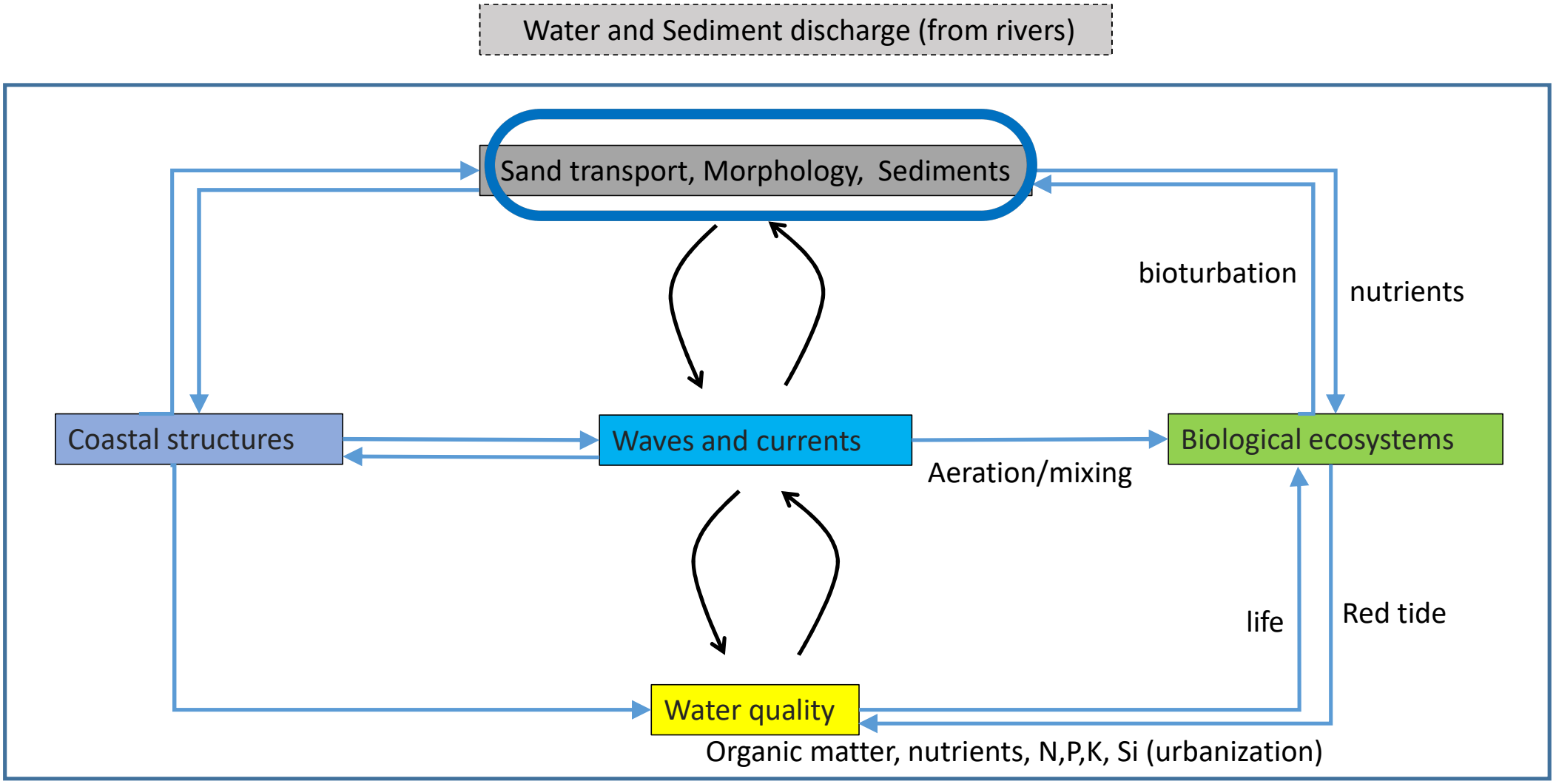
EWC 471: Basic Coastal Engineering

Lecture 17 and 18

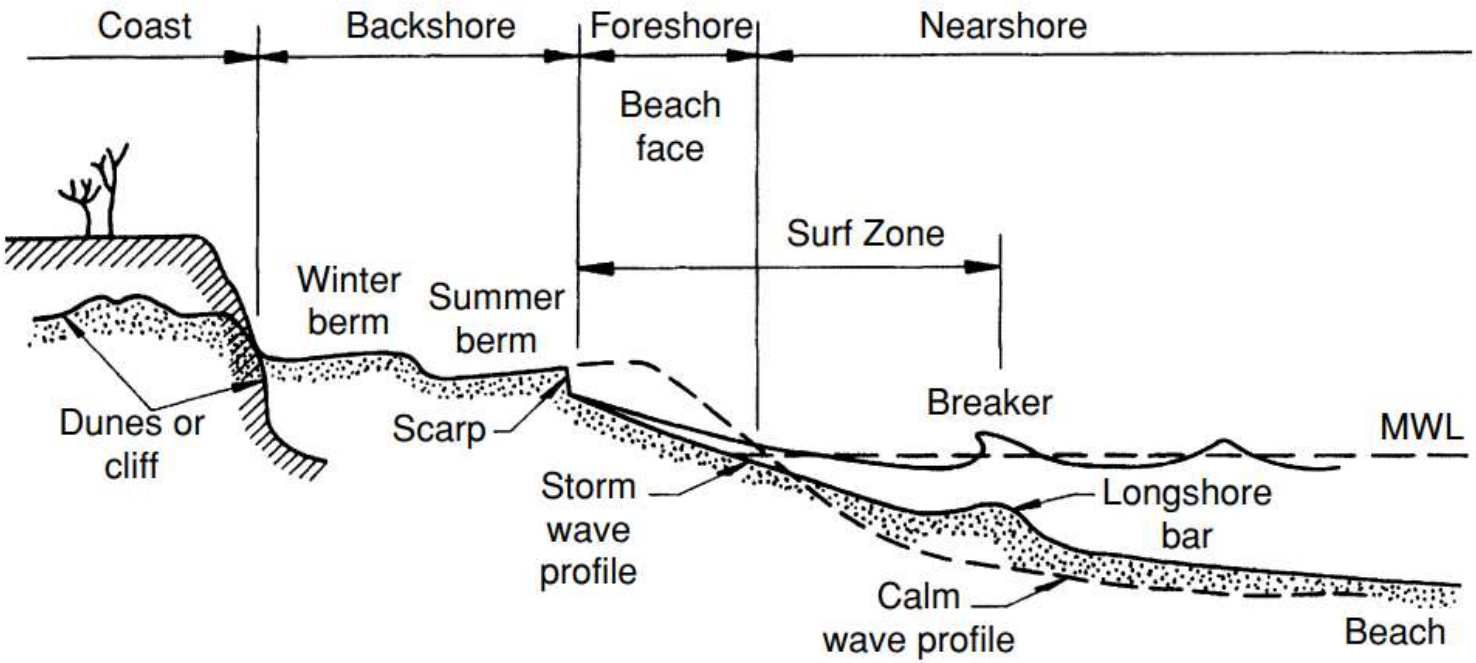
Topic: Coastal Morphology and Estuary

Putting things in context



COASTAL SEDIMENT TRANSPORT AND MORPHOLOGY

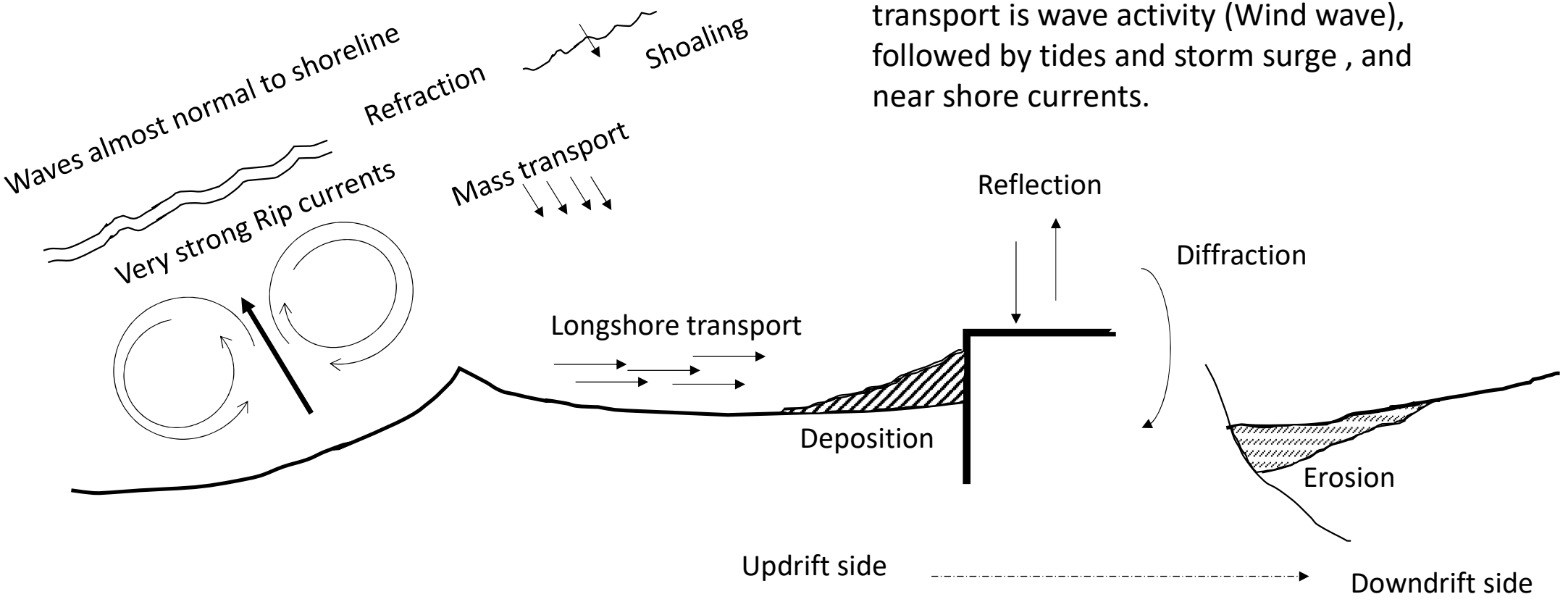
COASTAL SEDIMENT TRANSPORT AND MORPHOLOGY



Typical cross-shore beach profile (vertical scale exaggerated)

COASTAL SEDIMENT TRANSPORT AND MORPHOLOGY

The primary agent in coastal sediment transport is wave activity (Wind wave), followed by tides and storm surge , and near shore currents.



