BEROWRA CREEK ESTUARY PROCESS STUDY

TECHNICAL REPORT:

SEDIMENT CHARACTERISTICS AND PROCESSES

May, 1998

Report prepared for:

Hornsby Shire Council

by

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7 May, 1998

SUMMARY

Investigations of sediment characteristics and processes in Berowra Creek reported here provide an overview of the long-term evolution of the estuary as a context for contemporary management issues of estuarine sedimentation and sediment contamination. The work has provided new evidence on rates of estuarine infilling and levels of sediment contamination in Berowra Creek as well as highlighting the probable impact of the Hawkesbury River on sedimentation within the Study Area.

Accelerated rates of estuarine infilling associated with catchment clearing, urbanisation etc. were not detected in a volumetric analysis of fluvial delta deposits. The result is consistent with the observation that natural factors such as bushfires, natural vegetation cover change in response to long-term climatic change, rainfall variability, bioturbation etc. may mask anthropogenic influences on catchment denudation. Estuarine infilling is most evident in the vicinity of the Marramarra and Berowra Creek fluvial deltas. Estimated rates of delta advance for Berowra Creek based on limited dated core data suggest an increase in delta progradation from 0.9m/year (time-averaged over 7000 years) to around 1.3m/year over the past 460 years. The rate of delta advance over the past 460 years suggests a build up of sandy sediments at the Berowra Ferry is likely to take hundreds rather than tens of years.

Bathymetric trends in Berowra Creek indicate a convergence in mud deposition from upstream and downstream in the vicinity of Calabash Point. Downstream of here, mud from the Hawkesbury River accumulates in tidal mud flats along the estuary margin and within the main channel (mud basin). Time-averaged rates of sediment accumulation in the mud basin (3mm/year) are at the top end of estimates for mud basin sedimentation and possibly reflect the influx of fine grained sediments from the Hawkesbury River. A large proportion of the fine grained sediment from the Berowra catchment appears to be deposited within the mud basin upstream of Calabash Point. While no information is available on rates of mud basin deposition in this area, analysis of archived core samples would provide the necessary data.

Sediment contaminant studies have identified background levels for heavy metals and nutrients for the StudyArea and levels of enrichment in the surface sediments. The surface sediments are enriched in nutrients (TKN, TP) and heavy metals (Cu, Pb, Zn, Cr and As). Nutrient enrichment levels in surface sediments between Coba Point and Bar Island suggest an influx of nutrient laden sediment from the Hawkesbury River. A tentative link between high nutrient levels in surface sediments and areas of significant mangrove expansion downstream of Coba Point has been proposed.

Enrichment levels for metals in the surface sediments are most marked for chromium, copper, lead and zinc. Enrichment factors of between 3 to 5 times above background are common with a maximum enrichment of 10 times background recorded for lead. Levels of metal enrichment appear to increase upstream, reaching a maximum in the vicinity of the Berowra Ferry. Heavy metal contamination of the surface sediments presumably reflects the influence of point (sewage overflows, antifouling paints) and non-point sources (urban runoff, dust, vehicle emissions) in the catchment.

Recommendations made to clarify aspects of estuarine sedimentation and sediment contamination within the Study Area include:

1) Historic rates of sedimentation in key areas of Berowra Creek need to be addressed (ie. Berowra Ferry). The data should aim to provide greater temporal and spatial resolution of sedimentation rates estimated here. Recommendation is made for detailed analysis of selected core samples to establish historic sedimentation rates based on heavy metal profiles supplemented with radiometric dating (Carbon, Lead-Caesium). Archived core samples from the Berowra Ferry area (BCVC8) and Bar Island (BCVC1 and BCVC2) could be used for this purpose.

2) Sediment texture/composition and contamination relationships developed here need to be examined further. Detailed analysis of selected core samples is warranted and could be incorporated with the work suggested in the previous recommendation.

3) Environmental and geological data used in this report are available in digital format and should be utilised by Council Officers in the development and monitoring of estuarine management strategies. The data are of sufficient resolution to be used at a variety of spatial scales (site specific to regional) for a range of environmental/ planning initiatives. The viability and usefulness of the Project Geographic Information System will require an ongoing commitment of resources, particularly in the area of personnel training.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acknowledgements

The Berowra Creek sediment characteristics and process study benefited from the cooperation and assistance of many individuals.

Special mention needs to be made of Ross McPherson (Hornsby Shire Council) for his overall assistance with the project. Ross provided invaluable help with the field program (surface sediment sampling, Marramarra Creek drilling), facilitated access to Council files and data, and arranged for contaminant analyses of vibracore samples.

Bruce Coates and Martin Fitzhenry (NSW Dept. Land & Water Conservation) assisted with the field program (vibracoring and surface sediment sampling) and provided the extra funding required for vibracoring and radiocarbon dating. Col Browne and Phil Clark (Manly Hydraulics Laboratory) conducted the vibracoring. Riko Hashimoto and Justin Meleo (PhD. Students, University of Sydney) assisted with the Marramarra Creek drilling. Mark Howden (Manly Hydraulics Lab.) assisted with the GIS development.

Dr. Tony Roache (EPA) arranged for and reported on contaminant analyses of core samples. Dr. Wayne Erskine (Dept. Geography, UNSW) provided information on work conducted in the Crosslands area and background information on catchment erosion studies.

Dr. Peter Roy (DMR, NSW Geological Survey) supplied information on previous geological investigations in Berowra Creek and provided useful comments on the report draft.

1. Introduction

The Berowra Creek Estuary Process Study (BCEPS) is an investigation of the physical processes operating within Berowra Creek conducted for the purpose of providing information for the future management and monitoring of the estuarine system. The BCEPS represents Stage 3 of an eight-step structured approach to estuarine management described in the New South Wales State Government's Estuary Management Manual (NSW Government, 1992).

The process study has been undertaken by a team of consultants including the Manly Hydraulics Laboratory (Project Manager), Coastal & Marine Geosciences and The Ecology Lab. This report on sediment characteristics and processes has been prepared by Coastal & Marine Geosciences (CMG).

Berowra Creek is a tidal water body connected to the lower Hawkesbury River system in northern Sydney (Figure 1). For the purpose of the current investigations, the Study Area is defined as the tidal water bodies upstream of Bar Island including Berowra Creek, Marramarra Creek and their tributaries (Figure 1). Throughout the remainder of the report the estuarine system is referred to as either the Study Area or simply Berowra Creek. While this study has focused on processes operating within the estuary, it is clear that material loads delivered into the system from the surrounding catchments also have impacts and these catchment-wide influences have been addressed as part of the BCEPS.

The "Berowra Creek Sediment Characteristics and Processes" report is one of five technical documents to be produced for the BCEPS. Each report addresses key management issues identified in the study brief. The technical reports will form the basis of a final summary report to be prepared at the completion of the project.

The following contains an appreciation of the study brief (Section 2) and a review of background data relevant to sedimentation issues within the Study Area (Section 3). The remainder of the report outlines the study methodology (Section 4), results of the investigations (Section 5), a discussion of the results (Section 6) and concludes with a summary of the main findings plus a series of recommendations (Section 7). Detailed data referred to throughout the report are contained in the Appendices (Section 10).

2. Study Brief and Objectives

Management issues identified in the study brief prepared by the Hornsby Council Berowra Creek Estuary Management Committee are summarised in the MHL Proposal (MHL, 1996) and were discussed with Committee members prior to the commencement of the project. In general, the study brief underlined a need to understand the natural hydrodynamic and sedimentary processes operating within Berowra Creek for the purpose of assessing the impact of human activities within the estuary and its catchment.

The objectives for investigations into sediment characteristics and processes included:

1) Preparation of a review document establishing the level and reliability of existing information for the Berowra Creek estuary.

2) A description of the Berowra Creek catchment geology, geomorphology and soils with consolidation of the data in a digital format within a Geographic Information System (GIS).

3) An assessment of the spatial and temporal components of catchment erosion/ sedimentation with particular attention to potential anthropogenic impacts on natural erosion/sedimentation processes and rates.

4) A description of estuarine morphology and an examination of historic estuarine change within the context of past catchment modifications.

5) Identification of the distribution and character of the main in-channel fluvial and estuarine lithofacies (unconsolidated sediment types) and their associated levels and types of contamination.

6) Development of a conceptual sediment budget for the Berowra Creek catchment identifying the major sediment inputs and outputs over historic and contemporary time frames.

Central to the attainment of these objectives has been the development of a project GIS. Coastal & Marine Geosciences (CMG) and MHL have combined datasets from a variety of sources (ie. Government Departments/organisations, Hornsby Council, published and unpublished reports/plans) within a GIS developed specifically for the BCEPS. The GIS utilises industry-standard applications for data warehousing, interrogation and presentation. Details of how the GIS are contained in Section 10 (Appendix A).

Considerable effort has been expended in combining digital datasets, or coverages, for the Study Area. Apart from its immediate application in the present investigation, the GIS clearly has a utility beyond the BCEPS. The GIS provides for reliable and informed decision making in relation to a range of catchment-wide environmental and management issues.

3. Background

A detailed review of existing information on the geology and geomorphology of the Study Area has been completed as part of the review compiled by MHL (MHL, 1997). The main aspects of this review, as they relate to issues of catchment and estuarine erosion/ sedimentation, are included here as background to the investigations carried out over the past months. Place names and localities referred to below are shown on Figure 1.

Berowra Creek is an example of a drowned river valley estuary created in the lower Hawkesbury River valley by rising sea levels some 10,000 to 6,500 years ago (Roy, 1994). Geological data show that sea levels rose rapidly (up to 1.3m/century) over the period between 18,000 to 6,500 years ago (last glacial maximum and sea level stillstand respectively) as global ice volumes diminished with warming of the earth's surface and atmosphere. A conceptual model identifying key stages in the evolution of the lower Hawkesbury estuary is shown Figure 2 along with a relative sea level curve for the past 12,000 years.

The evolutionary model highlights the creation of a deep, bedrock-controlled estuary by rising sea levels around 9,000 years ago. Fine grained river sediments delivered from the Hawkesbury catchment became trapped within the estuary, forming extensive mud basin deposits landward of a sandy tidal delta deposited by wave and tidal currents at the entrance to Broken Bay. Coarser grained fluvial sediments (sands) initially accumulated in deltaic deposits remote from the coast and, in the case of the main arm of the Hawkesbury, upstream of Wisemans Ferry (Nichol et al., 1997). Over time and during the final stages of the sea level rise, the tidal delta extended further into the estuary, blanketing large areas of the mud basin. Fluvial sediments (sands) that were prograding downstream began to be deposited in the lower Hawkesbury estuary during mid to late Stillstand. Today, fluvial sands overlie both mud basin and tidal delta deposits near the estuary mouth (Figure 2).

Reconstruction of the late Holocene evolution of the lower Hawkesbury estuary is based primarily on investigations within the main channel and, with the exception of Pittwater and Brisbane Waters, few detailed studies are available for the drowned tributaries such as Cowan, Berowra and Mullet Creeks (Albani, 1974; PWD, 1987; Roy, 1994; Saintilan, 1995). The available data indicates that tributaries of the lower Hawkesbury are characterised by relatively deep water depths (in excess of 25m in some cases), soft estuarine muds, and small sandy fluvial deltas at the heads of the tributary valleys. Few tributaries are supplying fluvial sand directly to the main Hawkesbury channel and most remain underfilled with respect to sediment when compared to the Hawkesbury.

In effect, many of the tributaries are remnants of a much larger mud basin formed in the lower Hawkesbury estuary between 10,000 and 6,000 years ago (Figure 2). The downstream flux of coarse and fine grained sediments within the main arm of the Hawkesbury over the past 6,000 years has isolated the tributaries. Tributaries such as Berowra Creek act as traps for locally derived sediments and fine grained muds from the Hawkesbury River.

Berowra Creek is typical of many of the tributaries encountered in the lower Hawkesbury estuary. Information on its bathymetry, surficial sediment types, and stratigraphy defines a bedrock-controlled estuarine system presently infilling with both coarse and fine grained sediment. The fact that the Berowra Creek valley remains a relatively deep estuary indicates that its rate of infilling with sands and muds eroded from the catchments draining into Berowra and Marramarra Creeks is likely to be low (Roy, 1973; Wallace, 1974; PWD, 1987; Ambler and Hudson, 1990; Coles, 1995; Roy, 1994; Nichol et al., 1997).

The landforms, geology and soils of the Study Area are described at length in the Rural Lands and Sensitive Urban Lands studies prepared by the Hornsby Shire Council (Hornsby Shire, 1995; 1996). The geology is dominated by early to mid-Triassic sub-horizontally bedded sediments of the Sydney Basin. The Hawkesbury Sandstone is widespread and forms a dissected plateau some 200m+ above sea level. Deep gorges, incised drainage lines and prominent sandstone escarpments occur throughout much of the area. In the west of the Study Area, shales of the Wianamatta (Ashfield Shale) group overlie the Hawkesbury Sandstone and occupy ridgelines in the vicinity of Cherrybrook and Glenorie. Sandstones, shales, and claystones of the Narrabeen Group (Garie Formation) crop out below the Hawkesbury Sandstone escarpment in the lower reaches of Berowra and Marramarra Creeks. Isolated basaltic intrusions (volcanic breccia and dykes) occur in both catchments (Figure 3).

Unconsolidated fluvial and estuarine deposits of presumed mid to late Holocene age (less than 6,500 years old) partially infill the drowned bedrock valleys in Marramarra Creek, Peats Bight, Coba Bay, Bujwa Bay, Kimmerikong Bay, Joe Crafts Bay, Calabash Bay, and along the margins of Berowra Creek upstream of the Woolwash (Figure 1). These deposits represent the long-term accumulation of sediments within the estuary by material eroded from the local catchments and, in the lower portions of the Study Area, the Hawkesbury River catchment. River deposits (fluvial deltas), consisting of coarse grained quartzose sediments, are characterised by narrow elevated floodplains, emergent sandy shoals and shallow channels. The deltas have migrated slowly downstream over a period of thousands of years, partially infilling the deep estuarine mud basin. Fine grained fluvial muds from both the Berowra and Hawkesbury catchments continue to infill the estuarine mud basin downstream of the Woolwash. Many embayments in the lower section of Berowra Creek contain extensive mud flats built from the fine grained fluvial sediments.

Soil types in the Study Area are listed in Table 1. Soils associated with the Hawkesbury Sandstone include the Faulconbridge, Hawkesbury, Lambert, Gymea, and Oxford Falls soil landscapes with the Glenorie and Lucas Heights soil landscapes associated with the Wianamatta and Mittagong Formations (shales and fine grained sandstones) respectively. The Hawkesbury soil landscape (sandy soils, steep slopes) dominates much of the Study Area and occurs on the steep valley sides sloping to the main drainage lines. The Glenorie (clayey soils, low slopes), Gymea (sandy soils, upper slopes and benches) and Lucas Heights (clayey soils, low slopes) soil landscapes are common on the ridge tops and slopes around the western, southern and eastern perimeter of the Study Area.

All soil types are susceptible to erosion. Catchment modifications associated with urban development, agriculture and bushfire are capable of mobilising significant volumes of soil with sandy soils on steep slopes being the most erosion prone (Table 1; Hawkesbury soils landscape). Estimated and measured soil erosion rates for the Study Area and other sandstone landscapes in the Sydney region are summarised Table 2. Much of this data is drawn from a soil erosion survey of the Hornsby Shire prepared by Parmeter and Graham (1995) with additional information from Coles (1995), WP-Geomarine (1996) and Dr. Peter Roy (NSW Geological Survey, pers. comm.). The table shows a range of erosion rates with the highest rates occurring in developing residential areas on the Hawkesbury soil landscape. The lowest rates recorded for undisturbed bushland (Table 2).

Coles (1995) estimates an annual catchment denudation rate of 0.78t/ha for the Berowra Creek based on correlation between the suspended sediment discharge rating curve and total sediment load as measured at Galston Gorge. Dr. Peter Roy estimated a rate of 0.15t/ha for the Port Hacking catchment in southern Sydney based on the volume of mainly sandy sediment that has accumulated in the Hacking fluvial delta over the past 7000 years. Estimates of total annual sediment loads for residential areas elsewhere in the Sydney region range from 1.2 to 1.45t/ha (WP Geomarine, 1996).

Parmeter and Graham (1995) stress that the measured and estimated erosion rates for varying combinations of landuse and soil type are best used in assessing the relative risk of soil erosion rather than indicating absolute rates. The estimates given in Table 2 must, therefore, be used with caution. In reality, rates of soil erosion and landform denudation integrate a range of natural and anthropogenic factors (eg. soil types, topography, landuse, fire frequency, biological processes, climate change etc.), making it difficult to ascertain unusual or accelerated rates of erosion (Blong et al., 1982; Atkinson, 1984; Paton et al., 1995).

Despite these difficulties, measurement of the volumes of sediment contained in fluvio-deltaic deposits in the Study Area does provide an opportunity to examine long-term rates of catchment denudation. Inter-catchment comparisons of deltaic volumes can then be used to identify trends and, perhaps, catchments that have delivered disproportionately large volumes of sediment over comparable periods of time (Roy, 1994; WP-Geomarine, 1996).

Apart from the fluvial deltas, another manifestation of sedimentation within Berowra and Marramarra Creeks are the expanding areas of mangrove communities. Comparisons of historical aerial photography suggest that there has been a 30% increase in mangrove areas within the Study Area between 1941 and 1992. The areas of greatest mangrove expansion are in the lower portions of the estuary near the confluence of the Marramarra and Berowra Creeks (Williams and Watford, 1997) with much of the expansion occurring since the early 1960's (Bruce Coates, Estuaries Section, NSW Dept. Land and Water Conservation).

While there is some evidence for a link between estuarine shoaling and mangrove expansion (Williams and Watford, 1997), it is not entirely clear whether sedimentation alone can be used to explain change in mangrove areas (Saintilan, 1995; 1997). Previous investigations show no clear link between catchment clearing associated with urban development (ie. high rates of sediment erosion) and areas of greatest mangrove expansion (Williams and Watford, 1997). Other factors can influence change in mangrove areas. Possible factors contributing to mangrove expansion include higher nutrient levels within estuarine sediments, higher rainfall and decreased estuarine salinities, a rise in relative sea level due to land subsidence or absolute sea level rise (Saintilan, 1997).

Investigations of nutrient, metal and pesticide levels in Berowra Creek sediments are reported by Shotter (1994), EPA (1996), Mann et al. (1996) and Hawkesbury Nepean (1997). Much of this data is reviewed in MHL (1997). Elevated levels of nutrients (total Nitrogen and total Phosphorous) exceeding published criteria were found in muddy sediments infilling a depression in the estuary bed near Calabash Point. Elevated levels of trace metals including copper, lead, zinc and arsenic have also been detected in estuarine bed sediments in the vicinity of Berowra Waters and Calabash Bay. Some metal concentrations (ie. arsenic, nickel, lead) were found to exceed recommended levels and suggest a possible link between boating activities and sediment contamination.

Background information collected for the BCEPS and reported in MHL (1997) provides a generalised account of the character and long-term evolution of the Study Area. Sufficient data are available to characterise the estuary and surrounding catchment in terms of contemporary patterns of landform denudation and estuarine sedimentation. The available data are also suited to a more detailed assessment of the estuary and its physical context, particularly in terms of the potential impacts of anthropogenic activities over the past century.

4. Study Methods

Laboratory and field methods are briefly described below. Further detail can be found in Section 10 (Appendices A to D). Results of the laboratory and field investigations were combined and processed with the aid of the project Geographic Information System.

4.1 Laboratory Procedures and Rationale

A characterisation of the Study Area topography, geology and soils is presented in the Rural Lands and Sensitive Urban Lands studies (Hornsby Shire, 1995; 1996). Unfortunately, very little of this information was accessible in digital format at the commencement of the BCEPS.

Digital coverages were sought and acquired from the various Government departments and organisations including:

Topography - Land Information Centre digital 1:25,000 scale coverages including elevation and drainage data for the Hornsby (9130-4-S), Cowan (9130-4-N) and Gunderman (9131-3-S) sheets.

Geology - NSW Department of Mineral Resources digital 1:100,000 scale Sydney (9130) sheet.

Soils – NSW Department of Land and Water Conservation digital 1:100,000 Sydney (9130) sheet and 1:25,000 scaleAcid Sulphate Soil Risk maps H9130n4, H9130s1 and H9130s4.

Digital coverages of the major catchments in the Study Area were acquired from Sydney Water.

All digital data were imported into MapInfo for processing and presentation. Data exchange between CMG and MHL was facilitated by file import/export features contained within the software packages MapInfo and ArcView.

In view of the detailed catchment descriptions contained in existing reports (Hornsby Shire, 1995; 1996), the current investigations have concentrated on establishing the likely relationships between catchment characteristics, rates of erosion and estuarine sedimentation. Proportions of elevation and slope classes in each catchment were determined and merged with information on drainage and landuse to highlight the relative potential of catchments to supply sediment to the estuary.

A digital elevation model (DEM) with a grid cell size of 50m was constructed for the entire study area from the LIC digital 1:25,000 scale Gunderman, Cowan and Hornsby sheets. A slope model was generated from the DEM. Overlay of the catchment boundaries on both the DEM and slope model enabled characterisation of the elevation and slope classes for each catchment. A total of 32 catchments was used, 27 for Berowra Creek and 5 for Marramarra Creek. Elevation classes were 0-10m, 10-20m, 20-50m, 50-100m, 100-200m, 200m+. Slope classes were 0-10%, 10-20%, 20-40% and >40%.

Drainage data (drainage density) was extracted from LIC information combined with Sydney Water catchment areas. The relative proportions of major rock types in each catchment was calculated after merging the catchment and geology files. Proportions of landuse (by area) for each catchment were derived from published Hornsby Council zoning information (Local Environment Plan, 1994).

Catchment data (area, drainage density, elevation, slope, geology) were combined and processed with the aid of a non-parametric statistical clustering algorithm (ENTROPY). The program grouped like catchments on the basis of their physical attributes. A cross tabulation of ENTROPY groups and catchment landuse completed the characterisation of the catchments.

A measure of long-term catchment denudation is recorded in the fluvial deltas within the Study Area. An estimate of the amount of sandy sediment delivered into the estuary was calculated for some 13 fluvial deltas. Sediment volumes were calculated by multiplying the aerial extent of unconsolidated sediments identified on the 1:25,000 scaleAcid Sulphate Soil risk maps by an estimated sediment thickness (7m-10m) and bulk density ($1.4 m^3$/tonne). Results were expressed for each catchment in tonnes/square kilometre and tonnes/hectare/year. The latter calculation assumes the fluvial delta has accumulated over the past 7,000 years.

Patterns of historic bathymetric change within the estuary were examined in a comparison of Royal Navy survey data collected in 1872 and a 1995 hydrographic survey conducted by the PWD. Areas of significant bathymetric change (positive/accretion, negative/erosion) were identified and mapped. Visual inspection of vertical aerial photography of the estuary dating back to the early 1950's was also used in a qualitative assessment of historic estuarine sedimentation.

4.2 Field Procedures and Rationale

The distribution of in-channel sediment types was determined from existing data supplemented by additional fieldwork (grab and shallow core sampling). The field program aimed to produce a surface sediment map of the estuary plus data on the shallow estuarine stratigraphy. Details of the field program are contained in the Appendices (Section 10) and summarised below.

Surface sediment data were collected with the aid of either a Van Veen grab or drop core sampler operated from a small motorised vessel fitted with a differential global positioning system (DGPS). Samples were described in the field (ie. gross textural and compositional attributes) and latter inspected with the aid of a binocular microscope. Sample descriptions and locations were entered into the project GIS and combined with other surface sediment data (ie. Hornsby Council Sediment Monitoring Program samples, University of Sydney samples reported in Shotter, 1994) to produce an estuarine surface sediment map based on 189 sample sites.

Information on the shallow stratigraphy of the estuary was collected with the aid of a vibracorer and drilling platform provided by MHL. Core locations were based on the PWD 1995 hydro survey and results of the surface sediment sampling program. Vibracores were processed at laboratory facilities provided by MHL. Processing included logging, sampling and archiving of reference core material. Representative core samples were selected for detailed textural and compositional analysis at a NATA registered laboratory. A limited number of samples (n=4) was submitted for radiocarbon dating. All relevant data were entered into the project GIS.

5. Results

Results of the catchment modelling and field program are presented below. Detailed data are contained in the Section 10 (Appendices A to D).

5.1 Catchment and Estuary Modelling

5.1.1 Catchment Morphology and Landuse

Computer-aided modelling of the catchment and estuary was undertaken in an attempt to characterise the physical attributes of both systems as a basis for examining potential human impacts.

The first stage of the modelling involved the generation of a digital elevation model (DEM) of the Study Area (Figure 4). Modelled elevations vary from 0m (black shading) around the margins of the estuary up to 260m+ (light grey shading) on the plateau areas. The highest elevations occur in the Marramarra Creek catchment near Big Bay. A slope model derived from the DEM is shown in Figure 5. Slopes throughout the StudyArea are steepest (>40% or >22°) along margins of the incised drainage lines and lowest (<10% or <6°) in the plateau areas (light shades represent the steepest slopes).

The DEM and slope models highlight the rugged nature of the Study Area. Limited areas of low relief plateau around the perimeters of the Berowra and Marramarra catchments give way to deep bedrock gorges, steep slopes and incised drainage lines throughout much of the remaining area.

Relationships between geology, elevation, slope and landuse were examined on a catchment by catchment basis. The Study Area was divided into 32 sub-catchments, 27 for Berowra Creek and 5 for Marramarra Creek (Figure 6). Each sub-catchment is identified by either a "B" or "M" prefix depending on its location within the Berowra or Marramarra catchments respectively. Data derived for each catchment included total area, drainage density, elevation classes, slope classes, proportions of major rock types and landuse (Tables 3, 4, 5). In view of the number of derived parameters, similarities between the various catchments were examined with the aid of a non-parametric statistical clustering package (ENTROPY; Johnston and Semple, 1983). See Section 10 (Appendix A) for more information.

The ENTROPY analysis grouped like catchments on the basis of similarities in the catchment area, drainage density, elevation classes, slope classes, and rock types. The analysis identified an optimal 8 group solution. The results of the statistical analysis are summarised graphically in Figure 7. Cross-tabulation of physical catchment attributes (ENTROPY groups) and landuse type is shown in Table 6.

The eight ENTROPY catchment classes can be summarised as:

Group 1 (n=7): Relatively small, high level catchments with low slopes. These catchments (B1, B2, B3, B4, B7, B8, B17) all occur at the head of the Berowra catchment in a band extending from Castle Hill to Waitara. Ashfield Shale is a common rock type throughout these catchments.

Group 2 (n= 2): High level catchments with low to moderate slopes (B6, B13). Catchments are found in the upper portions of Berowra Creek east of Dural. Ashfield Shale and Hawkesbury Sandstone are the dominant rock types.

Group 3 (n=2): Catchment with low slopes and relatively high proportions of Ashfield Shale (B19, M1) located along the western perimeter of the Berowra and Marramarra catchments between Castle Hill and Glenorie.

Group 4 (n=3): Relatively large, elevated catchments with high proportions of Mittagong Formation lithologies (shales and sandstones) (B11, B12) located within the southwestern section of the Berowra catchment.

Group 5 (n=8): Rugged sandstone catchments with a mixture of high elevations and steep slopes (B5, B15, B16, B22, B23, B24, M3, M4) generally located in the lower sections of the Berowra and Marramarra catchments.

Group 6 (n=2): Catchments weakly discriminated from rest of matrix – relatively small size and slightly higher proportion of elevations in the 100-200m range (B9, B14). Located along eastern edge of Berowra catchment between Waitara and Mount Colah. Mixture of lithologies including Ashfield Shale and Mittagong Formation (shales and sandstones) on plateau surfaces and Hawkesbury Sandstone in remainder.

Group 7 (n=5): Catchments with a relatively high proportions of Newport Formation lithologies (shales and siltstones), elevations below 100m and moderate to steep slopes (B25, B26, B27, B28, M5). All catchments are clustered along the northeastern portion of the Study Area.

Group 8 (n=3): Middle level sandstone catchments with above average drainage densities and moderate to steep slopes (B10, B18, B21) located along the eastern slopes of the Berowra Catchment west of Hornsby.

Cross-tabulation of the ENTROPY groups with landuse provides a means of ranking the catchments in terms of their likelihood to have delivered (or currently delivering) significant amounts of sediment to the estuary (Table 6). The assumption is that the more rugged catchments (steep slopes and wide range of elevation) with high proportions of erodible lithologies (eg. Hawkesbury Sandstone) are likely to have proportionally higher sediment yields for a given landuse. This assumption is not entirely supported by previous investigations of soil erosion in Hornsby Shire which have highlighted the overwhelming impact urban development has on sediment erosion, overiding many physical catchment attributes (see Table 2) (Parmeter and Graham, 1995). A further complication is that the erosion of sediment from developing catchments varies over time, reaching a maximum in the early stages of clearing and the construction of buildings and infrastructure and reducing to below natural levels once construction has ceased (Parmeter and Graham, 1995; Coles, 1995).

In view of the disproportionate impact urban development can have on catchment denudation, Table 6 suggests that the most erosion prone catchments (rugged topography, sandy lithologies and high proportions of urbanisation) are contained in ENTROPY groups 5, 6 and 7 – most notably catchments B5, B9, B10, B14, B18, B15, B16, B21 (Table 6).

These catchments are found along the eastern margin of the Berowra catchment between Berowra and Waitara (Figure 7). Other catchments with a high level of urban development tend to occur in plateau areas characterised by low slopes and clayey soils (Entropy group 1; Table 6). These catchments occur at the head of the Berowra catchment from Waitara to Cherrybrook to Castle Hill (Figure 7). It is probable that urban development in these areas was/is accompanied by high discharges of fine sediment to the estuary.

5.1.2 Catchment Erosion and Estuarine Sedimentation

Converting contemporary estimates of soil erosion from both human and natural causes into actual sedimentation rates is fraught with difficulty (Martens, 1994; Parmeter and Graham, 1995). The approach here has been to calculate rates based on the volumes of sediment that have accumulated within fluvial deltas over a period of thousands of years. The deltas essentially store most of the sandy sediment delivered to the estuary over a prolonged period of time. If catchment clearing for urban development, agricultural purposes or whatever has had an impact, then it is likely to be manifest as an unusually high rate of catchment denudation (ie. a disproportionately large delta deposit for catchment) when compared with other deltas/catchments in the same area.

A total of 13 fluvial deltas have been mapped and their respective volumes estimated (Figure 8; Table 7). The various assumptions associated with the delta volume calculations are discussed in Section 10 (Appendix A). The results are expressed in total volumes of sandy sediment as well as rates of catchment denudation. A linear relationship exists between catchment size and delta volume (Figure 9a), while denudation rates appear to decrease with increased catchment size (Figure 9b). A similar relationship between denudation rates and catchment size has been observed elsewhere and can be related, in part, to the greater sediment storage capacity of large catchments. Another factor is the variable source area concept, a concept that recognises not all portions of a catchment will deliver equal volumes of sediment over a particular time frame so that sediment yields for large catchments may, in fact, reflect erosion from a relatively small proportion of the total catchment (see review in Martens, 1994)

The delta volumes suggest little differentiation of the catchments based on estimated denudation rates with many catchments falling below 0.3tonnes/hectare/annum. The Muogamarra catchment has the highest estimated denudation rate (0.38-0.55t/ha/yr) while the lowest rates are recorded for Still and Sams Creek (0.04-0.05t/ha/yr). Of the deltas associated with urbanised catchments (Berowra, Calna, Sams, Unnamed, Joe Crafts; Figure 8), data for the Joe Crafts and the nearby "Unnamed" delta suggest a weak trend of catchment denudation rates slightly above the average. Within the limitations of the method, it is difficult to identify any clear correspondence between catchment modification (ie. urbanisation) and accelerated rates of catchment denudation.

Computer modelling of the estuary involved a comparison of hydrographic surveys conducted in 1872 (RAN) and 1995 (PWD). It was anticipated that the comparison would give some indication of the fate of fine grained sediment delivered to the estuary from the surrounding catchments. A full description of the methodology is provided in Appendix A with the results summarised in Figure 10.

The irregular spacing of the 1872 and 1995 survey data (spot depths) necessitated projecting a 50m grid over that portion of the estuary covered by the two surveys (downstream of Calabash Bay to the Hawkesbury River junction), averaging the depths in each grid cell for each survey, then subtracting the average depths to determine a residual which represented the net change over the past 123 years. Uncertainty surrounding the accuracy of the datum (Low Water Ordinary Springs) and horizontal positioning of individual soundings in the 1872 survey clearly limits interpretations based on the comparison. Rather, the comparison was intended to show broad trends rather than detailed change.

The contemporary estuarine bed is characterised by a relatively shallow muddy sediment "sill" that slopes away from the Hawkesbury River channel and into Berowra Creek. Water depths at the Hawkesbury River - Berowra Creek confluence are around 3m and reach a maximum of some 18m 11km further upstream in the vicinity of Calabash Bay (see bathymetric section in Figure 11). Beyond Calabash Bay, the estuary bed shallows and is characterised by a series of emergent sand bars and shoals at low tide upstream of the Woolwash.

A comparison of the 1872 and 1995 surveys shown in Figure 10 and provides a breakdown of depth changes. The bathymetric comparison indicates a trend towards shoaling of the estuary over time with the number of data points recording a decrease in water depths of more than +2m (n=131) clearly exceeding those showing erosion of -2m or more (n=28) (Figure 10). The shoaling is most pronounced in the main channel between Calabash Bay and Joe Crafts Bay with little evidence of marked change elsewhere. The magnitude of the depth changes, between 5 to 10m of accretion in some places, suggest a maximum sedimentation rate of around 40 to 80mm/year over the past 123 years. This rate is at least an order of magnitude greater than rates based on dated core samples from estuarine mud basin deposits elsewhere (Roy, 1994) and Berowra Creek (see following section).

5.2 Estuarine Surface and Subsurface Sediments

Surface and subsurface sediment sampling programs were completed in May and September 1997 respectively. The surface sediment sampling (grab and gravity core) was designed to supplement existing information and lead to the preparation of a surficial sediment map for the estuary. The subsurface sediment sampling (vibracore) was intended to clarify the shallow stratigraphy of the estuary bed (to 7m) as well as providing samples for radiocarbon dating and background sediment contaminant investigations. Detailed information gathered in both field programs is contained in Section 10 (Appendices B and C).

5.2.1 Surface Sediment Types

The nature, distribution and bathymetric relationships of the major surficial sediment types in Berowra Creek are typical of those encountered in a drowned river valley estuary (Figure 11). The sediment map shows the extent of mud basin and fluvial delta deposits in the main channel plus deltaic and mud flat deposits in the tributaries. The fluvio-deltaic deposits commonly occur in water depths of less than 1m and consist of shoals of fawn-brown, gravelly, medium to coarse grained angular quartz sands. The sediments are typical of those derived from catchments dominated by Hawkesbury Sandstone lithologies. Gravel sized plant and charcoal fragments also occur within the sandy deposits. Mud basin sediments occur in the deeper parts of the estuary (>3m water depth) and range from cohesive to loose, dark grey to black, organic rich, sandy muds and muds. The organic material consists of fine grained plant material and charcoal. Very high organic contents occur in the bottom sediments immediately downstream of the Berowra Creek fluvial delta at the Woolwash. Here, matts of decaying plant material (leaves, twigs etc.) infill depressions in the estuary bed near the valley wall.

Fluvial deltas in the main arms of the Berowra and Marramarra Creeks extend downstream as far as the Woolwash and Big Bay respectively. A zone of sandy muds to muddy sands marks the transition from deltaic to mud basin deposits in each case (Figure 11). In Marramarra Creek the fluvial delta has bypassed the entrance to Big Bay, effectively isolating the bay and restricting tidal flows at its entrance. Small fluvial deltas occur in the tributaries to Berowra Creek upstream of the Woolwash and downstream as far as Joe Crafts Bay. The deltas are clearly defined by rapid changes in bathymetry (shoaling) and more sandy sediments away from the estuary mud basin. Side valleys downstream of Joe Crafts Bay contain small fluvial deltas and large intertidal mud flats (Figure 11).

Information on sediment types along the length of the estuary, including trace metals, nutrients and pesticides have been collected by Hornsby Council (Section 10; Appendix B). A selection from this data (total sample analyses) is shown in Figures 12 and 13. Along-channel trends in gross sediment texture illustrate the general uniform nature of the surficial estuarine muds and pronounced change to sandy sediments in the fluvial delta upstream of the Berowra Ferry (Figure 12). Total Organic Carbon (TOC), Total Kjeldahl Nitrogen (TKN) and Phosphorous values are highest for the mud basin sediments, reaching a peak in the vicinity of the Berowra Ferry. Along-channel trends for metals commonly associated with anthropogenic impacts (Copper, Lead, Zinc) show a similar upstream increase with maximum levels again occurring around the Berowra Ferry. Grainsize effects (ie. finer sediments tend to contain high levels of metals and nutrients) can be clearly seen in both sets of results (Figures 12, 13).

5.2.2 Subsurface Sediments and Shallow Estuarine Stratigraphy

A total of 11 vibracore samples were collected along the length of the main arm of Berowra Creek between the Woolwash and confluence of Berowra Creek - Hawkesbury River (Figure 14). Two additional boreholes were completed in the floodplain of Marramarra Creek. Details of the coring program and core logs are contained in Section 10 (Appendix C). Graphic logs of the vibracores and the two hand auger holes are shown in Figures 15 and 17.

Vibracores were collected from a variety of depositional settings within the estuary. Cores BCVC1, BCVC2 and BCVC3 were drilled in a relatively flat and shallow (<4.5m deep) section of the mud basin adjacent to the Hawkesbury River entrance. Core BCVC4 was located in 7m water depth further upstream where the estuary narrows near Berowra Point (Figure 14). Cores BCVC5, BCVC6 and BCVC7 were collected in water depths of 2.5m (BCVC5) to 15.5m (BCVC7) from the central portion of the estuary between Bujwa Bay and Calabash Bay (Figure 14). The remainder of the cores were collected in the Berowra Creek fluvial delta upstream of the vehicle ferry (BCVC9 to BCVC11; water depths <3.5m) and the mud basin immediately downstream of the ferry (BCVC8; 8m water depth) (Figure 14). The majority of cores were of a high quality with little evidence of bioturbation and good preservation of depositional structures.

Vibracores from the lower portion of Berowra Creek (BCVC1 to BCVC4) encountered a variable sediment sequence consisting of organic rich muds interbedded with thick (up to 0.6m) shell beds (estuarine species) and discrete sand lamina (less than 1cm thick) (Figure 15). The shell beds consist of both articulated and individual valves of a variety of estuarine molluscs (Notospisula and ?Mesodesma) that show no clear evidence of transport and appear to have accumulated largely in place. Shell layers in Cores BCVC2 and BCVC3 occur around the same level and may be part of a much larger shell bed within this section of the estuary. Also of note are the fine to medium grained quartz sand lenses interbedded with the estuarine muds adjacent to the Hawkesbury River channel (Figure 15; BCVC1). Core BCVC1 has at least 6 one centimetre thick sand lenses distributed through the lower half of the core, suggesting episodic influx of coarse grained sediment into this section of the estuary. No obvious sand lenses were observed in the cores immediately upstream (Figure 15; BCVC2 and BCVC3).

Core BCVC4, located in a 7m deep depression in the estuary bed near Berowra Point, encountered a surficial sequence of estuarine muds interbedded with thin sand lenses and shell beds of variable thickness (Figures 14 and 15). These sediments are around 2m thick and overlie a shelly, fine to medium grained, muddy quartzose sand with common charcoal layers and evidence of bioturbation (Figure 15). Bioturbation is in the form of several burrow casts at the base of the core infilled with oxidised fine grained sand. The sandy unit at the base of BCVC4 is relatively low in the mud basin sequence by virtue of the greater water depths (7m) at the site. It is probable that the sandy the sediments represent a stage of relatively energetic depositional conditions preceding the accumulation of the overlying mud basin deposit. The presence of oxidised material in burrow casts at the base of the unit suggests proximity of the pre-Holocene land surface to the contemporary estuarine bed.

