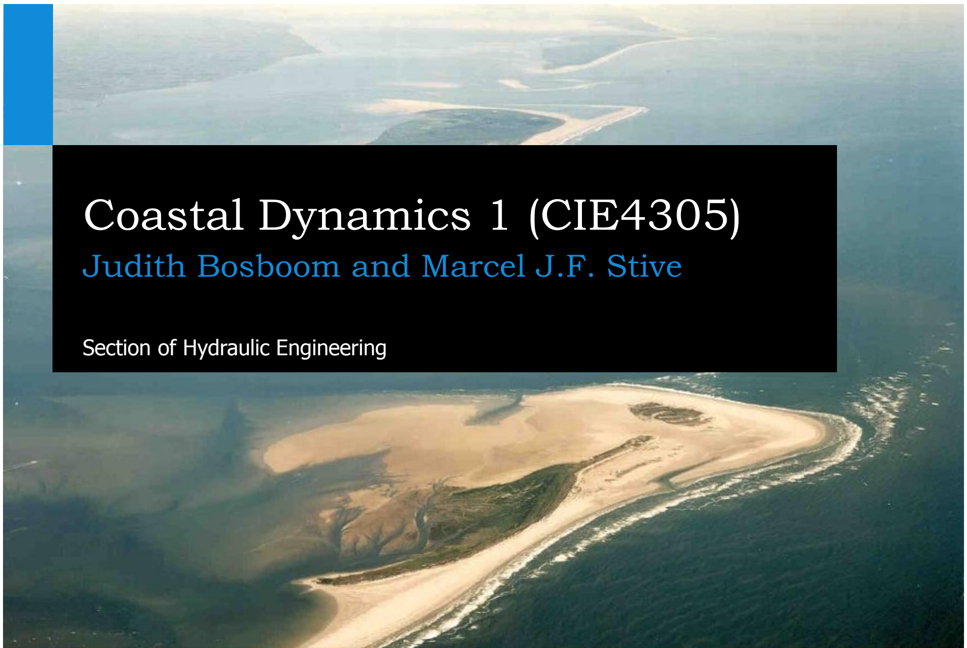


Coastal Dynamics 1 (CIE4305)

Judith Bosboom and Marcel J.F. Stive

Section of Hydraulic Engineering

8.

Longshore transport and coastline changes

Coastal Dynamics 1

Contents

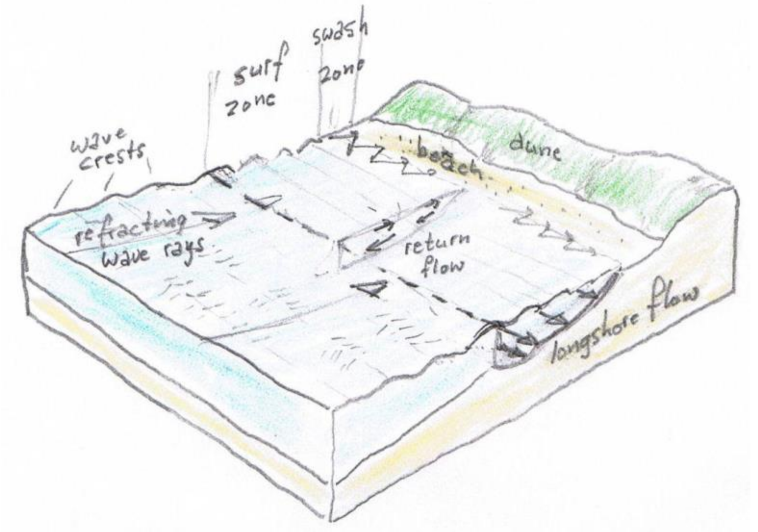
Longshore transport and coastline changes

Chapter 8 of lecture notes

A. Longshore transport
B. Calculation of coastline change
C. Coastline features
D. Growth of features
E. Example: Amager beach

8-A Longshore transport

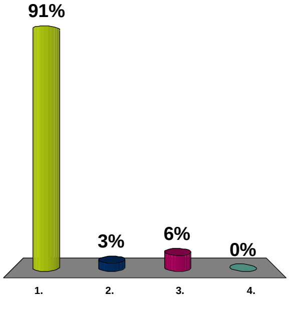
The beach – a 3D river of sand



8-A Longshore transport

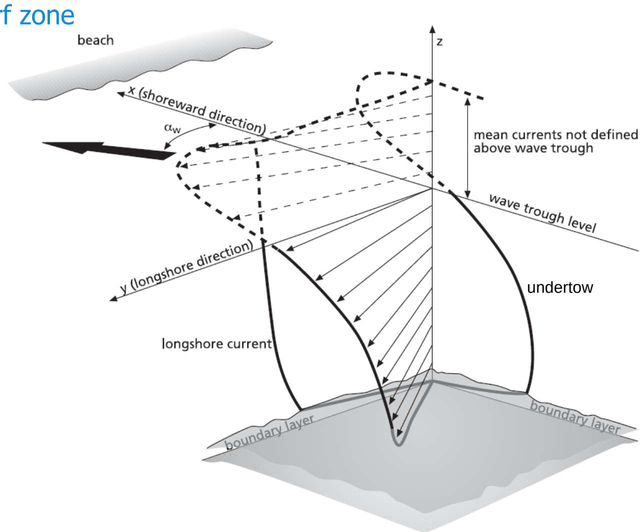
Consider the mean flow velocity in the surf zone. Which of the below statements is **wrong**?

1. The mean flow at mean water level is in longshore direction
2. The mean flow direction varies with height above the bed
3. Near the bottom, the mean current has an offshore directed component
4. Abstain



8-A Longshore transport

Depth-variation of the combined cross-shore and longshore velocity profiles in the surf zone



8-A Longshore transport

Stirring by short waves, transport by longshore current

$$\underbrace{\langle S_y \rangle}_{\text{time-averaged suspended sediment transport rate}} = \underbrace{\int_a^h VC\,dz}_{\text{current-related part}} + \cancel{\underbrace{\int_a^h \overline{\tilde{v}\tilde{c}}\,dz}_{\text{wave-related part}}}$$

$$\langle S_y \rangle = m_1 \left\langle |\vec{\tau}_b|^{(n-1)/2} \right\rangle V = m_2 \left\langle |\vec{u}|^{n-1} \right\rangle V$$

time-averaged bed /total load transport

$$|\vec{u}| = \sqrt{u^2 + V^2}$$

$$u = \hat{u}\cos\omega t$$

$$n = 3$$

$$\langle S_y \rangle = \underbrace{m_2 \left\langle u^2 + V^2 \right\rangle}_{\text{sediment load stirred by wave-current motion}} \underbrace{V}_{\text{longshore current responsible for transport}}$$

$$= \tfrac{1}{2} m_2 \hat{u}^2 V + m_2 V^3$$

8-A Longshore transport
Cross-shore distribution of longshore transport (1)

- Current V alone:
  - $S = mV^n$
  - where S is sediment transport in m^3/s/m (unit width)
  - m = coefficient
  - n is power between 3 and 5
- Bagnold (>1960), Engelund-Hansen (>1970), Van Rijn (>1980)

8-A Longshore transport
Cross-shore distribution of longshore transport (2)

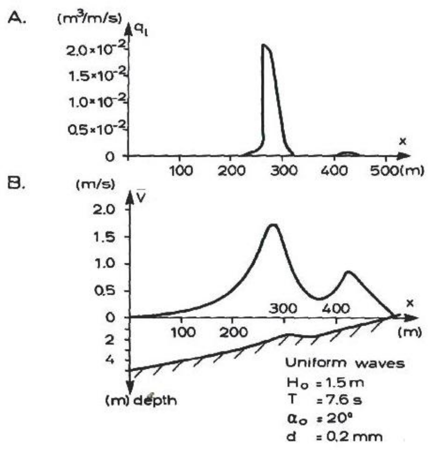
- Waves plus current V:
  - $S = m_2 \left\langle |\vec{u}|^{n-1} \right\rangle V$
  - where S is sediment transport in m^3/s/m (unit width)
  - m_2 = coefficient
  - n is power between 3 and 5
- For n = 3: $S = m_2 \left\langle u^2 + V^2 \right\rangle V$
- Bijker (1972), Inman/Bowen/Bailard (> 1980), Van Rijn/Soulsby (> 1990)

8-A Longshore transport

Cross-shore distribution of longshore transport (3)