Nearshore waves and current system

Estuary and Estuarine Systems

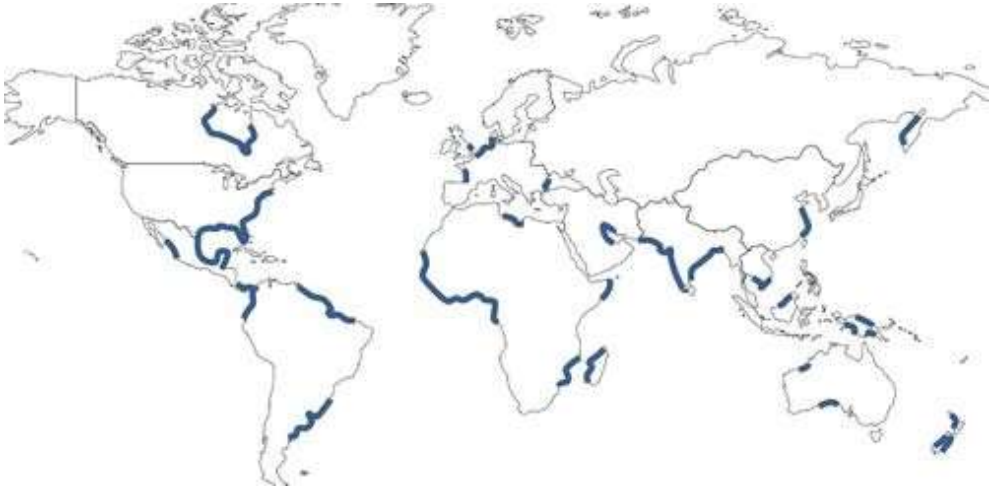
Estuary: A coastal inlet shaped in the Holocene era (Approximately last 10,000 years) by natural erosion, sedimentation and transport processes.

Estuaries include deltas and lagoons that communicate with the sea. Coastal plains are present along many coasts, as shown in figure. The estuarine systems considered here are typically situated in these zones.

From the above definition we can expect that estuarine systems with similar sediment inflow (quantity and quality of sediment), similar river discharge, similar tide and similar wave climate will exhibit similar morphologic characteristics. In practice, situations where these factors are exactly the same hardly exist. Morphologically, the estuary family is therefore highly diverse.



Coastal plains



Worldwide distribution of coastal plains

Estuary definition

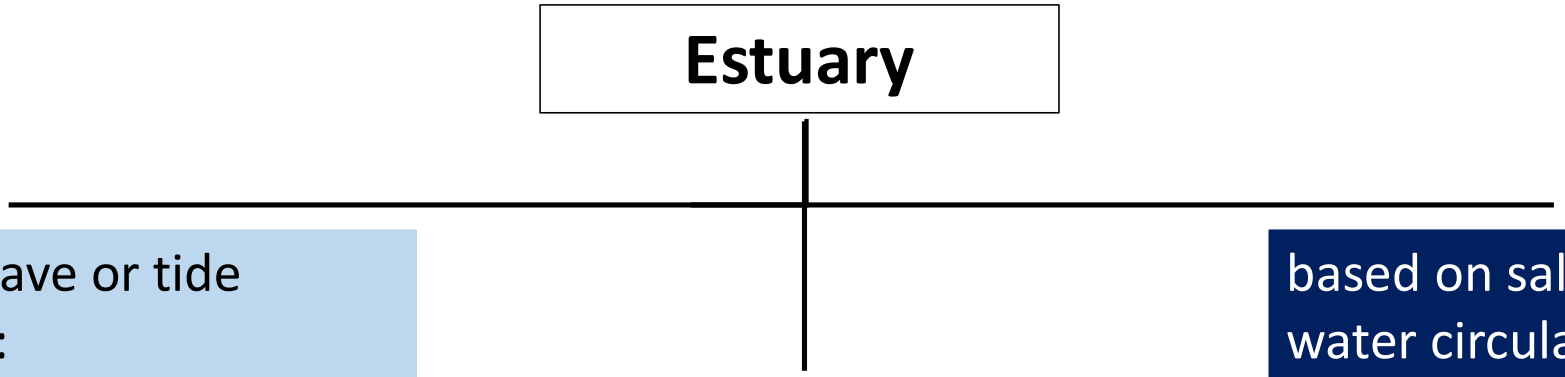
A classical definition of estuaries used by the United Nations Educational, Scientific and Cultural Organization (UNESCO) and reproduced in textbooks is

A semi-enclosed coastal body of water having free connection to the open sea and within which sea water is measurably diluted with fresh water deriving from land drainage.

This definition works well for estuaries in the temperate zone where estuaries are linked with river mouths but does not include bodies of anomalously high salinity such as lagoons, or coastal inlets which are connected to the ocean only occasionally. For Australian (and indeed world-wide) application it is advisable to amend the definition to:

An estuary is a semi-enclosed coastal body of water having free connection to the open sea at least intermittently, and within which the salinity is measurably different from the salinity in the adjacent open sea.

Estuary classification



based on wave or tide dominance:

- Tide-dominated systems
- Wave-dominated systems
- River-dominated systems
- Mixed estuarine systems

based on geomorphology:

1. Drowned river valleys
2. Lagoon-type or bar-built
3. Fjord-type
4. Tectonically produced

based on salinity or water circulation:

1. Well-mixed
2. Partially mixed
3. Salt wedge
4. Highly stratified
5. Inverse
6. Intermittent

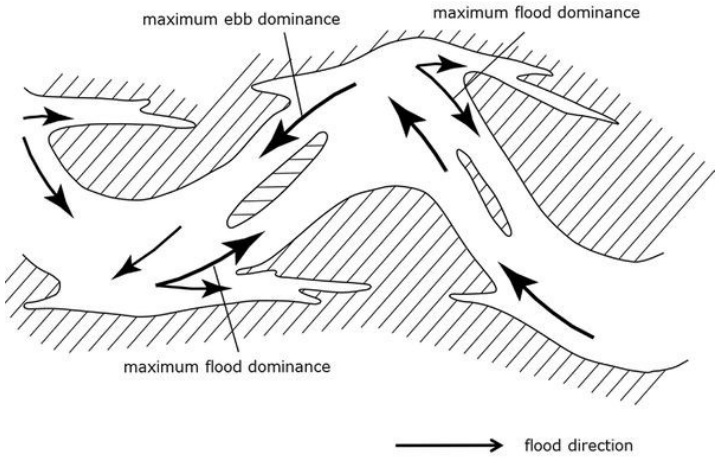
Estuary classification

Classification based on wave or tide dominance:

- Tide-dominated systems
- Wave-dominated systems
- River-dominated systems
- Mixed estuarine systems

Tide-dominated estuarine systems

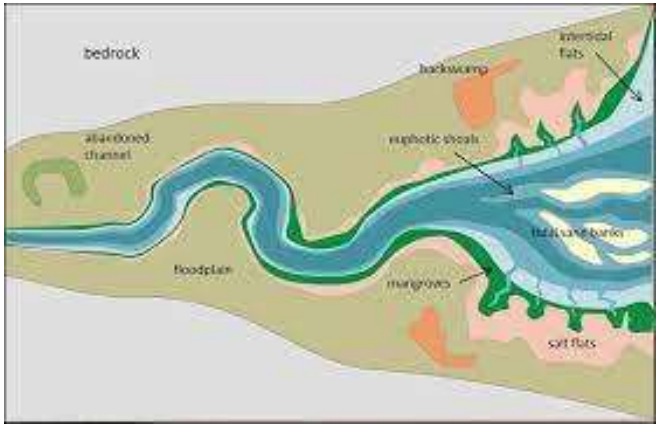
- Tide-dominated estuarine systems occur on coasts with strong semi-diurnal tides.
- These estuaries are characterised by a wide mouth; estuarine channels are narrowing inland.
- A mouth barrier is absent or reworked into a submarine ebb-tidal delta.
- At the head of the estuary a single main channel connects to the river upstream.
- Tidal flats are present along the channels; they are mostly built with sediment imported from the sea.
- The highest landward parts of tidal flats develop into vegetated salt marshes, unless this is prevented by frequent strong wave action. These marshes are flooded only at high water.
- The coarsest sediments are found at the estuarine mouth, where strong tide- and wave-induced currents act on the bed. Fine sediments are deposited on the tidal flats and in the inland channels.
- Most of the fine sediments in the upper estuarine zone are of fluvial origin.



Schematic picture of a flood and ebb dominant flow channels in a meandering channel system

Tide-dominated estuarine systems

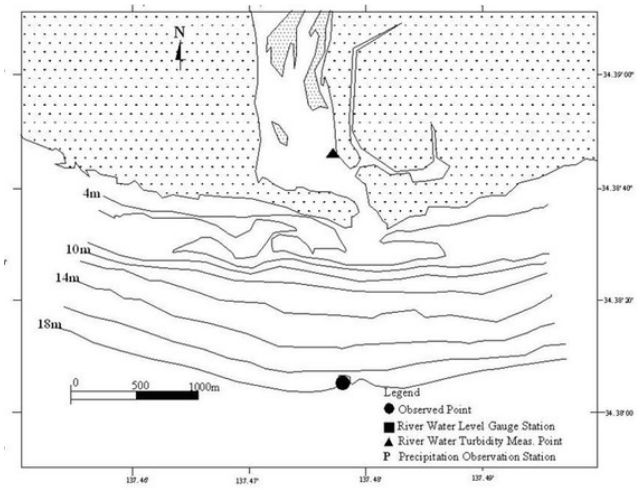
- The tidal wave is distorted when propagating up-estuary.
- For strongly converging (upstream narrowing) estuaries the tidal amplitude increases; after reaching a maximum the tidal amplitude decreases further upstream where the fluvial influence becomes substantial.
- In most tide-dominated estuaries the high-water (HW) crest of the tidal wave travels faster than the low-water (LW) trough, due to the greater water depth at HW compared to LW. In this case an asymmetry develops with shorter flood duration and longer ebb duration.
- Therefore, flood currents are generally stronger than ebb currents in the lower part of the estuary; this favors import of marine sediment.
- Estuarine circulation, driven by salinity gradients, also contributes to sediment import. Both processes contribute to the development of a high turbidity zone in the estuary, the so-called estuarine turbidity maximum.
- However, under conditions of high river discharge, sediment export dominates over import. Tide-induced import and river-induced export both contribute to the net long-term sediment balance of the estuary.



