2.

GEOMORPHOLOGY

Geomorphic variability among microtidal South African estuaries: a conceptual classification

2.1 Introduction

The study of the geomorphology of estuaries examines the link between estuary form and the processes that operate within it. It seeks to describe the morphology of individual estuaries and groups of estuaries and to examine variations in the present configuration of estuaries and to seek explanations of this variability in the potential controlling factors. In South Africa the range of controlling variables is highly diverse, as the subcontinent spans a number of climatic and morphological zones and is subjected to a range of marine conditions, however, there are several factors that may be regarded as virtually constant around the coast. These include the relatively low tidal range, high wave energy (although a gradient does exist), the predominantly bedrock coast (lacking a coastal plain) and a consistent sea level history. Variability in factors that contribute to estuary morphology arises from climatic variation (arid to humid and subtropical to cold temperate), discharge variation in rivers, hinterland gradient and coastal gradient, sediment supply rates from rivers, sediment type supplied from rivers and sediment availability in the coastal zone. The range of variation among these and other factors potentially produces a wide range of estuary types.

An estuary has been defined (in a South African context) as ‘a coastal body of water in intermittent contact with the open sea and within which sea water is measurably diluted with fresh water from land drainage’ (Day, 1980). This definition which is a variation on that of Cameron & Pritchard (1963) seeks to take account of the non-permanent nature of many South African estuary mouths. In doing so it also includes a number of systems that may be regularly hypersaline or even dry for prolonged periods. Since such systems are inhospitable for most forms of life normally associated with estuaries, (although notably not necessarily the avifauna) they are best regarded as distinct from estuaries. This is not to say that they have no importance, but rather to recognise them as environments distinct from estuaries and operating in quite a different manner.

Estuaries have long been recognised as an important element in the coastal geomorphology of South Africa. They are numerous and frequently are the focus of sand accumulations (sand barriers) that have achieved great importance as foci of recreational activity (often in conjunction with the adjacent water bodies both landward and seaward of the barrier). Estuaries too have achieved recognition through their ecological importance and are widely regarded as critical in terms of their contribution to marine fish and invertebrate stocks. As habitats in themselves they have received less attention, although in recent years much more attention has focused in this area of research. One of the major areas of importance among estuaries is in their contribution to the large marine ecosystems of the South African coast. When this perspective is taken and estuaries are regarded as a component of large marine ecosystems, their contribution in terms of nutrient sinks and sources is readily appreciated, particularly on the east coast of the subcontinent.

Geomorphologically, estuaries occupy a transitional position between land and sea and act as an interface between terrestrial and marine environments. As such they are affected by variations in the intensity of both sets of processes. This renders many estuaries highly dynamic environments in which geomorphological change may occur at timescales that range from almost instantaneous (as for example during floods) to progressive change due to sediment infilling and sea level rise. In all estuaries an interface exists between fluvial and marine processes, although the nature and intensity of processes operating at this interface may vary considerably. In some systems sea water may extend many kilometres upstream while in others it may be restricted to inputs from barrier overwash and be confined to areas adjacent to the barrier. A strong seasonal imprint exists in some estuaries such that they may be tidal for long distances during the dry season and freshwater extends right to the barrier (or beyond) during floods (Day, 1981a). In others a seasonal imprint is produced by variation between closed conditions in the dry season and open conditions during the rainy season.

In a sedimentological context, sediment that moves seaward from rivers must pass through an estuary and vice versa. Estuary morphology is likely to reflect the relative balance between these two competing sets of processes. The seaward transfer of sediment from rivers is not constant in time or space. Those that have steep readily eroded hinterlands are more likely to yield large quantities of sediment than those that are better vegetated and less steep. The former are more likely to fill their estuaries with fluvial sediment than the latter. Sediment moving landward from the sea into estuaries is a common phenomenon and is driven by the tidal asymmetry that exists in constricted inlets. These inlets have a shorter duration and hence faster current regime during flood tides than ebb tides and thus sediment accumulates preferentially in the estuary in the form of a flood-tidal delta. In many instances, these flood-tidal deltas gradually extend upstream. In others they are poorly developed or absent entirely.

Estuaries are widely regarded as sinks (net accumulation zones) of sediment. They receive sediment from a variety of sources including marine and fluvial inputs as well as detritus from fringing vegetation, material (mainly organic) generated within the estuary itself, aeolian sediment input and human-induced inputs. Estuaries are thus regarded as areas that should exhibit progressive shallowing and reduction in area. This is in fact not always the case. Floods periodically scour estuaries and remove accumulated sediment thus ‘resetting the evolutionary clock’. In addition, some estuaries function mainly as ‘conveyor belts’ by which excess sediment is transferred through them and deposited in the sea (such systems have no capacity to accumulate additional sediment).

In all estuaries, the presence and persistence of a mouth that permits a surface water connection between the estuary and the sea is dependant on the relative strength of surface currents (which act to maintain the mouth) and wave and tidal currents in the nearshore zone (which act to close to mouth by depositing marine sand in it). In some instances mouth-forming processes dominate over mouth closing processes and vice versa. The situation is variable with time. The persistence of a mouth has importance for the migration of flora and fauna between the estuary and the sea and this might thus be regarded as one of the key factors in producing variability between estuaries.

To conclude, there is wide geomorphological variability between the estuaries of South Africa in spite of the commonality of several factors that produce variability worldwide. In order to make sense of the observed variability it is necessary to classify systems to remove the inherent 'noise' that obscures the reasons for the variation between systems. 'Without classification one cannot hope to remember or manipulate the individuals or see relationships between them' (Van der Eyk *et al.*, 1969). To this end a classification that encompasses the range of variability observed in South African estuaries is presented in this report.

2.2 Coastal setting

The South African coast is highly variable geomorphologically and climatologically. These two main categories of variability contribute much to the variation between estuaries that exists at the present time. There are, however, a number of variables that do not vary so considerably and may be regarded as consistent for the purposes of this chapter.

The tidal range around the South African coast varies comparatively little with most areas experiencing a spring tidal range between 1.8 and 2.0 m. Neap tides are typically between 0.6 and 0.8 m, rendering the coast microtidal (Davies, 1980). Wave energy is also consistently high around the South African coast, although a peak in wave heights is evident in the southern Cape and wave height diminishes northward along both the east and west coasts. Even in the NE and NW coasts, wave height is great compared to other areas and the entire coast is regarded as a high energy, swell-dominated environment. A further common factor is that almost all estuaries in South Africa are located in incised bedrock valleys and thus are laterally confined. Some estuary channels fill their entire bedrock valley while others have a substantial floodplain, but most are nonetheless confined by their bedrock valley. Only a few examples of coastal plain estuaries (i.e. estuaries formed in semi-consolidated alluvium on coastal plains) are present on the South African coast. These are mainly confined to northern KwaZulu-Natal and to the Wilderness Lakes area and in both instances produce estuaries that are linked to substantial water bodies (coastal lakes).