Cores collected in the central part of the estuary (BCVC5, BCVC6, BCVC7) encountered a soft mud basin sequence consisting of uniform, organic rich muds with minor shell gravel and charcoal fragments (Figures 14, 15 and 16). The low core recoveries (recoveries less than 1.4m/penetrations exceeded 4.5m) for sites BCVC6 and BCVC7 reflect the very loose consistency of the estuarine muds between Joe Crafts Bay and Calabash Bay.

A series of cores was collected from the fluvial delta front in the main arm of Berowra Creek near the vehicle ferry (BCVC8 to BCVC11; Figures 14, 16). Cores BCVC9, BCVC10 and BCVC11 intersected a surficial unit of interbedded sands and organic rich muds (fluvial delta) overlying a gravelly (shell) organic rich mud. Core BCVC8, located downstream of the fluvial delta, consists of estuarine mud with thin (<5mm thick) interbeds of medium grained sand, organics and shell (Figure 16).

Cores recovered from the fluvial delta contain very good depositional structures defining multiple fining up sequences. The sequences consist of a basal clean, fine to medium grained quartzose sand grading up to coarse grained organics (charcoal and plant fragments) grading to fine grained muds (Figure 16). The fining up sequences appear to record discrete episodes, or events, when flood flows generated in the catchment have deposited coarse grained sediments on the delta front, blanketing the underlying estuarine deposits. It is likely sand lenses in the upper 1m of BCVC8 further downstream represent fluvio-deltaic sedimentation associated with major floods (Figure 16).

Hand auger/sludge pump holes from the Marramarra Creek floodplain show sandy levee and channel deposits up to 7m thick overlying shelly estuarine muds (Figure 17). These cores provide confirmation of the thickness of fluvial delta deposits used in the catchment modelling (see previous section).

Long and thalweg sections for the estuary are shown in Figure 18a along with an interpreted stratigraphic section based on the vibracore data (Figure 18b). The stratigraphic section includes four radiocarbon dates on organic material selected from cores BCVC1, BCVC5, BCVC9 and BCVC11 (see Section 10-Appendix D for details of dated material and results). Note that the radiocarbon dates have not been converted to calendar years owing to the transported nature of the dated material (plant fragments and fine grained organics). The dates represent a maximum age of deposition.

Bathymetric sections (long and thalweg) show a gradual increase in water depths towards the central part of the estuary from both upstream and downstream. Maximum water depths (c.18m) occur in the vicinity of Calabash Bay (Figure 18a). The stratigraphic section indicates the presence of an estuarine mud basin sequence in excess of 7m thick (limit of corer penetration) along the cored length of the estuary (Figure 18b). Thin sand lenses occur in the mud basin sediments near the junction of Berowra Creek and the Hawkesbury River, indicating a possible influx of coarse grained fluvial sediment into Berowra Creek from the Hawkesbury River during floods. An inferred basement high mantled by an interpreted transgressive fluvial delta occurs in the lower half of the estuary at BCVC4 (Berowra Point) (Figure 18b).

Cores in the area around the Berowra ferry (BCVC8 to BCVC11) define a sandy fluvio-deltaic sequence in excess of 5m thick overlying estuarine muds (Figure 18b). The bathymetric and stratigraphic relationships of the units show that the Berowra Creek deltaic deposits are prograding downstream.

5.2.3 Radiocarbon Dating and Deltaic Sedimentation Rates

Radiocarbon dates from representative sections of the estuary have been used to confirm the Holocene age of the sediment sequence infilling Berowra Creek and to assess sedimentation rates within the Berowra Creek fluvial delta.

Four dates are available; two from the estuarine mud basin (BCVC1 4.47-4.50m and BCVC5 4.30-4.50m) and two from the Berowra fluvial delta (BCVC9 5.52-5.56m and BCVC11 5.03-5.06m) (Figures 15, 16 and 18). All dates indicate that the sampled section is Holocene in age and has accumulated at present sea level. Dates on organic material from the lower and central mud basin (BCVC1 and BCVC5) range between 1,410 and 1,500 years before present. Converted to calendar years these dates become 590AD and 650AD respectively (Section 10; Appendix D). In terms of vertical sedimentation rates, the uncorrected radiocarbon dates give a long-term averaged rate of between 3.0 and 3.2mm/yr. The calibrated dates give rates of between 3.2 to 3.3mm/yr. These rates assume a linear relationship between sedimentation and time and are well below rates calculated from historic bathymetric changes (ie. 40-80mm/yr)

Radiocarbon dates from the Berowra fluvial delta do not record simple vertical accumulation of sediment. Rather, downstream migration of the delta front involves both horizontal and vertical sedimentation such that the dates reported here record the passage of the delta front downstream over the top of mud basin sediments. Dates from BCVC9 and BCVC11 are on charcoal and plant fragments near or at the contact between the fluvial delta and underlying estuarine mud basin deposits. Dates of 460 and 1,090 years before present were recorded for BCVC9 and BCVC11 respectively (Figure 16 and 18). Calibrated to calendar years these become 1440AD and 980AD respectively (Section 10; Appendix D).

Given that the dated samples occur at or close to the base of the fluvial delta and that the dated material was deposited soon after its incorporation into the channel sediments, it is possible to calculate both the rate of downstream migration of the delta front and the long-term sedimentation rate. Cores BCVC11 (upstream delta front) and BCVC9 (downstream delta front) are some 617m apart (Figure 14). The radiocarbon dates indicate that the delta front has advanced downstream blanketing the mud basin sediments over a period of 630 years (radiocarbon years) or 460 years (calendar years). Therefore, the delta front is building downstream at a time-averaged rate of 1.34m/year (calendar years). If the same rate of delta progradation persists, shoaling of the area around the Berowra Ferry by *fluvial sands* could be expected to occur over a period of 100's of years.

The volume of material that has accumulated on the delta front between BCVC11 and BCVC9 is around 1,004,500 tonnes (surface area 143,500m^2 X 5m thick X 1.4t/m^3) which represents a sedimentation rate of 2183 tonnes/year (calibrated dates), or 0.29tonnes/hectare/annum (Berowra Creek catchment equals 74.36km^2; Table 7). A time average rate of 0.29t/ha/yr for the past 460 years is about double the rate (0.15t/ha/yr) calculated for the entire Berowra Creek delta (7m thick) built over the past 7000 years. Both rates are less than the 0.78t/ha/yr calculated for the Berowra Creek catchment upstream of the Galstone Gorge road bridge (Coles, 1995).

5.2.4 Estimates of Background Sediment Contamination

Vibracore samples provide a unique opportunity to assess likely background levels (pre-European occupation) of sediment, nutrient and metal concentrations in Berowra Creek. Some 12 vibracore samples representing sediments from depths of between 1.2m and 4.5m below the estuary bed were analysed by the Environmental Protection Agency for a range of nutrients and metals (% Mud, TKN, TP, TOC, Ag, Al, As, Cr, Cu, Fe, Hg, Li, Ni, Pb, Se, Zn). Details of the analyses and plots of metal-grainsize relationships are contained in Section 10 (Appendix C). Results are summarised in Table 8 and Figure 19.

The enrichment factors for the metals plotted in Figure 19 are based on *estimated* background relationships between metal concentrations and grainsize for the Study Area. In view of the limited number of core samples analysed (n=12) and a reliance on total sample data, these "background values" must be used cautiously. Background metal levels for the Hawkesbury River are reported in Irvine and Birch (1998). Their data, based on analysis of the mud fraction of core samples, indicate background levels of 18mg/kg (Cu), 22mg/kg (Pb) and 57 mg/kg (Zn) (Table 2; Irvine and Birch, 1998). Estimates of background metal levels for 100% mud samples based on the relationships developed here (Table 8) are 13mg/kg (Cu), 16mg/kg (Pb), 60mg/kg (Zn) (see Section 10; Appendix C).

All surface samples in Berowra Creek appear to have elevated (enriched) levels of nutrients (TKN and P) and metals (Cr, Cu, Zn, Pb) (Table 8). Distribution of the metal enrichment factors, which may be as high as 10X in the case of Pb, all indicate a peak in the vicinity of the Berowra Ferry sample site. Arsenic shows a weak trend of decreased levels of enrichment away from the Hawkesbury River.

The maximum enrichment factor for Zn in the vicinity of Sams Creek must be viewed cautiously. Metal-sediment relationships developed here are from cores further downstream where mud contents exceed 20%. Clearly the %mud-metal relationships are less reliable where mud contents fall below this level. At Sams Creek the samples contain less than 4% mud. Similar caution must be used in the interpretation of the Crosslands data (Table 8).

Trends in total Kjeldahl Nitrogen (TKN) and Phosphorous in the surface sediments have been compared with analyses of nearby core samples. Enrichment factors for TKN in the surface sediments range from 0.2X (Woolwash) up to 4.1X (Coba Pt.), with the highest enrichment levels in the lower part of Berowra Creek between Bar Island and Coba Point. Total Phosphorous enrichment values also tend to be higher between Coba Point and Bar Island (2.53X-2.76X), decreasing to 1.2-1.6X further upstream and peaking at 2.3X near Berowra Ferry (Table 8).

It should be noted that "background" TKN and TP levels vary along the estuary and the enrichment factors noted above should be interpreted with some care (Table 8). Further sampling and analysis of core samples along the estuary would help determine the reliability of inferred "background" TKN and TP. The observation of higher levels of nutrient enrichment in lower Berowra Creek estuarine sediments is of interest as it occurs in an area of significant mangrove expansion. Saintilan (1995; 1997) has speculated on the link between elevated sediment nutrient levels and mangrove expansion in the lower Hawkesbury.

6. Discussion

Berowra Creek is a bedrock-controlled drowned river valley estuary forming part of the much larger lower Hawkesbury River estuary in the north of Sydney. Sediments infilling Berowra Creek have been deposited over a prolonged period of time (c.10,000 years), encompassing episodes of both rising and stable relative sea levels. The present-day configuration of the estuary was established when sea level reached its current position some 6,500 years ago. Since this time, the estuary has gradually infilled with sediments derived from the local river catchments and the Hawkesbury River – the estuary has effectively operated as a sediment sink for thousands of years. Today, fine and coarse grained sediments continue to be deposited within an estuary which remains underfilled.

Computer modelling and statistical analyses of derived catchment data (physiography, geology and landuse) show that there are clear differences between the catchments draining into Berowra Creek. Long-term denudation rates, and the possible links between the physical and cultural attributes of the catchments, have been examined through an analysis of fluvial delta volumes. These data identify estimated erosion rates in the range of 0.04–0.55t/ha/yr which are at the low end of estimates of catchment denudation calculated for Berowra Creek (Coles 1995 – 0.78t/ha/yr) and other urban areas in Sydney (WP-Geomarine 1.2-1.45t/ha/yr). The relatively low rates calculated here are due, in part, to an underestimation of the total sediment load from each catchment. The calculations based on sandy deltaic deposits do not account for all of the fine sediment (muds) eroded from the catchments, as evidenced by the thick (>10m) deposits of mud in the deeper parts of the estuary (mud basin). A similar observation has been made for catchment erosion rates (around 0.15t/ha/yr) based on the volumetric calculations for the Port Hacking fluvial delta in the south of Sydney (Dr. Peter Roy, pers.comm.).

While the absolute sedimentation rates based on delta volumes are likely to be conservative, the data contain no clear evidence of higher denudation rates in urbanised catchments. It is evident from the published data that urban expansion can generate extreme rates of erosion, how these rates are translated into long term patterns of sedimentation in drainage systems is less clear (Hean and Nanson, 1987; Martens, 1994; Parmeter and Graham, 1995). Consideration needs to be given to other natural factors (bushfire, short to medium term climatic changes, changes in catchment vegetation cover, levels of soil bioturbation etc..) which may be far more important in terms of total sediment yield by virtue of their regional influence and frequency. Clearly, disentangling the anthropogenic "signature" from the natural "noise" in a system is difficult.

A check on modelled long-term (thousands of years) sedimentation rates has been provided by dated core samples from the Berowra Creek delta. The core data have shown the rate of delta advance over the past 460 years to be of the order of 1.34m/yr, greater than the estimated rate of between 0.8-0.9m/yr for the past 6000 to 7000 years (Roy, 1973). Sedimentation rates for the Berowra catchment based on the same data are 0.29t/ha/yr, slightly above the estimated rate for the entire delta averaged over 7000 years (up to 0.22t/ha/yr). While these data support an increase in the rate of delta sedimentation/progradation over the past 460 years, it is uncertain as to whether this rate represents an increase in sedimentation associated with catchment clearing over the past 200 years or a general increase in sedimentation due to other factors (climatic, bushfire frequency and aboriginal occupation of the catchment etc.) over the dated interval. Finer temporal resolution of the sedimentation rates require more detailed analysis of core samples, particularly core BCVC8 immediately downstream of the Berowra Ferry.

The computer modelling has produced catchment erosion estimates consistent with the results of more detailed investigations within the estuary. Evidence of increased rates of estuarine sedimentation over the past 460 years provide the context for an investigation of change over the past decades.

Sediment sampling (surface and subsurface) within the Study Area has clarified the distribution of surficial sediment types as well as the shallow estuarine stratigraphy. The surface sediment distribution is typical of a drowned river valley estuary – mud basin deposits infill the deeper sections of the bedrock valley while sandy fluvial deltas occur around the valley margins and upstream channel sections.

Bathymetric and sediment data confirm the underfilled nature of the estuarine mud basin. The mud basin within Berowra Creek slopes towards its lowest point around Calabash Bay from both upstream and downstream. The estuary remains relatively deep (water depths of up to 18m) in this area as it is yet to be infilled with sediment. Potential sources of fine sediment (muds and organic material) include the local catchments draining into Berowra Creek and the Hawkesbury River. Preservation of the underfilled section of the estuary around Calabash Bay suggests that much of the fine sediment from the Berowra Creek catchment is deposited upstream of here. Similarly, while the influx of mud from the Hawkesbury River has extended well into Berowra Creek, the estuary downstream of Calabash Bay is also yet to be infilled. A rough calculation of the relative volumes of mud from the two sources deposited over the past 7000 years (average channel width X channel length X presumed thickness of mud basin sediments of 20m) indicates that the volume of mud deposited in Berowra Creek from the Hawkesbury River (c.120 million m^3) is an order of magnitude greater than that from the Berowra catchment (c.12 million m^3)

Rates of mud accumulation within Berowra Creek downstream of Calabash Bay based on dated core samples are around 3mm/yr and at the high end of estimates mud basin sedimentation in New South Wales (Port Hacking 1.2 to 2.9mm/yr; Roy, 1994: Sydney Harbour 1.5mm/yr to 3.5mm/yr; Irvine and Birch, 1998: and Lake Illawarra 1.4mm/yr to 3.0mm/yr; Roy and Peat, 1974; Ellis and Kanamori, 1977). Further dating is required to establish whether the rates calculated for Berowra Creek are consistently high when compared to drowned river valley estuaries elsewhere in Sydney. Comparisons with other estuaries are limited at this time by a general lack of the type and quality of data collected in Berowra Creek for the estuary process study.

An influx of large volumes of mud into Berowra Creek from the Hawkesbury River provides a likely explanation for the relatively high rates of mud basin sedimentation, the extensive areas of mud flats in the lower Berowra Creek estuary (ie. Peats Bight, Coba Bay, Kimmerikong Bay, Bennets Bay and Bujwa Bay), and, perhaps, the expansion of mangrove areas reported by Williams and Watford (1997). Vibracore data in the vicinity of Bar Island (Core BCVC1) also point to the deposition of fine sands from the Hawkesbury River within mud basin deposits of lower Berowra Creek. In effect, the lower sections of Berowra Creek appear to be infilling with pro-deltaic muds derived from the Hawkesbury River catchment.

An investigation of sediment contaminants has shown that many areas of the estuary are characterised by surface sediments with elevated levels of nutrients and metals. Patterns of nutrient enrichment (TKN and TP) suggest that the estuarine bed between Coba Point and Bar Island contains relatively high levels of P and TKN when compared to background levels recorded in core samples. Elevated levels of Phosphorous are also encountered in sediments near the Berowra Ferry. The distribution of TKN and TP may be interpreted as reflecting inputs from both regional (Hawkesbury River) and local (Berowra Ferry area) sources. A tentative link has been suggested between mangrove expansion and substrate nutrient contents in the lower Hawkesbury (Saintilan, 1995; 1997), a link supported by the sediment nutrient and mangrove area data collected in Berowra Creek (this study, Williams and Watford, 1997). Further analyses of background nutrient levels in core samples at key sites (eg. Coba Point to Bar Island; Berowra Ferry to Calabash Point) are required to confirm the conclusions presented here.

Estuarine sediments are also enriched in heavy metals, particularly those commonly associated with human activities (eg. Cu, Pb, Zn). The maximum enrichment factor for any metal occurs in the vicinity of the Berowra Ferry where Lead contents in surface sediments are up to 10X estimated background levels. Copper and Zinc also show maximum levels of enrichment (c. 5X estimated background) at the Berowra Ferry. Sources of the metals presumably reflect contributions from point (eg. anti-fouling paints on boats, sewage overflows) and non-point sources (eg. urban runoff, vehicle emissions) both within and external to the catchment. While the metal levels are high and there is evidence of their accumulation in oyster tissues (Birch et al. 1998; Ross McPherson, Hornsby Shire Council pers. comm), there is limited data on the bio-availability (Grove, 1997). Investigations of surficial sediments from Berowra Creek found that sediment elutriates from sites at Crosslands, Berowra Ferry and Joe Crafts Bay were significantly more toxic than control site sediments (Smiths Creek and Murray Anderson Bay). The scallop larvae toxicity tests suggested a strong correlation with Cu and Zn levels (Grove, 1997).

More work needs to be conducted on metal contaminants in the Study Area. The work should concentrate on verifying background %mud-metal and TOC-metal relationships developed here and seek to establish subsurface metal concentration profiles. The background metal concentrations determined here have yielded consistent results for the mud basin deposits and will help to establish reliable background levels for comparison with similar estuarine systems in the lower Hawkesbury. Subsurface metal profiles (ie. change in contaminant concentration with depth) would also prove invaluable in addressing issues such as rates of sediment accumulation over historic time frames (ie. post European occupation of the Berowra catchment) and potential adverse impacts of dredging. Archived vibracore samples could be used for this purpose.

A conceptual model of contemporary estuarine sedimentation for the Study Area is presented in Figure 21. The model builds on data discussed in PWD (1985) and Roy (1994). Local catchments draining into Berowra Creek and the Hawkesbury River are the main sources of fine (mud) and coarse (sand) grained sediment deposited in the estuary. The principal areas of sand accumulation are the fluvial deltas of Berowra and Marramarra Creeks with relatively minor contributions coming from the catchments upstream of Joe Crafts Bay (Figure 21). Fine grained muds accumulate in embayments in the lower estuary and mud basin areas remote from the fluvial deltas.

Much of the fine grained sediment and organic detritus from the Berowra Creek catchment is deposited in the mud basin upstream of Calabash Point. Downstream of here, Marramarra Creek and smaller tributaries contribute relatively minor amounts of mud compared with sediment derived from the Hawkesbury River (Figure 21). Mud flats infilling many of the bedrock embayments and tributary valleys downstream of Joe Crafts Bay are thought to be formed from fine sediments resuspended by bottom currents in the main Berowra channel and redeposited in protected environments along the estuary margin.

Continued accumulation of fine and coarse grained sediments on and adjacent to the Marramarra and Berowra Creek delta fronts will lead to siltation of the estuary immediately downstream. This is a natural phenomenon and entirely consistent with patterns of estuarine infilling produced by the high sea level conditions established some 6,500 years ago. Available data suggest that the Berowra Creek delta front is prograding downstream at around 1.3m/yr, at this rate significant accumulation of sandy sediments could be expected to occur at the Berowra Ferry over the next few centuries.

The model has some significant implications for the management of Berowra Creek.

Two issues of concern to the Berowra Estuary Management Committee have been rates of estuarine infilling and sediment quality. The information provided here demonstrates that the infilling of Berowra Creek by sediment from both local and remote sources is natural and part of a general pattern of infilling in the lower Hawkesbury River estuary. Estimates of sand and mud sedimentation, particularly in the vicinity of the Berowra Ferry, suggest that rates of deposition are slightly higher than would be anticipated from geologic data when compared with similar information from other estuarine systems. In the absence of detailed historic information of change in this area, it is uncertain as to whether the (estimated) higher rates of sedimentation represent a "siltation problem" at the Berowra Ferry. Better resolution of the rates of infilling can be established through monitoring bathymetric changes and a closer examination of (archived) vibracores samples (Lead-Caesium and Radiocarbon dating, determination of subsurface metal profiles).

Sedimentation in Berowra Creek has as much to do with material derived from the local catchment as it does with sediment derived from the Hawkesbury River. Management of "siltation issues" needs to be aware of these distinct sources and their relative influence upstream and downstream of Calabash Point.

Sediment quality will be influenced by the source. A majority of the surface sediments are enriched in heavy metals and nutrients relative to estimated background levels, with the highest levels of contamination occurring at the Berowra Ferry. While every effort should be made to control local sources of nutrients and heavy metals, the contribution of contaminants to the lower estuary from the Hawkesbury River poses a more difficult management problem.

The geologic and contemporary sediment process data indicate that much of the Hawkesbury-derived sediment is accumulating in the estuary below Calabash Point while the Berowra catchment is having an impact on surface sediments upstream of here. On-going monitoring of contaminants in surface sediments between the Woolwash and Calabash Point should provide some measure of the "mobility" of these high levels of contamination. In contrast, the contaminant load of fine grained sediments from the Hawkesbury entering the lower Berowra estuary is a regional issue and underlines the need for a coordinated approach to water-sediment quality management in the lower Hawkesbury.

7. Summary and Recommendations

Investigations of sediment characteristics and processes in Berowra Creek reported here provide an overview of the long-term evolution of the estuary as a context for contemporary management issues of estuarine sedimentation and sediment contamination. The work has provided new evidence on rates of estuarine infilling and levels of sediment contamination in Berowra Creek as well as highlighting the probable impact of the Hawkesbury River on sedimentation within the Study Area.

Accelerated rates of estuarine infilling associated with catchment clearing, urbanisation etc. were not detected in a volumetric analysis of fluvial delta deposits. The result is consistent with the observation that natural factors such as bushfires, natural vegetation cover change in response to long-term climatic change, rainfall variability, bioturbation etc. may mask anthropogenic influences on catchment denudation. Estuarine infilling is most evident in the vicinity of the Marramarra and Berowra Creek fluvial deltas. Estimated rates of delta advance for Berowra Creek based on limited dated core data suggest an increase in delta progradation from 0.9m/year (time-averaged over 7000 years) to around 1.3m/year over the past 460 years. The rate of delta advance over the past 460 years suggests a build up of sandy sediments at the Berowra Ferry is likely to take hundreds rather than tens of years.

The history of fine grained sediment deposition is recorded in the mud basin and tidal mud flat deposits of the Study Area. Bathymetric trends along the main arm of Berowra Creek indicate a convergence in mud deposition from upstream and downstream in the vicinity of Calabash Point. Downstream of here, mud from the Hawkesbury River accumulates in tidal mud flats along the estuary margin and within the main channel (mud basin). Time-averaged rates of sediment accumulation in the mud basin (3mm/year) are at the top end of estimates for mud basin sedimentation and possibly reflect the influx of fine grained sediments from the Hawkesbury River. A large proportion of the fine grained sediment from the Berowra catchment appears to be deposited within the mud basin upstream of Calabash Point. While no information is available on rates of mud basin deposition in this area, analysis of archived core samples would provide the necessary data.

Sediment contaminant studies have identified background levels for heavy metals and nutrients for the StudyArea and levels of enrichment in the surface sediments. The surface sediments are enriched in nutrients (TKN, TP) and heavy metals (Cu, Pb, Zn, Cr and As). Nutrient enrichment levels in surface sediments in the lower Berowra estuary between Coba Point and Bar Island suggest an influx of nutrient laden sediment from the Hawkesbury River. A tentative link between high nutrient levels in surface sediments and areas of significant mangrove expansion downstream of Coba Point has been proposed.

Enrichment levels for metals in the surface sediments are most marked for chromium, copper, lead and zinc. Enrichment factors of between 3 to 5 times above background are common with a maximum enrichment of 10 times background recorded for lead. Levels of metal enrichment appear to increase upstream, reaching a maximum in the vicinity of the Berowra Ferry. Heavy metal contamination of the surface sediments presumably reflects the influence of point (sewage overflows, antifouling paints) and non-point sources (urban runoff, dust, vehicle emissions) in the catchment.

A series of recommendations are made to clarify aspects of estuarine sedimentation and sediment contamination discussed above:

1) Historic rates of sedimentation in key areas of Berowra Creek need to be addressed (ie. Berowra Ferry). The data should aim to provide greater temporal and spatial resolution of sedimentation rates estimated here. Recommendation is made for detailed analysis of selected core samples to establish historic sedimentation rates based on heavy metal profiles supplemented with radiometric dating (Carbon, Lead-Caesium). Archived core samples from the Berowra Ferry area (BCVC8) and Bar Island (BCVC1 and BCVC2) could be used for this purpose. The results should provide site-specific information on historic rates of mud sedimentation plus a comparison of rates at either end of Berowra Creek (ie. probable local catchment versus Hawkesbury River influences).

2) Sediment texture/composition and contamination relationships developed here need to be examined further. Detailed analysis of selected core samples is warranted and could be incorporated with the work suggested in the previous recommendation. Confirmation of background levels for nutrients and heavy metals is essential to a sensible interpretation of surficial sediment data.

3) Environmental and geological data used in this report are available in digital format and should be utilised by Council Officers in the development and monitoring of estuarine management strategies. The data are of sufficient resolution to be used at a variety of spatial scales (site specific to regional) for a range of environmental/ planning initiatives. The viability and usefulness of the Project Geographic Information System will require an ongoing commitment of resources, particularly in the area of personnel training.

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9. Figures and Tables

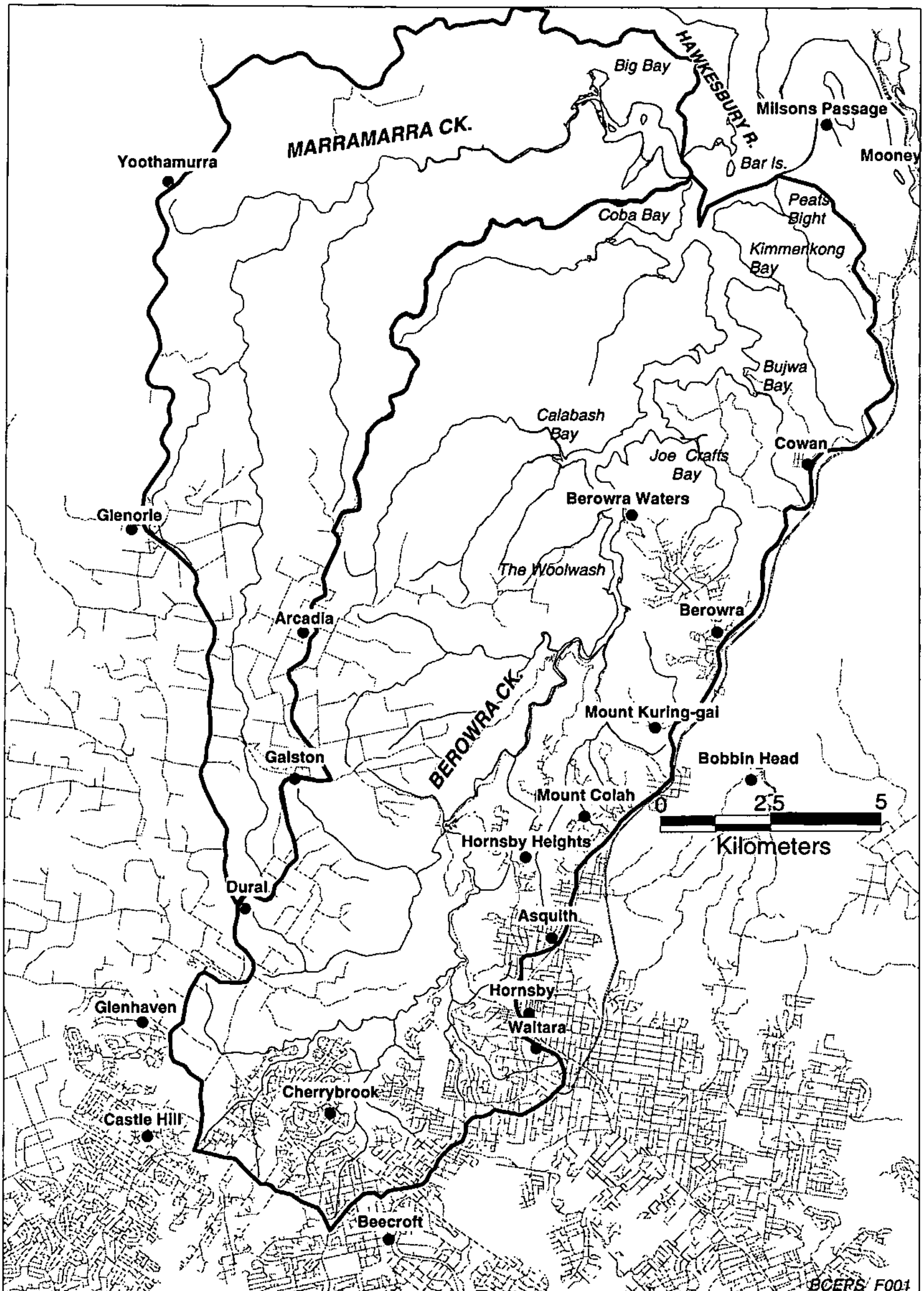


Figure 1. Berowra Creek Study Area. Berowra and Marramarra catchments shown.

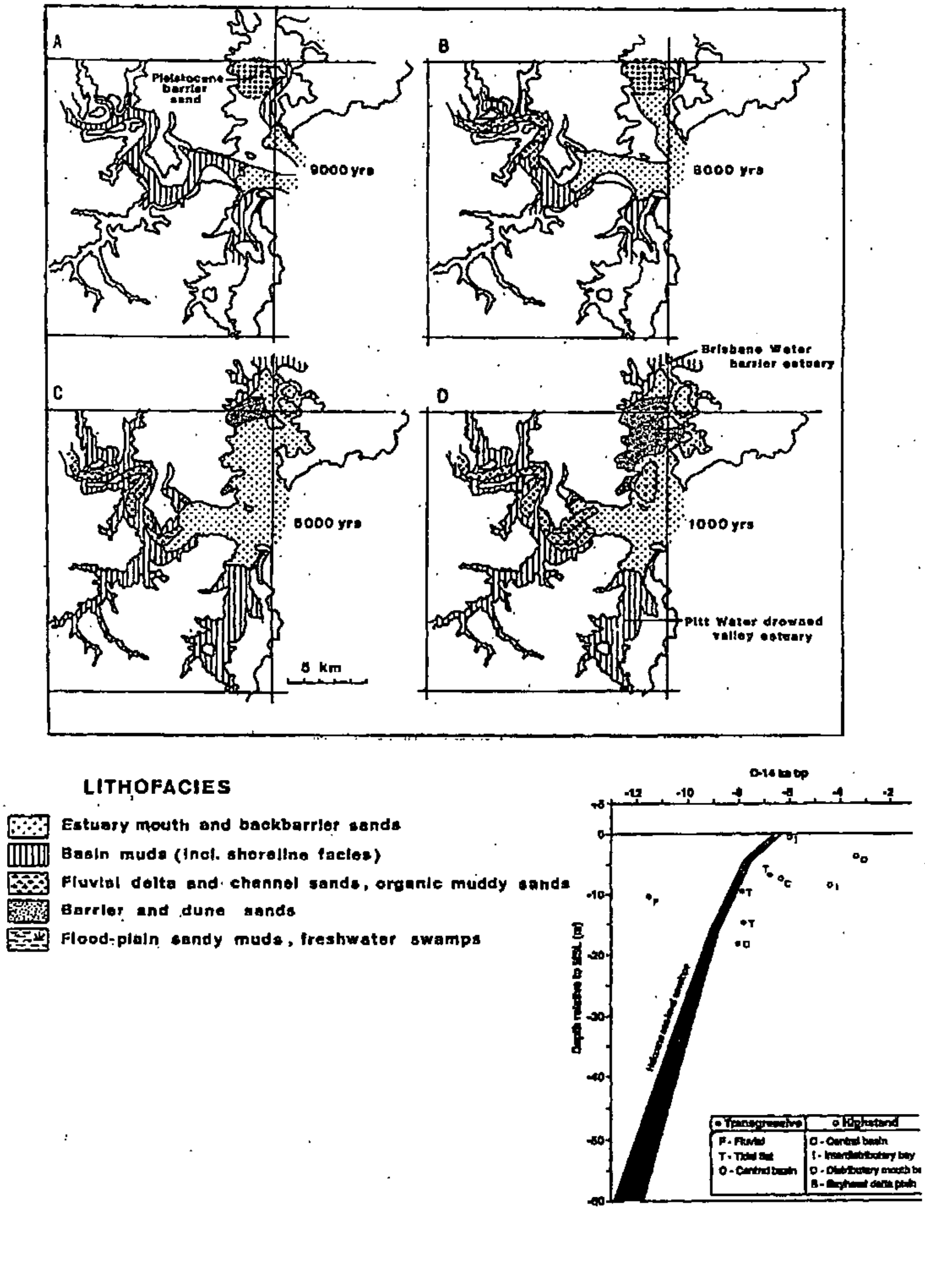


Figure 2. Lower Hawkesbury estuary late Pleistocene to Holocene evolutionary model (source Roy, 1994).

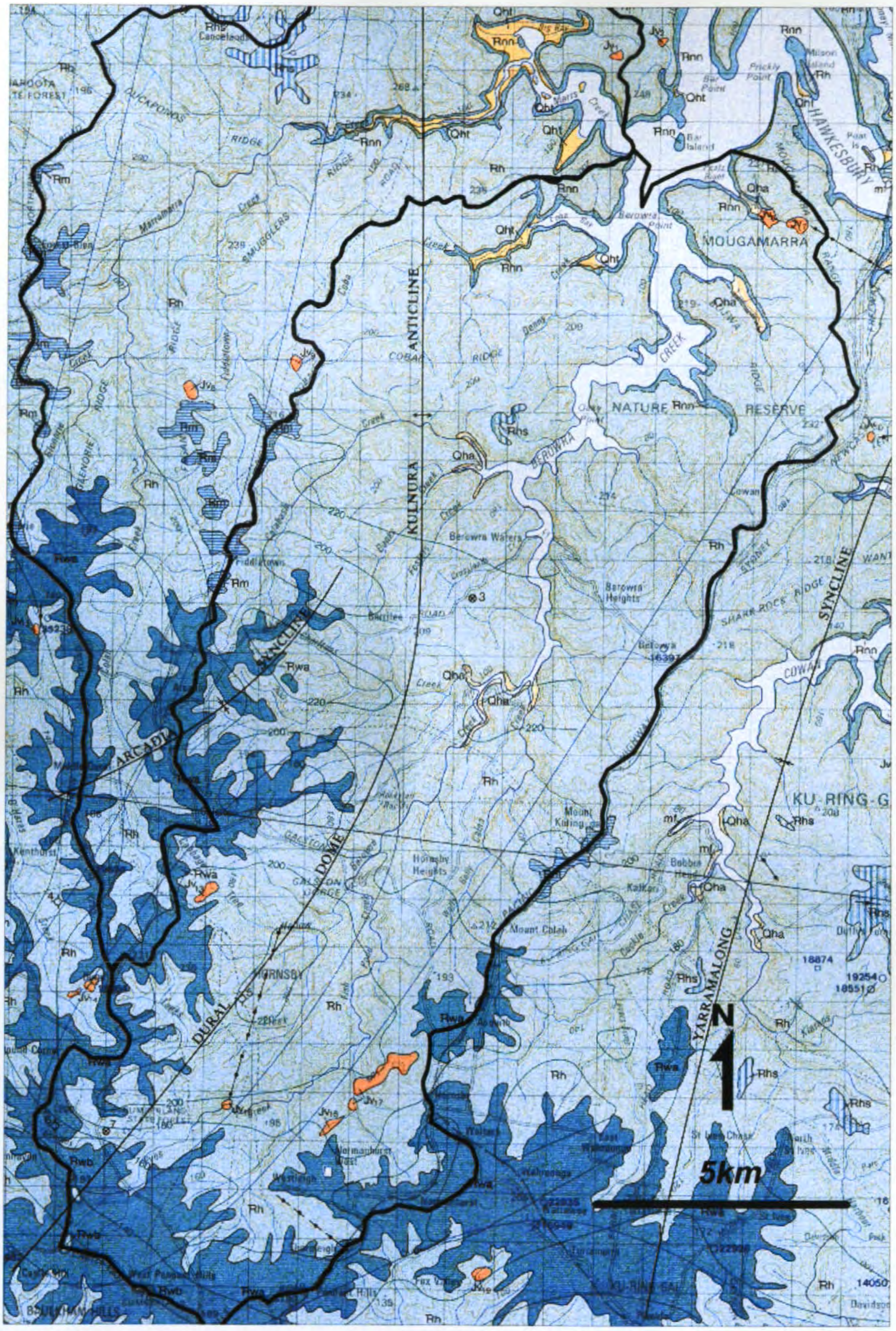


Figure 3. Geology of the Study Area. Berowra and Marramarra catchments shown. Rwa=Ashfield Shale; Rm=Mittagong shales and sandstones; Rh=Hawkesbury Sandstone; Rhs=Hawkesbury Sandstone-shale lense; Rnn=Narrabeen Group sandstones and shale; Jv=Volcanic breccia; Qha=alluvium (reproduced from NSW DMR 1:100,000 Sydney Sheet).

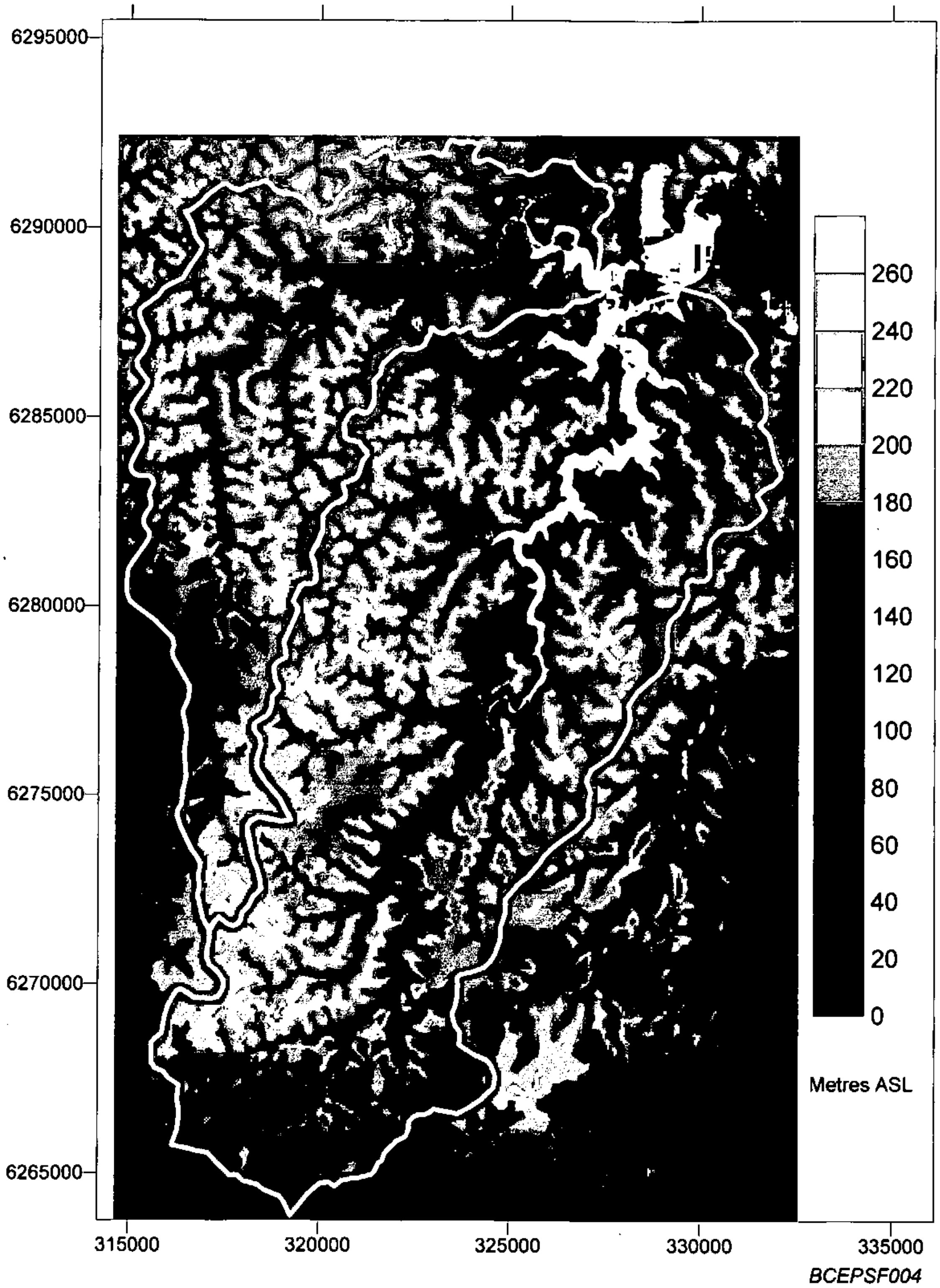


Figure 4. Study Area digital elevation model. Berowra and Marramarra catchments shown. See text for discussion.