Wave-dominated estuarine systems

- Wave-dominated systems are characterized by a coastal barrier, built shoreward of the breaking zone by wave-induced cross-shore sediment transport and longshore sediment transport.
- Breaching of a coastal barrier may occur under conditions of high storm surges or extreme river discharge.

- Ebb currents in the channels are generally stronger than flood currents. On the other hand, net sedimentation on tidal flats is favored as a consequence of the time lag involved in sediment deposition and resuspension.
- The finest sediments settle near the landward boundaries of the tidal flats, where salt marshes develop. Accretion of tidal flats and growth of salt marshes is limited, however, by the scouring action of waves in periods of strong winds.



Tenru river estuary, Japan

River-dominated estuarine systems

- A protruding (bulging) river delta develops if the fluvial sediment discharge is sufficiently high.
- However, in the case of strong longshore sand transport (littoral drift) fluvial sediment may be redistributed along the shoreline, especially if the fluvial grainsize does not exceed the grainsize of the sediment transported alongshore.
- The delta protuberance (bulging) arises by deposition of fluvial sediment around the tip of the river channel. When the outflow channel extends seaward and when the shoal at the tip of the channel grows, the hydraulic head decreases and river flow is impeded.
- The river will then seek other outflow pathways. When an alternative outflow path is found, a new distributary develops.
- The direction in which a new delta protrusion grows depends on the shoreline orientation at the new outlet channel and on the prevailing incidence angle of the highest incoming waves.

Yellow delta

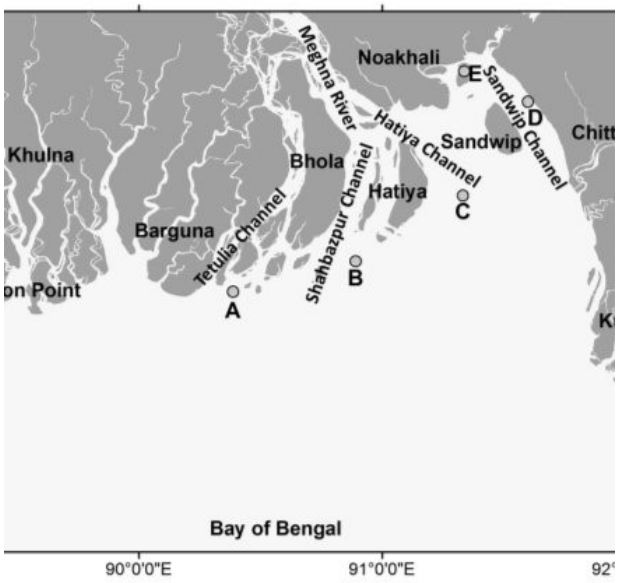




Mississippi delta

Mixed estuarine systems

- Many estuaries belong to an intermediate class, where all three forcing agents, tide, waves and river discharge, play a significant role.
- The influence of waves decreases with upstream distance from the mouth.
- The opposite holds for the river influence due to downstream widening of the estuary.
- The inner region of mixed estuaries has morphologic characteristics similar to tide-dominated systems.
- The major difference occurs at the inlet zone, where a mouth bar is present.
- In the case of estuaries with a high fluvial sediment supply, a mouth bar is formed by deposition of fluvial sediment.
- Mouth bars occur in many tropical and subtropical estuaries, such as the Hooghly, Mekong, Zambezi, Amazon, Meghna, Fly and Yangtze.
- Mouth bars can extend inward over a large part of the estuarine zone (tens of kilometres), due to net tide-induced sediment import. A mouth bar is self-sustained, as it generates tidal asymmetry favoring upstream sediment transport - especially in funnel-shaped estuaries .



Meghna Estuary

Estuary classification based on geomorphology

Estuaries are typically classified by their existing geology or their geologic origins (in other words, how they were formed). The four major types of estuaries classified by their geology are:

1. Drowned river valleys
2. Lagoon-type or bar-built
3. Fjord-type
4. Tectonically produced

Estuary classification based on geomorphology

1. Drowned river valley estuaries

Drowned river valleys are also known as coastal plain estuaries. In places where the sea level is rising relative to the land, sea water progressively penetrates into river valleys and the topography of the estuary remains similar to that of a river valley. This is the most common type of estuary in temperate climates.

The width-to-depth ratio of these estuaries is typically large, appearing wedge-shaped (in cross-section) in the inner part and broadening and deepening seaward. Water depths rarely exceed 30 m (100 ft). Examples of this type of estuary in the U.S. are the Hudson River, Chesapeake Bay, and Delaware Bay.

Estuary classification based on geomorphology

1. Drowned river valley estuaries



The Chesapeake Bay (center) and Delaware Bay (upper right) are both examples of drowned river valley estuaries. (Credit: NASA)

Estuary classification based on geomorphology

2. Lagoon-type or bar-built estuaries

- Bar-built estuaries are found in a place where the deposition of sediment has kept pace with rising sea levels so that the estuaries are shallow and separated from the sea by **sand spits or barrier islands**. They are relatively common in tropical and subtropical locations.
- These estuaries are semi-isolated from ocean waters by barrier beaches (barrier islands and barrier spits). Formation of barrier beaches partially encloses the estuary, with only narrow inlets allowing contact with the ocean waters. Bar-built estuaries typically develop on gently sloping plains located along tectonically stable edges of continents and marginal sea coasts. They are extensive along the Atlantic and Gulf coasts of the U.S. in areas with active coastal deposition of sediments and where tidal ranges are less than 4 m.



Estuary classification based on geomorphology

2. Lagoon-type or bar-built

The barrier beaches that enclose bar-built estuaries have been developed in several ways:

- building up of offshore bars by wave action, in which sand from the seafloor is deposited in elongated bars parallel to the shoreline,
- reworking of sediment discharge from rivers by a wave, current, and wind action into beaches, overwash flats, and dunes,
- engulfment of mainland beach ridges (ridges developed from the erosion of coastal plain sediments around 5000 years ago) due to sea level rise and resulting in the breaching of the ridges and flooding of the coastal lowlands, forming shallow lagoons, and
- elongation of barrier spits from the erosion of headlands due to the action of longshore currents, with the spits growing in the direction of the littoral drift



Estuary classification based on geomorphology

2. Lagoon-type or bar-built estuaries



Malibu Lagoon in Los Angeles County is a bar-built estuary that is periodically cut off from the ocean by the natural build-up of a sandy barrier at its mouth. This hydrologic isolation makes it particularly vulnerable to the impacts of land-based pollution and climate change.

Estuary classification based on geomorphology

3. Fjord-type estuaries

Fjord-type estuaries are formed in deeply eroded valleys formed by glaciers. These U-shaped estuaries typically have steep sides, rock bottoms, and underwater sills contoured by glacial movement. The estuary is shallowest at its mouth.



Geirangerfjord, Norway

Estuary classification based on geomorphology

3. Fjord-type estuaries

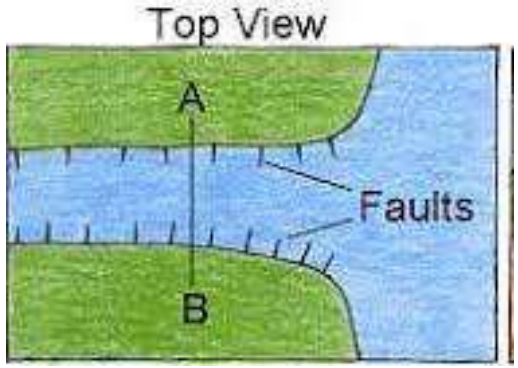


- In the upper reaches of the estuary, the depth can exceed 300 m (1,000 ft). The width-to-depth ratio is generally small.
- In estuaries with very shallow sills, tidal oscillations only affect the water down to the depth of the sill, and the waters deeper than that may remain stagnant for a very long time, so there is only an occasional exchange of the deep water of the estuary with the ocean.
- If the sill depth is deep, water circulation is less restricted, and there is a slow but steady exchange of water between the estuary and the ocean. Fjord-type estuaries can be found along the coasts of Alaska, the Puget Sound region of western Washington state, British Columbia, eastern Canada, Greenland, Iceland, New Zealand, and Norway.

Estuary classification based on geomorphology

4. Tectonically produced estuaries

- These estuaries are formed by subsidence or land cut off from the ocean by land movement associated with faulting, volcanoes, and landslides. Inundation from eustatic sea-level rise during the Holocene Epoch has also contributed to the formation of these estuaries.
- There are only a small number of tectonically produced estuaries; one example is the San Francisco Bay, which was formed by the crustal movements of the San Andreas fault system causing the inundation of the lower reaches of the Sacramento and San Joaquin rivers.



