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Bega River Estuary Sediment Study

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Bega Valley Shire Council

by:

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Acknowledgements

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1. Introduction and Study Brief

In April 1999, the New South Wales Department of Land and Water Conservation (DLWC) and Bega Valley Shire Council (BVSC) requested Coastal & Marine Geosciences (CMG) conduct an investigation of river flows and estuarine sedimentation in the Bega River catchment located on the New South Wales south coast (Figure 1). The investigation was initiated when an assessment of channel rehabilitation strategies for the lower Bega River highlighted a potential for significant estuarine degradation (siltation) in response to the proposed rehabilitation works (Fryirs and Brierley 1998a; 1998b).

The DLWC study brief sought to establish the likely impact of the proposed channel clearing (ie. removal of exotic vegetation - willows) on the Bega River estuary. Specifically, the brief called for:

1. A review of available information on the sedimentology, geomorphology and hydrodynamics of the Bega River estuary.

2. A review of vertical aerial photography held by DLWC from the 1940's through to 1990's to help develop an understanding of contemporary and historic patterns of estuarine sedimentation.

3. An estimate of sediment transport rates over a range of flood frequencies (annual to 1%) using appropriate sediment transport relationships.

4. An assessment of the likely impact on estuarine hydrodynamics and geomorphology caused by the delivery of fluvial bedload (sand) under existing and modified conditions. In the context of the present investigation, "modified conditions" refer to the removal of exotic vegetation from the Bega River channel.

The CMG proposal addressed each aspect of the study brief, referring to the investigations collectively as the Bega River Estuary Sediment Study (BRESS). BRESS incorporated a review of existing geologic and hydrodynamic data for the Bega River and its estuary, a limited field program of site inspections and drilling and preparation of a report summarising the main findings of the investigations. CMG engaged the services of Dr. David van Senden (Director, Environmental Science & Engineering P/L) to undertake sediment transport modelling and to assist with the field investigations (site inspections).

The following report contains an overview of previous investigations in the Bega River estuary (Section 2), a description of the estuarine geomorphology (Section 3) and an account of contemporary estuarine hydrodynamics under varying flood conditions (Section 4). A description of the field program and its results (Section 5) precedes a summary of the main findings of BRESS and recommendations for future work (Section 6).

Detailed data collected during BRESS are included in the Appendices (Section 9), the body of the report contains summaries of these data as they relate to the project objectives outlined previously. An electronic version of the report and supporting Geographic Information Systems (GIS) coverages are contained on a CD-ROM accompanying the report. Copyright of images gathered by the author resides with the author (Coastal & Marine Geosciences). Data from Kidd (1978) are reproduced with the express permission of the author (Rod Kidd; DLWC Newcastle, pers. comm.).

2. Previous Investigations

Previous geomorphological investigations of the lower Bega River valley have tended to focus on either the fluvial or estuarine systems with few attempts made to integrate the systems beyond general of models of catchment denudation and estuary evolution (Fluvial - Brooks and Brierley, 1997; Brooks, 1994; Fryirs and Brierley, 1998a; 1998b; Estuarine - Bird, 1967; Kidd, 1978; Gordon et al., 1980; Sundararamayya, 1983; Thom et al., 1986; Hancock and Murray; 1996). These and other investigations are summarised in the following paragraphs.

The Bega River, and its major tributary the Brogo River, drain a catchment of some 1940km^2 characterised by a steeply undulating upland province, very steep escarpment, and gently undulating lowland province (Figure 1) (Brooks, 1994). Catchment rock types include a variety of metamorphic and igneous lithologies (Ordovician and Devonian metasediments, mid-lower Devonian granites and granodiorites; Kidd, 1978; Sundararamayya, 1983) associated with the Lachlan Fold Belt (Figure 2). Granitic rocks which weather to a friable and readily eroded regolith crop out throughout much of the catchment while more erosion-resistant metasediments (slates, phyllites, siltstones) occur in the lower catchment, forming a bedrock gorge through which the Bega River flows to the coast (Figures 1 and 2).

The relatively steep nature of the catchment and proximity of the drainage divide to the coast results in a rapid flood response with flood peaks at Bega occurring within 24 hours of rainfall in the upper catchment (Brooks, 1994). Major flooding of the coastal lowland is linked to extreme rainfall events higher in the catchment. In the largest flood on record (February 1971), Bega and Candelo recorded 35% (302mm) and 43% (324mm) respectively of their mean annual rainfall over one 24hour period (Bureau Meteorology Rainfall Data).

The combination of a relatively steep catchment, highly erodible soils and infrequent extreme rainfall events has contributed to the delivery of large volumes of sediment to the coast and adjacent continental shelf over a prolonged period of time, both during and prior to European occupation of the catchment (Bird, 1967; PWD, 1980; Nott et al, 1991, Fryirs and Brierley, 1998a).

