Present State of the Noetzie Estuary

Prepared for

PEZULA
PRIVATE ESTATE

by

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Fronticepiece: Noetzie Estuary mouth, showing turbid water entering from a tributary.

IECM Survey: 7 – 8 April 2005

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Executive Summary

This study investigated the present state of the Noetzie Estuary and was commissioned by the Pezula Development Company, following exceptionally heavy rainfall events in July, August and December 2004 when run-off of discoloured water from a Pezula construction site known as the "Field of Dreams" (FoD), reached the Noetzie River and Estuary.

The Noetzie Estuary is relatively pristine and one of few Intermittently Open Estuaries that is still receiving most of its natural mean annual run-off. This run-off maintains the mouth in a semi-closed state for most of the year. The estuary is perched above sea level but has a small outflow channel to the sea. Seawater overtopping can occur on spring tides and this introduces saline water into the estuary. A salinity gradient is therefore maintained that increases the biodiversity of the estuary as different plants and animals are distributed along this gradient. Overtopping can also result in recruitment of fish that use the calm sheltered waters of the estuary as a nursery.

The survey showed that the physico–chemical characteristics of the estuary were normal for a small Intermittently Open Estuary in the open / semi-closed mouth phase. Water clarity was low and turbidity and light attenuation was high at Stations 2 and 4, which occurred adjacent to small tributaries flowing into the estuary. These stations also had high sediment organic content and a high fraction of fine particles (silt and clay). Although significantly different to the other stations in the estuary, it is not believed that these stations were indicative of a system that is experiencing severe turbidity or silt loading. Silt and organic matter naturally accumulate where the normal current velocity is low, i.e. fringes of reed beds, deep channels, channel bends and at points of river inflow.

Construction of the "Field of Dreams" at Pezula Private Estate did result in increased turbidity of the water column (Heydorn 2004) and probably resulted in increased siltation and sedimentation of fine material. These turbid waters and fine material were flushed out to sea during high run-off in December 2004. At this time the Knysna Estuary experienced a 1-in-100 year flood event. Conditions in the Noetzie Estuary as it was at the time of this study are probably similar to that prior to construction. Estuarine flora and fauna are adapted to extreme conditions and would be able to tolerate short periods of siltation and high turbidity. The ability of the Noetzie Estuary to absorb the effects of increased sedimentation in the past and at present is intrinsically related to its hydrodynamics. Adequate freshwater input, especially baseflow, is high enough to control the build-up of the berm, thereby increasing flushing of the system by the river and seawater.

A catchment, river and estuary management plan and monitoring programme should be developed and implemented to ensure the conservation of the near pristine Noetzie Estuary. This report will act as a benchmark against which future impacts and changes can be measured.

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1. Introduction

The Noetzie Estuary is situated in the Garden Route, Western Cape, between the towns of Knysna and Plettenberg Bay. The system is in a near natural condition due to the difficulty in accessing the estuary and the catchment areas. The estuary is a blackwater system that drains predominantly quartzites of the Table Mountain Group and as a result rarely becoming silt laden under natural conditions. In recent years Anthropogenic activities have increased the silt load of the Noetzie River and its tributaries. Most notably was the upgrading of the National Road N2 in the 1980s and the construction of the "Field of Dreams" sport complex at Pezula Private Estate in 2004 to 2005.

This report was commissioned by the Pezula Development Company, following exceptionally heavy rainfall events in July, August and December 2004 when run-off of discoloured water from a Pezula construction site known as the "Field of Dreams" (FoD), reached the Noetzie River and Estuary. The company was concerned about this, as its approach in the development of the Pezula Private Estate is orientated towards environmental conservation. Out of the total property area 612 ha, only some 100 ha are being developed for low-density residential purposes with associated infrastructure, while the remaining area of 504 ha, which was formerly under commercial pine and eucalyptus plantations, is being rehabilitated to original fynbos, wetland and afromontane forest state. Damage to the river and estuary would be contrary to this objective.

Immediately after the floods of August 2004, Allan Heydorn, a coastal ecologist who also serves as chairman of the Pezula Environmental Liaison Committee, conducted a preliminary investigation of the wetlands below the FoD, the section of the river between these wetlands and the estuary. The objective of this investigation was to determine whether the discoloured water run-off had resulted in ecological damage to the wetlands, river and estuary. No such damage was discerned, but in his report Dr Heydorn recommended that this preliminary finding was in need of confirmation through a more detailed investigation. This is a further objective of the present study by the Institute for Environmental and Coastal Management of the Nelson Mandela Metropolitan University. The urgency of this study became even greater following further severe floods in December 2004.

Scientific knowledge on the Noetzie Estuary is poor and consists of a single once-off study conducted by Harrison *et al.* (1995). It was difficult to assess the impacts of increased siltation and high turbidity without baseline information. Because we are unable to assess how the estuary has changed from a natural state, it was necessary to investigate the overall functioning of the Noetzie Estuary and compare that with available literature and knowledge on other similar Intermittently Open Estuaries in the country.

2. Location

The Noetzie Estuary is located south-east of Knysna. The position of the mouth was recorded as 34.07977º S; 23.12884º E.

Figure 1. Regional setting indicating the study site and the towns of Knysna and Plettenberg Bay.

2.1. Accessibility

The Noetzie Estuary is easily accessed from the National Road (N2). The Noetzie turnoff is on the eastern outskirts of Knysna and the 5 km gravel road passes through plantations and through Pezula Private Estate. The road ends at the coastal resort of Noetzie.

2.2. Local authorities

Eden District Municipality administers the district and all the local municipalities in the area and controls bulk water and electricity supply, bulk sewerage treatment and disposal, waste disposal and public works.

The Knysna Local Municipality controls the area from Sedgefield in the west to Noetzie in the east and provides basic services in terms of refuse removal, electricity, water, sewerage and building plan approval.

3. Abiotic characteristics

3.1. River catchment

3.1.1. Catchment characteristics

3.1.1.1. Area

The Noetzie River has a total catchment of 38.8 km^2 (NRIO 1987). A key feature of all Intermittently Open Estuaries is their small river catchments (Whitfield 1992).

3.1.1.2. River length

The Noetzie River has a total length of 13.5 km (NRIO 1987). Elevation at the source is 340 m above Mean Sea Level (MSL) creating a river gradient of 1:40 (NRIO 1987).

3.1.1.3. Tributaries

Most of the tributaries of the Noetzie River are small ephemeral streams less than a kilometre in length. Some of these include the Jantjiesrivier, Skuinskraalrivier, Taaiboskloofrivier and Skuinsbosrivier.

3.1.1.4. General geology and geomorhology

The catchment of the Noetzie River lies within the Peninsula Formation of the Cape Table Mountain Group (Ordovician age) that, due to its resistant nature to weathering, supplies minimal fluvial sediment to the estuary (Reddering & Esterhuysen 1984). This formation is overlain with various Tertiary and Quatenary formations, mostly aeolian sand, alluvial deposits and aeolianite. The western upper catchment drains through Enon pebble conglomerates that have a characteristic reddish colour (Grindley 1985). The conglomerates consist predominantly of rounded Table Mountain Group quartzite clasts set in a sandy matrix together with finer sandstones and mudstones. Generally the topsoil consists of fine medium sand that originated from the Table Mountain group quartzites and sandstones and / or are blown deposits from the littoral zone and coastal embayments (Grindley 1985).

The region is characterised by the west-east trending Cape Fold Belt forming the southern orographic line that includes the Outeniqua, Langkloof and Tsitsikamma Mountains and runs parallel to the regional trend of the southern coastline. The coastal marine platform lies seaward of the mountains and forms the coastal strip and is up 20 km wide. This coastal platform was formed through surf zone erosion during periods when relative sea level was much higher than present. With the drop in sea level the marine platform was eroded by the rivers to form the impressive gorges of the Tsitsikamma region. Zones of weakness along joint planes in the TMQ allowed the Noetzie River to excavate the steeply incised river valleys (see Figure 2 & 3). Approximately 18 000 years ago the sea level was 100 m lower than at present and it is expected that the Noetzie valley was even deeper (~ 50 m). Increases in sea level to present day heights led to back-filling of the valleys.

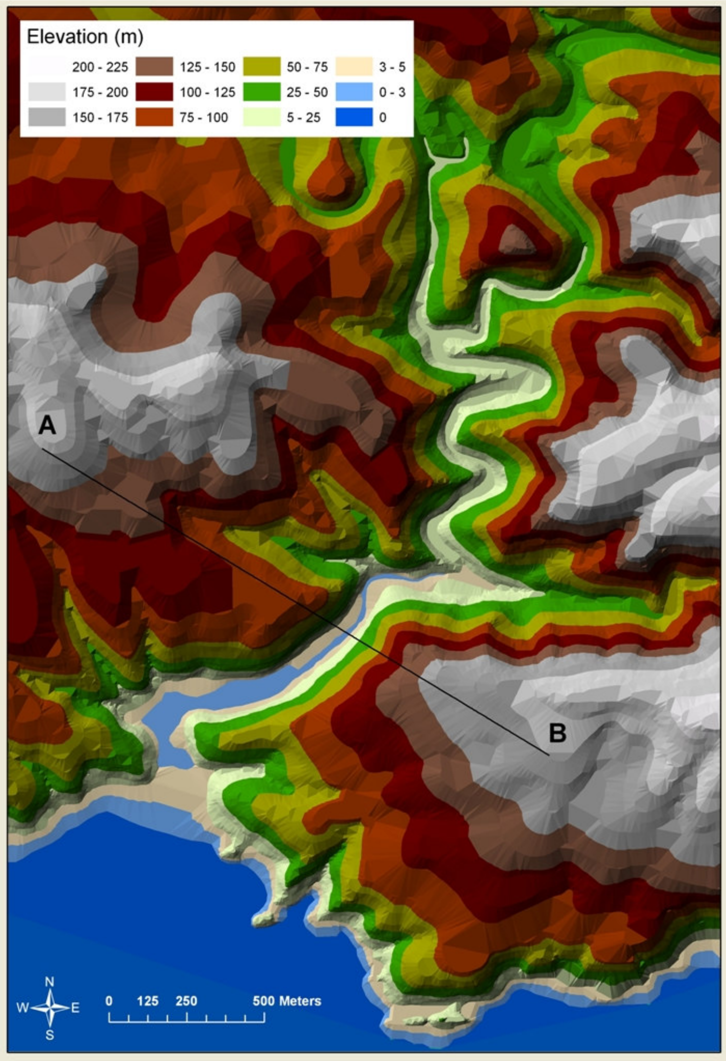


Figure 2. *Surface elevation map of the lower reaches of the Noetzie River (map was digitised in ArcGIS from the 1989 3423 AA 8 Noetzie orthophoto map).*

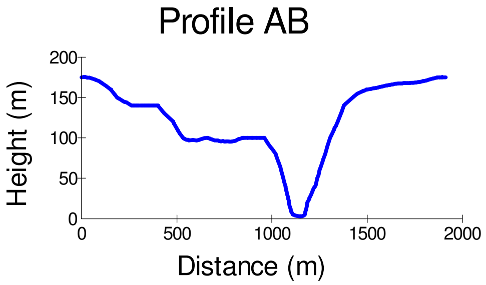


Figure 3*. Profile through valley from point A to B*

3.1.1.5. Climate

Temperature

The mean maximum and minimum temperatures for the Knysna area indicate mild summers and winters (Figure 4). Although high (during berg wind conditions) and close to zero temperatures have been recorded, the coastal zone is influenced by both the cooling and warming effects of the sea, resulting in an overall temperate climate.

Rainfall

The data presented in Figure 5 is the average of two rainfall recording stations in Knysna, i.e. Knysna Lake (2 m elevation) (34.0500º S; 23.0330º E) and Knysna Tnk (30 m elevation) (34.0500º S; 23.0500º E). Knysna receives rainfall all-year-round with peaks in autumn (March/April) and spring (August-November) (see Figure 5). The higher rainfall for Knysna in spring (dominant rainfall period) is a product of the late winter frontal systems together with the effect of orographic rain resulting from the proximity to the coastal mountains. The rain is mainly cyclonic and orographic while thunderstorms are rare. Winter rainfall is associated with the increase in cold fronts (east moving cyclones) passing over the coast. Autumn rain comes predominantly from the east (Stone *et al.* 1998). Hayes (2004) recorded 338 mm of rain for December 2004.

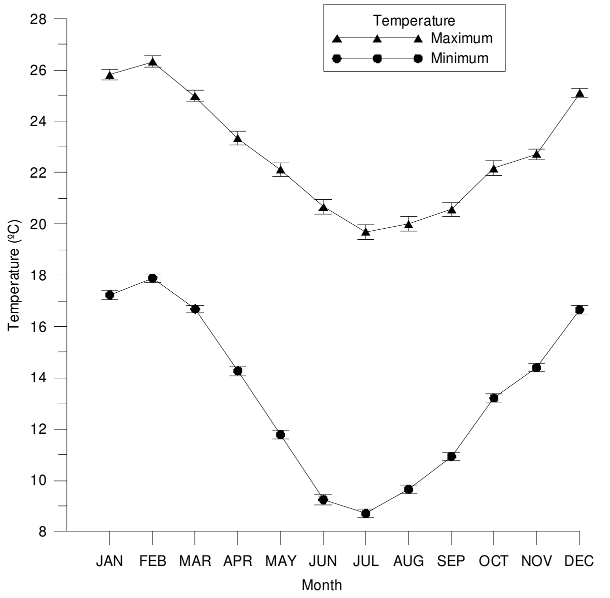


Figure 4. *Mean minimum and maximum temperatures over the last 8 years (1996 – 2004) (SA Weather Services).*

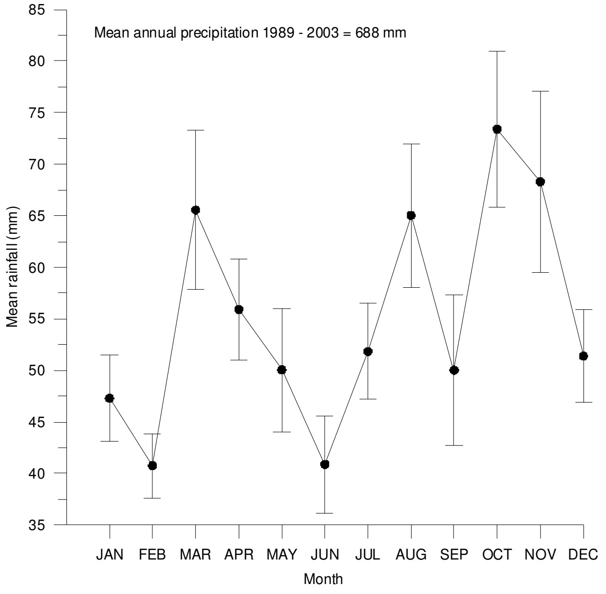
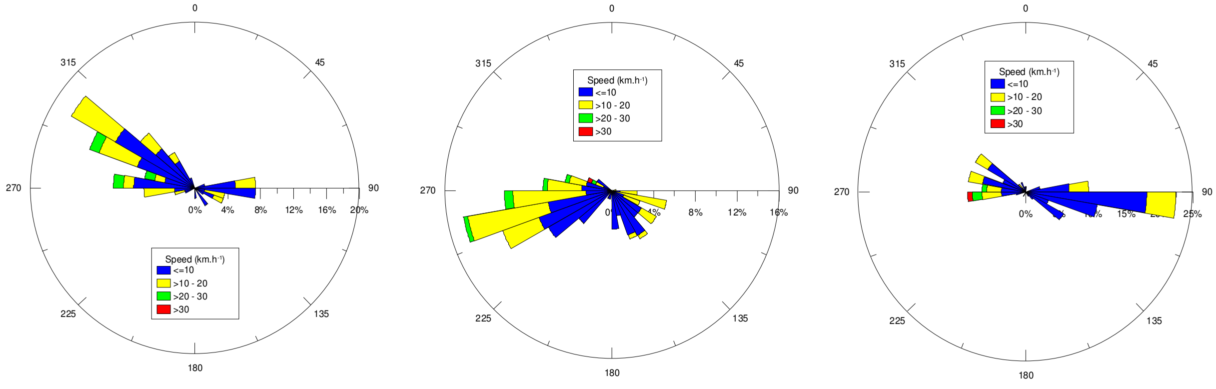


Figure 5. *Mean monthly precipitation over the last 15 years (1989 – 2004) (SA Weather Services).*

Wind

The Knysna area predominantly experiences westerly winds throughout the year. Precipitation along this coast occurs with the eastward passage of cyclonic low pressure systems or from the advection of cool moist air by the South Indian Ocean anticyclone towards low pressure cells inland. Easterly winds are reasonably well developed during March (Figure 6; responsible for the autumn rain) and September through to December (Figure 8 & 9). The strong easterly winds in summer are responsible for upwelling of cold water along the coastline. The South Atlantic and Indian anticyclones are responsible for the dominance of easterly winds in spring and summer. The dominance of north-westerly winds in winter (Figure 7) is the cause for the low rainfall experienced during that period. Berg winds occur periodically along the coast. These winds are extremely hot, dry and turbulent, composed of subsiding air masses that blow seawards from the interior and increase their temperature by descent and compression (Heydorn & Tinley 1980; Stone *et al.* 1998). Coastal lows appear a couple of times a month along this stretch of the coastline and although they have a relatively weak circulation they result in sharp changes in wind direction (to the SW), temperature and relative humidity (Heydorn and Tinley 1980).



a) b) c)

Figure 6. *Mean wind speed, direction and frequency over the last 8 years (1996 – 2004) for March; a) 08:00, b) 14:00 and c) 20:00 (SA Weather Services).*

