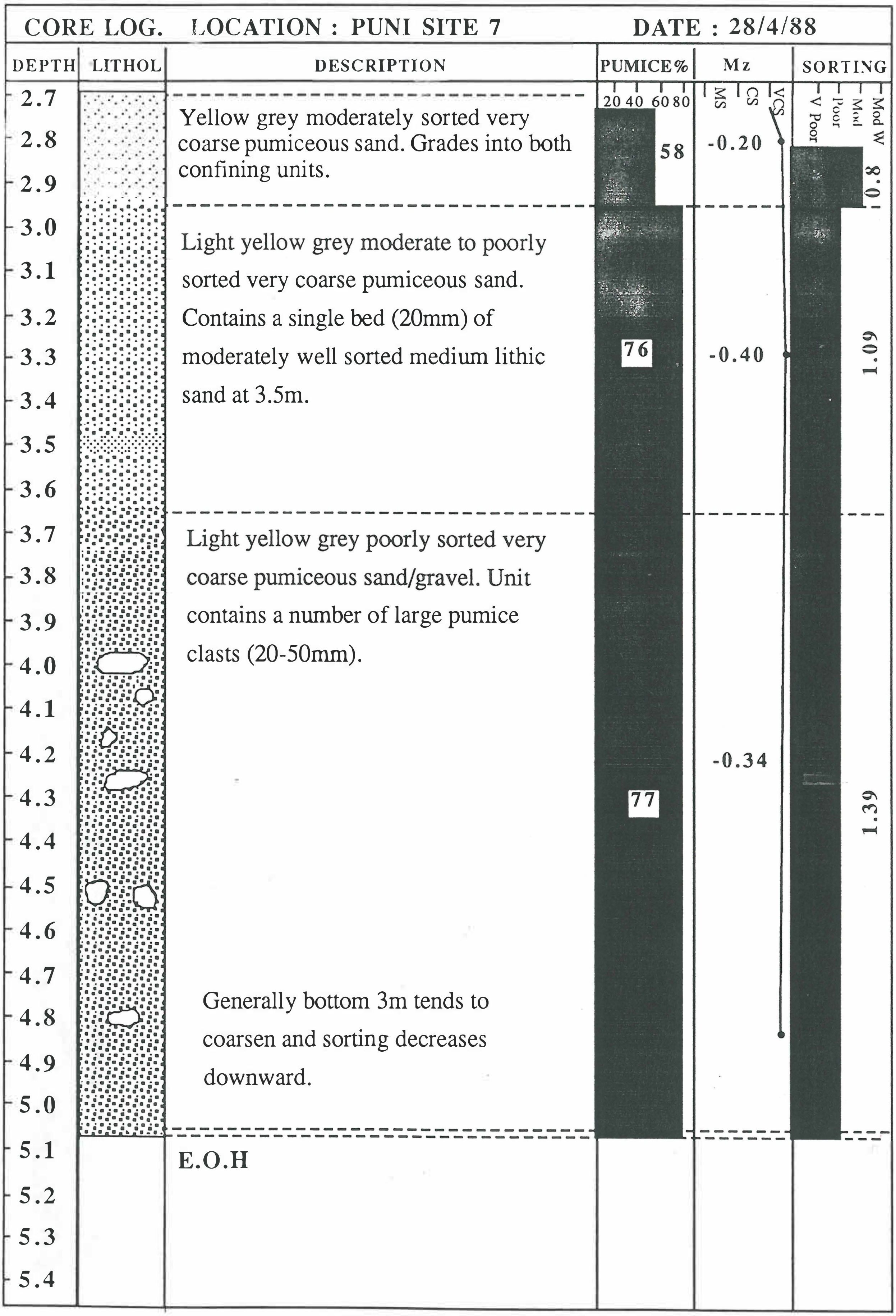
SORTING scale: V Poor, Poor, Mod, Mod W


CORE LOG. LOCATION : PUNI SITE 6
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
Grey moderately sorted medium lithic sand interbedded with light yellow grey poorly sorted coarse pumiceous sand (15-60mm). Layers of very coarse pumiceous sand at 2.5m & 3.6m. Sparse peaty material at 3.7m
24
0.66
1.12
Grey moderately sorted medium to fine pumiceous sand.
28
1.86
0.91
Light grey poorly sorted coarse pumiceous sand, with zones of grey medium pumice / lithic sand.
45
0.97
1.03
E.O.H

CORE LOG. LOCATION : PUNI SITE 7 DATE : 28/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE%	Mz	SORTING
0(m) 0.1 0.2 0.3 0.4		Grey brown moderate to poorly sorted coarse lithic sand.	18	0.84	0.99
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5		Dark grey moderately sorted medium lithic sand. Zones of lighter and darker material but no definable beds.	4	1.15	0.77
1.6 1.7 1.8 1.9 2.0 2.1 2.2		Grey moderately sorted medium lithic sand with some poorly defined beds (15-40mm) of poorly sorted coarse pumiceous sand.	13	0.87	0.76
2.3 2.4 2.5 2.6 2.7		Yellow grey moderately sorted coarse pumiceous sand. A layer of very coarse pumice sand/gravel in top 30mm.	37	0.25	0.76