Geomorphological investigations of the Bega/Brogo Rivers highlight the profound impact European settlement has had on the catchment (Brooks and Brierley, 1997; Fryirs and Brierley, 1998a; 1998b). Widespread clearing of the native vegetation, erosion of semi-consolidated valley-fills along low order drainage lines, accelerated rates of sediment delivery to the coastal lowland, channel degradation (widening and shoaling) and the introduction of exotic vegetation are all linked to European use of the catchment. Significant modification of the catchment is traced back to the mid-1800's with the clearing of native vegetation for agriculture (ie. dairying) and forestry. Since this time, the lower reaches of the Bega River have been transformed from a suspended/mixed load river system (ie. relatively deep channel with fine-grained banks and floodplain) to a predominantly bedload system (ie. broad shallow sandy channel, mid channel bars and islands, sandy floodplain).

The change in channel conditions is best documented in historic data (ie. photos, portion plans, bridge crossing surveys) collected around the Bega township. Here, an increase in channel width of up to 340% and decrease in channel depth by several metres is reported for the period between 1850 and 1926 (Figure 4; Brooks and Brierley, 1997).

The impact of European occupation on the catchment is also recorded in historic floodplain sedimentation rates for the lower Bega River (Brooks, 1994; Brooks and Brierley, 1997). Estimates of sedimentation, based on several radiocarbon dates from a stratigraphic section in the floodplain near Bega, suggest an average annual sedimentation rate of around 0.8mm between 4,720 and 100 years BP, increasing to an average of 12.5mm since this time. Calculations of river delta progradation based on the downstream migration of the tidal limit are purported to support a 28 fold increase in the rate of delta progradation between 1851 and the present day (Brooks, 1994; Brooks and Brierley, 1997). Note that the fluvial - estuary boundary referred to in Brooks and Brierley (1997) is defined by the tidal limit shown on the 1:25,000 Bega topographic sheet. This definition is likely to be more one of convenience than fact as the location of the tidal limit is likely to be quite dynamic, shifting either downstream or upstream in response to freshwater flows from the catchment and estuary entrance conditions (see Section 4).

Recent work by Fryirs and Brierley (1998a) has attempted to quantify the volumes of sediment released from the Bega/Brogo River catchments since the mid-1800's (Figure 3). The work entailed detailed mapping of the fluvial geomorphology of each river system, estimation of the degree of historic channel and floodplain change and calculation of sediment volumes released or stored. The investigations indicate some 14.2 million m^3 of bedload material (sand) has been delivered to the lowland plain since the mid 1800's of which 3.7 million m^3 has been deposited within the estuary, a delivery ratio of 16% (Figure 4).

Geomorphological and process investigations of the Bega River estuary are reported in Bird (1967), Kidd (1978), Gordon et al. (1980), Sundararamayya (1983), Nichol (1991), Nott et al. (1991) and Hancock and Murray (1996).

Estuarine investigations identify the Bega River as one of the few river systems in New South Wales currently delivering sand-sized sediment to the coast. This observation, first made by Bird (1967) and later confirmed by Kidd (1978), is based on similarities in the texture and composition of beach and river sediments and the advanced stage of estuarine infilling by river sediments. Both studies assumed that Mogareeka Inlet had infilled over a prolonged period of time since its formation c.6,500 years ago at the end of the postglacial marine transgression and no specific link was made between European occupation of the catchment and inlet filling. While no detailed data are available for the Bega River estuary, general support for this conclusion is found in stratigraphic investigations of fluvio-estuarine valley fills elsewhere in southeastern Australia which highlight the slow tempo (thousands of years) of sediment delivery to the coast and rates of estuarine infilling (Reiger and Olive, 1988; Nichol, 1991; Roy, 1994).

The extent of estuarine deposits in the lower Bega valley was initially indicated in groundwater investigations (Sundararamayya, 1983) and later mapped by Nichol (1991). A series of 8 stratigraphic sections constructed from 26 boreholes to basement between Bega and Jellat Jellat Swamp demonstrated that Holocene estuarine deposits (black organic-rich shelly muds) occurred as far inland as the Bega-Brogo River confluence, a distance of some 20km from the present day coast. Estuarine muds were also found to underlie Jellat Jellat Flat and much of Betunga Swamp (Figures 4-8; Sundararamayya, 1983). The estuarine muds are overlayen by a variable thickness of fluvial sands and silts with the contact between the two units varying from c.-5m AHD in the valley axis to around 0m AHD along the valley margin (Sundararamayya, 1983).

Nichol (1991) mapped fluvial and estuarine deposits in the lower Bega valley and highlighted the extent of the palaeo Bega River estuary (Figure 4). Mapping of potential acid sulphate soils (PASS) in the Bega valley by the DLWC (Soil Conservation Service) stopped at the tidal limit (Figure 5) and failed to recognise the extent of estuarine deposited reported previously. More recent investigations of PASS in Jellat Jellat Swamp have examined potential links between fish-kills and drained swamp land (ASSAY, 1999). The investigations concluded that PASS in the area are likely to be either at too great a depth (c. -5m AHD) or permanently waterlogged to present a risk.