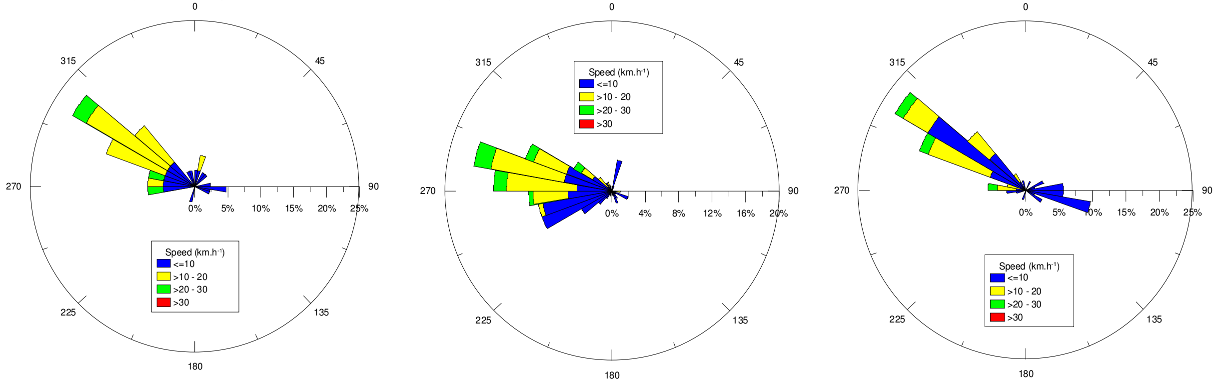


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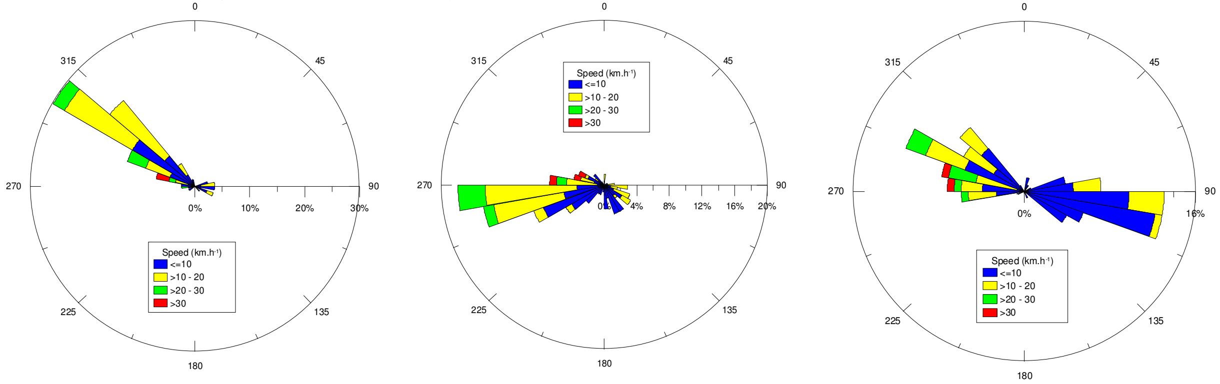
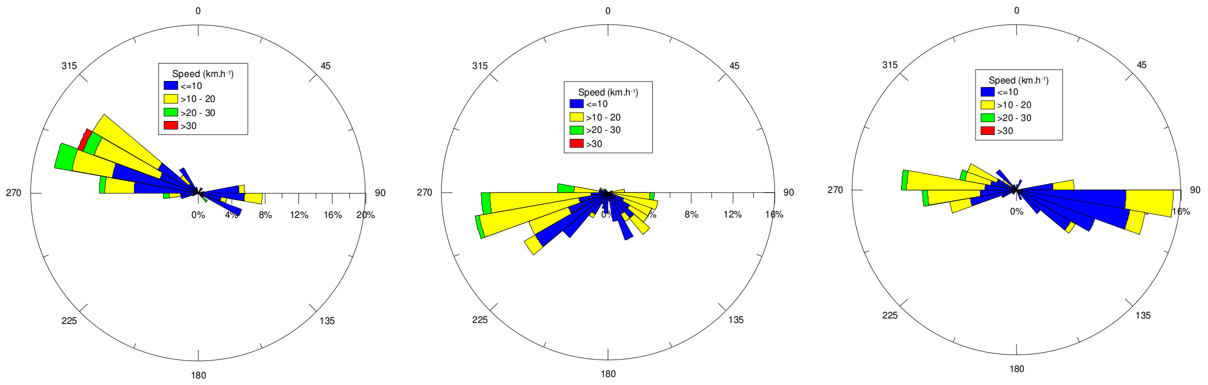
Figure 7. *Mean wind speed, direction and frequency over the last 8 years (1996 – 2004) for June; a) 08:00, b) 14:00 and c) 20:00 (SA Weather Services).*



a) b) c)

Figure 8. *Mean wind speed, direction and frequency over the last 8 years (1996 – 2004) for September; a) 08:00, b) 14:00 and c) 20:00 (SA Weather Services).*



a) b) c)

Figure 9. *Mean wind speed, direction and frequency over the last 8 years (1996 – 2004) for December; a) 08:00, b) 14:00 and c) 20:00 (SA Weather Services).*

Table 1. *Wind direction ranges applicable to Figure 6 – Figure 9.*

Direction	Degrees	Direction	Degrees
N	348.75 to 11.25	S	168.75 to 191.24
NNE	11.25 to 33.74	SSW	191.25 to 213.74
NE	33.75 to 56.24	SW	213.75 to 236.24
ENE	56.25 to 78.74	WSW	236.25 to 258.74
E	78.75 to 101.24	W	258.75 to 281.24
ESE	101.25 to 123.74	WNW	281.25 to 303.74
SE	123.75 to 146.24	NW	303.75 to 326.24
SSE	146.25 to 168.74	NNW	326.25 to 348.74

3.1.1.6. Run-off and flow records

The mean annual runoff (MAR) for the Noetzie River (K60G catchment) is 114 mm.y^{-1}, which is less than half that of the Knysna River (239 mm•y^{-1}) (K50B catchment) (Simpson pers. comm.). NRIO (1987) estimated the MAR at 4.78 × 10^{6} m^{3} or 123 mm•y^{-1}. Figure 10 shows the mean daily run-off during normal flows and during a simulated 20-year drought period. The trend in run-off is very similar to the Knysna River and correlates with the bimodal rainfall pattern of the region, i.e. peaks in April / May and September - November. From Figure 10 it was clear that abstraction of large volumes of freshwater (> 2 Ml•day^{-1}) from the Noetzie River would have a detrimental effect on the system during a drought. A freshwater requirement (Reserve) study has since been done on the river (not estuary), but we were unable to access the data in time to include in this report. NRIO (1987) estimated the

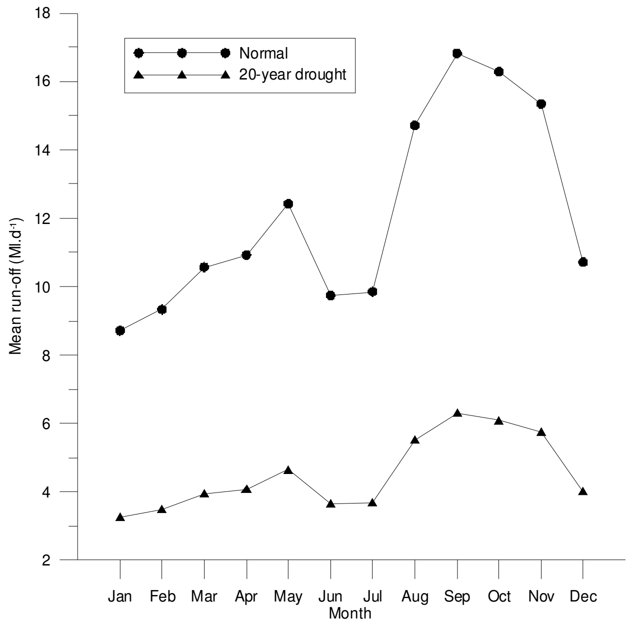


Figure 10. *Mean daily run-off (Ml•d^{-1}) during normal flows and equivalent run-off estimated during a 20-year drought (Simpson pers. comm.).*

simulated run-off / precipitation at 16 % (MAR = 123 mm; MAP = 769 mm), which is close to the 16.5% calculated from the other available information (MAR = 114 mm; MAP = 688 mm) (SA Weather Services; Simpson pers. comm.). The total discharge (measured in the river upstream of the head of the estuary) on 8 April 2005 was 0.075 $m^3 \cdot s^{-1}$.

3.1.2. Land ownership / uses

The Noetzie River and its tributaries flow mostly through pristine indigenous forest and State commercial plantations. A large section of private land is owned by Pezula Private Estate and the majority of the lower tributaries drain through their property. This property was previously forested but has been rezoned for residential development and has since been cleared of trees. The Department of Water Affairs and Forestry (DWAF) is the custodian of the State forest land, e.g. Kruisfontein Plantation that is in the process of being transferred to Cape Timber Resources by way of a long term lease (Stehle pers. comm.). DWAF is also the custodian of the Sinclair Nature Reserve that is in the process of being transferred to SANParks. DWAF will however retain a policy and regulatory function and will monitor and audit the transferred State forests (Stehle pers. comm.).

3.1.3. Obstructions and impoundments

There are no impoundments below the National Road and the only obstructions to flow are a few bridges in the Kruisfontein plantation.

3.1.4. Siltation

The Noetzie River and tributaries drain mostly quartzites of the Table Mountian Group and therefore naturally have a minimal silt load. The well vegetated catchment (both forested and natural) acts as a silt trap to minimise silt input into the estuary. Anthropogenic activities have in the past led to increased siltation of the river and estuary. Gravel roads in the plantations contribute small amounts of silt during rainfall events. Two major increases in siltation have occurred in the past. Both events have been of short duration and included the construction of the National Road (N2) and the Field of Dreams sports facility at Pezula Private Estate (Badenhorst 2004; Heydorn 2004; Stehle pers comm.; Newdigate pers. comm.). Other sources of sediment and probably pollution input into the river system are the township area in the vicinity of the N2, a gravel pit in the same region and run-off from the road between the N2 and the Noetzie. The latter might be more serious at present than

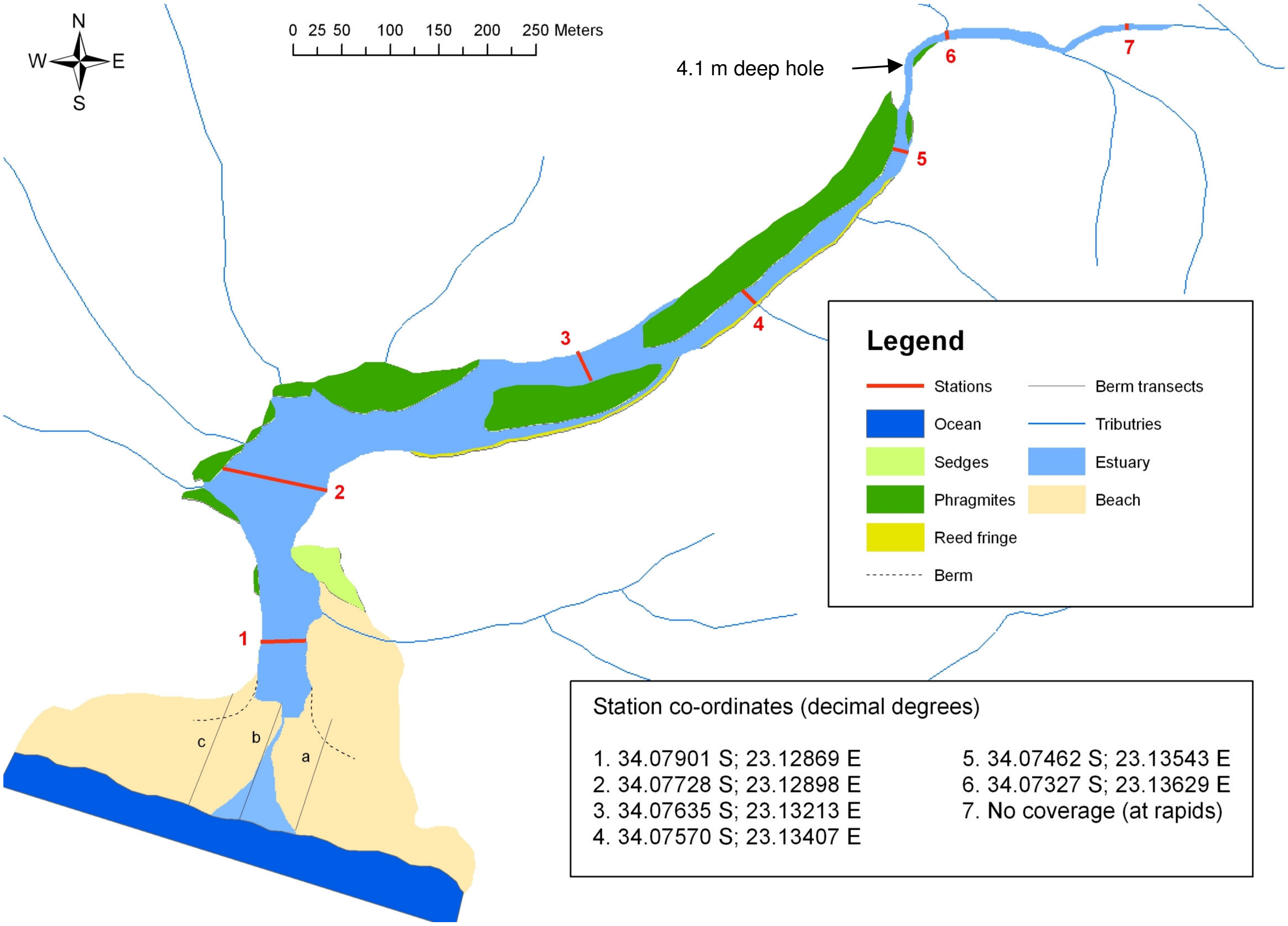
Plate 1. *Turbid water entering at Station 2 originating mostly from the Noetzie Road (photo courtesy of M. Newdigate).*

previously, because construction activities necessitate heavier traffic than normal (Heydorn 2004). Clay and silt particles will continue to enter the Noetzie River system from Pezula until construction comes to an end and rehabilitation and revegetation has stabilised the disturbed soil. Bopite Engineering Geologists (2004) reported six soil horizons in the FoD area, consisting predominantly of clay and sand (see Table 2).

Table 2. *The soil / rock horizons of the FoD site (after Bopite Engineering Geologists 2004).*

Material type	Description
Topsoil	Clayey sand with roots
Sandy aeolium	Grey-white loose sand
Clayey aeolium	Gleyed sandy clay
Hillwash	Quartzitic sandstone gravel in a sandy clay matrix
Alluvium	Quartzitic sandstone gravel in a sandy clay matrix
Residual Quartzitic sandstone	Completely weathered sandy clay, becoming highly to moderately weathered bedrock with depth.

3.2. Estuary



Station co-ordinates (decimal degrees)

1. 34.07901 S; 23.12869 E
2. 34.07728 S; 23.12898 E
3. 34.07635 S; 23.13213 E
4. 34.07570 S; 23.13407 E
5. 34.07462 S; 23.13543 E
6. 34.07327 S; 23.13629 E
7. No coverage (at rapids)

Figure 11. *Map of the Noetzie estuary indicating the position of the transects across the beach berm (a, b & c) and the stations in the estuary (1 – 7).*

3.2.1. Estuary characteristics

The Noetzie Estuary is an Intermittently Open Estuary (IOE) (previously described as temporarily open / closed estuaries – TOCEs). The state of the mouth (open / closed) is the single most important factor driving the ecology of IOEs. Mouth dynamics is in turn determined by the water balance that is largely controlled by river inflow. As a result, during the dry season and under low river flow conditions these estuaries are often closed off from the sea by a beach berm that forms at the mouth. Following periods of high rainfall and freshwater run-off, the water level inside the estuary will rise until it equals or exceeds the height of the sandbar at the mouth (Whitfield 1992). Breaching may then occur followed by a rapid decrease in water level in the estuary, often, as in the case of the Noetzie estuary, exposing large areas of substratum that may have been submerged for extended periods and colonised by a rich community of benthic flora and fauna. Decomposition of this organic material often leads to anoxic conditions developing in the exposed sediment that causes a foul smell. River conditions may briefly dominate the estuary during breaching events when flow rates significantly exceed MAR (Perissinotto *et al.* 2004). However, once the freshwater inflows decrease to that of or below the MAR, a typical estuarine open phase can occur with regular tidal exchange and seawater penetration into the middle and upper reaches. The tidal prism often remains small relative to the estuary's volume (Whitfield 1992). The open phase ends when the sand bar at the mouth is regenerated by along-shore and cross-shore sand movement in the surf-zone. This leads to another closed phase during which the only seawater inflow is provided by wash-over at the peak of the spring tide or during storm surges. Depending on the climatic conditions and rainfall patterns in the catchment areas, closure periods may vary naturally from days to months or even years. The Noetzie estuary is usually in the open or semi-closed phase and only closes completely for short periods (Newdigate pers comm.).

3.2.1.1. Mouth condition

The energetic wave climate of the Cape south coast means that direct wave action and associated cross-shore sediment transport plays an important role in the mouth dynamics of IOEs along this stretch of coastline. The maintenance of an open state depends on a complex balance between sediment removal by scouring and sediment deposition by wave action. The Noetzie Estuary is slightly perched (Figure 12) at elevations above mean sea level and as a result the tidal prism is usually small and the estuary may essentially drain most of its storage capacity when it breaches. The relationship between the closing forces (wave energy and sediment availability) and opening forces (river inflow and tidal flows) are unique for each individual estuary. The synergy of these forces defines the duration and frequency of open mouth conditions for Intermittently Open Estuaries (van Niekerk *et al.* 2002). Closing forces dominate in small IOEs because river inflow (baseflows) and tidal flows are low and these systems are therefore very sensitive to modifications in freshettes and floods, which facilitate breaching and scouring.