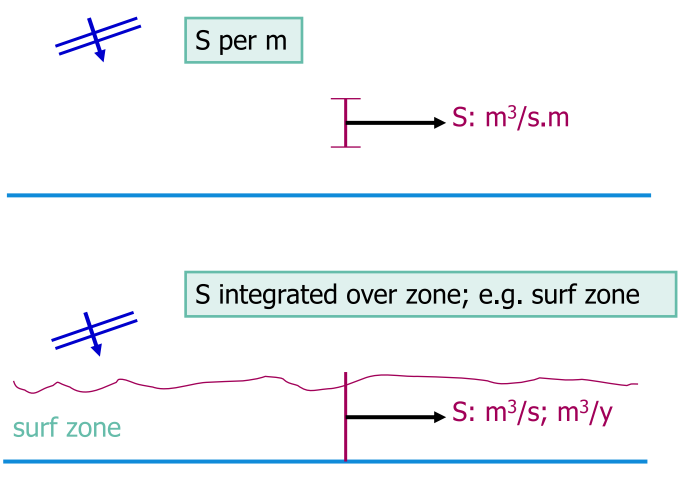
Littoral sediment transport rates

Littoral current and coastal profile



8-A Introduction

Bulk longshore transport



8-A Longshore transport

Dimensionally correct version

- Based on a large number of field and lab data:
  - $\boxed{I = K_c P}$
  - where $K_c = 0.77$ is an empirical constant (H_{rms} !)
  - $I = \rho(s-1)gS$ is the submerged weight of the transported sediment
  - where ρ is the density of water and s the relative density, and g the gravitational acceleration
  - S is the bulk longshore sediment transport rate **measured as a solid volume**

Komar and Inman (1970)

8-A Longshore transport

Dimensional form CERC-formula

- Using non-homogeneous units:
  - $S' = 7500P$
  - S' in cubic yards per year deposited volume (p!)
  - P in US Customary units (slugs, ft) with H_s as input
- Evaluation by Fredsøe and Deigaard (1992):
  - $\rho g(s-1)S = 0.41P$
- Difference mainly due to use of H_s instead of H_{rms}

SPM 1984

8-A Longshore transport

Energetics approach to bulk longshore transport (1963-1971)

Dissipated power per unit shoreline

$(Ec_g)_b \cos\varphi_b$

Mean frictional force per unit shoreline

$(Ec_g)_b \cos\varphi_b / \hat{u}_b$

Frictional resistance of sediment:

$\mu W = \tan\varphi W$

$(Ec_g)_b \cos\varphi_b / \hat{u}_b = \mu W$

$$I = WV = \varepsilon \times \frac{(Ec_g)_b \cos\varphi_b}{\mu \hat{u}_b} V$$

with $V \propto \frac{\tan\beta}{c_f} \hat{u}_b \sin\varphi_b \cos\varphi_b$

NB In Chapter 5 $\cos\varphi_b \approx 1$

and neglecting dependencies on slope and sediment properties:

$$I = \text{constant} \times (Enc)_b \cos^2\varphi_b \sin\varphi_b$$

Compare CERC equation!

Inman and Bagnold (1963)

8-A Longshore transport

Interpretation CERC formula?

$I = K_c P$

$P = (Enc)_b \cos(\varphi_b)\sin(\varphi_b)$

- In 1972: new concept of radiation stresses

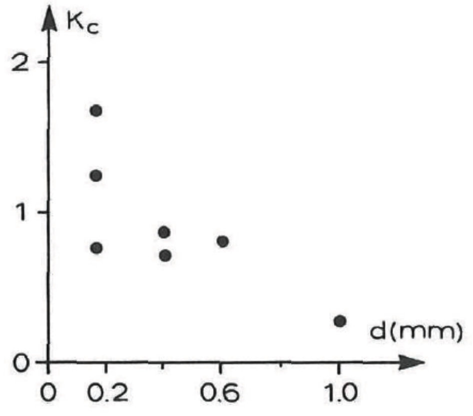
$P = S_{yx,b} c_b$

- Energetics approach

$I = \text{constant} \times (Enc)_b \cos^2\varphi_b \sin\varphi_b$

8-A Longshore transport

Grain-size dependency



Variation in K_c factor with grain size according to Dean et al. (1982)

8-A Longshore transport

Alternative analysis of field and lab data

$$I_m = 2.27 H_{s,b}^2 T_p^{1.5} \left(\tan\alpha_b\right)^{0.75} D^{-0.25} \left(\sin 2\varphi_b\right)^{0.6}$$

where $I_m = \rho(s-1)(1-p)S$ is in kg/s, H and D in m

- NB1: proportional to the beach slope
- NB2: inversely proportional to grain size

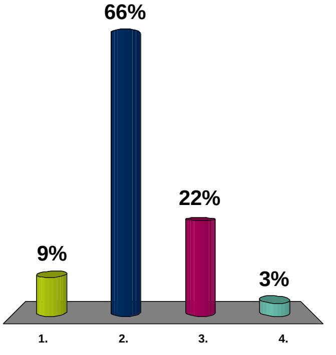
Kamphuis (1991)

8-A Longshore transport

Kamphuis' formula is proportional to the beach slope and inversely proportional to the grain size diameter.
The CERC formula contains neither of these variables.

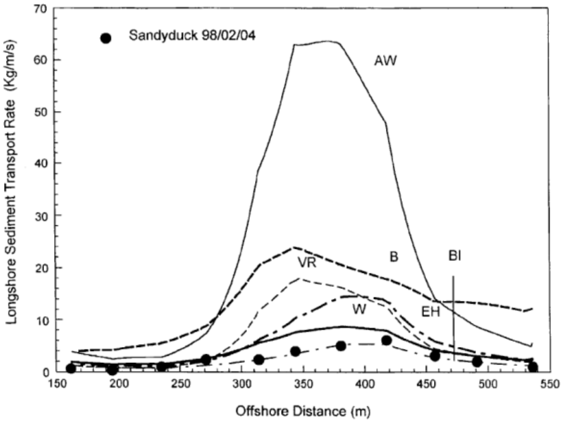
These two findings …

1. … contradict each other
2. … are in agreement with each other
3. … are completely unrelated
4. Abstain



8-A Longshore transport

Comparison measured and calculated cross-shore distribution



B: Bijker,

BI: Bailard-Inman,

VR: Van Rijn

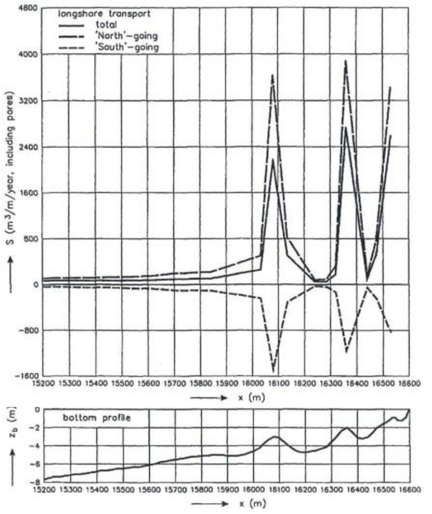
Bayram et al. 2001

8-A Longshore transport

Cross-shore distribution of longshore transport along Dutch coast

Noordwijk model computations

The effect of tidal currents is also taken into account



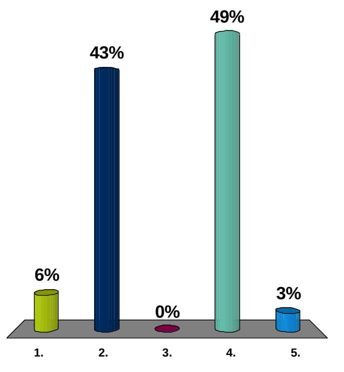
Van Rijn et al. 1997

8-A Longshore transport

The northward transport is larger on the inner bar than on the outer bar. The southward transport is larger on the outer bar.

Which of the following explanations is **true**?

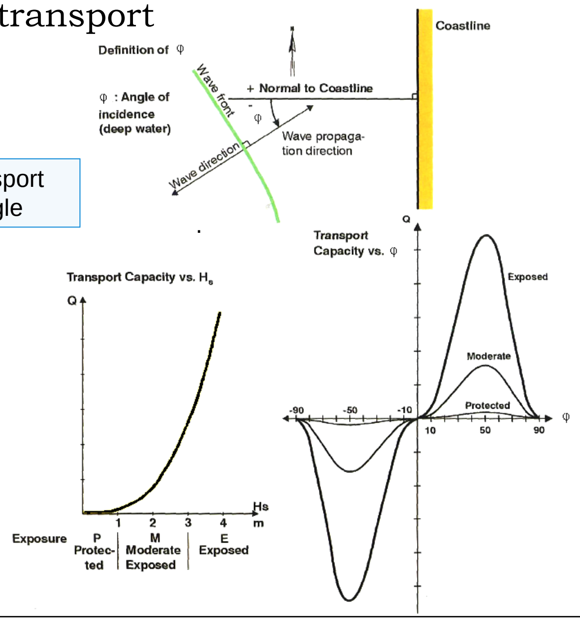
1. There is a correlation between SW waves and high tide
2. Swell generally arrives from the NW in the shallow North Sea basin
3. The wave-driven and tide-driven flows work in concert
4. Tidal water levels are different for the northward flood and southward ebb current
5. Abstain



8-A Longshore transport

S,φ diagram (1)

