- What is an estuary?
  - Pritchard (1967): *"An estuary is a semi-enclosed coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."*
  - The majority of South African estuaries close periodically and are tidal when open.

Great Brak Estuary

- The National Environmental Management: Integrated Coastal Management Act (No. 24 of 2008) (ICM Act) defines an estuary as:

A body of surface water - (a) that is part of a water course that is permanently or periodically open to the sea; (b) in which a rise and fall of the water level as a result of the tides is measurable at spring tides when the water course is open to the sea; or (c) in respect of which the salinity is measurably higher as a result of the influence of the sea.

Great Brak Estuary

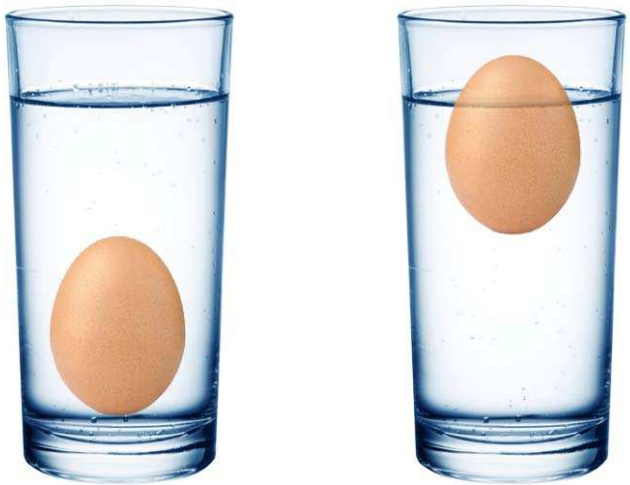
Three defining factors;

1. Tidal when open
2. Gradient in salinity when open
3. Mouth of the estuary can be open or closed

NB: Seawater typically has a salt content (salinity) of ~35 (Practical Salinity Units, parts per thousand/‰, or $g \cdot L^{-1}$)

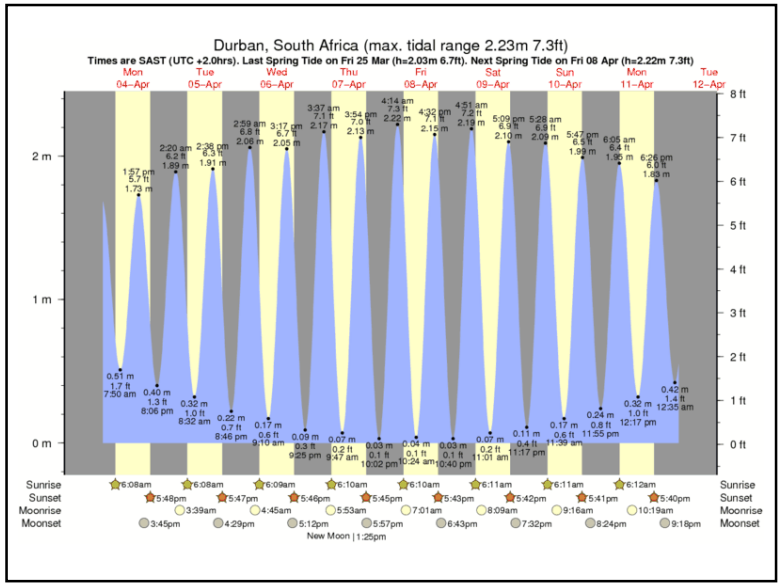
NB: Usually two high and two low tides a day and a spring tide every two weeks.

Great Brak Estuary



APRIL 2016

DAY	HIGH	HIGH	LOW	LOW	
1	09 31	23 04	02 51	15 59	**Semi-diurnal tidal pattern**
2	11 54	-----	05 33	18 23	
3	00 48	13 09	06 59	19 26	
4	01 40	13 58	07 49	20 09	
5	02 22	14 39	08 31	20 48	
6	03 01	15 19	09 10	21 25	
●	03 39	15 57	09 48	22 02	New moon; Spring tide (high tidal variation)
8	04 17	16 35	10 25	22 39	
9	04 55	17 13	11 03	23 16	
10	05 33	17 52	11 40	23 53	
11	06 11	18 31	-----	12 18	
12	06 51	19 14	00 32	12 58	
13	07 37	20 08	01 16	13 44	
☾	08 46	21 48	02 15	14 55	Waxing moon; Neap tide (low tidal variation)
15	10 58	-----	04 21	17 11	
16	00 03	12 38	06 30	18 47	
17	01 12	13 33	07 26	19 38	
18	01 54	14 12	08 03	20 14	
19	02 27	14 44	08 35	20 45	
20	02 56	15 13	09 03	21 14	
21	03 23	15 40	09 31	21 42	
○	03 49	16 07	09 58	22 09	Full moon; Spring tide (high tidal variation)
23	04 15	16 33	10 25	22 36	
24	04 42	17 00	10 52	23 03	
25	05 09	17 28	11 19	23 31	
26	05 38	17 59	11 48	-----	
27	06 10	18 33	00 02	12 20	
28	06 48	19 16	00 38	12 59	
29	07 40	20 21	01 24	13 52	
☽	09 04	22 17	02 39	15 20	Waning moon; Neap tide (low tidal variation)



Types of Estuaries

- Shape (geomorphology) of an estuary is determined by factors such as;
  - amount of rainfall
  - catchment size
  - supply and characteristics of fluvial and marine sediments
  - water currents/hydrodynamics (incl. coastal processes)
  - wave action