Factors that contribute to variability among estuaries around the South African coast include catchment size and gradient, fluvial sediment supply, marine sediment availability, climate and fluvial discharge. The South African coastal hinterland is typically gently sloping in the west and very steep in the east, with the south coast exhibiting variations in gradient according to whether mountain ranges intersect the coast or not. The hinterland gradients on the east coast are among the steepest found in the world.

Climatologically, the subcontinent may be divided into several zones. The east coast is a subtropical humid zone that experiences a peak in summer rainfall. The west coast is a highly arid zone with extremely erratic rainfall. The south coast experiences varying rainfall regimes with some areas exhibiting a summer peak and others a winter peak and some are bimodal (Heydorn & Tinley, 1980). A consequence of this climatological variability is a variation in rainfall and river runoff. If considered on a runoff per km^2 basis around the coast, the range of variability is clearly seen.

While wave energy is high everywhere around the coast there is a gradient of wave energy that decreases from south to north along both the east and west coasts. Waves are predominantly of the deep sea swell type but localised sea waves are also produced by local winds. An effect of the variability in wave energy is the linked variation in beach profiles. Generally, beach profiles become steeper as wave energy diminishes, thus the high wave energy of the southern Cape produces wide, gently sloping beaches with offshore bars while the lower waves of KwaZulu-Natal and Namaqualand produce characteristically steeper and narrower beaches with high berms.

2.3 Estuaries: Introduction to a conceptual classification

A hierarchical classification is presented below, based upon the main forms of morphological variability among estuaries of the South African coast. At the highest level, the major variation between estuaries is based upon the frequency of connection with the sea, via a surface channel. This immediately divides estuaries into those that are normally open and those that are more commonly closed by a barrier. This division, which is theoretically entirely gradational, appears in practice to identify two groups of estuary. In KwaZulu-Natal, where the most extensive set of observations on frequency of mouth opening exists, estuaries divide clearly into those that are open more than 70% of the time and those that are open less than 30% of the time. There is clearly longer term variability in this as drought cycles (Tyson, 1987) are more likely to be associated with reduced freshwater discharge and may cause estuaries to close for longer periods in drought years

The categories normally open and normally closed will be discussed below and further subdivisions are described within these two major categories, based upon geomorphological behaviour of various types of system.

2.4 Open estuaries

Those systems that are normally open display marked variability in size and in mouth dynamics. They are subdivided into systems that are essentially unbarred (i.e. they lack a sand accumulation at the mouth that is exposed above high tide) and those that have a supratidal barrier with a surface drainage channel. Further subdivisions may be made on the basis of the size of the individual estuary.

2.4.1 *Barred open estuaries*

Barred estuaries (those with a supratidal barrier) vary markedly in size and in the volume of fluvial discharge. Since the volume of the bedrock valley in which the estuary is formed is largely dependent on the amount of fluvial discharge.

Barred estuaries that are normally open range in discharge from small, localised stream catchment systems to large systems such as the Orange (Gariep), Great Fish and Tugela (Thukela) that drain large sections of the subcontinent. A division into several size categories can be made but for the purposes of this report a division was selected at a Mean Annual Runoff (MAR) of $15x10^6$ m^3 based on the complete distribution of systems of variable discharge volume. The smaller systems are incapable of maintaining large tidal prisms and are thus maintained in an open condition by river discharge. This is often assisted by the outlet configuration; in many cases e.g. Zotsha where a bedrock ledge permits enhanced scouring. Such outlets frequently form in the lee of a headland where wave energy is reduced. These systems seldom exhibit a flood tidal delta and many appear to operate almost exclusively as outlet channels. Estuarine characteristics are however imparted by the frequency of overwashing and by occasional surges that increase tidal penetration into the estuary. These systems tend to have short barriers that reduce the volume of discharge that can be accommodated by seepage through the barrier such as was noted in the barriers of SE Ireland by Carter & Orford (1984).

The larger typically open estuaries span a range of discharge characteristics and are divisible into two types.

Those systems that have insufficient tidal prisms to maintain an inlet against nearshore wave and tidal action, may arise through either pre-existing morphological constraints (steep gradient, high sediment supply during transgression and narrow bedrock valleys) or through sedimentation and infilling of formerly tidally maintained systems. These systems are especially well developed in KwaZulu-Natal and have been termed 'river-dominated' estuaries (Cooper 1993a,b; Cooper *et al.*, 1999) (Figure 2.1). Morphologically these systems differ from tidally dominated systems and in them flood-tidal deltas are much reduced in size or absent. Fluvial sediment typically extends to the barrier and tidal inflow is frequently minimised by elevated bed levels. Under lower wave energy conditions these systems would probably form deltas, but the only example of such a delta on the South African coast are those of the Orange (Gariep) River (submerged) (Van Heerden, 1986) and the Tugela (Thukela) and Berg which have offshore mud depocentres and a series of beach ridges located north (downdrift) of the estuary mouth. River flow in such systems is critical to the maintenance of an outlet channel. Under drought conditions such systems may close for prolonged periods. The impacts of impoundments are especially noteable in these types of systems. For example, The Mgeni estuary which was formerly open for more than 90% of the year is now closed for prolonged periods since the completion of Inanda Dam, some 35 km upstream of the mouth. Stratigraphical evidence suggests that many river-dominated systems have been in such a state throughout much of the Holocene period (Cooper 1993a). While many of these systems have relatively large surface areas, many are comparatively short, due to the steepness of the hinterland and this limits tidal penetration. The role of floods in these systems is important in eroding accumulated sediment and temporarily deepening the channel (Cooper *et al*., 1989). Erosion during extreme floods appears to be distributed throughout the channel and even cohesive sediments may be eroded. The Mgeni for example in 1987 lost an entire, vegetated and mangrove-fringed island from its lower reaches as a result of a flood.