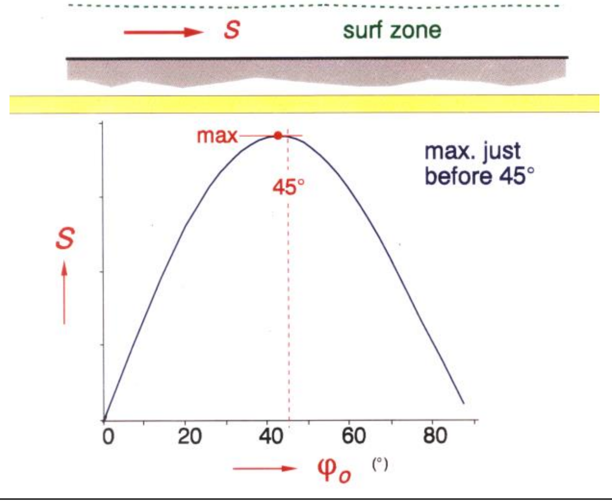
Variations in longshore transport with wave exposure and angle



Mangor, 2004

8-A Longshore transport

S,φ diagram (2)



8-A Longshore transport

Typical values of longshore transport (1)

Typical longshore sediment transport in surfzone Holland coast	
Integrated surfzone gross	O(10^6) m^3/year or per extreme event
Integrated surfzone net	O(10^5) m^3/year
Natural length scale gradients	10 - 100 km (long term scale)
Human-induced length scale gradients	1 - 10 km (medium term scale)
Net natural gradients	1 - 10 m^3/m/year
Net human-induced changes	10 - 100 m^3/m/year
Effective profile height	10 m
Net natural shoreline changes	O(0.1 - 1) m/year
Net human-induced shoreline changes	O(1 - 10) m/year

8-A Longshore transport

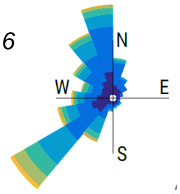
Typical values of longshore transport (2)

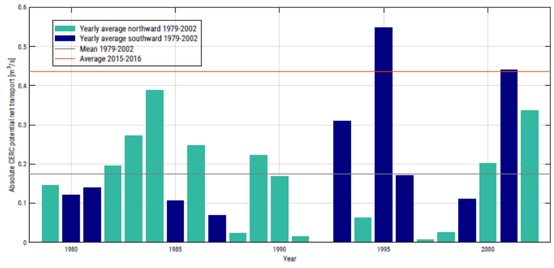
Typical longshore sed. transport in surfzone Mediterranean coast	
Integrated surfzone gross	O(10^5) m^3/year or per extreme event
Integrated surfzone net	O(10^4) m^3/year
Natural length scale gradients	10 km (long term scale)
Human-induced length scale gradients	1 - 10 km (medium term scale)
Net natural gradients	1 m^3/m/year
Net human-induced changes	1 - 10 m^3/m/year
Effective profile height	10 m
Net natural shoreline changes	O(0.1) m/year
Net human-induced shoreline changes	O(0.1 - 1) m/year

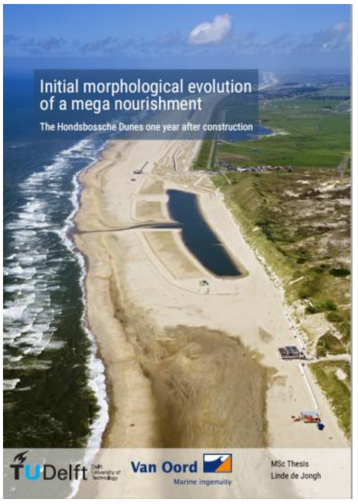
8-A Longshore transport

Engineering use of CERC formula (De Jong, 2017)

Net sediment transport 2015-2016 factor 2,5 larger than long-term average 1979-2002





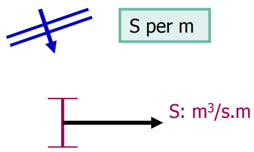


8.

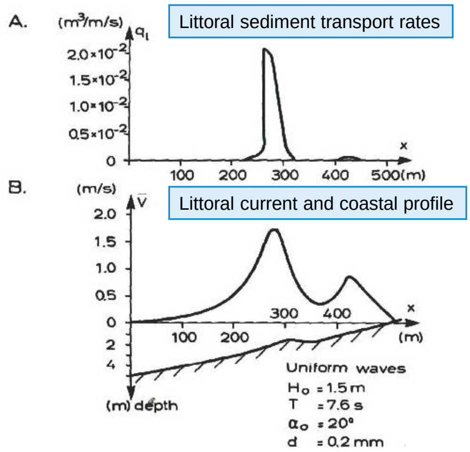
Longshore transport and coastline changes

8-A Recap: Longshore transport

Cross-shore distribution of longshore transport



Bulk transport: $S \sim H^{2.5}$, sin(



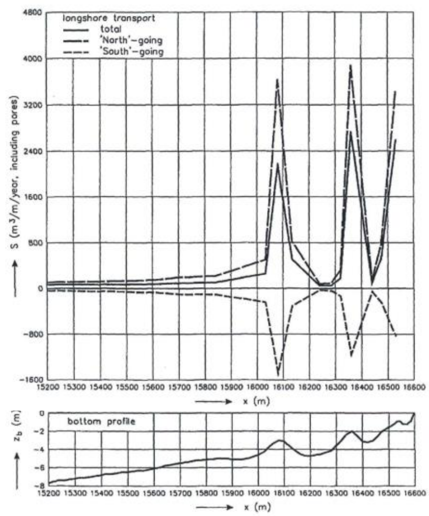
See Fredsøe and Deigaard (1992)

8-A Longshore transport

Cross-shore distribution of longshore transport along Dutch coast

Noordwijk model computations

The effect of tidal currents is also taken into account



Van Rijn et al. 1997

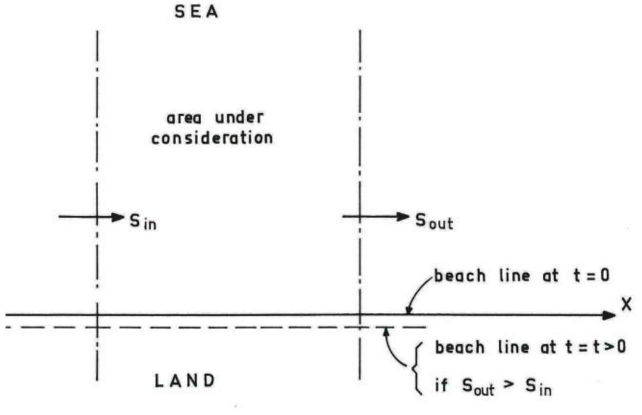
Longshore transport and coastline changes

Chapter 8 of lecture notes

A. Longshore transport
B. Calculation of coastline change
C. Coastline features
D. Growth of features
E. Example: Amager beach

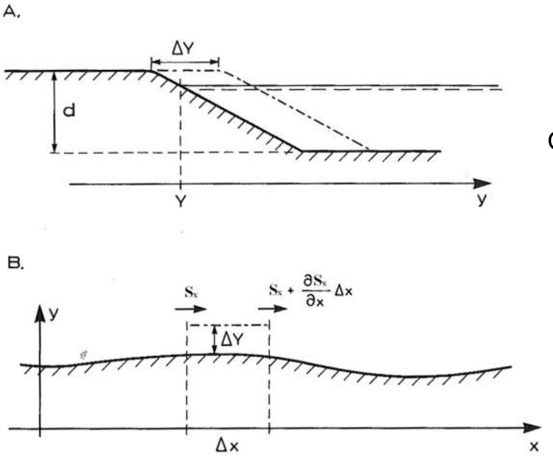
8-B Calculation of coastline change

Longshore transport continuity



8-B Calculation of coastline change

Longshore transport and coastal change in a coastline model

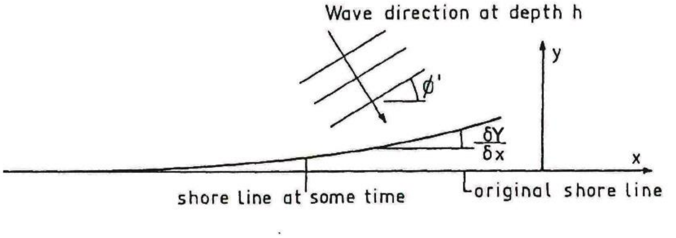


Continuity equation:

$$\frac{\partial Y}{\partial t} + \frac{1}{d}\frac{\partial S_x}{\partial x} = 0$$