Estuary classification based on geomorphology

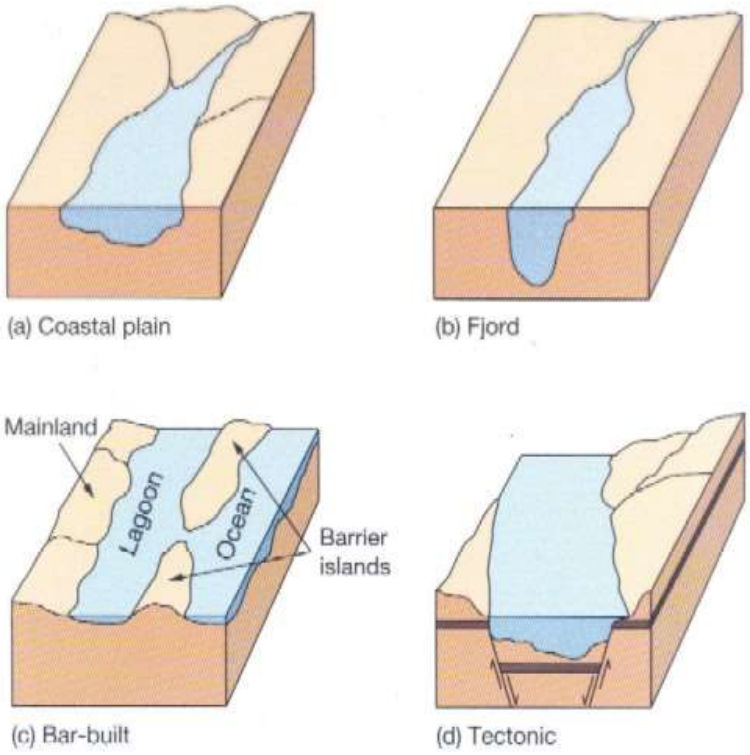
4. Tectonically produced estuaries

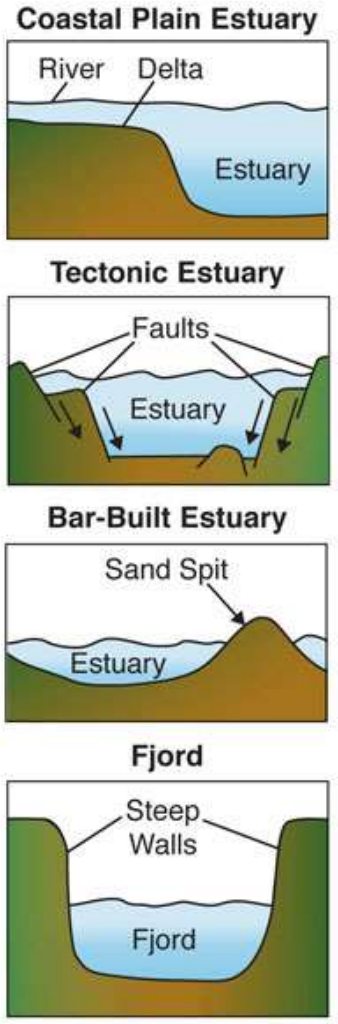


The San Francisco Bay in California is an example of a tectonic estuary. (Credit: NASA)



Estuary classification based on geomorphology





Schematic diagrams of four types of estuaries based on geomorphology

Estuary classification: based on salinity or water circulation

Estuaries are also classified based on their salinity and mixing patterns. The amount of mixing of fresh and salt water in an estuary depends on the rate at which fresh water enters the head of the estuary from river input, and the amount of seawater that enters the estuary mouth as a result of tidal movements. The input of fresh water is reflected in the flushing time of the estuary. This refers to the time it would take for the in-flowing fresh water to completely replace all the fresh water currently in the estuary.

Estuary classification: based on salinity or water circulation

Seawater input is measured by the tidal volume, or **tidal prism** (P=H*A), which is the average volume of sea water entering and leaving the estuary during each tidal cycle. In other words, it is the volume difference between high and low tides. The interaction between the flushing time, tidal volume, and the shape of the estuary will determine the extent and type of water mixing within the estuary.

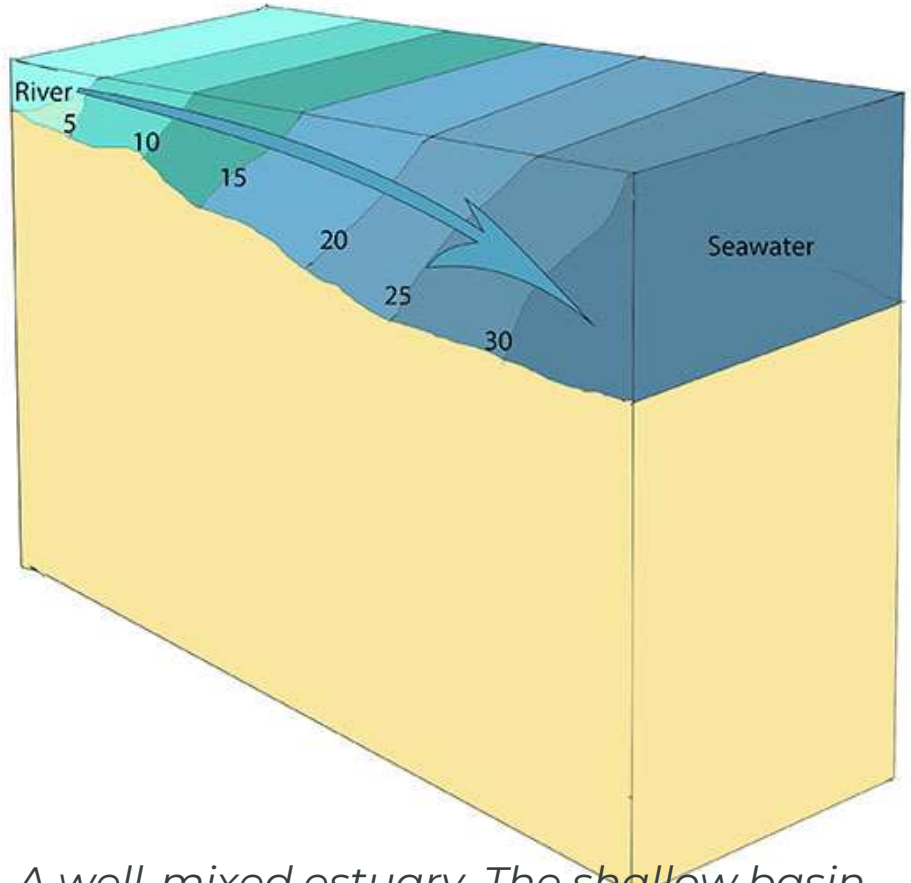
Classification based on water circulation

1. Well-mixed
2. Partially mixed
3. Salt wedge
4. Highly stratified
5. Inverse
6. Intermittent

Estuary classification: based on salinity or water circulation

1. Well-mixed estuaries

- In a vertically mixed, or well-mixed estuary there is complete mixing of fresh and salt water from the surface to the bottom.
- In a particular location the salinity is constant at all depths, but across the estuary the salinity is lowest at the head where the fresh water enters, and is highest at the mouth, where the seawater comes in.
- This type of salinity profile usually occurs in shallower estuaries, where the shallow depths allow complete mixing from the surface to the bottom. The lower reaches of Delaware Bay and the Raritan River in New Jersey are examples of vertically homogenous estuaries.

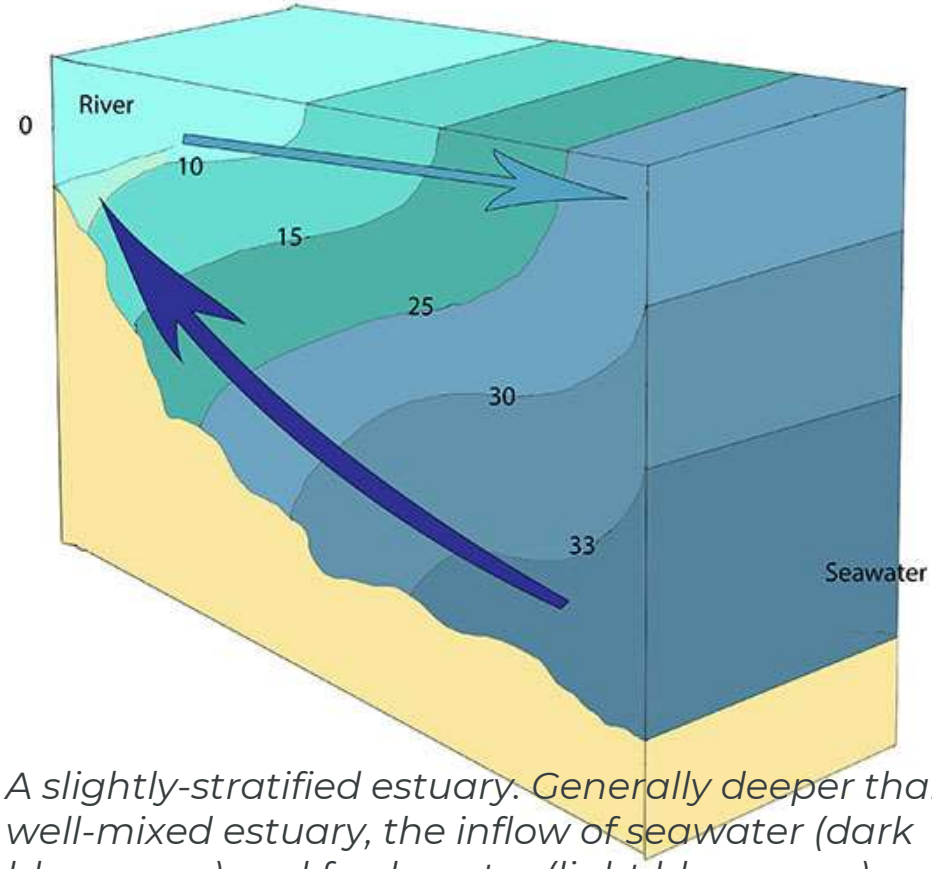


A well-mixed estuary. The shallow basin allows nearly complete mixing or fresh and seawater from top to bottom. Salinities are in ppt

Estuary classification: based on salinity or water circulation

2. Partially mixed estuaries

- Slightly stratified or partially mixed estuaries have similar salinity profiles to vertically mixed estuaries, where salinity increases from the head to the mouth, but there is also a slight increase in salinity with depth at any point.
- This usually occurs in deeper estuaries than those that are well-mixed, where waves and currents mix the surface water, but the mixing may not extend all the way to the bottom. Examples include the Chesapeake Bay and Narragansett Bay.