Bushmans Estuary

- The National Biodiversity Plan for South Africa (NBA 2011) identified 289 estuaries from the sub-tropical, warm temperate and cool temperate regions.
- Whitfield (1992) classified estuaries into five types;
  1. Permanently open
  2. Temporarily open/closed estuaries
  3. River mouths
  4. Estuarine lakes
  5. Estuarine bays

Bushmans Estuary

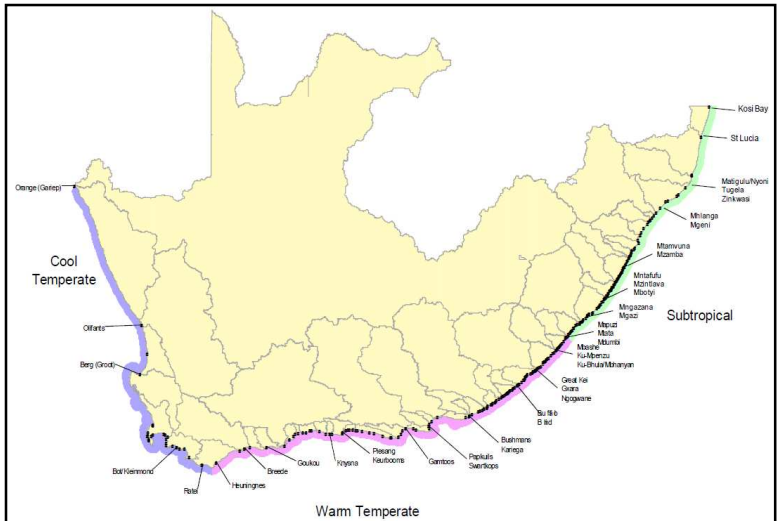


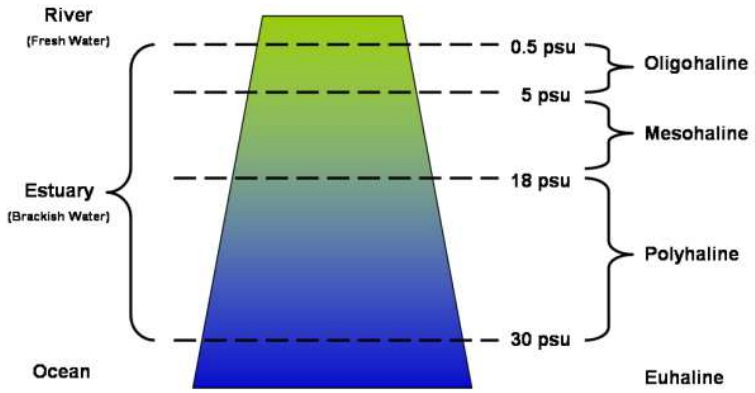
Figure 2.1 Distribution of estuaries in relation to the three biogeographic regions and secondary catchment areas

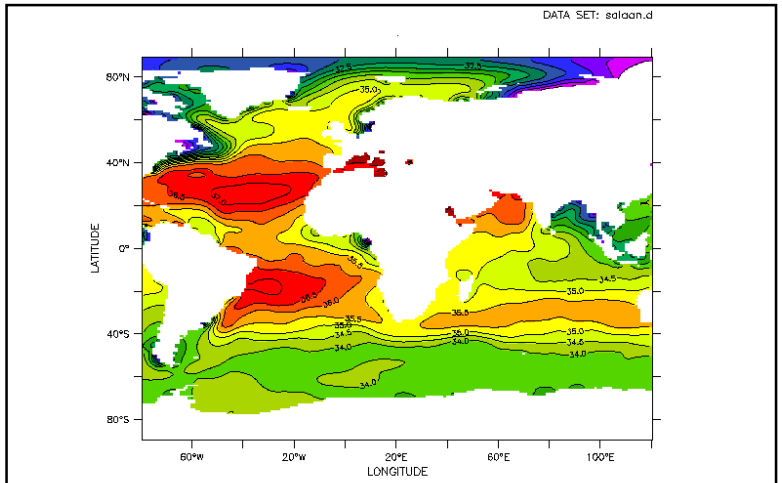
Permanently open

- Permanently open to the sea
- Moderate tidal prism; exchange between one and 10 million cubic meters of water over a full spring tide.
- A full longitudinal salinity gradient exists from the mouth to the head of the estuary.
- Vertical salinity stratification is dependent on factors such as tidal cycle, river inflow and channel depth profile.