Detailed information on estuarine water depths, salinities and sediment types for the lower Bega valley is limited to work reported in Kidd (1978). Kidd (1978) collected reconnaissance bathymetric data in Mogareeka Inlet (one long profile and three cross sections) which show the channel to be sandy and typically less than 4m deep, reaching a maximum depth of c.10m in areas of bedrock constriction. The same data (long profile) show a series “bedforms” spaced at approximately 500m to 1000m with amplitudes of c.6m and relatively steep downstream facing slopes. The bedforms are cited as evidence of both large-scale sediment transport during major floods and minimal reworking by tidal currents in the intervening periods. Water salinity measurements taken in February 1975 (Mogareeka Inlet entrance open) show tidal exchange of ocean and river waters to a distance of at least 4km upstream of the entrance (Kidd, 1978).

Kidd (1978) proposed that frequency and magnitude of sediment transport in the Bega River estuary was primarily determined by flood events. Major floods had the capacity to both transport large volumes of sand through the estuary and to breach the river entrance at the coast. Support for this observation is documented in changes to the Bega River entrance following the February 1971 flood (Gordon et al., 1980). The flood, the largest recorded in the catchment and estimated to have a recurrence interval of c.140 years, reached a height of 9.8m above mean sea level (MSL) at Bega and 2.9m above MSL at Hancocks Bridge near the coast (Gordon et al. 1980). Flood waters are estimated to have scoured the estuary bed by c.2m prior to the destruction of Hancocks Bridge, created a major breach in the river entrance and deposited river sands in water depths of around 10m some 800m offshore. An estimated 2 million m^3 was transported out of the estuary and offshore during the flood peak (Gordon et al., 1980).

The volume of sediment purported to have been moved offshore during the 1971 flood represents around 50% of the material calculated to have been delivered to the entire estuary over the past 150 years (Fryirs and Brierley, 1998a). While it was clear the 1971 flood was responsible for significant change in the Bega River estuary, geological investigations indicated that the flood was probably not unusual within the context of the long term (hundreds to thousands of years) evolution of Mogareeka Inlet (Gordon et al., 1980). Seabed sediment sampling and bathymetric profiling between Tathra Head and Cowdroys Beach and up to 2.5km offshore demonstrated a clear fluvial influence (angular quartz sands and high proportions of feldspar and rock fragments) in the seabed sediments. The occurrence of fluvial sediments was shown to decrease northwards of the Tathra embayment, with little evidence of river sediments in the beach and nearshore deposit north of Nelson Lagoon. These data suggested that the Bega River had delivered sufficient sediment to the Tathra Beach embayment over a prolonged period of time (past 6500 years) to have had a marked impact on the nature of the seabed sediments (Gordon et al., 1980), a conclusion consistent with investigations of the distribution of river sediments in marine environments elsewhere in New South Wales (Roy and Crawford, 1977; Hudson, 1991).

Previous investigations provide a general appreciation of the long term (thousands of years) evolution of the Bega River estuary and the processes influencing contemporary patterns of fluvial and estuarine sedimentation. The information is, however, not sufficient to address specific issues of estuarine sedimentation related to river channel rehabilitation. The review highlighted fundamental data gaps (ie. accurate bathymetric data, detailed information on estuarine sediment types) which had to be addressed prior to an analysis of the interaction of fluvial and estuarine processes in the lower Bega River valley.

3. Holocene Estuarine Geomorphology

3.1 Estuarine geomorphology

The Bega River estuary can be described as a barrier-type estuary following the classification scheme developed by Roy (1984;1994). A "barrier" is a term used by coastal geomorphologist to describe a body of sand built by waves within or across the mouth of a bedrock embayment extending roughly parallel to the coast and which wholly or partially encloses a lagoon or swamp (Chapman et al., 1982). Barrier estuaries are commonly characterised by narrow tidal entrance channels developed within broad back barrier sand flats.

The geomorphology of the Bega River estuary was mapped by Nichol (1991) as far upstream as Bottleneck Reach (Figure 4). The mapping identified an estuary largely infilled with river sediments. A prograded beach ridge barrier (Tathra Beach) defines the seaward boundary of the estuary and a small tidal delta occurs at the entrance downstream of the Hancock Bridge. Upstream of Bottleneck Reach, river sediments partially cover relict estuarine mud basin (shelly organic rich muds) deposits. Similar deposits are known to occur beneath the floodplain as far upstream as the Bega/Brogo River confluence (Sundararamayya, 1983). See discussion in Section 2.

The advanced stage of infilling of the Bega River estuary (Stage D Mature Barrier Estuary; Roy, 1983) and frequent breaching of the entrance during major floods has led to the deposition of river bed load (medium to coarse grained sand) at the coast. Geotechnical investigations (drilling) conducted for Hancocks Bridge in 1972 show between 10m to 20m of fluvial sediment overlying relict estuarine mud at the bridge crossing (Kidd, 1978). The Shoalhaven, Moruya, and Towamba Rivers are examples of the few coastal rivers in southern New South Wales delivering river sand to the coast (Kidd, 1978; Hudson, 1991). Of these, the lower Shoalhaven River shows many similarities in floodplain stratigraphy (alluvium over estuarine mud basin) and entrance breaching during floods (Roy, 1994; Edwards, 1995). Radiocarbon dates from the Shoalhaven floodplain indicate transition from an underfilled to infilled barrier estuary occurred over the past 2000 to 3000 years (Roy, 1994).

