



FINAL REPORT:

Balcombe Creek estuary sedimentation study: sediment coring and analysis

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- Balcombe Estuary Reserves Group Mount Martha (BERG MM) for background information to the study.

Summary

Context

Alluvium in partnership with The University of Melbourne was engaged by Mornington Peninsula Shire Council (MPSC) to undertake a study on the sedimentation history of Balcombe Creek estuary. The purpose of the study is to improve understanding on the historical and recent sources of sediment to the estuary, to assist with informing future management of estuary sedimentation. The technical work was completed over June 2016 – June 2017, and involved:

- Sediment coring in the estuary
- Analysis and dating of sediment samples from the cores
- A review of available historical and recent aerial imagery of the estuary zone
- Interpretation of results in the context of other investigations including the Balcombe Creek estuary review (Alluvium 2016) and recent sediment loads and water quality monitoring analysis (Sharps and Sharley 2017).

Outcomes

Sedimentation and associated infilling of an estuary is a natural process that occurs over time, and is influenced by a range of factors including catchment hydrology, sediment dynamics and disturbance (fire, flood, landuse change). However, where human activity contributes to an increased rate of sediment infill, there may be justification and opportunity to intervene. The findings from this investigation confirm a substantial increase in the rate of sediment deposition in the estuary associated with catchment disturbance since European settlement (clearing for agriculture and urbanisation). This has resulted in the rapid infilling of the estuary over the last 80 years, and with significant inputs from local urban areas in recent decades (last 40 years). The overall findings from the study include:

1. The estuary has an exceptionally well preserved sedimentation history, with the bottom sediments of the 2.5 – 3 m deep cores dating back to some 7000 years ago at the end of the last ice age. Sediment layers include sea grass beds, marine material, organic material and fine sediments, sand and gravel lenses. The well preserved layers within the core indicate minimal disturbance and movement of sediments once deposited in the estuary itself. As such the estuary has been prone to rapid infilling by sediment delivered to it from the catchment, as the deposited sediment is not readily flushed out.
2. A historical sea grass bed is evident in the cores. The sea grass is underlying 0.5 m of recent sediment (last 80 years) derived from rapid infilling due to catchment disturbance, including both agriculture and urbanisation. This infilling has smothered the old seagrass beds and built the islands that are now exposed at low water levels.
3. Sediment from the broader rural catchment, as well as from the local urban sub-catchments (local to the estuary itself), have historically contributed to estuary infilling since European settlement. In the rural areas, waterways are predominantly intact (not eroding) valley fill systems. The swampy form of the valley fill channels, plus the distance of rural areas from the estuary, and the presence of many established wetlands across the catchment, will assist to minimise liberation and delivery of fine sediment to the estuary (Alluvium 2016). In the local urban sub-catchments, reducing the liberation and delivery of sediment to the estuary zone is more challenging.
4. Major sources of recent fine sediment deposition in the estuary (last 40 years to date) from the local urban sub-catchments include: the Hopetoun Creek (Ferrero reserve) sub-catchment (Sharps and Sharley 2017), as well as the Henley Avenue sub-catchment (Sharps and Sharley 2017, and this investigation).
5. The laminations and coarser material (gravel) lenses observed within the top sediment layers of the cores are evidence of storm-induced sediment flows from the local urban sub-catchments. The sediment core data, and the bay-head delta at the southern edge of the estuary near Henley Avenue,

indicate that local runoff from this local urban sub-catchment is a significant source of both fine and coarser sediment to the estuary in recent years.

These findings are derived by the results from recent sediment loads and water quality monitoring analysis undertaken by Sharps and Sharley (2017), combined with the outcomes from this investigation and expert interpretation of the information. The outcomes from this investigation have included interpretation of the sediment layers observed in the sampled cores, as well as geomorphic form and changes observed in historical imagery of the estuary over the last 80 years.

Recommendations

Based on the outcomes from this investigation, the future focus for management of sedimentation in Balcombe Creek estuary includes the following:

- Investigate / implement measures to reduce fine sediment liberation and delivery from the Hopetoun Creek (Ferrero reserve) and Henley Street sub-catchments. This may include:
 - Identification of erosion hotspots / sources of fine sediment
 - Revegetation opportunities along waterways and wetlands
 - Other opportunities to minimise sediment entrained to the estuary
- Investigate / implement measures to reduce coarse sediment liberation and delivery from the local urban areas, in particular the Henley Avenue sub-catchment. This may include:
 - Sealing existing unsealed roads – plus - establishing grassed / vegetated swales along new sealed roads to trap and filter sediment (avoid curb and gutter arrangements). Vegetated swales may also be established along existing sealed roads where possible.
 - Reviewing stormwater management options for the area, and consider a broad range of options to reduce stormwater inflows at Henley Avenue (e.g. diversion of flow, interception, other treatment options).
- Sediment finger printing – matching specific sediments in the catchment (urban or rural) with location/presence in the sampled cores – is an option for further detail if required, however is not a priority recommendation. We propose that sufficient information is now known through the current coring results and water quality investigations to inform the progression of management actions. The samples cores are currently preserved at The University Melbourne if any further specific investigation is required in the future.
- A supplementary investigation to be considered for the future is a geomorphic assessment of the catchment waterways (form, condition, stability). A geomorphic assessment, combined with water quality monitoring in the rural areas, would provide additional confidence that erosion from catchment waterways is not likely to be major concern for future sediment delivery to the estuary. However, there is sufficient understanding from investigations to date a support a focus on immediate management activities in the urban sub-catchment areas, to address known sources of sediment to the estuary.

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1 Introduction

1.1 Project context and scope

Mornington Peninsula Shire Council (MPSC) and other management agencies work together with active community groups to protect and enhance the health of the Balcombe Creek estuary (Figure 1). Altered hydrology and sediment delivery to the estuary have been emerging as key issues for management in the past decade (Water Technology 2008, 2009, 2010; BERG MM 2013, 2015; MPSC 2013).

Alluvium in partnership with The University of Melbourne was engaged by Mornington Peninsula Shire Council (MPSC) to undertake this study on the sedimentation history in Balcombe Creek estuary. The purpose of the study is to improve understanding on historical and recent sources of sediment to the estuary, to assist with informing future management of estuary sedimentation. The technical work was completed over June 2016 – June 2017, and involved:

- Sediment coring in the estuary
- Analysis and dating of sediment samples from the cores
- A review of available historical and recent aerial imagery
- Interpretation of results in the context of other investigations including the Balcombe Creek estuary and catchment: summary report and desktop review (Alluvium 2016) and recent sediment loads and water quality monitoring analysis (Sharps and Sharley 2017).