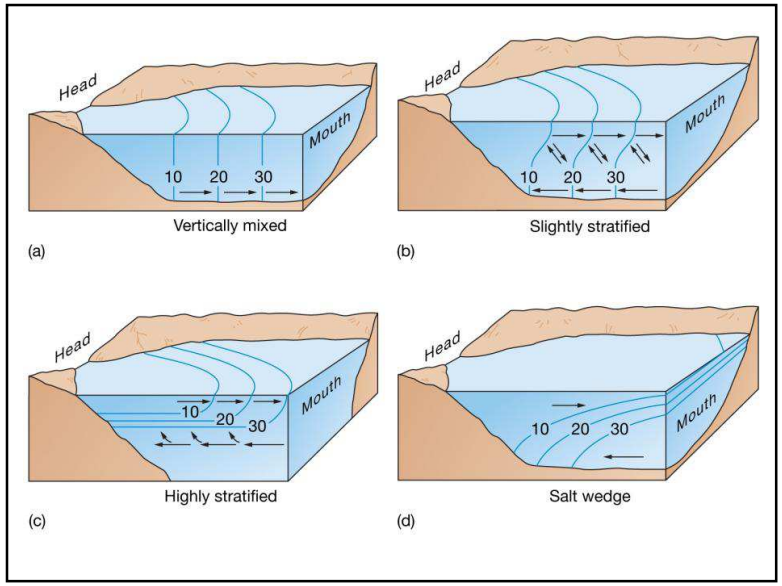
Swartkops Estuary

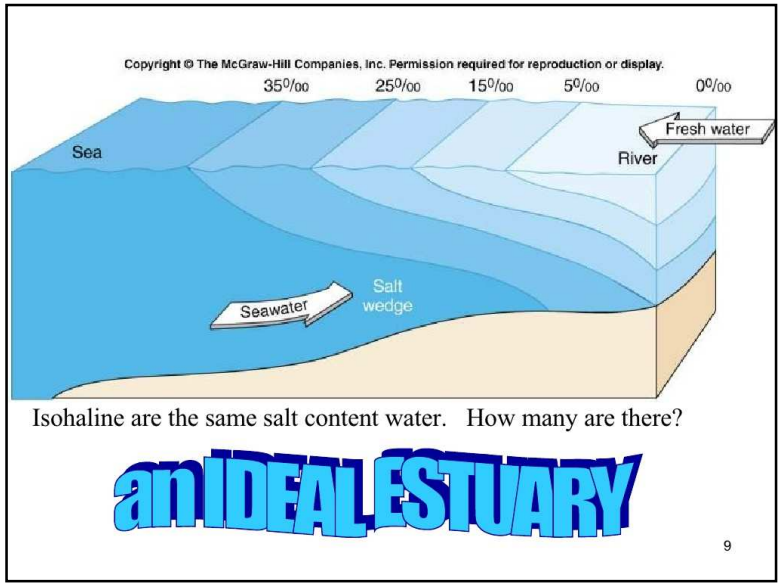
Salinity gradient





http://sam.ucsd.edu/sio210/gifimages/sal_atl_10m.gif


Head
Mouth
10 20 30
Vertically mixed
(a)
Slightly stratified
(b)
Highly stratified
(c)
Salt wedge
(d)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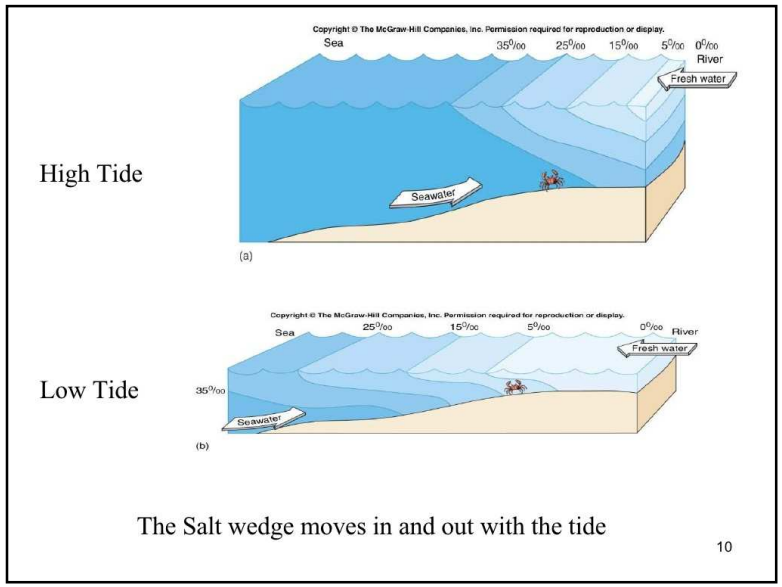
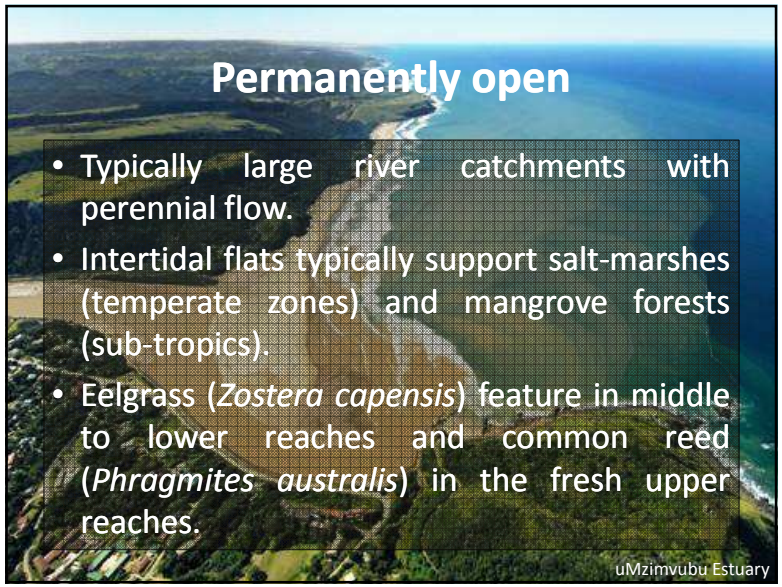
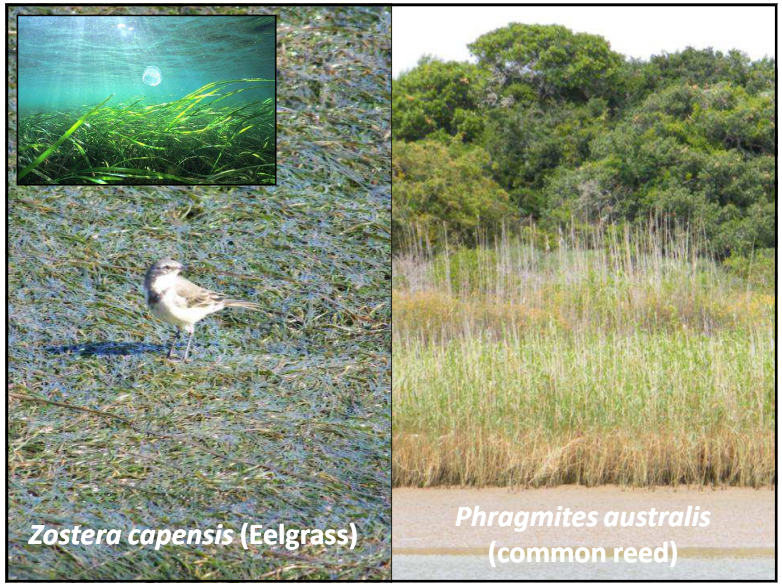
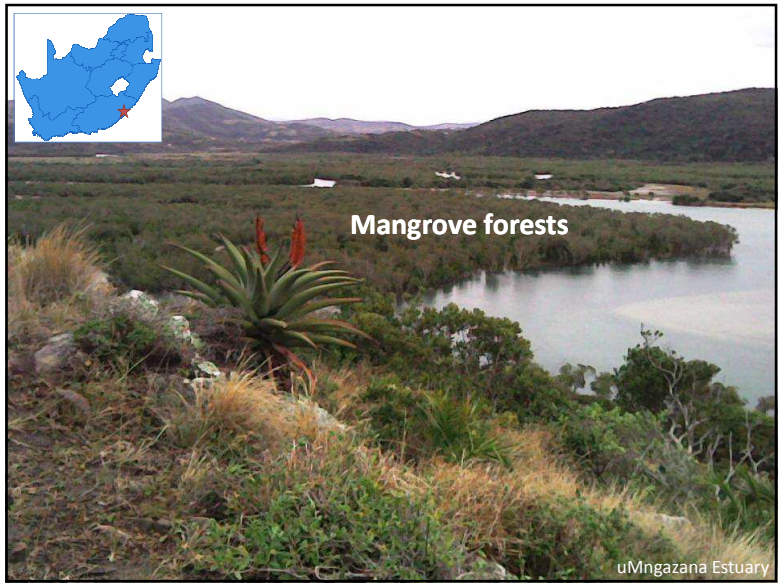
35‰ 25‰ 15‰ 5‰ 0‰
Sea
River
Fresh water
Seawater
Salt wedge
Isohaline are the same salt content water. How many are there?
an IDEAL ESTUARY
9


High Tide
Low Tide
Sea
River
Fresh water
Seawater
35‰
(a)
(b)
The Salt wedge moves in and out with the tide
10


Permanently open
• Typically large river catchments with perennial flow.
• Intertidal flats typically support salt-marshes (temperate zones) and mangrove forests (sub-tropics).