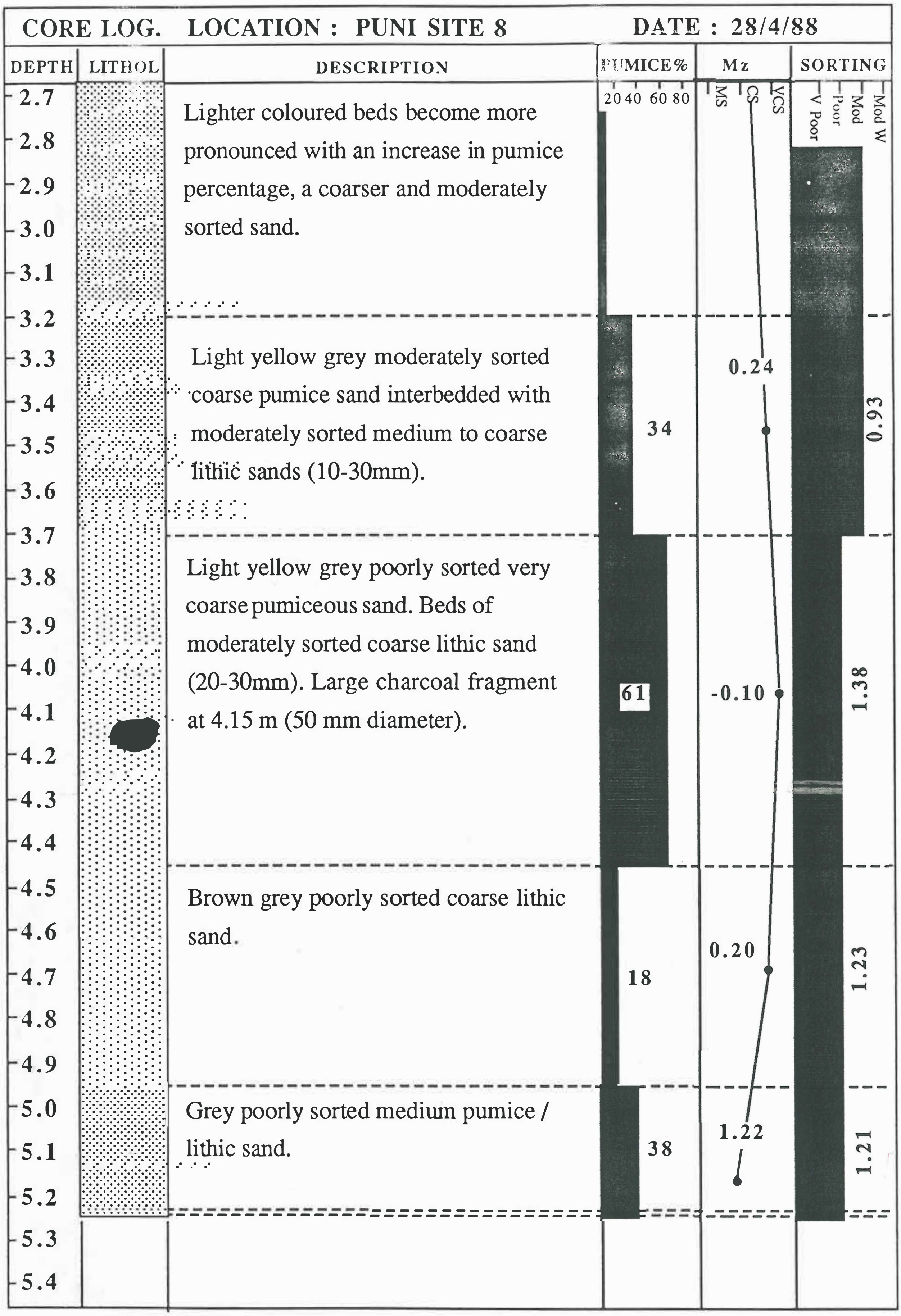
PUMICE% scale: 20 40 60 80 — Mz scale: MS CS VCS — SORTING scale: V Poor, Poor, Mod, Mod W