8-B Calculation of coastline change

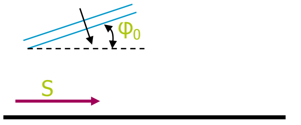
Governing equations



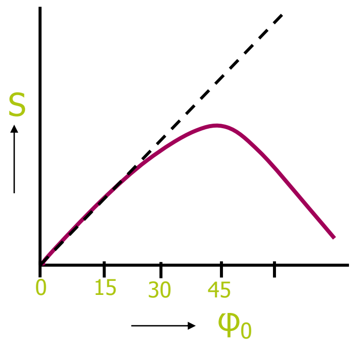
$$\frac{\partial Y}{\partial t} + \frac{1}{d}\frac{\partial S_x}{\partial \varphi}\frac{\partial \varphi}{\partial x} = 0 \xrightarrow{\partial \varphi = -\partial Y / \partial x} \frac{\partial Y}{\partial t} - \frac{1}{d}\frac{\partial S_x}{\partial \varphi}\frac{\partial^2 Y}{\partial x^2} = 0$$

8-B Calculation of coastline change

Simplify governing equations



S: linear function of φ ?



$$\left.\begin{aligned}&\frac{\partial Y}{\partial t}-\frac{1}{d}\frac{\partial S_x}{\partial \varphi}\frac{\partial^2 Y}{\partial x^2}=0\\&\frac{\partial S_x}{\partial \varphi}=s=\frac{S}{\varphi'}\end{aligned}\right\}$$

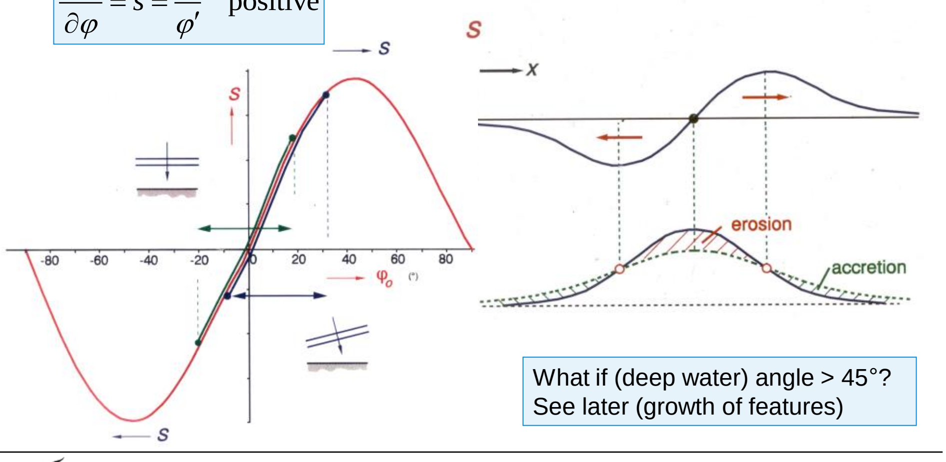
$$\boxed{\frac{\partial Y}{\partial t}-\frac{s}{d}\frac{\partial^2 Y}{\partial x^2}=0}$$

Heat or diffusion equation

8-B Calculation of coastline change

Perturbations (nourishment, delta after cut-off of sediment supply) smooth out if:

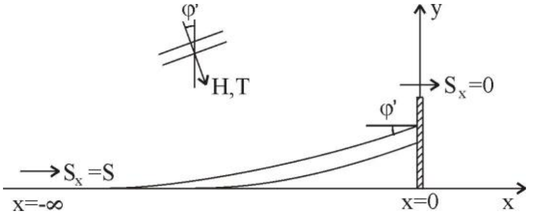
$$\frac{\partial S_x}{\partial \varphi}=s=\frac{S}{\varphi'} \quad \text{positive}$$

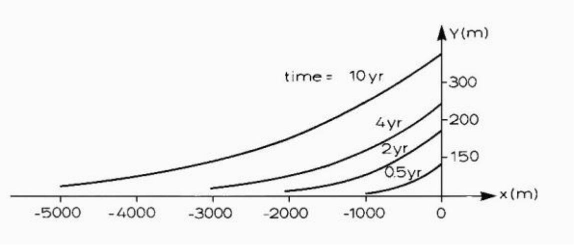


What if (deep water) angle > 45°?
See later (growth of features)

8-B Calculation of coastline change

Analytical solutions for accretion near breakwater

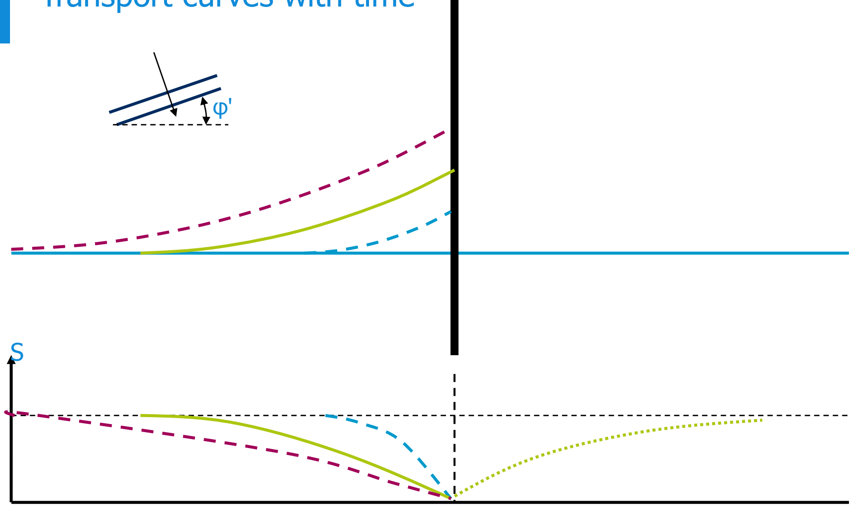




$$L(t) = 2\sqrt{\frac{\varphi' S t}{\pi d}}$$

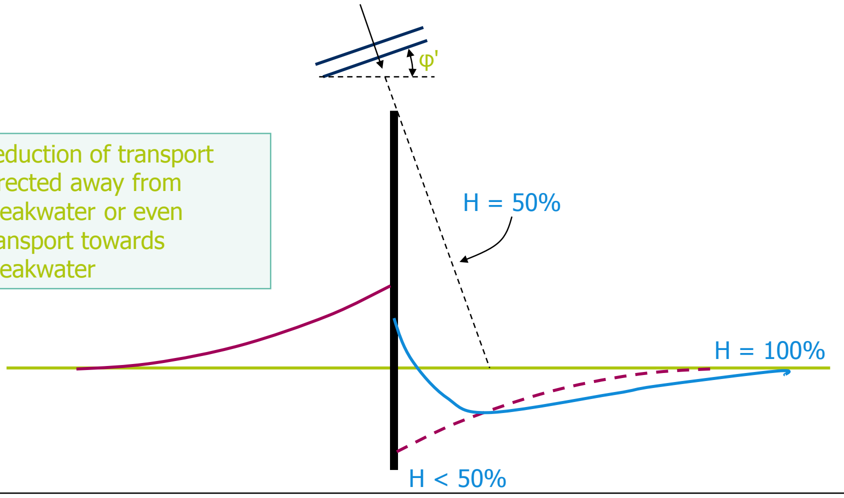
8-B Calculation of coastline change

Transport curves with time



8-B Calculation of coastline change

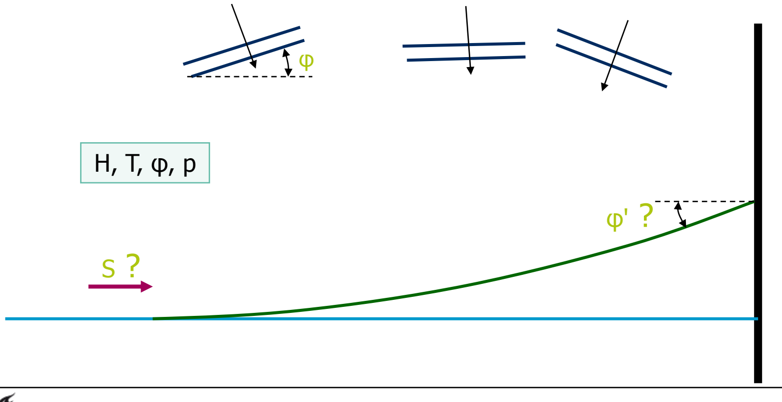
Sheltering and diffraction at lee-side affects wave angles, wave heights and set-up



8-B Calculation of coastline change

Wave climate instead of waves from one direction

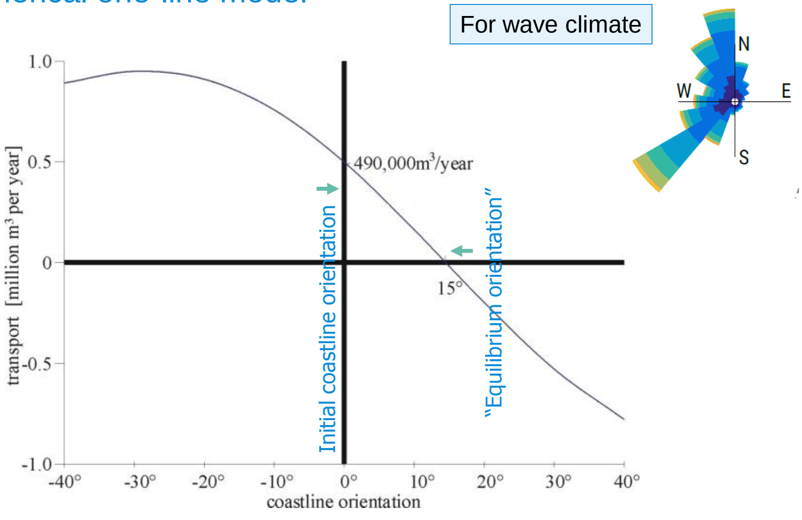
up till now: fixed φ'; reality varying φ (and wave heights)