• Eelgrass (*Zostera capensis*) feature in middle to lower reaches and common reed (*Phragmites australis*) in the fresh upper reaches.
uMzimvubu Estuary





Temporarily Open/Closed (TOCE)

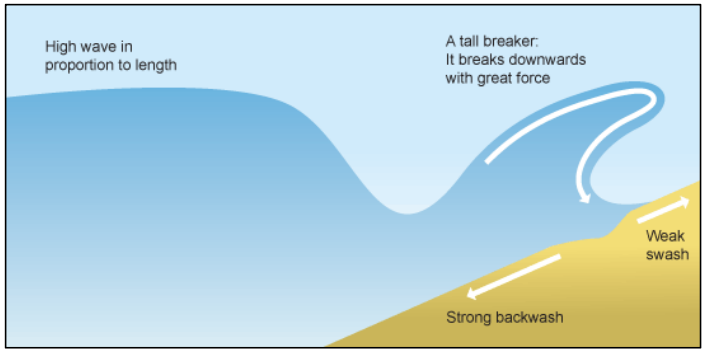
- Periodically blocked off from the sea by a sandbar at the mouth.
- Sandbar forms in response to low river flow and longshore sand movement in the adjacent marine environment.
- Catchments are generally small and river flow is periodic.
- Tidal prism is usually small when the mouth is open and absent when closed.

How is a beach formed?

Deconstructive waves (steep, reflective beach)

- High offshore energy wave environment creates high frequency (10-15 waves/min), tall waves.
- Weak swash brings in little sediment.
- Strong backwash removes beach material.
- Creates a steep, narrow beach.

Deconstructive waves



How is a beach formed?