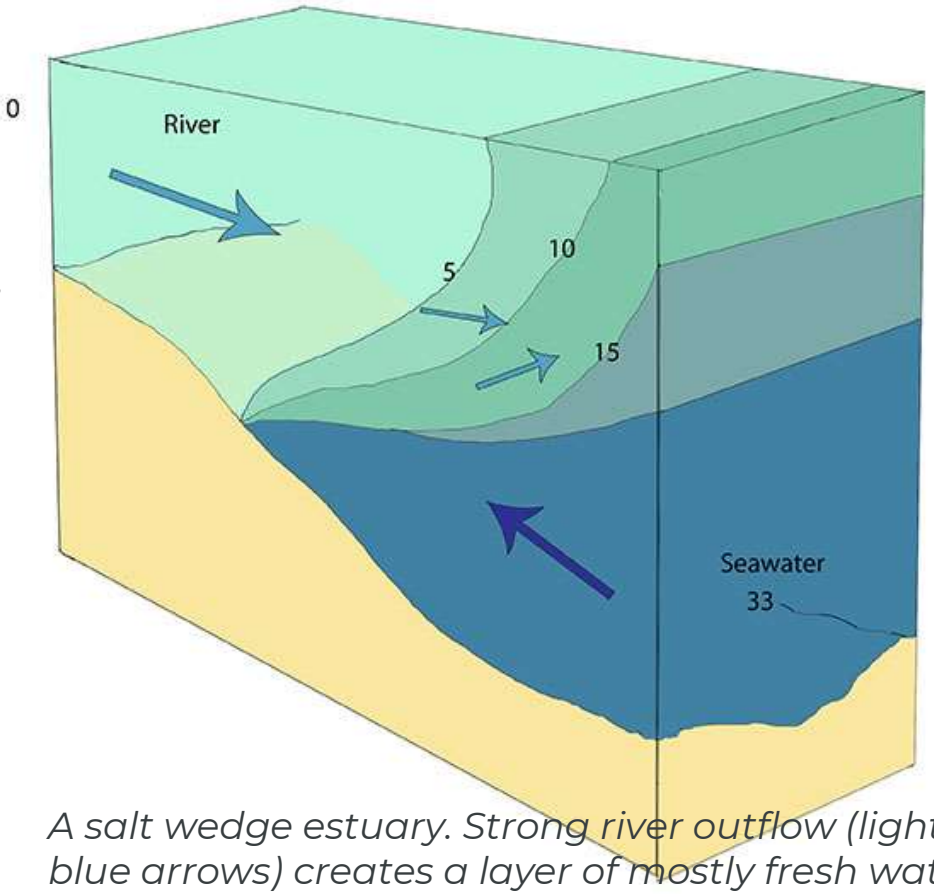


A slightly-stratified estuary. Generally deeper than a well-mixed estuary, the inflow of seawater (dark blue arrow) and fresh water (light blue arrow) create an estuary where salinity increases with depth, and at the surface when moving from the head to the mouth of the estuary. Salinities are in ppt

Estuary classification: based on salinity or water circulation

3. Salt wedge estuaries

- A salt wedge estuary occurs where the outflow of fresh water is strong enough to prevent the denser ocean water to enter through the surface, and where the estuary is deep enough that surface waves and turbulence have little mixing effect on the deeper water.
- Fresh water flows out along surface, salt water flows in at depth, creating a wedge shaped lens of seawater moving along the bottom. The surface water may remain mostly fresh throughout the estuary if there is no mixing, or it can become brackish depending on the level of mixing that occurs. An example of a salt wedge estuary is the Mississippi River.

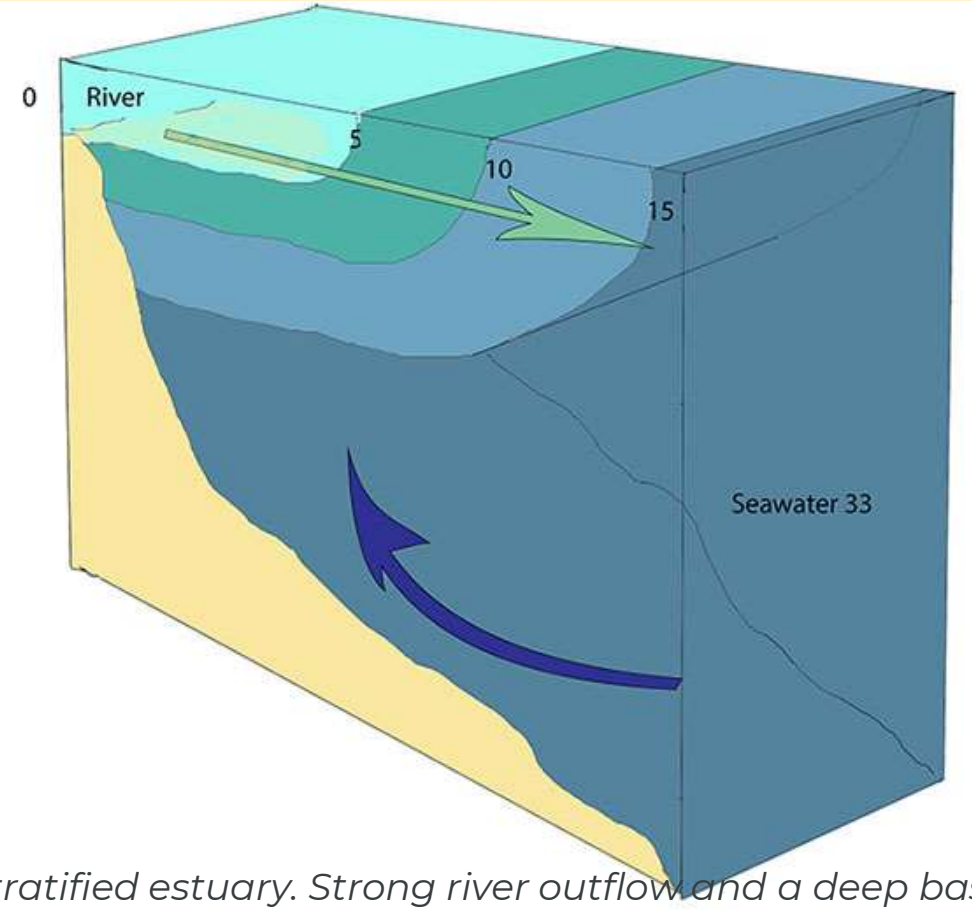


A salt wedge estuary. Strong river outflow (light blue arrows) creates a layer of mostly fresh water that sits on top of a wedge of encroaching seawater along the bottom (dark blue arrow). Salinities are in ppt

Estuary classification: based on salinity or water circulation

4. Highly stratified estuaries

- Highly stratified profiles are found in very deep estuaries, such as in fjords.
- Because of the depth, mixing of fresh and salt water only occurs near the surface, so in the upper layers salinity increases from the head to the mouth, but the deeper water is of standard ocean salinity.

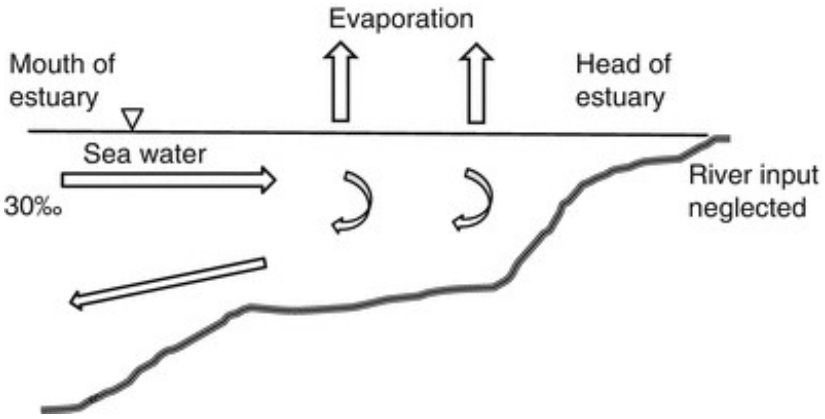


A highly stratified estuary. Strong river outflow and a deep basin prevent mixing between surface and bottom water, creating an estuary that is vertically stratified. Salinities are represented in ppt

Estuary classification: based on salinity or water circulation

5. Inverse estuaries

- These estuaries have no fresh water input from rivers and are in a region of high evaporation. Surface salinity does not decrease from the ocean to the inner estuary, but water loss from evaporation leads to a salinity increase as the inner end of the estuary is approached . This results in a density increase and sinking of high salinity water at the inner end.



- As a result, movement of water is directed inward at the surface and towards the sea at the bottom, with sinking at the inward end. Compared to the estuaries discussed before their circulation is reversed, which explains the name inverse estuary. An example of an inverse estuary is Spencer Gulf, South Australia

Estuary classification: based on salinity or water circulation

6. Intermittent estuaries

- Many estuaries change their classification type because of highly variable rainfall over the catchment area of their river input. River input may be small, but as long as some fresh water enters the estuary, the estuarine character is maintained (in the form of a salt wedge estuary). If the river input dries up completely during the dry season, estuaries loose their identity and turn into oceanic embayments. An example is the South West Arm of Port Hacking south of Sydney which turns into a highly stratified estuary for a few weeks after heavy rains.
- Marine life in intermittent estuaries undergoes a complete change of communities between the estuarine and oceanic phases - very few plants or animals can cope with the salinity changes that occur between the two phases.

Estuary eutrophication

Estuary eutrophication

- The most important variable characteristics of estuary water are the concentration of dissolved oxygen, salinity and sediment load.
- There is extreme spatial variability in salinity, with a range of near-zero at the tidal limit of tributary rivers to 3.4% at the estuary mouth.
- At any one point, the salinity will vary considerably over time and seasons, making it a harsh environment for organisms.
- Sediment often settles in intertidal mudflats which are extremely difficult to colonize.
- No points of attachment exist for algae, so vegetation based habitat is not established.
- Sediment can also clog feeding and respiratory structures of species, and special adaptations exist within mudflat species to cope with this problem.