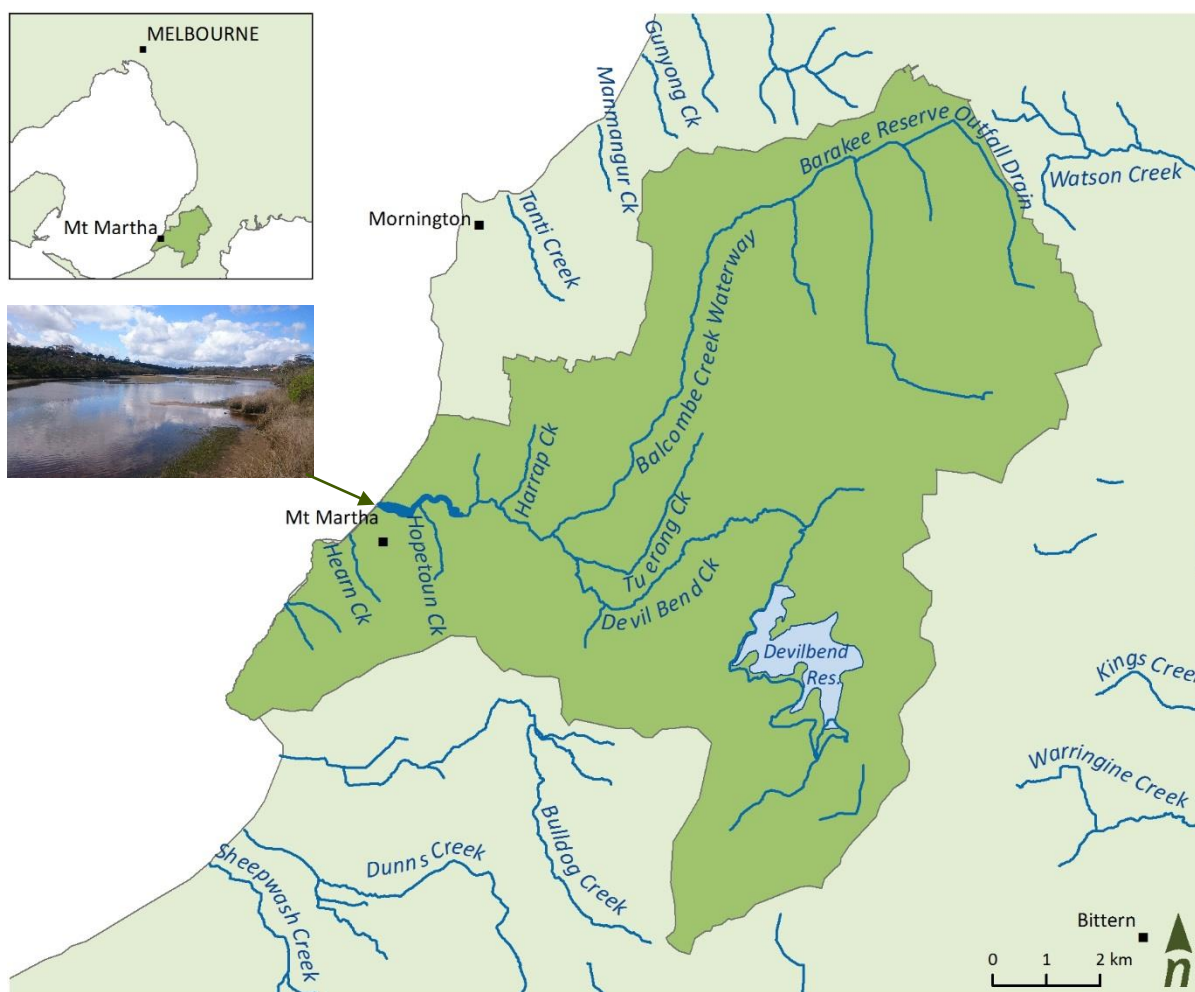


Figure 1. Balcombe Creek catchment and estuary (photo view of estuary from mouth looking upstream)

1.2 Structure of this report

This report builds on the existing body of literature on the Balcombe Creek estuary. A review of this literature is provided in the report entitled *Balcombe Creek estuary and catchment: summary report and desktop review* (Alluvium 2016). Please refer to Alluvium 2016 for more detailed background on the Balcombe Creek estuary and catchment (values, threats to values, opportunities).

This report is focused specifically on reporting the outcomes from the sedimentation study, and includes:

- Section 2: Background information
- Section 3: Sediment coring and results
- Section 4: Aerial imagery observations
- Section 5: Conclusions and recommendations.

2 Background

2.1 Estuary processes context

Like the majority of estuaries situated on the southern Australian coastline, the Balcombe Creek estuary is a wave dominated estuary (OzCoasts 2015). Wave dominated estuaries are also often referred to as; barrier estuaries, bar-built estuaries, and intermittently closed and open lakes and lagoons, with characteristic geomorphic features including the estuary barrier bar, fluvial delta and central basin (Figure 2).

Historically, estuaries such as Balcombe Creek form when sea level rise floods the lower area of a catchment. Over time wave energy drives the development of the barrier bar, resulting in a partly closed estuary. Over long time frames (100s to 1000s of years) the estuary will gradually start to infill due to sediment loads coming from the catchment, until the estuary transforms into a delta (Figure 3).

The accretion of fine and coarse sediments in estuary zones is an ongoing component of the geomorphic evolution of estuaries, with or without anthropogenic catchment disturbance. However, catchment disturbance associated with urban development, land clearing (for agriculture, forestry) and other disturbances (e.g. fire) will increase the degree of hillslope and channel erosion in the catchment, and increase the magnitude and rate of sediment delivery to the estuary. Management actions can be effective in reducing sediment loads associated with some catchment disturbances.

The current landscape trajectory for Balcombe Creek estuary is a gradual transition to become a wave dominated delta (Figure 3). However, the rate of sediment infill in the basin has been accelerated by catchment disturbance, and there is opportunity to reduce the rate through management interventions.

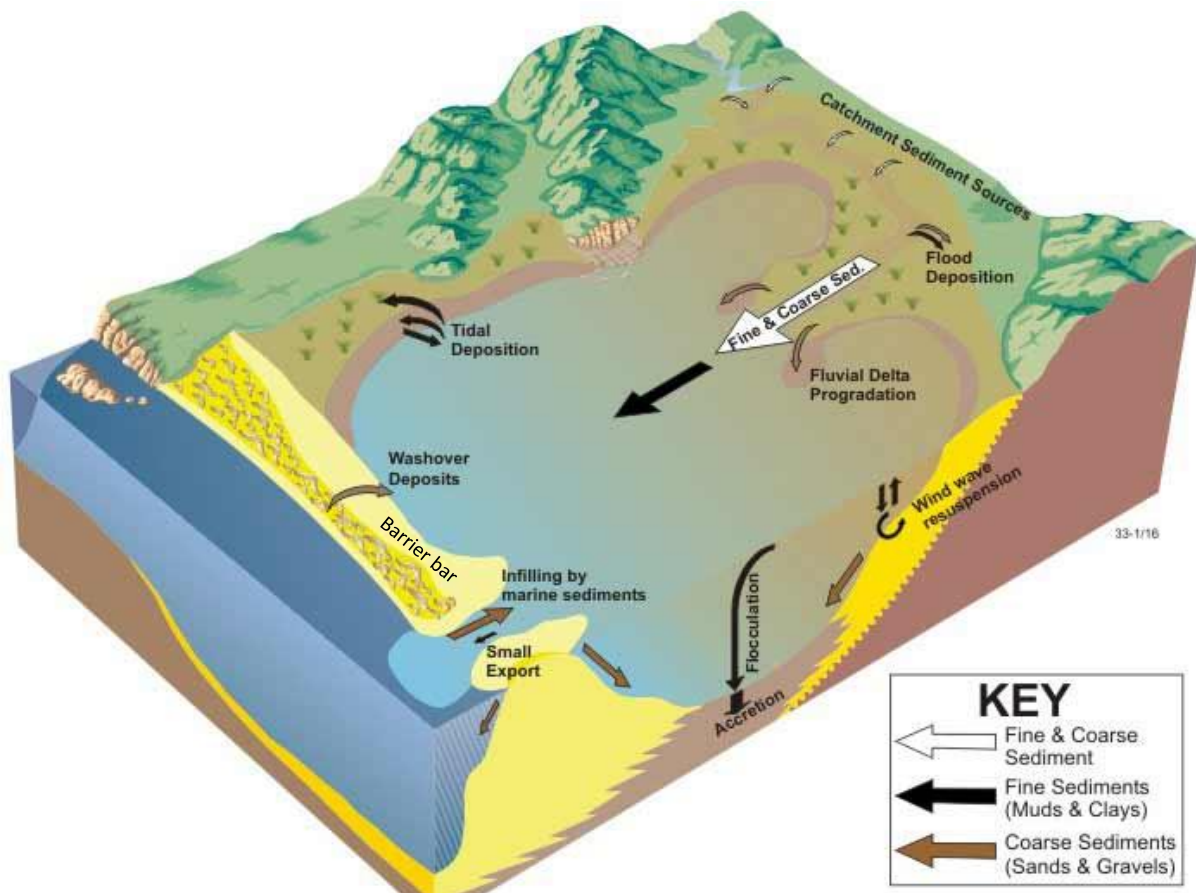


Figure 2. Sedimentation processes in wave-dominated estuaries (after OzCoasts 2015)