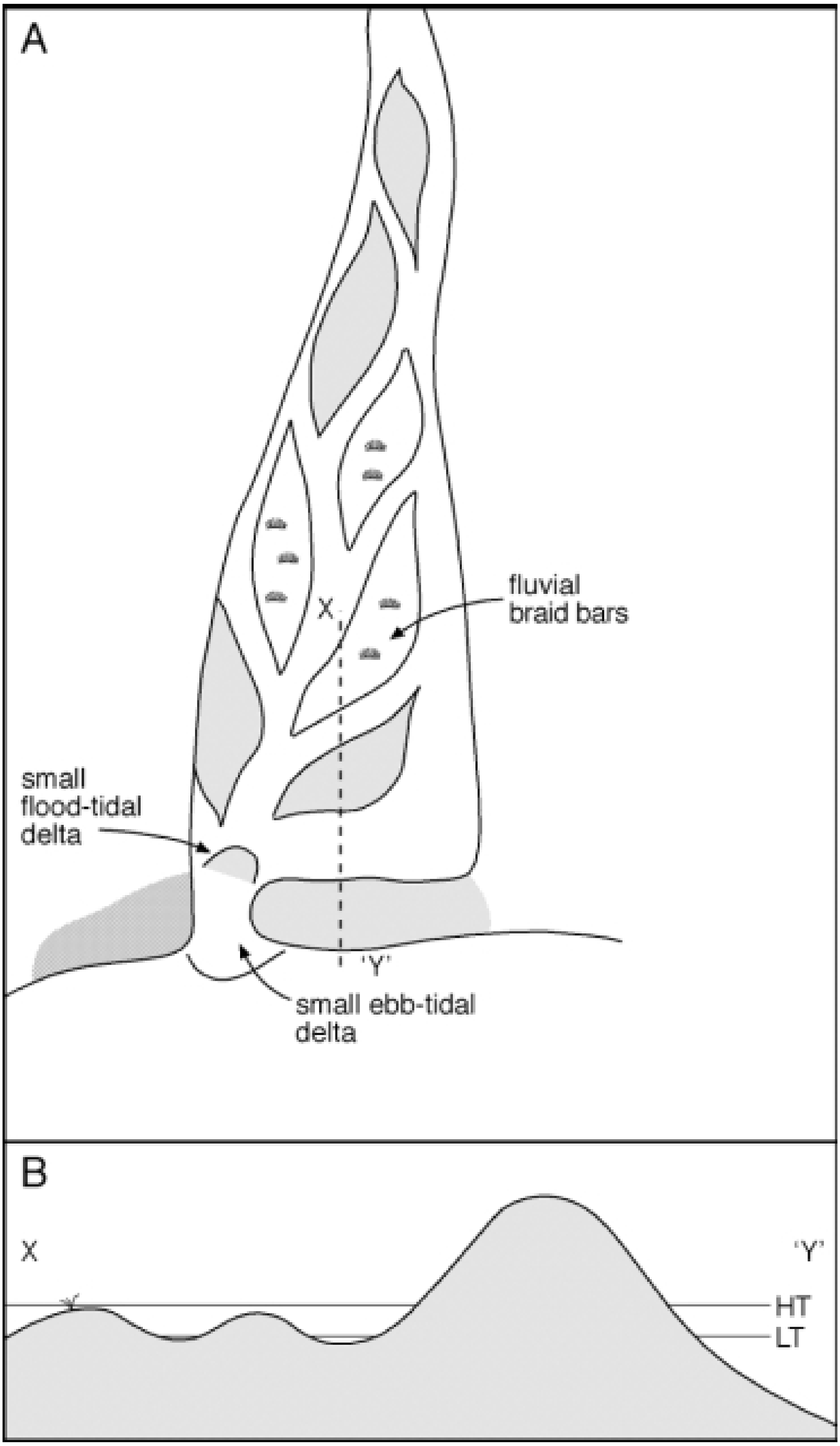

Figure 2.1. Diagram of river-dominated barred estuary morphology showing plan (A) and cross-sectional (B) perspective. Note the extension of riverine bars to the barrier and the small extent of flood- and ebb-tidal deltas.

Those systems maintained by tidal flow are recognisable by virtue of a distinctive morphology (Figure 2.2). They have well developed, often transgressive flood-tidal deltas (Reddering & Esterhuysen, 1981; Cooper, 1993c). This is accomplished as a result of flood-dominance at the tidal inlet and by the enhanced suspension of sediment by wave action, that is then entrained on the flood current. Wave action does not assist in the return flow and thus net accumulation takes place. Landward is a relatively deep section characterised by fine-grained sedimentation, and upstream is a coarse grained fluvial delta that progrades into the estuary, gradually reducing its volume. Floods in such systems serve an important geomorphological function in removing accumulating flood-tidal deltas

Tidally maintained systems may close through the effects of extreme marine events. Kosi Estuary with a tidal prism in excess of 350 million m^3, has closed (on August 17 1965) and this was probably as a result of a storm event. After tropical cyclone Claude (in January 1966), water levels rose by 1.6 m (Breen & Hill, 1969). The system, however, did not open of its own accord and was artificially opened to save the mangrove community. Smaller tidally maintained outlets may close as a result of less intense storms as the tidal flow that is required to be overcome is smaller. These systems may then be reopened by renewed freshwater discharge that re-establishes the tidal inlet and permits tidal currents to be reinstated.

It is important to note that tidally dominated systems have the capacity to evolve into river-dominated systems but that some estuaries are river-dominated by virtue of their geomorphological location. For the purposes of this report river- and tide-dominated systems have not been subdivided, mainly because of the relatively few numbers of estuary in each type when subdivided by biogeographic zone. Because of a lack of data on distinguishing attributes the large open systems which have been grouped here do exhibit some morphological variability in terms of floodplain development and the extent of open water area and depth (and by implication stratification/circulation parameters). Further subdivision of the group will require gathering of such data and will enable future refinement of the existing classification.