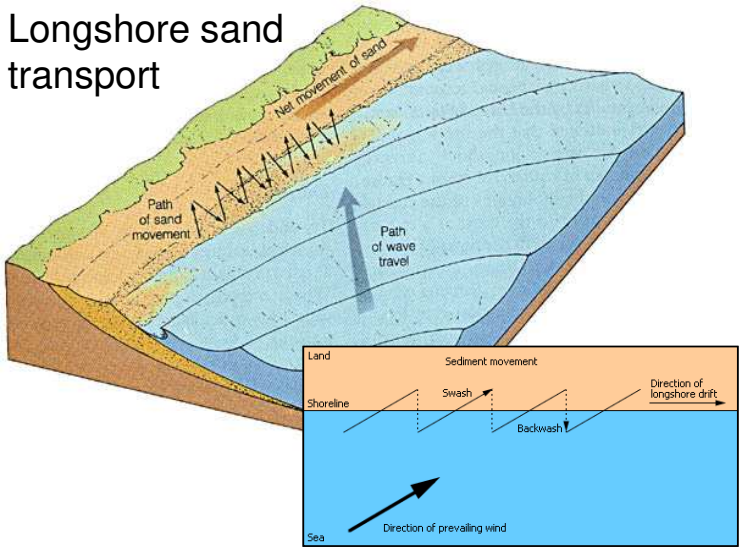
Constructive waves (gentle, dissipative beach)

- Low offshore energy wave environment creates low frequency (6-9 waves/min), short waves.
- Strong swash brings in large loads of sediment.
- Weak backwash removes little beach material.
- Creates a gently sloping, wide beach.

Reflective beach with deconstructive waves.

Dissipative beach with constructive waves.

Longshore sand transport



Temporarily Open/Closed (TOCE)

- Large floods effectively scour and remove sediment but subsequent infilling is rapid.
- Mouth is breached when river input exceeds rate of evaporation and water level in the estuary exceeds the height of the sandbar (What is a perched estuary?).
- Conditions in a TOCE can range from open and fresh throughout (flood) ➔ full salinity gradient ➔ closed and homogeneous.

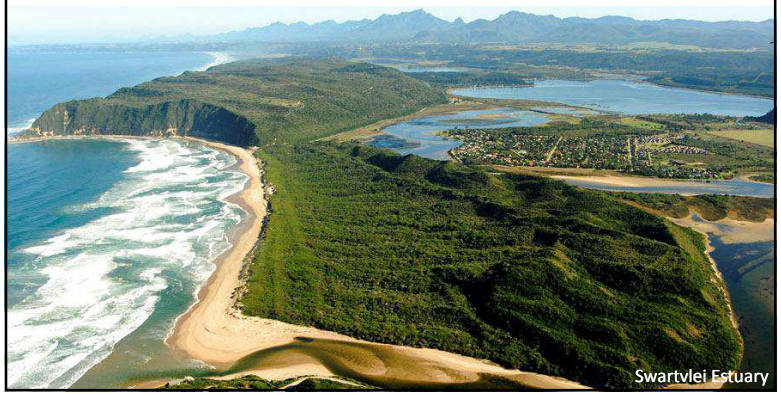
Temporarily Open/Closed (TOCE)

- During extended droughts, evaporation can exceed river inflow ➔ hypersaline conditions (>40 salinity).
- Estuarine water can seep through the sandbar (e.g. KZN) ➔ becomes fresh.
- Barrier overwash is possible during exceptionally high tides.
- Artificial breaching is common practice to prevent flooding of low lying properties.

Estuarine Lakes

- Mostly formed from drowned river valleys that filled in with sediments and become separated from the sea by vegetated sand dune systems (e.g. Swartvlei).
- There can be a permanent, seasonal or periodic connection with the sea.

Estuarine Lakes



Estuarine Lakes

- Salinity is determined by the balance between river input and evaporation, and duration of the marine connection.
- Wind is a dominant force driving mixing of the water column; a deep lake such as Swartvlei develops a strong halocline (anoxia is typical below this).

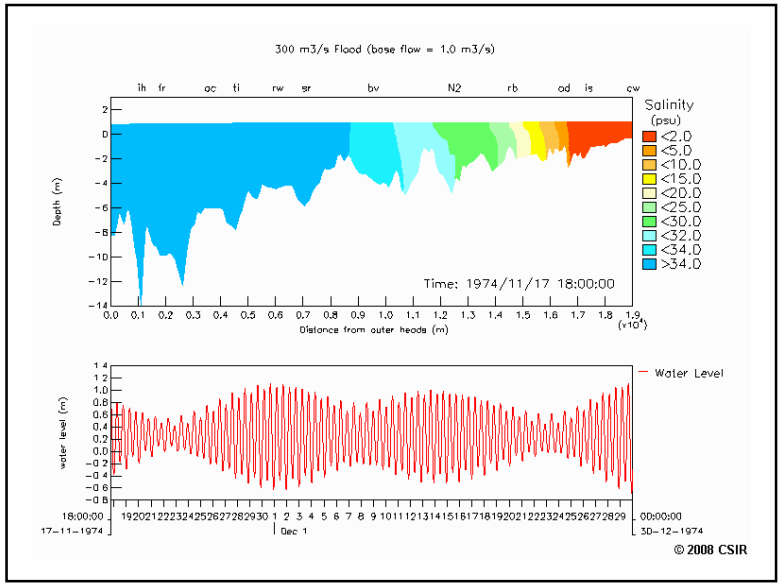
Estuarine Bays

- These systems may be natural (e.g. Knysna) or partly artificial through dredging (e.g. Durban Bay).
- They have a large tidal prism; >10 million cubic meters entering and leaving on a full spring tide → effective tidal flushing of estuarine water.
- Mixing is driven predominantly by the tides.