The major closing forces are:

- Wave energy, which is indicated by the co-variants: berm height, beach slope, grain size, breaker zone and wave direction; and
- Sediment availability, which is influenced by the longshore transport, sediment from the catchment, resident sediment available in the mouth region.

The opening forces can be defined as:

- River inflow, which consist of baseflows, freshettes and floods; and
- Tidal flows.

Open phase:

The mouth of the Noetzie Estuary was open during the field survey and flowed strongly into the sea. On 8 April 2005 the total discharge of the stream flowing from the estuary into the sea was measured at 0.263 $m^3 \cdot s^{-1}$ (SE = 0.024 $m^3 \cdot s^{-1}$; n = 3). On the same day the total discharge of the river above the river estuary interface zone (REI) was measured at 0.075 $m^3 \cdot s^{-1}$ (SE = 0.002 $m^3 \cdot s^{-1}$; n = 2). The discharge at the mouth was nearly 30% more than the discharge of the river into the estuary. There are several smaller tributaries (e.g. at Station 6) that also contribute to the volume of water flowing into the estuary, but it is believed that marine overtopping during spring high tide contributed most of the volume that was flowing out at low tide. The water level in the estuary increased by more than 30 cm during the night indicating a large intrusion of seawater during the spring tide. The slightly perched nature of the estuary (Figure 12 & 13) means that, even during the open phase, seawater intrusion is restricted to spring high tides and high sea conditions.

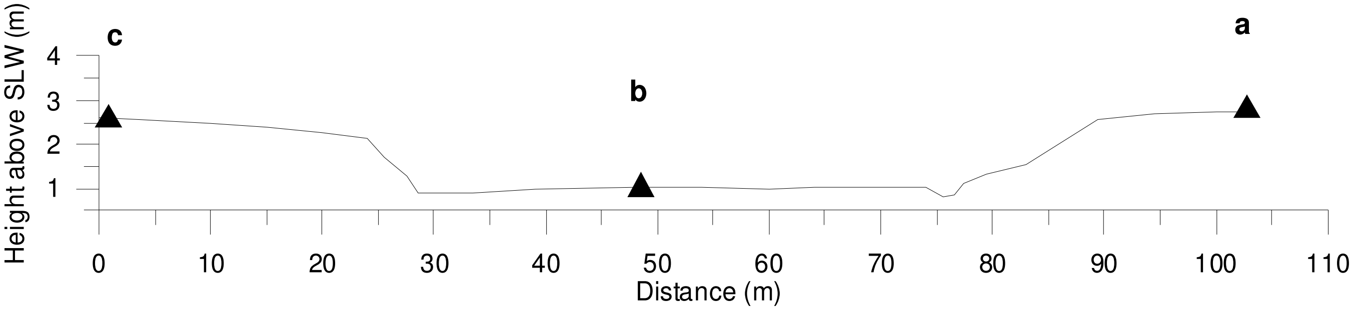


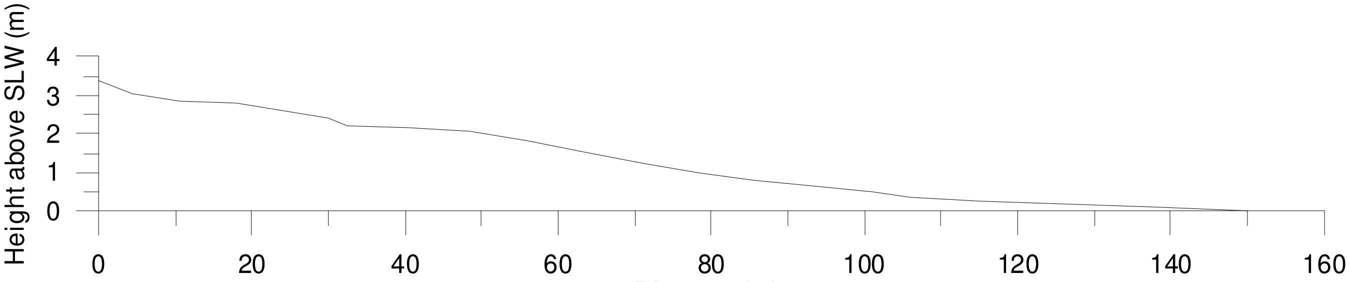
Figure 12. *Section across the mouth of the estuary showing the width of the channel and the height of the berm on either side (black triangles indicate the starting positions of the three transects across the berm to the spring low water mark; b is adjacent to the outflow channel).*

Closed phase:

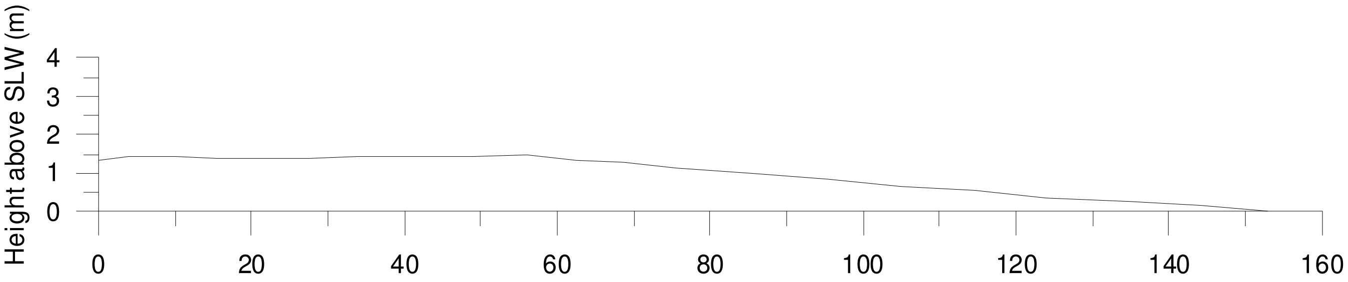
Figure 12 shows that the berm was elevated approximately 2.5 – 3.5 m above Spring Low Water (SLW) on either side of the channel and the channel itself was 1.5 m above SLW. To have breached the estuary would have had to be at least 1 m deeper than it was during the survey (open phase). During this survey a high discharge was measured at the mouth during spring low tide. Less than 7 hours later the mouth had closed completely. The water levels in the estuary remained high, so the closure of the mouth was not related to the water levels dropping below a certain threshold, but rather to an increase in the height of the berm at the mouth. During the survey period the estuary was slowly changing from the open phase to the semi-closed phase. The berm would continue to build up during every high tide and storm event, but the river flow would continue to maintain a channel to the sea (see semi-closed phase below). The mouth should normally only close completely during low river flows, i.e. December – February.

Semi-closed phase:

IOEs are often not fully open nor completely closed, and only a small outflow channel of a few metres wide and a few centimetres deep is present. This state is referred to as the semi-closed mouth condition (van Niekerk *et al.* 2002). In the semi-closed mouth state the mouth of an estuary is open but with limited sea water intrusion and very little to no tidal variation occurring. The state must also persist for a significant period (at least 14 days) to distinguish it from the normal transition phase between the open and closed mouth states. The semi-closed mouth state assists with overwash as it maintains low berm conditions. The semi-closed mouth state provides a conduit from the estuary to the marine environment. This is of great significance for the migration of juvenile fish and the export of invertebrate larvae. It is expected that the Noetzie Estuary falls within this state most of the year because of the relatively high river flow. The breaching process can give rise to significant morphological changes because the high breach outflows can scour large quantities of accumulated sediments from the mouth (Stretch & Parkinson 2005). The amount of sand removed from the berm during the last breaching event observed at Noetzie was greater than 7500 m^3 (calculated from the profiles in Figure 12 and 13).



a



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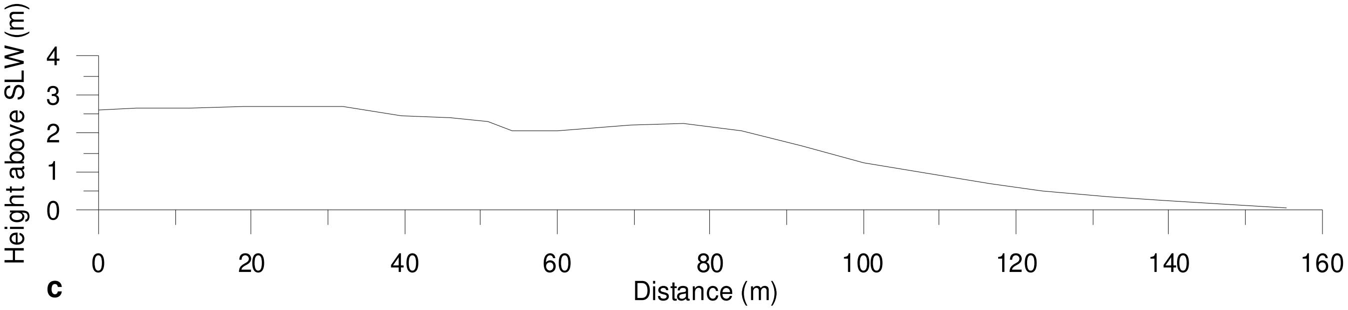


Figure 13. *Sections across the beach berm, a) east bank; b) mid-channel; c) west bank.*

3.2.2. Land ownership and uses

The land adjacent to the estuary is owned or under the jurisdiction of the following: sandy beach (DEA&DP), Sinclair Nature Reserve (DWAF / SANParks) and Noetzie town (Private & Knysna Municipality).

The estuary is currently used for recreation (non-motorised sport) and subsistence fishing (Plate 2). There are few permanent residents at Noetzie and rainwater collection is sufficient as a source of freshwater for most of the houses. Some of the larger castles required more water than the collected rainwater could provide and they are now abstracting freshwater directly from the Noetzie River at Station 6.

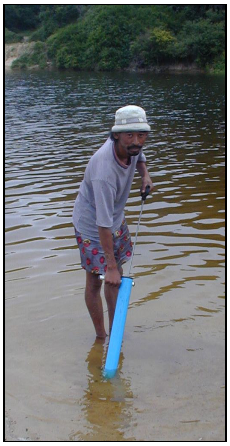


Plate 2. *Subsistence fisherman pumping prawns for bait.*

3.2.3. Conservation status

The Noetzie Estuary was rated by Heydorn (1986) as in a good condition and should be conserved in its present state. Turpie (2004) ranked the Noetzie Estuary as the 231st most important system in South Africa in terms of conservation importance (out of 256 functional estuaries). The conservation importance was calculated on the basis of size, habitat, zonal type rarity and biodiversity importance.

Criterion	Score
Estuary size	30
Zonal Type Rarity	10
Habitat Importance	10
Biodiversity Importance	18.5

The ranking of estuaries based on their conservation importance score developed by Turpie *et al.* (2002) and recently refined by Turpie (2004) appears discriminatory towards small estuarine systems with a low diversity and habitat variety. As an example, the adjacent, highly impacted, Piesang Estuary in Plettenberg Bay ranks 63rd because it has a higher diversity of habitats. There is also more information available on the Piesang Estuary compared to the Noetzie, which can influence the data used in the ranking. Although the Noetzie ranks very low in the current conservation importance ranking system, in terms of condition or health, the estuary is relatively pristine and all efforts should be made to keep it in that state.

The South African National Parks manages the Knysna National Lake Area. SANParks has direct management jurisdiction over the estuary up to the high water mark. SANParks also has a more limited jurisdiction within a broader area that covers Knysna, Brenton, Belvedere and Noetzie. Any proposed development within this area must have the approval of SANParks in addition to that of the local authority.

One of the goals from the SANP management plan for the Knysna National Lake Area, that includes the Noetzie Estuary, is the maintenance of ecological balance. The objective of this goal is:

- Tidal movement and water flow should not be disturbed.
- Volumes and quality of freshwater inflow should be protected.
- Erosion and sedimentation in the catchment should be controlled.
- Spilling of toxic fluids and waste must be strictly controlled.
- Identify critical species and processes and ensure that they are protected.

3.2.4. Abnormal flow patterns

Changes to flows into IOEs can have a significant impact on mouth dynamics and therefore on the overall functioning of the estuary. The increasing pressures on water resources have generally reduced the amount of flow into estuarine systems that implies an increasing proportion of time that IOEs are closed. Fortunately there is limited freshwater abstraction from the Noetzie River and its tributaries. Abnormal flow patterns will therefore be related to natural periods of drought and flooding. Irrigation of the Field of Dreams at Pezula Private Estate may increase the flow of water into the Noetzie River, but it is expected that the extensive wetland areas below the FoD will absorb most of the increased run-off.

3.2.5. Obstructions

There are no obstructions in the estuary itself other than the stone jetty close to the mouth. Recently some residents have started pumping freshwater from Station 6 to the houses in the lower reaches of the Noetzie Estuary. The set-up appears temporary as the pump is portable and the pipe has been left to float in sections of the estuary. The pipe does not form a serious obstruction to flow, but it is unsightly and should be removed from the channel. A more permanent route along the shore should be found if the abstraction is authorised by DWAF and the route approved by DEA&DP.

3.2.6. Physico-chemical characteristics of the water column

The regular alteration of open, closed and semi-closed states is responsible for fluctuating physico-chemical characteristics and a very dynamic system compared to that of permanently open estuaries. Mouth closure cuts off all tidal exchanges with the ocean, resulting in prolonged periods of stagnation during which salinity and temperature stratification may occur, along with dissolved oxygen and nutrient depletion of the water column. During mouth breaching, thorough mixing is accompanied by sediment scouring and often an increase in the silt load and turbidity of the water (Perissinotto *et al*. 2004). The only published data of physico-chemical conditions in the Noetzie Estuary was by Harrison *et al.* (1995). They only sampled at two stations in the lower reaches. Because of the paucity of data, the results from this survey (Table 4, Appendix A) will be compared with data from other similar systems.

3.2.6.1. Materials and methods

On the 7th of April 2005 i*n situ* measurements of salinity, temperature, dissolved oxygen (DO); pH and turbidity were made using an YSI 6-Series Multi-Probe (6600 Sonde with 650 MDS Display/Logger, incorporating the new YSI 6136 turbidity sensor). These measurements were repeated on the 8th of April 2005 to capture the influence of marine overtopping on the water column during the spring high tide of the previous evening. Visual clarity (using a Secchi Disc) and irradiance (using a LI COR underwater sensor) of the water column was determined on the 7th.

Benthic scrapes of the bottom material were collected, placed in pill-vials and frozen in the field for analyses of benthic chl-*a*. Water (500 ml) was collected at three depths (0 m, 0.5 m & 1 m; 3 replicates) with the aid of a pop-bottle and filtered through S&S GF 52 filter paper. The filter paper was wrapped in aluminium foil and stored in sealed plastic bags at 0ºC for later pigment analyses. Phytoplankton chl-*a* was extracted (for 24 h in 95% Ethanol) from the frozen filters (Strickland & Parsons 1972) and read on a high performance liquid chromatograph (HPLC). Phytoplankton chl-*a* was expressed as micrograms of chlorophyll *a* per litre of water ($\mu g \cdot l^{-1}$). For the benthic chlorophyll-*a*, 0.1 g was added to 4 ml of 95% ethanol and then stored for 24 hrs at 0°C. Once the chl-*a* had been extracted the samples were whirlimixed, filtered through glass-fibre filters (Whatman GF/C) and the extract was analyzed on a HPLC. Benthic chlorophyll-*a* was expressed as micrograms of chlorophyll *a* per gram of freeze-dried sediment ($\mu g \cdot g^{-1}$).

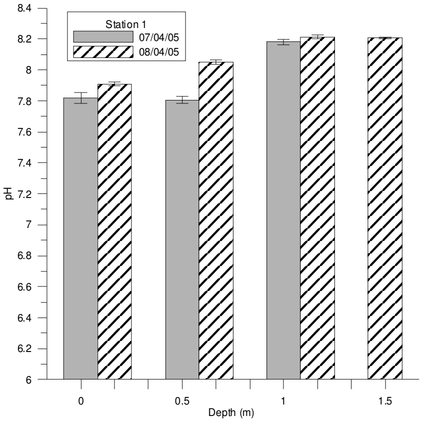
Bottom sediment was collected by a diver using a capped corer (100 g) to ensure that the fine material was not lost. Three replicates were collected from the west bank, mid-channel area and east bank at each station. The surface sediment was separated from the subsurface sediment for separate analyses of particle size and organic content. Organic content was determined using the ash-free dry weight method described in Briggs (1977).

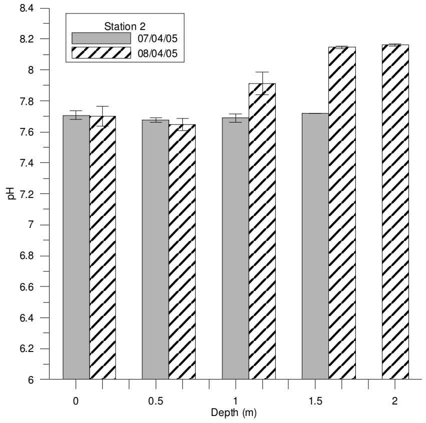
Particle size was determined by sieving (using 4000, 2000, 1000, 500, 355, 250, 180, 125, 90, 63 and 0 µm aperture sieves). Grain size distribution and statistics was calculated using GRADISTAT version 4.0 (Blott & Pye 2001).