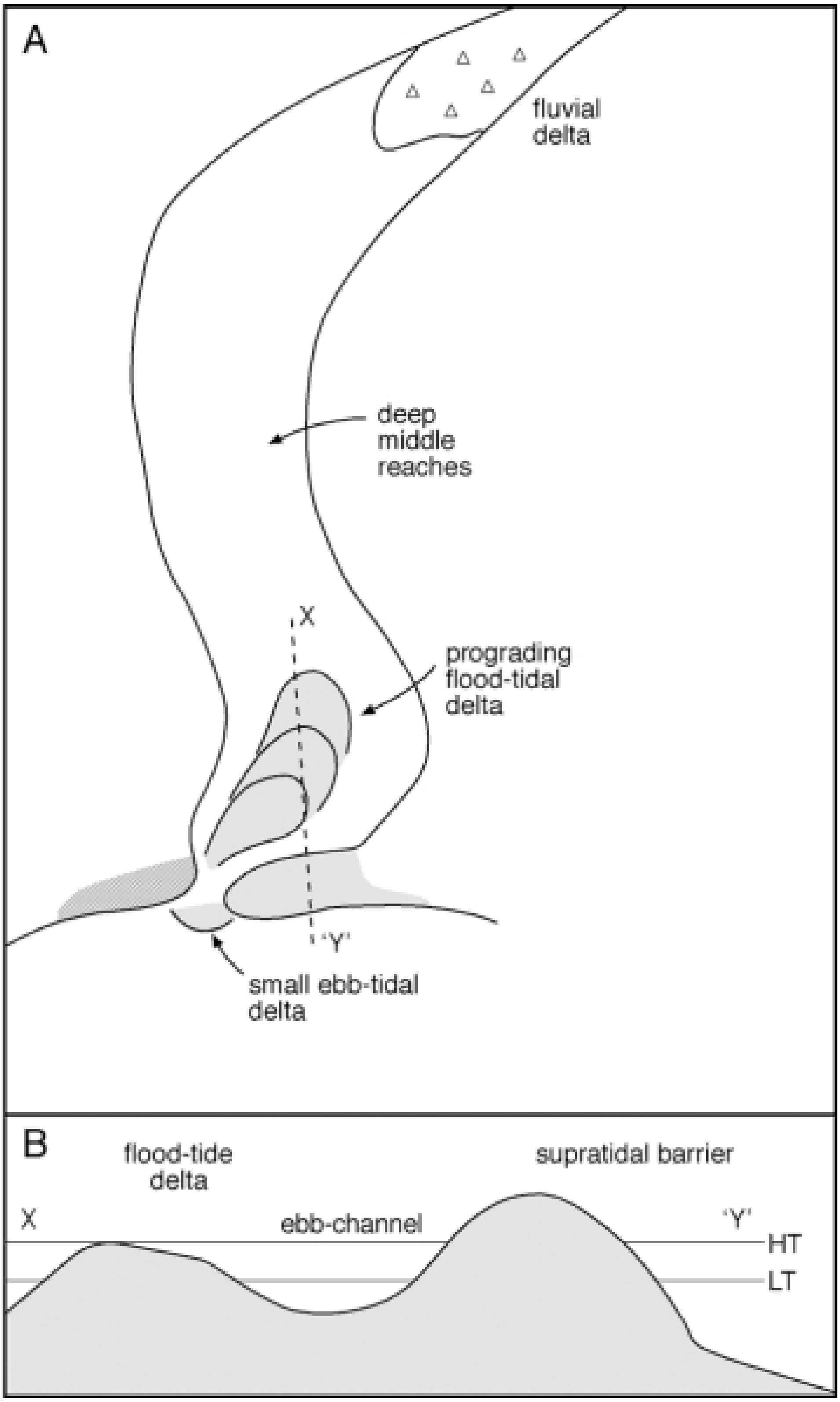

Figure 2.2. Diagram of tide-dominated barred estuary morphology showing plan (A) and cross-sectional (B) perspective. Note the extensive flood-tidal deltas which may show landward progradation, and the small ebb-tidal delta which is confined by high wave energy. The fluvial delta upstream marks the limit of progradation of coarse-grained riverine sediment.

2.4.2 *Non-barred open estuaries*

Several estuaries exist within drowned river valleys that have either no sand accumulation at their outlet (e.g. Storms River mouth) or have a barrier that is only intertidally exposed and is in effect the upper surface of a flood-tidal delta. These systems (Figure 2.3) are relatively uncommon and are largely restricted to rocky, cliffed coastal sections that have limited sediment supply. Thus while they may have relatively small surface areas and small tidal prisms they maintain permanent contact with the open sea. One large variation on this type of system exists (Knysna estuary, Reddering & Esterhuysen, 1987a). This has a large tidal prism but a paucity of sediment at the estuary mouth precludes closure of the tidal inlet.

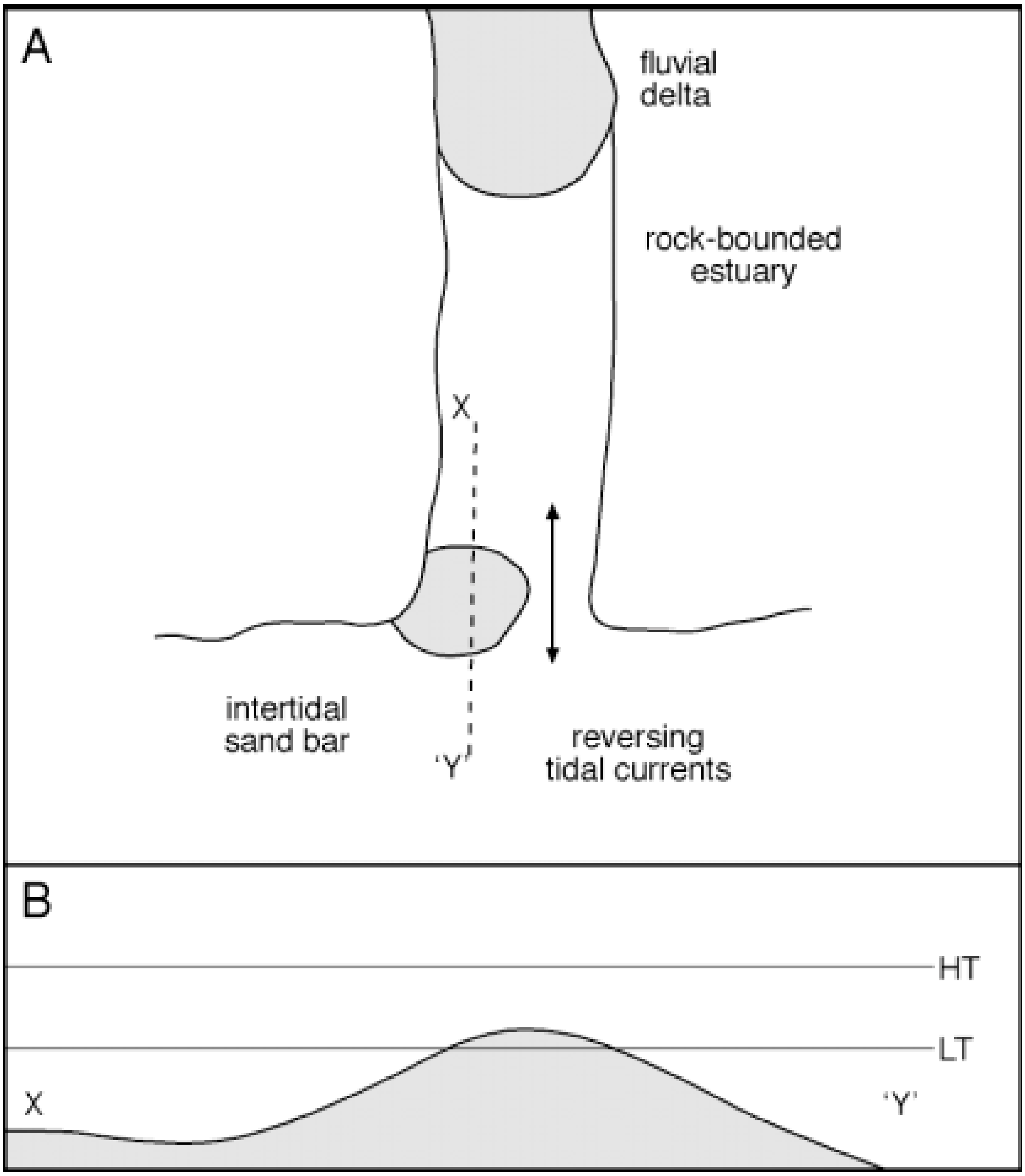

Figure 2.3. Diagram of non-barred estuary morphology showing plan (A) and cross-sectional (B) perspective. Note the intertidal barrier that is submerged at high tide and emergent at low tide. In such systems insufficient sediment is available to permit mouth closure. The fluvial delta upstream marks the limit of progradation of coarse-grained riverine sediment.