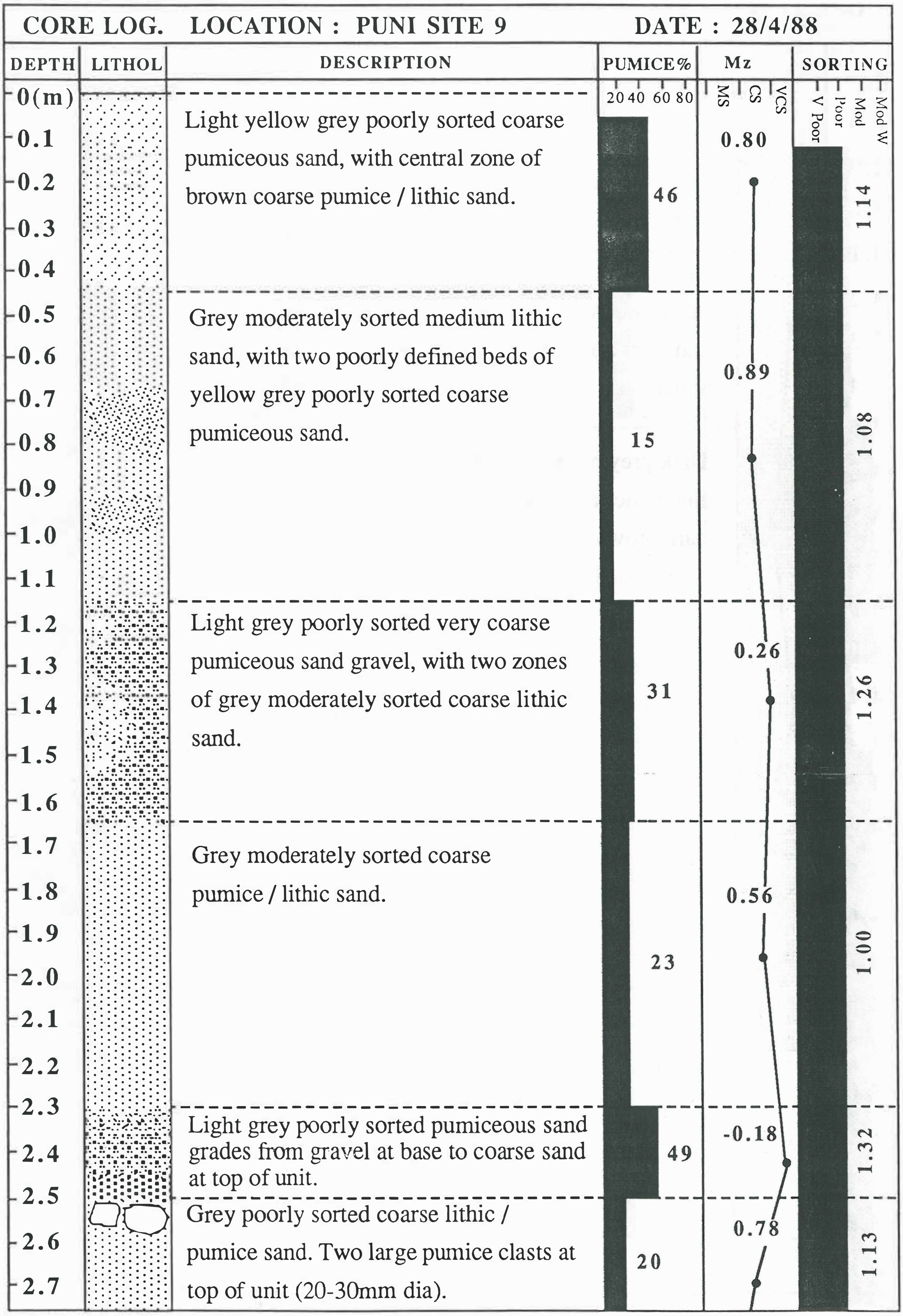

CORE LOG. LOCATION : PUNI SITE 7
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
Yellow grey moderately sorted very coarse pumiceous sand. Grades into both confining units.
58
-0.20
0.8
Light yellow grey moderate to poorly sorted very coarse pumiceous sand. Contains a single bed (20mm) of moderately well sorted medium lithic sand at 3.5m.
76
-0.40
1.09
Light yellow grey poorly sorted very coarse pumiceous sand/gravel. Unit contains a number of large pumice clasts (20-50mm).
-0.34
77
1.39
Generally bottom 3m tends to coarsen and sorting decreases downward.
E.O.H

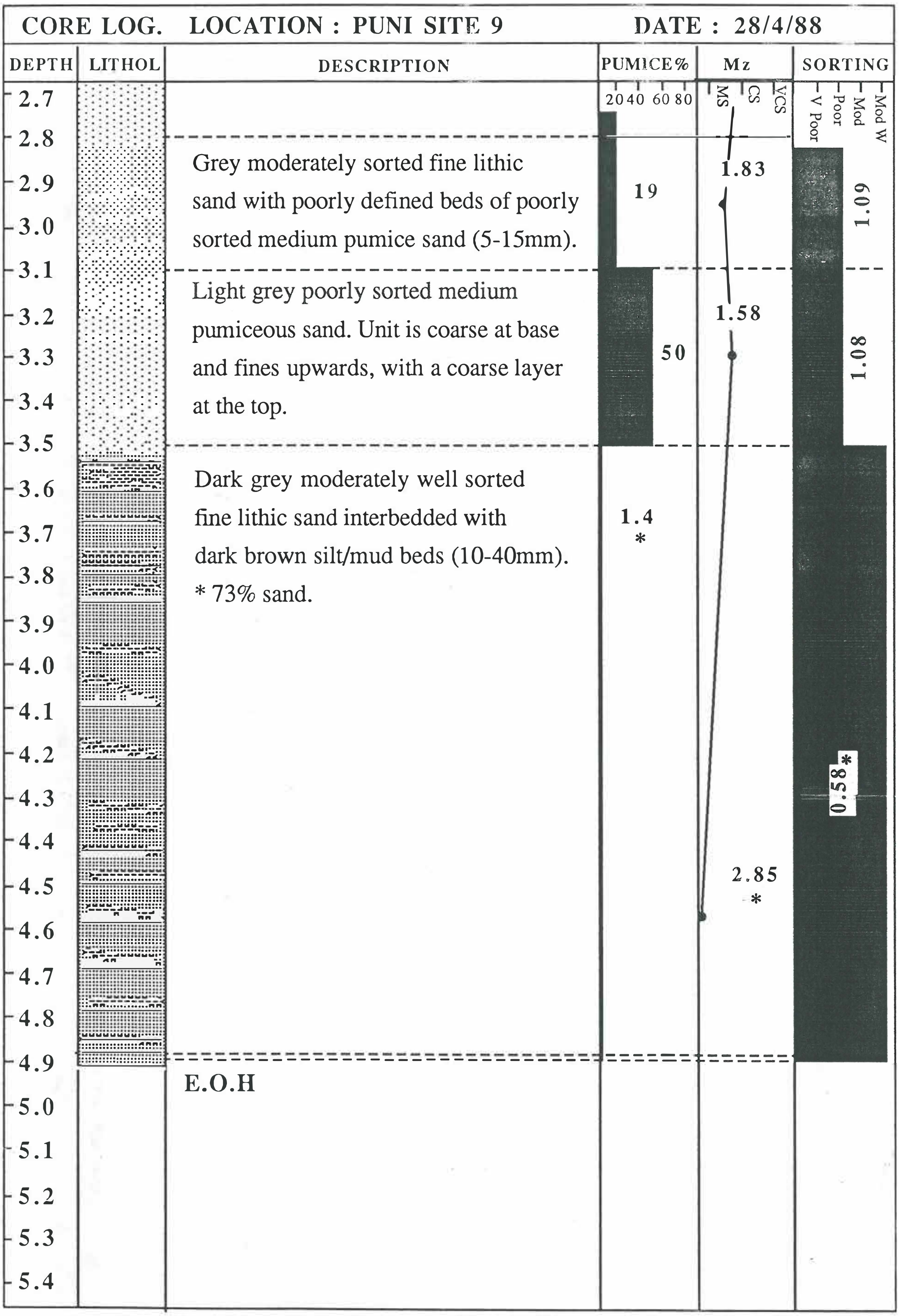
CORE LOG. LOCATION : PUNI SITE 8 DATE : 28/4/88