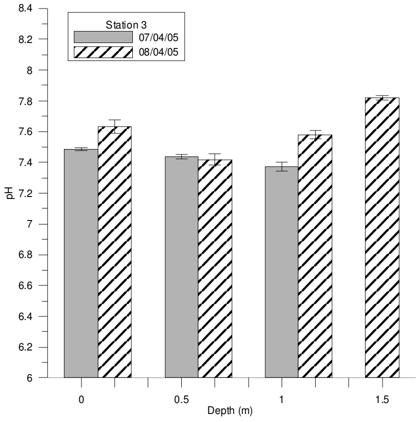
3.2.6.2. pH

A high variability in pH was recorded throughout the estuary, with a low of 6.26 in the upper reaches to a maximum of 8.21 at the mouth. The pH data indicates that the water column was relatively well mixed in the lower reaches on the 7th, with a significant decrease in pH at 1 m depth at Stations 4 and 5 and low pH readings at Station 6 and 7. Marine overtopping on the evening of the 7th resulted in stratification developing in the lower reaches, with the denser, higher pH, seawater sinking to the bottom. The middle reaches still showed stratification, but at a shallower depth. The lower pH river water was forced higher up in the water column by the denser seawater. The pH of the water at Station 6 was not significantly affected by the seawater intrusion. Station 7 had a significantly lower pH in the bottom water indicating that seawater had penetrated to the 1st rapids (REI zone for the Noetzie Estuary). Harrison *et al.* (1995) recorded pH values of 7.7 at Station 1 and 7.5 at Station 2 during an open phase.

The river water is acidic due to the humic acid leached from predominant fynbos vegetation in its catchment. The pH of seawater normally ranges between 7.9 and 8.2 and the range for the South African coastal zone is 7.3 – 8.2 (DWAF 1995). On both sampling dates the surface water pH at Station 6 was lower than at Station 7 further upstream. This indicates a significant water source to the Noetzie Estuary from this small tributary and the reason for the positioning of the freshwater pump.







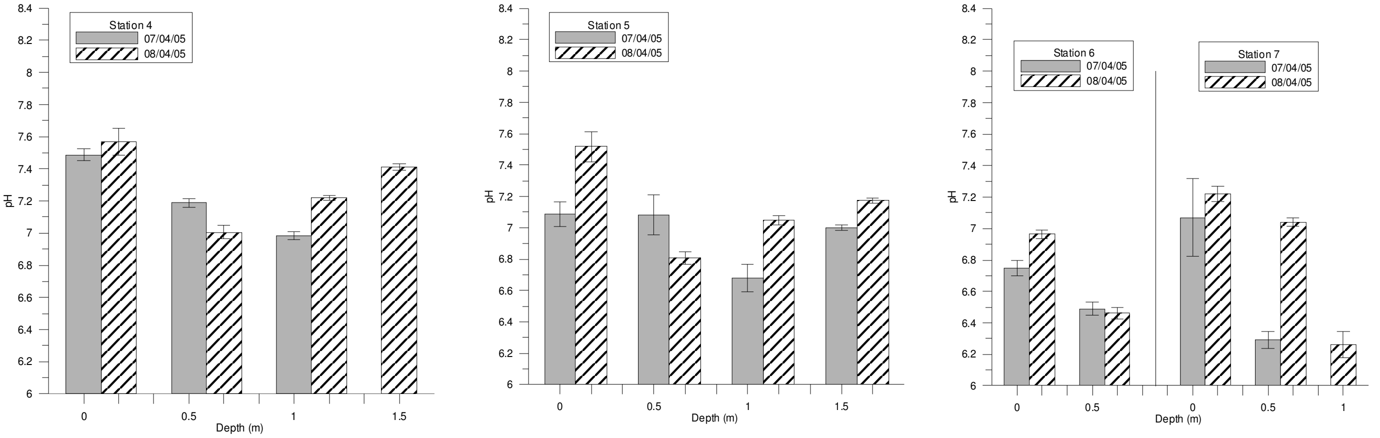


Figure 14. *pH profile during both sampling periods from Station 1 to 7.*

3.2.6.3. Temperature

The temperature in the Noetzie Estuary would be affected mostly by the seasonal climate and by mouth condition. Coastal upwelling events may be locally important and can result in major temperature changes in IOEs during open mouth conditions (Schumann *et al.* 1999). The surface temperature gradients established along the estuary when the mouth is open normally do not persist long after its closure. During their closed phases, IOEs virtually lack any temperature gradient along the length of the estuary (< 2ºC) (Perissinotto *et al.* 2004). Vertical temperature differences do persist longer though because of poor vertical mixing, which leads to the establishment of vertical density gradients, whereby the denser higher-salinity water from the sea during the open phase settle at the bottom of the water column.

The Noetzie estuary had a range of temperatures and vertical gradients along its length over the two-day period. These temperatures were linked to the stratification of the water column. The water flowing into the estuary from the Noetzie river had an average temperature of 18.4ºC and the seawater that entered the estuary on the 8th had an average temperature of 22.3ºC. In between was a range of temperatures linked to "old" estuarine water and new marine and freshwater inputs. The estuary was in a semi-closed state for most of the week prior to sampling and the sunny weather increased the surface water temperature to 23.55ºC. Seawater from the open phase occurred along the bottom of the water column and was, in the lower reaches, significantly colder than the surface waters. The temperature of the bottom saline water increased towards the middle and upper reaches and is indicative of "older" seawater that was being pushed up the estuary. In the region of Station 5, the surface water was significantly colder (5.2ºC) than the bottom water. Station 6 and 7 showed no stratification and had the same temperature as the river water. On the second day when marine overtopping took place, the mouth area was characterised by a well mixed water column that extended into the middle reaches. From station 4 upwards the surface water was significantly colder than the more saline deeper water. The warmer and more saline water was pushed up right to the REI at the first rapids and a significant vertical temperature gradient was evident at Stations 6 and 7. The denser nature of the warmer saline water prevented it from extending past the first rapids in spite of an increase in the water level of the estuary. Harrison *et al.* (1995) recorded surface and bottom temperatures of 10ºC at both their study sites.

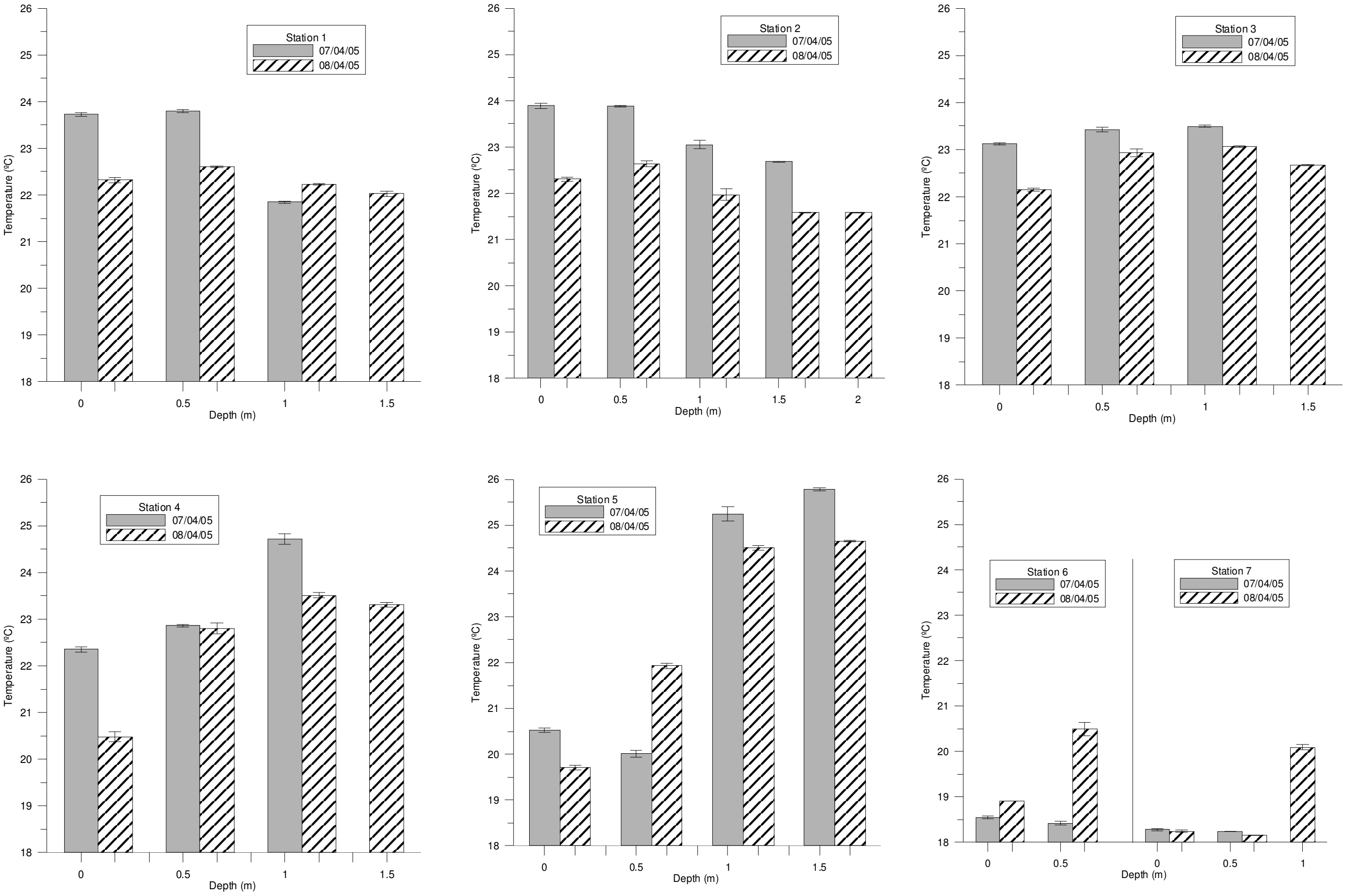


Figure 15. Temperature profile during both sampling periods from Station 1 to 7.

3.2.6.4. Salinity

Strong salinity gradients in the Noetzie Estuary indicate that the estuary has been in the open or semi-closed mouth phase for some time. Normally when IOEs are breached, riverine conditions prevail for some time, with freshwater replacing all resident water types. Horizontal salinity gradients tend to break down once the marine influence is cut off, although some contrast between the mouth and head areas may remain, depending on seepage and overtopping at the bar and the magnitude of freshwater input at the head. Mesohaline (5 – 18ppt) and oligohaline (0 – 0.5 ppt) conditions prevail during the closed phase in shallow systems (Perissinotto *et al.* 2004). The perched nature of the Noetzie estuary and the high seasonal rainfall of the Knysna area will normally result in near freshwater conditions prevailing soon after mouth closure. Limnetic conditions (0.1 – 0.5 ppt) may well prevail through most of the closed phase.

Strong vertical stratification was present from the mouth to Station 6 on the 7th April. The highest salinity of 23.24 ppt was measured at Station 2. Station 1 had a lower bottom salinity because of the mixing that takes place during marine overtopping. The salinity of the surface water increased from the head of the estuary to the mouth as the river water mixed with the denser seawater on the bottom. A vertical salinity difference between the surface and the bottom (1.5 m) water of 22 ppt was measured at Station 5. Seawater had a limited influence at Station 6 and 7 on the 7th. Marine overtopping on the 8th April created more pronounced vertical salinity gradients in the lower and middle reaches with higher values recorded throughout the water column. Once again the water with the highest salinity was found on the bottom at Station 2 (27.02 ppt). Increased water levels on the 8th meant that the more denser saline water could intrude past the shallow sill between Station 5 and 6 and extend all the way up to Station 7 where a bottom salinity of 10.66 ppt was measured. The first rapids were shallow enough, even with the elevated water levels on the 8th, to prevent further saline intrusion upstream. It is expected though that during the closed mouth phase the water should be deep enough to extend further upstream, but because of the low salinity conditions during that phase it is not expected that the REI will shift. Harrison *et al.* (1995) recorded salinities of 20 – 21 ppt during June 1990, indicating similar conditions as was experienced in April 2005.

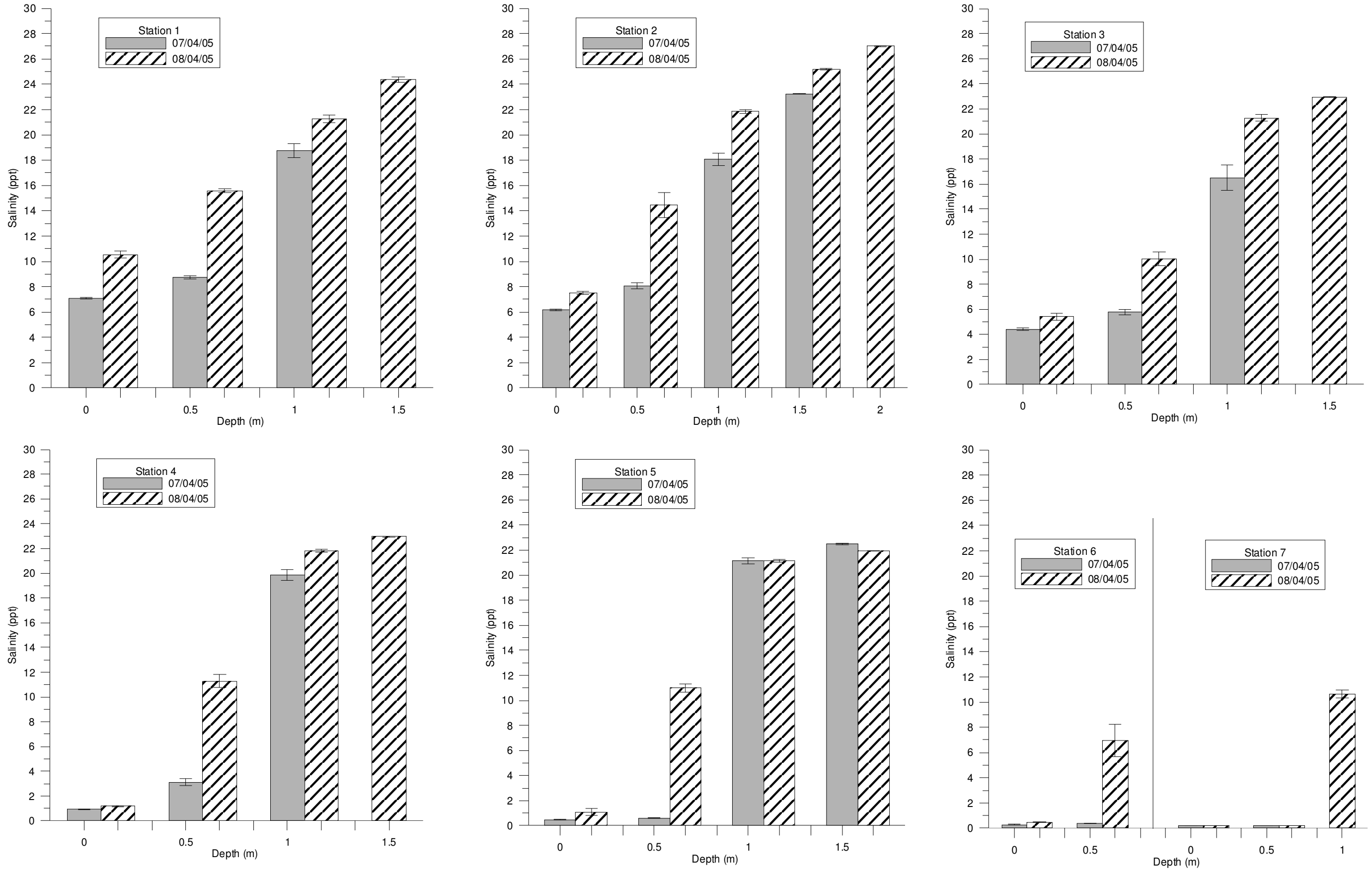


Figure 16. Salinity profile during both sampling periods from Station 1 to 7.

3.2.6.5. Dissolved oxygen

Dissolved oxygen is an essential requirement for most heterotrophic marine and estuarine life. In the absence of tidal currents and strong freshwater inflow, oxygen levels in closed estuaries may decrease in bottom waters, particularly if stratification develops and there is any organic accumulation on the bottom (Perissinotto *et al.* 2004). During the closed phase, the oxygen concentrations in the deeper layers of IOEs depend on the ratio of area to depth and water column circulation caused by wind (Day 1981). Narrow and sheltered estuaries, such as the Noetzie Estuary, can experience anoxic or hypoxic conditions, particularly towards the end of the closed phase, after a prolonged period of stagnation (Perissinotto *et al.* 2004).

Dissolved oxygen was measured during this survey, but unfortunately the instrument was not recording accurately enough and the results were therefore omitted. It is expected though that the recent seawater intrusions up the estuary would have increased the oxygen values of the bottom water. Personal observation of the estuarine bottom indicated a healthy benthic ecosystem and, although anoxic sediment was found at certain stations, it is believed that the oxygen content was high enough to sustain life. Organic matter, such as dead plant material that is readily available to micro-organisms (particularly aerobic heterotrophic bacteria) has the greatest impact on dissolved oxygen concentrations. These organisms utilise water column dissolved oxygen as they decompose the organic matter. Harrison *et al.* (1995) recorded oxygen levels of 10.7 mg·l^{-1} at Station 1 and 9.3 – 9.5 mg·l^{-1} at Station 2.

3.2.6.6. Clarity & turbidity

Numerous factors affect water clarity, e.g. sediment load from anthropomorphic sources and the concentration of algal cells in the water. Light is probably one of the most important components of an ecosystem and changes to the normal light regime will potential affect all species directly or indirectly. Plants require light to grow and other organisms, which feed on plants, are therefore indirectly dependant on light to produce their food. When light quality (colour) and quantity (clarity and penetration) are changed the effects can cascade throughout an ecosystem from the highest plants and animals right down to the micro-organisms. Measures of visual clarity, light penetration, and colour can be used to indicate how much an ecosystem is degraded by particle suspension.