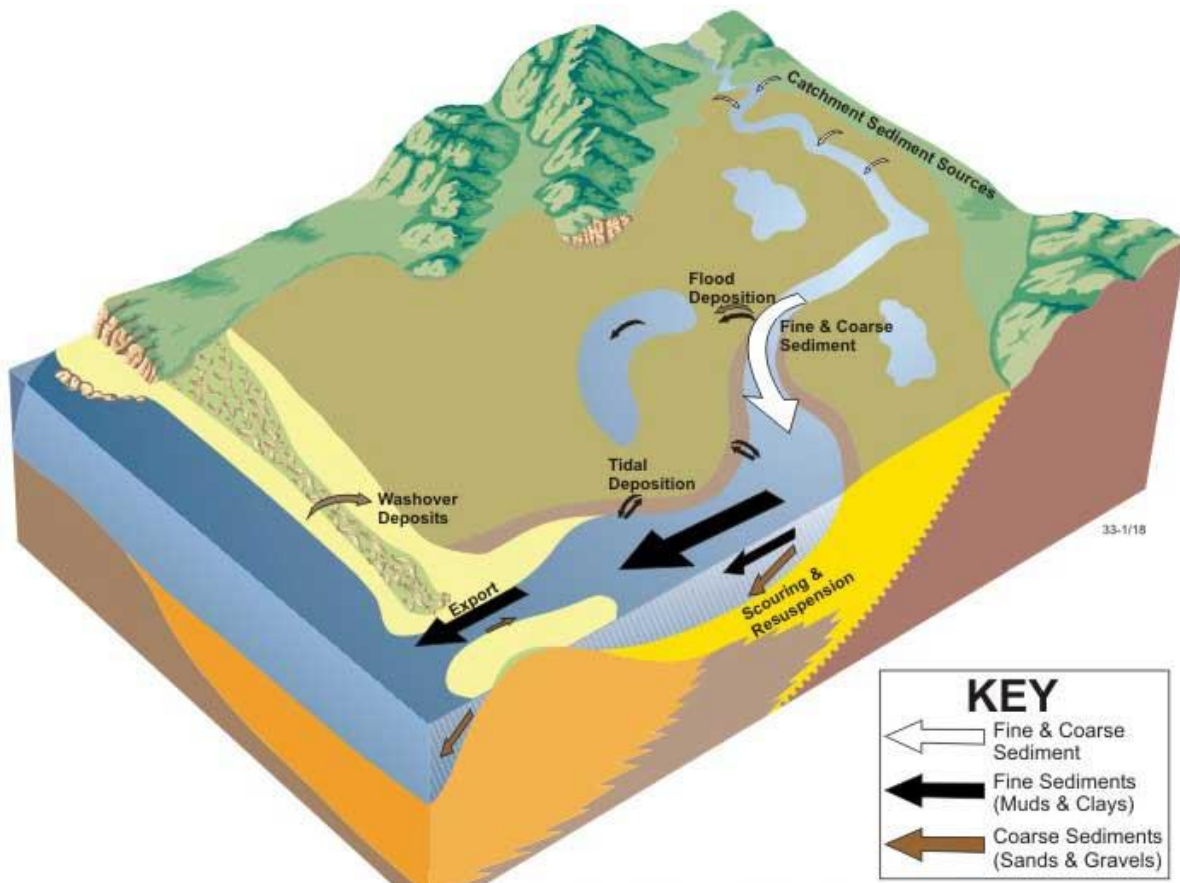


Figure 3. Long-term development into a wave-dominated delta (after OzCoasts 2015)

2.2 Management context

Sedimentation

Since 2008 there has been an increasing management focus for the Balcombe Creek catchment and estuary on geomorphology, sedimentation and water quality issues. Studies include a geomorphic study of waterways on the Mornington Peninsula (Water Technology 2008) an assessment of erosion in Harrap Creek (Water Technology 2009), estuary sedimentation studies (Water Technology 2010; BERG MM 2013, 2015) and recent water quality monitoring and suspended sediment load assessments (CAPIM 2015, Sharps and Sharley 2017).

The context for these investigations has included consideration of the influence of both:

- The broader catchment (including rural areas)
- Largely urban sub-catchments local to the estuary zone.

Broader catchment (rural)

The major concerns associated with the broader catchment zone include hydrology and water quality impacts from agriculture and areas of urbanisation in the upper catchment.

The current valley fill geomorphic form of catchment waterways is in relatively good condition with limited known erosion. Well vegetated valley fills are preventing erosion across the majority of catchment waterways, and acting as sediment sinks reducing the transport of sediment to and its deposition in the estuary.

Throughout the catchment there are a number of constructed wetlands and sediment basins that reduce the sediment and nutrient loads entering the waterways.

While in predominantly intact condition (minimal erosion), the status of catchment waterways has been previously recommended for review (Water Technology 2010, Alluvium 2016). The implication is that if valley fills become destabilised, a substantial volume of sediment would be eroded and potentially delivered to the estuary zone, a volume that is likely to be several orders of magnitude greater than inflows from urban areas adjacent to the estuary. Valley fills could be destabilised by a major change in hydrology and/or vegetation cover that can occur with land clearing, extensive urban development, bushfire or other landuse changes.

Local urban-sub catchments

The assessment of potential sediment loads to Balcombe Creek estuary from urban areas in the vicinity of the estuary have been the subject of several targeted investigations to date, including modelling (Water Technology 2008, 2009) and water quality monitoring (CAPIM 2015, Sharps and Sharley 2017). This current study builds on these and other past investigations, and is intended to provide additional clarity on the significance of local urban-sub catchments on estuary sedimentation, in the context of the broader catchment and historical sedimentation rates. The location of the Henley Avenue and Hopetoun Creek (Ferrero Reserve) sub-catchments that are referred to in this report are shown in Figure 4. These are two sub-catchments (of several) that are relatively close to the estuary zone that have substantial areas of urban development.