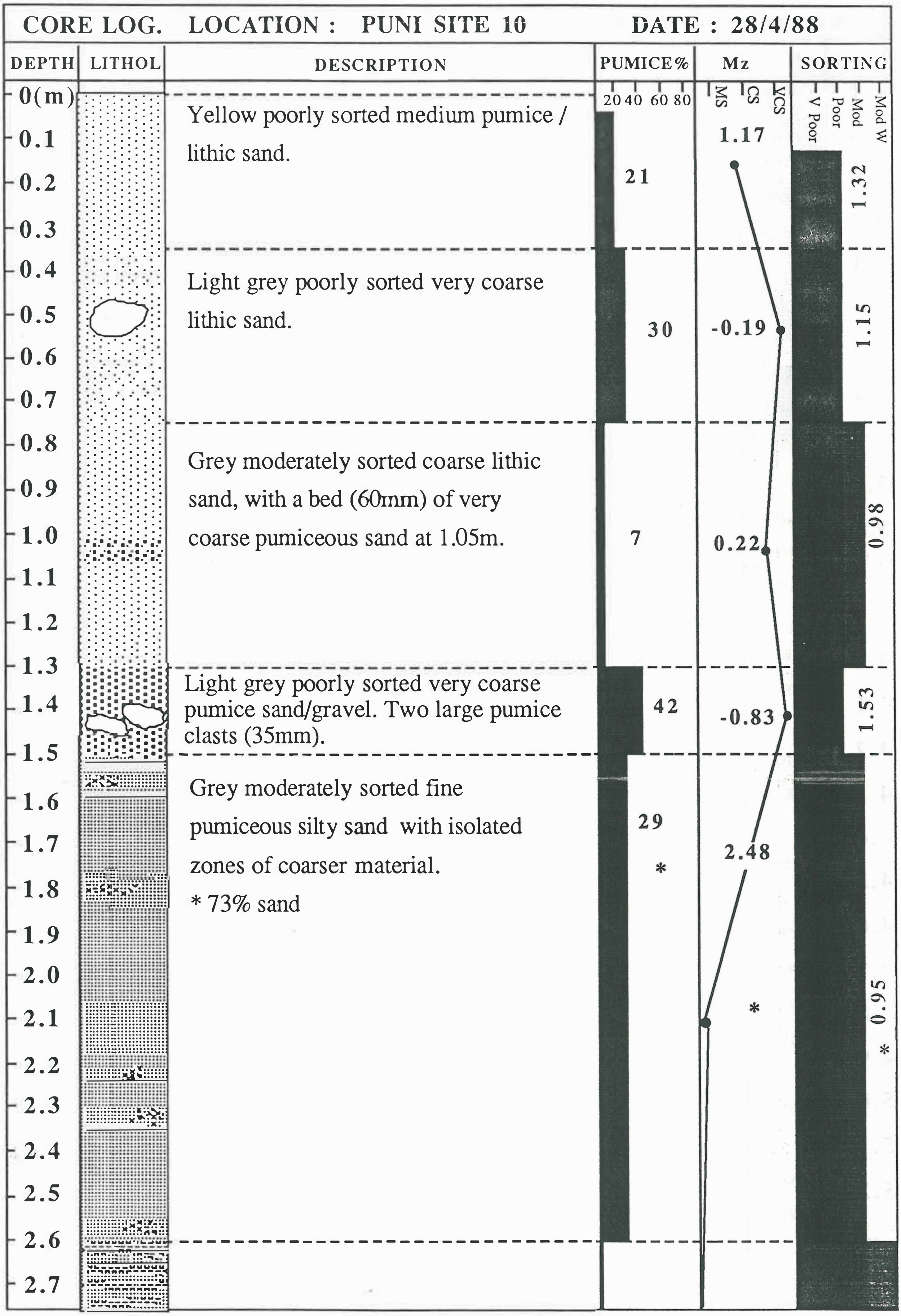
DEPTH (m)	DESCRIPTION	PUMICE%	Mz	SORTING
0–0.3	Brown grey poorly sorted coarse lithic / pumice sand.	25	0.13	1.27
0.3–1.1	Grey brown moderately sorted coarse lithic sand interbedded with light grey poorly sorted very coarse pumiceous sands/gravel.	29	0.16	1.19
1.1–1.4	Dark grey poorly sorted medium to coarse lithic sand. Unit coarsens downwards.	7	0.80	1.03
1.4–1.8	Grey moderately sorted coarse lithic sand, with poorly defined beds / zones of poorly sorted very coarse pumiceous sand.	24	0.24	1.02
1.8–2.3	1.8 to 3.7m is essentially one unit that grades from predominantly lithic sand interbedded with pumice sand to pumice sand interbedded with lithic sand. Grey moderately well sorted medium lithic sand, with thin (5-10mm) beds of darker rock fragment rich sand.	3	1.27	0.65
2.3–2.7	Lighter coloured beds become more pronounced with an increase in pumice percentage.This unit is a coarse, moderately sorted sand.	12	0.86	0.74

Scale labels: PUMICE% 20 40 60 80; Mz MS CS VCS; SORTING V Poor, Poor, Mod, Mod W. Depth axis 0(m) to 2.7 in 0.1 m steps.