The scale of inlet modification during a major flood is significant with millions of cubic metres of sand estimated to have been eroded and moved offshore in a single event (Gordon et al., 1980). Geological data from the Tathra Beach barrier suggest, however, that historic information may not provide a complete "picture" of long term entrance mobility.

Mapping of beach ridge lineaments on the Tathra barrier show a clear truncation of the ridges and development of a so-called “old spit” around 1.5km south of the present day entrance (Figure 6) (Gordon et al., 1980). An erosional contact and topographic low separates the Holocene beach ridges to landward and the “old spit” to seaward, an observation confirmed in site inspections (May 1999).

The maps and site observations suggest that the river entrance may have been located well to the south of its present position some time in the past and subsequently migrated back north under the influence of the prevailing southerly waves, leading to the constructing the “old spit”. It is highly likely that under natural conditions (no artificial opening) flood waters would back up and flood through this low point in the barrier to the south of the present day entrance.

Geomorphological data for the Bega River estuary point to profound changes over the past several thousand years as the system evolved from an immature, underfilled and relatively deep estuary to a mature estuary infilled with river sands. The same data also point to possible shifts in entrance position and partial reworking of the Tathra Beach barrier. An absence of radiocarbon dates for the estuary makes it uncertain as to the actual tempo of these changes. Evidence for historic change in the estuary and its entrance over the past 130 years is addressed in the following section.

3.2 Evidence for historic estuarine change.

Several sources of information including bathymetric charts and vertical aerial photography have been use to reconstruct a history of change in the Bega River estuary over the past 130 years. Details of the data sourced and methods used in the analyses of these data are outlined in Appendices A (bathymetric data) and Appendix B (aerial photography).

A comparison of water depth “change” for two dates (1870 and 1999) has been completed for Mogareeka Inlet using an historic chart (Rossbach, 1870) and a reconnaissance survey completed for this investigation (PWD 1999). Coverages of the respective surveys are shown in Figure 7 and a summary of the bathymetric comparison is contained in Figure 8 and Table 1.

In view of the differences in the horizontal and vertical datums and section orientations between the surveys, it was decided to compare the surveys in terms of maximum, minimum and average water depths at set distances from the entrance. Note that the river entrance was closed on each survey date. Overall, the comparison shows a general decrease in the minimum, average and maximum water depths from 1870 to 1999 (Figure 8). The magnitude of change is typically on the order of 1m to 2m (Table 1). The level of accuracy in the comparison of water depth change is thought to be around +/-1m, at best.

One interpretation of bathymetric comparison is that the inlet has shoaled over the past 129 years in response to the delivery of bedload (sand) material from the Bega River catchment. An alternative explanation is that there is no clear evidence for significant bathymetric change, particularly when the sensitivity of the analysis to water levels influenced by entrance conditions and fluvial inflows are considered, and what the comparison does suggest is a situation wherein a dynamic equilibrium has been established between the delivery and removal of river sands from the estuary.

Further evidence of historic change in the estuary was sought through a comparison of the available historic vertical aerial photography (Appendix B).

Four dates were chosen (1967, 1971, 1982 and 1998) with scales varying from 1:16,000 to 1:50,000 to assess change within the estuary from the entrance to Bottleneck Reach. While earlier dates provided some information on estuarine morphology in Mogareeka Inlet as early as 1943, the dates selected provided the best coverage for the entire estuary and brackets a period of major flooding in the Bega River (1971 Flood) (Figure 9).

It became apparent that the scale of the photography (1:16,000 up to 1:50,000) and sensitivity of the analysis to water levels at the time of the photography prevented a meaningful analysis of sedimentation/erosion trends. Consequently, evidence of sedimentation/erosion was sought in discernible change of larger depositional features within the channel (eg. sand shoals, channel thalweg position, point bar and mid channel islands), tributary valleys (eg. extent of deltaic deposits derived from the local catchment and Bega River) and floodplain.

Apart from removal of some riparian vegetation and deposition of sand sheets on the floodplain following the 1971 flood, there was little evidence of significant morphologic change between the four selected dates (Figure 9). Inspection of the earliest photographs for the estuary (back to 1943) supported this observation, within the limitations of the method.

Notes on the entrance conditions compiled from aerial photographs for the period 1943 to 1999 are summarised in Appendix B. Observations were made on the degree of entrance shoaling, position of the entrance and possible influence of major floods on the entrance conditions.

The entrance was found to be shut on 6 (30%) occasions over the entire set of 20 aerial photographs. Kidd (1978) had earlier estimated the entrance to Mogareeka Inlet was opened for much of the period between 1943 and the mid 1970's (90% of 19 images inspected). While the discrepancy between the two assessments of entrance condition (open/shut) is most likely due to the larger set of photographs used in this study (Kidd, 1978 provides no details of photographs inspected), the difference does highlight the caution needed in interpreting data which are subject to bias by virtue of the actual dates used.