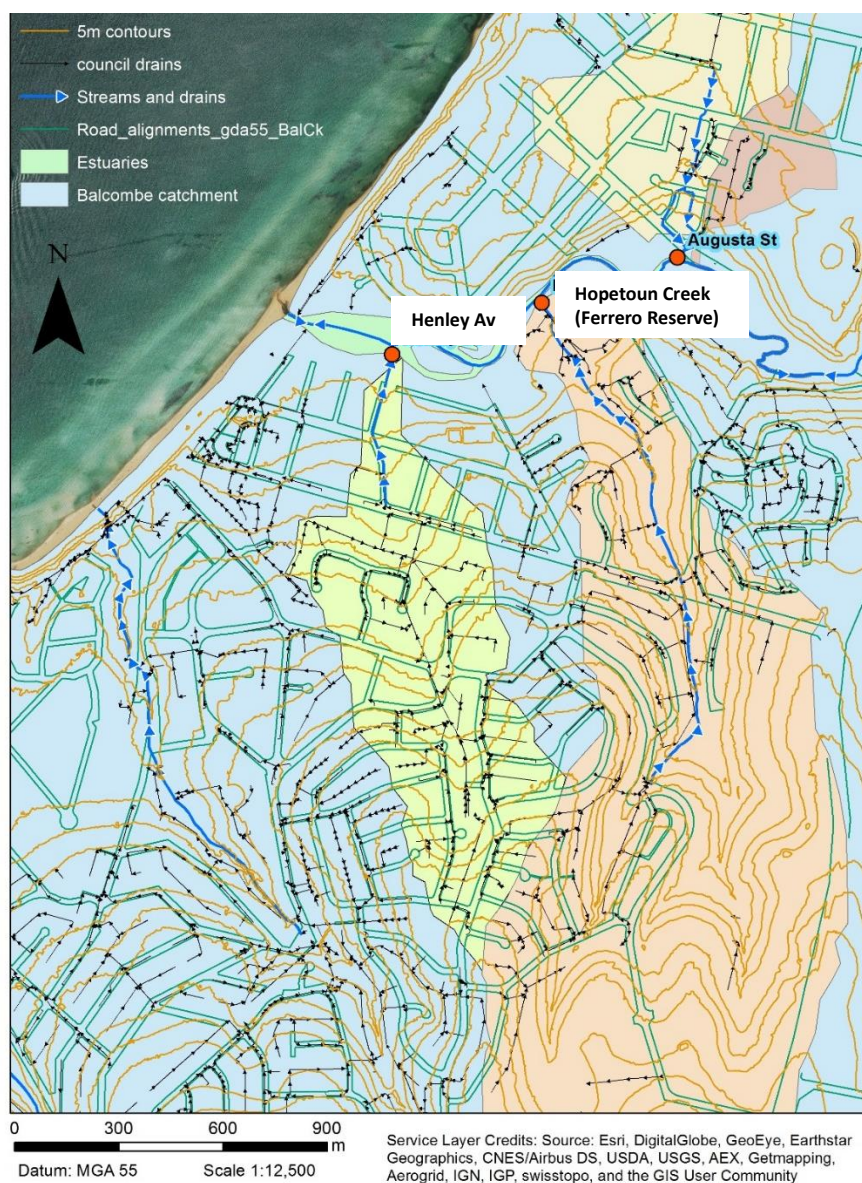


Figure 4. Location of local urban sub-catchments to Balcombe Creek estuary - including Henley Avenue and Hopetoun Creek (Ferrero Reserve) local urban sub-catchments (after Sharps and Sharley 2017)

3 Sediment coring and analysis

3.1 Overview

This section of the report outlines the results and conclusions from examination of the sedimentation history of Balcombe Creek. The conclusions are based on examination of sediment texture and pollen composition as well as radiocarbon and Lead 210 dating. It appears that the contemporary infill of Balcombe Creek is the result of sediment influx derived from human activities in the catchment in the past 100 years. These sediments have buried former seagrass meadows that would have been at subtidal elevation and dominated the estuary basin prior to influx of anthropogenically-derived sand and mud. Urbanisation around the lower, cored, part of the estuary is a key sediment source for infilling the lagoon, and the dominant source of sediment to the estuary in recent years. The coring methodology and detailed findings are outlined in the following sections.

3.2 Introduction

Coring was undertaken in Balcombe Creek in October 2016 and February 2017. The intertidal sediment flats in the lower estuarine basin were targeted to retrieve the longest possible history of infill of the creek. This area was also identified by the local community as the area that had undergone observable infill in recent times. Three cores were retrieved using vibrocoring from the estuary in October 2016 (Figure 5) with the depth of penetration ranging from 2.30 – 3.38 m. A total maximum core length of 2.50 m was captured with compaction rates ranging up to 27.5% (Table 1). The compaction observed is within the typical range of estuarine sediments and the depth achieved was excellent for understanding sedimentation within the creek. Two additional cores (# 4a and 4b) were collected by push coring in 2017 to gain high resolution samples of the uppermost part of the sedimentary sequence. A maximum depth of 60 cm was reached.



Figure 5. Location of cores within Balcombe Creek

Table 1. Length and depth of penetration of each core collected within Balcombe Creek

Core Number	Depth Penetration (m)	Length Extracted Core (m)	Compaction (%)
1	2.30	2.15	6.5
2	2.83	2.50	11.7
3	3.38	2.45	27.5
4a	0.94	0.68	27.6
4b	0.77	0.60	22.1

3.3 Methodology

Field sampling

Cores 1 - 3 were collected through vibrocoring. An aluminium pipe was sunk into the mud island using vibrations sourced from a modified concrete vibrator. The vibrations act to liquefy the water-saturated sediment and combined the weight of the vibrating head, the pipe sinks into the subsurface. The pipe is extracted through means of a tripod and winch (Figure 6) and allows for an undisturbed core to be retrieved.



Figure 6. Vibrocoring in Balcombe Creek estuary

Cores 4a and 4b were collected by push coring where a 50 mm diameter PVC pipe was manually pushed into the sediment and extracted by hand. The push core was retrieved for the specific purpose of quantifying the rate of modern sediment. The two cores were collected within 2 m of each other.

Sediment texture

Once the cores were returned to the Coastal Laboratory at The University of Melbourne they were cut and split lengthways and the sediment visually described. Grain size was analysed using a Beckman Coulter LP13320 laser particle sizer which can analyse grains from 2 mm to 0.4 μm in size. Grain texture was classified according to the criteria of Leeder (1982) and size statistics calculated using the graphical procedures of Folk and Ward (1957). All size results are reported in Phi (ϕ) units, the standard in coastal geomorphology (Table 2).

$$\text{Phi } (\phi) = -\log_2(\text{mm})$$

Table 2. Wentworth classification of grain size in millimetres and Phi units (Wentworth 1922)

Millimeters (mm)	Micrometers (μm)	Phi (ϕ)	Wentworth size class	Rock type
4096		-12.0	Boulder	Conglomerate/ breccia
256		-8.0	Cobble	
64		-6.0	Pebble	
4		-2.0	Granule	
2.00		-1.0	Very coarse sand	
1.00		0.0	Coarse sand	Sandstone
1/2	500.00	1.0	Medium sand	
1/4	250.00	2.0	Fine sand	
1/8	125.00	3.0	Very fine sand	
1/16	63.00	4.0	Coarse silt	Siltstone
1/32	31.00	5.0	Medium silt	
1/64	15.60	6.0	Fine silt	
1/128	7.80	7.0	Very fine silt	
1/256	3.90	8.0	Clay	Claystone
0.00006	0.06	14.0		

Pollen analysis

Pollen analysis, or Palynology, is a type of environmental archaeology in which microscopes are used to analyse the range of plant pollens present in sediment layers: these can tell us what crops, vegetation or ground cover were likely to have been present when a layer was deposited. Pollen analysis is one of the more accurate ways to determine when the influence of European settlement commenced in the sediment cores, in particular by examining when exotic (introduced) vegetation species start to appear in the sediment layers.

Analysis of pollen within core 2 was undertaken at the Pollen Laboratory at The University of Melbourne. Samples were taken at 10 cm intervals in the uppermost part of the core and chemically treated to concentrate the pollen grains. Samples once processed were identified under a microscope with identification based on species reference collections held by the Melbourne University School of Geography.

Radiometric dating

Radiocarbon dating was conducted at the University of Waikato Radiocarbon dating laboratory on shell and bulk organic material from the vibrocores using Atomic Mass Spectroscopy techniques. Lead 210 dating was undertaken at the Australian Nuclear Science and Technology Organisation in Sydney using alpha-counting techniques.

3.4 Results

Stratigraphy

All cores were visually and texturally examined and contain a similar sediment sequence (Figure 7). The maximum compaction observed was 28%, and is likely concentrated in the uppermost parts of the cores, based on the compaction observed in the shorted push cores. The depths referred to here are the core depth, as the precise compaction cannot be accurately assigned to specific sedimentological layers.