CORE LOG. LOCATION : PUNI SITE 8
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
Lighter coloured beds become more pronounced with an increase in pumice percentage, a coarser and moderately sorted sand.
Light yellow grey moderately sorted coarse pumice sand interbedded with moderately sorted medium to coarse lithic sands (10-30mm).
34
0.24
0.93
Light yellow grey poorly sorted very coarse pumiceous sand. Beds of moderately sorted coarse lithic sand (20-30mm). Large charcoal fragment at 4.15 m (50 mm diameter).
61
-0.10
1.38
Brown grey poorly sorted coarse lithic sand.
18
0.20
1.23
Grey poorly sorted medium pumice / lithic sand.
38
1.22
1.21

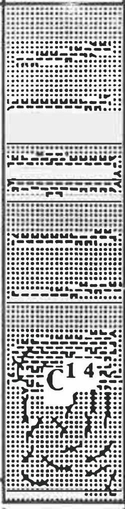

CORE LOG. LOCATION : PUNI SITE 9
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
Light yellow grey poorly sorted coarse pumiceous sand, with central zone of brown coarse pumice / lithic sand.
46
0.80
1.14
Grey moderately sorted medium lithic sand, with two poorly defined beds of yellow grey poorly sorted coarse pumiceous sand.
15
0.89
1.08
Light grey poorly sorted very coarse pumiceous sand gravel, with two zones of grey moderately sorted coarse lithic sand.
31
0.26
1.26
Grey moderately sorted coarse pumice / lithic sand.
23
0.56
1.00
Light grey poorly sorted pumiceous sand grades from gravel at base to coarse sand at top of unit.
49
-0.18
1.32
Grey poorly sorted coarse lithic / pumice sand. Two large pumice clasts at top of unit (20-30mm dia).
20
0.78
1.13


CORE LOG. LOCATION : PUNI SITE 9
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
2.7
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Grey moderately sorted fine lithic sand with poorly defined beds of poorly sorted medium pumice sand (5-15mm).
19
1.83
1.09
Light grey poorly sorted medium pumiceous sand. Unit is coarse at base and fines upwards, with a coarse layer at the top.
50
1.58
1.08
Dark grey moderately well sorted fine lithic sand interbedded with dark brown silt/mud beds (10-40mm).
* 73% sand.
1.4
*
2.85
*
0.58*
E.O.H



CORE LOG. LOCATION : PUNI SITE 10
DATE : 28/4/88
DEPTH
LITHOL
DESCRIPTION
PUMICE%
Mz
SORTING
0(m)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
20 40 60 80
MS
CS
VCS
V Poor
Poor
Mod
Mod W
Yellow poorly sorted medium pumice / lithic sand.
Light grey poorly sorted very coarse lithic sand.
Grey moderately sorted coarse lithic sand, with a bed (60mm) of very coarse pumiceous sand at 1.05m.
Light grey poorly sorted very coarse pumice sand/gravel. Two large pumice clasts (35mm).
Grey moderately sorted fine pumiceous silty sand with isolated zones of coarser material.
* 73% sand
21
30
7
42
29
*
1.17
-0.19
0.22
-0.83
2.48
*
1.32
1.15
0.98
1.53
0.95
*

CORE LOG. LOCATION : PUNI SITE 10 DATE : 28/4/88

DEPTH	LITHOL	DESCRIPTION	PUMICE%	Mz	SORTING
			20 40 60 80	MS CS VCS	V Poor Poor Mod Mod W
2.7–3.5		Dark grey brown well sorted fine lithic sand interbedded with dark brown silt/mud layers (10-100mm). Shell fragments in bottom 30cm of core. * 80% sand.	1 *	2.8 *	* 0.60

Depth scale: 2.7, 2.8, 2.9, 3.0, 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4.0, 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, 5.4

APPENDIX 6

COMPUTER PROGRAMS AND SEDIMENT TEXTURAL DATA

The contents of this appendix are contained on microfiche (see back cover). The following is a brief description of its contents and the methods and logic used in the programs, that are presented on the microfiche.

Appendix 6.1 : (8 pages) **DIGIT.PAS**. This program is used for the digitisation of X and Y coordinate data onto the VAX VMS system using a Summagraphic digitising table. In this study the program was used to digitise echo sounding traces of the bed morphology study area in order to produce the 3D diagrams of the river bed. Longitudinal echo sounding traces were also digitised onto the VAX for replotting and analysis. Core location base maps were produced by digitising aerial photos with the core sites on, and replotting with SAS.

Although this program was initially written for this project, it has a diverse application in all areas of Earth Sciences. The program contains an angle correction procedure, so that the document to be digitised does not have to be placed square with the digitising table.

Appendix 6.2 : (3 pages) **LCOORDS.PAS**. This program accepts digitised information for the longitudinal echo sounding runs of the bed morphology study area and converts the coordinates (which are in reality Y(longitudinal) and Z (depth) values) of the two dimensional trace into X, Y & Z coordinates for the production of a 3D diagram (given the end coordinates of each 2D trace).

Appendix 6.3 : (3 pages) **SCOORDS.PAS**. Similar to LCOORDS but converts lateral (X) and depth (Z) data into X, Y & Z.

Appendix 6.4 : (4 pages) **BEDFORM.PAS**. This program accepts converted, digitised data for the longitudinal profiles of the bed morphology study area. Taking values at approximately 10 m intervals, it then creates two new data points between each set of longitudinal profiles and the banks using linear interpolation. This process is required as SAS can only produce a 3D diagram or contour plot accurately if the input data approximates a grid.