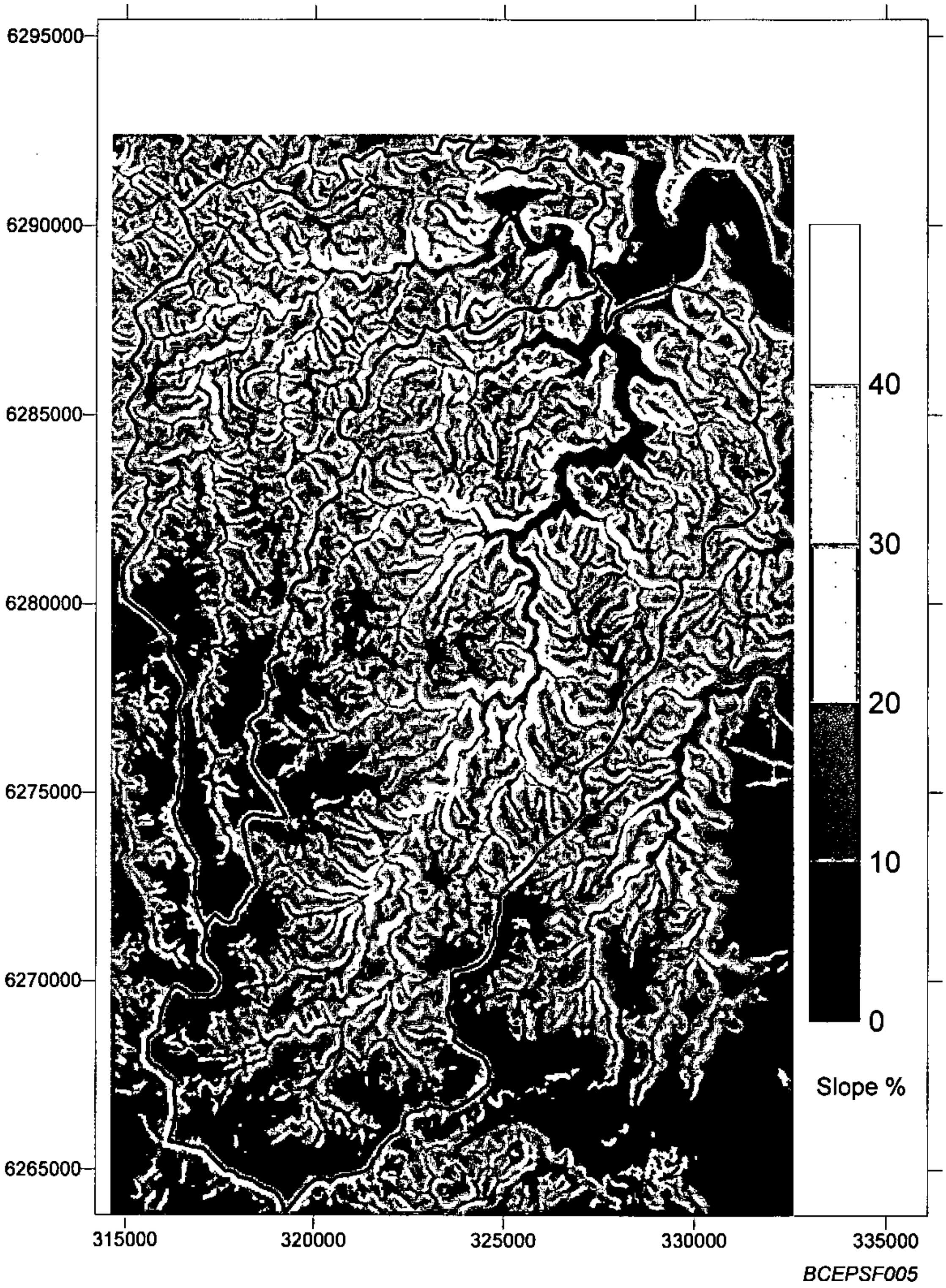


Figure 5. Study Area slope model. Berowra and Marramarra catchments shown. See text for discussion.

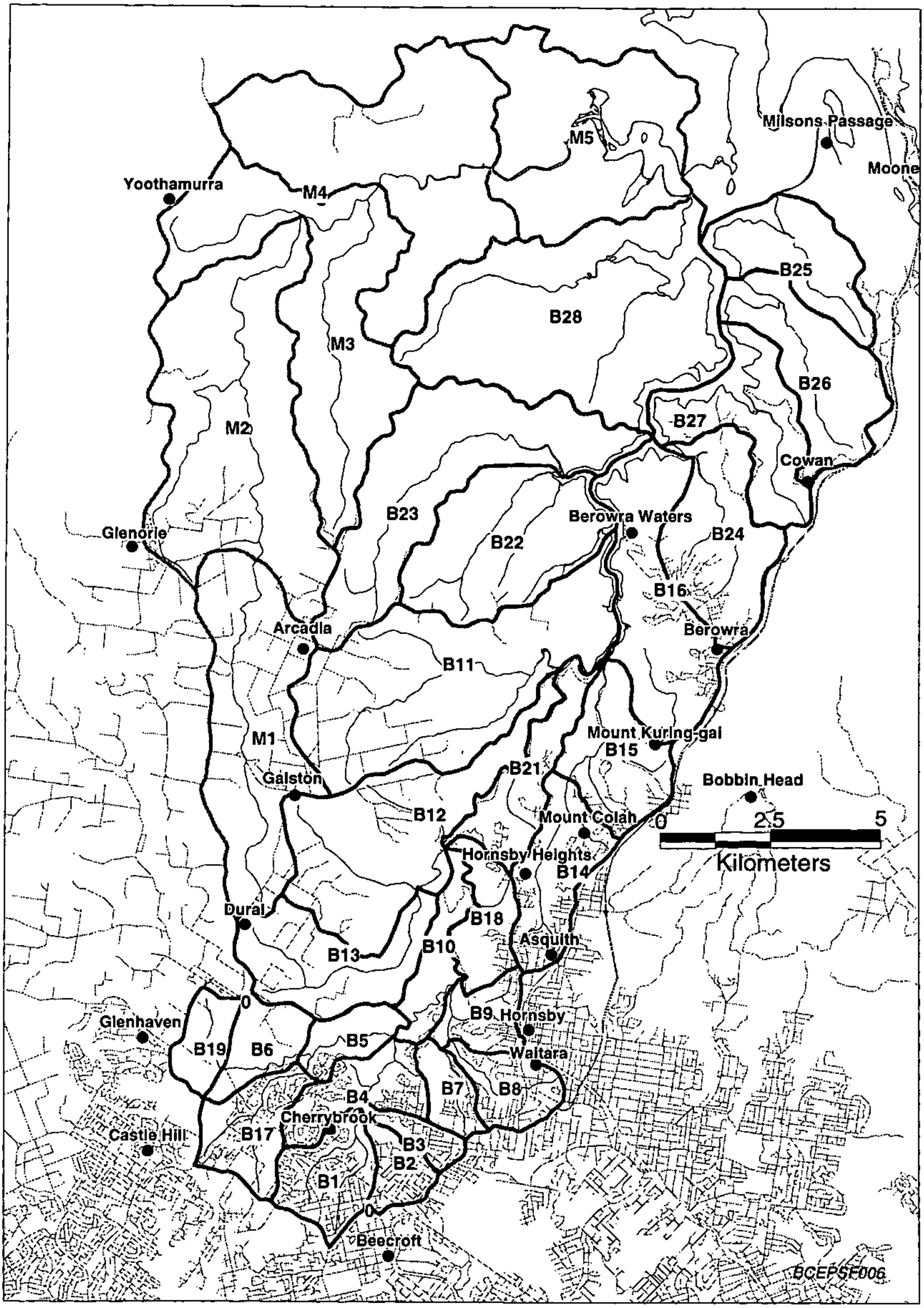


Figure 6. Study Area catchments and subcatchments used in modelling. Berowra (B prefix) and Marramarra (M prefix) catchments shown.

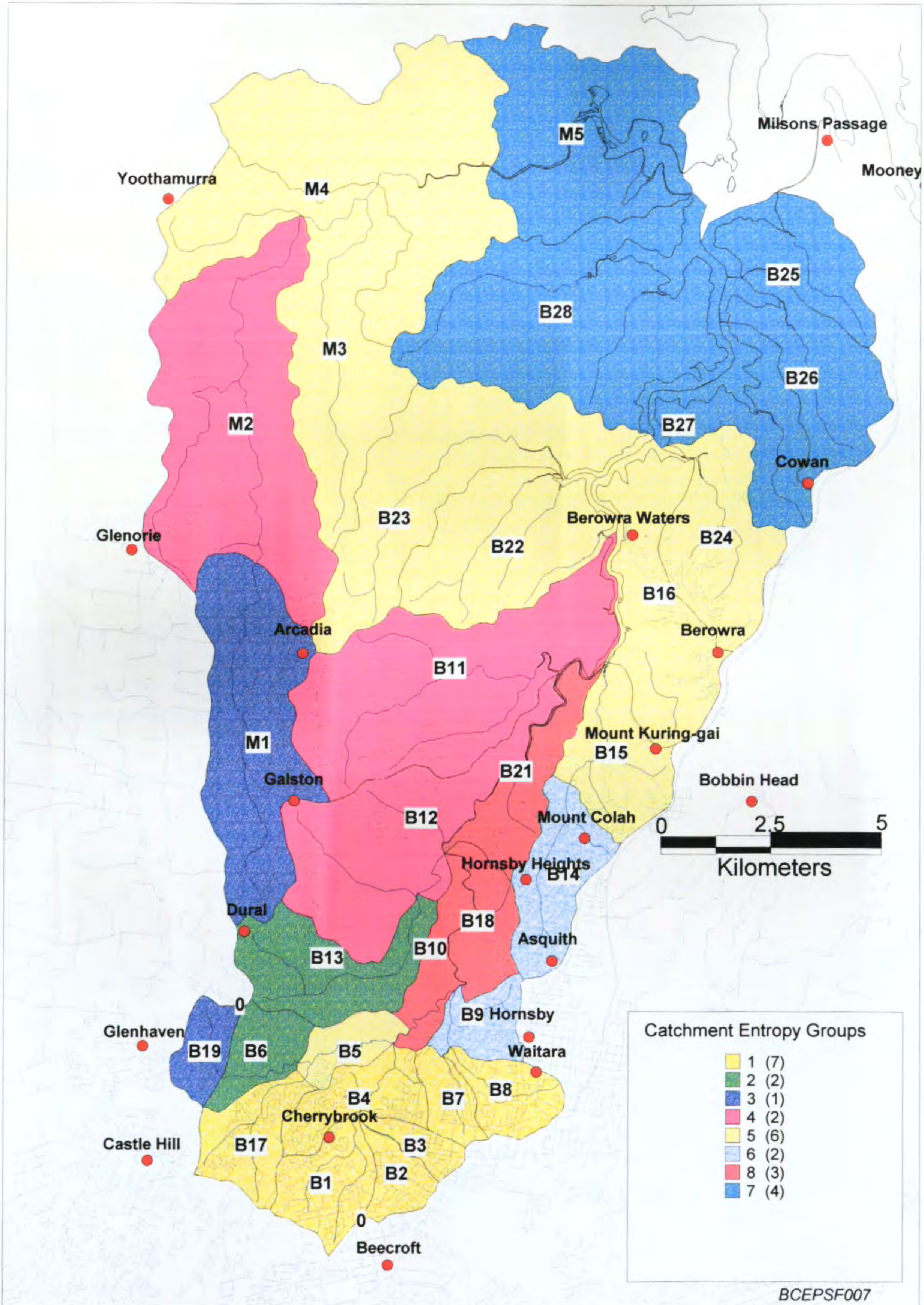


Figure 7. ENTROPY analysis catchment modelling results. See text for discussion.

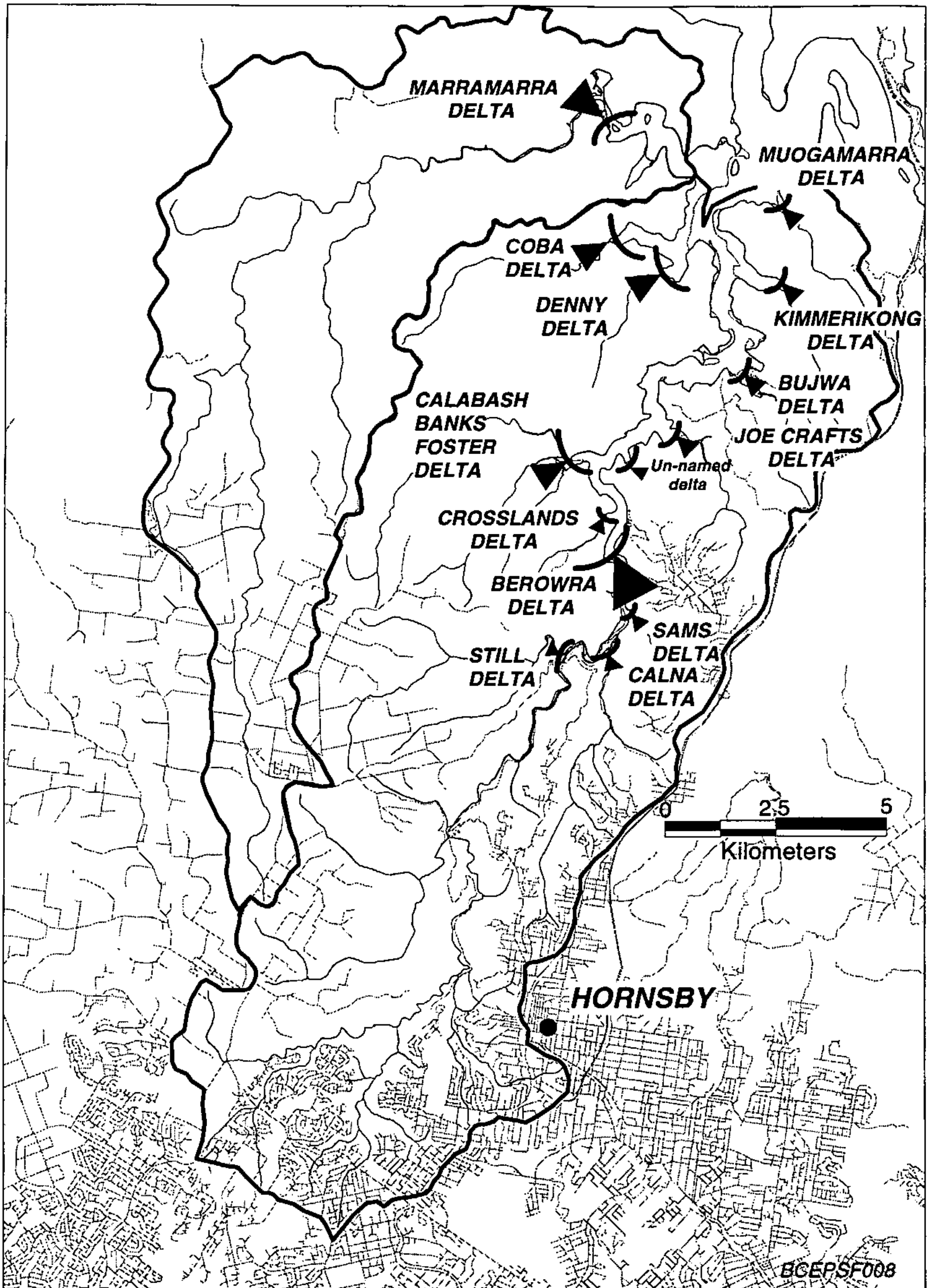
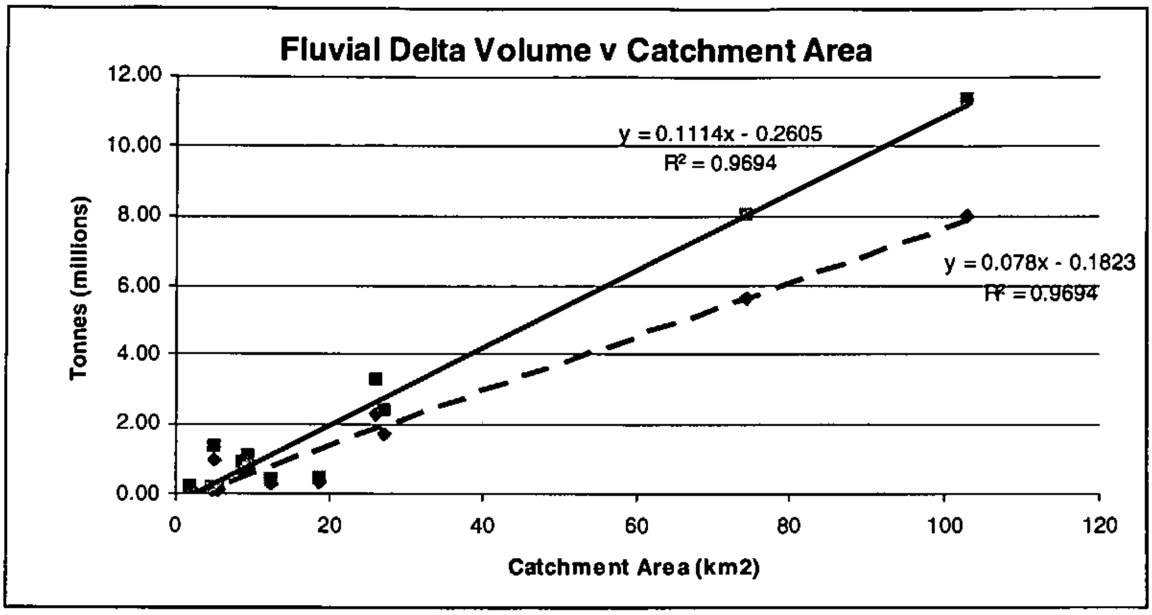


Figure 8. Location of major fluvial deltas within the Study Area.

A Calculated relationship between delta volume and catchment area.



B Calculated relationship between catchment denudation and catchment area.

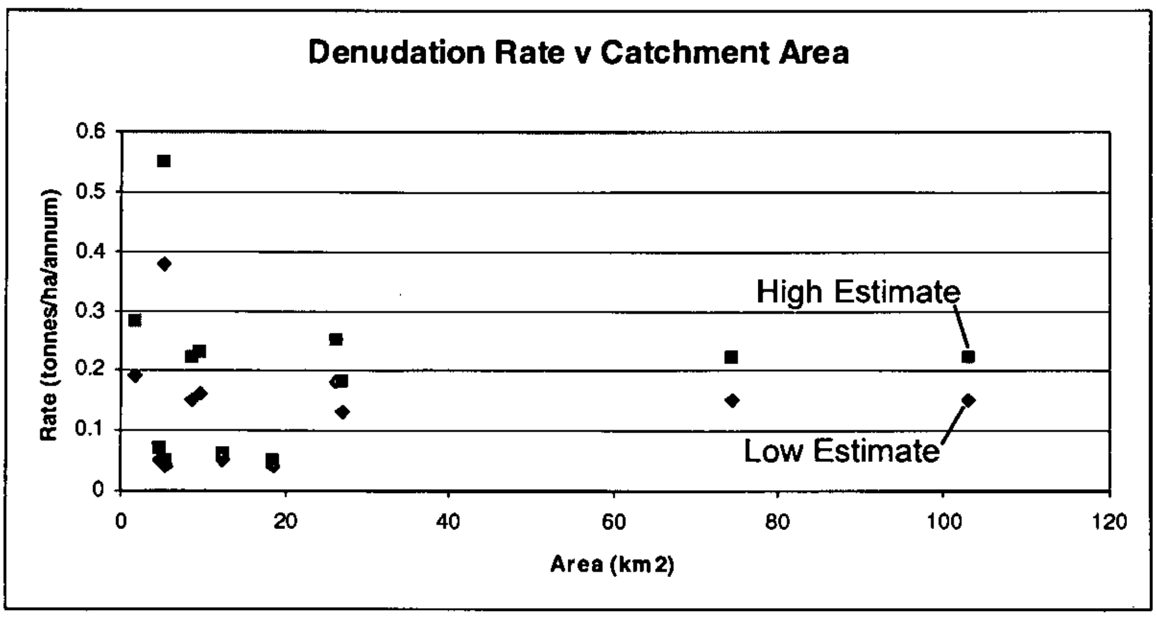


Figure 9. Calculated relationships between delta volume and catchment denudation rate for catchments in the Study Area. High and low estimates shown, see Table 7 for base data and text for discussion.

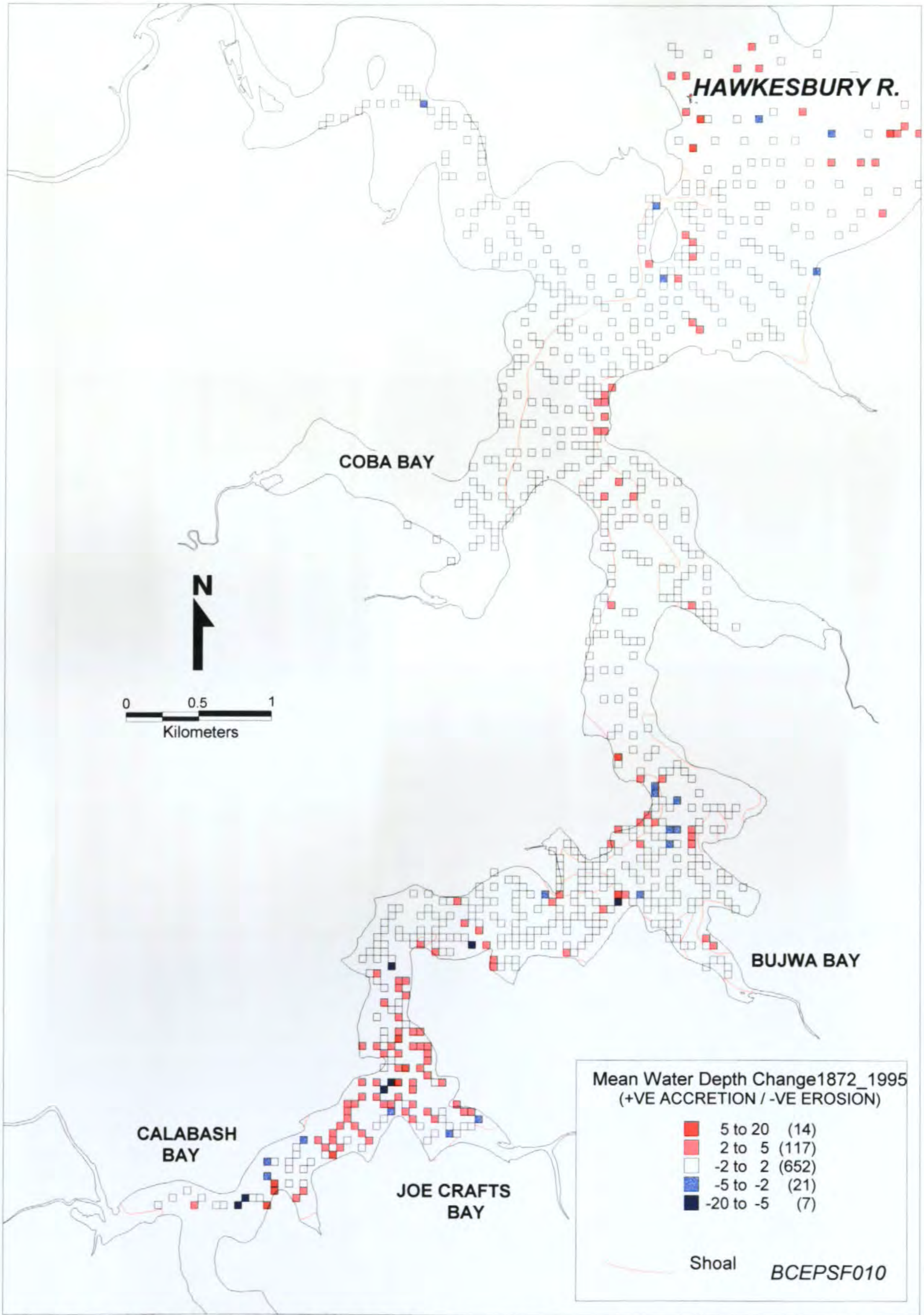


Figure 10. Comparison of 1872 and 1995 bathymetric surveys of Berowra Creek. Squares represent areas with data for each survey, colours indicate the net average depth change.

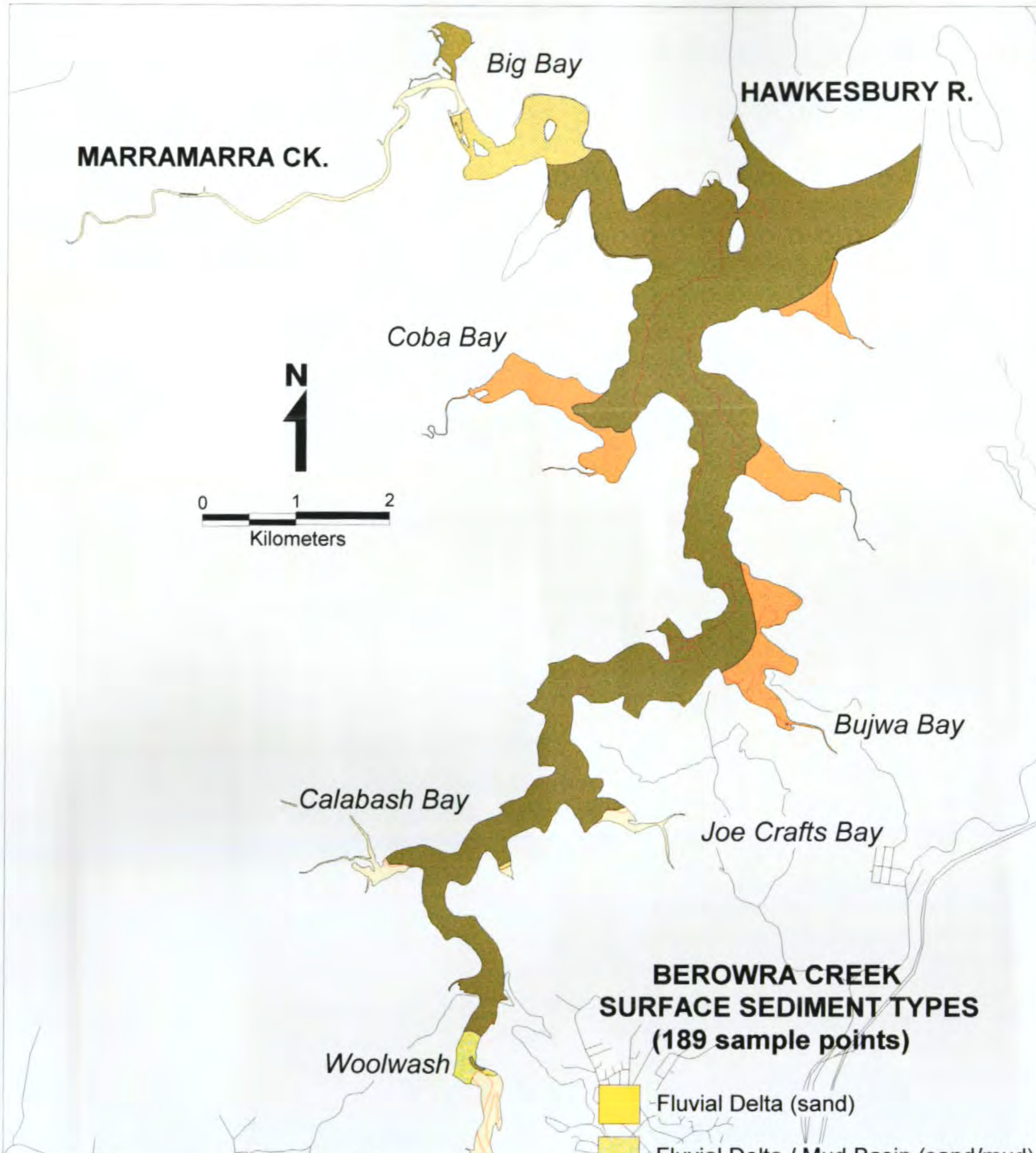


Figure 11. Surficial sediment types in the estuarine reaches of Berowra and Marramarra Creeks. Map based on 189 sample points, visual estimates and sediment analyses. Sample data from Hornsby Council, University of Sydney and CMG.

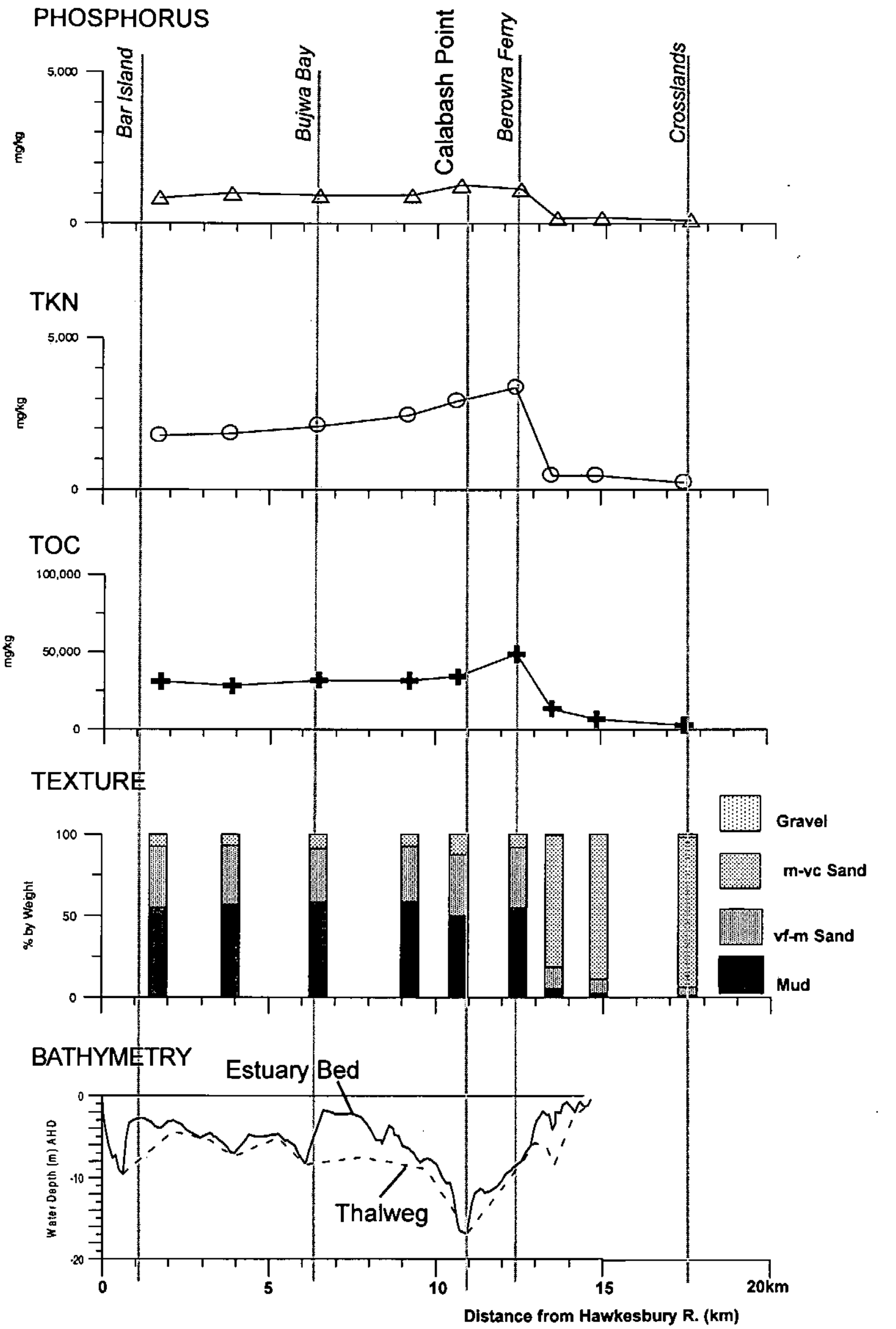


Figure 12. Along-estuary trends in Phosphorous, Nitrogen (TKN), Total Organic Carbon (TOC) and sediment texture for surficial samples collected by Hornsby Shire Council. Estuarine bathymetry is shown at base of figure.

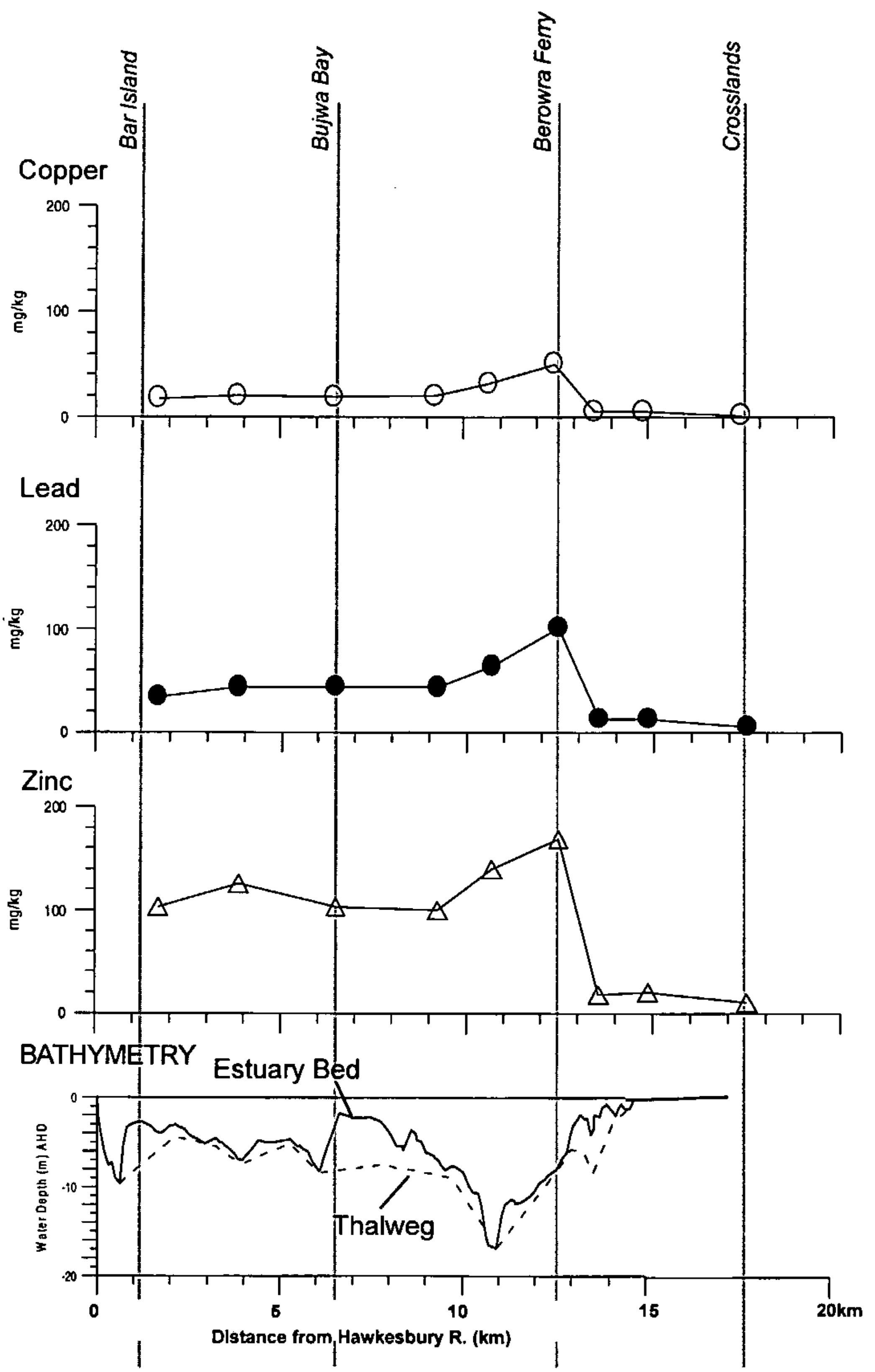


Figure 13. Along-estuary trends in Copper, Lead and Zinc concentrations (total sample) in surficial samples collected by Hornsby Shire Council. Estuarine bathymetry is shown at base of figure.

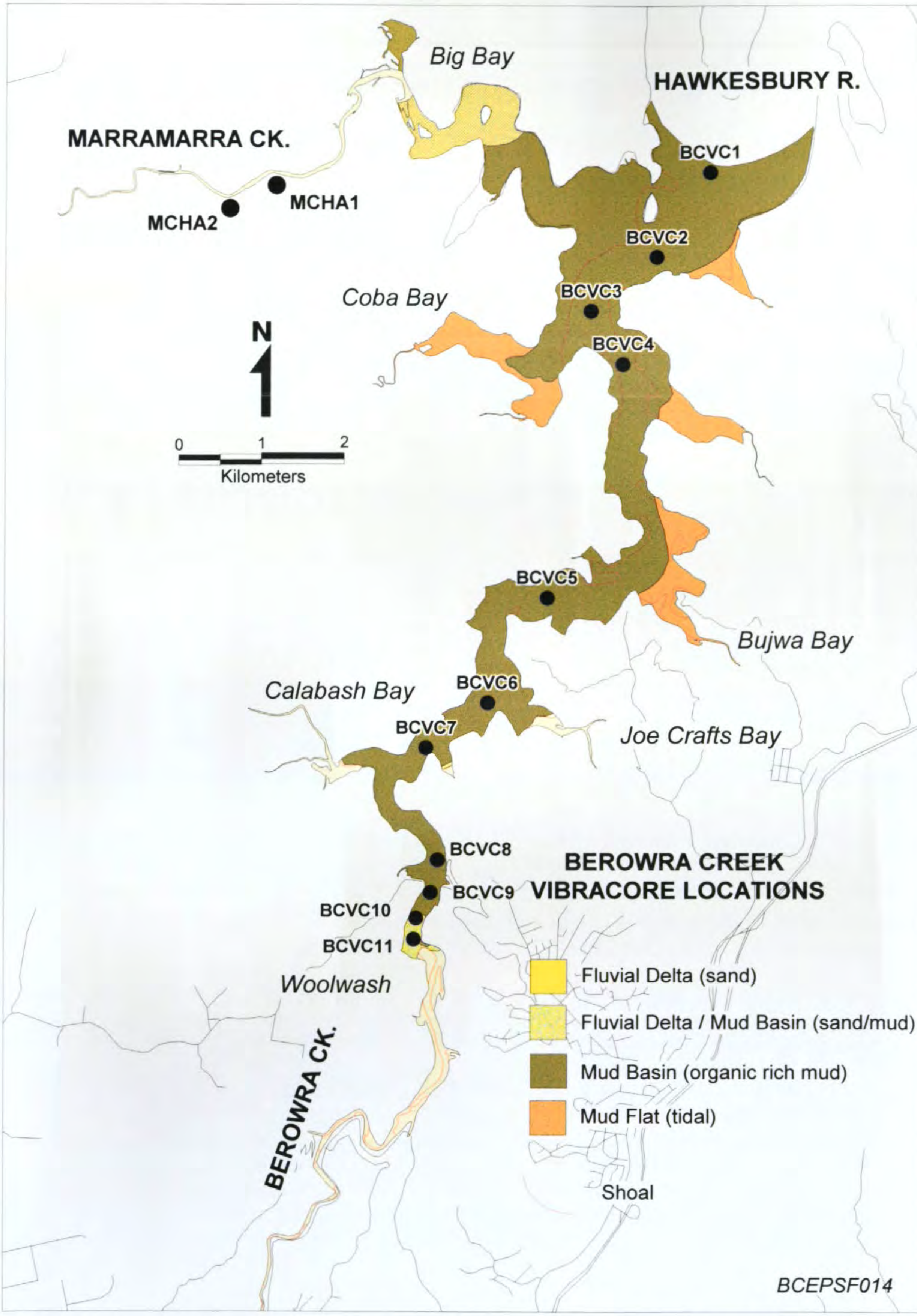


Figure 14. Location of vibracore sites in Berowra Creek (BCVC prefix) and hand auger sites in Marramarra Creek (MCHA prefix).