Estuary eutrophication

Lastly, dissolved oxygen variation can cause problems for life forms. Nutrient-rich sediment from man-made sources can promote primary production life cycles, perhaps leading to eventual decay removing the dissolved oxygen from the water; thus, hypoxic or anoxic zones can develop

Implications of eutrophication on estuaries
1 Effects of eutrophication on biogeochemical cycles
2 Effects of eutrophication on estuarine plants
3 Effects of eutrophication on estuarine animals
4 Effects of eutrophication on human activities

Estuary eutrophication: Effects of eutrophication on biogeochemical cycles

Nitrogen is often the lead cause of eutrophication in estuaries in temperate zones.[12] During a eutrophication event, biogeochemical feedback decreases the amount of available silica.[13] These feedbacks also increase the supply of nitrogen and phosphorus, creating conditions where harmful algal blooms can persist. Given the now off-balance nitrogen cycle, estuaries can be driven to phosphorus limitation instead of nitrogen limitation. Estuaries can be severely impacted by an unbalanced phosphorus cycle, as phosphorus interacts with nitrogen and silica availability.

With an abundance of nutrients in the ecosystem, plants and algae overgrow and eventually decompose, which produce a significant amount of carbon dioxide.[14] While releasing CO2 into the water and atmosphere, these organisms are also intaking all or nearly all of the available oxygen creating a hypoxic environment and unbalanced oxygen cycle.[15] The excess carbon in the form of CO2 can lead to low pH levels and ocean acidification, which is more harmful for vulnerable coastal regions like estuaries.

Estuary eutrophication: Effects of eutrophication on estuarine plants

Eutrophication has been seen to negatively impact many plant communities in estuarine ecosystems.[16] Salt marshes are a type of ecosystem in some estuaries that have been negatively impacted by eutrophication.[16] Cordgrass vegetation dominates the salt marsh landscape.[17] Excess nutrients allow the plants to grow at greater rates in above ground biomass, however less energy is allocated to the roots since nutrients is abundant.[16][18] This leads to a lower biomass in the vegetation below ground which destabilizes the banks of the marsh causing increased rates of erosion.[16] A similar phenomenon occurs in mangrove swamps, which are another potential ecosystem in estuaries.[18][19] An increase in nitrogen causes an increase in shoot growth and a decrease in root growth.[18] Weaker root systems cause a mangrove tree to be less resilient in seasons of drought, which can lead to the death of the mangrove.[18] This shift in above ground and below ground biomass caused by eutrophication could hindered plant success in these ecosystems[16][18].

Estuary eutrophication: Effects of eutrophication on estuarine animals

Across all biomes, eutrophication often results in plant death but the impacts do not end there. Plant death alters the entire food web structure which can result in the death of animals within the afflicted biome. Estuaries are hotspots for biodiversity, containing a majority of commercial fish catch, making the impacts of eutrophication that much greater within estuaries.[20] Some specific estuarine animals feel the effects of eutrophication more strongly than others. One example is the whitefish species from the European Alps.[21] Eutrophication reduced the oxygen levels in their habitats so greatly that whitefish eggs could not survive, causing local extinctions.[21] However, some animals, such as carnivorous fish, tend to do well in nutrient poor environments and can benefit from eutrophication.[22] This can be seen in populations of bass or pikes [22].

Estuary eutrophication: Effects of eutrophication on human activities

Eutrophication can affect many marine habitats which can lead to economic consequences. The commercial fishing industry relies upon estuaries for approximately 68 percent of their catch by value because of the great biodiversity of this ecosystem.[23] During an algal bloom, fishermen have noticed a significant increase in the quantity of fish.[24] A sudden increase in primary productivity causes spikes in fish populations which leads to more oxygen being utilized.[24] It is the continued deoxygenation of the water that then causes a decline in fish populations. These effects can begin in estuaries and have a wide effect on the surrounding water bodies. In turn, this can decrease fishing industry sales in one area and across the country.[25] Production in 2016 from recreational and commercial fishing contributes billions of dollars to the United States' gross domestic product (GDP).[23] A decrease in production within this industry can affect any of the 1.7 million people the fishing industry employs yearly across the United States.

Estuary: Implications for marine life

- Estuaries are incredibly dynamic systems, where temperature, salinity, turbidity, depth and flow all change daily in response to the tides.
- This dynamism makes estuaries highly productive habitats, but also make it difficult for many species to survive year-round. As a result, estuaries large and small experience strong seasonal variation in their fish communities.
- Estuaries provide a critical habitat to a variety of species that rely on estuarine water for life-cycle completion.
- Also, migratory bird populations rely on estuaries.
- Two of the main challenges of estuarine life are the variability in salinity and sedimentation. Many species of fish and invertebrates have various methods to control or conform to the shifts in salt concentrations and are termed osmoconformers and osmoregulators.
- Many animals also burrow to avoid predation and to live in a more stable sedimental environment.
- However, large numbers of bacteria are found within the sediment which has a very high oxygen demand. This reduces the levels of oxygen within the sediment often resulting in partially anoxic conditions, which can be further exacerbated by limited water flow.
- Phytoplankton are key primary producers in estuaries. They move with the water bodies and can be flushed in and out with the tides. Their productivity is largely dependent upon the turbidity of the water. The main phytoplankton present are diatoms and dinoflagellates which are abundant in the sediment.
- It is important to remember that a primary source of food for many organisms on estuaries, including bacteria, is detritus from the settlement of the sedimentation.

Estuary: Implications for human life

- Of the thirty-two largest cities in the world in the early 1990s, twenty-two were located on estuaries.
- As ecosystems, estuaries are under threat from human activities such as pollution and overfishing.
- They are also threatened by sewage, coastal settlement, land clearance and much more.
- Estuaries are affected by events far upstream and concentrate materials such as pollutants and sediments. Land run-off and industrial, agricultural, and domestic waste enter rivers and are discharged into estuaries. Contaminants can be introduced which do not disintegrate rapidly in the marine environment, such as plastics, pesticides, furans, dioxins, phenols and heavy metals.
- Such toxins can accumulate in the tissues of many species of aquatic life in a process called bioaccumulation.
- They also accumulate in benthic environments, such as estuaries and bay muds: a geological record of human activities of the last century.
- The elemental composition of biofilm reflect areas of the estuary impacted by human activities, and over time may shift the basic composition of the ecosystem, and the reversible or irreversible changes in the abiotic and biotic parts of the systems from the bottom up.
- Estuaries tend to be naturally eutrophic because land runoff discharges nutrients into estuaries. With human activities, land run-off also now includes the many chemicals used as fertilizers in agriculture as well as waste from livestock and humans. Excess oxygen-depleting chemicals in the water can lead to hypoxia and the creation of dead zones. This can result in reductions in water quality, fish, and other animal populations. Overfishing also occurs.
- Chesapeake Bay once had a flourishing oyster population that has been almost wiped out by overfishing. Oysters filter these pollutants, and either eat them or shape them into small packets that are deposited on the bottom where they are harmless. Historically the oysters filtered the estuary's entire water volume of excess nutrients every three or four days. Today that process takes almost a year,[35] and sediment, nutrients, and algae can cause problems in local waters.

Course review and wrap up

Topics Covered

Lecture #	Contents
#1	Definitions and nomenclature of the coastal zones
#2	Coastal landforms, coastal diversity
#3	Small Amplitude Wave Theory
#4	Small Amplitude Wave theory and Application Examples
#5 and 6	Small Amplitude Wave theory and Application Examples
#7 and 8	Small Amplitude Wave theory and Application Examples
#9 and 10	Wave Deformation/ Wave Transformation: shoaling, refraction, diffraction..
#11 and 12	Wave Deformation/ Wave Transformation: wave breaking
#13 and 14	Wave Forces on Coastal Structures
#15 and 16	Storm surge and Tsunami
#17 and 18	Coastal Morphology and Estuary; Course review

Wave forces:

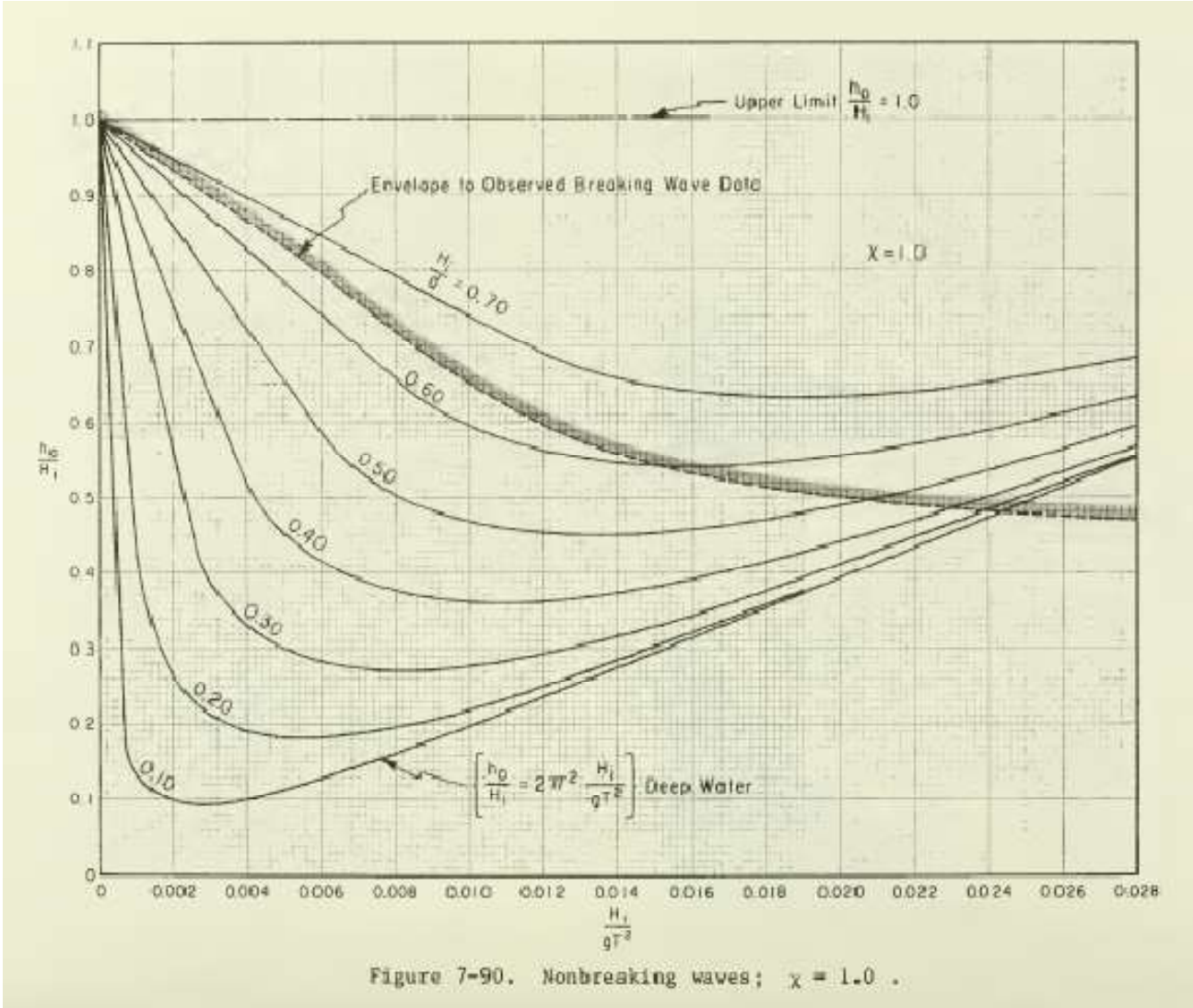


Figure 7-90. Nonbreaking waves; $\chi = 1.0$.

Wave forces:

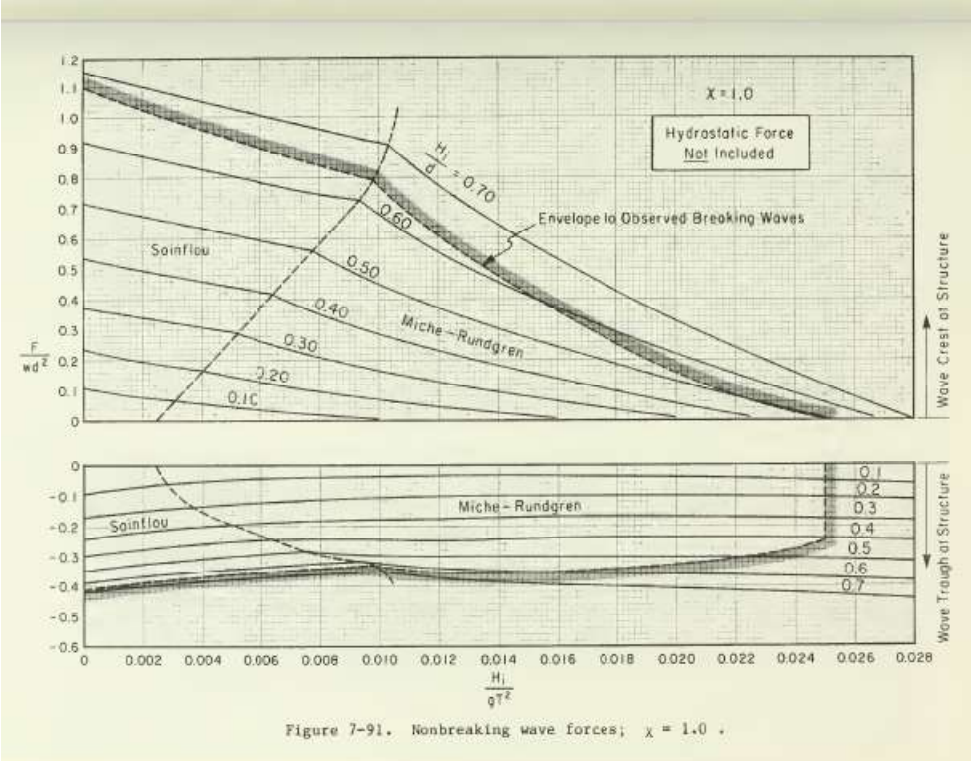


Figure 7-91. Nonbreaking wave forces; $\chi = 1.0$.

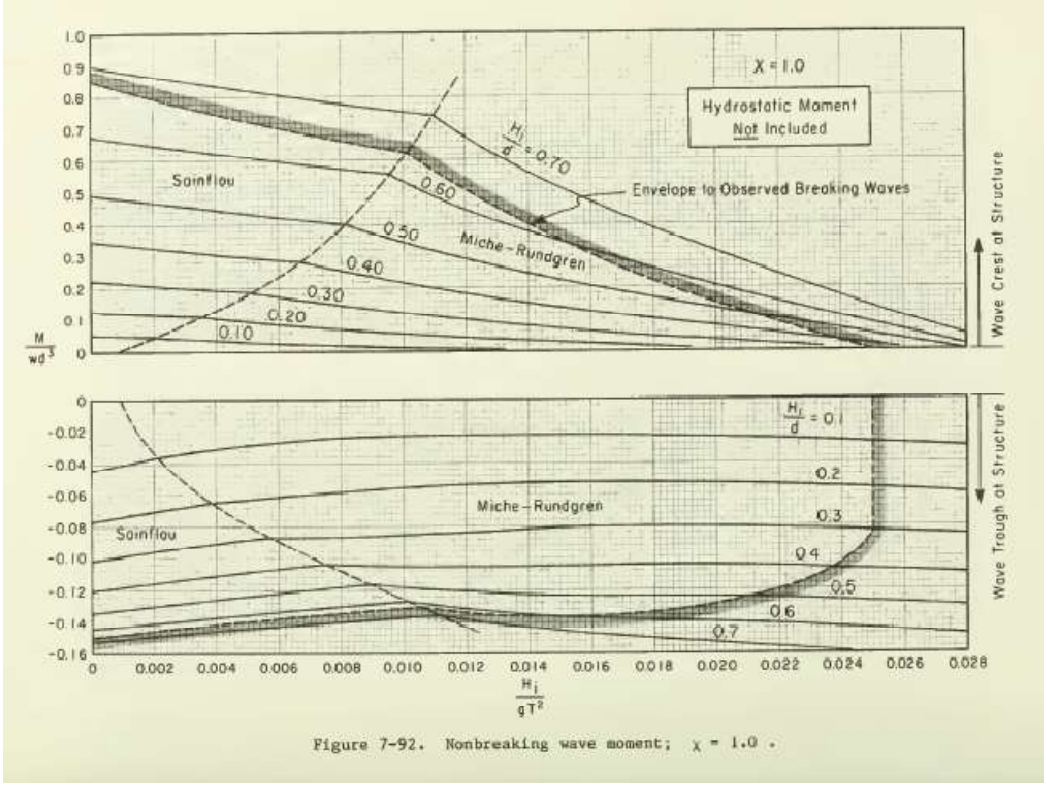
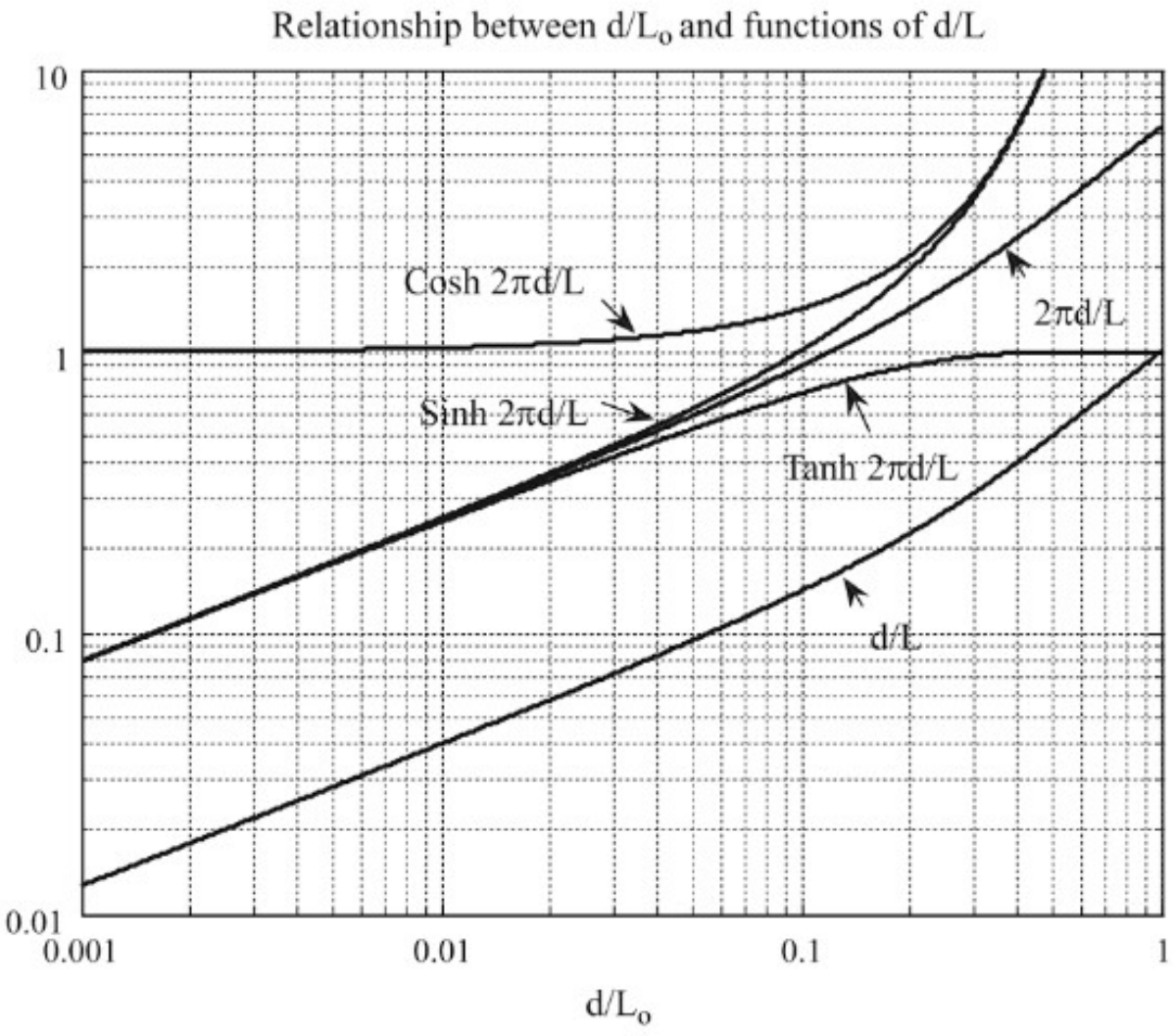
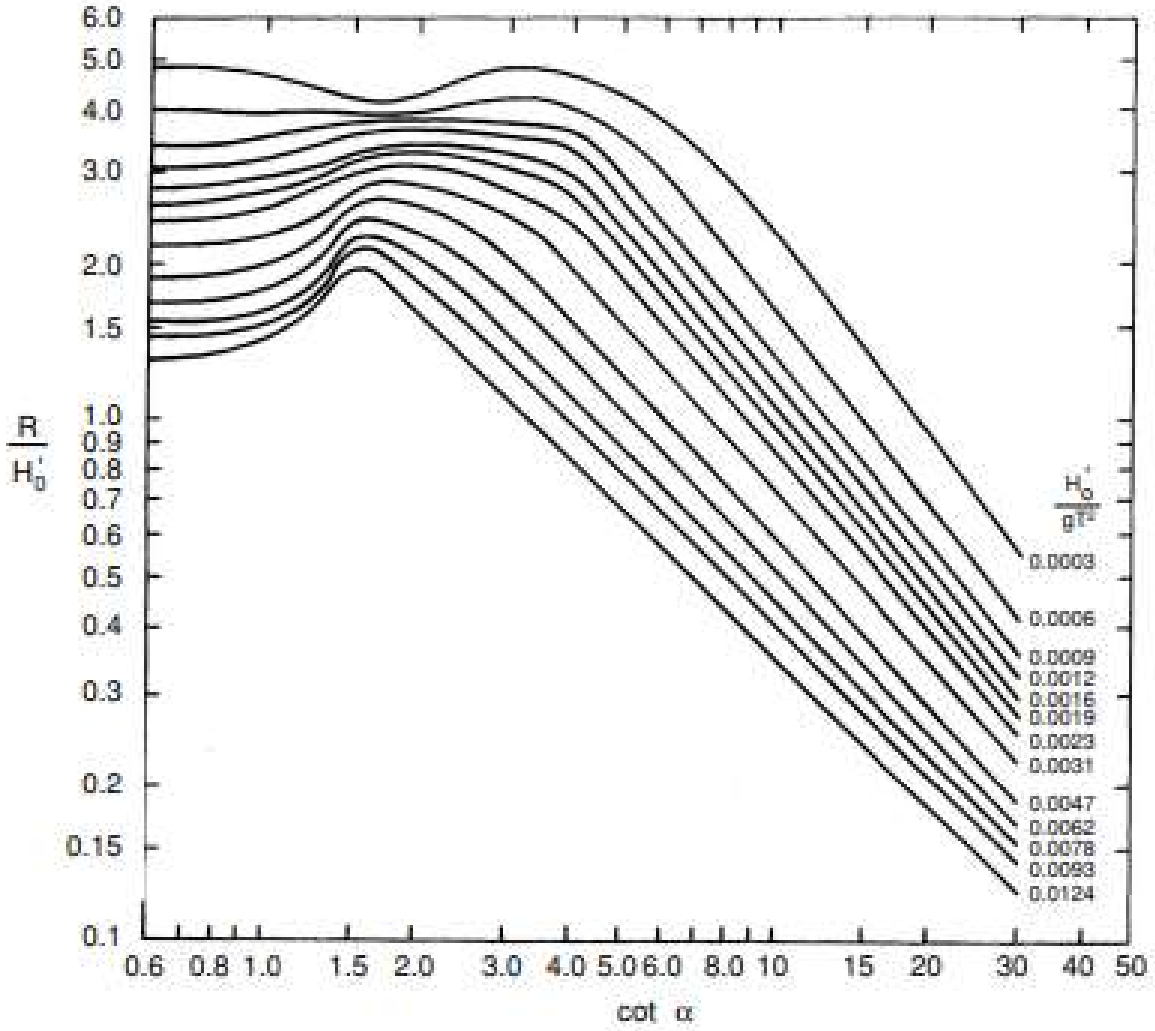