2.5 Closed estuaries

The normally closed estuaries of South Africa span great variation in size from tiny systems of <0.2 hectares surface area to systems such as the Bot and Klein that are over 1200 hectares in area. Two main forms of behaviour are exhibited by these systems, based on whether the back-barrier water level is higher than open sea tidal levels or within the range of open sea tidal elevations. This in turn is related to the elevation of the berm crest of barriers that enclose these systems. These normally closed systems may be subdivided into perched and non-perched categories. These are discussed below.

2.5.1 *Perched closed estuaries*

Those systems that have a high berm, produced as a result of coarse grained barrier sediment and relatively low wave energy (in a South African context) impound water levels behind them at elevations above the levels of most high tides. The enclosed water bodies exhibit a long term balance between inputs from freshwater inflow, barrier overwashing and rainfall, and outputs via evaporation, seepage and evapotranspiration by fringing vegetation (Figure 2.4). Vegetation within such systems is typically graded to a perched water level, as is sedimentation such that the bed of the estuary may be elevated above tidal levels. In such instances tidal inflow during open phases is precluded (Huizinga, 1994). Breaching occurs in such systems when inputs via overwash and freshwater discharge exceed outputs and a surface channel is cut to permit discharge. When this occurs, the elevated water level provides a marked hydraulic head and rapid downcutting occurs into the berm (its depth is dependent on the state of the tide when breaching occurs). Under such conditions such systems may drain within a few hours and a formerly large surface area is reduced to a narrow shallow channel through which fluvial discharge is effected. Barrier breaching of such systems typically deposits an ephemeral delta from which sediment is eroded and transported by cross-shore transport to close the breach, whereafter the estuary fills and attains equilibrium once again (Cooper 1989, 1990). Salinity in such systems is typically lowered and may even be totally fresh, dependent on the volume of overwash received.

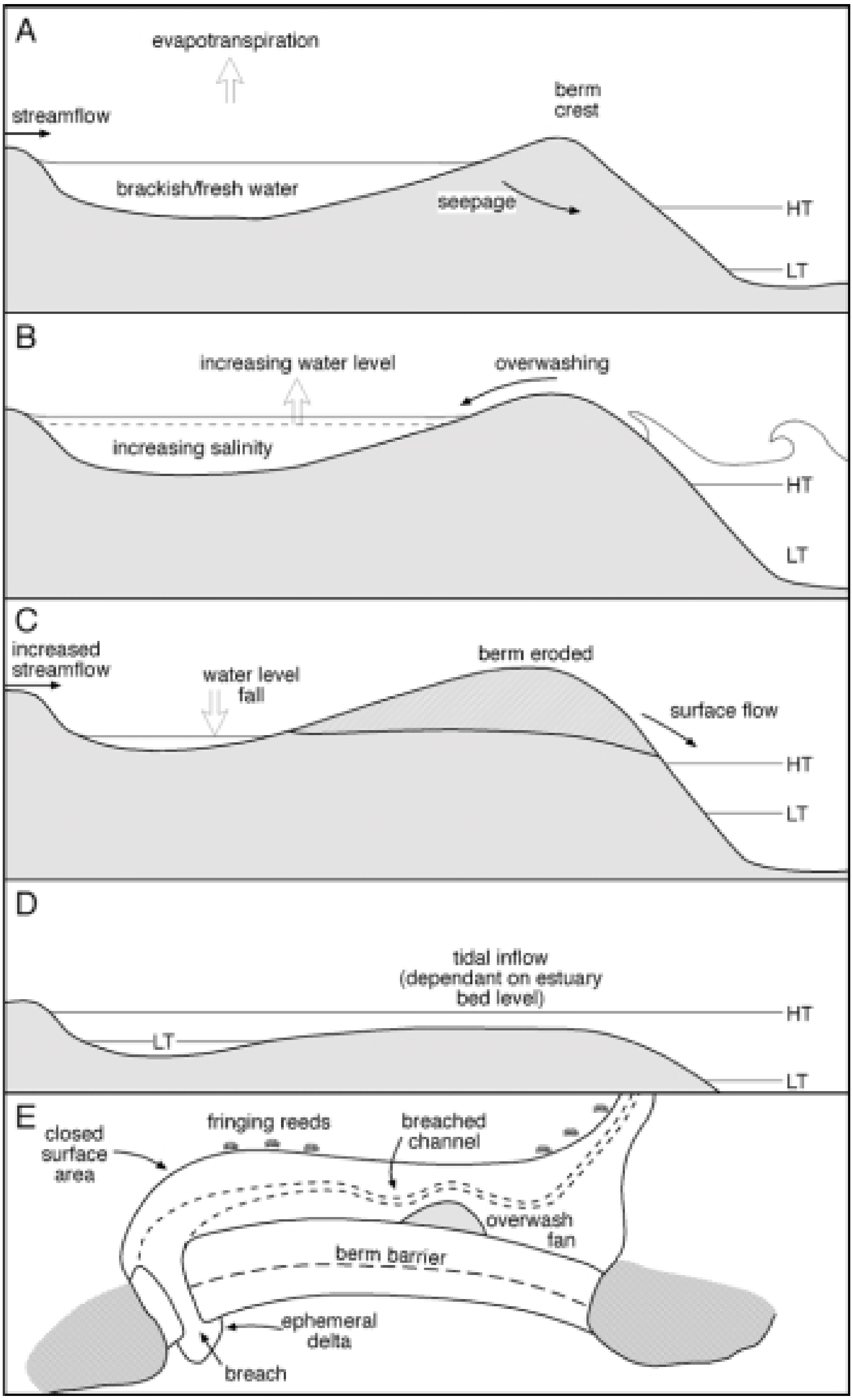

Figure 2.4. Diagram of perched normally closed estuary showing cross-sectional (A-D) and plan (E) views. Under balanced conditions (A), the stream inflow is matched by evapotranspiration and seepage. Overwashing (B) may elevate water levels and salinity and increased streamflow (C) may promote breaching. When breached (D) the water levels are lowered and tidal flow may take place if the berm level is sufficiently low. In plan view (E) the difference in water area during open and closed conditions is evident.

2.5.2 *Non-perched closed estuaries*

Those systems that do not have a high berm but which lack a common surface channel are impounded at or close to high tide level (Figure 2.5). The beaches that front these systems have a dissipative (low gradient) profile and are characterised by wide surf zones. The lack of a berm and high wave energy means that barrier overwash is more frequent in these systems and consequently they are typically saline. In addition, in areas of low coastal gradient saline influences may extend for 10 km upstream even in the absence of tidal inflow. These systems often exhibit salt marsh vegetation as a result. No definitive study has been undertaken of this type of system, however, a number of observations over the past 10 years by the authors permit some insights to be gained on their behaviour. Following increased fluvial discharge, these systems may form a surface connection with the sea. This may happen relatively frequently as the barrier is close to sea level and thus saturated which precludes seepage. When a surface channel forms it is typically shallow and broad and forms a braided pattern on the barrier surface. Water depths are typically a few centimetres as downward scour is precluded by the low water level in the enclosed estuary.