Several additional observations on entrance dynamics can be made from the aerial photography. Firstly, the inlet tends to infill relatively rapidly with beach/nearshore sand over a period of months following a major breach caused by flooding (Gordon et al., 1980). Secondly, entrance breaching and subsequent maintenance of an open entrance can occur when a series of moderate floods (<10% recurrence interval) occurs within a relatively short period of time (eg. 1975 floods). Entrance conditions are governed by the interaction between freshwater flows from the catchment and the prevailing ocean wave conditions.

A review of the available aerial photography for the Bega River estuary dating back to the early 1940's has not identified evidence of significant, progressive estuarine infilling due to the supply of river sands. A comparison of historic bathymetric data (1870 and 1999) for Mogareeka Inlet also showed no clear evidence of significant infilling. The implications of these observations are examined in relation to contemporary estuarine hydrodynamics in the following section.

4. Contemporary Estuarine Hydrodynamics

The purpose of this section is to expand the understanding of the sediment transport processes within the estuary described previously with the object of ascertaining whether the rate of estuarine infilling has increased over the past 100 years since catchment clearing. A detailed description of the sediment transport modelling is contained in Appendix D.

4.1 Estuary Hydrodynamics

The Bega River estuary extends some 12 kms inland to the tidal limit and is confined to a steep sided bedrock gorge for around 10 km before opening out into the lower Bega River floodplain. At the ocean inlet the estuary channel is confined by rocky outcrops overlain by sand. Under natural conditions the inlet opens to the sea intermittently and commonly following floods. A review of available data and site inspections have indicated that the hydraulics of the estuary are controlled by 3 sections - the Gorge, Hancock Bridge and the inlet channel (Figure 10). The narrow section at the Gorge, aptly named Bottleneck Reach, causes water to backup onto the floodplain upstream as flood waters are unable to pass through the Gorge unimpeded. The control at Hancock Bridge appears to be less important except during the very large floods when a significant water surface slope between the bridge and the ocean develops. At the coast, the inlet channel is a dynamic feature that operates as a flow control for nearly all flood flows. Generally the channel will infill within a few months of a major flood.

Existing studies in the Bega catchment and other river systems in southeastern Australia have demonstrated the importance of flood events in bedload sediment transport (Gordon et al., 1980; Erskine and Saynor, 1996; Fryirs and Brierley, 1998a). River channel morphology is primarily controlled by erosion and deposition associated with large flood events and the ratio of fluvial sediment delivered to an estuary to the amount of sediment exported from the estuary typically exceeds 1 only during large floods with recurrence intervals greater than about 10 - 15 years (Hossain, 1997). That is, an estuary is generally filling in for most of the time and then once every 10 years or so a large event causes the material to scour before the next period of infilling. While there are clear limitations in translating the results of catchment-specific process investigations, a similar situation of estuary infilling and scour to that described by Hossain (1997) for the Richmond River (northern NSW) probably occurs in the Bega River estuary.

The existing information demonstrate that sediment transport within the Bega River estuary is controlled by flood events when water flows in the river/estuarine channel attain sufficiently high velocities to mobilise the coarser bed sediments. The hydrodynamics (or flow regimes) of the estuary are determined by the interaction of tidal and freshwater inflows and the morphology.

Minimal bed load transport occurs during dry periods when low freshwater runoff from the catchment generates low river flows and estuarine water movements are dominated by tidal effects and to a lesser degree wind and density effects. At the inlet entrance, the estuarine morphology is more dynamic due to interactions between tides and ocean waves. Over time, the low river flows are insufficient to maintain a permanent connection to the sea and the inlet eventually closes as ocean waves first shoal and then close the entrance (Gordon et al., 1980). Under conditions of prolonged low river flow, the inlet entrance will remain closed and may need to be artificially breached so as to avoid flooding of low level areas around the estuary foreshore (Doug Mein, Bega Valley Council, pers. comm.).

In contrast, bedload transport increases dramatically during major floods. In very large floods, such as occurred in February 1971, the tidal delta and beach at the entrance are scoured and a large broad channel forms (Gordon et al., 1980). The actual size of the channel depends on the magnitude of the flood and the ocean conditions at the time of the peak flow. For floods that coincide with strong winds and large waves, rapid scouring of the entrance may occur while for floods that coincide with calm ocean conditions the scour rate is likely to be considerably less and hence lead to a smaller channel.

Mogareeka Inlet morphology upstream of the entrance is controlled by the occurrence of flood events - large floods tend to scour the channel while smaller flood flows generally lead to accretion and redistribution of bottom sediments within the channel.

4.2 Sediment transport modelling under varying river flood conditions.

The morphology of a riverine estuary such as the Bega River estuary is generally dependent upon the rate of sediment delivery to the system and the rate at which sediment is transported through the system. Fine particles form the largest fraction of the material delivered to the estuary but these particles are maintained in suspension at low flows and hence are generally transferred through the estuary to the ocean or deposited on the floodplain. The coarser, heavier sediments require significantly larger flows to be mobilized and therefore remain in the system much longer and are moved only during the major floods. It is this bed load transport that is of specific interest here.