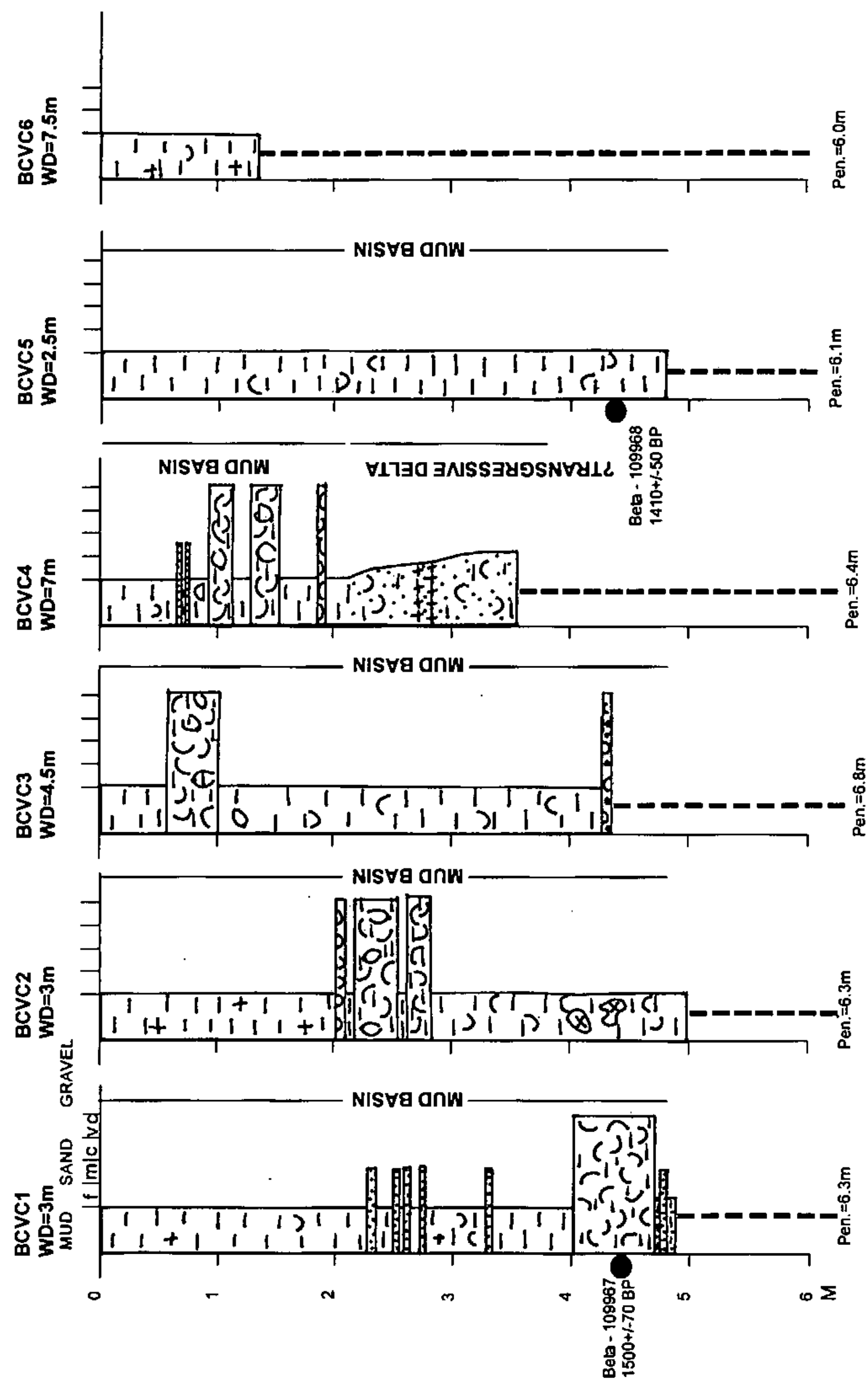


Figure 15. Graphic logs of vibracores BCVC1 to BCVC6. Locations shown in Figure 14 and legend for logs shown in Figure 17. Radiocarbon dates uncalibrated. Core and radiocarbon date details contained in Appendices

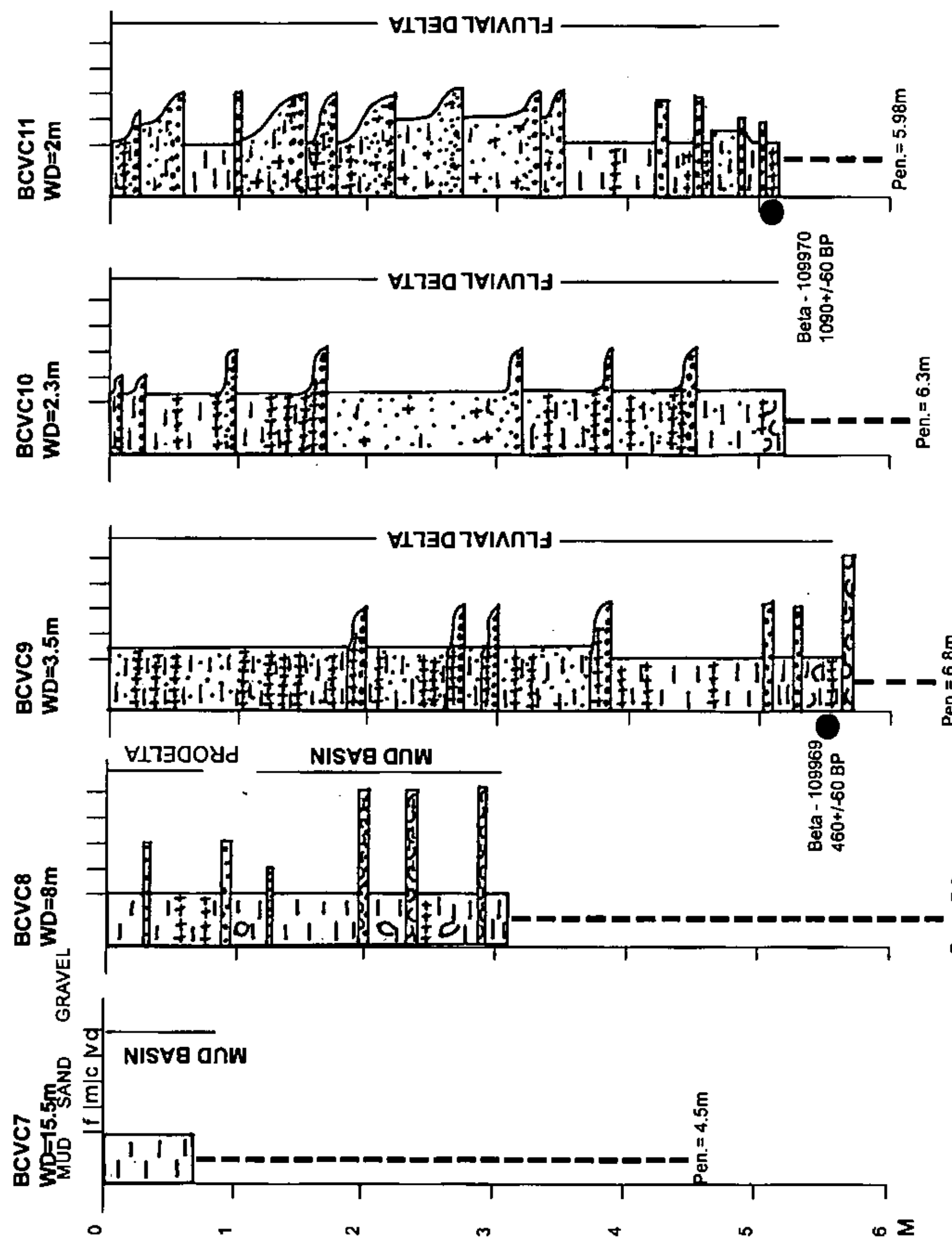


Figure 16. Graphic logs of vibracores BCVC7 to BCVC11. Locations shown in Figure 14 and legend for logs shown in Figure 17. Radiocarbon dates uncalibrated. Core and radiocarbon date details contained in Appendices

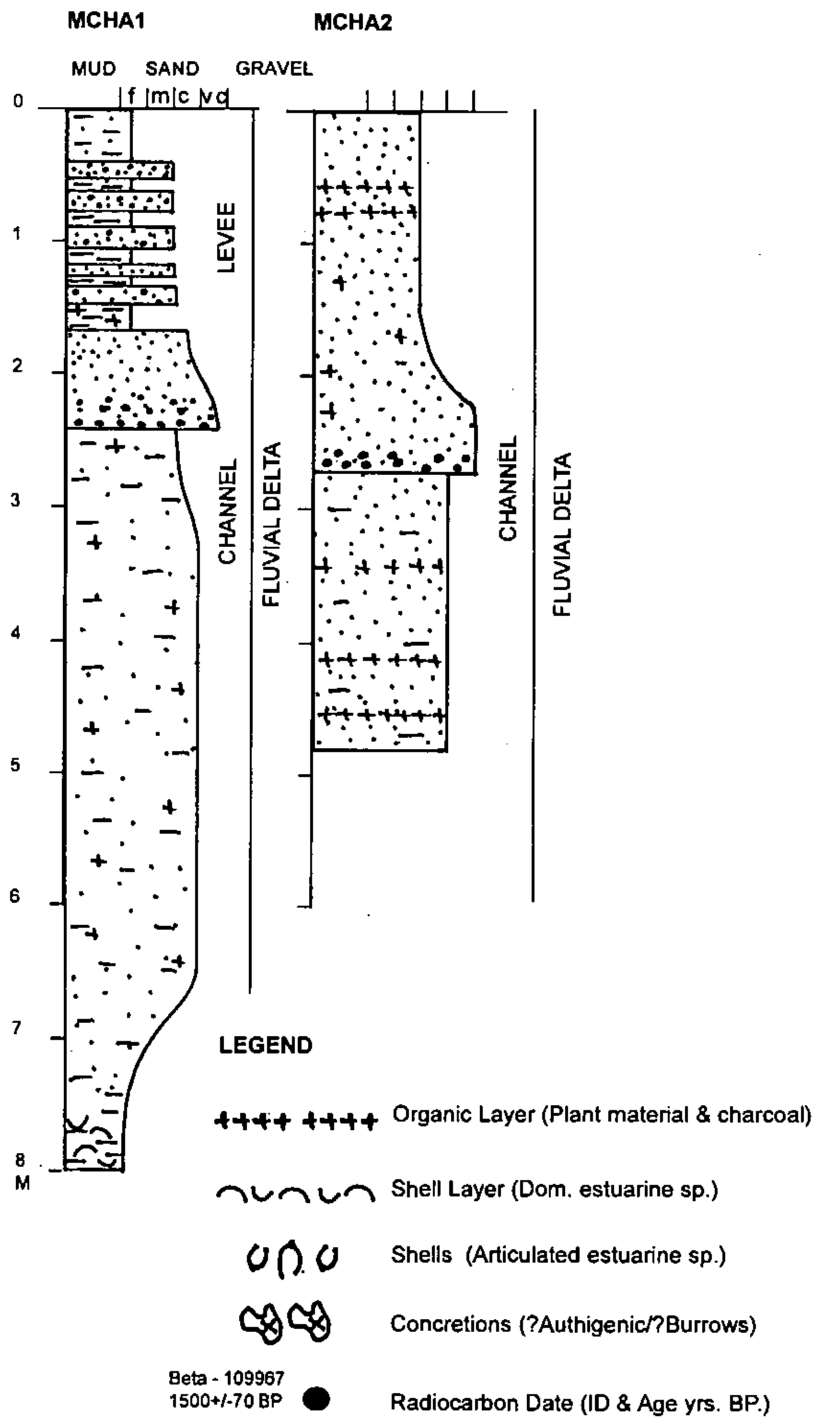


Figure 17. Graphic logs of vibracores MCHA1 and 2. Locations shown in Figure 14 and legend for logs shown in Figure 17. Graphic log legend shown. Core details contained in Appendices.

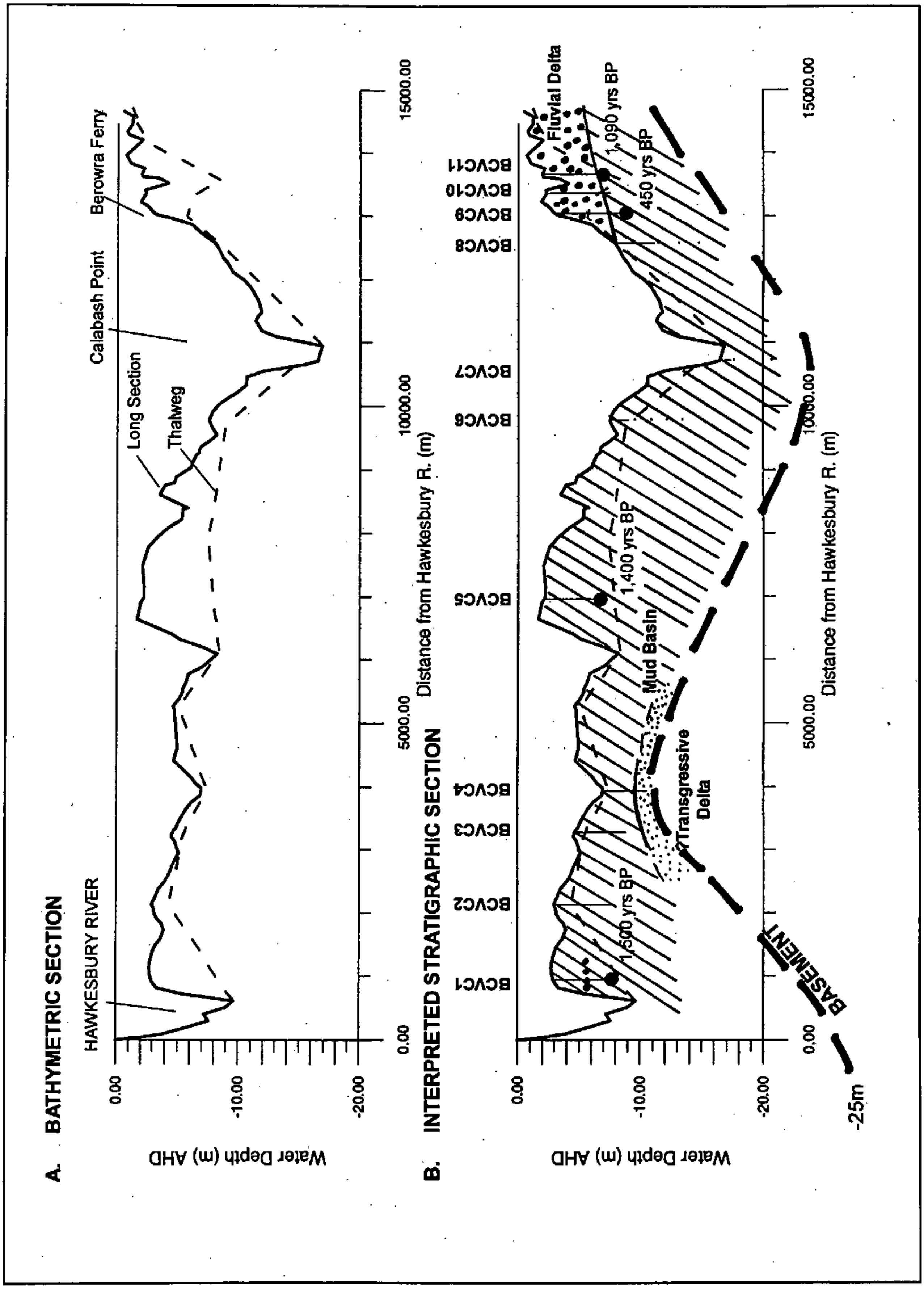
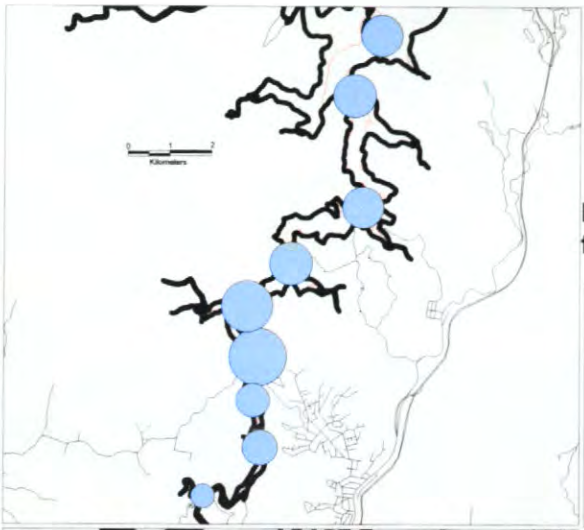
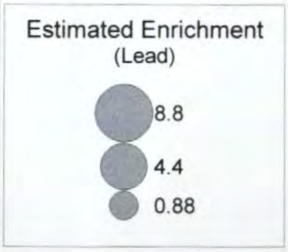


Figure 18. Interpreted stratigraphic section for Berowra Creek. Core locations indicated and shown in Figure 14. Location of basement and thickness of mud basin deposits inferred from vibracore penetrations and borehole data in main Hawkesbury River channel. See text for discussion.



Estimated Enrichment Factor for Copper in Surface Sediments

Estimated Enrichment Factor forLead in Surface Sediments



Estimated Enrichment Factor for Zinc in Surface Sediments

Figure 19. Estimated average enrichment factors for Copper, Lead and Zinc in surface samples collected by Hornsby Shire Council. Background levels determined from vibracore samples analysed by EPA. All data based on total sample analyses. See Table 8 and Appendices for further detail.

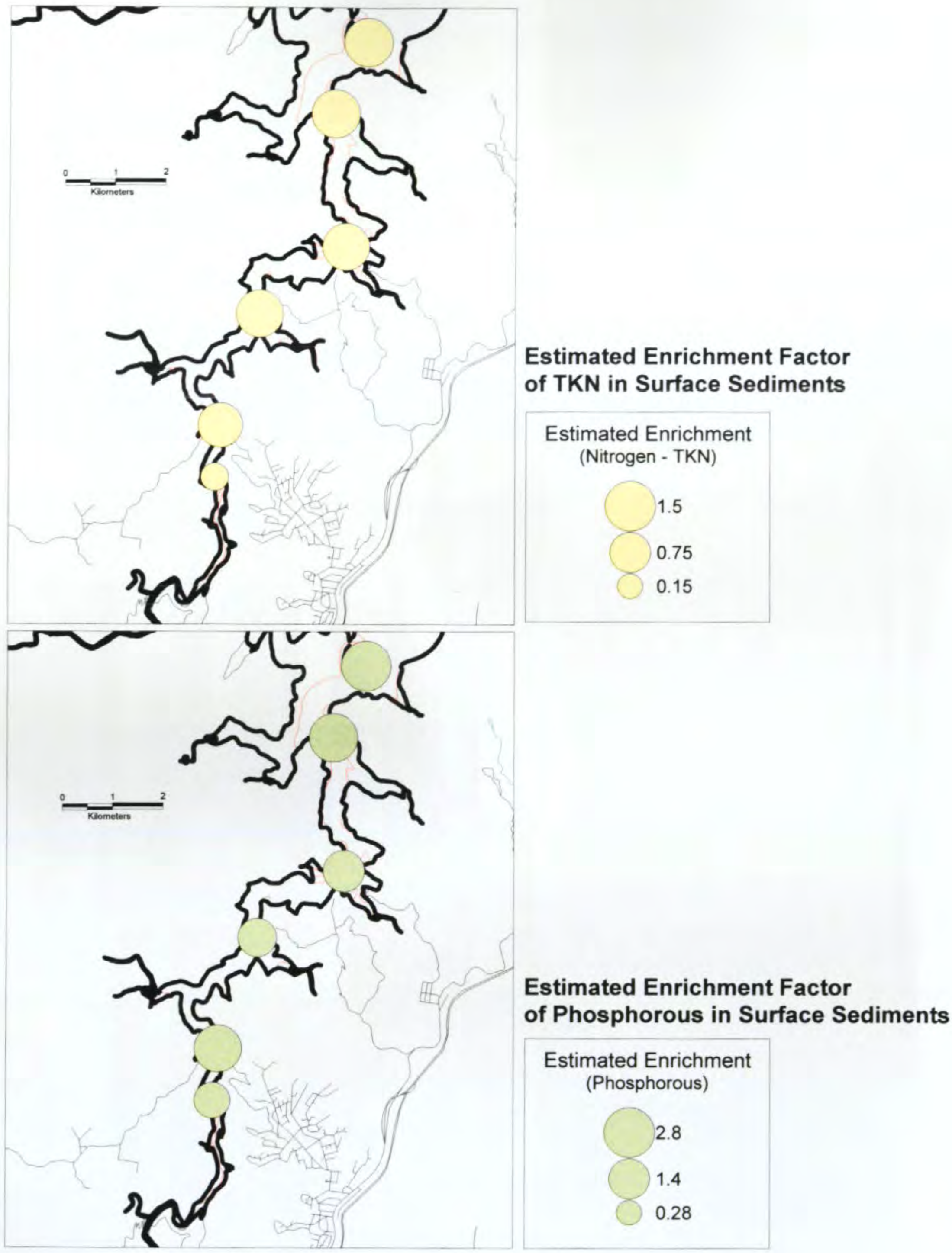


Figure 20. Estimated average enrichment factors for Nitrogen (TKN) and Phosphorous in surface samples collected by Hornsby Shire Council. Background levels determined from vibracore samples analysed by EPA and located near surface sediment sample sites. All data based on total sample analyses. See Table 8 and Appendices for further detail.

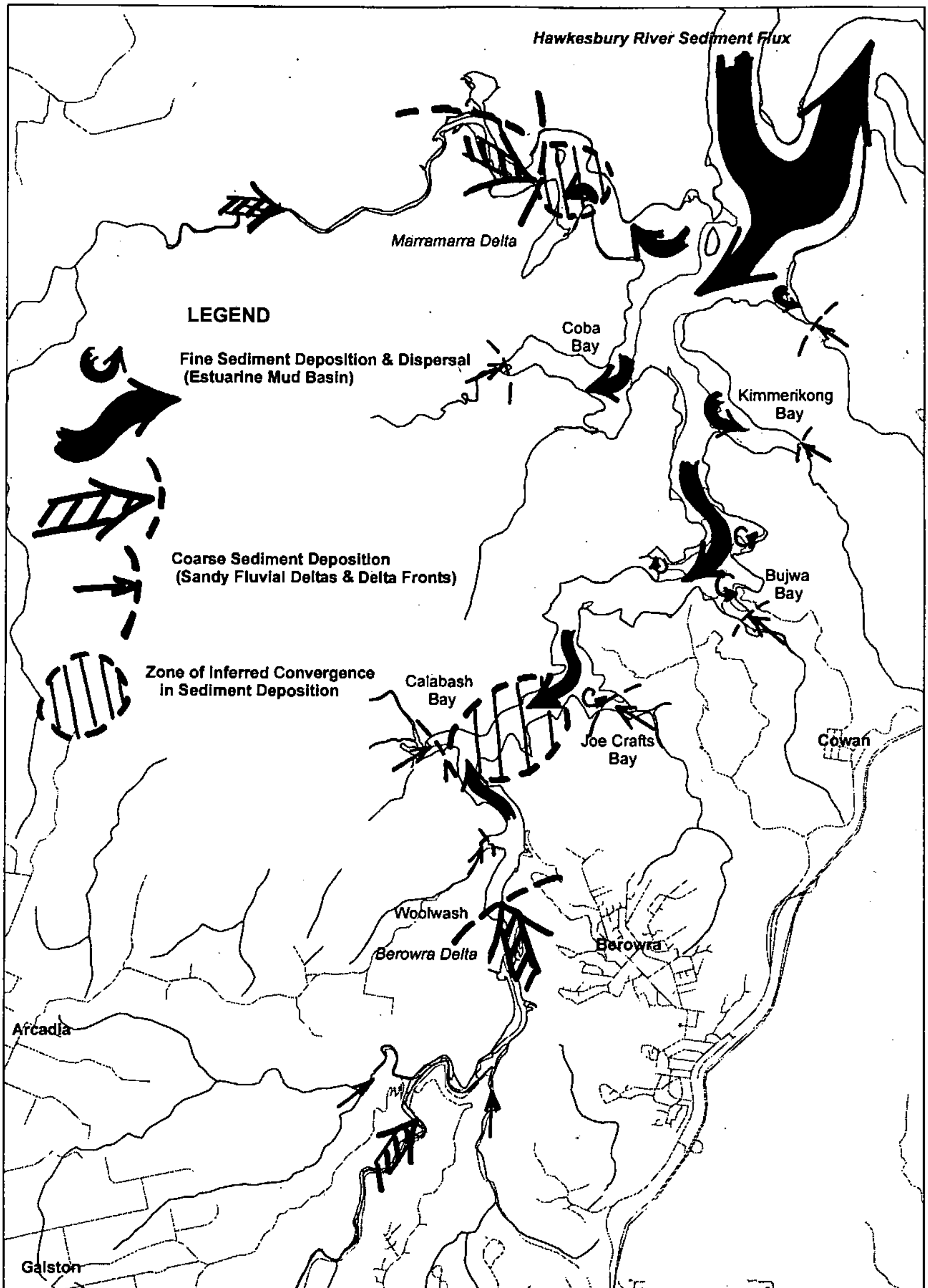


Figure 21. Study Area conceptual contemporary sedimentation model. Heavy black arrows indicate dispersal of fine grained sediments (mud and very fine sand), open hatched arrows show deposition of coarse grained sediments (sand and gravel) in fluvial deltas. Note influence of Hawkesbury sediments on Berowra Creek. See text for discussion.

Table 1. Soil Landscapes in Study Area

Geology	Soil landscape	Landscape position	Rural capability	Urban capability	Erosion hazard	Subsoil Dispersible
Wianamatta Group	Glenorie	Ridge top	High	Low - Mod	Mod - Very high	Yes
Hawkesbury sandstone						
	Faulconbridge	Ridge top	Mod	High	Low - Mod	No
	Hawkesbury	Valley side - Valley bottom	Not capable	Not capable	Mod - extreme	No
	Lambert	Valley side	Not capable	Low - Mod	Very high - extreme	Some
	Gymea	Valley side	Not capable	Low - Mod	High - extreme	Some
	Oxford Falls	Hanging valleys	Low	Low - Mod	High - extreme	No
Mittagong Formation	Lucas Heights	Ridge top	Mod	High	Mod - High	No
Igneous	Hornsby	Residual outcrops	Low	Low - Mod	Low - extreme	Yes
Alluvium	Hawkesbury River	Floodplains	Low - Mod	Not capable	Low	No
	Mangrove Creek	Mudflats	Not capable	Not capable	Low	Some
	Tacoma Swamp	Swamps	Not capable	Not capable	Low	No

(Source: Chapman and Murphy, 1989, Murphy, 1992)

Table 2. Berowra Creek Estuary Process Study - Estimated Sediment Erosion Rates (various sources)

LANDUSE		EROSION RATE	SOURCE
		Tonnes/hectare/annum	
Urban	Established	1 to 5	Parmeter and Graham (1995)
	Modern	1 to 5	
	Developing (Gymea)	19 to 464	
	(Hawkesbury)	109 to 394	
	(Pennant Hills)	219 to 372	
	(Glenorie)	65 to 117	
	Berowra Catchment	0.78	Coles (1995)*
	Hacking River	0.15	Roy (pers. comm.)**
	Sydney Region	1.2 to 1.45	WP-Geomarine (1996)
Rural	Pasture	0.1 to 1	Parmeter and Graham (1995)
	Crops	5 to 30	
Bushland	Undisturbed	<0.3	Parmeter and Graham (1995)
	Unstable	>20	Paton et al. (1995); Blong et al. (1982)

See reference list for full citation. Source is Parmeter and Graham (1995) unless specified.
*Coles(1995) based on river gauging data at Galston Gorge
**Roy estimate based on volumetric analysis of Hacking River delta and assumes catchment area of 181km2, 7000 years for delta formation.

TABLE 3. BEROWRA CREEK ESTUARY PROCESS STUDY - CATCHMENT ELEVATION AND SLOPE SUMMARY
(Modelled elevation and slope data)*

Berowra Catchment		Elevation Intervals (m)						Slope Intervals (Slopes in %)*			
Sub-Catchment ID	Area (km2)	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	% <10%	% 10-20%	% 20-40%	% 40%+
B1	4.58	0.00	0.00	0.00	0.38	99.62	0.00	77.78	15.21	6.95	0.05
B2	2.14	0.00	0.00	0.00	0.12	99.88	0.00	74.33	17.50	8.17	0.00
B3	1.53	0.00	0.00	0.00	0.33	99.67	0.00	63.90	19.84	16.10	0.16
B4	4.30	0.00	0.00	0.00	5.22	94.78	0.00	54.55	26.20	17.74	1.51
B5	2.51	0.00	0.00	0.00	11.33	75.45	13.22	21.27	24.65	37.08	17.00
B6	3.22	0.00	0.00	0.00	0.00	79.94	20.06	46.24	38.19	14.18	1.39
B7	2.15	0.00	0.00	0.00	0.47	99.53	0.00	54.67	24.88	17.99	2.45
B8	3.35	0.00	0.00	0.00	2.45	97.48	0.07	60.64	24.09	12.08	3.19
B9	2.83	0.00	0.00	0.00	20.97	79.03	0.00	22.39	29.47	35.40	12.74
B10	3.28	0.00	0.00	4.58	26.72	60.61	8.09	10.69	21.68	41.22	26.41
B11	21.99	0.87	0.75	2.53	8.71	75.15	11.99	37.68	23.28	26.47	12.57
B12	14.78	0.74	0.68	2.79	8.87	75.87	10.93	29.40	24.19	28.42	17.99
B13	7.98	0.00	0.00	0.03	3.78	55.92	40.26	45.45	22.91	22.69	8.94
B14	5.98	0.00	0.00	0.00	6.97	90.65	2.38	28.54	24.49	35.50	11.47
B15	6.35	1.06	1.14	4.01	13.17	67.96	12.62	16.40	20.60	39.39	23.62
B16	11.38	2.19	1.73	5.50	17.82	53.96	18.80	17.45	18.02	38.66	25.88
B17	4.52	0.00	0.00	0.00	0.00	100.00	0.00	72.10	24.35	3.55	0.00
B18	3.69	0.00	0.00	5.60	19.62	74.78	0.00	20.09	18.88	41.13	19.89
B19	2.48	0.00	0.00	0.00	0.00	82.26	17.74	84.78	15.22	0.00	0.00
B21	5.05	3.81	2.38	8.02	17.20	67.83	0.76	14.12	18.64	40.29	26.96
B22	12.21	1.12	0.93	3.23	14.96	72.26	7.51	18.56	20.46	38.29	22.69
B23	16.67	0.86	0.75	1.99	7.77	70.85	17.78	20.04	24.21	37.01	18.75
B24	9.03	0.64	0.56	3.07	16.12	62.90	16.71	16.97	23.85	41.32	17.86
B25	6.81	5.83	3.57	9.40	24.97	51.66	4.57	18.82	14.40	39.37	27.40
B26	8.61	1.84	1.74	6.66	20.83	59.30	9.62	13.28	19.94	46.03	20.75
B27	8.14	3.19	1.88	11.69	32.81	47.24	3.19	19.94	15.67	41.12	23.26
B28	26.23	2.58	2.05	6.85	20.00	58.93	9.59	17.11	16.44	42.26	24.19
AVERAGES	7.47	**0.92**	**0.67**	**2.81**	**11.17**	**76.06**	**8.37**	**36.19**	**21.75**	**28.46**	**13.60**

Marramarra Catchment		Elevation Intervals (m)						Slope Intervals (Slopes in %)*			
Sub-Catchment ID	Area (km2)	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	% <10%	% 10-20%	% 20-40%	% 40%+
M1	16.01	0.00	0.00	0.00	0.00	88.09	11.91	75.74	18.88	5.32	0.06
M2	25.01	0.00	0.00	0.04	8.84	80.23	10.88	28.67	26.47	30.95	13.91
M3	21.11	0.00	0.00	0.76	7.97	69.99	21.28	16.29	23.24	39.56	20.91
M4	22.88	1.07	0.83	2.77	10.08	53.95	31.28	12.34	24.07	43.22	20.36
M5	17.86	11.23	4.10	8.86	22.35	40.78	12.67	19.86	16.91	34.72	28.51
AVERAGES	**20.57**	**2.46**	**0.99**	**2.49**	9.85	**66.61**	**17.60**	**30.58**	**21.91**	30.76	**16.75**

*Modelling based on Digital Elevation Model (DEM) generated in SURFER from digital 1:25,000 LIC Homsby, Cowan and Gunderman Sheets.
DEM grid size 50m.

TABLE 4. BEROWRA CREEK ESTUARY PROCESS STUDY - CATCHMENT MORPHOLOGY & GEOLOGY SUMMARY

Berowra Catchment			Drainage_Length	Drainage_Density	CATCHMENT GEOLOGY (%)*						
Sub-Catchment ID	Area (km2)	Perimeter (km)	(km)	(km/km2)	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv
1	4.58	9.18	13.39	2.92	0.00	6.88	0.00	93.12	0.00	0.00	0.00
2	2.14	7.27	4.29	2.00	0.00	6.15	0.00	93.85	0.00	0.00	0.00
3	1.53	6.28	1.53	1.00	0.00	2.53	0.00	97.47	0.00	0.00	0.00
4	4.30	10.80	10.05	2.34	0.00	3.39	0.00	96.61	0.00	0.00	0.00
5	2.51	7.15	6.78	2.70	0.00	0.44	0.00	99.44	0.00	0.00	0.12
6	3.22	8.15	9.64	3.00	0.00	1.48	0.00	98.52	0.00	0.00	0.00
7	2.15	6.50	3.21	1.50	0.00	4.57	0.00	95.11	0.00	0.00	0.32
8	3.35	8.08	5.52	1.65	0.00	5.72	0.00	94.28	0.00	0.00	0.00
9	2.83	8.34	7.60	2.69	0.00	5.84	0.00	92.71	0.00	0.00	1.45
10	3.28	12.61	11.95	3.65	0.00	0.00	0.00	100.00	0.00	0.00	0.00
11	21.99	24.49	51.56	2.35	0.00	2.15	0.00	97.85	0.00	0.00	0.00
12	14.78	23.12	34.64	2.34	0.00	1.39	0.00	98.55	0.00	0.00	0.06
13	7.98	15.33	22.12	2.77	0.00	2.58	0.00	97.31	0.00	0.00	0.11
14	5.98	11.89	14.38	2.40	0.00	1.43	0.00	98.57	0.00	0.00	0.00
15	6.35	11.33	14.12	2.22	0.00	0.00	0.60	100.00	0.00	0.00	0.00
16	11.38	18.74	22.86	2.01	0.00	0.00	0.00	100.00	0.00	0.00	0.00
17	4.52	10.12	12.15	2.69	0.35	7.84	0.00	91.80	0.00	0.00	0.00
18	3.69	10.71	9.48	2.57	0.00	0.24	0.00	99.76	0.00	0.00	0.00
19	2.48	6.93	7.66	3.09	0.00	7.05	0.00	92.95	0.00	0.00	0.00
21	5.05	15.84	16.92	3.35	0.00	0.00	0.00	100.00	0.00	0.00	0.00
22	12.21	14.88	30.66	2.51	0.00	0.20	0.00	99.80	0.00	0.00	0.00
23	16.67	25.48	42.31	2.54	0.00	0.52	0.25	99.36	0.12	0.00	0.00
24	9.03	14.84	18.05	2.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
25	6.81	12.39	14.58	2.14	0.00	0.00	0.00	89.13	0.00	7.97	2.90
26	8.61	15.29	24.96	2.90	0.00	0.00	0.00	93.85	0.00	6.15	0.00
27	8.14	16.59	13.86	1.70	0.00	0.00	0.00	90.54	0.00	9.46	0.00
28	26.23	24.98	62.36	2.38	0.00	0.00	0.00	93.96	0.00	6.04	0.00
TOTALS	**201.77**	**357.30**	**486.60**	**65.41**	**0.35**	**60.40**	**0.85**	**2604.54**	**0.12**	**29.62**	**4.96**
AVERAGES	**7.47**	**13.23**	**18.02**	**2.42**	**0.01**	**2.24**	**0.03**	**96.46**	**0.00**	**1.10**	**0.18**

Marramarra Catchment			Drainage_Length	Drainage_Density							
Sub-Catchment ID	Area (km2)	Perimeter (km)	(km)	(km/km2)	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv
1	16.01	22.04	42.32	2.64	0.00	46.29	0.00	53.71	0.00	0.00	0.00
2	25.01	28.01	77.71	3.11	0.00	8.46	7.44	84.10	0.00	0.00	0.00
3	21.11	33.71	62.57	2.96	0.00	0.00	1.71	97.68	0.00	0.00	0.62
4	22.88	29.43	56.76	2.48	0.00	0.00	0.00	93.24	4.27	2.49	0.00
5	17.86	20.44	22.63	1.27	0.00	0.00	0.00	88.45	0.00	11.36	0.18
TOTALS	**102.87**	**133.64**	**261.99**	**12.46**	**0.00**	**54.75**	**9.14**	**417.18**	**4.27**	**13.85**	**0.80**
AVERAGES	**20.57**	**26.73**	**52.40**	**2.49**	**0.00**	**10.95**	**1.83**	**83.44**	**0.85**	**2.77**	**0.16**

***Rwb**:Bringelly Shale; **Rwa**:Ashfield Shale; **Rm**:Mittagong Fm.(Shale&Sandstone); **Rh**; Hawkesbury Sandstone; **Rhs**: Shale;
Rnn:Newport Fm.(Shale & Sandstone); **Jv**: Basaltic Dyke-Diatreme

Table 5. Berowra Creek Estuary Process Study - Catchment Landuse Summary
Approximate Land Zoning Proportions (%)*

Berowra Catchments							
Sub-catchment ID	Area (km2)	Large Rural	Small Rural	Residential	Business	Industrial	Bushland**
B1	4.58	0	3	70	0	0	27
B2	2.14	0	0	78	0	0	22
B3	1.53	0	0	83	0	0	17
B4	4.30	0	8	55	0	0	37
B5	2.51	0	0	14	0	0	86
B6	3.22	0	28	0	12	0	61
B7	2.15	0	6	73	0	0	22
B8	3.35	0	0	87	0	0	13
B9	2.83	0	12	55	0	0	34
B10	3.28	0	1	7	0	0	91
B11	21.99	17	32	0	0	0	51
B12	14.78	0	37	0	0	0	63
B13	7.98	0	53	2	0	0	45
B14	5.98	0	0	60	0	0	40
B15	6.35	0	0	25	0	11	64
B16	11.38	0	0	19	0	2	79
B17	4.52	0	52	25	0	0	23
B18	3.69	0	0	45	0	0	55
B19	2.48	0	100	0	0	0	0
B21	5.05	0	0	38	0	0	62
B22	12.21	31	0	0	0	0	69
B23	16.67	37	2	0	0	0	60
B24	9.03	0	0	23	0	0	77
B25	6.81	0	0	0	0	0	100
B26	8.61	0	0	2	0	0	98
B27	8.14	0	0	2	0	0	98
B28	26.23	0	0	0	0	0	100
AVERAGES	**7.47**	**3.14**	**12.40**	**28.15**	**0.44**	**0.47**	**55.38**

Marramarra Catchments							
Sub-catchment ID	Area (km2)	Large Rural	Small Rural	Residential	Business	Industrial	Bushland**
M1							
M2	16.01	3	77	1	0	0	19
M3	25.01	25	17	0	0	0	57
M4	21.11	28	0	0	0	0	72
M5	22.88	17	0	0	0	0	83
AVERAGES	17.86	1	0	0	0	0	99
	20.57	**14.71**	**18.83**	**0.37**	**0.00**	**0.00**	**66.09**

* Data derived from zoning information supplied by Hornsby Shire Council in digital and hard copy formats. NOTE that the derived proportions of landuse are therefore approximate and should only be used for a generalised account of landuse patterns within drainage catchments within the study area.