When such systems begin to experience reduced water levels through drought, landward seepage may occur as evidenced by rill marks and microchannels and deltas on the landward slope of the barrier. In some instances these systems have been known to become hypersaline. The large surface areas of such systems coupled with a strong wind regime means that the water column is frequently well mixed. Since the surface channels are typically very shallow, tidal inflow is also reduced, although evidence of flood-tidal delta morphology in some systems of this type does suggest that under certain conditions (probably associated with positive surges and/or low estuary water levels), tidal inflow may occur. A characteristic of these systems is the constancy of their water area and volume which provides a more stable habitat than the perched systems.

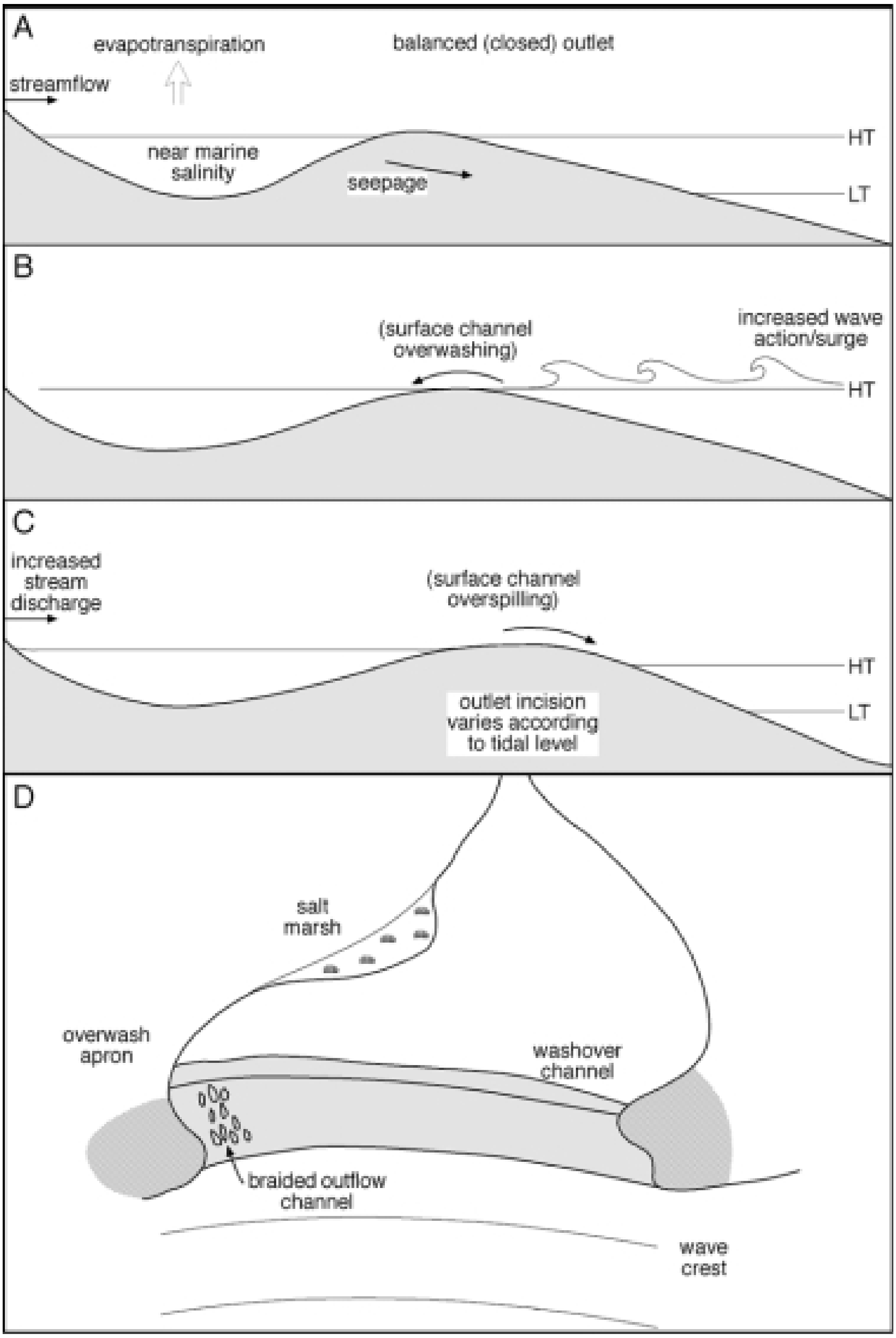

Figure 2.5. Diagram of non-perched and normally closed estuary in cross-section (A-C) and plan (D) view. Under balanced conditions (A) streamflow is balanced by losses through evapotranspiration and seepage. Under high wave energy (B) overwashing introduces marine water into the system. Under enhanced inputs from overwashing (B) or streamflow (C), the system may breach. The depth of incision is low since the estuary water level is so close to sea level. In plan view (D) the consistency of surface water area between open and closed phases is clear.

Although individual systems may be identified as perched or non-perched lagoons, it is not possible with existing data to classify every system according to this division. For the purposes of this report, a subdivision of normally closed systems was however made according to whether they had a surface area greater or less than 2 hectares. Although this introduces a group of larger systems that is highly diverse in terms of size, the low numbers of systems in each biogeographic zone mitigates against further subdivision.

2.6 Discussion

The hierarchical classification system for South African estuaries is shown in Figure 2.6. The first subdivision is made on the basis of whether a stream outlet constitutes an estuary or not. Non estuaries were selected on the basis of permanent separation from the sea, very small size, ephemeral surface water and/or hypersalinity, and if they were waterfalls. For the remaining systems an estuarine function was determined on the basis of periodic communication with the sea and the permanent occurrence of fresh to brackish surface water in the estuary. These systems were then divided on whether they were normally open or normally closed.

Those that are normally open may be barred or non-barred and outlets in the barred variety may be maintained by tidal prisms or river discharge thus defining river- and tide-dominated systems. In this report, the two types are not identified but the barred systems are subdivided on the basis of whether their mean annual runoff exceeds or is less than 15 million cubic metres.

The systems that are normally closed were subdivided on the basis of surface area with the division placed at 2 hectares. While a further subdivision is recognised it cannot be implemented with the current level of knowledge and thus perched and non-perched systems are grouped in this report. Since there is however, a likely regional element to the distribution of perched and non-perched systems according to wave height, the subdivision of the coast into biogeographic zones may incorporate, at least partly, this division.