Details of the sediment transport modelling summarised here can be found in Appendix D.

The bed load sediment transport rate was estimated for three sections along the estuary and a range of discharges using the formula of van Rijn (1993). Note that this formula is better suited to large river flows in estuarine and river situations than the Ackers-White formula used by Fryirs and Brierley (1998a).

The van Rijn equation requires derivation of representative depth-averaged velocities and water depths for selected cross sections and sediment characteristics. Grain size data have been reported by Fryirs and Brierley (1998a) for a number of sections in the Bega River and additional data has been collected for the estuary as part of the present investigations (Appendix D).

Bed load transport in rivers is a non-linear process so that essentially no transport occurs until a critical velocity is achieved and then as the velocity increases above this value the transport rate increases very quickly. Since bed particles are only mobilised at higher flows, the regular flows in the river do not transport the coarser bed material. In fact, the sediment transport rate increases in proportion to the shear stress to the power 1.5. This relationship is the reason that the bed morphology is shaped primarily by catastrophic events that may seldom occur.

To assess the likely transport behaviour we chose sections in the estuary where flow conditions are known to be controlled by a finite width and depth constriction (see Figure 10). Inspection of topographic and bathymetric charts and past flood levels suggests that there are three major control points that determine the flow rates and water levels within the estuary during floods. These three cross sections are located at :

- the Gorge : Section 24 of the recent DPWS survey,
- Hancocks Bridge : Section 1 of the recent DPWS survey, and
- the inlet channel at the entrance (derived from discussions with the local community).

As the Bega River flows downstream of the Bega township the terrain opens onto a broad floodplain before it enters the narrow gorge, about 5 km downstream of the town, and then wends its way to the sea some 10 km further downstream. The gorge forms a major restriction to the flow and causes water to back up during floods. The water velocity and depth of flow at the three control sections are estimated for a range of flood flows.

Flood Frequencies

Discharge data for three gauging stations within the catchment were provided by DLWC Bega office. The total discharge entering the estuary was derived from these data as the sum of the three stations multiplied by 1.3. The factor 1.3 accounts for the catchment area downstream of the gauging sites. Fryirs and Brierley (1998a) estimated flood recurrence frequencies using the Rational Method as outlined in Australian Rainfall and Runoff (1978). This technique provides estimates of the peak river discharge that generally may last for a short period (hours) and is important for estimating the peak water level. In terms of the sediment transport capacity, it is more important to estimate the duration of high flows as it is during this period that the maximum bed load transport occurs.

Gordon et al (1980) estimated the maximum daily flows for a range of floods recorded over the past 130 years. Assuming the recurrence interval of the flood levels (DLWC) is similar for the flood discharge estimates, the daily discharge recurrence intervals may be extracted from the recurrence statistics for the flood levels (DLWC). The water level and range of discharges (Annual to 1%) was estimated for each control section.

Estimates of Bed Load Transport

The total daily bed load transport estimates at each section for the range of flood recurrence interval discharges is listed in Table 2 (see Figure 10). Note that these estimates are based on the section-averaged velocity and hence represent an average daily condition during the maximal flood flow. It appears that Fryirs and Brierley (1998a) used peak flow transport rates extrapolated over the day and hence their estimates are higher than those derived here.

The estimates provide a good indication of the potential bed load transport. At the entrance the transport rates are extremely sensitive to the inlet channel dimensions and indeed it is the transport rate that effectively scours the entrance area. Note the transport at Hancock Bridge is considerably less than the inlet channel and hence the channel area scours very quickly during floods (ie. supply limited). It is only during the very large floods that the transport rate at the bridge increases and the scours the bottom.

We estimate that flood events of greater than about 5 year recurrence interval will lead to substantial entrance scour but little morphological readjustment within the upper estuary. The larger flood events > 10-20 years recurrence interval will lead to more significant adjustments within the upper estuary but these adjustments are still likely to be relatively minor compared to the changes at the inlet. The calculations indicate that any extra material delivered to the estuary over the past 150 years due to European occupation of the catchment has probably been transported through the system. The increased delivery rate is likely to have led to more frequent periods of shallower conditions than prior to catchment clearing though these changes would be difficult to quantify. In any event, the scour potential of the larger floods will cause erosion of the bed material to depths similar to the pre-catchment clearing.

Sediment transport modelling for the Bega River estuary indicates estuarine morphology is not limited by the sediment delivery rate. The scour potential of the large floods is sufficient to transport bed load material (sand) through the system and maintain a fairly stable morphology as evidenced by comparisons of estuary depths over the past 100 years. Even if the sediment delivery has increased dramatically over the past 200 years the transport potential within the estuary is sufficient to remove this extra material during the major floods.

5. Field Investigations

5.1 Site inspections

Site inspections of the estuary and entrance conditions were made in late May 1999 (21/5 – 28/5/99). The object of the inspections was to verify the state of estuarine infilling, characterise estuarine sediment types and to gather recollections from local residents on estuary infilling.