Estuarine Bays

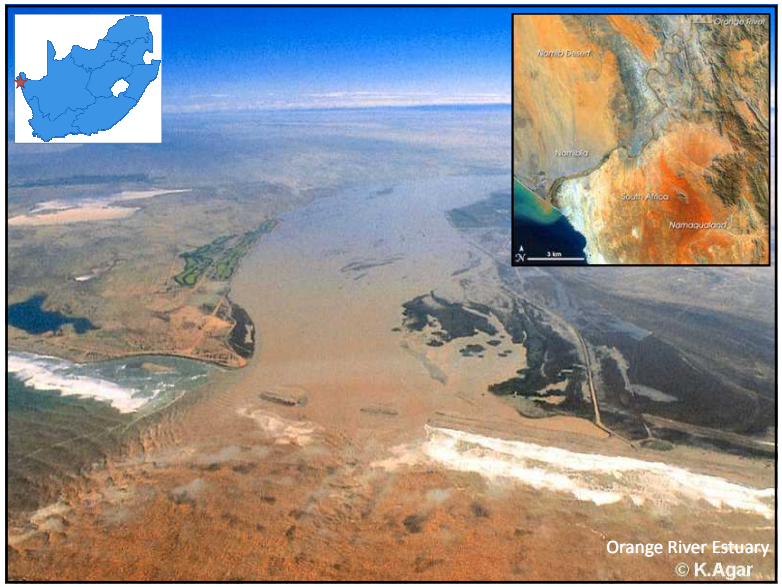
- Strong salinity stratification is typically limited to the upper reaches.
- Mouth is usually >3 m deep and tidal height fluctuation in lower reaches is similar to the marine environment.
- Water temperature is strongly influenced by the sea (What is upwelling and how can this affect water chemistry in an open estuary?).


Knysna seahorse



River mouths

- River-dominated, permanently open systems.
- Intrusion of marine water and the tidal prism are small.
- During floods, freshwater conditions can extend far offshore.
- Mixing and temperature of water in these systems are largely determined by riverine water.



Orange River Estuary
© K.Agar

Table 1. Some of the generalised physical characteristics of southern African estuarine systems.

System	Tidal prism	Mixing process	Average salinity
Estuarine bay	Large[a]	Tidal	20 - 35 g kg^{-1}
Permanently open estuary	Moderate[b]	Tidal/riverine	10 - >35 g kg^{-1}
River mouth	Small[c]	Riverine	<10 g kg^{-1}
Estuarine lake	Negligible[d]	Wind	1 - >35 g kg^{-1}
Temporarily closed estuary	Absent	Wind	1 - >35 g kg^{-1}

[a] >10 x 10^6 m^3 per spring tidal cycle
[b] 1-10 x 10^6 m^3 per spring tidal cycle
[c] <1 x 10^6 m^3 per spring tidal cycle
[d] <0.1 x 10^6 m^3 per spring tidal cycle

Panel 2: Langebaan Lagoon – an estuarine bay, lagoon or coastal embayment?

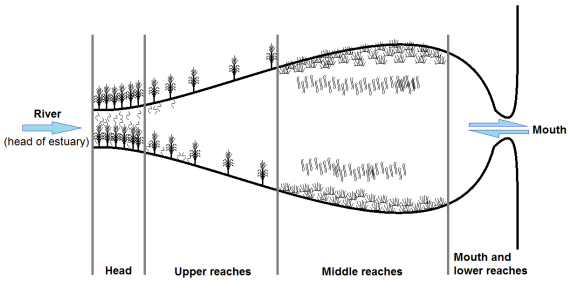
Langebaan Lagoon has many of the characteristics of an estuary, including calm coastal waters that are protected from marine wave action (see photograph) and a biota that reflects many of the species usually found in estuaries. However, the system lacks a conventional estuarine salinity gradient due to the absence of any inflowing river, although there is groundwater that feeds into certain sections of the 'lagoon'. Lagoon is a poor description for the system since Langebaan (16 km long, 2-4 km wide and up to 5 m deep) is much larger and deeper than conventional coastal lagoons which are usually small and shallow.

Because Langebaan does receive a freshwater inflow from land drainage (aquifer input), and also has typical estuarine biota, Whitfield (2005) suggested that the term "coastal embayment" type of estuary be used to describe the system. Such a term would separate it from "estuarine bays" along the South African coast, all of which are fed by rivers.