8-B Calculation of coastline change

Numerical one-line model

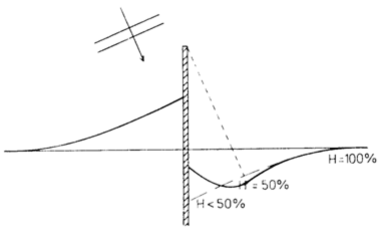
For wave climate



8-B Calculation of coastline change

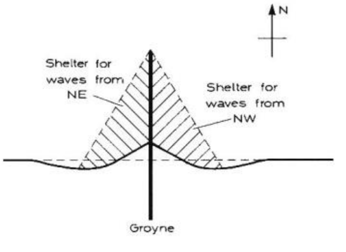
Leeside

One wave condition



Effect diffraction + set-up gradient

Mirrored wave climate

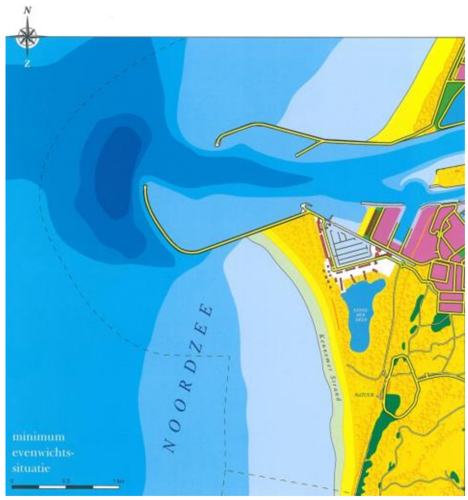


Sheltering effect around a groyne immediately after construction

From Fredsøe and Deigaard (1992)

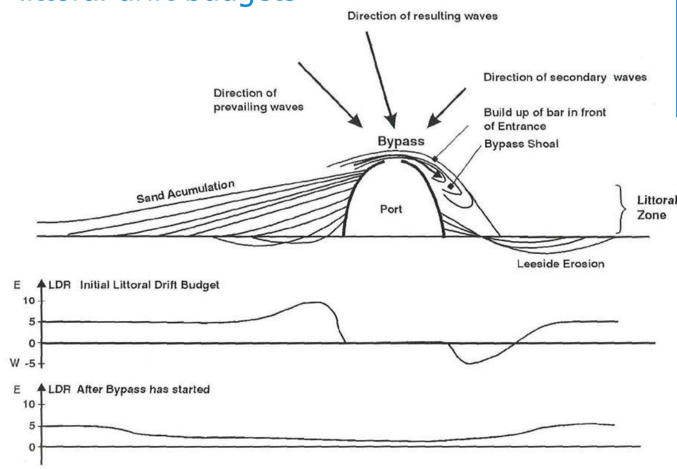
8-B Calculation of coastline change

Accretion next to jetties in IJmuiden



8-B Calculation of coastline change

Schematic shoreline, morphological development and littoral drift budgets



Note:

Erosion volume must be equal to accretion volume

Mangor, 2004

8.

Longshore transport and coastline changes

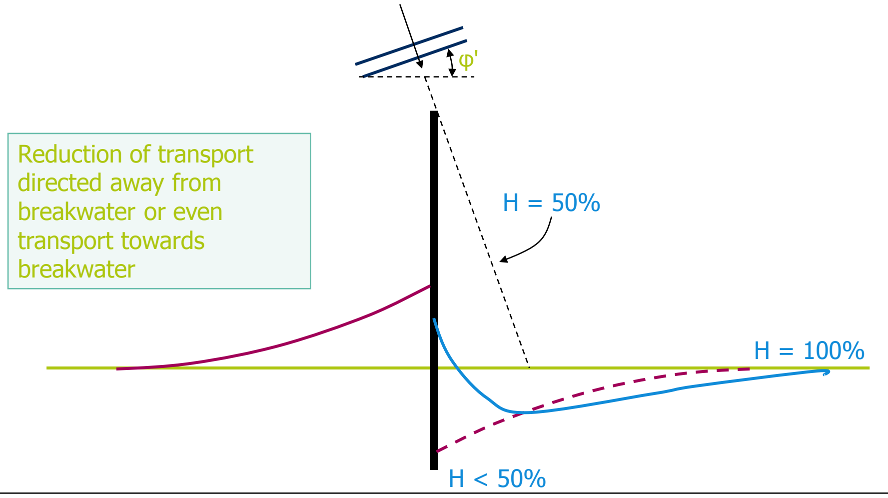
8.

Household announcements

- Extra class on Thu 22 March
  - 13:45-15:30 hr: Tidal inlets by Marcel Stive
  - 15:45-17:30 hr: Extra class by students CD-1
- Maple-TA questions Ch.8 -> Start on time!
  - Sun. 25 March: Deadline submission
  - Tue. 27 March: Special course by TA's

8-B Recap: Calculation of coastline change

Shoreline changes around breakwater (first / second order effects due to wave sheltering & diffraction)



Longshore transport and coastline changes

Chapter 8 of lecture notes

A. Longshore transport
B. Calculation of coastline change
C. Coastline features
D. Deltaic coastlines
E. Growth of features
F. Example: Amager beach

8-C Coastline features

Tombolo

Tombolos behind two breakwaters at Almanzora, Spain

Natural tombolo at Chesterman Beach (Tofino, Vancouver Island)

8-C Coastline features

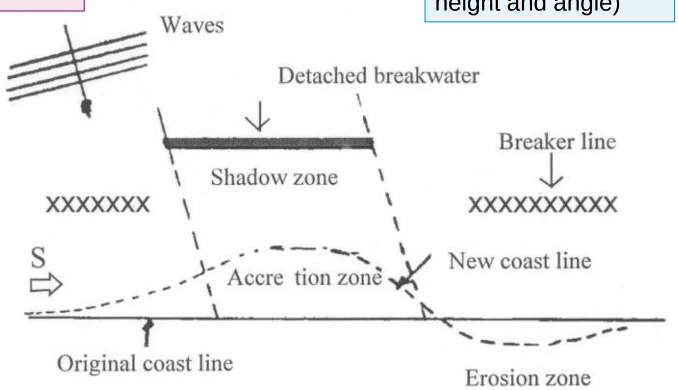
Salient and tombolo development (1)

Effect 1:
Gradients in longshore transport due to shadow zone (variations in wave height and angle)

First: what happens for normally incident waves?

Note:

Total erosion volume = total accretion volume

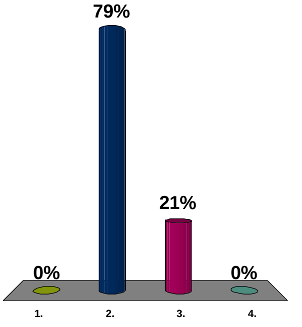


8-C Coastline features

Deposition in the shadow zone occurs for normally incident waves also.

Which of the below explanations is **invalid**?

1. Set-up gradients drive a net current from both ends of the breakwater into the shadow zone
2. ✔ Refracting waves cause this transport into the shadow zone
3. Diffracting waves induce a longshore transport towards the shadow zone
4. Abstain

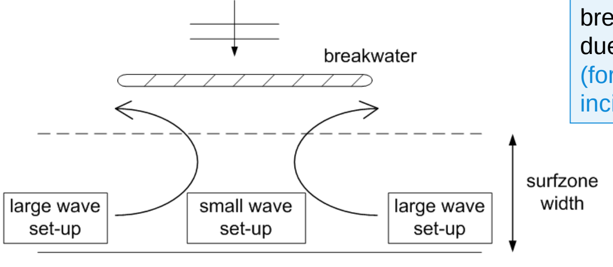


Also for oblique wave incidence!