A series of 30 images collected during the site inspections recorded condition of the Bega River channel at Bega, depositional features in the estuarine reach downstream of Bottleneck Reach and a sequence of entrance closure which occurred between the 22/5 to 26/599. Sites inspected are shown in Figure 11 and stored within the project GIS.

Sediment sample locations are shown in Figure 12 along with sample sites reported in Kidd (1978). Particle size grading curves for samples collected for this investigation are included in Figure 13.

The site inspections and sediment sampling confirmed the relatively shallow water depths (<2m) which occur throughout much of the estuary, the sandy nature of the estuary bed and banks and the coarse grained (D_{50} 0.6 to 1.2mm), subangular, feldspathic character of the river sediments infilling the estuary. Apart from a minor carbonate component (shells), beach sands at the entrance to Mogareeka Inlet were essentially the same texturally and compositionally to those encountered in the estuary. A similar observation about the fluvial nature of the sediments infilling the estuary was made by Kidd (1978).

The entrance conditions changed from open and heavily shoaled to closed within a tidal cycle on the 23/5/99. Ocean waves (c.1-2m high) were responsible for driving nearshore sediments into the inlet and constructing a beach berm across the entrance. The beach berm was built to high tide level and extended c.30m across the estuary entrance.

5.2 Floodplain Drilling

The BRESS proposal identified shallow (<6m) drilling of floodplain and estuarine deposits as a method for establishing the thickness of river sand deposited in the lower Bega River valley since European occupation. Brooks and Brierley (1997) have indicated that the contact between pre- and post-European fluvial deposits in the lower Bega River valley is within several metres of the floodplain surface and characterised by a marked textural change from fine grained silts to fine to coarse grained sands. A review of borehole information for the lower Bega valley demonstrated that while fluvial sand thickness are less than a metre thick along the valley margins, thicknesses of river sands in excess of 10m occur along the valley axis (Sundararamayya, 1983). Geotechnical information for the Hancock Bridge crossing confirmed the presence of a considerable thickness (>10m) of river sediments over old estuarine deposits within the estuarine reach of the Bega valley.

It was apparent that an assessment of the volume of fluvial sediment infilling the estuary and timing of deposition required deep drilling (>10m) and radiocarbon dating of selected borehole samples. Extra funding for the completion of a deep borehole within the estuary was sought and obtained from DLWC. The NSW Department of Mineral Resources (Dr. Peter Roy) offered to pay for radiocarbon dating of borehole samples. Details of the drilling are contained in Appendix C and summarised in Figure 14.

A deep borehole to 50m below ground level was completed over three days in late May 1999 by the DLWC Groundwater Drilling Unit at a site on the Bega River floodplain (levee) in the vicinity of Duckhole Lagoons (Figure 12). The borehole intersected a thick sequence of Holocene-aged sediments infilling the bedrock valley.

The borehole penetrated c.16.5m of fluvio-deltaic deposits (gravelly sands) and then some 33m of shelly estuarine mud before terminating at 50m (-46m AHD) in fluvial gravels and sand. Bedrock was not encountered but presumed to directly underlie the basal gravels (Figure 14).

Radiocarbon dates on estuarine shell and organic material (charcoal, plant fragments) show a progressive increase in age with depth to c.45m (2320 to 8120 Yrs. B.P.). An anomalously young date of 4,950Yrs. B.P. on shell material recovered from the base of the hole (c.50m) is presumably due to contamination of the sample with material from higher in the sequence. The dates from the fluvial deposits range from 2320 to 3690 Yrs. B.P. Note that all dates are on transported material and therefore represent the likely maximum age of deposition.

The valley fill stratigraphy records the long term transition of the lower Bega River valley from a relatively low energy estuarine mud basin environment to higher energy fluvial channel and floodplain deposition over the period between 8000 to 3500 years ago. Fluvial deposition has prevailed at the site from 3,500 years ago up to the present day (Figure 14). The stratigraphic relationships (thickness and elevation relative to mean sea level) of the fluvial and estuarine deposits encountered at the borehole site are consistent with those observed upstream (Sundararamayya, 1983) and downstream (Hancock Bridge geotechnical information). Similar valley fill stratigraphies are reported for other major south coast estuaries (eg. Shoalhaven River; Edwards, 1995; Roy, 1994).

The transition from estuarine mud basin to fluvial delta has occurred over a period of geologic time characterised by a rapid rise in sea level following the last glacial maximum (c.18,000 years ago, sea levels at c.-120m) and subsequent stabilisation of sea level around its current position 6,500 years ago (Roy, 1984; 1994). The borehole data point to a change from fine grained estuarine deposition to coarse grained fluvial deposition some thousands rather than hundreds of years ago, suggesting that fluvial sands have been delivered to the estuary over a long period and not just in recent historic time (ie. <200 years).

Clearly the transported nature of the material used to date the valley fill sequence is a limitation in the resolution of the tempo of fluvial deposition. Despite this limitation, the borehole data are consistent with the lack of significant historic change in estuarine geomorphology (Section 3) and the capacity for floods in the Bega River to move bedload material (sand) through the estuary and deliver it to the coast (Section 4).