Table 3. *Secchi depth at the 7 stations.*

Station	Depth (m)	On bottom
1	1.35	✓
2	1.21	
3	0.97	✓
4	1.15	
5	1.2	✓
6	0.5	✓
7	0.5	✓

The measured Secchi depth is an indicator of the relative clarity of the water. When Secchi depth is relatively low, less light penetrates the water column and is available as an energy source for photosynthesis. The secchi disk was visible to the bottom at stations 1, 3, 5, 6 and 7, indicating that sufficient light was available for benthic microalgae to photosynthesise. Stations 2 and 4 had the lowest water clarity and Station

1 had the highest (Table 3). In the Tsitsikamma Estuary, Secchi depths greater than 2 m have been reached. This is a similar system to the Noetzie Estuary as it is small and intermittently open with dark stained water.

Turbidity is usually measured in Nephelometric Turbidity Units (NTU), which provide a measure of the capacity of light to penetrate through water. The turbidity values (Table 5, Appendix A) showed large variability, but in general were highest closer to the bottom. Station 2 and 4 had significantly higher bottom turbidity readings compared to Stations 1, 3 and 5, which supports the Secchi depth data. The high turbidity values at Station 6 and 7 were related to the inflow of the river and tributary over a shallow rocky substrate causing re-suspension of settled fine material.

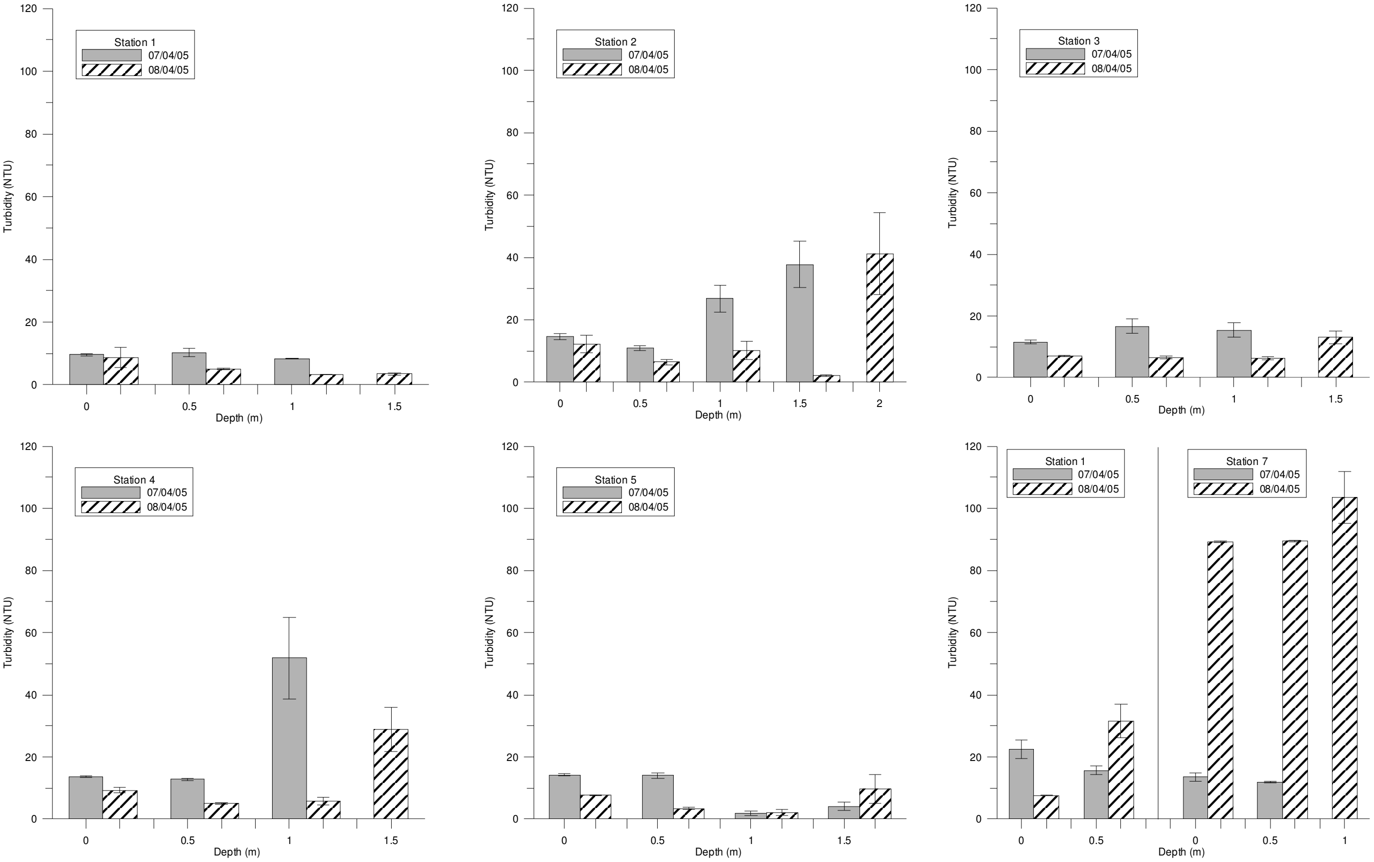


Figure 17. *Turbidity profile during both sampling periods from Station 1 to 7.*

3.2.6.7. Irradiance

Photosynthetic available radiation (PAR, 400 – 700 nm) in IOEs may vary widely, in response to weather conditions, time of day and suspended solids in the water (Perissinotto *et al.* 2004). Light attenuation (Kd) in the water column shows a positive relationship with rainfall, reflecting the increase in turbidity as a result of run-off from the catchment area. During the closed phase of an IOE, Kd may vary between 0.4 and 3 $\cdot m^{-1}$, with > 1% of the surface light intensity reaching the bottom of the water column at any time (Perissinotto *et al.* 2004).

Table 4. *Light attenuation (Kd) and percentage of surface light reaching the bottom.*

Station	Kd (·m^{-1})	%
1	2.51	34.70
2	3.85	24.54
3	1.61	51.56
4	4.03	20.94
5	2.98	30.37
6	0.77	77.66
7	0.77	78.94

The diffuse vertical attenuation coefficients of downward irradiance (Kd) were determined from the surface to the bottom using the following equation: Kd=ln(E(z2)/E(z1))*(z1-z2)-1, where Kd is the diffuse vertical attenuation coefficient of downward irradiance between depth 1 and depth 2, E is the energy of irradiance reaching depth 1 and 2, and z1 and z2 is the depth where irradiance measurements are done. High coefficients refer to strong attenuation of irradiance, e.g. a value of 1m^{-1} indicates very turbid water and an attenuation of about 63% per meter. Perissinotto *et al.* (2004) reported Kd values of 8 – 29 ·m^{-1} during increases in silt loading and turbidity. Aphotic conditions at the sediment surface and in part of the water column will result if the percentage of surface light reaching the bottom is less than 0.1%. The photosynthetic efficiency of the microalgae in the water column and in the benthos will decrease substantially if the depth of the euphotic zone drops to values much shallower than the estuary's total depth. The Noetzie Estuary did not have a high silt load during the sampling period of 7 - 8 April 2005. Stations 2 and 4 had higher turbidity, lower water clarity and higher light attenuation than any of the other stations. This could be attributed to the fact that the two stations occurred adjacent to tributaries flowing into the Noetzie Estuary. The effect is not as pronounced at Station 6 and 7 due to the shallow water depth, strong vertical mixing and fast flowing bottom currents.

3.2.6.8. Pollution

Trace metals

No data are available and no analyses were done during this survey. It is expected though that because of the relatively natural state of the catchment there would be no anthropogenically elevated concentrations of trace metals.

Nutrients

River inflow is the major source of inorganic nutrients to the water column of IOEs. Immediately after closure, inorganic nutrients (particularly N) in the water column are sufficient to trigger significant phytoplankton production, becoming the dominant primary food source for a limited period. Water column nutrients then become depleted, because there is no significant *in situ* regeneration of inorganic nutrients into the water column of small IOEs. During prolonged closure periods benthic primary production, driven by ground water/sediment inorganic nutrient loading, becomes the important primary food source. Harrison *et al.* (1995) recorded phosphate (PO_4^{3-}) values between 0 and 20 mg·l^{-1}, nitrate (NO^3-N) values ranging from 0 to 220 mg·l^{-1} and no detectable concentrations of ammonia (NH_3) in the Noetzie Estuary.

Sewage

No water quality measurements were taken during this survey. Harrison *et al.* (1995) recorded *Escherichia coli* counts of $8 \cdot 100\ ml^{-1}$. The DWAF (1995) guidelines state that *E. coli* counts should be below $130 \cdot 100\ ml^{-1}$ for recreational use. Septic tank water will not influence the mineral nutrient quality or the *E. coli* counts of the estuary water, provided there is no surface flow. This is because the high density of such seepage water causes it to flow below the bottom of the estuary and the bacteria are filtered out after passing through 200 mm of normal compacted soil. Harrison *et al.* (1995) reported that the overall water quality was very good.

3.2.7. Sediment characteristics

Sedimentation of estuaries is an important issue that is intrinsically related to hydrodynamics. The breaching of IOEs is thought to play an important role in maintaining an approximate equilibrium with respect to sedimentation. Changes to breaching patterns due to flow changes can be expected to have severe impacts on the morphology of the estuaries concerned (Perissinotto *et al.* 2004). Sediment scouring is one of the main features that characterise the onset of the open phase in IOEs. Large amounts of sediment (both fluvial and marine origin) accumulate during the closed phase and this result in generalised shoaling. The process is reversed regularly by breaching events at the mouth, during which the fluvial flood is sufficient to remove a substantial proportion of the accumulated sediment (Reddering & Rust 1990). The average catchment sediment yield of the Noetzie Estuary is $5850\ tons \cdot y^{-1}$ at an average rate of $150\ tons.km^{-2} \cdot y^{-1}$ (NRIO 1987). Most of this sediment consists of large quartzitic grains. Finer grains (clays & silt) are weathered material from siltstone, mudstone and clay of the Enon Conglomerate Formation to the west of the Noetzie River. These sediments are characteristically reddish to yellow.

3.2.7.1. Sediment organic content

Estuarine sediments include organic and mineral particles of a wide range of sizes and composition. The organic content of the sediment tends to increase with the fineness of the deposit. Marine sediment input is almost exclusively inorganic and occurs through tidal inflow, barrier overwash and wind action (Cooper *et al.* 1999). Fluvial inputs include a large organic component, mainly in the form of plant detritus, and an inorganic component of sand, silt and clay that is generally proportional to the rainfall rate, the degree of soil erosion in the area, the geology of the catchment and its agricultural management (Perissinotto *et al.* 2004). Estuarine sediment in Cape IOEs is mostly of marine origin (Reddering & Rust 1990). The marine influence in the Noetzie Estuary is limited to the mouth region (Figure 18). Marine sediment with a low organic content extends to the western and eastern banks of Station 2 (Figure 18). The surface sediment in the middle channel had a significantly higher organic content than the subsurface sample and the rest of the sediment in the mouth area. Station 3 had a low organic content along the western bank and the middle reaches where rock and large quartz grains were dominant. The eastern bank of station 3 (adjacent to the reed bank) had a significantly higher organic content in

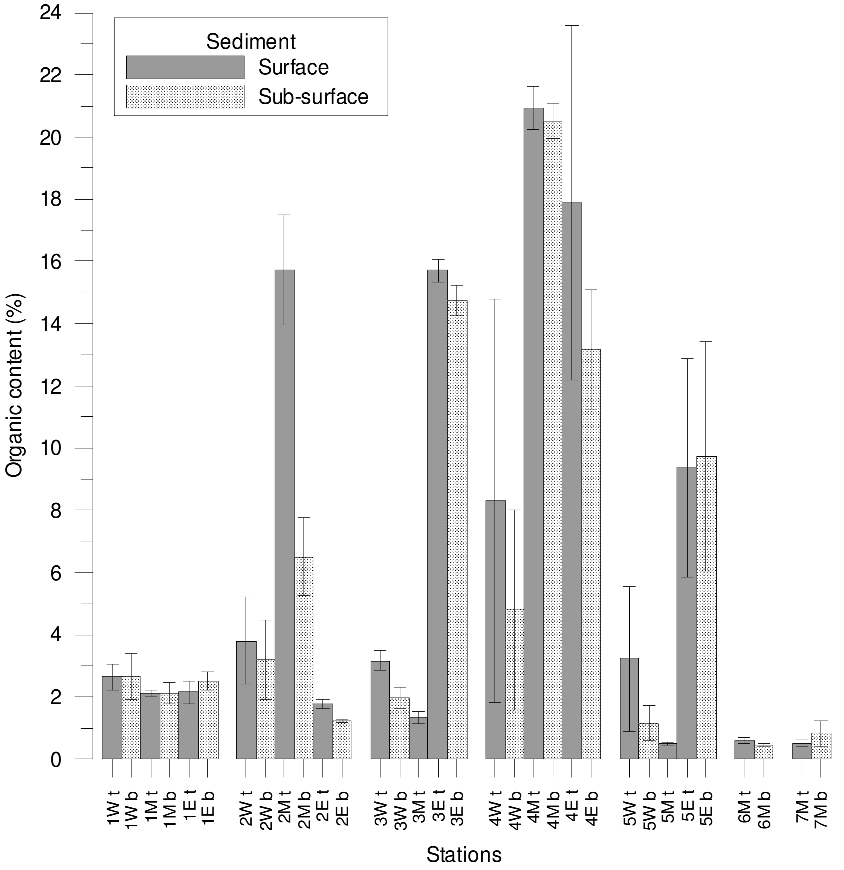


Figure 18. *Surface (0 – 0.05 m) and subsurface (0.05 – 0.15 m) sediment organic content of the Noetzie Estuary at 7 stations from the mouth (Station 1) to the river (Station 7) (t [top] = surface sediment; b [bottom] = subsurface sediment; W = west bank; M = mid-channel; E = east bank).*

both the surface and subsurface sediment. No significant difference was recorded between the sediment of Station 4 and Station 2 middle reaches and 3 east bank. Station 5 had a high organic content on the east bank. Low sediment organic contents were measured at Station 6 and 7, probably due to the shallow well mixed water and fast flow rates. From Figure 18 it is clear that organic material is generally absent, with the exception of Station 4, from the mid-channel where it is mostly gravel and large rocks. The organic content of the sediment is highest where the flow rate is lowest, i.e. shallow banks on channel bends (5E), reed beds (3E) and deep channels (2M). The high values recorded at Station 4 could be related to the close proximity of a tributary stream.

3.2.7.2. Sediment particle size

Grain size is the most fundamental property of sediment particles, affecting their entrainment, transport and deposition (Blott & Pye 2001). During the open phase, the typical sediment distribution in IOEs is an abundance of coarse/medium sand (0.25 – 2 mm) towards the mouth and a predominance of silt (4 – 63 µm) and mud/clay (< 4 µm) in the middle and upper reaches (Day 1981). Grains of different sizes are found in any sediment type, however, well sorted sediments tending towards a homogeneous type are typical of high current velocity conditions (Perissinotto *et al.* 2004).

Station 1:

The sediment of Station 1 was characterised by a high percentage of well sorted fine grained sand and a minimal concentration of silt (< 0.5%) and clay (<0.1%) (Figure 19 & 20; Appendix B, Table 6). The sediment is of mostly of marine and aeolian origin.

Station 2:

The sediment of Station 2 was very similar to that of Station 1, with the following exceptions: The subsurface sediment of the west bank (concave bank) consisted of slightly gravely sand, a result of the main current impinging on the concave bank, thereby eroding the finer material. Finer alluvium is deposited on the convex side, explaining the finer material at depth on the east bank. The mid-channel region was characterised by a muddy sand on the surface consisting of 2.4% clay and 11.8% silt (Figure 19 & 20; Table 7).

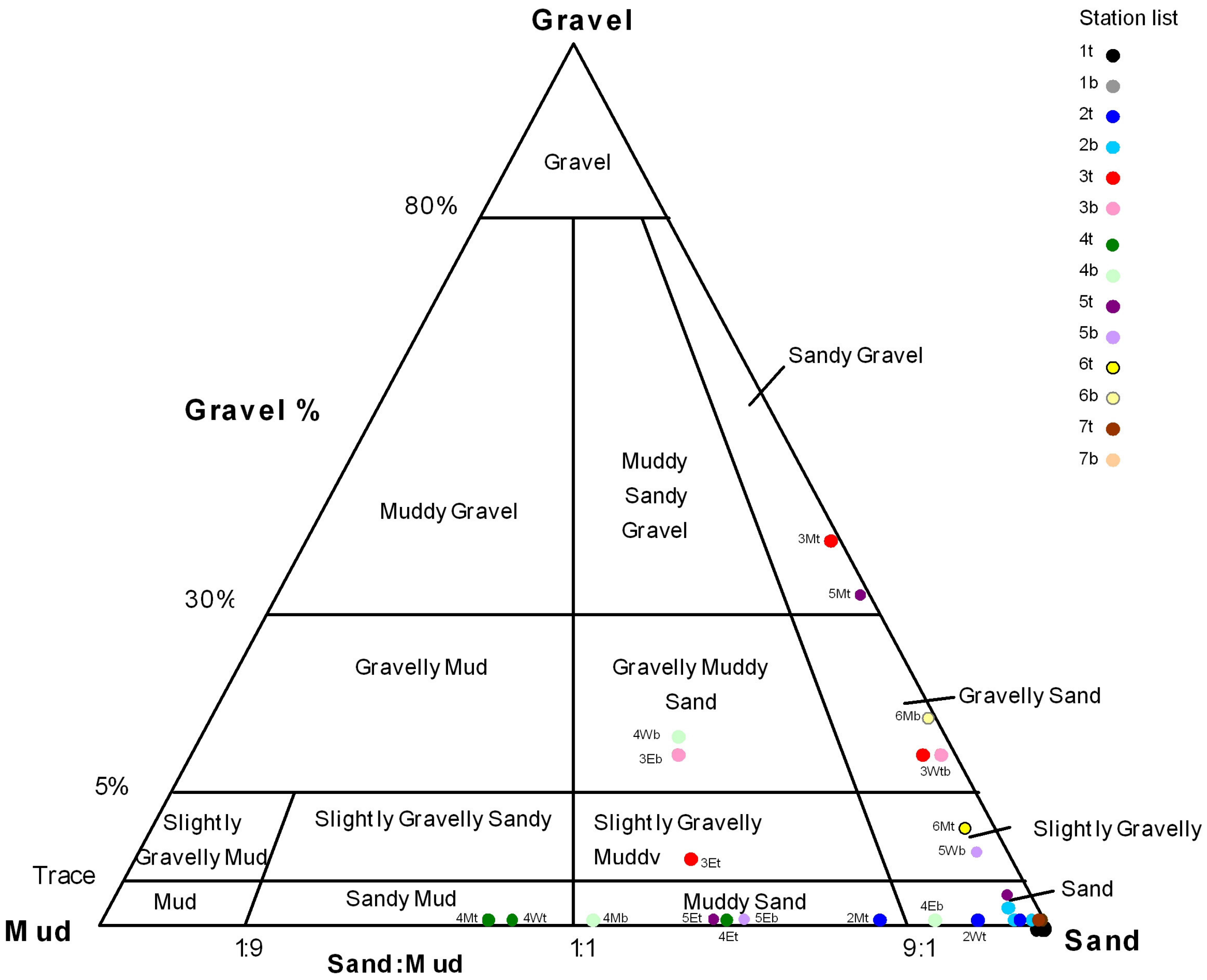


Figure 19. Gravel-sand-mud ternary diagram of the Noetzie Estuary sediment. (E = east bank, W = west bank, t = surface sediment, b = subsurface sediment).