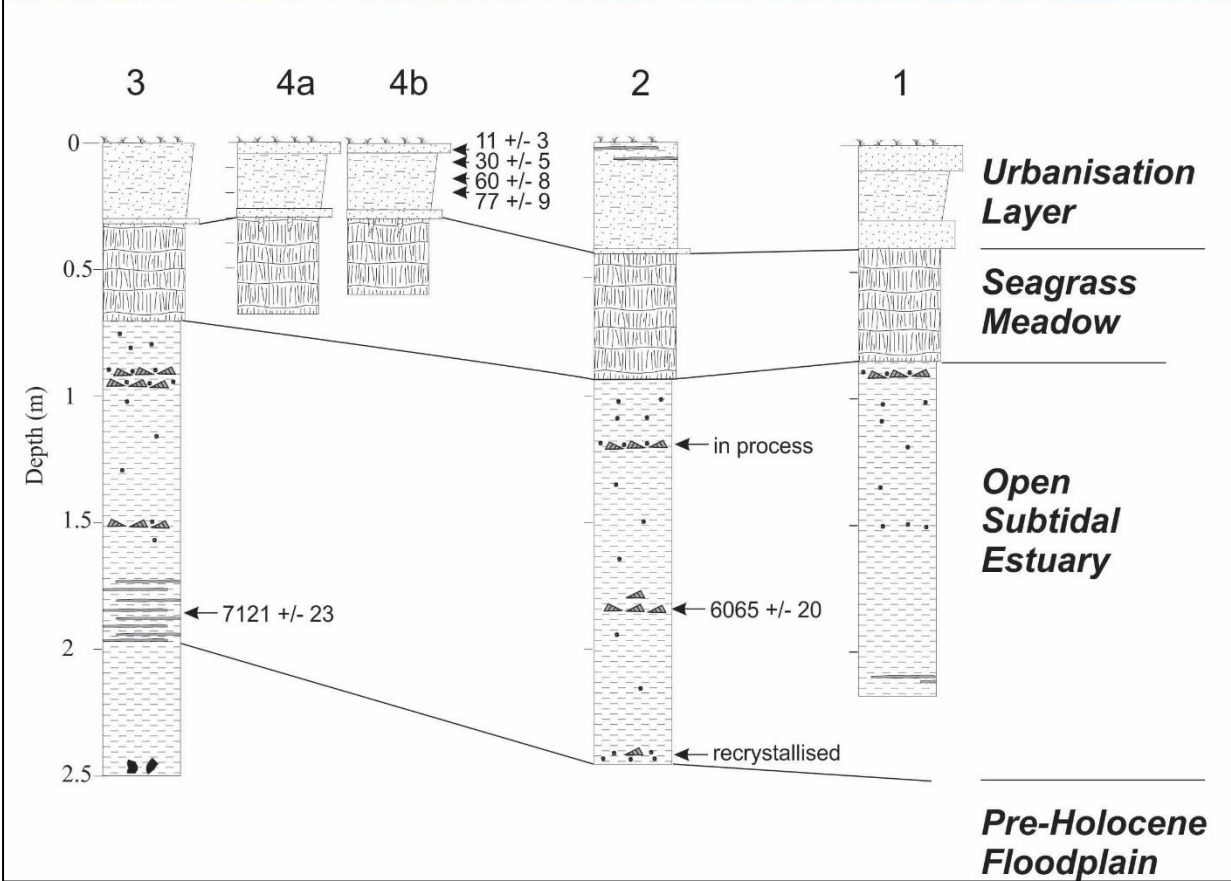


Figure 7. Stratigraphy and age structure (in years) of Balcombe Creek, showing the variation in depositional environments that have occurred since sea level flooded the coast after the last Ice Age.

The deepest and oldest sediment sampled was found in core 3. Here the 0.5 m lowest portion of the core encountered compact mud-size sediment with evidence of mottling typical of subaerial weathering that occurs during the process of soil formation (Figure 7, Figure 8). This unit was devoid of macrofossils and is interpreted as representing the pre-existing land surface before the river channel was flooded at the end of the last ice age.

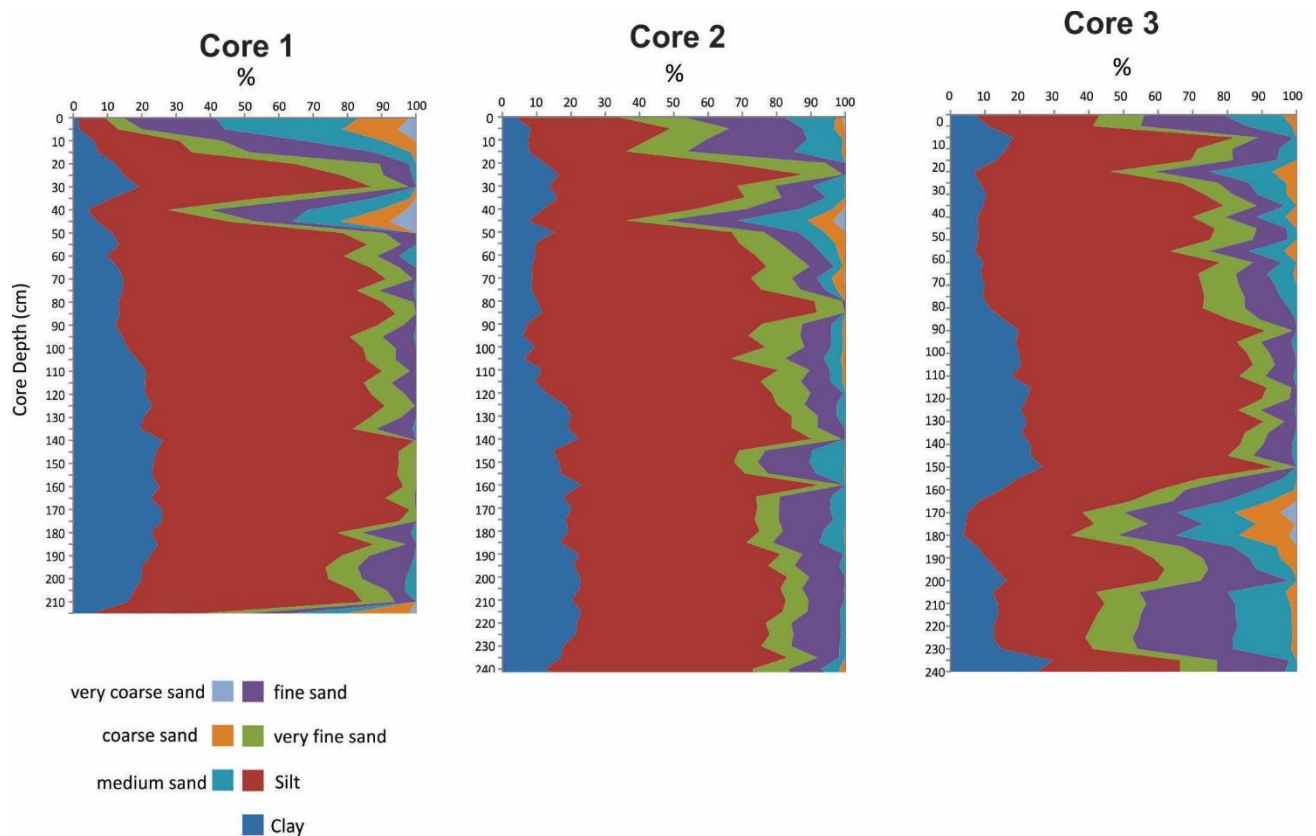


Figure 8. *Vibrocore sediment texture*

Overlying this unit is a layered sequence of highly organic material some of which contained charcoal. This unit is dated at 7121 +/- 23 years by radiocarbon dating (Table 3). It most likely represents a flooded marsh surface or a basin of accumulated plant material. Sea level at this time would have been close to, or slightly higher than, present elevations, based on regional sea level curves (predictions) in eastern Australia (Lewis et al., 2013). This part of the core is likely a ‘flooding surface’ representing the first stage of marine influence on Balcombe Creek. A shell at the base of core 2 was undatable, and indicates recrystallization from freshwater supporting this interpretation.