8-C Coastline features

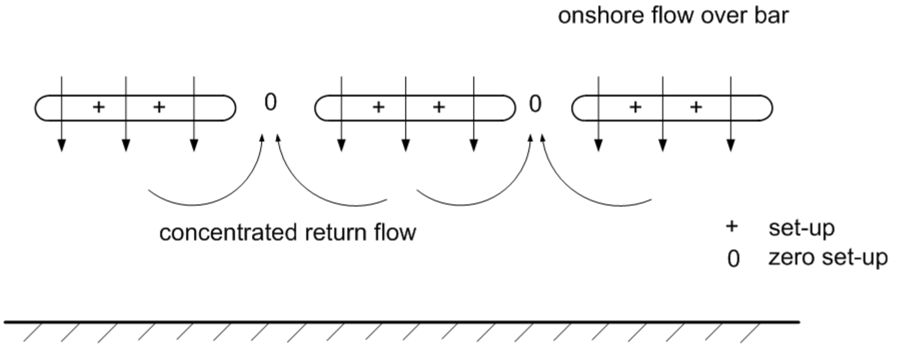
Salient and tombolo development (2)

Effect 2:
Transport towards breakwater by current due to set-up variations
(for normal and oblique incidence)



Question:
Now consider a submerged breakwater. Which **counteracting erosional effect** can play a role?

8-C Coastline features
Possible erosional effect in case of submerged breakwater



8-C Coastline features
Salient and tombolo development in case of emerged breakwater

Salients

Question:
Salient or tombolo?
Dependent on…..

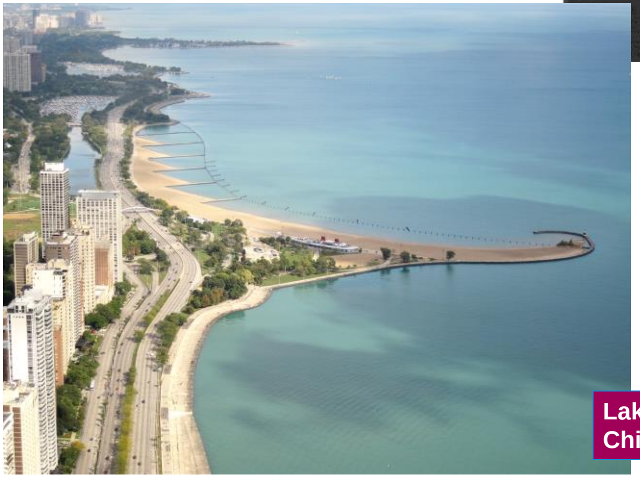
8-B Coastline features
Sitges (Spain)

8-B Coastline features
Sitges (Spain)

8-C Coastline features

Saw tooth pattern of groyned coast

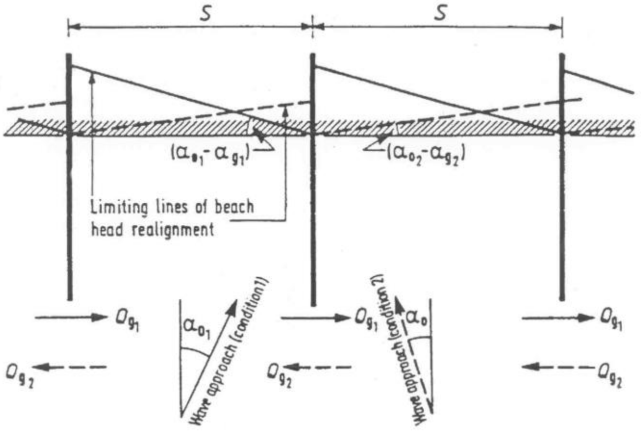
Walcheren, NL



Lake Michigan, Chicago (Oct 2009)

8-C Coastline features

Variation of beach on a groyne shore

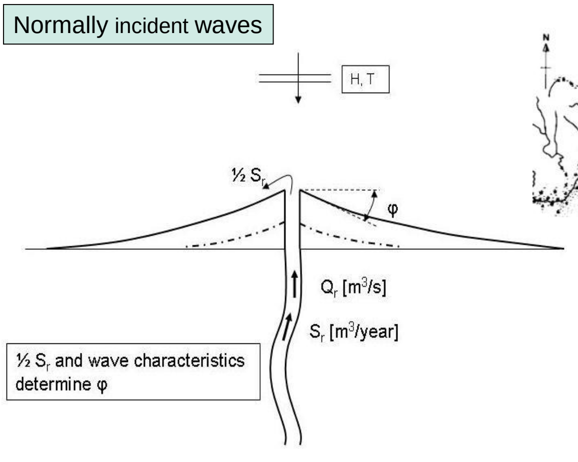


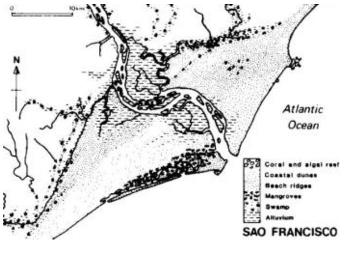
8-C Coastline features

Spit (formed with alongshore transported sediment)

8-C Coastline features

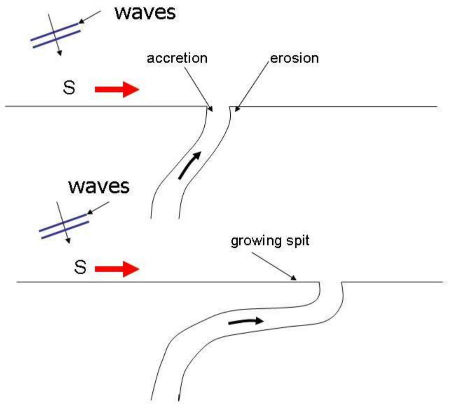
Development of wave-dominated delta





8-C Coastline features

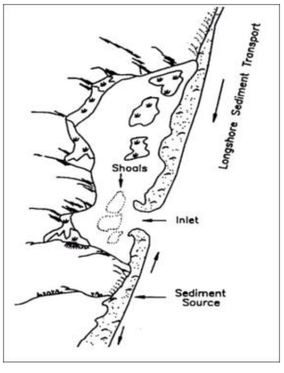
Spit at river mouth



Kiawah Island, SC

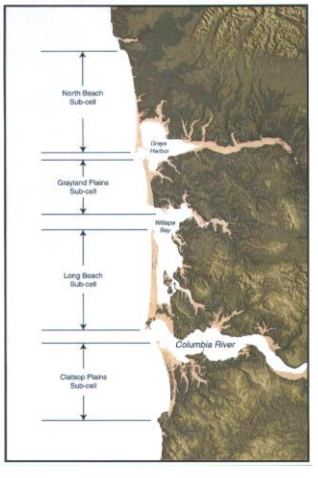
8-C Coastline features

Spit (partially) closing off tidal basin



Dorset, UK

Columbia River Littoral Cell



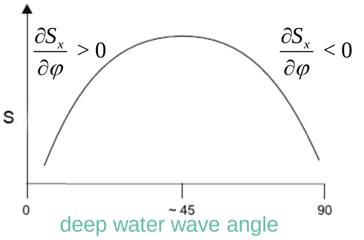
Longshore transport and coastline changes

Chapter 8 of lecture notes

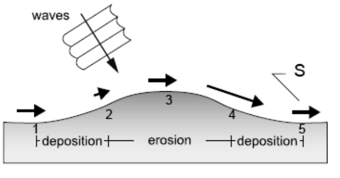
A. Longshore transport
B. Calculation of coastline change
C. Coastline features
D. Growth of features
E. Example: Amager beach

8-E Growth of features

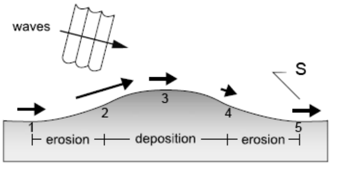
Negative versus positive feedback



- Low-angle waves (< ~ 45°):
  - Sediment transport increases **along the crest** from 2 to 4 (positive gradient) => **erosion**
  - Sediment transport decreases **along flanks** from 1 to 2 and from 4 to 5 (negative gradient) => **accretion**
  - Shape (nourishment, delta, …) flattens: negative feedback



- High-angle waves (> ~ 45°):
  - **Opposite response**
  - Erosion along flanks (increasing S)
  - Accretion along the crest (decreasing S)
  - Features grow: positive feedback

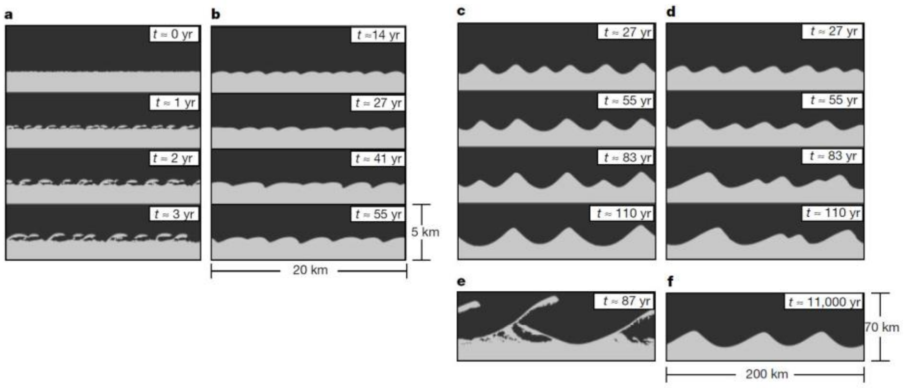


Ashton et al.