Appendix 6.5 : (1 page) **3D SAS Program**. Takes data output from BEDFORM.PAS and plots a three dimensional diagram of the river bed, for each month.

Appendix 6.6 : (1 page) **CONTOUR SAS Program**. Takes data output from Bedform.pas and produces a contour plot of the river bed, for each month (see Appendix 4).

Appendix 6.7 : (9 pages) **GSIZE.PAS**. This program only accepts grain size data in Phi (Ø) units as defined by Kurmbein (1934) as;

$\emptyset = -\log_2 d(\mathrm{mm})$

The sieve analysis data is used to calculate the following textural parameters; mean, sorting, skewness and kurtosis using both graphical and moment methods, D65, D35, C (coarsest 1 %), and % gravel, sand and silt.

The formulae used are those defined by Carver (1971) and are given below, with these graphical formulae producing the highest efficiency according to Carver (1971). Verbal descriptions of sorting, skewness and kurtosis are given in accordance with Folk (1968).

MOMENT STATISTICS FORMULAE

Mean $\bar{X}_\phi = \dfrac{\Sigma fm}{n}$ Sorting $\sigma_\phi = \sqrt{\dfrac{\Sigma f(m - \bar{x}_\phi)^2}{100}}$

Skewness $Sk_\phi = \dfrac{\Sigma f(m - \bar{x}_\phi)^3}{100\,\sigma_\phi^3}$ Kurtosis $K_\phi = \dfrac{\Sigma f(m - \bar{x}_\phi)^4}{100\,\sigma_\phi^4}$

GRAPHICAL STATISTICS FORMULAE

Mean $\bar{X}_g = (\phi 5 + \phi 15 + \phi 25 + \phi 35 + \ldots\ldots + \phi 85 + \phi 95)/10$

Sorting $\sigma_g = (\phi 70 + \phi 80 + \phi 90 + \phi 97 - \phi 3 - \phi 10 - \phi 20 - \phi 30)\,/9.1$

Skewness $Sk_g = \dfrac{\phi 84 + \phi 16 - 2\phi 50}{2(\phi 84 - \phi 16)} + \dfrac{\phi 95 + \phi 5 - 2\phi 50}{2(\phi 95 - \phi 5)}$

Kurtosis $K_g = \dfrac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)}$

Where $\phi j = j^{th}$ Percentile in Phi

Appendix 6.8 : (34 pages) **Mercer Core Textural Data**. Contains the textural data output of GSIZE for the Mercer core samples.

Appendix 6.9 : (46 pages) **Puni Core Textural Data**. Contains the textural data output of GSIZE for the Puni core samples.

Appendix 6.10 : (32 pages) **Surface Sediment Textural Data**. Contains the textural data output of GSIZE for surface sediment samples used in this study.

APPENDIX 7

WAIKATO SAMPLE NUMBERS

Correlation of personal field numbers with University of Waikato Earth Science Department sample numbers. Refer to Figure 5.3 and 5.4 for location of core samples. All samples are loose sand.

Waikato Uni. No.	Field No.
WT 26401	Mercer Site 1, 0 - 0.45 m
WT 26402	Mercer Site 1, 0.45 - 0.95 m
WT 26403	Mercer Site 1, 0.95 - 1.75 m
WT 26404	Mercer Site 1, 1.75 - 2.5 m
WT 26405	Mercer Site 1, 2.5 - 3.45 m
WT 26406	Mercer Site 1, 3.45 - 3.9 m
WT 26407	Mercer Site 2, 0 - 0.35 m
WT 26408	Mercer Site 2, 0.35 - 1.05 m
WT 26409	Mercer Site 2, 1.05 - 1.5 m
WT 26410	Mercer Site 2, 1.5 - 1.7 m
WT 26411	Mercer Site 2, 1.7 - 2.15 m
WT 26412	Mercer Site 2, 2.15 - 2.65 m
WT 26413	Mercer Site 2, 2.65 - 3.8 m
WT 26414	Mercer Site 2, 3.8 - 4.35 m
WT 26415	Mercer Site 2, 4.35 - 4.8 m
WT 26416	Mercer Site 2, 4.8 - 5.45 m
WT 26417	Mercer Site 3, 0 - 0.7 m
WT 26418	Mercer Site 3, 0.7 - 0.85 m
WT 26419	Mercer Site 3, 0.85 - 2.0 m
WT 26420	Mercer Site 3, 2.0 - 2.7 m
WT 26421	Mercer Site 3, 2.7 - 2.8 m
WT 26422	Mercer Site 3, 2.8 - 3.55 m
WT 26423	Mercer Site 3, 3.55 - 4.1 m
WT 26424	Mercer Site 3, 4.1 - 4.7 m
WT 26425	Mercer Site 3, 4.7 - 4.8 m
WT 26426	Mercer Site 3, 4.8 - 5.0 m
WT 26427	Mercer Site 4, 0 - 1.2 m
WT 26428	Mercer Site 4, 1.2 - 1.55 m
WT 26429	Mercer Site 4, 1.55 - 2.0 m
WT 26430	Mercer Site 4, 2.0 - 2.1 m
WT 26431	Mercer Site 4, 2.1 - 3.05 m
WT 26432	Mercer Site 4, 3.05 - 3.45 m
WT 26433	Mercer Site 4, 3.45 - 4.0 m
WT 26434	Mercer Site 4, 4.0 - 4.35 m
WT 26435	Mercer Site 4, 4.35 - 4.65 m
WT 26436	Mercer Site 4, 4.65 - 5.2 m
WT 26437	Mercer Site 4, 5.2 - 5.3 m
WT 26438	Mercer Site 4, 5.3 - 5.4 m
WT 26439	Mercer Site 5, 0 - 0.25 m
WT 26440	Mercer Site 5, 0.25 - 1.0 m
WT 26441	Mercer Site 5, 1.0 - 1.7 m
WT 26442	Mercer Site 5, 1.7 - 2.1 m
WT 26443	Mercer Site 5, 2.1 - 2.35 m
WT 26444	Mercer Site 5, 2.35 - 2.5 m
WT 26445	Mercer Site 5, 2.5 - 3.4 m
WT 26446	Mercer Site 5, 3.4 - 3.8 m
WT 26447	Mercer Site 5, 3.8 - 4.2 m
WT 26448	Mercer Site 5, 4.2 - 4.7 m
WT 26449	Mercer Site 5, 4.7 - 4.95 m