Figure 7-92. Nonbreaking wave moment; $\chi = 1.0$.

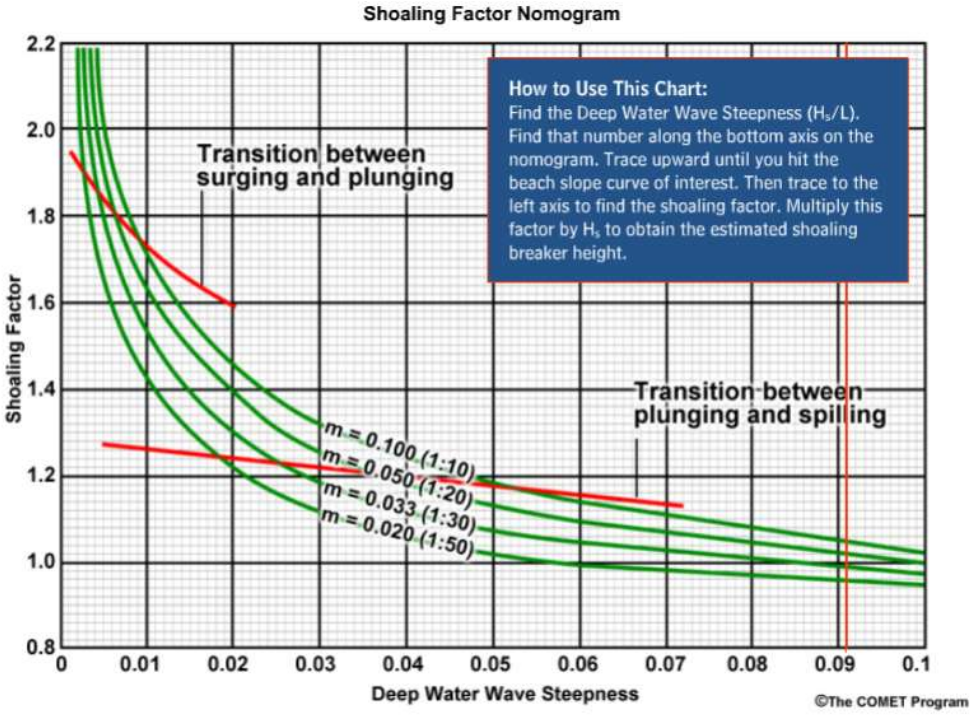
Small amplitude wave theory:

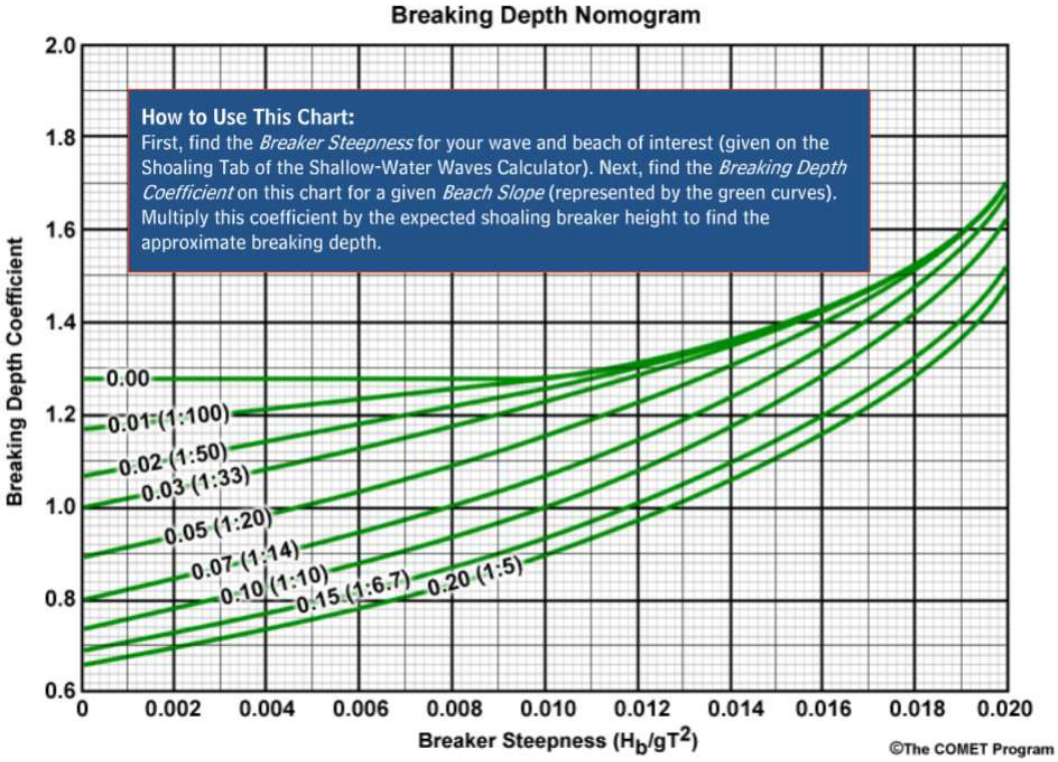


Wave runup:


6.0
5.0
4.0
3.0
2.0
1.5
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.15
0.1
R / H'0
0.6 0.8 1.0 1.5 2.0 3.0 4.0 5.0 6.0 8.0 10 15 20 30 40 50
cot α
H'0 / gT2
0.0003
0.0006
0.0009
0.0012
0.0016
0.0019
0.0023
0.0031
0.0047
0.0062
0.0078
0.0093
0.0124

Wave breaking:





Thank You

and Good luck!