Station 3: (Figure 19 & 20; Appendix B, Table 8).

The west bank of Station 3 consisted of gravelly sand (~ 11% gravel) and the middle reaches of sandy gravel (39.9% gravel). The surface sediment of the eastern bank belongs to the textural group "slightly gravely muddy sand" and 34.5% consisted of fine silt and clay particles. The subsurface sediment had a similarly high mud content, but also a higher gravel fraction.

Station 4: (Figure 19 & 20; Appendix B, Table 9).

The surface sediment of Station 4 was characterised by a high ratio of sand to mud. All the samples, with the exception of the subsurface soil on the east bank, had a high concentration of silt (29.7 - 62.6%). Very fine gravel was only present in the subsurface sediment of the west bank.

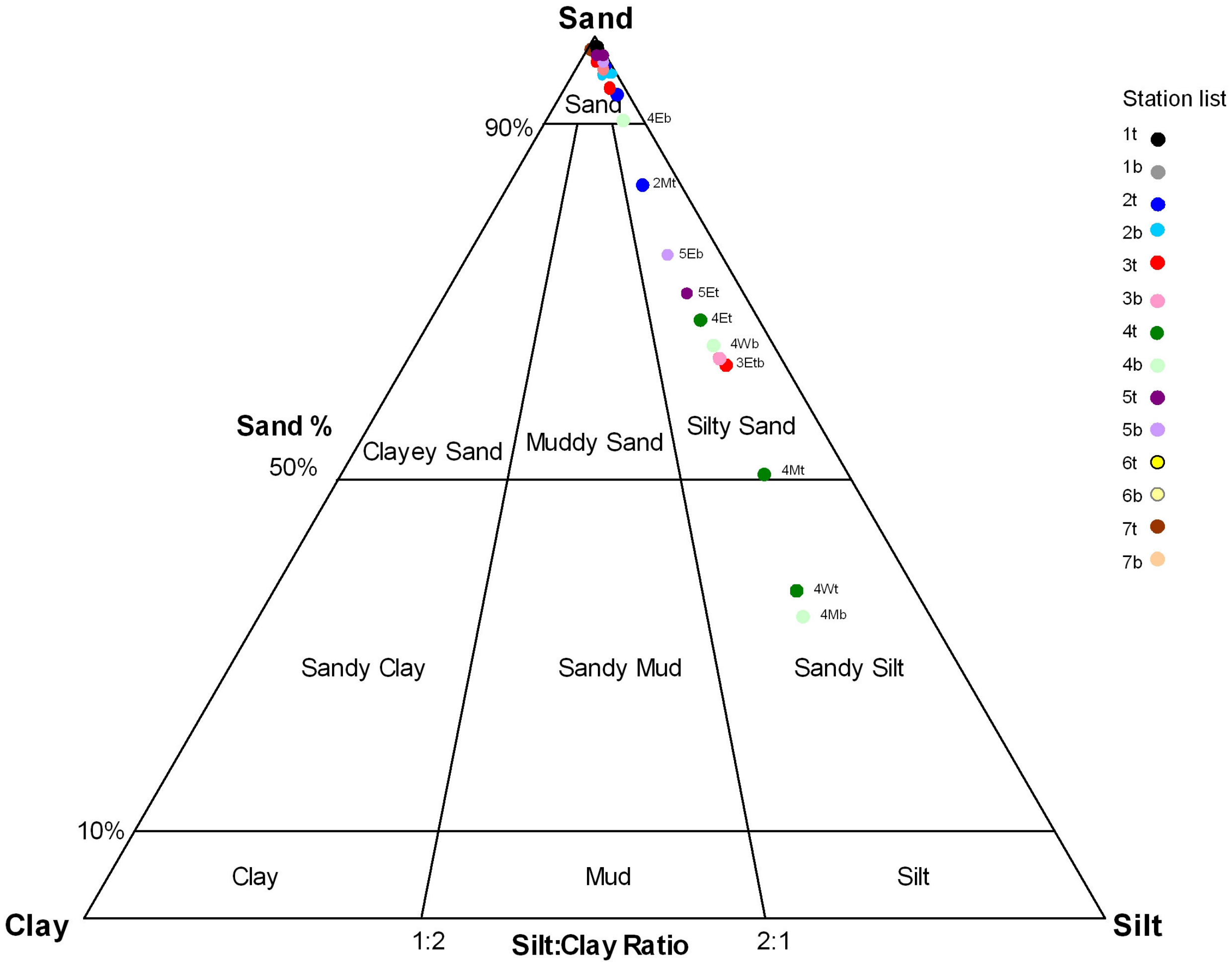


Figure 20. *Sand-silt-clay ternary diagram of the Noetzie Estuary sediment.(E = east bank, W = west bank, t = surface sediment, b = subsurface sediment).*

Station 5: (Figure 19 & 20; Appendix B, Table 10).

The west bank of Station 5 consisted of slightly gravely sand with a high (> 50%) fraction of fine sand. The mid-channel region consisted of sandy gravel with virtually no fine material (reason why no subsurface sample could be collected). The east bank consisted of poorly sorted muddy sand (25% silt, 5% clay & 70% medium to fine sand) throughout the depth profile.

Station 6: (Figure 19 & 20; Appendix B, Table 11).

The sediment of Station 6 consisted of slightly gravely sand on the surface and gravely sand below that. The dominant fraction was medium sand.

Station 7: (Figure 19 & 20; Appendix B, Table 11).

The surface and subsurface sediment consisted of moderately well sorted medium grained sand (>99% sand).

These data will serve as a baseline for future studies that may need to assess changes over time.

4. Biotic characteristics

4.1. Flora

4.1.1. Microalgae

Chlorophyll is the pigment that allows plants to convert sunlight into organic compounds (photosynthesis). Chlorophyll-*a* (chl-*a*) concentration is often used as a general indicator of plant biomass because all plants, algae and cyanobacteria contain about 1-2% (dry weight) chlorophyll-*a.* Excessive amounts of chl-*a* in the water column indicate the presence of algal blooms. Too little chl-*a* would mean that not enough "fish food" is available to fuel the food web. Excessive nutrients can stimulate nuisance algae blooms, resulting in reduced water clarity, reduced amount of good quality food and depleted oxygen levels in deeper water.

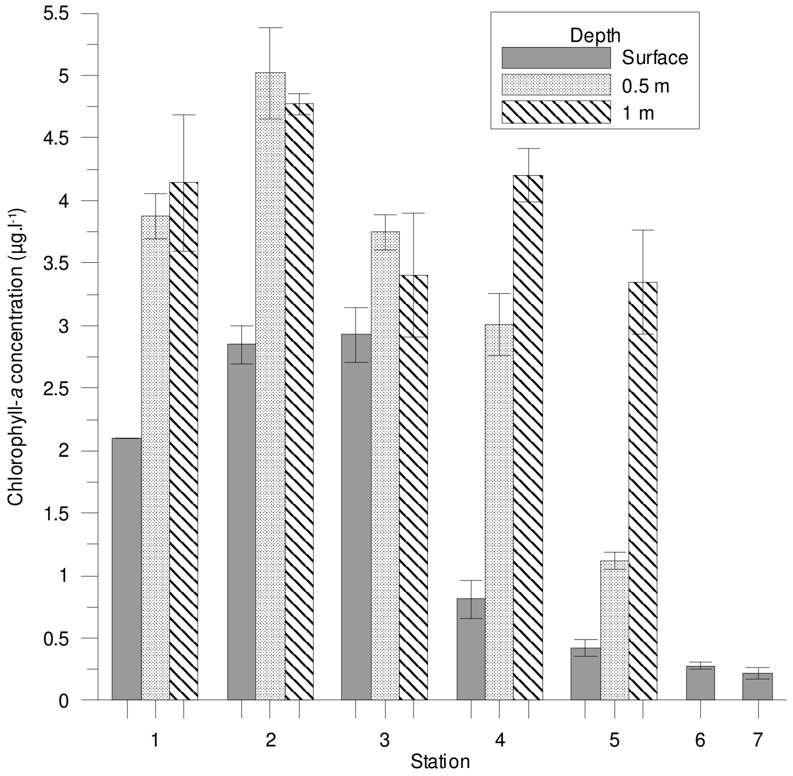


Figure 21. *Water column chlorophyll-a along 7 stations.*

Microalgae are key primary producers in IOEs, and while phytoplankton biomass in these systems is often lower than in permanently open estuaries, microphytobenthic biomass has been found to be much higher in IOEs (Perissinotto *et al.* 2004). A similar result was found in the Noetzie Estuary where the benthic chl-*a* values were several orders of magnitude higher (Figure 22) than the phytoplankton chl-*a* concentrations (Figure 21). Phytoplankton chl-*a* concentrations were lower (not always significantly so) in the surface water compared to the bottom water. This could be attributed to the faster flowing freshwater flowing over the denser more stable saline bottom water. The calmer water at depth is more suitable for phytoplankton production. The river water flowing into the estuary (Station 6 and 7) had very low chl-*a* concentrations, probably because of the turbulent flow over the shallows. The slightly higher chl-*a* at Stations 1 and 2 could possibly be as a result of nutrient introduction via seawater.

The Noetzie Estuary is probably a benthic driven system with detrital input from the streams and fringing reeds driving the food chain. Microphytobenthic biomass has been shown to contribute a significant fraction of the total primary biomass in IOEs (Perissinotto *et al.* 2004). This could be attributed to low turbidity and current speed, a more stable sediment and salinity environment and a large nutrient pool available within the substratum (Adams & Bate 1999). The benthic chl-*a* concentrations in the Noetzie Estuary increased from the mouth to the head of the estuary. This distribution is related to the stability of the benthic material onto which the benthic microalgae attach themselves. Station 1 and 2 consisted mostly of fine marine sand that is frequently reworked by marine overtopping, breaching events, floods, etc. Most of Station 3 consisted of gravel and rocks forming stable habitats for benthic microalgae, hence the high concentration. There was no significant difference in chl-*a* concentration between Station 4 and 5 and, although these areas were characterised by muddy sediment, they had a relatively high benthic biomass. This could be related to the high organic content of these areas and the possible higher nutrient levels associated with it. In the upper reaches there were large boulders with finer sediment in the interstitial spaces. These large rocks form ideal habitats for epipelic (rock-loving) diatoms to settle.

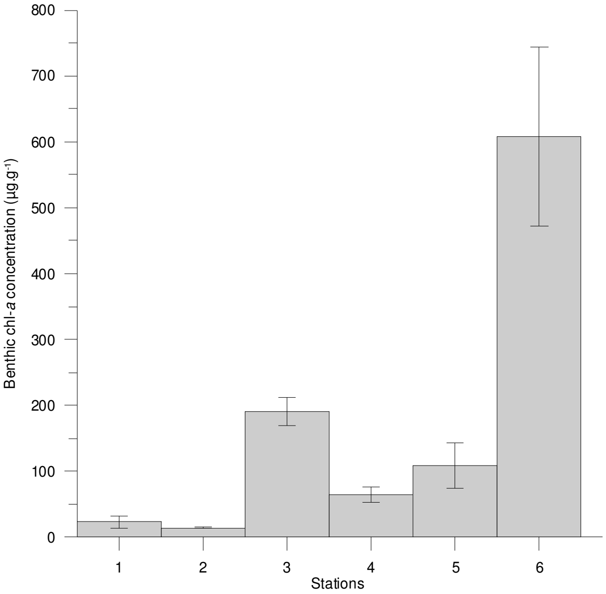


Figure 22. *Benthic chl-a concentration at six stations.*

4.1.2. Macroalgae

Only filamentous algae were recorded in the Noetzie Estuary. Dominant species found were *Ulva intestinalis* (previously *Enteromorpha intestinalis*), *Compsopogon* sp., *Cladophora* sp., *Stigeoclonium* sp. and *Vaucheria* sp.

4.1.3. Macrophytes

4.1.3.1. Submerged

During the closed phase of IOEs, absence of tidal currents, cleaner water and greater light penetration may result in the proliferation of submerged macrophytes. These may be brackish or freshwater species depending on the salinity. Only one submerged macrophyte species was found in the Noetzie Estuary, i.e. *Eleocharis* sp. (species still need to be identified). This species was only recorded at Station 6 growing in between the rocks in the shallow fast flowing waters and submerged species of this genus is indicative of oligotrophic (low nutrient) water. The presence of this species and the low diversity in submerged macrophytes and macroalgae in the Noetzie Estuary indicates that the system was oligotrophic at the time of sampling. Fragments of *Zostera capensis* (eelgrass) were found in the mouth region but these were washed in on the high spring tide and probably originated in the Knysna Estuary.

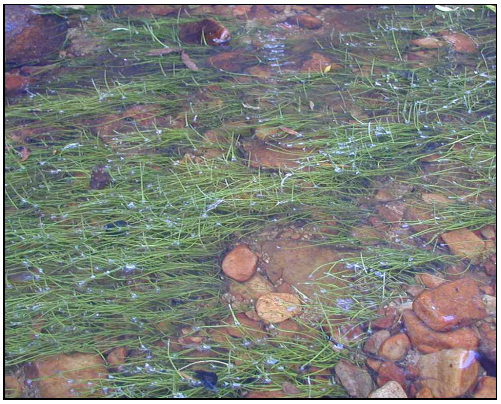


Plate 3. *Submerged Eleocharis sp. at Station 6.*

4.1.3.2. Emergent

The dominant emergent macrophyte in the Noetzie Estuary was the common reed, *Phragmites australis* (Figure 11). *Phragmites* covered 2.51 ha, which is half of the area covered by open water (5.06 ha). This species formed dense near monospecific stands in the lower and middle reaches of the estuary. Analysis of past (1936) and present (1998) aerial photographs indicated that there had been no net increase or loss of reed bed habitat throughout the estuary over that period. Increased sedimentation to small estuaries and a decrease in water depth often results in reed encroachment and a loss of open water habitat. However there is no indication of this in the Noetzie Estuary.

Phragmites can tolerate high salinities as long as their roots are in fresher water, i.e. < 15 ppt (Adams & Bate 1999). The large reed beds are indicative of an estuary that is predominantly brackish to fresh. There are no large salt marsh areas which would indicate a persistent saline influence. The steep cliffs on either side of the estuary also provide sufficient run-off to sustain the reed beds even when the estuary is saline when the mouth is open to the sea. *Cladium mariscus* (saw-grass) occurred as large clumps within the *Phragmites* beds.

A large sedge community (0.2 ha) occurred near the mouth (Figure 11) and was made up of the following species: *Ficinia nodosa* (dominant), *Juncus kraussii*, *Phragmites australis*, *Cotula coronopifolia* and *Sporobolus virginicus*. The reed fringe on the east bank of the middle reaches covered 0.11 ha and the dominant macrophyte was *Phragmites australis*. The reed fringe was different from the *Phragmites* beds in that there were more than just the two species making up the community. Other species included *Schoenoplectus scirpoideus*, *Samolus porosus* and *Cyperus textiles*. The banks of the estuary in the region of Station 6 and 7 were covered with grasses, most notably the wetland species, *Paspalum distichum* and *Paspalum scrobiculatum. Persicaria lapathifolia, Eleocharis limosa, Cyperus laevigatus* and *Hydrocotyle* spp. were also noted upstream.

4.1.4. Terrestrial vegetation

The terrestrial vegetation consisted of some pockets of dune fynbos near the mouth and near pristine Afromontane forest throughout the rest of the catchment. Both these vegetatation types have been well described by, amongst others, Von Breitenbach (1974), Grindley (1985) and Geldenhuys (1993). A recent bibliography of scientific and environmental literature pertaining to the Knysna area has been published by Allanson (2000).

4.2. Fauna

4.2.1. Zooplankton

No data are available.

4.2.2. Macrobenthos

No data are available. Local subsistence fishermen pump sand prawn (*Callianassa kraussi*) and the abundant prawn holes showed that this species was dominant in the mouth region and on the banks opposite Station 2. The Knysna crab (*Scylla serrata*) used to occur in the Noetzie Estuary, but has not been seen in recent years (Newdigate pers. comm.).