Waikato Uni. No.	Field No.
WT 26450	Mercer Site 5, 4.95 - 5.15 m
WT 26451	Mercer Site 6, 0 - 0.3 m
WT 26452	Mercer Site 6, 0.3 - 0.65 m
WT 26453	Mercer Site 6, 0.65 - 1.95 m
WT 26454	Mercer Site 6, 1.95 - 2.3 m
WT 26455	Mercer Site 6, 2.3 - 3.2 m
WT 26456	Mercer Site 6, 3.2 - 3.6 m
WT 26457	Mercer Site 6, 3.6 - 4.55 m
WT 26458	Mercer Site 6, 4.55 - 5.4 m
WT 26459	Mercer Site 7, 0 - 0.5 m
WT 26460	Mercer Site 7, 0.5 - 0.95 m
WT 26461	Mercer Site 7, 0.95 - 1.65 m
WT 26462	Mercer Site 7, 1.65 - 2.45 m
WT 26463	Mercer Site 7, 2.45 - 2.75 m
WT 26464	Mercer Site 7, 2.75 - 3.15 m
WT 26465	Mercer Site 7, 3.15 - 3.4 m
WT 26466	Mercer Site 7, 3.4 - 3.55 m
WT 26467	Mercer Site 7, 3.55 -4.5 m
WT 26468	Mercer Site 7, 4.5 - 5.1 m
WT 26469	Puni Site 1, 0 - 0.55 m
WT 26470	Puni Site 1, 0.55 - 1.15 m
WT 26471	Puni Site 1, 1.15 - 1.5 m
WT 26472	Puni Site 1, 1.5 - 1.85 m
WT 26473	Puni Site 1, 1.85 - 2.4 m
WT 26474	Puni Site 1, 2.4 - 2.55 m
WT 26475	Puni Site 1, 2.55 - 2.85 m
WT 26476	Puni Site 1, 2.85 - 2.95 m
WT 26477	Puni Site 1, 2.95 - 3.1 m
WT 26478	Puni Site 1, 3.1 - 3.45 m
WT 26479	Puni Site 1, 3.45 - 4.35 m
WT 26480	Puni Site 1, 4.35 - 5.0 m
WT 26481	Puni Site 2, 0 - 1.1 m
WT 26482	Puni Site 2, 1.1 - 1.3 m
WT 26483	Puni Site 2, 1.3 - 1.8 m
WT 26484	Puni Site 2, 1.8 - 2.15 m
WT 26485	Puni Site 2, 2.15 - 2.4 m
WT 26486	Puni Site 2, 2.4 - 2.65 m
WT 26487	Puni Site 2, 2.65 - 3.1 m
WT 26488	Puni Site 2, 3.1 - 3.45 m
WT 26489	Puni Site 2, 3.45 - 3.8 m
WT 26490	Puni Site 2, 3.8 -4.15 m
WT 26491	Puni Site 2, 4.15 - 4.6 m
WT 26492	Puni Site 2, 4.6 - 5.3 m
WT 26493	Puni Site 3, 0 - 0.45 m
WT 26494	Puni Site 3, 0.45 -0.7 m
WT 26494	Puni Site 3, 0.7 - 1.55 m
WT 26496	Puni Site 3, 1.55 - 2.15 m
WT 26497	Puni Site 3, 2.15 - 2.7 m
WT 26498	Puni Site 3, 2.7 - 3.0 m

Waikato Uni. No.	Field No.
WT 26499	Puni Site 3, 3.0 - 3.7 m
WT 26500	Puni Site 3, 3.7 - 3.95 m
WT 26501	Puni Site 3, 3.95 - 4.65 m
WT 26502	Puni Site 3, 4.65 - 5.2 m
WT 26503	Puni Site 4, 0 - 0.1 m
WT 26504	Puni Site 4, 0.1 - 0.8 m
WT 26505	Puni Site 4, 0.8 - 1.05 m
WT 26506	Puni Site 4, 1.05 - 1.35 m
WT 26507	Puni Site 4, 1.35 - 2.15 m
WT 26508	Puni Site 4, 2.15 - 3.45 m
WT 26509	Puni Site 4, 3.45 - 3.7 m
WT 26510	Puni Site 4, 3.7 - 4.7 m
WT 26511	Puni Site 4, 4.7 - 5.1 m
WT 26512	Puni Site 4, 5.1 - 5.4 m
WT 26513	Puni Site 5, 0 - 0.3 m
WT 26514	Puni Site 5, 0.3 -0.75 m
WT 26515	Puni Site 5, 0.75 - 1.0 m
WT 26516	Puni Site 5, 1.0 - 1.3 m
WT 26517	Puni Site 5, 1.3 - 1.8 m
WT 26518	Puni Site 5, 1.8 - 2.15m
WT 26519	Puni Site 5, 2.15 - 2.85 m
WT 26520	Puni Site 5, 2.85 - 3.85 m
WT 26521	Puni Site 5, 3.85 - 4.25 m
WT 26522	Puni Site 5, 4.25 - 5.1 m
WT 26523	Puni Site 6, 0 - 0.3 m
WT 26524	Puni Site 6, 0.3 - 1.65 m
WT 26525	Puni Site 6, 1.65 - 3.75 m
WT 26526	Puni Site 6, 3.75 -4.0 m
WT 26527	Puni Site 6, 4.0 - 5.05 m
WT 26528	Puni Site 7, 0 - 0.45 m
WT 26529	Puni Site 7, 0.45 - 1.55 m
WT 26530	Puni Site 7, 1.55 - 2.25 m