** Bushland includes zoning areas of environmental protection, open space, reserves and National Park.

Table 6. Berowra Creek Estuary Process Study - Entropy Catchment Class and Landuse Crosstabulation.

Catchments		Approximate Land Zoning Proportions (%)*						Entropy
Sub-catchment	Area (km2)	Large Rural	Small Rural	Residential	Business	Industrial	Bushland**	Group
B1	4.58	0	3	70	0	0	27	1
B2	2.14	0	0	78	0	0	22	1
B3	1.53	0	0	83	0	0	17	1
B4	4.30	0	8	55	0	0	37	1
B7	2.15	0	6	73	0	0	22	1
B8	3.35	0	0	87	0	0	13	1
B17	4.52	0	52	25	0	0	23	1
B6	3.22	0	28	0	12	0	61	2
B13	7.98	0	53	2	0	0	45	2
B19	2.48	0	100	0	0	0	0	3
M1	16.01	3	77	1	0	0	19	3
B11	21.99	17	32	0	0	0	51	4
B12	14.78	0	37	0	0	0	63	4
M2	25.01	25	17	0	0	0	57	4
B5	2.51	0	0	14	0	0	86	5
B15	6.35	0	0	25	0	11	64	5
B16	11.38	0	0	19	0	2	79	5
B22	12.21	31	0	0	0	0	69	5
B23	16.67	37	2	0	0	0	60	5
M3	21.11	28	0	0	0	0	72	5
M4	22.88	17	0	0	0	0	83	5
B9	2.83	0	12	55	0	0	34	6
B14	5.98	0	0	60	0	0	40	6
B24	9.03	0	0	23	0	0	77	7
B25	6.81	0	0	0	0	0	100	7
B26	8.61	0	0	2	0	0	98	7
B27	8.14	0	0	2	0	0	98	7
B28	26.23	0	0	0	0	0	100	7
M5	17.86	1	0	0	0	0	99	7
B10	3.28	0	1	7	0	0	91	8
B18	3.69	0	0	45	0	0	55	8
B21	5.05	0	0	38	0	0	62	8

Table 7. Berowra Creek Estuary Process Summary - Fluvial Delta Volumes and Catchment Dnudation Estimates

Delta ID	Catchment Area (km2)	Delta Area(m2)	Volume I (m3) (Delta 7m Thick)	Tonnes I (1.4t/m3)	Volume II (m3) (Delta 10m Thick)	Tonnes II (1.4t/m3)	Sedimentation Rate* (Range tonnes/year)	Catchment Denudation Rate* (Range tonnes/ha/year)
Marramarra	102.87	1136054	7952378	11133329	11360540	15904756	1590 - 2272	0.15 - 0.22
Coba & Denny	26.23	328548	2299836	3219770	3285480	4599672	460 - 657	0.18 - 0.25
Calabash,Banks,Foster	27.07	243732	1706124	2388574	2437320	3412248	341 - 487	0.13 - 0.18
Crosslands**	1.81	24935	174545	244363	249350	349090	35 - 50	0.19 - 0.28
Still	18.61	47033	329231	460923	470330	658462	66 - 94	0.04 - 0.05
Calna	12.34	39942	279594	391432	399420	559188	56 - 80	0.05 - 0.06
Sams	5.45	14599	102193	143070	145990	204386	20 - 29	0.04 - 0.05
Unnamed	1.08	15200	106400	148960	152000	212800	21 - 30	0.20 - 0.28
Joe Crafts	9.61	108856	761992	1066789	1088560	1523984	152 - 218	0.16 - 0.23
Budjwa	4.79	15666	109662	153527	156660	219324	22 - 31	0.05 - 0.07
Kimmerikong	8.61	92632	648424	907794	926320	1296848	130 - 185	0.15 - 0.22
Muogamarra	5.08	139181	974267	1363974	1391810	1948534	195 - 278	0.38 - 0.55
Berowra	74.36	802367	5616569	7863197	8023670	11233138	1123 - 1605	0.15 - 0.22

*Sedimentation and denudation rates assume delta has accumulated over a period of 7,000 years. Range refers to either 7m or 10m estimated delta thickness.
(see text for discussion of estimates of mud volumes deposited in estuary over past 7,000 years)
** Unknown proportion of fill for road and parking area construction, probable overestimate of delta volume.

Table 8. Berowra Creek Estuary Process Study - Assessment of surface sediment contamination from vibracore sample analyses.

Sample	Sediment Type*	%Mud	TOC mg/kg	TKN mg/kg	TKN* (CORE)	P mg/kg	P* (CORE)	Cr_Factor** (Enrichment)	Cu_Factor** (Enrichment)	Zn_Factor** (Enrichment)	As_Factor** (Enrichment)	Pb_Factor** (Enrichment)
BAR ISLAND												
BP01	sM	50.09	31400	1770	1300	839	310	3.4	1.9	3.5	1.7	2.9
BP02	sM	54.33	30300	1620		929		3.0	1.9	3.3	1.6	2.5
BP03	sM	50.60	30600	1630		931		3.0	1.9	3.5	1.7	2.8
BP04	sM	57.85	30800	1980		834		3.8	1.9	2.8	1.4	3.6
BP05	sM	61.31	31600	1850		747		2.9	1.7	2.5	1.2	3.0
COBA POINT												
CPT01	M	59.00	26000	1750	1300	1020	400	3.8	2.1	3.6	1.7	3.7
CPT02	sM	58.61	28000	1900		962		3.7	2.1	3.7	1.7	3.7
CPT03	sM	52.93	27200	1920		1020		4.1	2.1	4.0	1.9	3.8
CPT04	sM	55.83	27200	1670		1030		4.0	2.1	3.7	1.8	3.8
CPT05	sM	58.34	31700	1970		1030		3.8	2.1	3.1	1.8	3.6
BUDJWA BAY												
BB01	sM	57.58	31400	2100	1700	915	600	3.8	2.2	3.2	1.5	4.1
BB02	sM	59.29	32100	2160		977		2.8	2.0	2.7	1.4	3.7
BB03	sM	54.71	31900	1910		821		3.6	2.0	3.1	1.4	3.9
BB04	sM	61.68	31100	2110		959		2.5	1.8	2.5	1.3	3.3
BB05	sM	58.18	32300	2210		1040		2.7	1.7	3.0	1.5	3.5
JOE CRAFTS BAY												
JC01	sM	55.36	32000	2390	2000	955	750	3.3	2.2	3.0	1.5	3.8
JC02	sM	58.45	33000	2440		914		3.0	2.1	2.8	1.3	3.8
JC03	sM	59.88	32800	2510		1080		2.7	2.1	2.9	1.4	3.8
JC04	sM	59.37	33000	2480		1000		2.9	2.1	2.8	1.3	3.7
JC05	sM	59.60	27000	2430		794		2.8	1.8	2.5	1.1	3.4
CALABASH BAY												
CAL01	sM	57.04	33500	2800	NA	1240	NA	4.3	3.2	4.0	1.2	5.5
CAL02	mS	46.16	33900	3010		1380		5.1	3.5	4.7	1.8	5.7
CAL03	sM	50.04	33800	3230		1290		5.1	3.6	4.7	1.6	5.9
CAL04	mS	48.97	34200	2750		1280		5.3	3.6	4.7	1.5	6.0
CAL05	mS	48.05	33800	2810		1180		5.3	3.4	4.7	1.5	6.2
BEROWRA FERRY												
BF01	sM	60.02	48800	3600	3300	1160	500	3.8	5.1	4.6	0.8	8.4
BF02	sM	57.65	43500	3220		1140		4.4	5.4	4.7	1.0	8.4
BF03	sM	54.02	49200	3080		1090		4.8	5.2	5.0	1.0	8.6
BF04	sM	52.14	52700	3480		1240		4.3	5.5	5.7	0.9	10.0
BF05	sM	52.89	49800	3430		1080		4.6	5.2	5.0	1.0	8.7
THE WOOLWASH												
WW01	S	8.17	28800	1500	2100	381	190	6.0	2.4	7.7	0.8	4.9
WW02	S	2.69	5090	273		161		3.5	0.5	3.0	0.4	1.6
WW03	mS	13.24	9270	276		172		1.3	0.6	1.9	0.4	1.9
WW04	gS	1.70	22400	193		102		2.6	0.4	2.9	0.3	0.9
WW05	S	1.69	1260	156		96		3.8	0.4	2.8	0.3	0.9
SAMS CREEK												
SM01	mS	2.59	5510	407	NA	159	NA	6.2	0.7	5.7	0.4	1.8
SM02	mS	2.58	6780	438		266		9.5	1.3	8.9	0.6	2.7
SM03	mS	1.70	1480	181		93		4.1	0.3	2.9	0.2	0.9
SM04	mS	3.59	8900	852		256		6.9	1.3	7.8	0.6	2.8
SM05	mS	3.43	9370	469		268		6.9	1.2	7.6	0.6	2.7
CROSSLANDS												
CR01	gmS	1.40	4330	342	NA	132	NA	5.2	0.3	5.1	0.3	1.0
CR02	mS	3.04	2220	242		120		4.5	0.4	4.2	0.2	1.1
CR03	mS	1.65	2610	248		137		5.3	0.4	5.7	0.3	1.1
CR04	gmS	0.44	3130	159		74		4.9	0.2	4.1	0.2	0.5
CR05	gmS	0.49	1320	159		83		5.9	0.3	5.2	0.3	0.8

*Value from analysis of core in vicinity of surface sample location

**Enrichment factors calculated from relationships between metal levels and mud contents reported by EPA using Digest 200.2. See Section 10 Appendix C.

(All results based on total sample analyses; surface samples collected in Berowra Creek channel by Hornsby Shire Council)

Metal-%Mud Relationships (Section 10, Appendix C)

As	y=0.1503x + 1.9379
Cr	y=0.2184x + 0.217
Cu	y=0.0767x + 5.2689
Ni	y=0.1458x + 3.386
Pb	y=0.1109x + 5.3548
Zn	y=0.5873x + 1.3623

Where y = estimated metal concentration in mg/kg
x=percent mud in sampled

10. Appendices

Appendix A: Project Geographic Information System

Design, Application and Modelling

Project Geographic Information System

Data collected as part of the Berowra Creek Estuary Process Study have been consolidated within a computer-based relational database for archival, analytical and presentation purposes. Coastal & Marine Geosciences (CMG) has utilised a variety of industry-standard computer applications (Microsoft Access, Microsoft Excel, MapInfo, ARCINFO, IDRISI and SURFER) throughout the project with MapInfo providing the primary means of spatial database interrogation and analysis. Data transfer to other members of the study team has been via software specific or common third party file formats.

GIS Components/Coverages

The project GIS has been constructed from a variety of datasets, or coverages, either collected specifically for the project or purchased from the relevant government authority. The datasets utilised by CMG include:

Topography: Topographic information for the study area was supplied to the Manly Hydraulics Laboratory by the Land Information Centre. Specifically, digital contour and drainage line data for the 1:25,000 scale Hornsby (9130-4-S), Cowan (9130-4-N) and Gunderman (9131-3-S) sheets.

Geology: Information for the study area was supplied to the Manly Hydraulics Laboratory by the NSW Department of Mineral Resources in the form of the digital 1:100,000 Sydney 9130 geology sheet.

Soils: Soils data were supplied to the Manly Hydraulics Laboratory by the NSW Department of Land and Water Conservation and included the digital 1:25,000 Acid Sulphate Soil Risk maps for the area (H9130n4, H9130s1, H9130s4). The 1:100,000 Sydney Soils Sheet was also made available but not used in the current investigations due to file format translation problems.

Drainage: Information on drainage catchments and subcatchments was supplied by Sydney Water. The data were supplied as MapInfo format files which identified the majority of the drainage catchments within the study area. CMG supplemented the Sydney Water data with additional catchment boundaries for the lower part of the Berowra system as determined from the LIC topographic and drainage line datasets.

Catchment: General catchment information including the location of dwellings, roads and other cultural features was supplied by DLAWC as DXF format files.

Landuse: Catchment landuse/zoning data were not readily available in a digital format suited for incorporation into the project GIS. In view of the importance of this data to investigation of sediment erosion, a composite digital coverage of Hornsby Shire Land Zonings was constructed by CMG from hard copy (area west of Berowra Creek) and digital (DXF format; area east of Berowra Creek) information relating to the Hornsby Shire Local Environment Plan (1994). It must be stressed that the landuse coverage produced by CMG is approximate and intended solely for characterising landuse on a catchment by catchment basis for the study area.

Bathymetry: Water depths within the estuary were supplied by DLAWC from a 1995 survey of Berowra and Marramarra Creeks. The data were supplied as contoured depth intervals to Mean Sea Level (DXF format) and spot depths to Mean Sea Level (ASCII format), the latter being better suited to historic bathymetric comparisons.

Historic bathymetric data for the Berowra estuary were digitised from a 1:24915 scale paper copy of an 1872 Royal Navy hydro survey of the lower Hawkesbury (ref. Lieut. J.T. Gowlland and J.F. Loxton; Plan No. 210/7). Survey datum is identified as Low Water Ordinary Springs. Water depths are assumed to have been recorded by lead line and the horizontal positioning by triangulation. The coverage extends from the confluence of the Hawkesbury River and Berowra Creek upstream to Calabash Bay. More recent bathymetric data used in this report includes the 1984 Muogamarra Point to Berowra Ferry PWD survey. Survey data are available as a series of 28 channel cross sections at 1:4000/ 1:2,000 (horizontal) and 1:400 (vertical) scales to mean sea level datum.

Copies of the 1872 survey plan and 1984 channel cross sections were supplied by the NSW PWD (Sydney) from their Hydrographic Surveys Catalogue of the Hawkesbury River.

Estuarine Sediments: Coverages of estuarine sediment samples and analyses were entered into the project GIS using location coordinates recorded with the original data. Plots of sample locations produced in MapInfo highlighted innaccuracies in the sample positions for the Hornsby Council (n=64) and University (n=56) datasets, due primarily to the use of GPS equipment with no differential correction. Fortunately, many of the Council and University samples contain information on prominent landmarks (ie. bays, points, creek entrances) near the sample site which has helped in clarifying their locations.

The University of Sydney sediment data is reported in Shotter (1994) while the Hornsby Shire sediment data was collected during February 1997 and summarised in the AWT EnSight Report No.42660/42643. An additional set of surface samples (n=69) was collected by CMG to supplement existing sediment data and to aid in the production of a surface sediment map for the entire estuary. See separate Appendix on Surface Sediments.

Subsurface sediment information was collected by hydraulic vibracorer capable of recovering *in situ* sediment samples to a depth of 7m below the estuary bed. A total of 11 sites were cored and their locations recorded with the aid of a Differential Global Positioning System. Coordinates for all core sites were entered into the project GIS. See separate Appendix on Subsurface Sediments.

GIS Modelling

Catchment Physical Attributes

The various coverages described above have been processed to address specific issues of catchment denudation and estuarine sedimentation. While the datasets are also suited to more generalised accounts of the physical and cultural attributes of the study area, this has not been attempted here in view of the GIS analyses reported elsewhere (Hornsby Shire Rural Lands Study, 1995; Sensitive Urban Lands Study, 1996).

The GIS modelling has concentrated on characterising the topography and geology of the catchments draining into Berowra/Marramarra Creeks plus the physical changes (ie. changes in water depth and sediment types) observable within the estuary.

Characterisation of catchment topography and geology required manipulation of the following datasets:

- 1:25,000 scale Gunderman, Cowan and Hornsby contour and drainage data.
- 1:100,000 scale Sydney geology sheet.
- Sydney Water catchment maps.

The topographic data was imported into MapInfo wherein successive nodes for each contour line were extracted over a rectangular area some 32 X 22km covering all of the catchments draining into Berowra and Marramarra Creeks. Data nodes (X,Y,Z) were extracted and exported from MapInfo as an ASCII format elevation file. The ASCII file was imported into SURFER and a digital elevation model (DEM) generated for the entire area. A 50m grid cell size was adopted and the DEM generated via a Kriging gridding algorithm. The same grid was processed in IDRISI to create a slope model based on the gridded elevation data.

The elevation and slope data were displayed graphically and plots produced in SURFER. Classification of the gridded elevation and slope data into suitable intervals preceded characterisation of the elevation and slope character of each drainage catchment. Elevation classes included 0-10m, 10-20m, 20-50m, 50-100m, 100-200m and 200m+. Slope classes ranged from 0-10%, 10-20%, 20-40% and >40%. The upper range for the first three slope intervals correspond approximately to 6°, 11° and 22°. Proportions of the various elevation and slope intervals for each catchment were calculated and tabulated.

The LIC drainage data and Sydney Water catchment maps were merged in MapInfo and data for stream lengths and drainage densities calculated. It must me noted that the catchment maps required some modification to include drainage areas in the lower Berowra Creek area. Moreover, the catchments identified by Sydney Water are rather generalised and could easily be further subdivided. Despite this limitation, it was felt that the catchment maps were suitable for a broad characterisation of the study area drainage.

Proportions of each rock type (by catchment) were calculated by (digitally) overlaying the study area catchment map on the 1:100,000 Sydney geology. Proportions of each catchment subject to various landuses were also calculated by digitally overlaying the catchment map and "derived" landuse map.

All of these modelled data are summarised in spreadsheets located at the end of this Appendix.

Catchment Physical Attributes - Statistical Analysis

Integration of the topographic, drainage and geologic information for the entire study area was achieved with the aid of a statistical analysis of the slope, elevation and drainage data. The statistical analysis utilised the non-parametric ENTROPY clustering program (Johnston and Semple, 1983). The analysis generates a series of solutions based on subdivision of the dataset into an increasing number of groups with the addition of each subsequent group raising the level of matrix variance explained. A 100% explanation of the variance within the data is achieved when the number of groups equals the number of samples. An optimal number of groups is identified when the addition of extra groups provides minimal explanation of the matrix variance. The ENTROPY analysis makes few demands on the nature and format of the original data and is ideally suited to examining patterns within large datasets (Johnston & Semple, 1983).

For the purpose of the current project, each catchment (n=32) was described by its drainage area, drainage density, aerial proportion of various rock types, and aerial proportions of derived elevation and slope classes. A summary of the ENTROPY analysis results is included at the end of this Appendix. An 8 group solution with 87% explanation of the matrix variance was selected as the optimal grouping. An inspection of the ENTROPY program output demonstrates that the clustering of catchments is reasonable within the limitations of the source data.

Definition of the salient attributes of each ENTROPY group can be seen in the corresponding calculated Z-scores for each variable. In general the eight groups can be summarised as follows:

Group 1 (n=7): Catchments of below average size and drainage density with above average proportions of elevations in the 100-200m range. This group displays above average proportions of areas with relatively low slopes (0-10%) and below average proportions of areas with high slopes (20%+). Geology adds little to differentiation of the group.

Group 2 (n=2): Catchments characterised by above average drainage densities and areas with slopes between 10-20%. Very little difference from matrix average across other variables.

Group 3 (n=2): Catchments discriminated primarily by above average proportions of Ashfield Shale (Rwa) and low slopes (0-10%).

Group 4 (n=3): Catchments discriminated on the basis of above average size and proportions of Mittagong Fm. (shales and sandstone) lithologies. Near matrix average for remainder of variables.

Group 5 (n=8): Catchments identified by above average proportions of 200m+ elevations and steep slopes (>20%) plus below average proportions of low slopes (0-10%).

Group 6 (n=2): Catchments with very little difference from the matrix average across all variables with a weak trend to below average catchment size and proportions in the 200m+ elevation range.

Group 7 (n=5): Catchments discriminated on basis of above average proportions of Newport Fm. (shales and siltstones) lithologies, elevations below 100m, and slopes above 20%.

Group 8 (n=3): Catchments discriminated on basis of above average drainage densities, elevations between 20-100m and slopes greater than 20%. Generally weak trend away from matrix average across most variables.

Crosstabulation of ENTROPY groups and landuse is also included with the entropy results.

The statistical analysis provides a convenient means of characterising/grouping each catchment in terms of its geology and physiography. In turn, these data can be reviewed in terms of the potential for individual catchments to deliver sediment to the drainage lines and, eventually, the estuary.

Modelling Historic Bathymetric Change

Historic bathymetric change within the estuary was examined by digitally overlaying soundings from the 1872 and 1995 surveys noted previously. Imperfect registration of the 1872 plan on the 1995 plan, plus uncertainty surrounding the datum of the earlier survey, limits the usefulness of the comparison beyond identifying overall trends and areas of significant bathymetric change. Despite these limitations, the coverage of the 1872 survey data as spot depths provided a good basis for comparison with similar data (spot depths) recorded in the 1995 hydrographic survey. A qualitative comparison of the 1984 cross sections with the 1872 and 1995 data was also undertaken.

Bathymetric data from the 1872 and 1995 surveys were imported into MapInfo. The Low Water Ordinary Springs datum for the earlier survey was assumed to approximate Indian Springs Low Water (ISLW). Water depths for the 1872 survey were converted from feet to metres and recorded as depths to ISLW. Data from the 1995 survey were converted from elevations above -100m MSL to depths to ISLW by subtracting 100.9 from each value (ISLW assumed 0.9m below 0 AHD for the purposes of the comparison).

Owing to the variable coverage of spot depths between surveys (sparse for 1872 and dense for 1995), both datsets were averaged over a unit area to facilitate the comparison. This was achieved by projecting a 50m grid over the entire survey area and calculating the average value for spot depths falling within each cell. An added benefit of the averaging procedure was to smooth out irregularities in the bed so that only significant bathymetric changes over comparable areas were likely to be highlighted. The residual (Grid1995-Grid1872) was prepared as a thematic map in MapInfo showing ranges of water depth change over the 123 year period. The 1984 cross section survey data were examined in light of the results of the 1872-1995 comparison.

Catchment Physical Attributes - Fluvial Delta Volumes

A number of fluvial deltas have accumulated within Berowra Creek and Marramarra Creek since stabilisation of sea level around its present position some 6,500 years ago. The deltas are formed primarily from coarse grained sediments (sand) derived from the adjacent catchment and deposited at or below present sea level. As there is little evidence for any coarse grained sediment bypassing the deltas, these deposits represent the total load of sandy sediment delivered to the estuary from each catchment over the past 7000 years or so.

The deltas provide a means of determining conservative long term time averaged rates of sedimentation and catchment denudation. The sedimentation rates are conservative (underestimate) as the delta volumes do not account for all of the sediment delivered to the estuary from the adjacent catchments. Clearly, fine grained muds will bypass the deltas to be deposited further downstream within the estuarine mud basin. An estimate of the volume of mud delivered into the system over the past 7,000 years has been attempted based on probable thicknesses of mud basin sediments within the study area (see main text for further discussion).

The delta volumes have been estimated from the aerial extent of unconsolidated deposits mapped on the 1:25,000 ASS sheets supplemented with information on estuary bed sediments. These data are multiplied by an assumed delta thicknesses of between 7m and 10m and a bulk density of $1.4m^3$/tonne to arrive at a delta volume. Probable delta thicknesses were established from boreholes in the Marramarra delta and bathymetric data in the vicinity of deltas in Berowra Creek. Calculated rates of deltaic sedimentation assume formation of the delta over 7000 years. Rates of catchment denudation are based on a simple division of delta volume by catchment area.

A summary of the delta volume calculations is shown at the end of this Appendix.

BEROWRA CREEK ESTUARY PROCESS STUDY - CATCHMENT ELEVATION AND SLOPE SUMMARY
(Modelled elevation and slope data)*

Berowra Catchment		Elevation Intervals (m)						Slope Intervals (Slopes in %)*			
Sub-Catchment ID	Area (km2)	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	% <10%	% 10-20%	% 20-40%	% 40%+
B1	4.58	0.00	0.00	0.00	0.38	99.62	0.00	77.78	15.21	6.95	0.05
B2	2.14	0.00	0.00	0.00	0.12	99.88	0.00	74.33	17.50	8.17	0.00
B3	1.53	0.00	0.00	0.00	0.33	99.67	0.00	63.90	19.84	16.10	0.16
B4	4.30	0.00	0.00	0.00	5.22	94.78	0.00	54.55	26.20	17.74	1.51
B5	2.51	0.00	0.00	0.00	11.33	75.45	13.22	21.27	24.65	37.08	17.00
B6	3.22	0.00	0.00	0.00	0.00	79.94	20.06	46.24	38.19	14.18	1.39
B7	2.15	0.00	0.00	0.00	0.47	99.53	0.00	54.67	24.88	17.99	2.45
B8	3.35	0.00	0.00	0.00	2.45	97.48	0.07	60.64	24.09	12.08	3.19
B9	2.83	0.00	0.00	0.00	20.97	79.03	0.00	22.39	29.47	35.40	12.74
B10	3.28	0.00	0.00	4.58	26.72	60.61	8.09	10.69	21.68	41.22	26.41
B11	21.99	0.87	0.75	2.53	8.71	75.15	11.99	37.68	23.28	26.47	12.57
B12	14.78	0.74	0.68	2.79	8.87	75.87	10.93	29.40	24.19	28.42	17.99
B13	7.98	0.00	0.00	0.03	3.78	55.92	40.26	45.45	22.91	22.69	8.94
B14	5.98	0.00	0.00	0.00	6.97	90.65	2.38	28.54	24.49	35.50	11.47
B15	6.35	1.06	1.14	4.01	13.17	67.96	12.62	16.40	20.60	39.39	23.62
B16	11.38	2.19	1.73	5.50	17.82	53.96	18.80	17.45	18.02	38.66	25.88
B17	4.52	0.00	0.00	0.00	0.00	100.00	0.00	72.10	24.35	3.55	0.00
B18	3.69	0.00	0.00	5.60	19.62	74.78	0.00	20.09	18.88	41.13	19.89
B19	2.48	0.00	0.00	0.00	0.00	82.26	17.74	84.78	15.22	0.00	0.00
B21	5.05	3.81	2.38	8.02	17.20	67.83	0.76	14.12	18.64	40.29	26.96
B22	12.21	1.12	0.93	3.23	14.96	72.26	7.51	18.56	20.46	38.29	22.69
B23	16.67	0.86	0.75	1.99	7.77	70.85	17.78	20.04	24.21	37.01	18.75
B24	9.03	0.64	0.56	3.07	16.12	62.90	16.71	16.97	23.85	41.32	17.86
B25	6.81	5.83	3.57	9.40	24.97	51.66	4.57	18.82	14.40	39.37	27.40
B26	8.61	1.84	1.74	6.66	20.83	59.30	9.62	13.28	19.94	46.03	20.75
B27	8.14	3.19	1.88	11.69	32.81	47.24	3.19	19.94	15.67	41.12	23.26
B28	26.23	2.58	2.05	6.85	20.00	58.93	9.59	17.11	16.44	42.26	24.19
AVERAGES	7.47	0.92	0.67	2.81	11.17	76.06	8.37	36.19	21.75	28.46	13.60

Marramarra Catchment		Elevation Intervals (m)						Slope Intervals (Slopes in %)*			
Sub-Catchment ID	Area (km2)	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	% <10%	% 10-20%	% 20-40%	% 40%+
M1	16.01	0.00	0.00	0.00	0.00	88.09	11.91	75.74	18.88	5.32	0.06
M2	25.01	0.00	0.00	0.04	8.84	80.23	10.88	28.67	26.47	30.95	13.91
M3	21.11	0.00	0.00	0.76	7.97	69.99	21.28	16.29	23.24	39.56	20.91
M4	22.88	1.07	0.83	2.77	10.08	53.95	31.28	12.34	24.07	43.22	20.36
M5	17.86	11.23	4.10	8.86	22.35	40.78	12.67	19.86	16.91	34.72	28.51
AVERAGES	20.57	2.46	0.99	2.49	9.85	66.61	17.60	30.58	21.91	30.76	16.75

*Modelling based on Digital Elevation Model (DEM) generated in SURFER from digital 1:25,000 LIC Hornsby, Cowan and Gunderman Sheets.
DEM grid size 50m.

BEROWRA CREEK ESTUARY PROCESS STUDY - CATCHMENT MORPHOLOGY & GEOLOGY SUMMARY

Berowra Catchment			Drainage_Length	Drainage_Density	CATCHMENT GEOLOGY (%)*						
Sub-Catchment ID	Area (km2)	Perimeter (km)	(km)	(km/km2)	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv
1	4.58	9.18	13.39	2.92	0.00	6.88	0.00	93.12	0.00	0.00	0.00
2	2.14	7.27	4.29	2.00	0.00	6.15	0.00	93.85	0.00	0.00	0.00
3	1.53	6.28	1.53	1.00	0.00	2.53	0.00	97.47	0.00	0.00	0.00
4	4.30	10.80	10.05	2.34	0.00	3.39	0.00	96.61	0.00	0.00	0.00
5	2.51	7.15	6.78	2.70	0.00	0.44	0.00	99.44	0.00	0.00	0.12
6	3.22	8.15	9.64	3.00	0.00	1.48	0.00	98.52	0.00	0.00	0.00
7	2.15	6.50	3.21	1.50	0.00	4.57	0.00	95.11	0.00	0.00	0.32
8	3.35	8.08	5.52	1.65	0.00	5.72	0.00	94.28	0.00	0.00	0.00
9	2.83	8.34	7.60	2.69	0.00	5.84	0.00	92.71	0.00	0.00	1.45
10	3.28	12.61	11.95	3.65	0.00	0.00	0.00	100.00	0.00	0.00	0.00
11	21.99	24.49	51.56	2.35	0.00	2.15	0.00	97.85	0.00	0.00	0.00
12	14.78	23.12	34.64	2.34	0.00	1.39	0.00	98.55	0.00	0.00	0.06
13	7.98	15.33	22.12	2.77	0.00	2.58	0.00	97.31	0.00	0.00	0.11
14	5.98	11.89	14.38	2.40	0.00	1.43	0.00	98.57	0.00	0.00	0.00
15	6.35	11.33	14.12	2.22	0.00	0.00	0.60	100.00	0.00	0.00	0.00
16	11.38	18.74	22.86	2.01	0.00	0.00	0.00	100.00	0.00	0.00	0.00
17	4.52	10.12	12.15	2.69	0.35	7.84	0.00	91.80	0.00	0.00	0.00
18	3.69	10.71	9.48	2.57	0.00	0.24	0.00	99.76	0.00	0.00	0.00
19	2.48	6.93	7.66	3.09	0.00	7.05	0.00	92.95	0.00	0.00	0.00
21	5.05	15.84	16.92	3.35	0.00	0.00	0.00	100.00	0.00	0.00	0.00
22	12.21	14.88	30.66	2.51	0.00	0.20	0.00	99.80	0.00	0.00	0.00
23	16.67	25.48	42.31	2.54	0.00	0.52	0.25	99.36	0.12	0.00	0.00
24	9.03	14.84	18.05	2.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00
25	6.81	12.39	14.58	2.14	0.00	0.00	0.00	89.13	0.00	7.97	2.90
26	8.61	15.29	24.96	2.90	0.00	0.00	0.00	93.85	0.00	6.15	0.00
27	8.14	16.59	13.86	1.70	0.00	0.00	0.00	90.54	0.00	9.46	0.00
28	26.23	24.98	62.36	2.38	0.00	0.00	0.00	93.96	0.00	6.04	0.00
TOTALS	**201.77**	**357.30**	**486.60**	**65.41**	**0.35**	**60.40**	**0.85**	**2604.54**	**0.12**	**29.62**	**4.96**
AVERAGES	**7.47**	**13.23**	**18.02**	**2.42**	**0.01**	**2.24**	**0.03**	**96.46**	**0.00**	**1.10**	**0.18**

Marramarra Catchment			Drainage_Length	Drainage_Density							
Sub-Catchment ID	Area (km2)	Perimeter (km)	(km)	(km/km2)	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv
1	16.01	22.04	42.32	2.64	0.00	46.29	0.00	53.71	0.00	0.00	0.00
2	25.01	28.01	77.71	3.11	0.00	8.46	7.44	84.10	0.00	0.00	0.00
3	21.11	33.71	62.57	2.96	0.00	0.00	1.71	97.68	0.00	0.00	0.62
4	22.88	29.43	56.76	2.48	0.00	0.00	0.00	93.24	4.27	2.49	0.00
5	17.86	20.44	22.63	1.27	0.00	0.00	0.00	88.45	0.00	11.36	0.18
TOTALS	**102.87**	**133.64**	**261.99**	**12.46**	**0.00**	**54.75**	**9.14**	**417.18**	**4.27**	**13.85**	**0.80**
AVERAGES	**20.57**	**26.73**	**52.40**	**2.49**	**0.00**	**10.95**	**1.83**	**83.44**	**0.85**	**2.77**	**0.16**

*__Rwb__:Bringelly Shale; **Rwa**:Ashfield Shale; **Rm**:Mittagong Fm.(Shale&Sandstone); **Rh**; Hawkesbury Sandstone; **Rhs**: Shale;
Rnn:Newport Fm.(Shale & Sandstone); **Jv**: Basaltic Dyke-Diatreme

BEROWRA CREEK ESTUARY PROCESS STUDY - CATCHMENT LANDUSE SUMMARY
Approximate Land Zoning Proportions (%)*

Berowra Catchments							
Sub-catchment ID	Area (km2)	Large Rural	Small Rural	Residential	Business	Industrial	Bushland**
B1	4.58	0	3	70	0	0	27
B2	2.14	0	0	78	0	0	22
B3	1.53	0	0	83	0	0	17
B4	4.30	0	8	55	0	0	37
B5	2.51	0	0	14	0	0	86
B6	3.22	0	28	0	12	0	61
B7	2.15	0	6	73	0	0	22
B8	3.35	0	0	87	0	0	13
B9	2.83	0	12	55	0	0	34
B10	3.28	0	1	7	0	0	91
B11	21.99	17	32	0	0	0	51
B12	14.78	0	37	0	0	0	63
B13	7.98	0	53	2	0	0	45
B14	5.98	0	0	60	0	0	40
B15	6.35	0	0	25	0	11	64
B16	11.38	0	0	19	0	2	79
B17	4.52	0	52	25	0	0	23
B18	3.69	0	0	45	0	0	55
B19	2.48	0	100	0	0	0	0
B21	5.05	0	0	38	0	0	62
B22	12.21	31	0	0	0	0	69
B23	16.67	37	2	0	0	0	60
B24	9.03	0	0	23	0	0	77
B25	6.81	0	0	0	0	0	100
B26	8.61	0	0	2	0	0	98
B27	8.14	0	0	2	0	0	98
B28	26.23	0	0	0	0	0	100
AVERAGES	**7.47**	**3.14**	**12.40**	**28.15**	**0.44**	**0.47**	**55.38**

Marramarra Catchments							
Sub-catchment ID	Area (km2)	Large Rural	Small Rural	Residential	Business	Industrial	Bushland**
M1							
M2	16.01	3	77	1	0	0	19
M3	25.01	25	17	0	0	0	57
M4	21.11	28	0	0	0	0	72
M5	22.88	17	0	0	0	0	83
AVERAGES	17.86	1	0	0	0	0	99
	20.57	**14.71**	**18.83**	**0.37**	**0.00**	**0.00**	**66.09**

* Data derived from zoning information supplied by Hornsby Shire Council in digital and hard copy formats. NOTE that the derived proportions of landuse are therefore approximate and should only be used for a generalised account of landuse patterns within drainage catchments within the study area.