Table 3. Radiocarbon ages from Balcombe Creek

Lab Number	Material	Core # / Depth (cm)	Conventional age (years BP +/- 1σ)
45081	Zeacumantus sp (Common Mud Whelk)	Core 2 / 120	5000
45082	Zeacumantus sp (Common Mud Whelk)	Core 2 / 186	6065 +/- 20
45083	Zeacumantus sp (Common Mud Whelk)	Core 2 / 240	recrystallised
45084	Bulk Organics	Core 3 / 186	7121 +/- 23

The main part of the three vibrocores is composed of a fine muddy unit with a mean grain size in the medium silt range (Figure 7, Figure 8). It is very poorly sorted (Figure 10) related to the presence of fine shell material derived from bivalves and mud whelk gastropods. Shells are present throughout this unit decreasing in density with depth. The gastropods tend to be concentrated in distinct shelly bands, representing either a former mud flat surface or a storm deposit. This is a typical estuarine sequence formed in a moderate-low energy basin. A radiocarbon date at 1.8 m depth in core 2 indicates rapid deposition during the early to mid-part of the Holocene when sea level was higher than present.

Overlying the open estuary sequence is an organic rich dark mud with a high density of root material (Figure 7, Figure 9). The roots are identified as sea grass based on their morphology. The sediments are finer grained being mostly medium silt and are poorly sorted. The skewness is markedly different to the upper layer being mostly near-symmetrical (Figure 10). Shell material is not observed within this root-rich organic mud. This unit is ubiquitous through the estuary indicating a vibrant and widespread sea grass meadow was present in Balcombe Creek.

The top of the core, from the surface to a maximum of 0.5 m depth is dominated by fine sand and mud (Figure 8, Figure 10). The unit is thickest in core 1, located on a delta on the southern edge of the estuary (Figure 5, Figure 7). This indicates that the delta is a primary zone of sediment deposition for sediment sources from the nearby sub-catchment area. The material appears to be laminated close to the surface. The laminations may represent specific depositional events related to high flows from the catchment. This uppermost part of the core is devoid of fossil material such as roots or shells. The mean grain size ranges from very fine sand to fine silt, is very poorly sorted and is fine to strongly fine-skewed (Figure 8, Figure 10). This surface unit is separated from the seagrass meadow by a fine sand layer (Figure 7). In cores 4a and 4b the sand penetrates the seagrass bed as it infilled invertebrate burrows, suggesting rapid sedimentation. The widespread nature of this centimetre-thick sand layer throughout the cores suggests a rapid disturbance to the immediate catchment.