Waikato Uni. No.	Field No.
WT 26531	Puni Site 7, 2.25 - 2.7 m
WT 26532	Puni Site 7, 2.7 - 2.95 m
WT 26533	Puni Site 7, 2.95 - 3.65 m
WT 26534	Puni Site 7, 3.65 -5.1 m
WT 26535	Puni Site 8, 0 - 0.3 m
WT 26536	Puni Site 8, 0.3 - 1.1 m
WT 26537	Puni Site 8, 1.1 - 1.4 m
WT 26538	Puni Site 8, 1.4 - 1.8 m
WT 26539	Puni Site 8, 1.8 - 2.25 m
WT 26540	Puni Site 8, 2.25 - 3.2 m
WT 26541	Puni Site 8, 3.2 - 3.7 m
WT 26542	Puni Site 8, 3.7 - 4.45 m
WT 26543	Puni Site 8, 4.45 - 4.95 m
WT 26544	Puni Site 8, 4.95 - 5.25 m
WT 26545	Puni Site 9, 0 - 0.45 m
WT 26546	Puni Site 9, 0.45 - 1.15 m
WT 26547	Puni Site 9, 1.15 - 1.65 m
WT 26548	Puni Site 9, 1.65 - 2.3 m
WT 26549	Puni Site 9, 2.3 - 2.5 m
WT 26550	Puni Site 9, 2.5 - 2.8 m
WT 26551	Puni Site 9, 2.8 - 3.1 m
WT 26552	Puni Site 9, 3.1 - 3.5 m
WT 26553	Puni Site 9, 3.5 - 4.9 m
WT 26554	Puni Site 10, 0 - 0.35 m
WT 26555	Puni Site 10, 0.35 - 0.75 m
WT 26556	Puni Site 10, 0.75 -1.3 m
WT 26557	Puni Site 10, 1.3 -1.5 m
WT 26558	Puni Site 10, 1.5 - 2.6 m
WT 26559	Puni Site 10, 2.6 - 3.5 m

Waikato Uni. No.	Field No.	Grid Ref.
WT 26562	Bar profile Opp C.S L	see Figure 3.16
WT 26563	Bar profile Opp C.S K	see Figure 3.16
WT 26564	Bar profile peg 1	100 m upstream of crest
WT 26565	Bar profile peg 2	80 m upstream of crest
WT 26566	Bar profile peg 3	60 m upstream of crest
WT 26567	Bar profile peg 4	40 m upstream of crest
WT 26568	Bar profile peg 5	20 m upstream of crest
WT 26569	Bar profile top crest	see Figure 3.19
WT 26570	Bar profile bottom crest	see Figure 3.19
WT 26571	Bar profile peg 6	20 m downstream of crest
WT 26572	Bar profile peg 7	40 m downstream of crest
WT 26573	Bar profile peg 8	60 m downstream of crest
WT 26574	Bar profile peg 9	80 m downstream of crest
WT 26575	Surface sample 1	S15/275642
WT 26576	Surface sample 2	S15/234645
WT 26577	Surface sample 3/1	S15/187674
WT 26578	Surface sample 3/2	S15/187674
WT 26579	Surface sample 3/3	S15/187674
WT 26580	Surface sample 4/1	S14/155716
WT 26581	Surface sample 4/2	S14/155716
WT 26582	Surface sample 4/3	S14/155716
WT 26583	Surface sample 5/1	S14/116768
WT 26584	Surface sample 5/2	S14/116768

WT 26585	Surface sample 5/3	S14/116768
Waikato Uni. No.	Field No.	Grid Ref.
WT 26585	Surface sample 5/4	S14/116768
WT 26586	Surface sample 5/5	S14/116768
WT 26587	Surface sample 6/1	S14/068839
WT 26588	Surface sample 6/2	S14/068839
WT 26589	Surface sample 6/3	S14/068839
WT 26590	Surface sample 6/4	S14/068839
WT 26591	Surface sample 6/5	S14/068839
WT 26592	Surface sample 7/1	S14/018892
WT 26593	Surface sample 7/2	S14/018892
WT 26594	Surface sample 7/3	S14/018892
WT 26595	Surface sample 7/4	S14/018892
WT 26596	Surface sample 7/5	S14/018892
WT 26597	Surface sample 17	S13/917276
WT 26598	Surface sample 18	S13/933298
WT 26599	Surface sample 19	S12/921333
WT 26600	Surface sample 20	R12/862332
WT 26601	Surface sample 20a	R12/828318
WT 26602	Surface sample 21	R12/813336
WT 26603	Surface sample 22	R12/746352
WT 26604	Surface sample A	R12/861333
WT 26605	Surface sample B	R12/814336
WT 26606	Surface sample C	R12/782346
WT 26607	Surface sample D	R12/744346
WT 26608	Surface sample E	R12/731319
WT 26609	Bedload sample 1	C.S 73
WT 26610	Bedload sample 2	C.S 73
WT 26611	Bedload sample 3	C.S 73
WT 26612	Bedload sample 4	C.S 73