8-E Growth of features

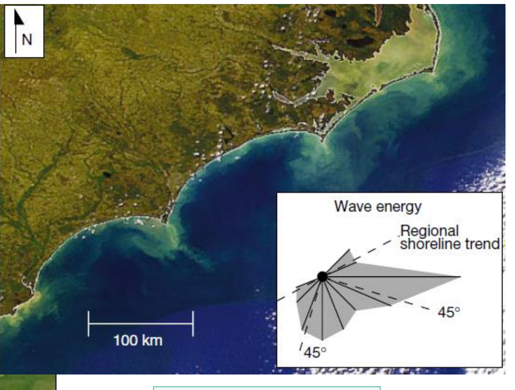
Model results Ashton et al. (2001)

Variations in magnitude and asymmetry of wave angles



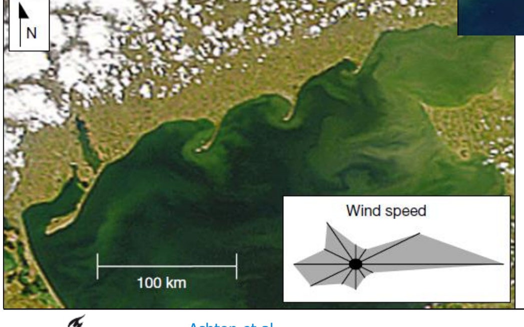
8-E Growth of features

Examples of large angle incidence



Carolina coast, USA

Sea of Azov, Ukraine



Ashton et al.

Exam question june 2010

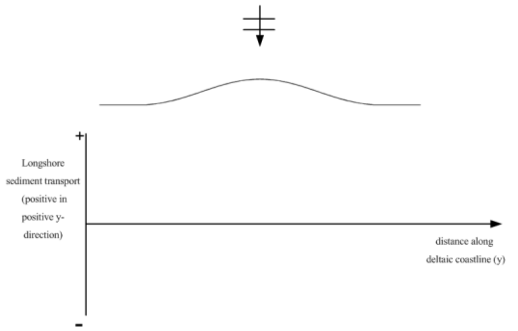
75 points in total

Assume normally incident waves and ignore all effects of refraction.

c. **[4]** Draw the alongshore sediment transport rate as a function of the distance along the deltaic shoreline just after the damming of the river. *Use the figure on the answer sheet.*

d. **[2]** Indicate in the same figure with + and – in which zones erosion and in which zones accretion can be expected. Explain your reasoning.

e. **[1]** What do you conclude about the long-term fate of the delta?



Exam question june 2010 (continued)

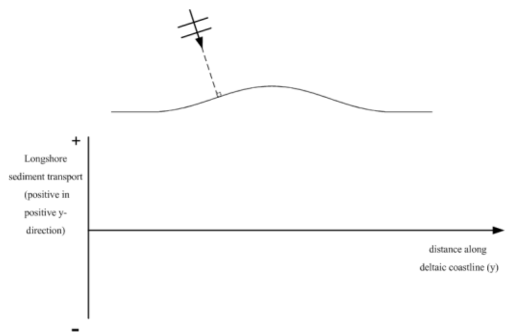
Now assume that instead of normally incident, the waves were obliquely incident under a small angle. The wave angle is indicated in the figure on the answer sheet.

f. **[4]** Draw the alongshore sediment transport rate along the delta just after the damming of the river. Use the same vertical scale as in your answer to a). *Use the figure on the answer sheet.*

g. **[2]** Now draw in the same figure the alongshore sediment transport rate after a new equilibrium has been reached. Explain your reasoning.

Compare Exercise 8-2 in your lecture notes!

Possible variations:
- Detached breakwater
- Harbour
- Groyne field
- ….

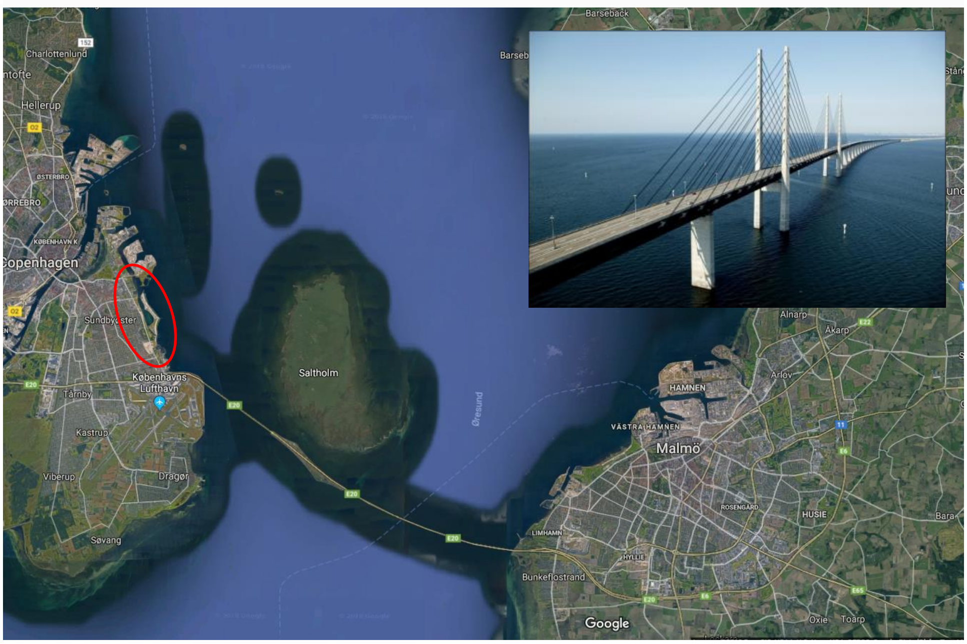


Longshore transport and coastline changes

Chapter 8 of lecture notes

A. Longshore transport
B. Calculation of coastline change
C. Coastline features
D. Growth of features
E. Example: Amager beach

Amager beach park

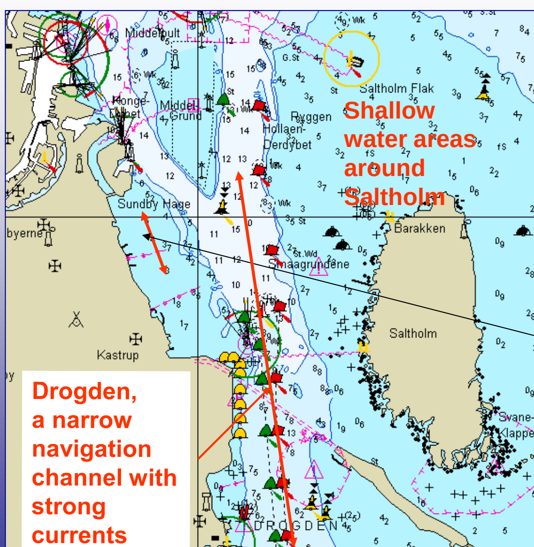


Conditions in 2004

Flat profile approx. 1:200 on the inner 200 m

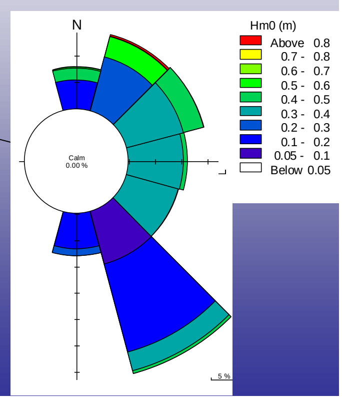
"beach" sand behind a wooded seawall, soft muddy bottom in front of wall

Conditions on the site



Extreme high water level: 1.25 m

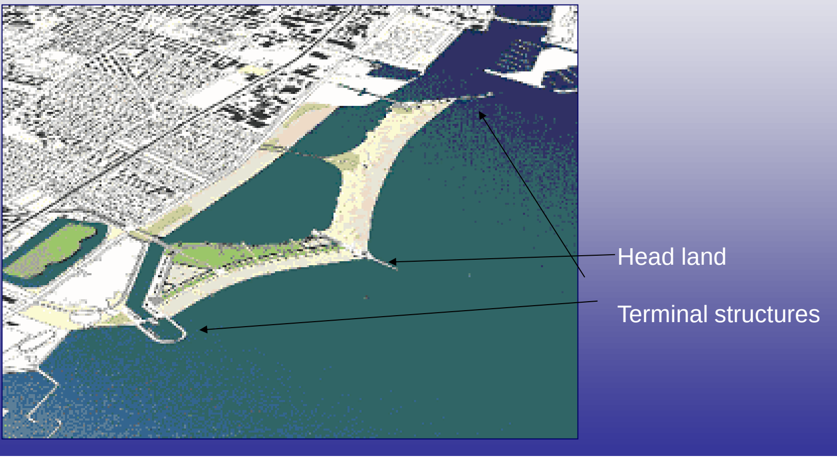
Waves off the beach park



Requirements to the new beach park

- The beaches shall be exposed to waves to obtain good quality
- Plan form shall be “stable”
- Profiles shall be “stable”
- Loss of sand shall be avoided
- No corners and deep bays to avoid sea weed
- Beach sand shall be coarse enough to avoid problems with wind blown sand
- Not too coarse because the profile will be too steep
- Not too fine as the profile will be too flat and swampy
- Good water quality