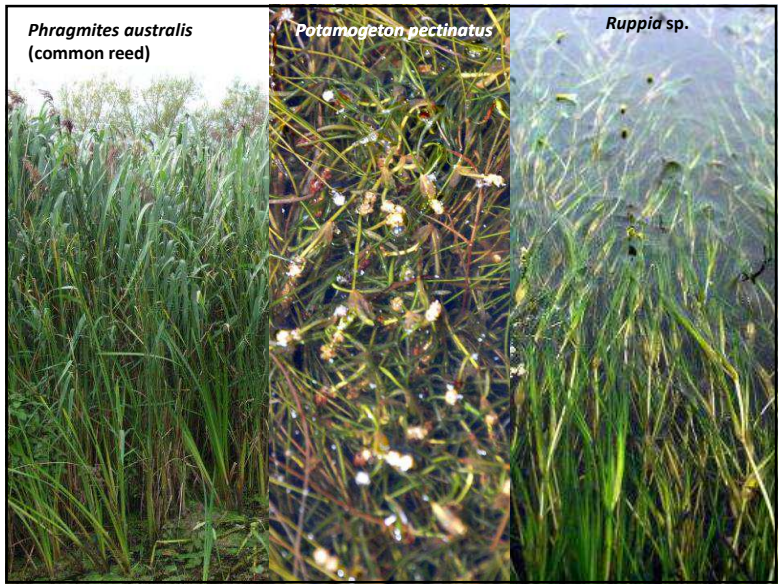
Whether viewed as an estuary or as a marine ecosystem, Langebaan Lagoon, separates out as a unique coastal ecosystem type. The 2011 NBA recognised the "transitional" nature of Langebaan Lagoon and assessed it as part of the Marine Component for consistency reasons.

Source: AK Whitfield

Regions of an estuary - Cape



	Head	Upper reaches	Middle reaches	Mouth and lower reaches
Salinity	<5	5-15	15-25	25-35
Current	Varies	Slow	Slow	Rapid
Substratum	Sand/Silt	Mud/Sand	Mud/Sand	Sand
Plants	Reeds & Aquatic grasses	Reeds & Aquatic grasses	Salt-marsh plants & Eelgrass	Seaweeds
Animals	Freshwater & Estuarine	Estuarine & Marine	Marine & Estuarine	Marine



Tides and currents

- Tidal variation depends largely on how wide or deep the estuary mouth is.
- There is a delay in the time taken for a tide to move up an estuary; e.g. up to a 3 hr delay in the 18 km long Kariega Estuary.
- During the normal tidal cycle, more sediment is typically transported in on the flood tide compared to the ebb tide.

Duiwenhoks Estuary

Tides and currents

- If sediment deposition (blocking forces) exceeds scouring forces (forces associated with river flow and ebb tide) then the mouth is likely to close.
- Although periodic floods may appear destructive, they are essential to remove accumulated sediment and organic matter.

uMzimvubu Estuary

Water and substrate properties

- **Salinity** is an important factor responsible for regional differences within an estuary and is a function of river and marine inputs.
- Too little river input can result in hypersaline conditions (>40‰) and strong floods can make the estuary fresh throughout.
- Estuarine biota are adapted to tolerate average conditions but may be subjected to variable conditions.

Water and substrate properties

- **Dissolved oxygen** availability depends on;
  - (1) water temperature
  - (2) photosynthetic activity
  - (3) amount of decaying matter
  - (4) water circulation.
- Strong river flow or tidal exchange ➔ well oxygenated conditions.
- Salinity stratification can prevent bottom waters from mixing with oxygenated upper layers ➔ **hypoxia** (<4 mg L^{-1}) or **anoxia** (0 mg L^{-1}).

Water and substrate properties

- Rivers transport loads of sediment and other materials (incl. pollutants) into estuaries.
- Coarse sediment (sand & gravel) settles out in the upper reaches when river current slows.
- Fine, muddy particles are carried further downstream into the estuary (finest are carried out to sea).
- Substrate is therefore sand or soft mud.

Look at the shallow roots of this mangrove tree reaching above the mud to get oxygen.

Why does mud not have much oxygen in it?

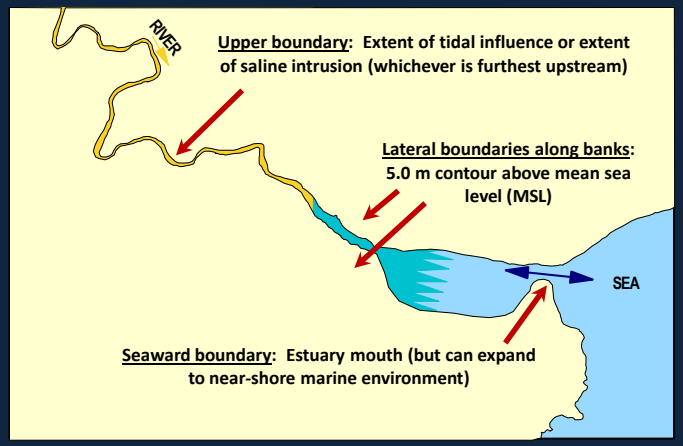
Water and substrate properties

- Mud (silt & clay) is rich in organic matter.
- Respiration by decay bacteria use up oxygen in the interstitial water.
- Flushing within fine sediment is poor leading to oxygen depletion.
- Fines are typically anoxic within millimetres of the surface; black in colour with smell of rotten eggs (H_2S).
- Anaerobic bacteria thrive here.

Water and substrate properties

- The pH of rivers range from 8 – 9 (Eastern Cape) down to 4 – 6 (southern Cape).
- The pH of estuaries is stable due to the buffering effect of sea water (typically 8.0 – 8.2).
- Water turbidity (NTU, Secchi depth or mg L^{-1}) is typically highest in the upper reaches (river input), especially under high flow conditions.