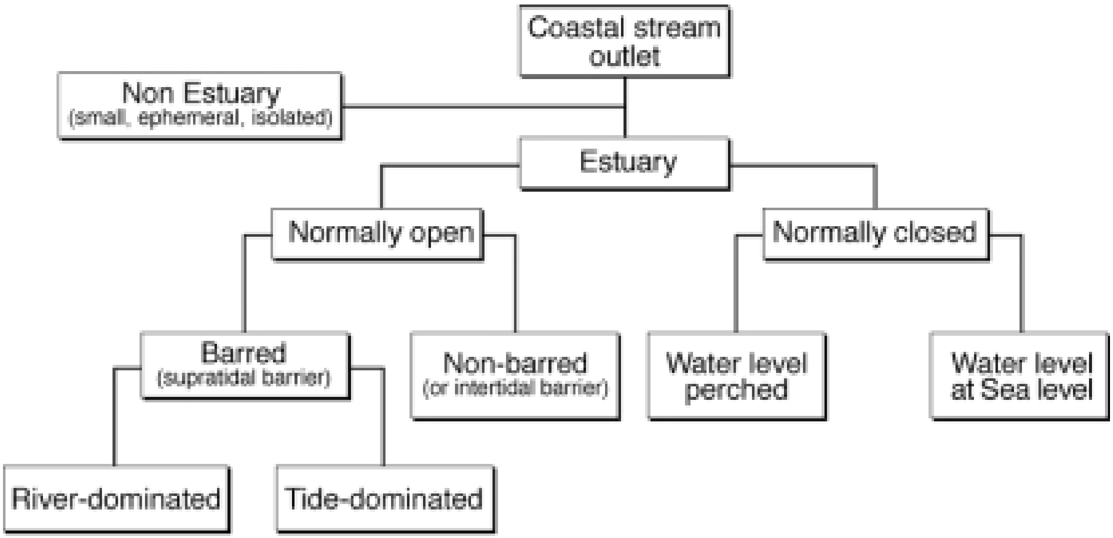

Figure 2.6. Conceptual hierarchical classification scheme for South African estuaries based on the range of estuaries present. This identifies the types of estuaries and processes operative within them. At the present time it is not possible to categorise every estuary to the lowest level of the hierarchy illustrated. A practical alternative is shown in Figure 2.7.

2.6.1 ***Practical classification***

Whereas the above account provides an assessment of the range of estuary types present in South Africa on the basis of the major geomorphological features and physical behaviour, it is not presently feasible to categorise every estuary to the finest subdivision recognised. Insufficient data are available on, for example, water level and barrier elevation to categorise normally closed systems into perched and non-perched types. This would require a targeted assessment of the barrier condition of each system under 'normal' conditions. To ascertain whether tidal inflow occurred during open phases would require additional assessment during open periods which occur infrequently and irregularly in such systems. Similarly, while the variability between river and tide-dominated open systems is obvious in many instances (evidenced by, for example, the presence of riverine braid bars right to the estuary barrier in some river-dominated systems), the division between the two estuary types cannot readily be made in all cases. A further difficulty arises in the identification of 'normal' or most common conditions in estuaries. In KwaZulu-Natal where data are available a clear division seems to exist between normally open systems and normally closed systems. Where this information does not exist, a subjective judgement made on the basis of historical accounts, geomorphology and aerial photographic evidence must be made. This situation may change in the future, but for the present, available indicative data coupled with empirical information has been used. It is possible therefore, that in the light of future data some systems may change classification. Further it is to be hoped that the additional data necessary to more closely classify all of the normally open and normally closed estuary types to the finest subdivisions recognised above will eventually be available.

In addition, the classification presented above takes account of variations in processes operative in each type of system but does not identify potential variations in habitat that may arise on account of variations in estuary size. For these reasons, in addition to the data limitations outlined above, it has been necessary to employ a modified classification scheme (which is limited by data availability) in this report (Figure 2.7).

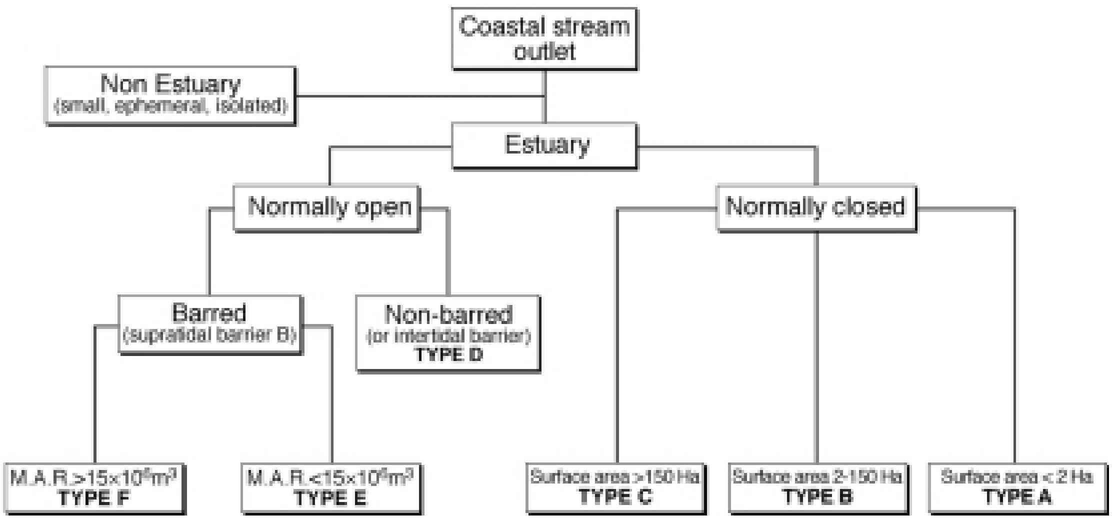

Figure 2.7. Classification of South African estuaries based on available data. Since inadequate data exists to subdivide to the finest levels of detail identified above (Figure 2.6) the barred open estuaries were subdivided according to their Mean Annual Runoff into groups E and F. Non-barred estuaries were readily identified (Group D). Normally closed systems were subdivided on the basis of surface area into very large (Type C), large (Type B) and small (Type A) systems. The estuaries assigned to each group are listed in Table 2.1.

This scheme follows that outlined in Figure 2.6 as far as the open/closed division. Thereafter only the non-barred type of system is fully identified. The closed systems are subdivided on the basis of their surface area into three groups, one (Type A) comprising those systems smaller than 2 hectares, a second (Type B) those between 2 and 150 hectares, and a third (Type C), those over 150 hectares. These subdivisions were made on the basis of identified gaps in a frequency distribution chart of all closed estuaries studied. The open systems were subdivided into the non-barred systems (Type D) but excluded from this grouping were the rare large systems that lacked a barrier (Knysna, Msikaba and Mtentu). These were included with the barred estuaries. The barred open estuaries were subdivided according to a well-defined gap in the frequency distribution of Mean Annual Runoff (MAR) values, with a group of smaller systems recognised that had MAR values less than $15x10^6$ m^3 (Type E) and a group of systems that had larger values (Type F). The mouths of those in the smaller category are almost certainly all maintained by freshwater discharge as their small size precludes the development of a sizeable tidal prism. They are therefore of the river-dominated type. Those in the larger category comprise a combination of tide- and river-dominated systems and some that vary seasonally between the two modes of behaviour (for example, Breë, Berg).