** Bushland includes zoning areas of environmental protection, open space, reserves and National Park.

ENTROPY ANALYSIS SUMMARY

BEROWRA CREEK ESTUARY PROCESS STUDY - CATCHMENT ENTROPY ANALYSIS SUMMARY

%Explai	Groups		
54.3	2		
70.3	3	16	
74.1	4	3.8	
77.3	5	3.2	
82.7	6	5.4	
84.1	7	1.4	
87.1	8	3	Optimum
88.5	9	1.4	
89.4	10	0.9	
90.1	11	0.7	
91.4	12	1.3	
92.4	13	1	
92.6	14	0.2	
93.9	15	1.3	

Data groupings for 8 groups

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
1 B1	4.58	2.92	0	6.88	0	93.12	0	0	0	0	0	0	0.38	99.62	0	77.78	15.21	6.95	0.05
1 B2	2.14	2	0	6.15	0	93.85	0	0	0	0	0	0	0.12	99.88	0	74.33	17.5	8.17	0
1 B3	1.53	1	0	2.53	0	97.47	0	0	0	0	0	0	0.33	99.67	0	63.9	19.84	16.1	0.16
1 B4	4.3	2.34	0	3.39	0	96.61	0	0	0	0	0	0	5.22	94.78	0	54.55	26.2	17.74	1.51
1 B7	2.15	1.5	0	4.57	0	95.11	0	0	0.32	0	0	0	0.47	99.53	0	54.67	24.88	17.99	2.45
1 B8	3.35	1.65	0	5.72	0	94.28	0	0	0	0	0	0	2.45	97.48	0.07	60.64	24.09	12.08	3.19
1 B17	4.52	2.69	0.35	7.84	0	91.8	0	0	0	0	0	0	0	100	0	72.1	24.35	3.55	0

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
2 B6	3.22	3	0	1.48	0	98.52	0	0	0	0	0	0	0	79.94	20.06	48.24	38.19	14.18	1.39
2 B13	7.98	2.77	0	2.58	0	97.31	0	0	0.11	0	0	0.03	3.78	55.92	40.26	45.45	22.91	22.69	8.94

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
3 B19	2.48	3.09	0	7.05	0	92.95	0	0	0	0	0	0	0	82.26	17.74	84.78	15.22	0	0
3 M1	16.01	2.64	0	46.29	0	53.71	0	0	0	0	0	0	0	88.09	11.91	75.74	18.88	5.32	0.06

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
4 B11	21.99	2.35	0	2.15	0	97.85	0	0	0	0.87	0.75	2.53	8.71	75.15	11.99	37.68	23.28	26.47	12.57
4 B12	14.78	2.34	0	1.39	0	98.55	0	0	0.06	0.74	0.68	2.79	8.87	75.87	10.93	29.4	24.19	28.42	17.99
4 M2	25.01	3.11	0	8.46	7.44	84.1	0	0	0	0	0	0.04	8.84	80.23	10.88	28.67	26.47	30.95	13.91

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
5 B5	2.51	2.7	0	0.44	0	99.44	0	0	0.12	0	0	0	11.33	75.45	13.22	21.27	24.65	37.08	17
5 B15	6.35	2.22	0	0	0.6	100	0	0	0	1.06	1.14	4.01	13.17	67.96	12.62	16.4	20.6	39.39	23.62
5 B16	11.38	2.01	0	0	0	100	0	0	0	2.19	1.73	5.5	17.82	53.96	18.8	17.45	18.02	38.66	25.88
5 B22	12.21	2.51	0	0.2	0	99.8	0	0	0	1.12	0.93	3.23	14.96	72.26	7.51	18.56	20.46	38.29	22.69
5 B23	16.67	2.54	0	0.52	0.25	99.36	0.12	0	0	0.86	0.75	1.99	7.77	70.85	17.78	20.04	24.21	37.01	18.75
5 B24	9.03	2	0	0	0	100	0	0	0	0.64	0.56	3.07	16.12	62.9	16.71	16.97	23.85	41.32	17.86
5 B29	9.03	1.97	0	0	0	100	0	0	0	0.64	0.56	3.07	16.12	62.82	16.79	17.03	23.83	41.29	17.86
5 M3	21.11	2.96	0	0	1.71	97.68	0	0	0.62	0	0	0.76	7.97	69.99	21.28	16.29	23.24	39.56	20.91
5 M4	22.88	2.48	0	0	0	93.24	4.27	2.49	0	1.07	0.83	2.77	10.08	53.95	31.28	12.34	24.07	43.22	20.36

ENTROPY ANALYSIS SUMMARY

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
6 B9	2.83	2.69	0	5.84	0	92.71	0	0	1.45	0	0	0	20.97	79.03	0	22.39	29.47	35.4	12.74
6 B14	5.98	2.4	0	1.43	0	98.57	0	0	0	0	0	0	6.97	90.65	2.38	28.54	24.49	35.5	11.47

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
7 B25	6.81	2.14	0	0	0	89.13	0	7.97	2.9	5.83	3.57	9.4	24.97	51.66	4.57	18.82	14.4	39.37	27.4
7 B26	8.61	2.9	0	0	0	93.85	0	6.15	0	1.84	1.74	6.66	20.83	59.3	9.62	13.28	19.94	46.03	20.75
7 B27	8.14	1.7	0	0	0	90.54	0	9.46	0	3.19	1.88	11.69	32.81	47.24	3.19	19.94	15.67	41.12	23.26
7 B28	26.23	2.38	0	0	0	93.96	0	6.04	0	2.58	2.05	6.85	20	58.93	9.59	17.11	16.44	42.26	24.19
7 M5	17.86	1.27	0	0	0	88.45	0	11.36	0.18	11.23	4.1	8.86	22.35	40.78	12.67	19.86	16.91	34.72	28.51

Group	Area (km2)	Drainage_Dens	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200m	%200m+	<10%	10-20%	20-40%	>40%
8 B10	3.28	3.65	0	0	0	100	0	0	0	0	0	4.58	26.72	60.61	8.09	10.69	21.68	41.22	26.41
8 B18	3.69	2.57	0	0.24	0	99.76	0	0	0	0	0	5.6	19.62	74.78	0	20.09	18.88	41.13	19.89
8 B21	5.05	3.35	0	0	0	100	0	0	0	3.81	2.38	8.02	17.2	67.83	0.76	14.12	18.64	40.29	26.96

87.06813 % explained

	Area (km	Drainage	Rwb	Rwa	Rm	Rh	Rhs	Rnn	Jv	%0-10m	%10-20m	%20-50m	%50-100m	%100-200	%200m+	Slope<10	Slope10-	Slope20-	Slopes>4
<< Group Z Statistics >>																			
Group 1	-2.16	-1.56	-1.78	0.51	-0.42	0.41	-0.32	-1.10	-0.18	-0.90	-0.89	-1.87	-2.81	3.40	-2.58	3.60	0.23	-3.07	-3.37
Group 2	-0.70	1.16	0.25	-0.32	-0.23	0.48	-0.17	-0.59	-1.15	-0.48	-0.47	-1.23	-1.35	-0.28	3.05	0.73	2.26	-0.99	-1.25
Group 3	-0.00	1.12	0.25	4.16	-0.23	-1.47	-0.17	-0.59	0.20	-0.48	-0.47	-1.00	-1.57	0.90	0.73	2.83	-1.01	-2.50	-1.92
Group 4	2.66	0.62	0.30	0.04	3.08	0.16	-0.21	-0.72	-0.92	-0.70	-1.02	-0.77	-0.41	0.42	0.24	-0.14	1.01	0.03	0.16
Group 5	1.26	-0.00	0.52	-1.16	-0.61	1.18	1.02	-1.06	-0.48	-0.92	-1.23	-0.28	0.63	-0.94	2.35	-2.12	0.68	2.34	2.02
Group 6	-0.93	0.38	0.25	-0.03	-0.23	0.30	-0.17	-0.59	0.88	-0.48	-0.47	-1.00	0.48	0.87	-1.25	-0.51	1.39	0.70	-0.26
Group 7	1.29	-1.08	0.39	-0.80	-0.36	-0.08	-0.27	5.13	1.35	3.73	4.17	4.21	3.31	-2.21	-0.49	-1.54	-1.74	1.92	2.47
Group 8	-1.23	2.28	0.30	-0.68	-0.28	0.79	-0.21	-0.72	0.24	0.24	0.47	1.73	1.98	-0.36	-1.24	-1.40	-0.44	1.51	1.85

BEROWRA CREEK ESTUARY PROCESS STUDY - FLUVIAL DELTA VOLUMES & SEDIMENTATION CALCULATIONS

Delta ID	Catchment Area (km2)	Delta Area(m2)	Volume I (m3) (Delta 7m Thick)	Tonnes I (1.4t/m3)	Volume II (m3) (Delta 10m Thick)	Tonnes II (1.4t/m3)	Sedimentation Rate* (Range tonnes/year)	Catchment Denudation Rate* (Range tonnes/ha/year)
Marramarra	102.87	1136054	7952378	11133329	11360540	15904756	1590 - 2272	0.15 - 0.22
Coba & Denny	26.23	328548	2299836	3219770	3285480	4599672	460 - 657	0.18 - 0.25
Calabash,Banks,Foster	27.07	243732	1706124	2388574	2437320	3412248	341 - 487	0.13 - 0.18
Crosslands**	1.81	24935	174545	244363	249350	349090	35 - 50	0.19 - 0.28
Still	18.61	47033	329231	460923	470330	658462	66 - 94	0.04 - 0.05
Calna	12.34	39942	279594	391432	399420	559188	56 - 80	0.05 - 0.06
Sams	5.45	14599	102193	143070	145990	204386	20 - 29	0.04 - 0.05
Unnamed	1.08	15200	106400	148960	152000	212800	21 - 30	0.20 - 0.28
Joe Crafts	9.61	108856	761992	1066789	1088560	1523984	152 - 218	0.16 - 0.23
Budjwa	4.79	15666	109662	153527	156660	219324	22 - 31	0.05 - 0.07
Kimmerikong	8.61	92632	648424	907794	926320	1296848	130 - 185	0.15 - 0.22
Muogamarra	5.08	139181	974267	1363974	1391810	1948534	195 - 278	0.38 - 0.55
Berowra	74.36	802367	5616569	7863197	8023670	11233138	1123 - 1605	0.15 - 0.22

*Sedimentation and denudation rates assume delta has accumulated over a period of 7,000 years. Range refers to either 7m or 10m estimated delta thickness.
(see text for discussion of estimates of mud volumes deposited in estuary over past 7,000 years)
** Unknown proportion of fill for road and parking area construction, probable overestimate of delta volume.

Appendix B: Surface Sediment Samples

Methods and Results

Surface Sediment Samples

Surface sediment samples from the bed of Berowra and Marramarra Creeks have been collected by a variety of organisations utilising methods suited to their own particular objectives. Sample data are readily available from the Hornsby Shire Council's sediment monitoring program and the Department of Geology and Geophysics (University of Sydney) study of sediment contaminants in the lower Hawkesbury. These datasets have been supplemented with new surface sediment data collected by Coastal & Marine Geosciences for the Berowra Creek Estuary Process Study.

Details of the analyses conducted by the Hornsby Shire Council (64 samples) and University of Sydney (56 samples) are summarised in the following pages. Sample preparation and analytical methodologies are available for both sample sets and described elsewhere for University (Shotter, 1994) and Hornsby Shire Council samples (AWT EnSight Report No. 42660/42643).

Grab and shallow drop-core samples of the estuary bed were collected by Coastal & Marine Geosciences to fill gaps in the University and Council sample sets. A total of 69 surface samples were collected over a two day period from 5-6 May, 1997. Sample locations were recorded with the assistance of a Differential Global Positioning System (DGPS), samples were collected from a motorised vessel supplied by the NSW Department of Land and Water Conservation (DLAWC). DLAWC and Hornsby Shire Council staff assisted with the sampling program. Samples were described in the field with visual estimates made of sediment texture and composition. These data were combined with similar information from existing University and Council sample sets in the construction of a generalised surface sediment map based on 189 sample points.

Surface samples collected by CMG (5-6 May, 1997)

Sample ID	AMG E (m)	AMG N (m)	Water Depth (m - Uncorrect.)	Sed. Typ(Visual)	Composition note
BC1	325955.06	6281703.92	1.59	S	medium to coarse grained quartz
BC2	328391.07	6286072.32	1.24	M	dk olive-grey, fine grained organics
BC5	328390.39	6284697.77	8.35	M	dk olive-grey, fine grained organics, minor shell
BC6	328495.72	6284701.19	3.10	M	dk olive-grey, fine grained organics, minor shell
BC7	328593.28	6284691.17	1.15	M	dk grey-brown, fine grained organics, minor shell, cohesive
BC8	328855.11	6284673.45	1.32	M	dk grey-brown, fine grained organics, minor shell, cohesive
BC9	328436.26	6284271.73	1.29	M	dk grey-brown, fine grained organics and ?root mat, pellets, cohesive
BC10	328551.91	6284176.64	1.35	M	dk olive-grey, fine grained organics, cohesive
BC11	328811.71	6284050.47	1.25	M	dk olive-grey, fine grained organics, cohesive
BC12	328591.81	6283821.61	1.42	M	dk olive-grey, fine grained organics, cohesive
BC13	328690.45	6283662.43	1.16	M	dk olive-grey, fine and rounded coarse grained organics, cohesive
BC14	326646.54	6282702.55	8.54	M	dk grey, silt sized sand, fine grained organics, cohesive
BC15	326881.73	6282438.67	1.29	M	dk grey, silt sized sand, fine grained organics, cohesive. Dk grey bown floc at surface
BC16	326971.64	6282423.97	1.64	M	dk grey-brown to black, organic rich mud
BC17	327022.18	6282414.11	0.00	mS	dk grey, organic rich m-c qtz sand. Common leaf and plant fragments
BC18	325850.60	6282174.33	1.11	M	dk grey-brown cohesive mud
BC19	325912.36	6281976.77	8.68	M	dk grey-brown cohesive mud
BC20	325963.16	6281864.84	6.39	mS	grey-brown, muddy, mws, mg qtz sand. Common decaying plant frags
BC21	325312.91	6281841.18	12.86	M	dk grey-black, floc-cohesive mud, common fg organics
BC22	325082.07	6281944.12	9.49	M	dk grey-black, floc-cohesive mud, common fg organics, some ?plant mat
BC23	324756.66	6281868.15	8.46	M	dk grey-black, floc-cohesive mud, common fg organics, some ?plant mat
BC24	324685.19	6281841.64	1.20	S	fawn-yellow brown, mws, m-c, qtz sand, minor organics as decaying plant frags.
BC26	325520.56	6280569.65	6.73	M	dk grey-black, floc-cohesive mud, common fg organics
BC28	325661.32	6278803.69	1.44	mS	dk fawn-grey, mws, mg, qtz sand, common organics as blackened plant frags.
BC29	325776.83	6278795.50	1.78	S	fawn-yellow brown, mws, m-c, qtz sand, minor organics as decaying plant frags.
BC30	325800.75	6280366.73	1.30	M	black, organic rich mud, common decaying plant fragments
BC31	325708.50	6280229.20	3.47	M	black, organic rich mud, common decaying plant fragments
BC32	325660.98	6280102.33	2.68	M	black, organic rich mud, common decaying plant fragments
BC33	325558.15	6279913.30	3.27	mS	dk grey-black, muddy f-m qtz sand, trace shell, common decaying plant frags
BC34	325542.27	6279677.12	2.89	mS	dk grey-black, muddy f-m qtz sand, trace shell, common decaying plant frags
BC35	325704.70	6279574.15	1.38	S	fawn-grey, mws, m-c qtz sand, minor organics and shell
BC36	325649.28	6279697.78	5.80	gM	dk grey-black, loose, gravelly mud. Gravel is shell - barnacle and gastropod frags.
BC37	327928.28	6284104.88	1.95	M	dk grey-brown, cohesive mud, pellets
BC38	327796.52	6284233.43	1.52	M	dk grey-brown, cohesive mud

* M=Mud; sM=sandy Mud; mS=muddy Sand; s=Sand; g=gravel

Page 1 of 2

Surface samples collected by CMG (5-6 May, 1997)..contd.

Sample II	AMG E (m)	AMG N (m)	Water Depth (m - Uncorrect.)	Sed. Typ((Visual)	Composition note
BC39	327777.75	6284271.71	1.23	M	dk grey-brown, cohesive mud
BC40	325958.76	6278126.25	1.57	S	fawn-brown ws c-vc qtz sand. Minor shell frags
BC42	329265.90	6289556.39	7.20	S	fawn-brown ws m-c qtz sand. Minor shell frags
BC43	329137.60	6289290.04	8.57	mS	dk grey brown to black muddy mws mg sand. Common organics (fg & cg), minor shell
BC44	329054.05	6289168.11	3.48	sM	dk grey-brown to dk grey, slightly sandy mud, common plant fragments
BC45	328906.27	6288833.66	2.29	sM	dk grey-brown to dk grey, slightly sandy mud, common plant fragments
BC46	328735.63	6288196.18	2.48	sM	dk grey-brown to dk grey, slightly sandy mud, common plant fragments
BC47	329113.01	6287998.71	1.91	M	dk grey-brown mud with common decaying plant material
BC48	329200.48	6287935.95	1.30	M	dk grey-brown mud with common decaying plant material
BC50	328042.95	6288062.21	3.67	sM	dk grey-brown to dk grey, slightly sandy mud,plant fragments, intact estuarine molluscs
BC51	327833.91	6288272.28	1.17	M	dk olive-grey firm mud
BC52	327246.92	6288579.00	1.79	M	dk olive-grey firm mud
BC53	326601.00	6289369.39	1.34	sM	dk olive grey sandy mud. Sand f-m, common coarse grained organics
BC54	325774.27	6289378.02	1.00	sM	dk olive grey sandy mud. Sand f-m, common coarse grained organics.
BC55	325362.01	6290620.96	0.00	M	dk olive-grey firm mud
BC56	325149.99	6290185.27	1.81	mS	dk olive-grey, mws, m-c qtz sand and common cg blackened plant fragments
BC57	327581.35	6287221.53	2.86	M	dk olive-grey firm mud
BC58	327238.17	6286848.45	1.28	M	dk olive-grey firm mud
BC59	327080.04	6286567.30	1.20	M	dk olive-grey firm mud
BC61	328231.29	6286288.65	3.68	M	dk olive-grey firm mud
BC62	327153.04	6286512.19	1.20	M	dk olive-grey firm mud
BC63	326738.65	6283839.39	4.21	M	dk olive-grey firm mud
BC65	328448.33	6288379.89	10.18	sM	dk brown-grey, sandy mud. Sand f-m, common leached shell frags
BC66	327496.49	6287093.75	1.12	M	dk olive-grey firm mud
BC67	326766.70	6283727.88	4.35	M	dk olive-grey firm mud
BC68	325827.71	6280519.97	1.30	sM	dk olive -grey organic rich sandy mud, common shell and ?root mat material at depth
BC70	325966.63	6278356.58	1.22	S	fawn-grey, mws, m-c qtz sand, minor organics
BC71	325545.23	6277600.73	1.04	S	fawn-grey, mws, m-c qtz sand, minor organics
BC34a	325673.16	6279535.12	2.33	O	dense matt of decaying organic fragments
BC34b	325665.56	6279549.63	2.22	O	dense matt of decaying organic fragments
BC53a	326620.46	6289684.86	1.53	sM	dk olive grey sandy mud. Sand f-m, common coarse grained organics
BC53b	326706.16	6289531.25	4.97	sM	dk olive grey sandy mud. Sand f-m, common coarse grained organics
BC55a	325360.13	6290438.67	1.31	M	dk olive-grey firm mud
BC55b	325372.54	6290261.06	1.92	M	dk olive-grey firm mud
BC56a	323857.85	6288998.73	1.87	mS	dk olive-grey, mws, m-c qtz sand and common cg blackened plant fragments

* M=Mud; sM=sandy Mud; mS=muddy Sand; s=Sand; g=gravel

Page 2 of 2

Hornsby Council Surface Samples (2 Feb., 1997)

Sample ID	Lat. (Deg)	Long. (Deg)	Water Depth (m-Uncorrect)	Sediment Type*	<0.063mm	>0.063mm	>0.25mm	>2.0mm	NOX mg/kg	TKN mg/kg	TOC mg/kg
MA01	33.63235	151.18995	1.00	S	0.31	12.87	86.82	0	<0.20	104	822
MA02	33.63235	151.19035	1.00	S	0.17	7.94	91.81	0.08	<0.20	115	1280
MA03	33.63273	151.18995	1.00	S	0.37	7.48	92.12	0.03	<0.20	137	1500
MA04	33.63268	151.19070	1.00	S	0.46	6.79	92.75	0	<0.20	131	1080
MA05	33.63238	151.19135	1.00	S	0.32	9.6	90.08	0	0.25	129	1810
MA06	33.63250	151.19208	22.00	M	36.09	32.72	31.19	0	<0.20	3060	39000
MA07	33.62948	151.19263	22.40	M	43.35	30.96	25.69	0	<0.20	3120	38100
MA08	33.62945	151.19258	22.80	M	31.65	29.23	39.12	0	<0.20	3460	44400
MA09	33.63012	151.19220	18.80	M	18.51	31.49	50	0	0.33	2330	29900
MA10	33.62970	151.19237	22.50	M	46	35.29	18.71	0	<0.20	3040	39000
CR01	33.62868	151.10830	1.00	gmS	1.4	2.81	93.36	2.43	0.87	342	4330
CR02	33.62860	151.10853	1.00	mS	3.04	12.28	84.68	0	0.25	242	2220
CR03	33.62845	151.10852	1.00	mS	1.65	5.65	92.7	0	<0.20	246	2610
CR04	33.62813	151.10913	1.00	gmS	0.44	1.03	96.42	2.11	<0.20	159	3130
CR05	33.62743	151.10820	1.00	gmS	0.49	1.45	94.51	3.54	<0.20	159	1320
SM01	33.61752	151.12423	1.80	mS	2.59	8.87	88.54	0	<0.20	407	5510
SM02	33.61770	151.12413	1.60	mS	2.58	7.8	89.62	0	<0.20	438	6780
SM03	33.61726	151.12382	1.00	mS	1.7	2.92	95.38	0	<0.20	181	1480
SM04	33.61800	151.12397	1.70	mS	3.59	10.8	85.61	0	0.25	852	8900
SM05	33.61830	151.12370	1.60	mS	3.43	12.87	83.7	0	<0.20	469	9370
SC06	33.64663	151.21050	1.00	mS	1.31	12.66	86.03	0	<0.20	159	1020
SC07	33.64645	151.21003	1.00	mS	0.59	11.94	87.47	0	<0.20	150	1030
SC09	33.64652	151.20997	1.00	mS	2.79	13.11	84.1	0	<0.20	168	2540
SC10	33.64687	151.21053	1.00	mS	0.83	10.98	88.19	0	0.25	150	1610
CPT01	33.54300	151.14895	5.00	M	59	35.69	5.31	0	<0.20	1750	26000
CPT02	33.54350	151.15003	4.30	sM	58.61	34.76	6.63	0	<0.20	1900	28000
CPT03	33.54410	151.14970	5.40	sM	52.93	43.53	3.54	0	<0.20	1920	27200
CPT04	33.54332	151.15032	4.10	sM	55.83	36	8.17	0	<0.20	1670	27200
CPT05	33.54320	151.15038	1.00	sM	58.34	31.4	10.26	0	0.31	1970	31700
CAL01	33.58740	151.12110	11.60	sM	57.04	38.85	4.11	0	<0.20	2800	33500
CAL02	33.58697	151.12048	16.10	mS	48.16	40.91	10.93	0	<0.20	3010	33900
CAL03	33.58725	151.12078	14.30	sM	50.04	35.59	14.37	0	<0.20	3230	33800
CAL04	33.58748	151.12083	12.30	mS	48.97	37.49	13.54	0	<0.20	2750	34200
CAL05	33.58688	151.12130	12.80	mS	46.05	35.19	18.76	0	<0.20	2810	33800

*M=Mud; S=Sand; G=Gravel
sM=sandy Mud; mS=muddy Sand

Analyses by AWT Ensight
Results on dry weight basis.
See AWT Report 42660
Page 1 of 4

Hornsby Council Surface Samples (2 Feb., 1997)

Sample ID	Lat. (Deg)	Long. (Deg)	Water Depth (m-Uncorrect)	Sediment Type*	<0.063mm	>0.063mm	>0.25mm	>2.0mm	NOX mg/kg	TKN mg/kg	TOC mg/kg
BF01	33.59877	151.12338	6.20	sM	60.02	32.87	7.11	0	<0.20	3600	48800
BF02	33.59848	151.12253	6.10	sM	57.65	36.13	6.22	0	<0.20	3220	43500
BF03	33.59845	151.12320	6.00	sM	54.02	37.09	8.89	0	<0.20	3080	49200
BF04	33.59940	151.12377	6.00	sM	52.14	38.99	8.87	0	<0.20	3480	52700
BF05	33.59900	151.12290	6.10	sM	52.89	38.73	8.38	0	<0.20	3430	49800
BB01	33.59740	151.15013	2.60	sM	57.58	32.88	9.54	0	<0.20	2100	31400
BB02	33.56777	151.14997	1.20	sM	59.29	32	8.71	0	<0.20	2160	32100
BB03	33.56682	151.15072	2.80	sM	54.71	30.58	14.71	0	<0.20	1910	31900
BB04	33.56778	151.15028	9.80	sM	61.66	33.38	4.96	0	<0.20	2110	31100
BB05	33.56770	151.15087	5.00	sM	58.18	36.57	5.25	0	<0.20	2210	32300
JC01	33.57805	151.13383	6.00	sM	55.36	38.18	6.46	0	<0.20	2390	32000
JC02	33.57811	151.13300	6.60	sM	58.45	37.67	3.88	0	<0.20	2440	33000
JC03	33.57847	151.13357	6.40	sM	59.88	31.86	8.26	0	0.33	2510	32800
JC04	33.57877	151.13275	6.90	sM	59.37	31.56	9.07	0	<0.20	2480	33000
JC05	33.57852	151.13153	7.70	sM	59.6	30.44	9.96	0	<0.20	2430	27000
WW01	33.60717	151.12220	1.00	S	8.17	30.02	61.81	0	<0.20	1500	28800
WW02	33.60825	151.12255	1.00	S	2.69	10.33	86.33	0.65	0.25	273	5090
WW03	33.60802	151.12220	1.00	mS	13.24	17.41	68.6	0.17	0.37	276	9270
WW04	33.60800	151.12237	1.00	gS	1.7	3.68	94.06	0.56	0.26	193	22400
WW05	33.60800	151.12237	1.00	S	1.69	5.88	92.43	0	0.25	156	1260
SC01	33.64200	151.21233	11.10	sM	60.9	36.74	3.17	0	<0.20	3380	60900
SC02	33.64270	151.21233	8.90	mS	30.66	36.3	33.04	0	<0.20	1950	34600
SC03	33.64283	151.21200	10.50	sM	55.45	29.76	14.79	0	<0.20	2860	61800
SC04	33.64400	151.21183	9.90	sM	61.51	30.34	8.15	0	<0.20	3300	63600
SC05	33.64320	151.21182	9.70	sM	61.3	37.22	1.47	0	<0.20	3480	58800
BP01	33.53043	151.15538	2.90	sM	50.09	44.14	5.77	0	<0.20	1770	31400
BP02	33.53068	151.15590	2.30	sM	54.33	41.85	3.82	0	<0.20	1620	30300
BP03	33.53132	151.15530	2.30	sM	50.6	35.02	14.38	0	<0.20	1630	30600
BP04	33.53113	151.15745	1.80	sM	57.85	33.54	8.61	0	<0.20	1980	30800
BP05	33.53155	151.15695	1.90	sM	61.31	33.38	5.31	0	0.3	1850	31600

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Analyses by AWT Ensight
Results on dry weight basis.
See AWT Report 42660
Page 2 of 4

Hornsby Council Surface Samples (2 Feb., 1997)

Sample ID	Ca mg/kg	Mg mg/kg	P mg/kg	Bo mg/kg	Al mg/kg	V mg/kg	Cr mg/kg	Mn mg/kg	Fe mg/kg	Co mg/kg	Cu mg/kg	Zn mg/kg	As mg/kg	Sr mg/kg	Ba mg/kg	Pb mg/kg
MA01	206	578	56	3.5	1560	2.22	1.26	2.3	698	0.11	0.52	1.7	1.03	13.6	6.46	1.48
MA02	528	467	61	3.6	1620	2.73	1.4	0.5	882	0.1	0.55	1.4	1	13.3	6.47	1.55
MA03	249	546	61	4	1880	2.78	1.35	0.4	841	0.08	0.42	0.8	0.95	13.9	7.36	1.61
MA04	225	579	61	4.6	2110	2.99	1.54	1.1	996	0.11	0.5	1.8	1.22	14.4	7.51	1.88
MA05	230	624	61	4.5	1740	2.76	1.32	2.4	767	0.1	0.47	1.5	1.06	15.3	7.44	1.63
MA06	9440	9810	1360	96.5	58800	103	53.3	485	36700	13	36.5	159	18.7	156	158	71.8
MA07	9100	9720	1450	104	64700	111	55.6	534	37400	13.1	35.6	155	18.6	156	169	70.8
MA08	8670	9320	1270	104	68400	106	54.8	525	35300	12.2	32.8	139	17.1	146	170	65.3
MA09	34400	6820	1460	71.4	42700	73.8	39.2	320	25700	9.89	25.1	109	13.3	178	116	50.3
MA10	10200	9440	1350	95.8	52600	101	50.5	476	36000	13.2	35.9	154	17.4	139	137	71.2
CR01	424	542	132	3	3140	4.29	2.71	81.9	2270	0.92	1.87	11.1	0.59	16.5	15.3	5.44
CR02	284	539	120	3.2	4420	5.54	4	68.6	2200	0.8	2.11	13.3	0.52	18.6	14.5	6.38
CR03	346	540	137	3.1	3430	4.84	3.04	64.4	2340	0.76	2.3	13.4	0.6	15.2	12.8	6.05
CR04	304	373	74	2.6	2030	2.35	1.53	61.7	1580	0.54	0.82	6.6	0.31	12.4	8.67	2.44
CR05	249	386	93	2.3	1730	2.8	1.9	12.9	1720	0.61	1.39	8.6	0.51	12.8	10	4.16
SM01	1660	828	159	6.8	5410	7.49	4.87	24.8	3110	0.88	4.05	16.4	0.91	25.5	17.4	10.2
SM02	630	1210	266	11.7	8330	11.8	7.38	46	4990	1.27	6.94	25.7	1.48	28.6	26	15.5
SM03	214	514	93	3.3	2890	3.71	2.42	25.7	1530	0.44	1.74	6.8	0.49	13.3	10.5	4.72
SM04	1610	1200	256	10.9	6680	10.7	6.91	38.9	4950	1.35	7.02	27.1	1.52	34.1	22.3	16.2
SM05	786	1230	266	11.2	7140	10.8	6.7	40.2	5000	1.3	6.61	25.6	1.51	27.1	23.5	15.6
SC06	315	580	65	4.5	1770	2.53	1.38	0.5	810	0.13	0.66	2.2	0.75	13.8	8.66	1.84
SC07	250	551	61	4.3	1600	2.48	1.44	0.5	819	0.13	0.61	1.8	0.63	13.5	8.5	1.89
SC09	390	675	73	6.8	2850	3.87	2.2	2.3	1240	0.23	1.21	4.4	0.96	18.3	13	3.07
SC10	346	635	60	5	2130	2.9	1.54	0.8	957	0.14	0.67	3.2	0.83	15.1	9.62	1.98
CPT01	2760	6360	1020	57	55700	88.8	49.2	659	45200	19.6	20.1	131	18.3	102	162	43.6
CPT02	2830	5840	962	52	49900	88.2	48.5	546	41600	18.3	20.9	131	18.1	90.9	147	43.8
CPT03	2960	6500	1020	54.7	52000	88.1	47.7	811	46700	20.2	19.6	130	19.2	101	150	43
CPT04	3440	5770	1030	55.6	54100	88.4	49.3	572	43500	19.4	20.2	128	18.2	95.2	156	43.8
CPT05	2900	4130	1030	51.3	57200	83.5	48.9	564	38700	15.7	20.1	109	16.6	90.6	150	42
CAL01	6910	8150	1240	77.4	64700	99.8	54.6	778	41400	15.6	31.1	140	12.6	144	189	63.8
CAL02	3680	8220	1380	82.6	66000	100	55.2	1580	42300	15.9	31	140	16.1	130	194	60.7
CAL03	3650	8140	1290	82.5	64600	105	57.2	1430	42200	16.5	33	143	15.3	133	194	64.8
CAL04	3590	8170	1280	80.2	67000	104	57.6	1050	42500	16.4	32.4	141	13.9	133	200	65.2
CAL05	3690	8220	1180	75.2	64700	99.4	54.5	866	41600	14.8	29.9	133	13.2	132	188	64.5

Analyses by AWT Ensight
Results on dry weight basis.
See AWT Report 42660
Page 3 of 4

*M=Mud; S=Sand; G=Gravel
sM=sandy Mud; mS=muddy Sand

Hornsby Council Surface Samples (2 Feb., 1997)

Sample ID	Ca mg/kg	Mg mg/kg	P mg/kg	Bo mg/kg	Al mg/kg	V mg/kg	Cr mg/kg	Mn mg/kg	Fe mg/kg	Co mg/kg	Cu mg/kg	Zn mg/kg	As mg/kg	Sr mg/kg	Ba mg/kg	Pb mg/kg
BF01	3580	7440	1160	73.7	51000	81.3	51.3	193	32800	10	50.1	169	9.13	124	156	101
BF02	3480	7440	1140	77.9	56800	90.5	56.8	220	35000	10.7	52.5	167	10.3	127	176	98.6
BF03	3520	5880	1090	75.2	58200	87.2	55.5	201	33100	10.3	49.4	166	9.8	114	174	97.2
BF04	3730	7780	1240	81.3	51800	80.5	50	179	32800	9.87	50.6	182	8.58	138	162	111
BF05	3430	7270	1080	78.3	57300	84.5	53.9	189	32400	9.88	48.8	162	9.42	133	180	97.6
BB01	2750	6110	915	61.8	54400	89.8	49.1	559	38700	17	21	112	15.5	99.1	170	48.3
BB02	2620	5520	977	40.5	35100	72.6	37.2	651	33700	15	19.3	99.2	14.7	80.4	117	44.1
BB03	2500	5630	821	54.7	47100	84.3	44.4	513	35100	14.9	19.2	103	13.8	97.2	155	44.6
BB04	2490	5330	959	35.9	31300	66.1	33.7	574	33000	14.5	18	94.7	14.6	73.8	97.7	40.4
BB05	2530	4530	1040	35.8	32700	68.2	34.6	522	36600	16.5	17	105	16.1	69.1	96.9	41.4
JC01	2610	6050	955	55.7	41200	79.2	40.6	1230	34700	14.8	20.7	103	15.1	94.8	134	43.6
JC02	2410	5610	914	49.7	39100	75.8	38.5	1010	33000	14.4	20.4	100	13.6	89.1	130	44.4
JC03	2650	5910	1080	41.6	33700	70.8	35.8	1310	35100	15	20.9	105	15.8	82.3	112	45.3
JC04	2510	5770	1000	47.3	37100	75	37.6	1120	34100	14.3	20.7	102	14.5	88.1	121	44.4
JC05	2240	5110	794	45.6	39800	71.3	37.5	905	30200	13	18.1	91.1	11.8	83.9	128	40.5
WW01	5680	2310	381	32.1	13300	19.9	12.1	31.3	7780	2.22	14.1	47.3	2.4	60.2	43.3	30.9
WW02	348	621	161	4.9	3110	4.65	2.79	48.9	2030	0.62	2.85	8.8	0.84	18.5	14.4	8.81
WW03	568	871	172	7.1	3900	5.99	3.99	18.9	3060	1.05	4.76	17.6	1.41	20.2	14.4	13
WW04	1180	542	102	2.9	1440	2.5	1.51	65.8	1370	0.52	2.09	6.8	0.67	16.3	9.59	5
WW05	1140	535	96	3.3	2500	3.31	2.22	74.1	1420	0.54	1.99	6.6	0.63	18.5	9.86	4.92
SC01	4120	5290	690	78.6	40900	62.1	36.1	94.6	18300	4.28	24.1	85.7	12.1	130	157	44.1
SC02	14000	3780	552	54.4	24100	36.7	21.4	88.5	11900	2.86	14.3	55.6	8.92	113	84.7	28.6
SC03	4350	5280	744	69.8	31300	52.2	29.4	78	17900	3.92	25.6	92.2	11	116	127	43.5
SC04	3750	5240	731	68.6	29100	51.4	28.6	69.1	17800	3.89	25.5	91.1	11.4	114	126	42.6
SC05	4190	4570	653	55.7	27800	45.7	26.2	79.9	16000	3.28	21.8	81.2	9.91	98.6	115	36.2
BP01	2380	4800	839	34	37200	65.2	37.4	410	33200	15	17.7	108	16.1	78.5	104	32
BP02	2290	2880	929	24.9	30400	62.1	36.8	390	32300	15.8	17.6	109	16.1	61.1	75.7	28.8
BP03	2260	3860	931	25.4	28500	59.1	33.7	408	32300	15.7	17.5	108	16.7	66	77.6	30.8
BP04	2520	5510	834	58.8	57000	83.8	49.4	351	35900	14.4	18	100	14.4	96.1	179	42.6
BP05	2660	4490	747	43.8	43000	70.8	39.1	349	31700	13.7	16.6	92.5	13.5	78.2	128	36.1

Analyses by AWT Ensight
Results on dry weight basis.
See AWT Report 42660
Page 4 of 4

*M=Mud; S=Sand; G=Gravel
sM=sandy Mud; mS=muddy Sand

University of Sydney Samples (1984)

Sample ID	LAT	LONG	Sediment Type	Distance Upstream (km)	%Mud	%Sand	%Gravel	<63micron Fraction (ug/g) Cu	Pb	Zn	Fe	Mn	Ni	Cr	Co	Cd	Total Sediment (ug/g) CU	PB	ZN	FE	MN	NI	CR	CO
110G	-33.504	151.177	M	0	53.86	44.84	1.3	25	42	112	3.76	841	48	43	14	0	17	32	76	2.7	532	32	30	10
111D	-33.612	151.123	S	14.19	3.96	96	0.04	67	97	138	3.54	211	28	74	11	0	7	26	15	0.3	18	7	6	9
112G	-33.608	151.12	sM	13.6	81.04	18.96	0	62	112	147	2.94	119	37	51	7	2	56	107	135	2.7	110	33	46	9
113G1	-33.601	151.123	M	12.72	79.81	20.19	0	58	107	148	3.21	158	39	50	7	1	54	108	149	3	151	35	45	10
115G	-33.594	151.117	M	11.68	90.75	9.25	0	42	98	126	3.71	208	38	48	10	1	40	98	126	3.5	196	36	45	10
117G	-33.576	151.131	M	8.887	96.19	3.81	0	27	69	109	4.29	1057	41	44	14	1	27	70	108	4.3	1059	40	44	14
118G	-33.572	151.14	M	7.596	94.62	5.38	0	26	69	104	4.05	752	39	43	14	1	25	72	101	4	752	38	42	14
119G	-33.567	151.151	M	6.448	92.67	7.33	0	26	71	103	4.1	856	41	43	16	1	25	67	102	4.1	848	40	42	16
120G1	-33.556	151.149	sM	5.112	87.27	12.67	0.06	26	47	117	4.17	716	44	45	17	0	25	47	123	4.3	716	41	42	17
121G	-33.549	151.149	M	4.359	87.04	12.88	0.09	27	47	118	3.93	559	47	45	16	0	27	47	117	4	555	44	43	16
122G	-33.55	151.151	M	4.415	90.62	9.38	0	25	44	117	4.43	909	29	44	17	0	25	45	123	4.4	902	29	44	17
123G	-33.543	151.132	M	0	98.16	1.84	0	19	36	105	3.82	533	36	40	14	0	19	37	106	3.8	524	36	40	14
124G	-33.539	151.142	M	3.145	80.56	18.57	0.86	23	39	112	3.97	668	36	42	16	0	22	40	107	3.8	605	34	39	15
125G	-33.539	151.145	sM	3.1	64.19	35.81	0	21	41	107	4.18	1025	34	43	15	0	18	50	192	11	1417	33	42	30
126G	-33.513	151.119	mS	0	16.59	82.63	0.78	24	66	130	4.2	559	59	23	12	0	5	16	26	0.9	128	15	6	4
127G	-33.511	151.12	mS	0	12.57	87.29	0.14	20	45	109	5.25	629	33	44	12	0	4	11	17	2.9	91	13	7	2
128G	-33.518	151.123	mS	0	16.53	82.97	0.51	26	84	117	3.52	395	38	25	56	0	6	20	25	0.8	106	12	6	11
129G	-33.52	151.134	M	0	80.85	18.85	0.3	22	46	114	4.4	529	37	44	14	0	21	45	105	3.6	484	34	40	12
130G	-33.527	151.139	M	0	77.39	22.61	0	21	42	110	4.16	536	38	42	14	0	22	44	106	4	527	35	39	13
131G	-33.532	151.148	M	2.111	66.62	32.98	0.4	19	34	102	3.82	658	39	41	15	0	16	32	94	3.5	587	31	32	13
135G	-33.516	151.165	gM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
136G	-33.516	151.166	gM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
138G	-33.518	151.169	gmS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
139G	-33.522	151.171	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
140G	-33.52	151.17	gM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
141G	-33.523	151.162	mS	0.65	22.01	75.23	2.76	27	54	107	4.1	692	40	44	14	0	11	38	62	2.9	351	18	18	18
142G	-33.529	151.162	M	1.149	63.49	36.19	0.33	24	51	106	4.59	422	37	40	13	0	22	54	99	4.2	369	32	35	17
144G	-33.526	151.155	M	1.149	50.69	47.05	2.26	23	47	95	3.75	790	34	37	13	0	19	49	92	3.4	640	26	30	18
145G	-33.518	151.153	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
147G	-33.515	151.159	gM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
149C1	-33.49	151.148	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150G	-33.489	151.152	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W01D	-33.704	151.078	gS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Shotter, N, 1994, Anthropogenic impacts on the central Hawkesbury River, part of a large NSW estuary.
BSc. (Hons) Thesis (unpubl.) Dept. Geology Geophysics, University of Sydney

University of Sydney Samples (1984)

Sample			Sediment	Distance				<63micron Fraction									Total Sediment							
ID	LAT	LONG	Type	Upstream (km)	%Mud	%Sand	%Gravel	Cu	Pb	Zn	Fe	Mn	Ni	Cr	Co	Cd	CU	PB	ZN	FE	MN	NI	CR	CO
W02D	-33.703	151.078	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W03D	-33.702	151.078	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W04D	-33.701	151.079	gS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W05D	-33.7	151.079	gS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W07D	-33.7	151.079	M+S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W08D	-33.7	151.079	mS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W09D	-33.699	151.079	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B/W10D	-33.696	151.081	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B/W11D	-33.694	151.083	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B12D	-33.666	151.079	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
B13D	-33.631	151.108	S	17.62	6.85	92.83	0.32	21	95	76	2.4	137	13	24	5	0	4	23	20	0.4	21	13	4	10
W14G	-33.704	151.078	M	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W15D	-33.706	151.078	gS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W16D2	-33.706	151.08	gS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W17D	-33.672	151.102	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W18D	-33.63	151.119	S	16.03	1.93	98	0.08	51	116	183	1.96	50	43	32	6	0	2	8	11	0.1	5	21	2	1
W19D	-33.635	151.118	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
W20D	-33.635	151.118	S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Shotter, N, 1994, Anthropogenic impacts on the central Hawkesbury River, part of a large NSW estuary. BSc. (Hons) Thesis (unpubl.) Dept. Geology Geophysics, University of Sydney

Appendix C: Sediment Coring

Methods and Core Logs

Vibracoring

Vibracoring in the Berowra Creek estuary was conducted over a three day period from the 8/9/97 to 10/9/97. Cores to a maximum length of 5.2m were recovered using the drilling platform and hydraulic coring system provided by the Manly Hydraulics Laboratory (NSW Dept. Public Works and Services). Core locations were selected on the basis of bathymetric and sedimentological trends within the estuary. All positioning was by a Differential Global Positioning System (DGPS). A summary of core locations, penetrations and recoveries is shown below:

Core_ID	Xcoord_amg	Ycoord_amg	Water_depth	Penetration_m	Recovery_m
BCVC1	329,090	6,289,010	3.0	6.30	4.64
BCVC2	328,454	6,287,982	3.0	6.30	4.73
BCVC3	327,668	6,287,327	4.5	6.80	4.10
BCVC4	328,052	6,286,683	7.0	6.40	3.65
BCVC5	327,149	6,283,864	2.5	6.10	4.90
BCVC6	326,438	6,282,596	7.5	6.00	1.37
BCVC7	325,705	6,282,049	15.5	4.50	0.79
BCVC8	325,846	6,280,688	8.0	7.00	3.10
BCVC9	325,761	6,280,295	3.5	6.80	5.70
BCVC10	325,587	6,279,982	2.3	6.30	5.20
BCVC11	325,560	6,279,726	2.0	5.98	5.15

Core samples were retained in a disposable aluminium core barrel (ID. 76mm) and transported to a laboratory for subsequent processing. Processing involved cutting the barrels longitudinally, photographing/videoing the exposed core sample, and logging. Logging the cores involved preparation of a detailed (visual) description of the core sample with particular note being made of changes in sediment texture, composition and consistency along the length of the core. Stratigraphic markers indicating clear changes in sediment type and/or style of deposition were noted. The results of the logging are contained within the detailed core logs included here.