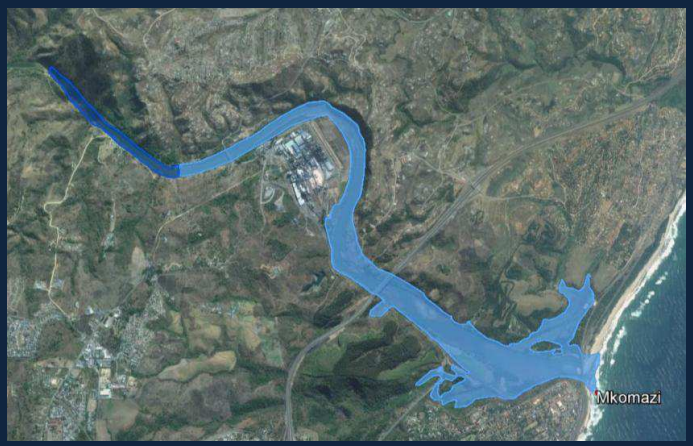
Geographical boundaries



Examples: Estuary Functional Zone

Mhlali Estuary

Examples: Estuary Functional Zone



uMkomazi Estuary

Examples: Estuary Functional Zone

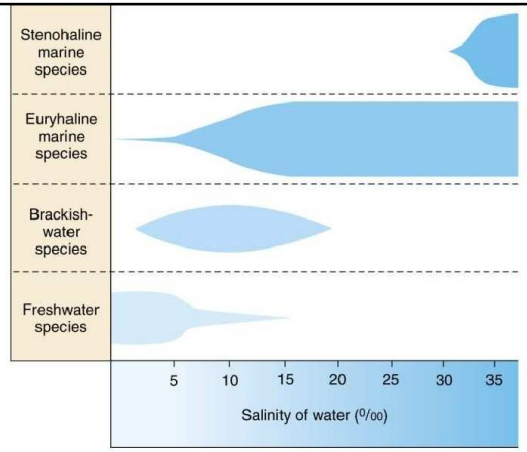
Mvoti Estuary

Stresses & Adaptations

- What are the greatest stresses in the water column for organisms?
- What are the greatest stresses in the sediments for organisms?

Living in an estuary

- There are large spatial and temporal variations in temperature, salinity and other physical factors.
- Maintaining the correct salt and water balance is key to survival.
- **Euryhaline** organisms can tolerate a wide range of salinity; ideal for estuaries, most common.



Types of species living in an idealized estuary in relation to salinity. The width of the bars = relative numbers of species

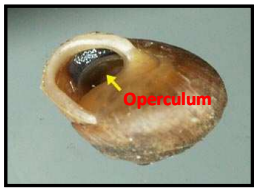
13

Living in an estuary

- **Stenohaline** species can only tolerate a narrow range of salinity; limited to upper (fresh) and lower (marine) ends of an estuary.
- Some species are adapted to living in brackish – intermediate – water.
- Most estuarine species have a marine background so face a problem when estuaries become diluted with fresh water.

Living in an estuary

- If internal salt concentration is higher than surrounding water then they are likely to take on water through osmosis.
- Some animals adapt by changes in behaviours; hide in mud burrows, close their shells or swim away.



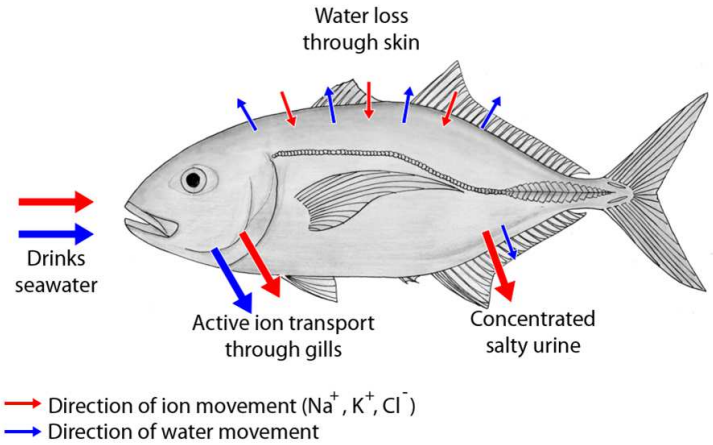
Living in an estuary

- Many soft-bodied animals (polychaete worms) change with the surrounding water; **osmoconformers**.

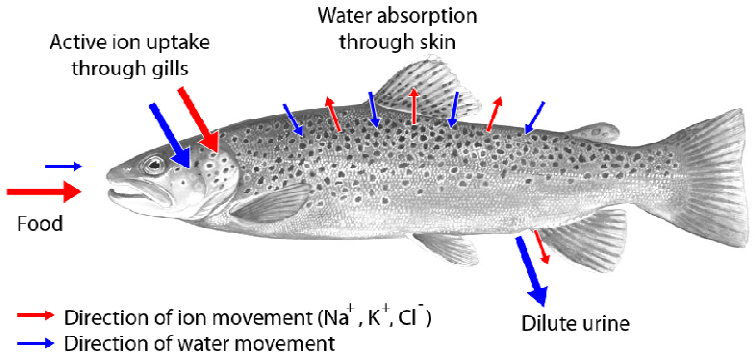
- Many fish, crabs and molluscs maintain constant internal salinity regardless of surrounding salinity; **osmoregulators**.
- When salinity of blood exceeds surrounding water they get rid of excess water through **active transport***.

*Transfer of substances across a membrane **against** a concentration gradient.

Osmoregulation – Marine fish



Osmoregulation – Freshwater fish



Living in an estuary

- When salinity of blood is higher than surrounding water they get rid of excess water and, via **active transport**, absorb solutes from the surrounding water to compensate for that lost in the eliminated water.