4.2.3. Ichthyofauna

Harrison *et al.* (1995) recorded 7 fish species in the Noetzie Estuary. Two species, *Gilchristella aestuaria* (Estuarine Round-herring) and *Psammogobius knysnaensis* (Knysna Sand Goby) are species that depend on estuaries for their entire life cycle. The remaining five species, *Lithognathus lithognathus* (White Steenbras), *Liza richardsonii* (Southern Mullet), *Mugil cephalus* (Flathead Mullet), *Myxus capensis* (Freshwater Mullet) and *Rhabdosargus holubi* (Cape Stumpnose), are all inshore marine species that depend upon estuaries during the juvenile phase of their life cycle. Harrison *et al.* (1995) rated the Noetzie system as depauperate in terms of its fish species composition but there seems to be little justification in this statement, if one considers the size and structure of the river. *Lichia amia* (Leervis), that is dependent on estuaries during the juvenile phase of their life cycle, have been caught in the Noetzie Estuary in the past and is still frequently spotted (Newdigate pers. comm.). The dominance of estuarine and estuarine-dependant marine fish in the Noetzie estuary is an indication of the important nursery function of the estuary. *Rhabdosargus holubi* and several Mugilidae species exhibit an extended spawning season and the ability of juveniles to recruit into IOEs not only when the mouth opens, but also during marine overwash events (Perissinotto *et al.* 2004).

4.2.4. Avifauna

Birds are the most mobile of all estuarine faunal species. When abnormal conditions such as noise and movement occur they readily move to other areas. However, under such conditions they are vulnerable to the availability of alternative sites. Waders are absent from the Noetzie estuary because of the absence of intertidal feeding areas. Most species that do occur are piscivorous and include herons, egrets, kingfishers, cormorants and darters that catch a variety of fish species either from the surface or by diving and swimming underwater. Mr. Donald Fabian has recorded 140 bird species in the Noetzie area consisting of 10 sea/littoral species, 28 species of river/estuarine birds and 102 terrestrial species (Everett pers. comm.). During the April 2005 survey, 103 Kelp Gulls (*Larus dominicanus*) and 76 Common Terns (*Sterna hirundo*) and Swift Terns (*Sterna bergii*) were recorded on the beach. These three species use the Noetzie beach as a roosting site. The Sinclair Nature Reserve also forms part of the Birds In Reserves Project (BIRP) of the Avian Demography Unit, University of Cape Town.

4.2.5. Mammals

An account of the mammals of the Knysna area is presented by Von Breitenbach (1974) who lists 46 species with notes on their habitats and distribution. No comprehensive game count has been conducted in the area, but field ranger observation data is available for Pezula Private Estate. Common residents of the Noetzie Estuary itself are the Cape Clawless Otter (*Aonyx capensis*) and water mongoose (*Atilax paludinosus*).

5. Concluding remarks

The Noetzie Estuary is a relatively pristine estuary and one of few Intermittently Open Estuaries that is still receiving most of its natural mean annual run-off. The relatively high run-off maintains the mouth in a semi-closed state for most of the year, thus enabling marine overtopping to occur on spring tides. A salinity gradient is therefore maintained and the regular nutrient input from the sea is vital for the maintenance of a healthy ecosystem. The physico-chemical characteristics of the estuary are normal for a small IOE in the open / semi-closed mouth phase. Turbidity was high, water clarity low and the light attenuation high at Stations 2 and 4. These stations also had high sediment organic content and a high fraction of fine particles (silt and clay). Although significantly different to the other stations in the estuary it is not believed that these stations are indicative of a system that is experiencing severe turbidity or silt loading. Silt and organic matter naturally accumulates where the normal current velocity is low, i.e. fringes of reed beds, deep channels, channel bends and at points of river inflow.

Construction of the “Field of Dreams” at Pezula Private Estate did result in increased turbidity of the water column (Heydorn 2004) and probably resulted in increased siltation and sedimentation of fine material. These turbid water and fine material have been flushed out to sea, and the system during the sampling period was probably as close to natural as it was prior to construction. The Noetzie Estuary was in a good condition, with no evidence of sedimentation from the catchment and no discernable impact on the fauna and flora. Estuarine flora and fauna are adapted to extreme conditions and would be able to tolerate short periods of siltation and high turbidity. The ability of the Noetzie Estuary to have absorbed the effects of increased siltation in the past and at present is intrinsically related to its hydrodynamics, especially the fact that baseflow is high enough to control the build-up of the berm thereby increasing flushing of the system. Any reduction in freshwater input to the estuary would alter this state.

The pristine nature of the Noetzie Estuary and its catchment should be conserved at all cost. Nationally the Noetzie Estuary ranks relatively low in terms of conservation importance, mostly because of paucity in scientific information on the system. It is recommended that an estuary management plan and monitoring programme is implemented for the Noetzie Estuary to ensure the conservation of the system.

Synthesis:

- If the ecology of the Noetzie Estuary is to be safeguarded on a sustainable basis, more is required than simply addressing the effects of individual occurrences of sediment of pollution input into the river or estuary. What is required is a management strategy for the river as a whole encompassing its catchments, its middle reaches and its estuary.

- Primary responsibility for this must lie with the responsible authorities, especially DWAF, Cape Nature Conservation and SANParks. Implementation of such a strategy will not be possible without the cooperation of private landowners.
- Thus, while individual occurrences of pollution-, sediment- or other input into the river and estuary must be dealt with swiftly and strictly, a holistic approach to river management requires the development of a collaborative approach between the authorities and landowners. Rectification of present shortcomings in land or river management must therefore be instituted within the framework of an overall river management policy.
- Using Pezula as an example, it should be accepted that large-scale clearing of plantations during the rehabilitation process, is likely to cause at least some destabilisation, until some time when the indigenous plant communities that originally occurred in the region, once again provide ground covers. Heavy use of the untarred Noetzie road during the Pezula construction period and earth moving at the head of a tributary draining the FoD site undoubtedly contributed to run-off of discoloured water. However, it is fortunate that these negative effects can be regarded as temporary and – as both the investigation by Dr Heydorn and the present one showed - the ecological processes governing this river and estuarine system have not been affected detrimentally to any discernible extent, in spite of unusually heavy rainfall events. In the long run, transformation of commercial plantations into ecologically functional habitat will be of substantial benefit to the Noetzie River and Estuary.
- What does need attention is amelioration of storm water run-off from the Noetzie Road, rehabilitation of earth quarries in the catchment and efficient handling of inevitably pollution laden run-off from township and other residential areas in the river catchments.
- As far as agricultural activities and the maintenance of sport fields (including the FoD) in the river catchments are concerned, care must be taken to avoid nutrient enrichment through the use of fertilisers or pollution by pesticides.

All of these points, which are by no means exhaustive, underline the need for a cooperative approach in the development of an overall management strategy for the Noetzie River system. While it might go beyond the brief of this report, it is recommended that the responsible authorities, perhaps under the guidance of DWAF, organise a workshop with property owners as a first step towards the development of such a strategy.

6. Acknowledgements

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Appendix A

Table 5. *Physico-chemical data of the water column over the two sampling periods (07 & 08/04/2005).*

		Temperature (ºC)		Salinity (psu)		pH		Turbidity (NTU)		Redox	
	Depth	**07/04/05**	**08/04/05**	**07/04/05**	**08/04/05**	**07/04/05**	**08/04/05**	**07/04/05**	**08/04/05**	**07/04/05**	**08/04/05**
St 1	0.0	23.73 ± 0.04	22.32 ± 0.06	7.09 ± 0.07	10.54 ± 0.27	7.82 ± 0.03	7.91 ± 0.01	9.63 ± 0.34	8.72 ± 3.11	132.25 ± 5.20	104.22 ± 5.06
	0.5	23.80 ± 0.03	22.60 ± 0.01	8.74 ± 0.12	15.57 ± 0.16	7.81 ± 0.02	8.05 ± 0.02	10.30 ± 1.25	5.04 ± 0.21	136.44 ± 4.65	113.22 ± 3.86
	1.0	21.85 ± 0.02	22.23 ± 0.01	18.75 ± 0.53	21.27 ± 0.31	8.18 ± 0.02	8.21 ± 0.01	8.26 ± 0.16	3.30 ± 0.10	147.40 ± 0.51	119.33 ± 0.33
	1.5		22.03 ± 0.06		24.37 ± 0.21		8.21 ± 0.00		3.50 ± 0.38		123.00 ± 0.58
St 2	0.0	23.89 ± 0.06	22.31 ± 0.04	6.18 ± 0.05	7.53 ± 0.13	7.71 ± 0.03	7.70 ± 0.06	14.63 ± 0.93	12.21 ± 2.78	115.10 ± 6.35	99.40 ± 3.48
	0.5	23.88 ± 0.02	22.65 ± 0.06	8.06 ± 0.23	14.46 ± 0.99	7.67 ± 0.01	7.65 ± 0.04	10.92 ± 0.68	6.46 ± 0.84	127.50 ± 5.49	110.67 ± 3.73
	1.0	23.06 ± 0.09	21.97 ± 0.12	18.06 ± 0.47	21.85 ± 0.16	7.69 ± 0.03	7.91 ± 0.07	26.82 ± 4.29	10.23 ± 2.97	138.00 ± 5.28	110.33 ± 2.54
	1.5	22.68 ± 0.01	21.59 ± 0.01	23.24 ± 0.02	25.19 ± 0.08	7.72 ± 0.00	8.15 ± 0.01	37.73 ± 7.47	2.07 ± 0.35	146.67 ± 0.33	120.33 ± 0.33
	2.0		21.59 ± 0.01		27.02 ± 0.04		8.16 ± 0.01		41.17 ± 13.13		122.33 ± 0.33
St 3	0.0	23.13 ± 0.02	22.15 ± 0.03	4.41 ± 0.09	5.41 ± 0.26	7.49 ± 0.01	7.63 ± 0.05	11.52 ± 0.58	7.00 ± 0.15	93.90 ± 4.20	76.56 ± 2.95
	0.5	23.43 ± 0.05	22.93 ± 0.08	5.77 ± 0.19	10.04 ± 0.55	7.43 ± 0.01	7.42 ± 0.04	16.61 ± 2.35	6.50 ± 0.59	102.6 ± 4.08	90.00 ± 2.29
	1.0	23.5 ± 0.02	23.06 ± 0.02	16.51 ± 0.98	21.27 ± 0.28	7.37 ± 0.03	7.58 ± 0.03	15.40 ± 2.38	6.17 ± 0.47	117.25 ± 2.43	101.17 ± 1.90
	1.5		22.67 ± 0.02		22.93 ± 0.03		7.82 ± 0.01		13.07 ± 2.05		99.33 ± 0.33
St 4	0.0	22.35 ± 0.05	20.49 ± 0.11	0.93 ± 0.02	1.17 ± 0.04	7.49 ± 0.04	7.57 ± 0.08	13.66 ± 0.28	9.30 ± 0.85	63.33 ± 1.45	35.33 ± 1.56
	0.5	22.87 ± 0.02	22.81 ± 0.11	3.12 ± 0.26	11.29 ± 0.52	7.19 ± 0.03	7.01 ± 0.04	12.76 ± 0.32	5.03 ± 0.34	82.50 ± 1.06	66.44 ± 2.26
	1.0	24.71 ± 0.12	23.51 ± 0.06	19.84 ± 0.43	21.81 ± 0.13	6.98 ± 0.02	7.22 ± 0.01	51.86 ± 13.15	5.76 ± 1.18	106.89 ± 0.20	73.33 ± 1.01
	1.5		23.31 ± 0.04		22.95 ± 0.04		7.41 ± 0.02		28.78 ± 7.18		72.67 ± 0.76
St 5	0.0	20.53 ± 0.05	19.71 ± 0.04	0.48 ± 0.01	1.09 ± 0.29	7.09 ± 0.08	7.52 ± 0.10	14.16 ± 0.37	7.62 ± 0.08	50.70 ± 2.24	0.50 ± 3.72
	0.5	20.02 ± 0.08	21.93 ± 0.06	0.61 ± 0.04	10.99 ± 0.34	7.08 ± 0.13	6.81 ± 0.04	14.06 ± 0.84	3.34 ± 0.38	51.88 ± 3.38	37.56 ± 0.80
	1.0	25.24 ± 0.15	24.50 ± 0.05	21.13 ± 0.24	21.12 ± 0.12	6.68 v 0.09	7.05 ± 0.03	1.78 ± 0.80	2.10 ± 1.08	98.50 ± 2.13	39.33 ± 1.55
	1.5	25.78 ± 0.03	24.65 ± 0.02	22.50 ± 0.06	21.92 ± 0.0	7.00 ± 0.02	7.17 ± 0.02	4.13 ± 1.36	9.78 ± 4.64	92.67 ± 0.33	35.50 ± 2.19
St 6	0.0	18.56 ± 0.03	18.91 ± 0.01	0.30 ± 0.01	0.47 ± 0.02	6.75 ± 0.05	6.96 ± 0.03	22.47 ± 2.96	7.55 ± 0.15	81.83 ± 0.41	60.67 ± 0.67
	0.5	18.42 ± 0.04	20.50 ± 0.15	0.40 ± 0.02	6.97 ± 1.31	6.49 ± 0.04	6.46 ± 0.04	15.67 ± 1.42	31.50 ± 5.38	86.17 ± 1.45	99.50 ± 0.87
St 7	0.0	18.28 ± 0.02	18.24 ± 0.03	0.22 ± 0.00	0.22 ± 0.00	7.07 ± 0.25	7.22 ± 0.05	13.50 ± 1.39	89.27 ± 0.27	148.75 ± 3.33	55.50 ± 3.23
	0.5	18.24 ± 0.00	18.15 ± 0.0	0.22 ± 0.00	0.22 ± 0.00	6.29 ± 0.05	7.04 ± 0.03	11.98 ± 0.25	89.50 ± 0.31	120.00 ± 5.29	40.33 ± 1.45
	1.0		20.09 ± 0.06		10.66 ± 0.30		6.26 ± 0.08		103.5 ± 8.30		103.00 ± 1.53

Appendix B

Table 6. *Sample statistics of the surface and subsurface sediment collected at the western, middle and eastern section of Station 1 (GRADISTAT programme, version 4.0).*

		1Wt	**1Wb**	**1Mt**	**1Mb**	**1Et**	**1Eb**
	SAMPLE TYPE:	Unimodal, Well Sorted	Unimodal, Well Sorted	Unimodal, Well Sorted	Unimodal, Well Sorted	Unimodal, Well Sorted	Unimodal, Well Sorted
	TEXTURAL GROUP:	Sand	Sand	Sand	Sand	Sand	Sand
	SEDIMENT NAME:	Well Sorted Fine Sand	Well Sorted Fine Sand	Well Sorted Fine Sand	Well Sorted Fine Sand	Well Sorted Fine Sand	Well Sorted Fine Sand
FOLK AND WARD METHOD (µm)	MEAN (M_G):	228.5	231.6	218.0	205.9	216.6	212.5
	SORTING (σ_G):	1.330	1.321	1.326	1.381	1.310	1.333
	SKEWNESS (Sk_G):	0.045	0.085	0.009	0.034	0.025	0.004
	KURTOSIS (K_G):	1.102	1.088	1.319	1.016	1.343	1.288
FOLK AND WARD METHOD (ϕ)	MEAN (M_z):	2.130	2.111	2.197	2.280	2.207	2.235
	SORTING (σ_I):	0.411	0.401	0.407	0.466	0.389	0.415
	SKEWNESS (Sk_I):	-0.045	-0.085	-0.009	-0.034	-0.025	-0.004
	KURTOSIS (K_G):	1.102	1.088	1.319	1.016	1.343	1.288
FOLK AND WARD METHOD (Description)	MEAN:	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand
	SORTING:	Well Sorted	Well Sorted	Well Sorted	Well Sorted	Well Sorted	Well Sorted
	SKEWNESS:	Symmetrical	Symmetrical	Symmetrical	Symmetrical	Symmetrical	Symmetrical
	KURTOSIS:	Mesokurtic	Mesokurtic	Leptokurtic	Mesokurtic	Leptokurtic	Leptokurtic
	MODE 1 (µm):	215.0	215.0	215.0	215.0	215.0	215.0
	MODE 1 (ϕ):	2.237	2.237	2.237	2.237	2.237	2.237
	% GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% SAND:	99.1%	99.6%	99.1%	99.5%	99.6%	99.7%
	% MUD:	0.9%	0.4%	0.9%	0.5%	0.4%	0.3%
	% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% MEDIUM GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% FINE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% V FINE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% V COARSE SAND:	0.0%	0.1%	0.1%	0.3%	0.0%	0.0%
	% COARSE SAND:	0.2%	0.3%	0.1%	0.6%	0.1%	0.2%
	% MEDIUM SAND:	31.4%	31.6%	24.9%	23.0%	22.8%	22.9%
	% FINE SAND:	65.8%	66.3%	72.0%	72.9%	75.4%	75.0%
	% V FINE SAND:	1.7%	1.3%	2.0%	2.7%	1.2%	1.6%
	% V COARSE SILT:	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
	% COARSE SILT:	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
	% MEDIUM SILT:	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
	% FINE SILT:	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
	% V FINE SILT:	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%
	% CLAY:	0.1%	0.1%	0.1%	0.1%	0.1%	0.0%

Table 7. *Sample statistics of the surface and subsurface sediment collected at the western, middle and eastern section of Station 2 (GRADISTAT programme, version 4.0).*