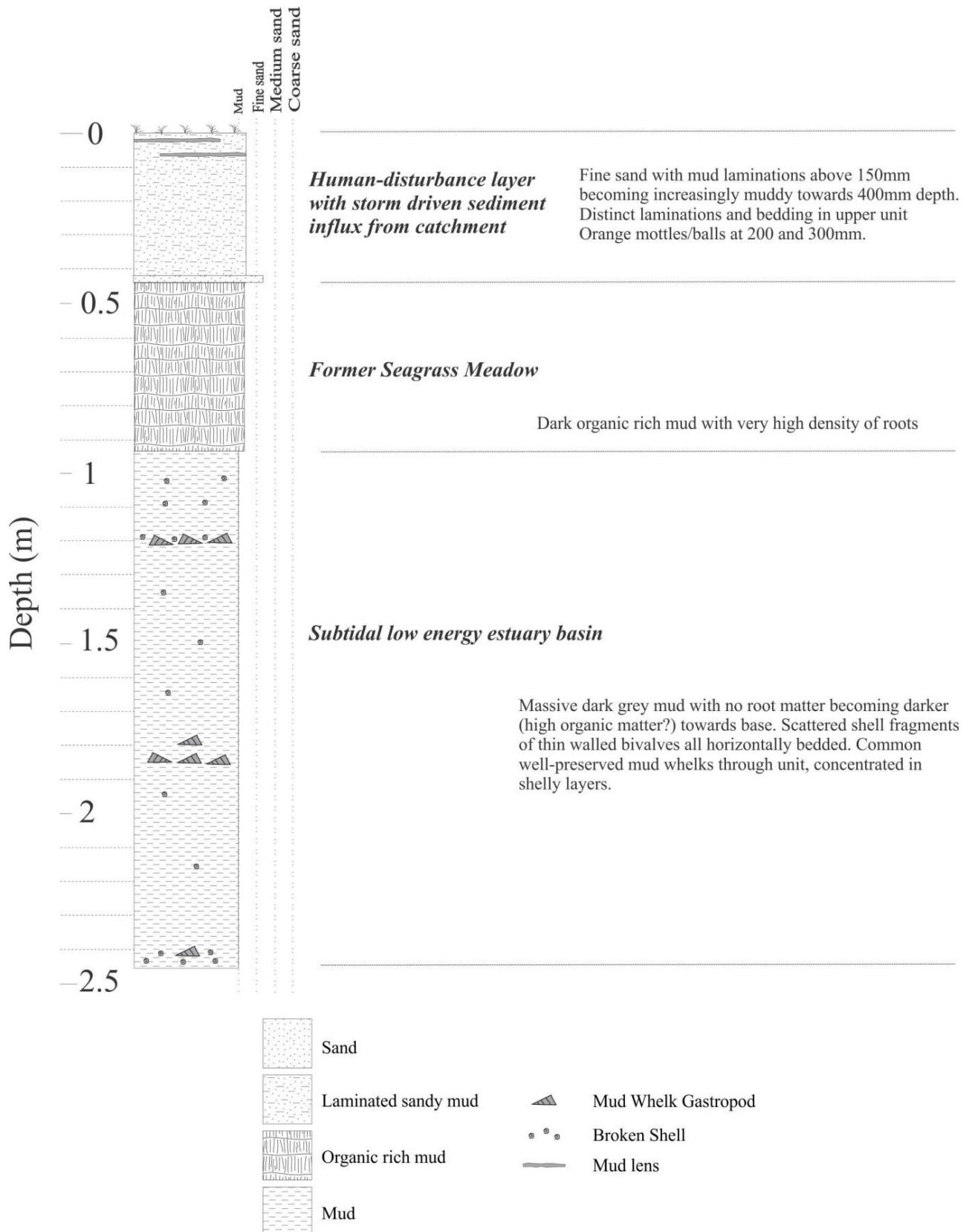


Figure 9. Detailed textural log of core 2 from Balcombe Creek

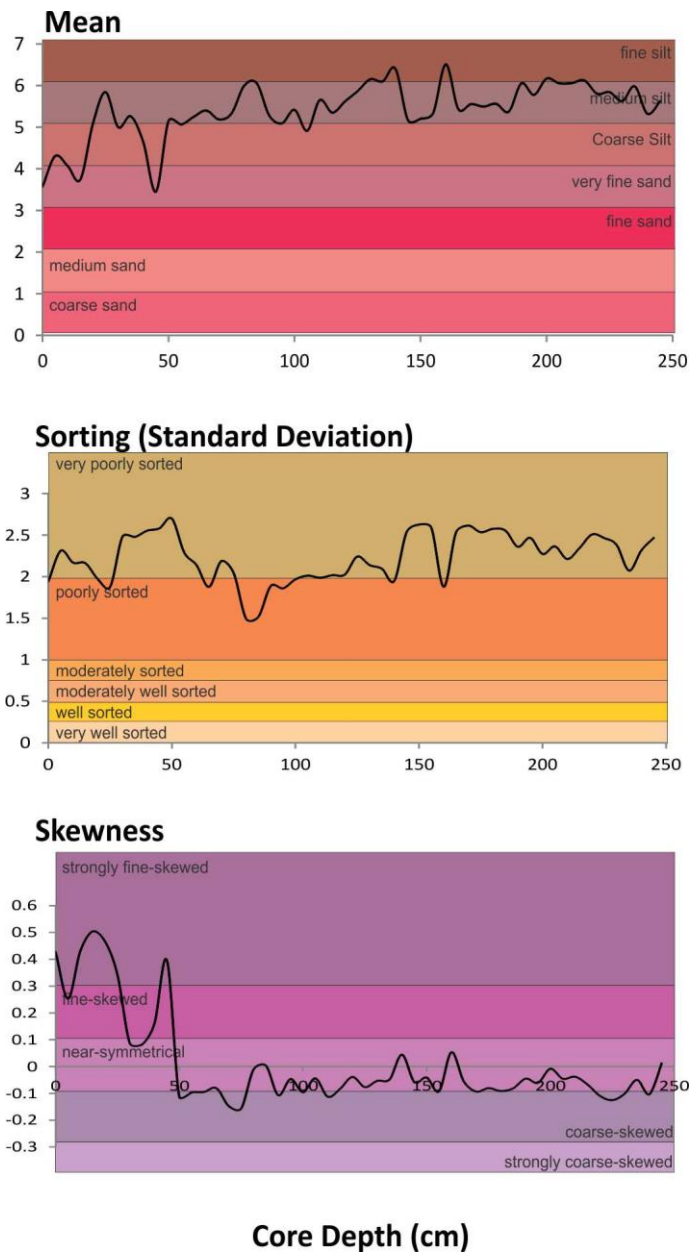


Figure 10. Detailed sediment texture of core 2 within Balcombe Creek. Texture is calculated using the graphical classifications of Folk and Ward (1957). X-axis is depth in cm, y-axis grain size in Phi units.

Palynology

Pollen was extracted from the entire core with the concentration of grains being low, typical of these environments. Between 100 - 300 terrestrial pollen grains were counted per sample with pollen diversity also being low (<20 types).

There is a clear difference in the sequence within the top 45 cm (Figure 11). Exotic pollen grains are persistently present and relatively abundant. This sequence also corresponds to the sandier portion of the core. Before this phase, the pollen diagram is dominated by *Casuarina* and *Eucalyptus*, which indicate a large abundance of native vegetation (Figure 11).

The abundance of aquatic species peaks in the uppermost unit and then is virtually absent below 1.0 m, which is close to the base of the inferred seagrass unit (Figure 9).

Pb210 Dating

Lead 210 dating was undertaken in the uppermost layer to determine its age. Lead 210 is a short lived isotope and is therefore ideal for quantifying the age of sediments younger than 200 years old. Sediments from both cores 4a and 4b were homogenised and analysed. The results indicate this surface layer is less than 80 years old and is still accreting today (Table 4).

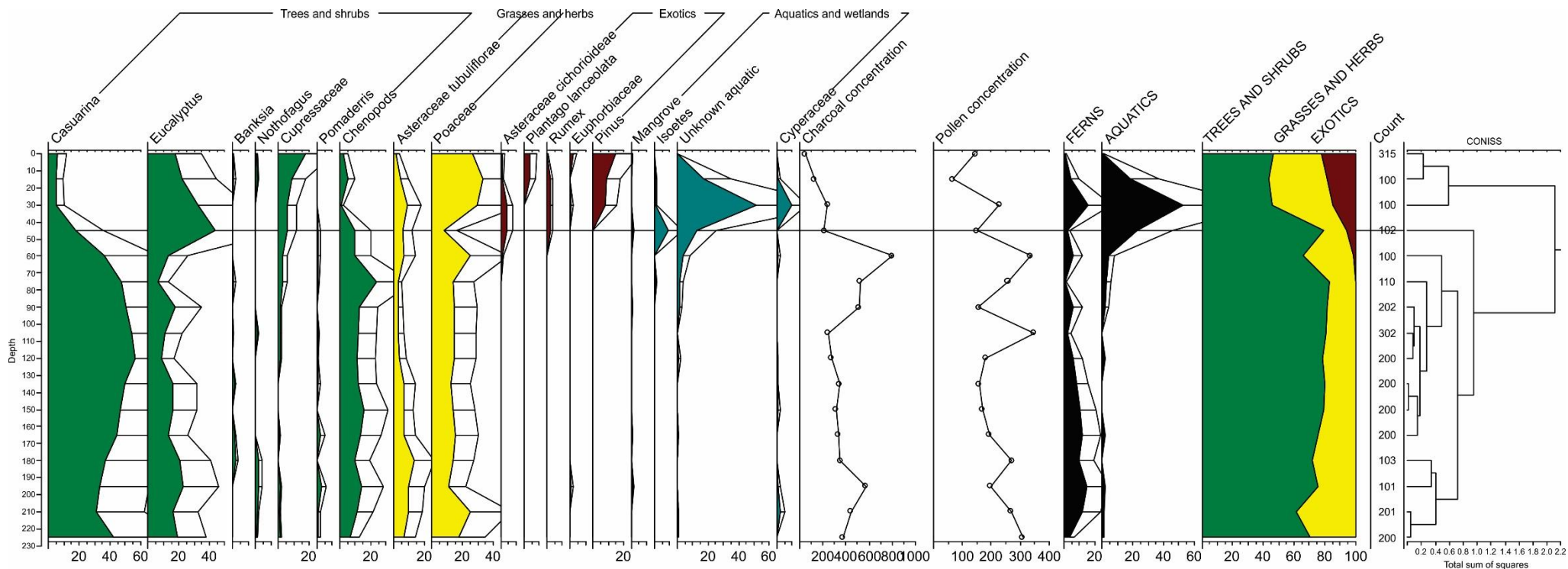


Figure 11. Pollen concentrations and species abundance for core 2 within Balcombe Creek. The abundance of exotic species suggests the uppermost unit was deposited after European settlement.

Table 4. Lead 210 dating results from cores 4a and 4b

ANSTO ID	Depth (cm)	Dry Bulk Density (g/cm ³)	Cumulative Dry Mass (g/cm ²)	Count Date	Total ²¹⁰ Pb (Bq/kg)	Supported ²¹⁰ Pb (Bq/kg)	Unsupported ²¹⁰ Pb Decay corrected to 11-Apr-17 (Bq/kg)	Calculated CIC Ages (years)	Calculated CRS Ages (years)	CRS model Mass Accumulation Rates (g/cm ² /year)
T317	0 - 4	1.60	3.3 ± 3.3	20-Apr-17	60 ± 3	13 ± 2	47 ± 3	9 ± 10	11 ± 3	0.29 ± 0.03
T318	4 - 8	1.44	9.4 ± 3.1	20-Apr-17	27 ± 2	5 ± 1	22 ± 2	27 ± 10	30 ± 5	0.33 ± 0.03
T320	12 - 16	1.09	19.5 ± 2.8	20-Apr-17	16 ± 1	8 ± 1	8 ± 2	56 ± 11	60 ± 8	0.35 ± 0.06
T321	16 - 20	1.29	24.2 ± 2.7	20-Apr-17	18 ± 1	11 ± 1	7 ± 2	70 ± 12	77 ± 9	0.23 ± 0.03
T322	20 - 24	1.11	29.0 ± 2.6	20-Apr-17	32 ± 2	9 ± 1	23 ± 2			
T319	8 - 12	1.47	13.6 ± 2.7	20-Apr-17	12 ± 2	13 ± 2	Not detected			

3.5 Environmental interpretation

The detailed sedimentological and palynological information provides the basis for an interpretation of the history of infill within Balcombe Creek. The environment at the site has developed through three distinct environmental phases as outlined in Table 5.