Samples were selected for a range of textural and compositional analyses to confirm the visual descriptions. These samples were processed by a laboratory contracted by the Hornsby Shire Council. Representatives of the Environmental Protection Agency and Hornsby Shire Council also selected samples for nutrient and metals analysis. The results of these analyses are listed below. A limited number of samples (4) were selected and submitted for radiocarbon dating (see Appendix D).

Reference sections of the cores were retained and archived with the NSW Dept. of Mineral Resources.

Hand Augering

Two boreholes (MCHA1 & MCHA2) were drilled by hand auger and sludge-pump with the assistance of PhD. students from the Department of Geography, University of Sydney (Riko Hashimoto and Justin Meleo) and Ross McPherson from Hornsby Shire Council. Both holes were located within the Marramarra Creek floodplain (see core log for core locations). Site coordinates were determined from 1:25,000 topographic sheets of the area, core samples were logged in the field (see logs).

BEROWRA CREEK ESTUARY PROCESS STUDY - VIBRACORE SAMPLE METALS ANALYSIS (EPA)

Digest 200.2 (Aqua Rega)

	Ag	Al	As	Cr	Cu	Fe	Hg	Li	Ni	Pb	Se	Zn	TKN	TP	%TOC	%Mud	Depth	Comments (Dr. Anthony Roache; EPA)
bcvc1	0.05	9100	8.3	18	14	22200	0.02	12	15	15	0.20	40	1100	410	1.82	59.4	2.0-2.4m	My analysis of the data indicate this is high in Cu & Ni
bcvc2	0.04	11700	18	22	11	36000	0.03	23	17	15	0.39	61	1300	310	2.11	99	2.5-2.8m	
bcvc2b	0.04	10900	20	22	12	36000	0.03	22	18	15	0.36	63					2.5-2.8m	CSIRO QC duplicate analysis
bcvc3	0.05	11100	17	22	12	33000	0.03	22	19	16	0.38	61	1200	410	2	91.9	1.1-1.5m	
bcvc4	0.04	11100	18	20	12	32000	0.03	22	18	15	0.37	56	1300	400	2.08	83.1	1.1-1.5m	
bcvc5	0.04	13100	15	23	14	33000	0.03	20	18	17	0.25	53	1700	600	2.66	99	2.0-2.4m	
bcvc6	0.04	13200	15	21	12	37000	0.03	21	17	17	0.26	50	2000	750	2.89	99.5	0.9-1.2	
bcvc7	0.12	13200	14	20	21	35000	0.08	16	16	35	0.22	77	2000	800	2.19	99.7	0.5-0.8m	My analysis of the data indicate this is high in Cu, Hg, Pb & Zn*
bcvc8	0.08	12200	12	17	13	31000	0.03	24	13	15	0.86	39	3300	500	7.96	88.8	1.4-1.7m	
bcvc9	0.07	8500	12	12	11	26400	0.05	19	12	13	1.03	32	4200	440	14.4	72.9	3.4-3.6m	
bcvc10	0.06	7400	10	11	10	23200	0.05	19	11	12	1.06	27	4200	320	15.9	54.7	2.6-2.8m	
bcvc11	0.03	4100	7.5	5.9	5	12400	0.03	14	6	7	0.51	15	2100	190	7.6	27.9	2.2-2.5m	My analysis of the data indicate this is high in Se
bcvc12	0.05	7300	11	13	9	21600	0.02	12	13	11	0.18	36			2.87	60.1	4.1-4.5m	This is the deepest section from BCVC1

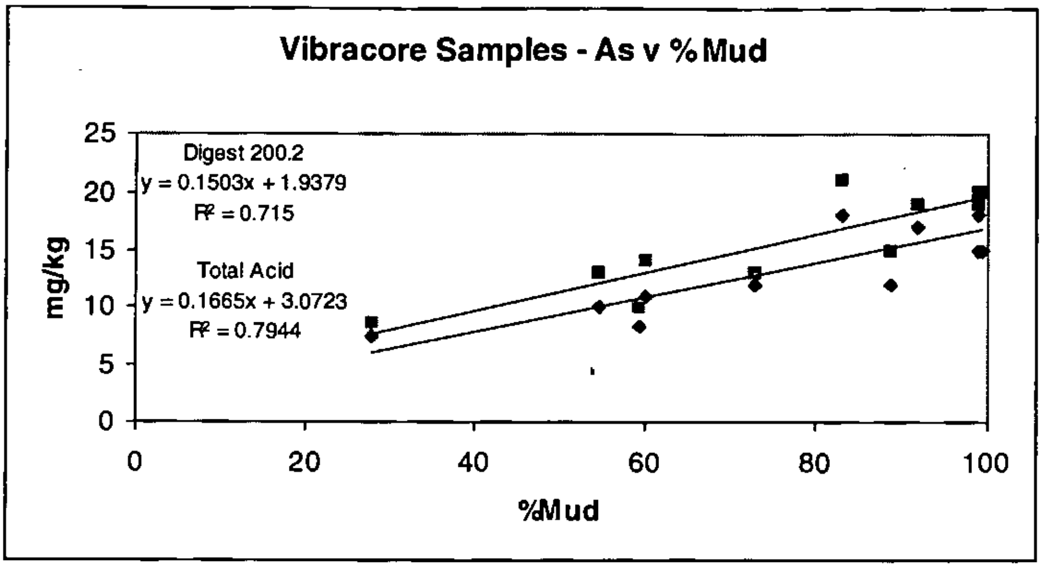
*Core sample disturbed, probable contamination by surficial sediments.

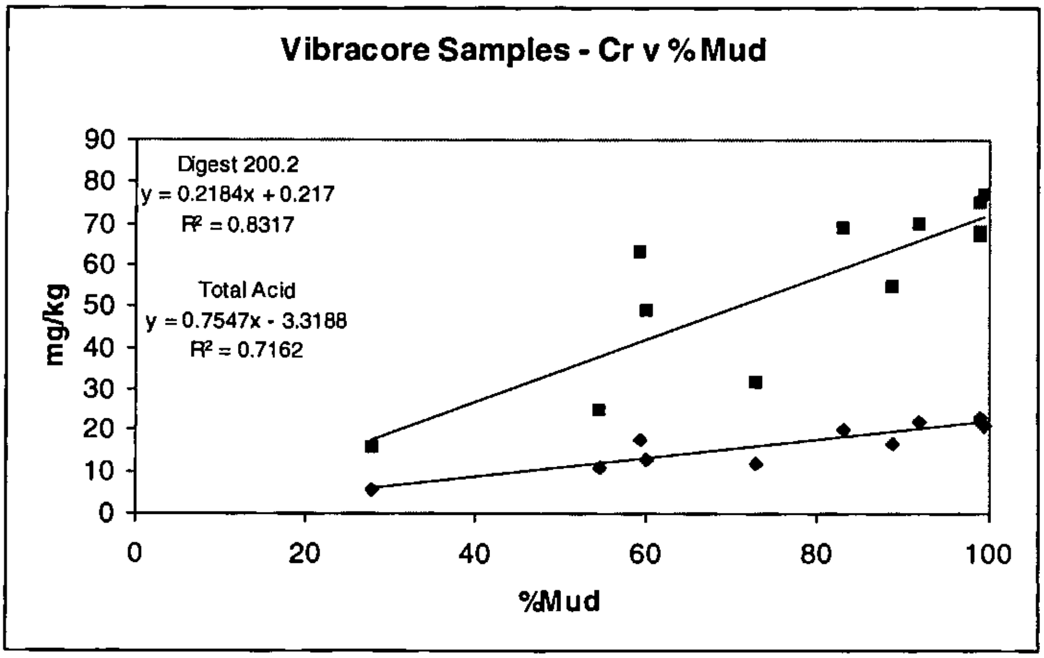
Total Acid Digest

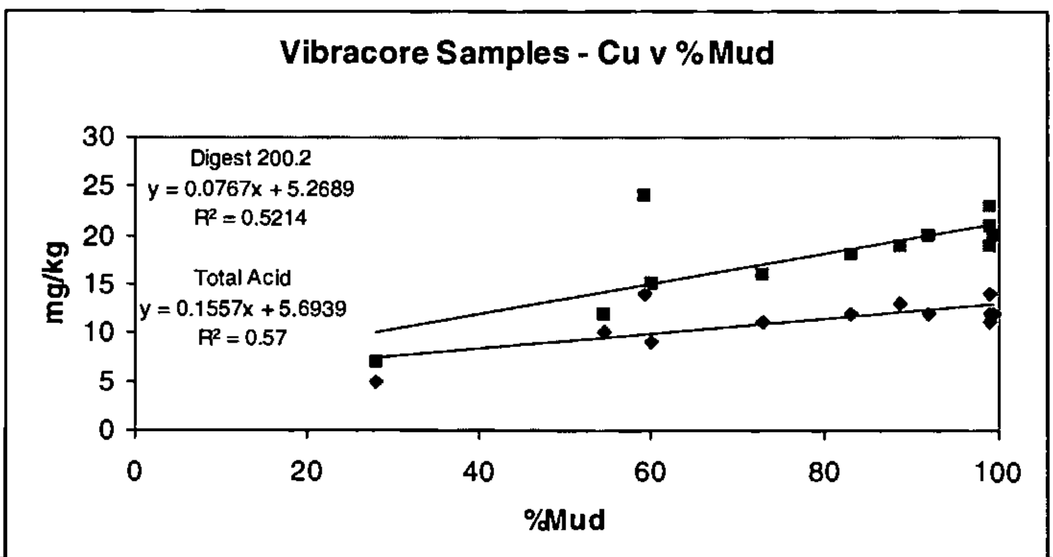
	Ag	Al	As	Cr	Cu	Fe	Hg	Li	Ni	Pb	Se	Zn	TKN	TP	%TOC	%Mud	Depth	Comments
bcvc1	0.11	67000	10	63	24	31000	0.03	45	31	22	0.32	87	1100	410	1.82	59.4	2.0-2.4m	My analysis of the data indicate this is high in Cu & Ni
bcvc2	0.09	75000	20	67	21	43000	0.03	62	33	23	0.46	115	1300	310	2.11	99	2.5-2.8m	
bcvc2b	0.10	75000	20	68	23	42000	0.03	63	34	23	0.50	116					2.5-2.8m	CSIRO QC duplicate analysis
bcvc3	0.09	81000	19	70	20	42000	0.03	64	32	26	0.59	101	1200	410	2	91.9	1.1-1.5m	
bcvc4	0.10	78000	21	69	18	41000	0.03	62	30	24	0.52	93	1300	400	2.08	83.1	1.1-1.5m	
bcvc5	0.08	79000	19	75	19	37000	0.04	57	29	23	0.47	89	1700	600	2.66	99	2.0-2.4m	
bcvc6	0.08	91000	20	77	20	46000	0.04	65	32	28	0.54	96	2000	750	2.89	99.5	0.9-1.2	
bcvc7	0.17	96000	20	85	35	45000	0.09	64	37	51	0.57	150	2000	800	2.19	99.7	0.5-0.8m	My analysis of the data indicate this is high in Cu, Hg, Pb & Zn**
bcvc8	0.13	68000	15	55	19	36000	0.04	66	24	23	0.88	73	3300	500	7.96	88.8	1.4-1.7m	
bcvc9	0.10	38000	13	32	16	29100	0.05	45	19	17	1.05	57	4200	440	14.4	72.9	3.4-3.6m	
bcvc10	0.09	30000	13	25	12	25400	0.05	36	15	15	1.08	44	4200	320	15.9	54.7	2.6-2.8m	
bcvc11	0.07	18200	8.6	16	7	13600	0.03	28	8	10	0.62	25	2100	190	7.6	27.9	2.2-2.5m	My analysis of the data indicate this is high in Se
bcvc12	0.09	57000	14	49	15	28200	0.03	43	22	19	0.34	68			2.87	60.1	4.1-4.5m	This is the deepest section from BCVC1

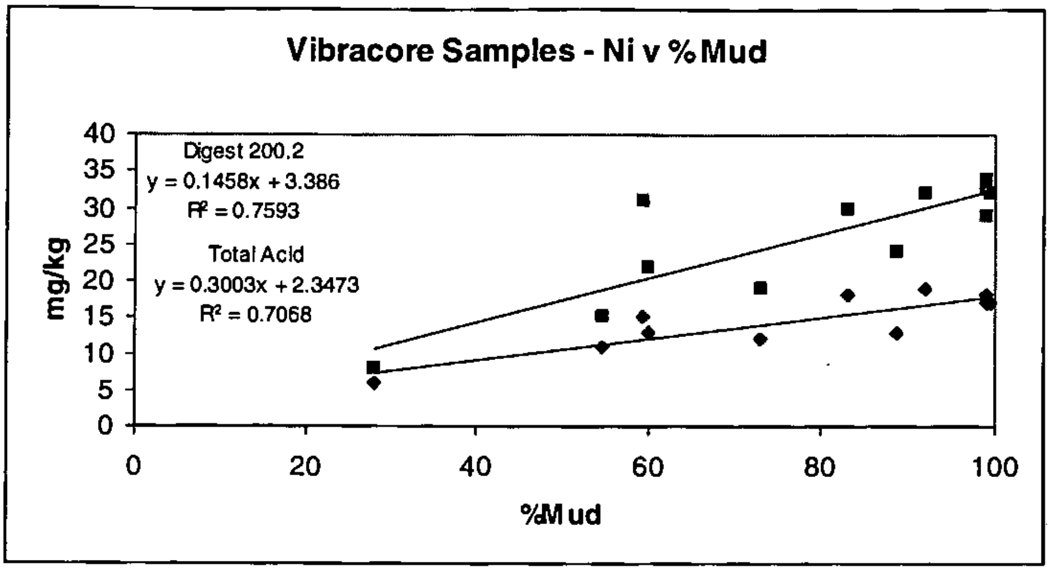
**Core sample disturbed, probable contamination by surficial sediments.

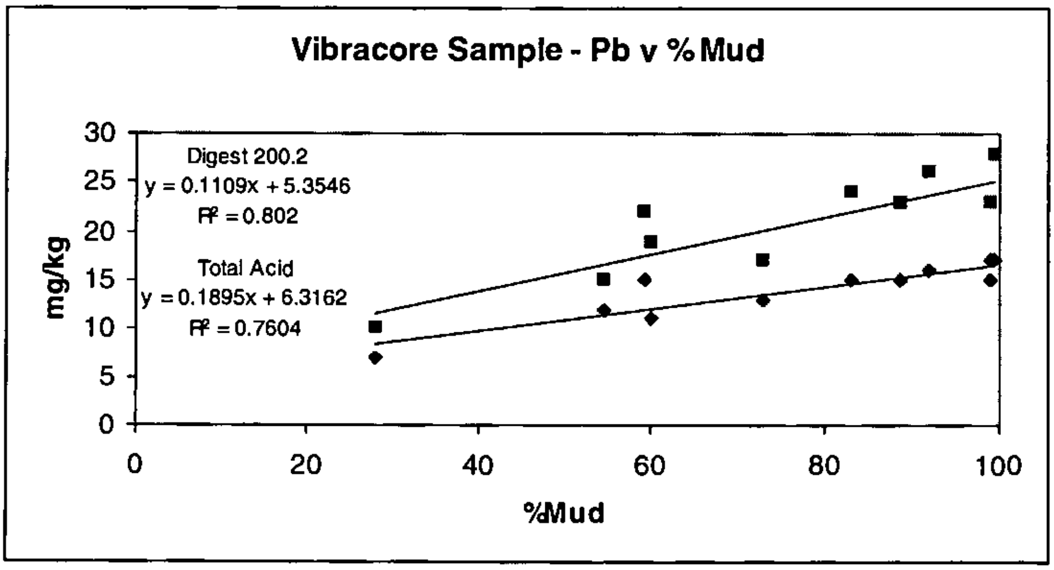
Results expressed as mg/kg sample dry weight or % of sample

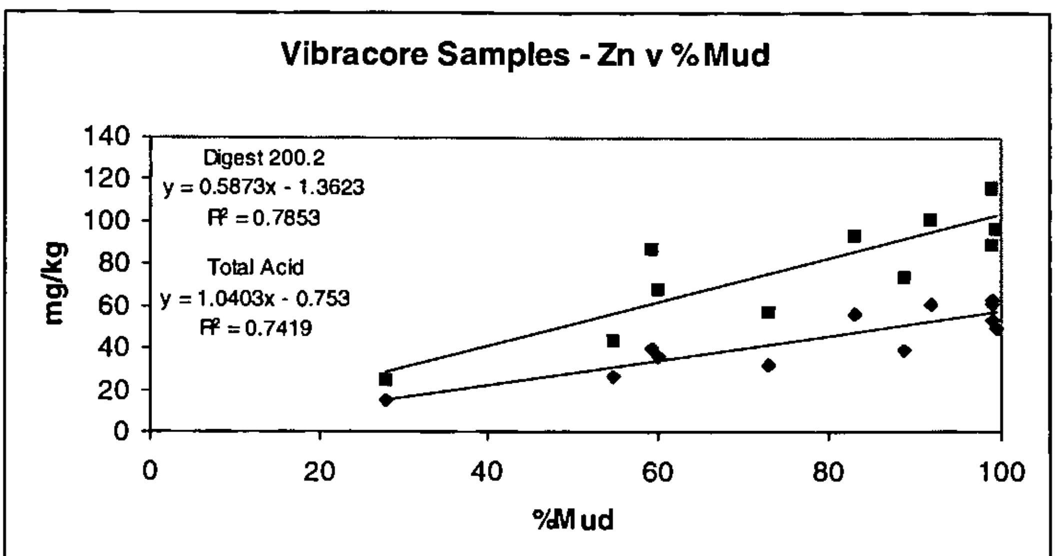

Vibracore Samples - As v %Mud
Digest 200.2
y = 0.1503x + 1.9379
R² = 0.715
Total Acid
y = 0.1665x + 3.0723
R² = 0.7944
mg/kg
%Mud
0 5 10 15 20 25
0 20 40 60 80 100

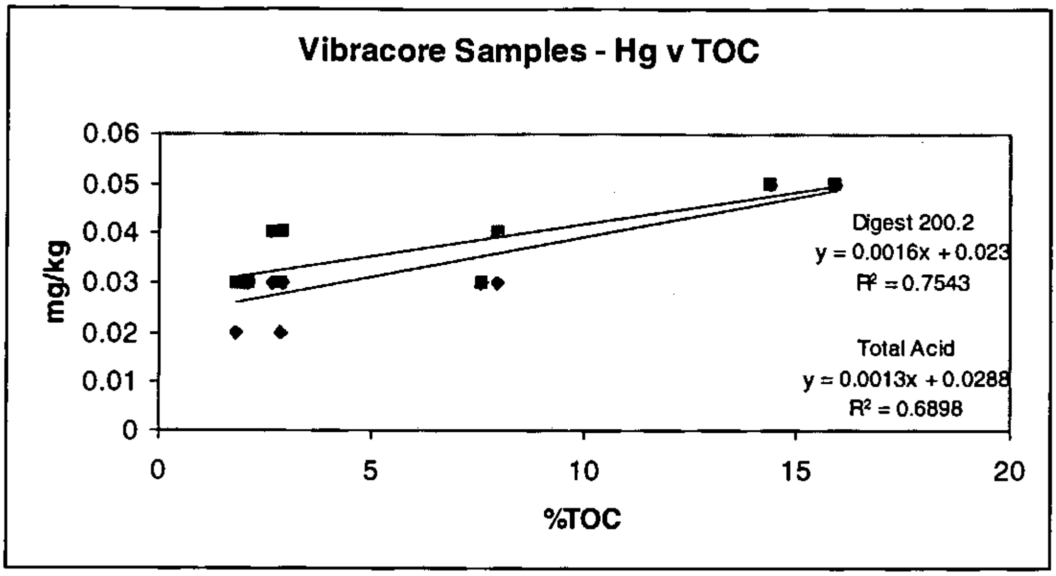

Vibracore Samples - Cr v %Mud
Digest 200.2
y = 0.2184x + 0.217
R² = 0.8317
Total Acid
y = 0.7547x - 3.3188
R² = 0.7162
mg/kg
%Mud
0 10 20 30 40 50 60 70 80 90
0 20 40 60 80 100

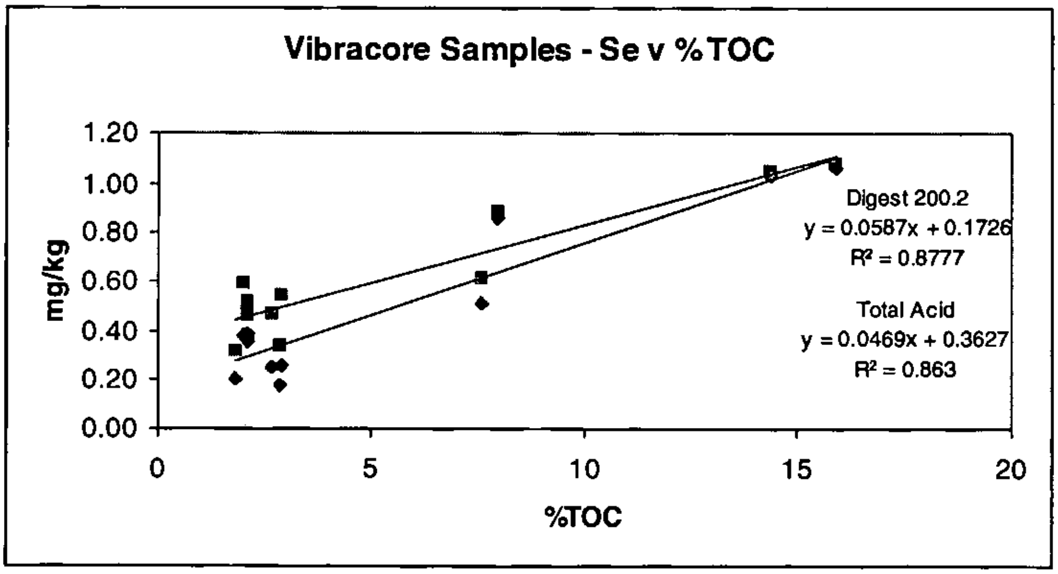

Vibracore Samples - Cu v %Mud
Digest 200.2
y = 0.0767x + 5.2689
R² = 0.5214
Total Acid
y = 0.1557x + 5.6939
R² = 0.57
mg/kg
%Mud
0 5 10 15 20 25 30
0 20 40 60 80 100


Vibracore Samples - Ni v %Mud
Digest 200.2
y = 0.1458x + 3.386
R² = 0.7593
Total Acid
y = 0.3003x + 2.3473
R² = 0.7068
mg/kg
%Mud
0
5
10
15
20
25
30
35
40
0
20
40
60
80
100


Vibracore Sample - Pb v %Mud
Digest 200.2
y = 0.1109x + 5.3546
R² = 0.802
Total Acid
y = 0.1895x + 6.3162
R² = 0.7604
mg/kg
%Mud
0
5
10
15
20
25
30
0
20
40
60
80
100


Vibracore Samples - Zn v %Mud
Digest 200.2
y = 0.5873x - 1.3623
R² = 0.7853
Total Acid
y = 1.0403x - 0.753
R² = 0.7419
mg/kg
%Mud
0
20
40
60
80
100
120
140
0
20
40
60
80
100


Vibracore Samples - Hg v TOC
0.06
0.05
0.04
0.03
0.02
0.01
0
mg/kg
0
5
10
15
20
%TOC
Digest 200.2
y = 0.0016x + 0.023
R² = 0.7543
Total Acid
y = 0.0013x + 0.0288
R² = 0.6898


Vibracore Samples - Se v %TOC
1.20
1.00
0.80
0.60
0.40
0.20
0.00
mg/kg
0
5
10
15
20
%TOC
Digest 200.2
y = 0.0587x + 0.1726
R² = 0.8777
Total Acid
y = 0.0469x + 0.3627
R² = 0.863

Berowra Creek Estuary Process Study - Assessment of surface sediment contamination from vibracore sample analyses.

Sample	Sediment Type*	%Mud	TKN mg/kg	TOC mg/kg	P mg/kg	Cr mg/kg	Cr (Calc) mg/kg	Cr_Factor (Enrichment)	Cu mg/kg	Cu (Calc) mg/kg	Cu_Factor (Enrichment)	Zn mg/kg	Zn (Calc) mg/kg	Zn_Factor (Enrichment)
BAR ISLAND														
BP01	sM	50.09	1770	31400	839	37.40	11.2	3.4	17.7	9.1	1.9	108.0	30.8	3.5
BP02	sM	54.33	1620	30300	929	36.80	12.1	3.0	17.6	9.4	1.9	109.0	33.3	3.3
BP03	sM	50.60	1630	30600	931	33.70	11.3	3.0	17.5	9.1	1.9	108.0	31.1	3.5
BP04	sM	57.85	1980	30800	834	49.40	12.9	3.8	18.0	9.7	1.9	100.0	35.3	2.8
BP05	sM	81.31	1850	31600	747	39.10	13.6	2.9	16.6	10.0	1.7	92.5	37.4	2.5
COBA POINT														3.1
CPT01	M	59.00	1750	26000	1020	49.20	13.1	3.6	20.1	9.8	2.1	131.0	36.0	3.6
CPT02	sM	58.61	1900	28000	962	48.50	13.0	3.7	20.9	9.8	2.1	131.0	35.8	3.7
CPT03	sM	52.93	1920	27200	1020	47.70	11.8	4.1	19.6	9.3	2.1	130.0	32.4	4.0
CPT04	sM	55.83	1670	27200	1030	49.30	12.4	4.0	20.2	9.6	2.1	128.0	34.2	3.7
CPT05	sM	58.34	1970	31700	1030	48.90	13.0	3.8	20.1	9.7	2.1	109.0	35.8	3.1
BUJWA BAY														
BB01	sM	57.58	2100	31400	915	49.10	12.8	3.8	21.0	9.7	2.2	112.0	35.2	3.2
BB02	sM	59.29	2160	32100	977	37.20	13.2	2.8	19.3	9.8	2.0	99.2	36.2	2.7
BB03	sM	54.71	1910	31900	821	44.40	12.2	3.6	19.2	9.5	2.0	103.0	33.5	3.1
BB04	sM	61.66	2110	31100	959	33.70	13.7	2.5	18.0	10.0	1.8	94.7	37.6	2.5
BB05	sM	58.18	2210	32300	1040	34.60	12.9	2.7	17.0	9.7	1.7	105.0	35.5	3.0
JOE CRAFTS BAY														
JC01	sM	55.36	2390	32000	955	40.60	12.3	3.3	20.7	9.5	2.2	103.0	33.9	3.0
JC02	sM	58.45	2440	33000	914	38.50	13.0	3.0	20.4	9.8	2.1	100.0	35.7	2.8
JC03	sM	59.88	2510	32800	1080	35.80	13.3	2.7	20.9	9.9	2.1	105.0	36.5	2.9
JC04	sM	59.37	2480	33000	1000	37.60	13.2	2.9	20.7	9.8	2.1	102.0	36.2	2.8
JC05	sM	59.60	2430	27000	794	37.50	13.2	2.6	18.1	9.8	1.8	91.1	36.4	2.5
CALABASH BAY														
CAL01	sM	57.04	2800	33500	1240	54.60	12.7	4.3	31.1	9.6	3.2	140.0	34.9	4.0
CAL02	mS	48.16	3010	33900	1380	55.20	10.7	5.1	31.0	9.0	3.5	140.0	29.6	4.7
CAL03	sM	50.04	3230	33800	1290	57.20	11.1	5.1	33.0	9.1	3.6	143.0	30.8	4.7
CAL04	mS	48.97	2750	34200	1280	57.60	10.9	5.3	32.4	9.0	3.6	141.0	30.1	4.7
CAL05	mS	48.05	2610	33800	1180	54.50	10.3	5.3	29.9	8.8	3.4	133.0	28.4	4.7
BEROWRA FERRY														
BF01	sM	60.02	3600	48800	1160	51.30	13.3	3.8	50.1	9.9	5.1	169.0	36.6	4.6
BF02	sM	57.65	3220	43500	1140	56.80	12.8	4.4	52.5	9.7	5.4	167.0	35.2	4.7
BF03	sM	54.02	3080	49200	1090	55.50	12.0	4.6	49.4	9.4	5.2	166.0	33.1	5.0
BF04	sM	52.14	3480	52700	1240	50.00	11.6	4.3	50.6	9.3	5.5	182.0	32.0	5.7
BF05	sM	52.89	3430	49800	1080	53.90	11.8	4.6	48.8	9.3	5.2	162.0	32.4	5.0
THE WOOLWASH														
WW01	S	8.17	1500	26600	361	12.10	2.0	6.0	14.1	5.9	2.4	47.3	6.2	7.7
WW02	S	2.69	273	5090	161	2.79	0.8	3.5	2.9	5.5	0.5	8.8	2.9	3.0
WW03	mS	13.24	276	9270	172	3.99	3.1	1.3	4.8	6.3	0.8	17.6	9.1	1.9
WW04	gS	1.70	193	22400	102	1.51	0.6	2.6	2.1	5.4	0.4	6.8	2.4	2.9
WW05	S	1.69	156	1260	96	2.22	0.6	3.8	2.0	5.4	0.4	6.6	2.4	2.8
SAMS CREEK														
SM01	mS	2.59	407	5510	159	4.87	0.8	6.2	4.1	5.5	0.7	16.4	2.9	5.7
SM02	mS	2.58	438	6780	266	7.36	0.8	9.5	6.9	5.5	1.3	25.7	2.9	8.9
SM03	mS	1.70	181	1480	93	2.42	0.6	4.1	1.7	5.4	0.3	6.8	2.4	2.9
SM04	mS	3.59	852	8900	256	6.91	1.0	6.9	7.0	5.5	1.3	27.1	3.5	7.8
SM05	mS	3.43	469	9370	268	6.70	1.0	6.9	6.6	5.5	1.2	25.6	3.4	7.6
CROSSLANDS														
CR01	gmS	1.40	342	4330	132	2.71	0.5	5.2	1.9	5.4	0.3	11.1	2.2	5.1
CR02	mS	3.04	242	2220	120	4.00	0.9	4.5	2.1	5.5	0.4	13.3	3.1	4.2
CR03	mS	1.65	246	2610	137	3.04	0.6	5.3	2.3	5.4	0.4	13.4	2.3	5.7
CR04	gmS	0.44	159	3130	74	1.53	0.3	4.9	0.8	5.3	0.2	6.6	1.6	4.1
CR05	gmS	0.49	159	1320	93	1.80	0.3	5.9	1.4	5.3	0.3	8.6	1.7	5.2

*Calculated values based on relationships determined from all subsurface sediment analyses performed by EPA using Digest 200.2. See following page and plots.
(All results based on total sample analyses; surface samples collected in Berowra Creek channel by Hornsby Shire Council)

Page 1 of 2

Berowra Creek Estuary Process Study - Assessment of surface sediment contamination from vibracore sample analyses.

Sample	Sediment Type*	%Mud	As mg/kg	As (Calc) mg/kg	As_Factor (Enrichment)	Pb mg/kg	Pb (Calc) mg/kg	Pb_Factor (Enrichment)
BAR ISLAND								
BP01	sM	50.09	16.1	9.5	1.7	32.0	10.9	2.9
BP02	sM	54.33	16.1	10.1	1.6	28.8	11.4	2.5
BP03	sM	50.60	16.7	9.5	1.7	30.8	11.0	2.8
BP04	sM	57.85	14.4	10.8	1.4	42.6	11.8	3.6
BP05	sM	61.31	13.5	11.2	1.2	36.1	12.2	3.0
COBA POINT								
CPT01	M	59.00	18.3	10.8	1.7	43.6	11.9	3.7
CPT02	sM	58.61	18.1	10.7	1.7	43.8	11.9	3.7
CPT03	sM	52.93	19.2	9.9	1.9	43.0	11.2	3.8
CPT04	sM	55.83	18.2	10.3	1.8	43.8	11.5	3.8
CPT05	sM	58.34	18.6	10.7	1.8	42.0	11.8	3.6
BUJWA BAY								
BB01	sM	57.58	15.5	10.6	1.5	48.3	11.7	4.1
BB02	sM	59.29	14.7	10.8	1.4	44.1	11.9	3.7
BB03	sM	54.71	13.8	10.2	1.4	44.6	11.4	3.9
BB04	sM	61.68	14.6	11.2	1.3	40.4	12.2	3.3
BB05	sM	58.18	16.1	10.7	1.5	41.4	11.8	3.5
JOE CRAFTS BAY								
JC01	sM	55.36	15.1	10.3	1.5	43.6	11.5	3.8
JC02	sM	58.45	13.6	10.7	1.3	44.4	11.8	3.8
JC03	sM	59.88	15.8	10.9	1.4	45.3	12.0	3.8
JC04	sM	59.37	14.5	10.9	1.3	44.4	11.9	3.7
JC05	sM	59.60	11.8	10.9	1.1	40.5	12.0	3.4
CALABASH BAY								
CAL01	sM	57.04	12.8	10.5	1.2	63.8	11.7	5.5
CAL02	mS	48.16	16.1	9.2	1.8	60.7	10.7	5.7
CAL03	sM	50.04	15.3	9.5	1.6	64.8	10.9	5.9
CAL04	mS	48.97	13.9	9.3	1.5	65.2	10.8	6.0
CAL05	mS	48.05	13.2	8.9	1.5	64.5	10.5	6.2
BEROWRA FERRY								
BF01	sM	60.02	9.1	11.0	0.8	101.0	12.0	8.4
BF02	sM	57.65	10.3	10.6	1.0	98.6	11.7	8.4
BF03	sM	54.02	9.6	10.1	1.0	97.2	11.3	8.6
BF04	sM	52.14	8.8	9.8	0.9	111.0	11.1	10.0
BF05	sM	52.89	9.4	9.9	1.0	97.6	11.2	8.7
THE WOOLWASH								
WW01	S	8.17	2.4	3.2	0.8	30.9	6.3	4.9
WW02	S	2.69	0.8	2.3	0.4	8.8	5.7	1.6
WW03	mS	13.24	1.4	3.9	0.4	13.0	6.8	1.9
WW04	gS	1.70	0.7	2.2	0.3	5.0	5.5	0.9
WW05	S	1.69	0.6	2.2	0.3	4.9	5.5	0.9
SAMS CREEK								
SM01	mS	2.59	0.9	2.3	0.4	10.2	5.6	1.8
SM02	mS	2.58	1.5	2.3	0.6	15.5	5.8	2.7
SM03	mS	1.70	0.5	2.2	0.2	4.7	5.5	0.9
SM04	mS	3.59	1.5	2.5	0.6	16.2	5.8	2.8
SM05	mS	3.43	1.5	2.5	0.6	15.6	5.7	2.7
CROSSLANDS								
CR01	gmS	1.40	0.6	2.1	0.3	5.4	5.5	1.0
CR02	mS	3.04	0.5	2.4	0.2	6.4	5.7	1.1
CR03	mS	1.65	0.6	2.2	0.3	6.1	5.5	1.1
CR04	gmS	0.44	0.3	2.0	0.2	2.4	5.4	0.5
CR05	gmS	0.49	0.5	2.0	0.3	4.2	5.4	0.8

Calculated background metal-grainsize relationships:

As	y=0.1503x + 1.9379	(R2 = 0.715)
Cr	y=0.2184x + 0.2170	(R2 = 0.8317)
Cu	y=0.0767x + 5.2689	(R2 = 0.5214)
Ni	y=0.1458x + 3.3860	(R2 = 0.7593)
Pb	y=0.1109x + 5.3546	(R2 = 0.802)
Zn	y=0.5873x + 1.3623	(R2 = 0.7853)

Where y = estimated metal value and x= %Mud

Relationships based on regression analyses summarised in plots
Coefficient of determination (R2) indicates reliability of correlation

Enrichment factor calculated from actual measured value in surface sediment divided by estimated background level for sample with comparable mud content.

PROJECT: Berowra Creek Estuary Process Study

DATE: 9 September, 1997

BORE HOLE ID.: BCVC1
LOCATION: Berowra Creek
AMG: 56 329090E 6289010N
AHD (m): -3.0
METHOD: Hydraulic Vibrocore
PENETRATION (m): 6.3 **RECOVERY (m):** 4.64
COMMENTS: Corer reached full penetration in around 4 minutes. Catcher closed on recovery, minimal core loss, core condition good. Compaction estimated at 35%.

INTERVAL (M) **DESCRIPTION**

0.0 - 2.30 MUD. Uniform, dark olive grey, soft, organic rich mud. Sediment increases in consistency from soft to firm at depth. Isolated large (2cm long by 1cm diameter) plant fragment at 0.6m and small shell (estuarine sp.) valve at 1.7m. Grades to...

2.30 - 3.80 MUD and SAND. Dark olive grey, firm, organic rich mud with isolated decaying plant fragments (1cm long/0.02cm diameter) and small leached shell fragments/ valves (<2cm). Interval has a series of distinct, well preserved, horizontally bedded, sand lenses at 2.3 (0.2cm thick), 2.54 (0.3cm thick), 2.59 (0.1cm thick), 2.70 (0.2cm thick) and 3.28 (0.3cm thick). Sand is typically slightly muddy to clean, fawn grey, moderately well sorted, fine to medium grained, quartzose. Clear to...