The estuaries of each type are listed below in Table 2.1. This listing is based on the entire number of systems sampled and is not subdivided according to biogeographic zones. It excludes those systems that were not considered estuaries on the basis of very small size, regular dry or hypersaline back-barrier conditions, extensive human modification or which were permanently isolated from the sea, either by a permanent, continuous barrier or by a sea cliff. A number of systems were, however, not sampled in the course of this research and omission of those systems from this list does not imply that they are not estuaries. In the Transkei area, for example, only about a third of known river mouths were sampled; the remainder have not been classified.

Table 2.1. Grouping of estuaries according to their geomorphological classification.

Type A	Type B	Type C	Type D	Type E	Type F
Houtbaai	Verlore	Bot	Steenbras	Lourens	Gariep (Orange)
Schuster	Diep	Klein	Maalgate	Sir Lowry's	Olifants
Silwermyn	Wildevoel		Gwaing	Rooiels	Berg
Klipdriftfontein	Krom		Kaaimans	Buffels (Oos)	Eerste
Noetsie	Sand		Sout	Onrus	Palmiet
Matjies	Kleinmond		Bloukrans	Ratel	Uilkraals
Klipdrif (Oos)	Blinde		Lottering	Piesang	Heuningnes
Slang	Hartenbos		Elandsbos	Rufane	Bree
Maitland	Touw		Storms	Ngculura	Duiwenhoks
Thatshana	Groot (Wes)		Elands	Shelbertsstroom	Goukou (Kafferkuils)
Lilyvale	Tsitsikamma		Groot (Oos)	Bulura	Gourits
Hlozi	Seekoe			Cwili	Klein Brak
Blind	Kabeljous			Jujura	Groot Brak
Hlaze	Van Stadens			Ngadla	Swartvlei
Cunge	Boknes			Ku-Mpenzu	Goukamma
Imtwendwe	Kasuka			Ku-Bhula	Knysna
Mtendwe	Riet			Kwa-Suku	Keurbooms
Ncizele	Wes-Kleinemond			Ntlonyane	Kromme
Sundwana	Oos-Kleinemond			Nkanya	Gamtoos
Thsani	Old Womans			Nenga	Swartkops
Gxwaleni	Mpekweni			Mapuzi	Sundays
Mvutshini	Mtati			Mpande	Bushmans
Kongweni	Mgwalana			Bulolo	Kariega
Damba	Bira			Mtumbane	Kowie
Mkumbane	Gqutywa			Ntlupeni	Great Fish
Mzimayi	Mtana			Butsha	Keiskamma
	Ngqinisa			Mgwegwe	Tyolomnqa
	Kiwane			Mgwetyana	Buffalo
	Ross' Creek			Sandlundlu	Nahoon
	Ncera			Tongazi	Gqunube
	Mlele			Zotsha	Kwelera
	Mcantsi			Mhlabatshane	Quko
	Gxulu			Mbokodweni	Great Kei
	Goda			Mgobezeleni	Kobonqaba
	Hickmans				Ngqusi/Inxaxo
	Qinira				Qora
	Cintsa				Shixini
	Cefane				Mbashe
	Kwenxura				Xora
	Nyara				Mtata
	Haga-Haga				Mdumbi
	Morgan				Sinangwana
	Gxara				Mngazana
	Ngogwane				Mngazi
	Qolora				Mzimvubu
	Cebe				Mntafufu
	Zalu				Msikaba
	Ngqwara				Mtentu
	Mtentwana				Mzamba

Table 2.1. cont. Grouping of estuaries according to their geomorphological classification.

Type A	Type B	Type C	Type D	Type E	Type F
	Kandandlovu				Mtamvuna
	Mpenjati				Mzimkulu
	Umhlangankulu				Mkomazi
	Kaba				Lovu
	Mbizana				Mngeni
	Bilanhlolo				Mhlali
	Mlangeni				Mvoti
	Mtentweni				Thukela (Tugela)
	Mhlangamkulu				Matigulu/Nyoni
	Intshambli				Mlalazi
	Fafa				Mfolozi/Msunduzi
	Sezela				St Lucia
	Mpambanyoni				Kosi Bay
	Mahlongwa				
	L.Manzimtoti				
	Manzimtoti				
	Sipingo				
	Mhlanga				
	Mdloti				
	Mdlotane				
	Zinkwasi				
	Siyai				

It should be borne in mind in using this classification that it has been compiled for a specific purpose and that it is based on the available data at the time of writing. It is possible that some systems may prove to behave differently from what is suggested by this data and future revisions may be necessary. The classification does, however, provide a starting point for further research. Further, it is recognised that there is considerable within-group variability due to additional factors that have not been considered at this national scale. Estuaries within a group may exhibit variation in salinity, for example according to the time passed since the last opening, or since the last flood or marine storm – these factors are not included in the classification as they are time-dependant and the classification is based on a time-averaged condition. Physical factors such as floodplain dimensions in relation to estuary open water area, length of shoreline, barrier length, barrier composition and back-barrier sediment type are not considered and may indeed be responsible for habitat variation between estuaries of a given type. While this is recognised as a source of variability, and may aid in the further subdivision, the groupings presented are based on a value judgement as to how far subdivisions should proceed. Endless subdivision is possible right down to the extent of recognising each estuary as unique, while at the other end of the scale all river points of contact with the sea, however infrequent, might be regarded as estuaries. A balance has been sought between these two end points in compiling the present classification.

The classification does reveal that much available knowledge pertaining to South African estuaries is derived from studies of a limited range of system types and, for example, identifies that studies of the behaviour of non-barred estuaries and non-perched closed estuaries are rare. Importantly it indicates that estuaries should not be regarded simply in terms of progression along a single evolutionary path. A river-dominated estuary is not by definition less valuable or more degraded than a tide-dominated system. Neither is a closed system, necessarily less valuable or more degraded than an open system. In many instances these systems are behaving in a predictable manner for the type of estuary they are and to envisage a hypothetical estuary with deep middle reaches, a wide, permanently open mouth and non-turbid waters as the pristine archetype is erroneous. A management strategy for estuaries should ideally recognise the diversity of estuary types present and be based on management targets for each estuary type. Certainly some may be deemed more important than others in terms of their contribution to marine fish stocks, or contributions of nutrients to the ocean and targets for these might be more stringent than others, but each type of estuary (and indeed non-estuary) deserves a management strategy based on its own mode of geomorphological and ecological functioning.