Table 5. Environmental interpretation of the sedimentation history in Balcombe Creek estuary

Environment	Description
Phase 1: Subtidal low energy basin (7,000 – 5,000 years ago)	For the majority of the history represented in the sediment cores, Balcombe Creek was a deep open estuary. The basin was likely several metres deep with mud flats exposed at the margins when the entrance was open.
Phase 2: Accretion of Seagrass. (5,000 years to near present)	Progressive infill of the estuary, derived from sediment sourced from the catchment, built the bottom of the estuary to a depth where seagrass could thrive. A seagrass community was then established with the estuary likely 1-2 m deep.
Phase 3: Rapid sedimentation and island accretion (last century)	<p>Major catchment disturbance following European settlement, including clearing for agriculture and urbanisation, has led to an influx of sediment into the estuary. Rapid sedimentation in the estuary smothered the seagrass beds and built the islands that are now exposed at low water levels. The increased rate of sedimentation directly relates to human activity in the last 80 years, based on the dominance of exotic pollen species within these sediments and Pb210 dating results.</p> <p>The laminations observed with the sediments of the upper layers of sediment (dated to the last 40 years) are likely caused by storm-induced sediment flows in the estuary from the local urbanised catchment. The sediment core data, and the delta at the southern edge of the estuary (where core 1 is located), indicates a dominant source of sediment is now local runoff from the urbanised areas.</p>

4 Geomorphic form changes – aerial imagery review

4.1 Context

A set of aerial images is available from Nearmap (2010-2017) and historical aerals. The imagery is from varying perspectives, scale and resolution, however highlights the development of several geomorphic features that indicate the nature of sediment delivery to the estuary. Specific features of note include the position of the central low flow channel, and progression of the fluvial bay-head delta at the end of Henley Avenue – these are the main changes in geomorphic form in recent decades observable from the imagery. A bay-head delta is a geomorphic feature created by the deposition of sediment over time at the location where a significant waterway / inflow point meets the depositional estuary basin (e.g. Figure 12).

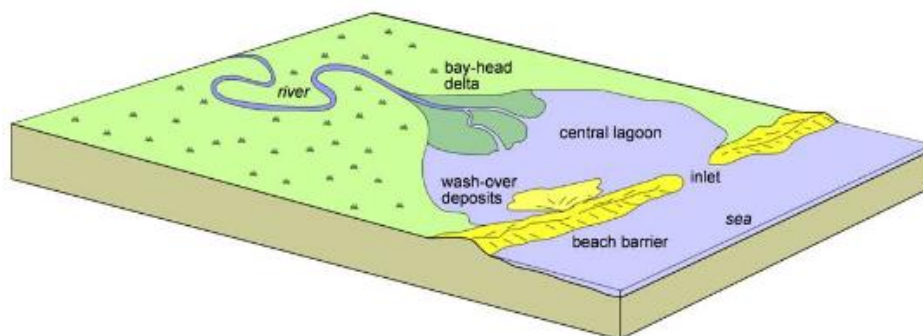


Figure 12. Conceptual example of a bay-head delta

4.2 Observations

The bay-head delta at the end of Henley Avenue is evident from the aerals from 1985 (see area circled in orange in aerial images provided below). The presence and persistence of this bay-head delta at the Henley Avenue location (Figure 13 to Figure 19) indicates that a significant recent source of sediment to the estuary (at a minimum in the last 40 years) is from local runoff from the adjacent urbanised catchment. The coring results support these observations. No other major changes in the presence of main bayhead delta on Balcombe Creek are observable over this timeframe, although there is likely to have been sediment accretion on the already established features.



Figure 13. April 1977 historical aerial imagery (courtesy MPSC) – orange circle identifying area at the end of Henley Avenue – absence of defined bayhead delta. Main bayhead delta on Balcombe Creek indicated in blue circle.

September 1985



Figure 14. September 1985 historical aerial imagery (courtesy MPSC) – orange circle identifying area at the end of Henley Avenue – bayhead delta form establishing

09/10/2010



Figure 15. October 2010 nearmap aerial imagery – orange circle identifying area at the end of Henley Avenue – bayhead delta well established – vegetation infilling surrounding area.

31/03/2014



Figure 16. March 2014 nearmap aerial imagery – orange circle identifying area at the end of Henley Avenue – persistence of bayhead delta

05/10/2015



Figure 17. May 2015 nearmap aerial imagery – orange circle identifying area at the end of Henley Avenue – persistence of bayhead delta

16/01/2016



Figure 18. January 2016 nearmap aerial imagery – orange circle identifying area at the end of Henley Avenue – persistence of bayhead delta

08/03/2017



Figure 19. March 2017 nearmap aerial imagery – orange circle identifying area at the end of Henley Avenue – persistence of bayhead delta

5 Conclusions and recommendations

5.1 Summary

Summary points drawn from the sediment coring and observations of geomorphic form changes include the following:

6. The estuary has an exceptionally well preserved sedimentation history, with the bottom sediments of the 2.5 – 3 m deep cores dating back to some 7000 years ago at the end of the last ice age. Sediment layers include sea grass beds, marine material, organic material and fine sediments, sand and gravel lenses. The well preserved layers within the core indicate minimal disturbance and movement of sediments once deposited in the estuary itself. As such the estuary has been prone to rapid infilling by sediment delivered to it from the catchment, as the deposited sediment is not readily flushed out.
7. A historical sea grass bed is evident in the cores. The sea grass is underlying 0.5 m of recent sediment (last 80 years) derived from rapid infilling due to catchment disturbance, including both agriculture and urbanisation. This infilling has smothered the old seagrass beds and built the islands that are now exposed at low water levels.
8. Sediment from the broader rural catchment, as well as from the local urban sub-catchments (local to the estuary itself), have historically contributed to estuary infilling since European settlement. In the rural areas, waterways are predominantly intact (not eroding) valley fill systems. The swampy form of the valley fill channels, plus the distance of rural areas from the estuary, and the presence of many established wetlands across the catchment, will assist to minimise liberation and delivery of fine sediment to the estuary (Alluvium 2016). In the local urban sub-catchments, reducing the liberation and delivery of sediment to the estuary zone is more challenging.
9. Major sources of recent fine sediment deposition in the estuary (last 40 years to date) from the local urban sub-catchments include: the Hopetoun Creek (Ferrero reserve) sub-catchment (Sharps and Sharley 2017), as well as the Henley Avenue sub-catchment (Sharps and Sharley 2017, and this investigation).
10. The laminations and coarser material (gravel) lenses observed within the top sediment layers of the cores are evidence of storm-induced sediment flows from the local urban sub-catchments. The sediment core data, and the bay-head delta at the southern edge of the estuary near Henley Avenue, indicate that local runoff from this local urban sub-catchment is a significant source of both fine and coarser sediment to the estuary in recent years.

5.2 Recommendations

Based on the outcomes from this investigation, the future focus for management of sedimentation in Balcombe Creek estuary includes the following:

- Investigate / implement measures to reduce fine sediment liberation and delivery from the Hopetoun Creek (Ferrero reserve) and Henley Street sub-catchments. This may include:
 - Identification of erosion hotspots / sources of fine sediment
 - Revegetation opportunities along waterways and wetlands
 - Other opportunities to minimise sediment entrained to the estuary
- Investigate / implement measures to reduce coarse sediment liberation and delivery from the local urban areas, in particular the Henley Avenue sub-catchment. This may include:
 - Sealing existing unsealed roads – plus - establishing grassed / vegetated swales along new sealed roads to trap and filter sediment (avoid curb and gutter arrangements). Vegetated swales may also be established along existing sealed roads where possible.

- Reviewing stormwater management options for the area, and consider a broad range of options to reduce stormwater inflows at Henley Avenue (e.g. diversion of flow, interception, other treatment options).
- Sediment finger printing – matching specific sediments in the catchment (urban or rural) with location/presence in the sampled cores – is an option for further detail if required, however is not a priority recommendation. We propose that sufficient information is now known through the current coring results and water quality investigations to inform the progression of management actions. The samples cores are currently preserved at The University Melbourne if any further specific investigation is required in the future.
- A supplementary investigation to be considered for the future is a geomorphic assessment of the catchment waterways (form, condition, stability). A geomorphic assessment, combined with water quality monitoring in the rural areas, would provide additional confidence that erosion from catchment waterways is not likely to be major concern for future sediment delivery to the estuary. However, there is sufficient understanding from investigations to date to support a focus on immediate management activities in the urban sub-catchment areas, to address known sources of sediment to the estuary.

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