6. Summary and Recommendations

A review of the existing geomorphic and hydrodynamic data for the Bega River estuary highlighted a general lack of information suited to the assessment of historic change within the system. Investigations initiated as part of the Bega River Estuary Sediment Study (BRESS) have addressed this lack of fundamental data (ie. estuary bathymetry, stratigraphy and age of estuarine valley-fill, rates of sediment transport), provided the first detailed assessment of long term evolution of the Bega River estuary and a reliable context for determining the likely impacts of river channel clearing on sediment (sand) delivery to the estuary.

The Bega River estuary occupies a drowned bedrock river valley that has infilled with estuarine and fluvial sediment over the past 10,000 years as the sea level rose to its present day level some 6,500 years ago. Classified as a mature stage barrier estuary, the tidal waterway is relatively shallow and confined to a bedrock gorge which extends some 12 kms inland to the tidal limit near Bottleneck Reach.

Geotechnical investigations conducted in the lower Bega Valley have highlighted the extent and thickness of estuarine deposits (shelly, organic rich, estuarine muds) contained in the bedrock valley. Radiocarbon dating of the fluvial and estuarine deposits (this investigation) indicates that the transition from estuarine basin to alluvial lowland occurred around 3,000 years ago. Since this time, the Bega River has delivered sufficient bedload material to the coastal lowland to infill the estuary and to have a significant impact on the composition of beach and inner continental shelf deposits. Historic data (bathymetry and aerial photography) show no significant change in the estuary over the past 130 years, supporting geomorphic evidence for infilling of the estuary several thousand years before European occupation of the catchment.

The most dynamic portion of the estuary is the Mogareeka Inlet entrance. Historic data show entrance conditions may change from fully open to shut over a matter of months and in response to river floods and ocean waves. Historic vertical aerial photography dating back to the early 1940’s show the entrance to be open on 6 of the 20 images (30%) inspected. Today, the frequency of entrance opening is regulated so as to avoid local flooding of facilities around the inlet foreshores. Under natural conditions it is probable that the entrance would have remained closed for prolonged periods of time, only opening after major floods. Closure would have caused flood waters to backup, leading to the inundation of low lying land within several metres elevation of mean sea level and, possibly, the breaching of the Tathra Beach barrier at a low point south of the present day inlet entrance.

It appears the hydraulics of the estuary are controlled by 3 sections - the Gorge, Hancock Bridge and the inlet channel. The narrow section at the Gorge causes water to backup onto the floodplain upstream as water can not escape through this section. The control at the bridge appears to be less important except during the very large floods when a significant water surface slope between the bridge and the ocean develops. The inlet channel is a dynamic feature and operates as a flow control for nearly all flood flows. Generally the channel will fill in within a few months of major flood events when the discharge scours the channel.

The Bega River estuary morphology is not limited by the sediment delivery rate. The scour potential of the large floods is sufficient to transport the bed load material through the system and maintain a fairly stable morphology as evidenced by comparisons of estuary depths over the past 100 years. Even if the sediment delivery has increased dramatically over the past 200 years the transport potential within the estuary is sufficient to remove this extra material during the major floods.

Recommendations for further work focus on building baseline data on estuarine sediment and water quality plus monitoring of the impacts of river channel clearing on sediment delivery to the estuary. Specifically:

1. Monitoring of sediment levels in the estuary should continue on a regular basis to provide meaningful data on which to assess the impact of channel rehabilitation strategies further upstream. The monitoring should utilise the cross sections surveyed for this investigation, with the proviso that the cross sections are fully surveyed to a level above the 1% flood line, to determine change in bed (sand) levels within the channel and on the adjacent floodplain over a range of flow conditions.

2. Episodic surveys of bedload material deposited on the floodplain downstream of Bega after major flood events should be undertaken with the results mapped in terms of aerial extent and volumes of sands. These data will provide baseline information floodplain sedimentation rates and a means of assessing the rates/volumes estimated by Fryirs and Brierley (1998a).

3. In view of the incomplete mapping of potential acid sulphate soils for the lower Bega River valley, further examination of the thickness of alluvial sediments overlying relict estuarine muds needs to be undertaken in Jellat Jellat Swamp and other backswamp areas along the valley margins where PASS may occur close to present sea level.

4. Regular sampling of channel sediments should accompany cross section surveys. Sediments should be analysed for their gross textural attributes and potential contaminant load (nutrients, metals, synthetic organic compounds) to monitor how activities higher in the catchment are translated to and through the estuary.

5. Monitoring of water quality within the estuary and linking the results to river flows and inlet condition (open/shut) are recommended. Full documentation of entrance conditions and periods of manual opening need to be maintained as a baseline for monitoring inlet water quality.

6. All monitoring datasets should be incorporated into, or be capable of being accessed by, geographic information systems (GIS) software. The use of GIS will greatly enhance the utility of the data and provide for their routine analysis and presentation.