		2Wt	**2Wb**	**2Mt**	**2Mb**	**2Et**	**2Eb**
	SAMPLE TYPE:	Unimodal, Moderately Sorted	Unimodal, Moderately Well Sorted	Unimodal, Poorly Sorted	Unimodal, Moderately Well Sorted	Unimodal, Well Sorted	Unimodal, Well Sorted
	TEXTURAL GROUP:	Sand	Slightly Gravelly Sand	Muddy Sand	Sand	Sand	Sand
	SEDIMENT NAME:	Moderately Sorted Fine Sand	Slightly Very Fine Gravelly Fine Sand	Coarse Silty Fine Sand	Moderately Well Sorted Fine Sand	Well Sorted Fine Sand	Well Sorted Fine Sand
FOLK AND WARD METHOD (µm)	MEAN (M_G):	212.0	220.1	127.5	173.2	216.2	219.0
	SORTING (σ_G):	1.684	1.559	2.158	1.417	1.352	1.338
	SKEWNESS (Sk_G):	-0.151	-0.054	-0.462	0.024	0.000	0.025
	KURTOSIS (K_G):	1.430	1.410	2.068	1.140	1.327	1.291
FOLK AND WARD METHOD (ϕ)	MEAN (M_Z):	2.238	2.184	2.971	2.530	2.209	2.191
	SORTING (σ_I):	0.752	0.640	1.110	0.503	0.435	0.420
	SKEWNESS (Sk_I):	0.151	0.054	0.462	-0.024	0.000	-0.025
	KURTOSIS (K_G):	1.430	1.410	2.068	1.140	1.327	1.291
FOLK AND WARD METHOD (Description)	MEAN:	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand	Fine Sand
	SORTING:	Moderately Sorted	Moderately Well Sorted	Poorly Sorted	Moderately Well Sorted	Well Sorted	Well Sorted
	SKEWNESS:	Fine Skewed	Symmetrical	Very Fine Skewed	Symmetrical	Symmetrical	Symmetrical
	KURTOSIS:	Leptokurtic	Leptokurtic	Very Leptokurtic	Leptokurtic	Leptokurtic	Leptokurtic
	MODE 1 (µm):	215.0	215.0	152.5	152.5	215.0	215.0
	MODE 1 (ϕ):	2.237	2.237	2.737	2.737	2.237	2.237
	% GRAVEL:	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
	% SAND:	95.0%	96.8%	85.8%	97.1%	98.5%	99.1%
	% MUD:	5.0%	3.0%	14.2%	2.9%	1.5%	0.9%
	% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% MEDIUM GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% FINE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% V FINE GRAVEL:	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%
	% V COARSE SAND:	0.4%	0.4%	0.0%	0.3%	0.2%	0.2%
	% COARSE SAND:	2.5%	2.3%	0.2%	0.4%	0.6%	0.5%
	% MEDIUM SAND:	30.9%	31.6%	5.3%	10.4%	24.6%	25.2%
	% FINE SAND:	53.9%	57.0%	57.9%	75.2%	70.6%	71.3%
	% V FINE SAND:	7.3%	5.4%	22.4%	10.8%	2.6%	1.9%
	% V COARSE SILT:	0.8%	0.5%	2.4%	0.5%	0.2%	0.2%
	% COARSE SILT:	0.8%	0.5%	2.4%	0.5%	0.2%	0.2%
	% MEDIUM SILT:	0.8%	0.5%	2.4%	0.5%	0.2%	0.2%
	% FINE SILT:	0.8%	0.5%	2.4%	0.5%	0.2%	0.2%
	% V FINE SILT:	0.8%	0.5%	2.4%	0.5%	0.2%	0.2%
	% CLAY:	0.8%	0.5%	2.4%	0.5%	0.2%	0.2%

Table 8. *Sample statistics of the surface and subsurface sediment collected at the western, middle and eastern section of Station 3 (GRADISTAT programme, version 4.0).*

		3Wt	**3Wb**	**3Mt**	**3Et**	**3Eb**
	SAMPLE TYPE:	Unimodal, Poorly Sorted	Unimodal, Poorly Sorted	Bimodal, Poorly Sorted	Bimodal, Very Poorly Sorted	Trimodal, Very Poorly Sorted
	TEXTURAL GROUP:	Gravelly Sand	Gravelly Sand	Sandy Gravel	Slightly Gravelly Muddy Sand	Gravelly Muddy Sand
	SEDIMENT NAME:	Very Fine Gravelly Fine Sand	Very Fine Gravelly Fine Sand	Sandy Very Fine Gravel	Slightly Very Fine Gravelly Coarse Silty Very Fine Sand	Very Fine Gravelly Very Coarse Silty Very Fine Sand
FOLK AND WARD METHOD (μm)	MEAN (M_G):	339.0	382.3	962.9	75.60	108.0
	SORTING (σ_G):	2.778	2.751	2.668	4.974	6.716
	SKEWNESS (Sk_G):	0.391	0.459	-0.285	-0.125	0.027
	KURTOSIS (K_G):	1.475	1.572	0.380	1.150	1.243
FOLK AND WARD METHOD (ϕ)	MEAN (M_Z):	1.561	1.387	0.055	3.726	3.211
	SORTING (σ_I):	1.474	1.460	1.416	2.315	2.748
	SKEWNESS (Sk_I):	-0.391	-0.459	0.285	0.125	-0.027
	KURTOSIS (K_G):	1.475	1.572	0.380	1.150	1.243
FOLK AND WARD METHOD (Description)	MEAN:	Medium Sand	Medium Sand	Coarse Sand	Very Fine Sand	Very Fine Sand
	SORTING:	Poorly Sorted	Poorly Sorted	Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
	SKEWNESS:	Very Coarse Skewed	Very Coarse Skewed	Fine Skewed	Fine Skewed	Symmetrical
	KURTOSIS:	Leptokurtic	Very Leptokurtic	Very Platykurtic	Leptokurtic	Leptokurtic
	MODE 1 (μm):	215.0	215.0	302.5	107.5	107.5
	MODE 1 (ϕ):	2.237	2.237	1.747	3.237	3.237
	% GRAVEL:	11.2%	11.0%	39.9%	1.3%	8.9%
	% SAND:	85.0%	86.8%	59.3%	64.2%	59.2%
	% MUD:	3.8%	2.2%	0.9%	34.5%	32.0%
	% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% MEDIUM GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% FINE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% V FINE GRAVEL:	11.2%	11.0%	39.9%	1.3%	8.9%
	% V COARSE SAND:	5.6%	6.3%	9.5%	6.5%	5.4%
	% COARSE SAND:	5.9%	7.7%	9.9%	3.5%	3.7%
	% MEDIUM SAND:	25.9%	32.6%	26.2%	8.3%	8.0%
	% FINE SAND:	41.2%	36.1%	12.3%	18.5%	19.1%
	% V FINE SAND:	6.4%	4.2%	1.4%	27.4%	22.9%
	% V COARSE SILT:	0.6%	0.4%	0.1%	5.8%	5.3%
	% COARSE SILT:	0.6%	0.4%	0.1%	5.8%	5.3%
	% MEDIUM SILT:	0.6%	0.4%	0.1%	5.8%	5.3%
	% FINE SILT:	0.6%	0.4%	0.1%	5.8%	5.3%
	% V FINE SILT:	0.6%	0.4%	0.1%	5.8%	5.3%
	% CLAY:	0.6%	0.4%	0.1%	5.8%	5.3%

Table 9. *Sample statistics of the surface and subsurface sediment collected at the western, middle and eastern section of Station 4 (GRADISTAT programme, version 4.0).*

		4Wt	**4Wb**	**4Mt**	**4Mb**	**4Et**	**4Eb**
	SAMPLE TYPE:	Bimodal, Poorly Sorted	Trimodal, Very Poorly Sorted	Bimodal, Poorly Sorted	Bimodal, Very Poorly Sorted	Unimodal, Poorly Sorted	Unimodal, Moderately Sorted
	TEXTURAL GROUP:	Sandy Mud	Gravelly Muddy Sand	Sandy Mud	Muddy Sand	Muddy Sand	Sand
	SEDIMENT NAME:	Very Fine Sandy Fine Silt	Very Fine Gravelly Medium Silty Medium Sand	Very Fine Sandy Very Coarse Silt	Very Coarse Silty Very Fine Sand	Coarse Silty Very Fine Sand	Moderately Sorted Fine Sand
FOLK AND WARD METHOD (µm)	MEAN (M_G):	34.09	203.0	32.19	48.85	66.65	187.4
	SORTING (σ_G):	3.377	7.655	3.647	4.079	3.147	1.931
	SKEWNESS (Sk_G):	-0.201	-0.273	-0.048	-0.215	-0.482	-0.317
	KURTOSIS (K_G):	0.787	0.791	0.873	0.920	1.123	1.976
FOLK AND WARD METHOD (ϕ)	MEAN (M_z):	4.874	2.301	4.957	4.355	3.907	2.416
	SORTING (σ_I):	1.756	2.936	1.867	2.028	1.654	0.949
	SKEWNESS (Sk_I):	0.201	0.273	0.048	0.215	0.482	0.317
	KURTOSIS (K_G):	0.787	0.791	0.873	0.920	1.123	1.976
FOLK AND WARD METHOD (Description)	MEAN:	Very Coarse Silt	Fine Sand	Very Coarse Silt	Very Coarse Silt	Very Fine Sand	Fine Sand
	SORTING:	Poorly Sorted	Very Poorly Sorted	Poorly Sorted	Very Poorly Sorted	Poorly Sorted	Moderately Sorted
	SKEWNESS:	Fine Skewed	Fine Skewed	Symmetrical	Fine Skewed	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Platykurtic	Platykurtic	Platykurtic	Mesokurtic	Leptokurtic	Very Leptokurtic
	MODE 1 (µm):	107.5	427.5	76.50	107.5	107.5	215.0
	MODE 1 (ϕ):	3.237	1.247	3.731	3.237	3.237	2.237
	% GRAVEL:	0.0%	12.9%	0.0%	0.0%	0.0%	0.0%
	% SAND:	42.0%	57.4%	37.4%	51.1%	69.8%	92.7%
	% MUD:	58.0%	29.7%	62.6%	48.9%	30.2%	7.3%
	% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% MEDIUM GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% FINE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	% V FINE GRAVEL:	0.0%	12.9%	0.0%	0.0%	0.0%	0.0%
	% V COARSE SAND:	0.3%	10.3%	0.4%	1.8%	0.0%	0.4%
	% COARSE SAND:	0.3%	10.1%	1.2%	2.0%	0.0%	1.8%
	% MEDIUM SAND:	3.0%	21.1%	4.7%	7.0%	3.9%	22.2%
	% FINE SAND:	6.2%	5.8%	8.6%	9.9%	29.1%	57.7%
	% V FINE SAND:	32.2%	10.1%	22.4%	30.4%	36.8%	10.7%
	% V COARSE SILT:	9.7%	4.9%	10.4%	8.2%	5.0%	1.2%
	% COARSE SILT:	9.7%	4.9%	10.4%	8.2%	5.0%	1.2%
	% MEDIUM SILT:	9.7%	4.9%	10.4%	8.2%	5.0%	1.2%
	% FINE SILT:	9.7%	4.9%	10.4%	8.2%	5.0%	1.2%
	% V FINE SILT:	9.7%	4.9%	10.4%	8.2%	5.0%	1.2%
	% CLAY:	9.7%	4.9%	10.4%	8.2%	5.0%	1.2%

Table 10. *Sample statistics of the surface and subsurface sediment collected at the western, middle and eastern section of Station 5 (GRADISTAT programme, version 4.0).*

		5Wt	**5Wb**	**5M**	**5Et**	**5Eb**
	SAMPLE TYPE:	Unimodal, Moderately Well Sorted	Unimodal, Moderately Well Sorted	Bimodal, Poorly Sorted	Bimodal, Poorly Sorted	Bimodal, Poorly Sorted
	TEXTURAL GROUP:	Slightly Gravelly Sand	Slightly Gravelly Sand	Sandy Gravel	Muddy Sand	Muddy Sand
	SEDIMENT NAME:	Slightly Very Fine Gravelly Fine Sand	Slightly Very Fine Gravelly Fine Sand	Sandy Very Fine Gravel	Very Coarse Silty Very Fine Sand	Very Coarse Silty Very Fine Sand
FOLK AND WARD METHOD (μm)	MEAN (M_G):	230.6	231.5	1144.6	72.64	85.17
	SORTING (σ_G):	1.531	1.508	2.456	3.479	3.206
	SKEWNESS (Sk_G):	-0.037	-0.041	-0.356	-0.381	-0.392
	KURTOSIS (K_G):	1.216	1.180	0.536	1.077	1.449
FOLK AND WARD METHOD (ϕ)	MEAN (M_z):	2.116	2.111	-0.195	3.783	3.554
	SORTING (σ_I):	0.614	0.593	1.296	1.799	1.681
	SKEWNESS (Sk_I):	0.037	0.041	0.356	0.381	0.392
	KURTOSIS (K_G):	1.216	1.180	0.536	1.077	1.449
FOLK AND WARD METHOD (Description)	MEAN:	Fine Sand	Fine Sand	Very Coarse Sand	Very Fine Sand	Very Fine Sand
	SORTING:	Moderately Well Sorted	Moderately Well Sorted	Poorly Sorted	Poorly Sorted	Poorly Sorted
	SKEWNESS:	Symmetrical	Symmetrical	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Leptokurtic	Leptokurtic	Very Platykurtic	Mesokurtic	Leptokurtic
	MODE 1 (μm):	215.0	215.0	1500.0	107.5	107.5
	MODE 1 (ϕ):	2.237	2.237	-0.500	3.237	3.237
	% GRAVEL:	2.3%	0.4%	33.6%	0.0%	0.0%
	% SAND:	96.2%	98.3%	66.1%	70.0%	75.4%
	% MUD:	1.5%	1.3%	0.3%	30.0%	24.6%
	% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% MEDIUM GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% FINE GRAVEL:	0.0%	0.0%	0.0%	0.0%	0.0%
	% V FINE GRAVEL:	2.3%	0.4%	33.6%	0.0%	0.0%
	% V COARSE SAND:	0.3%	0.6%	24.1%	0.0%	0.3%
	% COARSE SAND:	1.2%	1.6%	15.8%	0.8%	0.7%
	% MEDIUM SAND:	38.3%	39.7%	19.3%	10.7%	11.8%
	% FINE SAND:	50.9%	51.2%	6.0%	25.1%	30.6%
	% V FINE SAND:	5.5%	5.2%	0.9%	33.3%	31.9%
	% V COARSE SILT:	0.3%	0.2%	0.0%	5.0%	4.1%
	% COARSE SILT:	0.3%	0.2%	0.0%	5.0%	4.1%
	% MEDIUM SILT:	0.3%	0.2%	0.0%	5.0%	4.1%
	% FINE SILT:	0.3%	0.2%	0.0%	5.0%	4.1%
	% V FINE SILT:	0.3%	0.2%	0.0%	5.0%	4.1%
	% CLAY:	0.3%	0.2%	0.0%	5.0%	4.1%

Table 11. *Sample statistics of the surface and subsurface sediment collected in the middle of the channel at Station 6 and 7 (GRADISTAT programme, version 4.0).*

		6Mt	**6Mb**	**7Mt**	**7Mb**
	SAMPLE TYPE:	Unimodal, Moderately Sorted	Unimodal, Poorly Sorted	Unimodal, Moderately Well Sorted	Unimodal, Moderately Well Sorted
	TEXTURAL GROUP:	Slightly Gravelly Sand	Gravelly Sand	Sand	Sand
	SEDIMENT NAME:	Slightly Very Fine Gravelly Medium Sand	Very Fine Gravelly Medium Sand	Moderately Well Sorted Medium Sand	Moderately Well Sorted Medium Sand
FOLK AND WARD METHOD (μm)	MEAN (M_G):	389.1	534.6	340.7	313.5
	SORTING (σ_G):	1.962	2.584	1.448	1.495
	SKEWNESS (Sk_G):	0.418	0.526	0.151	0.152
	KURTOSIS (K_G):	1.337	0.870	1.188	1.164
FOLK AND WARD METHOD (ϕ)	MEAN (M_z):	1.362	0.904	1.553	1.674
	SORTING (σ_I):	0.972	1.370	0.534	0.580
	SKEWNESS (Sk_I):	-0.418	-0.526	-0.151	-0.152
	KURTOSIS (K_G):	1.337	0.870	1.188	1.164
FOLK AND WARD METHOD (Description)	MEAN:	Medium Sand	Coarse Sand	Medium Sand	Medium Sand
	SORTING:	Moderately Sorted	Poorly Sorted	Moderately Well Sorted	Moderately Well Sorted
	SKEWNESS:	Very Coarse Skewed	Very Coarse Skewed	Coarse Skewed	Coarse Skewed
	KURTOSIS:	Leptokurtic	Platykurtic	Leptokurtic	Leptokurtic
	MODE 1 (μm):	302.5	302.5	302.5	302.5
	MODE 1 (ϕ):	1.747	1.747	1.747	1.747
	% GRAVEL:	3.7%	16.4%	0.0%	0.0%
	% SAND:	95.9%	83.2%	99.9%	99.7%
	% MUD:	0.4%	0.3%	0.1%	0.3%
	% V COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%
	% COARSE GRAVEL:	0.0%	0.0%	0.0%	0.0%
	% MEDIUM GRAVEL:	0.0%	0.0%	0.0%	0.0%
	% FINE GRAVEL:	0.0%	0.0%	0.0%	0.0%
	% V FINE GRAVEL:	3.7%	16.4%	0.0%	0.0%
	% V COARSE SAND:	8.3%	4.7%	0.7%	1.0%
	% COARSE SAND:	13.4%	7.2%	11.0%	9.3%
	% MEDIUM SAND:	50.6%	42.1%	72.1%	63.9%
	% FINE SAND:	23.0%	28.2%	15.9%	24.8%
	% V FINE SAND:	0.7%	1.0%	0.2%	0.7%
	% V COARSE SILT:	0.1%	0.1%	0.0%	0.0%
	% COARSE SILT:	0.1%	0.1%	0.0%	0.0%
	% MEDIUM SILT:	0.1%	0.1%	0.0%	0.0%
	% FINE SILT:	0.1%	0.1%	0.0%	0.0%
	% V FINE SILT:	0.1%	0.1%	0.0%	0.0%
	% CLAY:	0.1%	0.1%	0.0%	0.0%