3.80 - 4.44 GRAVELLY MUD. Dark olive grey, firm, organic rich mud with common gravel size shell fragments and intact valves. Shells have pale grey, leached appearance, and are mainly intact valves of estuarine species (Notospisula, ?Mesodesma). Clear to...

4.44 - 4.64 SANDY MUD. Dark grey, cohesive, sandy mud with common charcoal and decaying plant fragments. Distinct sand lense at 4.54 (1cm thick) comprised of fawn, moderately well sorted fine grained quartz sand.

4.64 END OF CORE

Radiocarbon Date 4.47-4.50

PROJECT: Berowra Creek Estuary Process Study

DATE: 9 September, 1997

BORE HOLE ID.: BCVC2
LOCATION: Berowra Creek
AMG: 56 328454E 6287982N
AHD (m): -3.0
METHOD: Hydraulic Vibrocore
PENETRATION (m): 6.3 **RECOVERY (m):** 4.73
COMMENTS: Corer reached full penetration in around 4 minutes. Catcher partially closed on recovery, some core loss, core condition good. Compaction estimated at 25%.

INTERVAL (M) **DESCRIPTION**

0.0 - 1.96 MUD. Uniform, dark brown-grey to dark olive grey (below 1.0m), olive grey, soft to firm (below 1.5m), organic rich mud. No obvious quartz sand, common fine grained organics as decaying plant material and occasional sand-sized charcoal. Clear to...

1.96 - 2.80 GRAVELLY MUD. Dark olive-grey, slightly sandy, cohesive organic rich mud with common gravel-sized (<2cm) shell. Majority of shells are estuarine species (Notospisula and Mesodesma) and intact. Shells occur as both discrete layers (1.96m) and more massive units (2.03-2.50m; 2.60-2.80m). Organics fine grained. Grades to...

2.80 - 4.73 MUD. Dark olive grey, uniform, organic rich, very slightly sandy, mud. Scattered shell (estuarine sp.) and large (7cmX4cm) gravel sized concretions at 3.95m and 4.15m.

4.73 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 9 September, 1997

BORE HOLE ID.: BCVC3
LOCATION: Berowra Creek
AMG: 56 327668E 6287327N
AHD (m): -4.5
METHOD: Hydraulic Vibrocore
PENETRATION (m): 6.8 **RECOVERY (m):** 4.15
COMMENTS: Corer reached full penetration in around 4 minutes. Catcher open on recovery, some core loss, core condition good.

INTERVAL (M) **DESCRIPTION**

0.0 - 0.57 MUD. Uniform, dark brown-grey, firm, very slightly sandy, organic rich mud. Common very fine grained organics as decaying plant material. Sharp to...

0.57 - 1.00 GRAVELLY MUD. Dark olive-grey, slightly sandy, cohesive organic rich mud with gravel-sized (<1cm) shell. Majority of shells are intact valves of estuarine species (Notospisula, Oyster?Saccostrea), some valves still articulated. Rare oyster shell with barnacle encrustation. No clear depositional structure, massive bed. Sharp to...

1.00 - 4.05 MUD. Dark olive-grey slightly sandy, cohesive organic rich mud. Organics very fine grained. Occasional shell (intact and articulated estuarine bivalves) scattered throughout interval. Sharp to...

4.05 - 4.10 GRAVELLY MUDDY SAND. Olive-grey, massive, gravelly muddy sand. Sand is fine to medium grained, moderately well sorted, quartzose. Shells as gravel sized leached valves and fragments (Notospisula and Velacumantis common sp.)

4.10 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 9 September, 1997

BORE HOLE ID.: BCVC4
LOCATION: Berowra Creek
AMG: 56 328052E 6286683N
AHD (m): -7.0
METHOD: Hydraulic Vibrocore
PENETRATION (m): 6.4 **RECOVERY (m):** 3.55
COMMENTS: Corer reached full penetration in around 4 minutes, steady progress. Catcher open on recovery, some core loss, core condition good.

INTERVAL (M) DESCRIPTION

0.0 - 0.40 MUD. Uniform, dark brown-grey, soft, very slightly sandy, organic rich mud. Common very fine grained organics as decaying plant material, sand very fine grained. Grades to...

0.40 - 0.87 MUD. Dark olive-grey, slightly sandy, cohesive, organic rich mud with isolated gravel-sized (<1cm) shell valves (Notospisula). Three, thin (mm thickness), discrete clean sand laminae between 0.65 and 0.70m. Sand is fawn-grey, moderately well sorted, fine grained, quartzose. Clear to...

0.87 - 1.50 GRAVELLY MUD. Dark olive-grey, very slightly sandy, cohesive, organic rich mud with common gravel-sized (<2cm) shell. Majority of shells are estuarine species (Notospisula, Mesodesma, Anadara) and occur as either intact or articulated valves. Shells as massive layers with no clear depositional structure (0.87-1.08m and 1.15-1.50m) separated by a shell-free mud layer (1.08-1.15m). Grades to...

1.50 - 2.06 GRAVELLY MUD. Similar to previous unit (0.87-1.50m) but with less shell. Estuarine shell scattered throughout as separate and articulated valves,. Distinct horizontal shell layer 1.86-1.90m. Grades to...

2.06 - 3.00 MUD to SANDY MUD. Dark olive grey, cohesive, organic rich, sandy mud. Sand is fine grained, quartzose. Organics mostly very fine grained with layers (<0.5cm thick) of plant fragments and charcoal (2.7m and 2.8m). Grades to...

3.00 - 3.55 SANDY MUD. Dark olive-grey, cohesive, organic rich sandy mud with minor shell gravel. Sand is quartzose, fine to medium grained. Shell as fragmented and intact Notospisula valves. Base of core recovers ?burrows lined with oxidised (orange-brown) silt suggesting proximity to pre-transgression surface.

3.55 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 10 September, 1997

BORE HOLE ID.: BCVC5
LOCATION: Berowra Creek
AMG: 56 327149E 6283864N
AHD (m): -2.5
METHOD: Hydraulic Vibrocore
PENETRATION (m): 6.1 **RECOVERY (m):** 4.79
COMMENTS: Corer reached full penetration in around 5 minutes, steady progress at first and then with some resistance at depth. Catcher open on recovery, some minor core loss, core condition good. Core compaction estimated at 22%.

INTERVAL (M) **DESCRIPTION**

0.0 - 0.40 MUD. Uniform, dark brown-grey, soft, organic rich mud. Common very fine grained organics, minor estuarine shell (Notospisula) and charcoal. Grades to...

0.40 - 4.79 MUD. Uniform, dark olive-grey, very slightly sandy, cohesive, organic rich mud with isolated gravel-sized (<1cm) shell valves (Notospisula). Very little change in the character of sediments in this interval beyond slight increase in consistency and darkening of sediment colour below 3.5m.

4.79 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 10 September, 1997

BORE HOLE ID.: BCVC6
LOCATION: Berowra Creek
AMG: 56 326438E 6282596N
AHD (m): -7.5
METHOD: Hydraulic Vibrocore
PENETRATION (m): 6.0 **RECOVERY (m):** 1.37
COMMENTS: Corer progressed under own weight for top c.3m, vibration for c.2minutes over the final 3m of penetration. Catcher open on recovery with core sample extruding from base of barrel. Significant core loss. Recovered core in good condition.

INTERVAL (M) **DESCRIPTION**

0.0 - 1.37 MUD. Uniform, dark brown-grey, soft, organic rich mud. Common very fine grained organics, minor estuarine shell (Notospisula) and decaying plant fragments.

1.37 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 10 September, 1997

BORE HOLE ID.: BCVC7
LOCATION: Berowra Creek
AMG: 56 325705E 6282049N
AHD (m): -17.0
METHOD: Hydraulic Vibrocore
PENETRATION (m): 4.5 **RECOVERY (m):** 0.79
COMMENTS: Corer progressed under own weight for entire penetration. Vibration of barrel not required. Catcher partially closed on recovery with some core sample extruding from base of barrel. Amount of core loss uncertain. Sample oxidises quickly on exposure to air. Recovered core reasonable good condition - very loose sediment.

INTERVAL (M)	DESCRIPTION
0.0 - 0.79	MUD. Uniform, black, soft, organic rich mud. Common very fine grained organics - no evidence of any sand sized material.
0.79	END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 8 September, 1997

BORE HOLE ID.: BCVC8
LOCATION: Berowra Creek
AMG: 56 325846E 6280688N
AHD (m): -8.0
METHOD: Hydraulic Vibrocore
PENETRATION (m): 7.0 **RECOVERY (m):** 3.10
COMMENTS: Corer progresses steadily throughout, operated for around 5 minutes. Catcher open on recovery, significant core loss, recovered core condition good.

INTERVAL (M) **DESCRIPTION**

0.0 - 3.10 MUD with SAND. Uniform, dark brown-grey, soft, organic rich mud grading to black cohesive mud below 2.0m with discrete sand and organic rich lenses. Mud comprised of very fine grained organics and occasional minor estuarine shell valves (Notospisula), some articulated with vitreous lustre. Gravel sized (<3cm), solitary ariculated shells at 1.0m, 2.23m, 2.65m. Horizontal shell layers (1cm thick) comprised of single valves at 1.95m, 2.4m, 2.9m.

Sand lenses occur at 0.32-0.35m, 0.95-0.97, 1.15m (<0.5cm thick), and 2.0m (<0.5cm thick). Sand is fawn grey, moderately well sorted, medium grained, quartzose. Sand lenses horizontal, less distinct, and typically finer grained below 1.0m. Common coarse grained organics (decaying plant material and charcoal) associated and interbedded with sand lenses. Organic rich layers comprised of decaying plant material and charcoal and *not* associated with sand lenses occur at 0.50-0.53m, 0.67-0.72m, and 2.46-2.50m.

3.10 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 8 September, 1997

BORE HOLE ID.: BCVC9
LOCATION: Berowra Creek
AMG: 56 325761E 6280295N
AHD (m): -3.5
METHOD: Hydraulic Vibrocore
PENETRATION (m): 6.8 **RECOVERY (m):** 5.7
COMMENTS: Corer progresses steadily throughout, operated for around 5 minutes. Catcher closed on recovery, minimal core loss, recovered core condition good. Estimated core compaction 17%.

INTERVAL (M) **DESCRIPTION**

0.0 - 0.65 SANDY MUD and ORGANICS. Interbedded sandy mud and organic material. Unit grossly described as dark olive-grey, sandy mud to muddy sand with clear horizontal bedding structures. Sand is very fine grained to fine grained , quartzose. Organic rich layers consist of decaying plant material and charcoal grains. Organic rich layers at 0.07-0.14m, 0.20-0.24m, 0.30-0.35m, 0.42m, 0.46-0.56m, 0.61-0.65m. Some sand mixed with organic rich layers. Grades to...

0.65 - 1.82 SANDY MUD and ORGANICS. Similar to above but with more widely separated and fewer organic rich layers. Organic layers separated by muds encountered at 1.09m, 1.19-1.28m, 1.34-1.38m, 1.40-1.49m and 1.82m. Muds consist of very fine grained organics and minor very fine grained sand. Sharp basal contact between organic layers and muds. Clear to...

1.82 - 3.84 MUD and SAND and ORGANICS. Interval comprised of dark olive-grey to black organic rich slightly sandy muds interbedded with coarse grained organics and sand. Differs from previous unit in that fine to medium grained sands typically form the lower contact of organic rich lenses. Organics consist of decaying plant material (leaf, twig, gum nuts) and charcoal. Sand is fawn-grey, fine to medium grained, quartzose. Minor shell (estuarine bivalve fragments and gastropods) associated with coarse grained interbed at base of interval (3.82-3.84m).

Horizontally bedded organic rich lenses (no obvious coarser grained sand component) occur at 2.05-2.10m, 2.23-2.31m, 3.10-3.14m, and 3.20-3.31m. Organic rich lenses with basal sand layer occur at 1.82-1.91m, 2.64-2.71m, 2.96-2.99, 3.7-3.84m. Sand thickness associated with each of these layers is between 1 to 3cm. Sharp basal contact between organic/sand layers and mud. Grades to...

3.84 - 5.03 MUD and ORGANICS. Dark grey to black, organic rich, slightly sandy mud interbedded with organic material. Organic rich layers, comprised of decaying plant material and charcoal, occur at 3.86-3.88m, 3.94m, 4.17-4.18m, and 4.61-4.70m. Sharp basal contacts between organic layers and mud. Grades to...

5.03 - 5.70 SHELLY MUD and ORGANICS. Dark grey to black organic rich mud with layers of coarse grained organics (plant material/charcoal) and clean sand lenses. Sand is fawn grey, fine to medium grained, quartzose. Coarse grained organic layers have sharp basal contacts with underlying mud. Horizontal sand lenses at 5.03-5.06m and 5.30m. Organic layers at 5.1-5.15m and 5.52-5.60. Common estuarine shell fragments and intact valves below 5.50m. Sharp basal contacts between organic layers and mud.

5.70 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 8 September, 1997

BORE HOLE ID.: BCVC10
LOCATION: Berowra Creek
AMG: 56 325587E 6279982N
AHD (m): -2.3
METHOD: Hydraulic Vibrocore
PENETRATION (m): 5.9 **RECOVERY (m):** 5.2
COMMENTS: Corer progresses steadily throughout, operated for around 5 minutes. Catcher plugged on recovery, minimal core loss, recovered core condition good. Estimated core compaction 12%.

INTERVAL (M) **DESCRIPTION**

0.0 - 0.24 MUDDY SAND. Interbeds of fawn-grey, cohesive, organic rich, muddy sand and sandy mud. Clear basal contacts for muddy sand layers. Sandy mud layers 0-0.03m, 0.08-0.20m, muddy sand layers 0.03-0.08m and 0.20-0.24m. Mud consists of fine grained organics and silt sized quartz. Muddy sand layers contain well sorted fine grained quartz sand and coarser grained organics (decaying plant material and charcoal). Clear to...

0.24 - 1.65 MUD and ORGANICS and SAND. Alternating layers of dark grey to olive-grey, organic rich, slightly sandy mud and coarse grained organics (plant material and charcoal), basal contact of later frequently defined by medium grained quartz sand lense. Organic rich layers at 0.55-0.64m, 0.70-0.92m (sand layer <0.5cm thick at 0.92), 1.20-1.24m, 1.30-1.40m, 1.45-1.63 (sand layer 2cm thick at 1.63m). Clear to...

1.65 - 3.35 MUDDY SAND. Dark grey, cohesive, poorly layered muddy sand interval. Mud comprised of very fine grained organics and fine grained quartz. Coarser organics decaying plant material and charcoal. Horizontal, 0.5cm thick clean sand lense at 3.14m. Sand is fine to medium grained. Grades to...

3.35 - 5.20 MUD and ORGANICS and SAND. Marked increase in organic content of sediments. Alternating layers of dark grey to black, organic rich, slightly sandy mud and coarse grained organics (plant material and charcoal); basal contact of later frequently defined by relatively clean, fawn grey, fine to medium grained quartz sand lense. Organic rich layers at 3.35-3.44m, 3.75-3.80m (sand lense 3.80-3.85m), 4.00-4.03m, 4.30-4.46m (sand lense 4.46-4.50m), 4.60-4.70m, 5.05-5.10m (minor shell fragments). Organic lense 4.30-4.46m has high proportion of coarse grained charcoal compared to other layers.

5.20 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 8 September, 1997

BORE HOLE ID.: BCVC11
LOCATION: Berowra Creek
AMG: 56 325560E 6279726N
AHD (m): -2.0
METHOD: Hydraulic Vibrocore
PENETRATION (m): 5.9 **RECOVERY (m):** 5.15
COMMENTS: Corer progresses steadily throughout, operated for around 6 minutes. Catcher plugged with muds on recovery, minimal core loss, recovered core condition good. Estimated core compaction 13%.

INTERVAL (M) DESCRIPTION

0.0 - 0.24 MUDDY SAND and ORGANICS. Fawn-grey muddy sand grading to fawn, clean, fine grained sand 0.1-0.12m. Organic rich layer 0.12-0.20m, basal contact marked by thin (<0.5cm thick), well sorted, fine grained sand lense. Organic layer consists of decaying plant material and charcoal. Clear to...

0.24 - 0.89 MUDDY SAND. Fawn-grey, cohesive, muddy, fine to medium grained quartz sand. Grades to slightly muddy, medium grained quartz sand below 0.50m. Organic layer (charcoal/plant fragments) at base of interval. Clear fining up sequence. Sharp to...

0.89 - 1.47 MUD and MUDDY SAND. Dark grey, cohesive, organic rich mud from 0.89-0.98 over dark fawn-grey muddy fine grained quartz sand grading to slightly muddy, fine to medium grained quartz sand below 1.25m. Scattered coarse grained organics (charcoal, plant fragments). Thin (<0.5cm) clean sand lenses at 0.98. Fining up sequence. Clear to...

1.47 - 2.20 MUD and MUDDY SAND. As above. Two fining up sequences from 1.71-1.47m and 1.71-2.20m. Each unit characterised by mud (1.47-1.50m and 1.71-1.75m) over coarse grained organic rich layer (1.5-1.6m and 1.75-1.90m) over relatively clean, fawn grey, fine to medium grained quartz sand layer. Sharp basal contacts. Clear to....

2.20 - 3.52 MUDDY SAND. Alternating layers of organic rich, dark grey, muddy sand and fawn-grey sand. Sand fine grained in muddy layers, fine to medium grained in sand layers. Diffuse contacts. Muddy sand layers 2.20-2.50m, 2.70-3.24m, 3.32-3.47m. Sand layers 2.50-2.70m, 3.24-3.32m, 3.47-3.52m. Clear contact to...

3.52 - 4.63 MUD and ORGANICS and SAND. Marked increase in coarse grained organic content (decaying plant material and charcoal) of sediments. Clear layering of sediments. Black, organic rich muds comprise much of interval with coarse grained organic rich layers at 3.87-3.96m, 4.46m (<0.5cm thick) and 4.52-4.63m. Interbeds of fawn-grey, relatively clean, fine to medium grained quartz sand at 4.22-4.24m (two distinct laminae c.0.5cm thick) and 4.46-4.52m. Clear to....

4.63 - 5.15 MUDDY SAND and MUD. Dark grey to black, cohesive muddy sand grading to slightly sandy mud below 4.85m. Core looks disturbed (?bioturbated) from 4.63-4.85m with better preservation of depositional structures below 4.85m to base of core where thin (<0.5cm) laminae of clean sand are interbedded with the organic rich muds. Common blackened plant fragments and fine grained quartz sand at base of core.

5.15 END OF CORE

PROJECT: Berowra Creek Estuary Process Study

DATE: 27 August, 1997

BORE HOLE ID.: MCHA1
LOCATION: Marramarra Creek
AMG: 56 323843E 6288976N
AHD (m): ?1.5
METHOD: Hand Auger and Sludge Pump
PENETRATION (m): 8.0 **RECOVERY (m):** 8.0
COMMENTS: Hand operated coring on levee deposit, near orchards, on southern bank of Marramarra Creek channel. Disturbed samples recovered. Elevations approximated from tide level, core locations estimated from 1:25,000 topographic sheets.

INTERVAL (M) **DESCRIPTION**

0.0 - 0.35 SANDY SILT. Pale grey-brown to dark brown-grey, organic rich sandy silt. Organics plant fragments and charcoal. Sand fine grained, quartzose. Grades to...

0.35 - 1.15 SILT and SAND. Laminated dark grey-black organic rich silt and fine to medium grained quartz sand. Common fine grained charcoal and Casuarina roots. Sand content increases near lower contact. Clear to...

1.15 - 1.26 SAND. Pale grey , loose, sand. Sand moderately well sorted, medium grained, quartz. Grades to...

1.26 - 1.63 MUD and MUDDY SAND. Layered dark grey-black, sticky, organic rich, slightly sandy mud interbedded with dark grey, moderately sorted, muddy, medium to coarse grained, quartz sand. Common large (2cm diameter) wood fragments - mangrove (?Avicennia) - near base of interval. Clear to...

1.63 - 2.40 SAND. Clean, pale grey, moderately well sorted, medium to very coarse grained quartz sand. Mud content increases near base of interval. Grades to...

2.40 - 3.50 MUDDY SAND. Dark grey, muddy, moderately sorted, coarse grained quartz sand with common granule sized charcoal. Grades to dark grey-black muddy medium to coarse grained quartz sand at depth. Grades to...

3.50 - 6.70 MUDDY SAND. Dark grey-brown, muddy, medium to coarse grained quartz sand. Common granule sized charcoal. Grades to...

6.70 - 8.00 MUDDY SAND and MUD. Interbedded organic rich muds and pale grey, moderately well sorted, medium grained quartz sand. Common decaying plant material, strong H_2S smell. Estuarine shell fragments below 7.7m.

8.00 END OF HOLE

PROJECT: Berowra Creek Estuary Process Study

DATE: 27 August,1997

BORE HOLE ID.: MCHA2
LOCATION: Marramarra Creek
AMG: 56 322175E 6289012N
AHD (m): ?0
METHOD: Hand Auger and Sludge Pump
PENETRATION (m): 4.8 **RECOVERY (m):** 4.8
COMMENTS: Hand operated coring on point bar deposit along southern margin of of Marramarra Creek channel upstream of Borehole MCHA1. Disturbed samples recovered. Elevations approximated from tide level, core locations estimated from 1:25,000 topographic sheets.

INTERVAL (M) **DESCRIPTION**

0.0 - 0.05 SAND. Clean, fawn, moderately well sorted, medium grained quartz sand. Clear to...

0.05 - 0.90 SAND and ORGANICS. Alternating layers (1-5cm thick) of dark grey-brown organics (plant material) and pale grey clean sand. Grades to...

0.90 - 2.75 MUDDY SAND to GRAVELLY SAND. Dark grey, muddy, medium grained quartz sand with common organic fragments grades to gravelly coarse grained sand below 1.5m. Gravel typically quartz pebbles <1.0cm diameter. Grades to...

2.75 - 4.80 MUDDY SAND and ORGANICS. Dark grey-brown, muddy, medium grained quartz sand with common organic fragments (plant material). Organic material commonly occurs as layers containing plant material and gravel sized charcoal.

4.80 END OF HOLE

Appendix D: Radiocarbon Dating

Sample Details and Results

Sample Selection

A total of four samples were selected for radiocarbon dating. Sample details are listed below and the results of the dating summarised in the enclosed Beta Analytic Laboratory report sheets.

Samples were selected from four of the eleven vibrocores collected within the Berowra Creek estuary - Cores BCVC1, BCVC5, BCVC9 and BCVC11. Cores BCVC1 and BCVC5 are located in the lower and central portion respectively of the estuary, while BCVC9 and BCVC11 are located within the fluvial delta upstream of the Berowra Creek ferry. The cores are of such high quality (ie. good preservation of bedding structures and little evidence of bioturbation) that more dating (ie. more radiocarbon or Lead/Caesium dates) is likely to yield a detailed record of sedimentation covering the last 1000 years. Note that none of the dated organic material (large plant fragments, fine grained organicsl) was found *in situ* and therefore has been transported prior to its deposition and incorporation into the estuary bed. Reported dates must be considered the maximum age of deposition for each interval.

A limited number of samples was chosen to determine the maximum age of deposition at key sites within the estuary. All dates were on organic material (decaying plant fragments); the enclosed laboratory sheets detail the analytical procedures for the samples and calibration of radiocarbon age to calendar years.

Sample	Lab. ID	Depth (m)*	Material	Radiocarbon Age (Years BP)**	Calibrated Age (Years AD)***
BCVC1	Beta109967	4.47-4.5	Organics	1,500±70	590 (530-640)
BCVC5	Beta109968	4.30-4.50	Organics	1,410±50	650 (620-665)
BCVC9	Beta109969	5.52-5.56	Plant frag.	460±60	1440 (1420-1470)
BCVC11	Beta109970	5.03-5.06	Plant frag.	1,090±60	980 (890-1010)

* Depth below bed of estuary as measured from recovered core sample.
** Year Before Present with "present"=1950AD
*** See attached calibration curves. Uncertainty as to the elapsed time between transportation and deposition necessitates that the dates are considered as approximate.

BETA ANALYTIC INC.

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REPORT OF RADIOCARBON DATING ANALYSES

FOR: Ms. G. Taylor and Dr. M. Barbetti
The University of Sydney

DATE RECEIVED: Auth. Nov. 5, 1997
DATE REPORTED: November 15, 1997

Sample Data	Measured C14 Age	C13/C12 Ratio	Conventional C14 Age (*)
Beta-109967	1500 +/- 70 BP	-25.0* o/oo	1500 +/- 70* BP

SAMPLE #: BCVC1(4470-4500)
ANALYSIS: radiometric-standard
MATERIAL/PRETREATMENT:(organic sediment): acid washes

Sample Data	Measured C14 Age	C13/C12 Ratio	Conventional C14 Age (*)
Beta-109968	1410 +/- 50 BP	-25.0* o/oo	1410 +/- 50* BP

SAMPLE #: BCVC5(4300-4500)
ANALYSIS: radiometric-standard
MATERIAL/PRETREATMENT:(organic sediment): acid washes

NOTE: It is important to read the calendar calibration information and to use the calendar calibrated results (reported separately) when interpreting these results in AD/BC terms.

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By International convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calendar years. Calibration to calendar years should be calculated using the Conventional C14 age.

BETA ANALYTIC INC.

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REPORT OF RADIOCARBON DATING ANALYSES

FOR: Ms. G. Taylor and Dr. M. Barbetti
The University of Sydney

DATE RECEIVED: October 2, 1997
DATE REPORTED: November 5, 1997

Sample Data	Measured C14 Age	C13/C12 Ratio	Conventional C14 Age (*)
Beta-109969	460 +/- 60 BP	-25.0* o/oo	460 +/- 60* BP

SAMPLE #: BCVC9 (5520-5560)
ANALYSIS: radiometric-standard
MATERIAL/PRETREATMENT:(plant fragments): acid/alkali/acid

Sample Data	Measured C14 Age	C13/C12 Ratio	Conventional C14 Age (*)
Beta-109970	1090 +/- 60 BP	-25.0* o/oo	1090 +/- 60* BP

SAMPLE #: BCVC11 (5030-5060)
ANALYSIS: radiometric-standard
MATERIAL/PRETREATMENT:(plant fragments): acid/alkali/acid

NOTE: It is important to read the calendar calibration information and to use the calendar calibrated results (reported separately) when interpreting these results in AD/BC terms.

NOTE: Two additonal samples from this set were submitted but not analyzed.

Dates are reported as RCYBP (radiocarbon years before present, "present" = 1950A.D.). By International convention, the modern reference standard was 95% of the C14 content of the National Bureau of Standards' Oxalic Acid & calculated using the Libby C14 half life (5568 years). Quoted errors represent 1 standard deviation statistics (68% probability) & are based on combined measurements of the sample, background, and modern reference standards.

Measured C13/C12 ratios were calculated relative to the PDB-1 international standard and the RCYBP ages were normalized to -25 per mil. If the ratio and age are accompanied by an (*), then the C13/C12 value was estimated, based on values typical of the material type. The quoted results are NOT calibrated to calendar years. Calibration to calendar years should be calculated using the Conventional C14 age.

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:estimated C13/C12=-25:lab mult.=1)

Laboratory Number: Beta-109967

Conventional radiocarbon age*: 1500 ± 70 BP

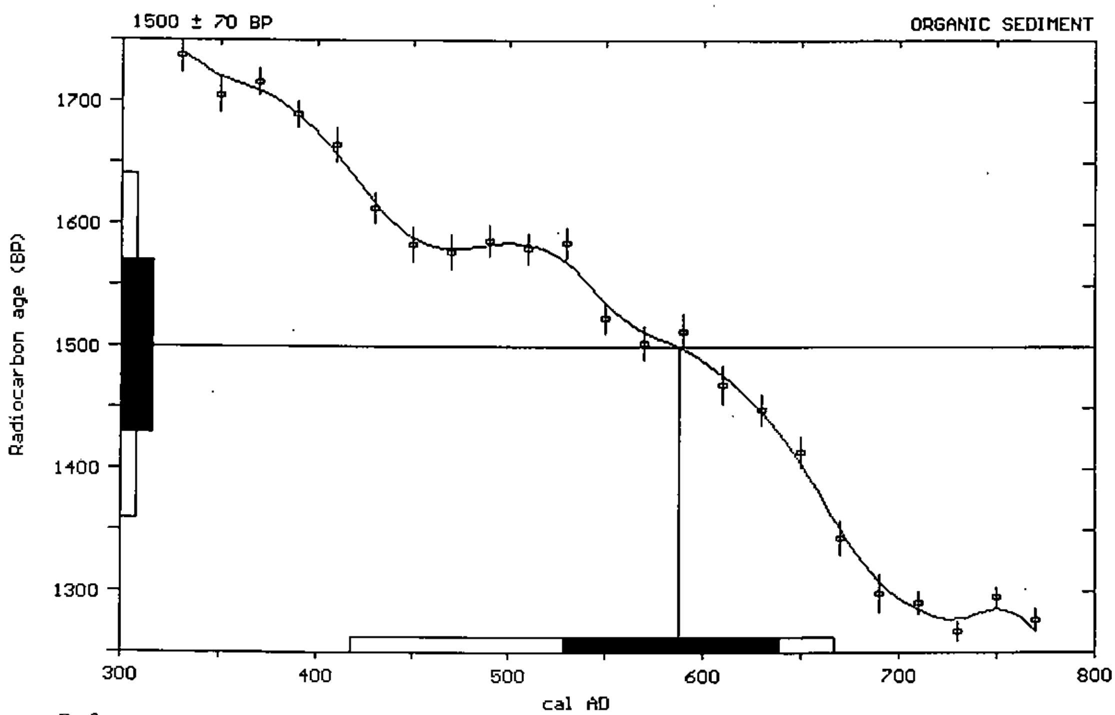
Calibrated results: cal AD 420 to 665
(2 sigma, 95% probability)

* C13/C12 ratio estimated

Intercept data:

Intercept of radiocarbon age with calibration curve: cal AD 590

1 sigma calibrated results: cal AD 530 to 640
(68% probability)



References:

Pretoria Calibration Curve for Short Lived Samples
Vogel, J. C., Fuls, A., Visser, E. and Becker, B., 1993, Radiocarbon 35(1), p73-86
A Simplified Approach to Calibrating C14 Dates
Talma, A. S. and Vogel, J. C., 1993, Radiocarbon 35(2), p317-322
Calibration - 1993
Stuiver, M., Long, A., Kra, R. S. and Devine, J. M., 1993, Radiocarbon 35(1)

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:estimated C13/C12=-25:lab mult.=1)

Laboratory Number: Beta-109968

Conventional radiocarbon age*: 1410 ± 50 BP

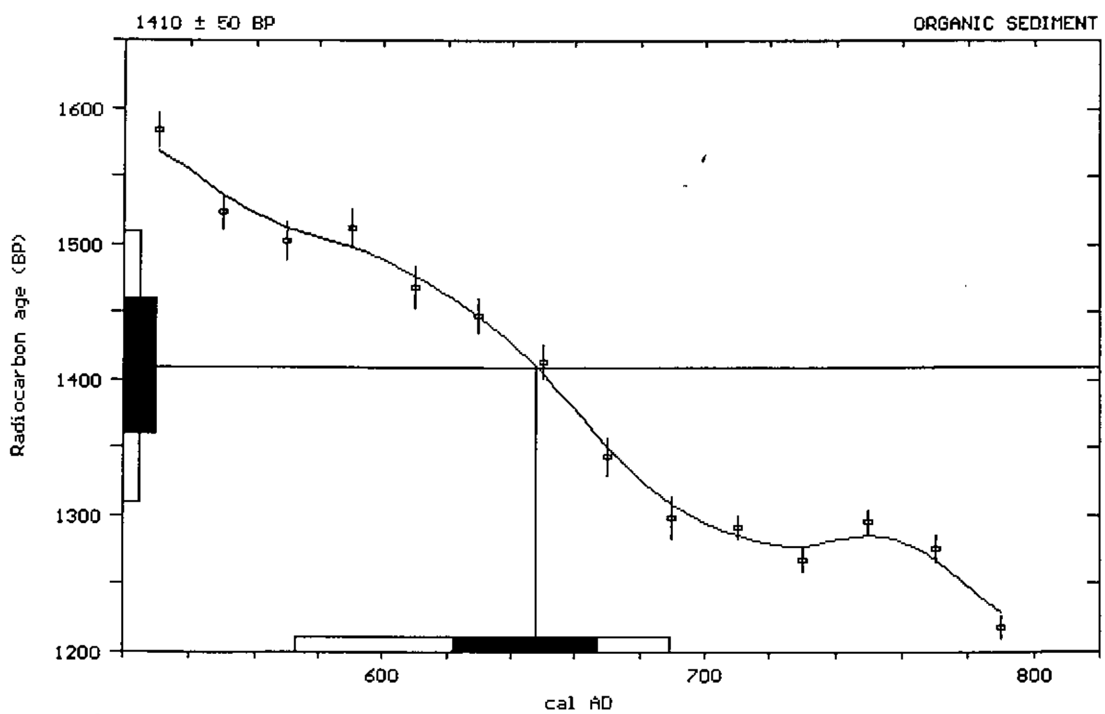
Calibrated results: cal AD 575 to 690
(2 sigma, 95% probability)

* C13/C12 ratio estimated

Intercept data:

Intercept of radiocarbon age
with calibration curve: cal AD 650

1 sigma calibrated results: cal AD 620 to 665
(68% probability)



References:

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A Simplified Approach to Calibrating C14 Dates
Talma, A. S. and Vogel, J. C., 1993, Radiocarbon 35(2), p317-322
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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:estimated C13/C12=-25:lab mult.=1)

Laboratory Number: Beta-109969

Conventional radiocarbon age*: **460 ± 60 BP**

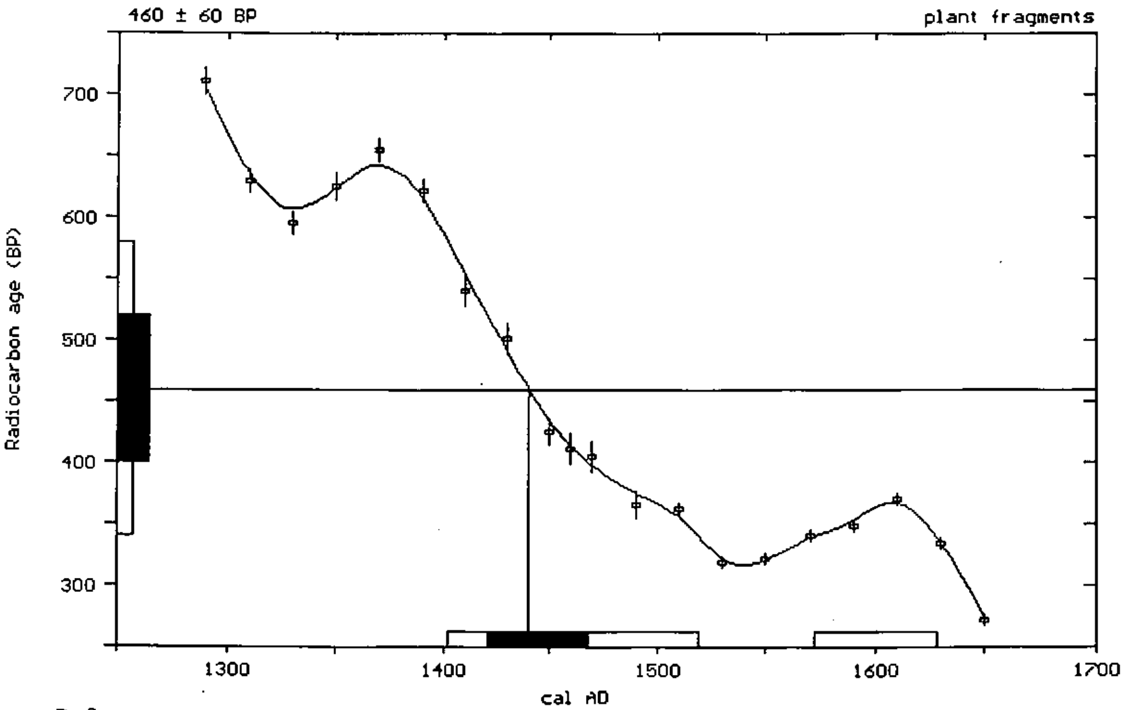
Calibrated results: **cal AD 1400 to 1520 and**
(2 sigma, 95% probability) **cal AD 1570 to 1630**

* C13/C12 ratio estimated

Intercept data:

Intercept of radiocarbon age with calibration curve: cal AD 1440

1 sigma calibrated results: (68% probability) cal AD 1420 to 1470



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A Simplified Approach to Calibrating C14 Dates
Talma, A. S. and Vogel, J. C., 1993, Radiocarbon 35(2), p317-322
Calibration - 1993
Stuiver, M., Long, A., Kra, R. S. and Devine, J. M., 1993, Radiocarbon 35(1)

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables:estimated C13/C12=-25:lab mult.=1)

Laboratory Number: Beta-109970

Conventional radiocarbon age*: **1090 ± 60 BP**

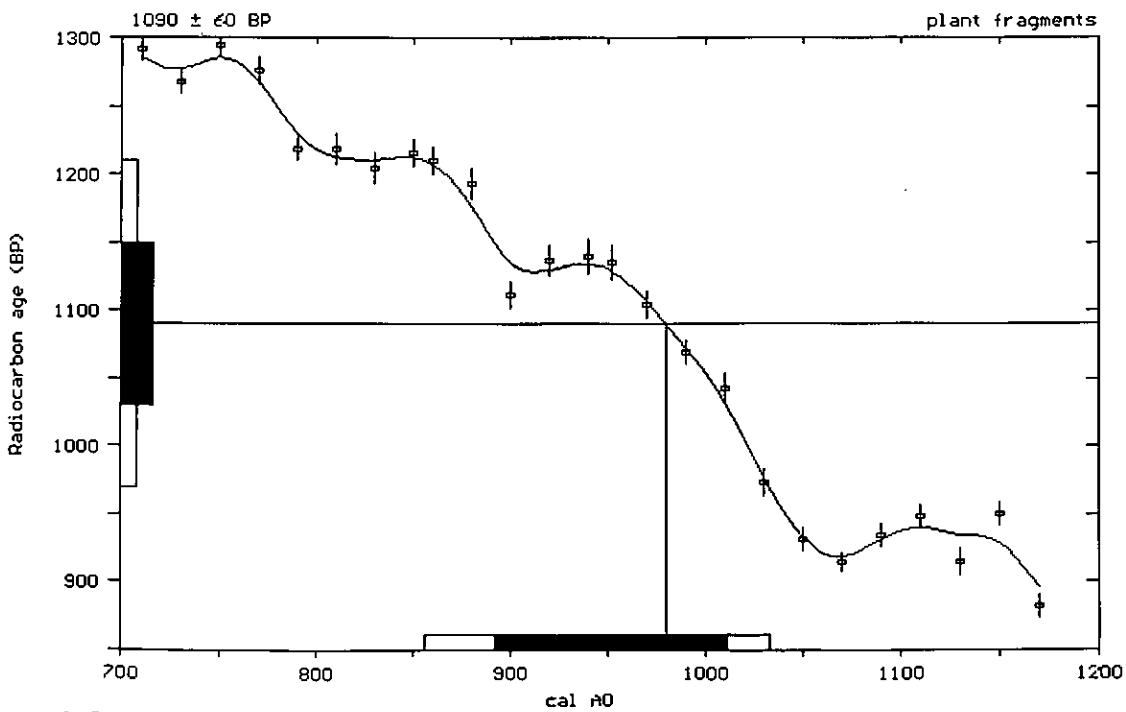
Calibrated results: **cal AD 855 to 1035**
(2 sigma, 95% probability)

* C13/C12 ratio estimated

Intercept data:

Intercept of radiocarbon age with calibration curve: cal AD 980

1 sigma calibrated results: (68% probability) cal AD 890 to 1010



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