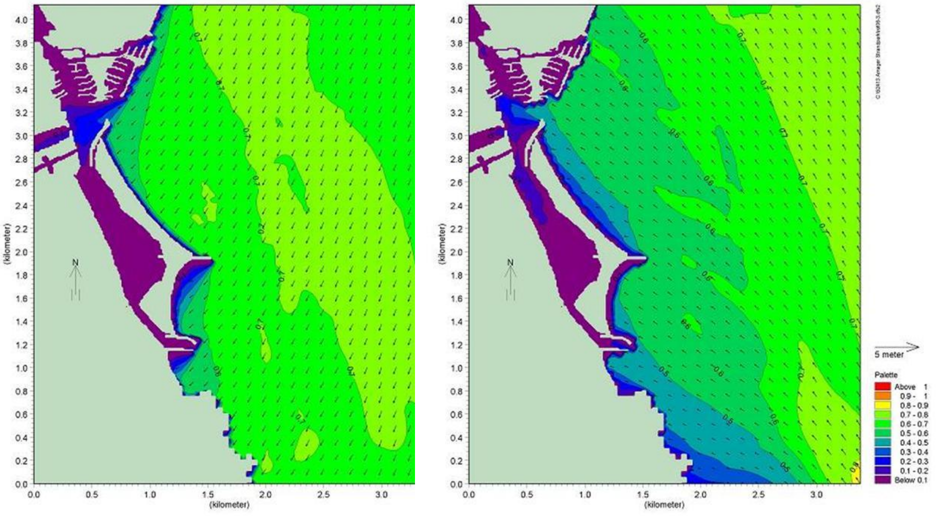
Concept:
Move beach seaward to obtain wave exposure
Utilise natural gradient to flush lagoon



Wave modelling

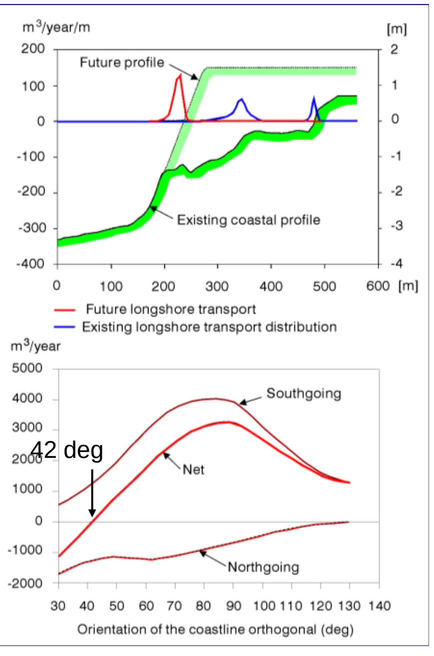
Wind from NNE

Wind from SSE

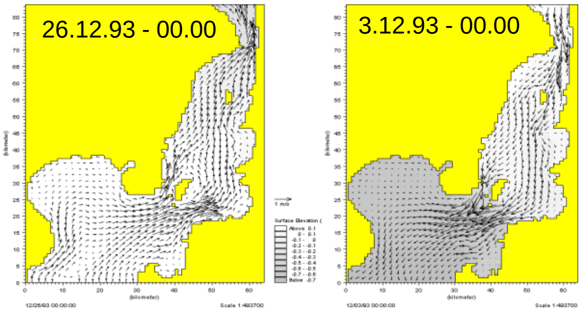


Obtain maximum mobility of the beach sand – steeper profile in deeper water

Align beaches to equilibrium

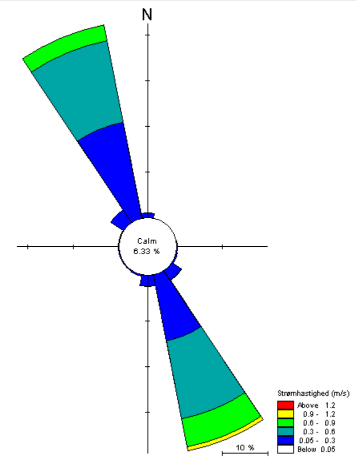


Regional currents

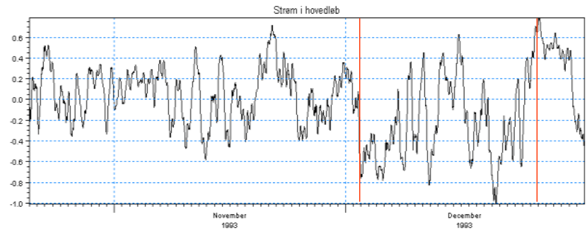


•Good flushing

•Swimmers safety to be checked

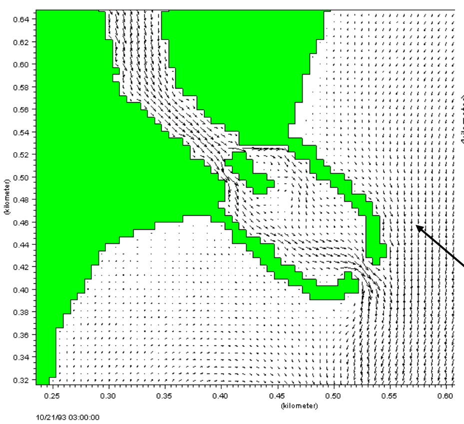


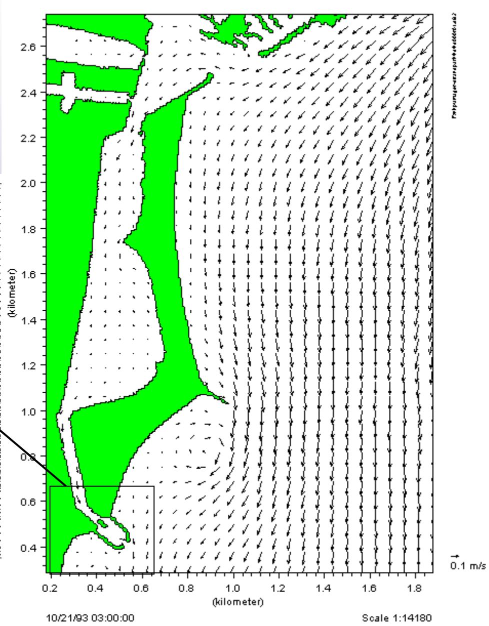
Currents in the navigation channel off the beach park

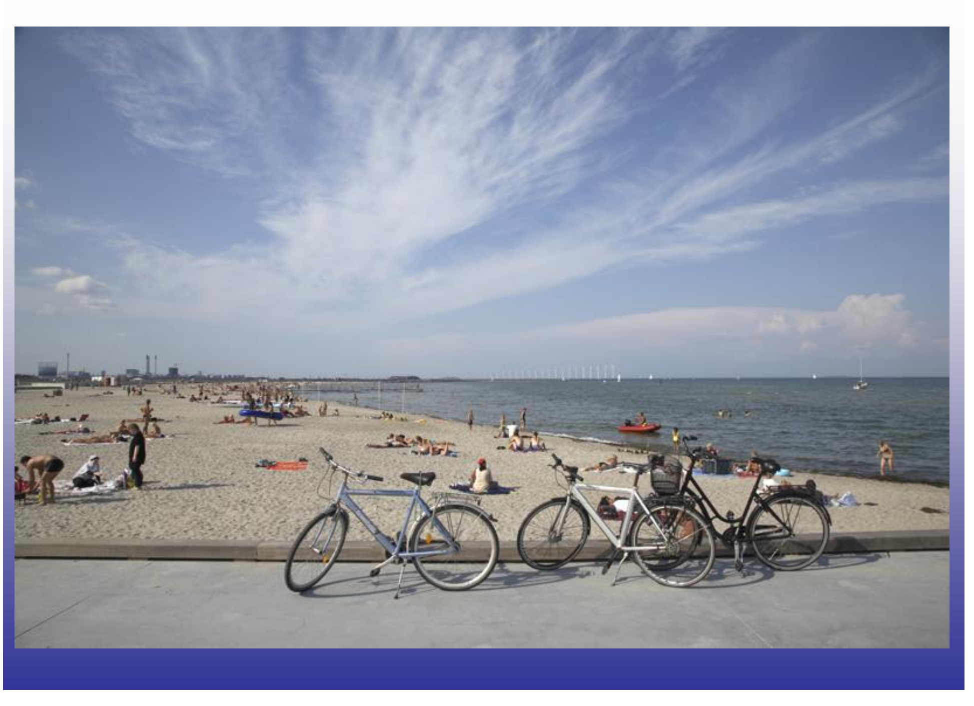


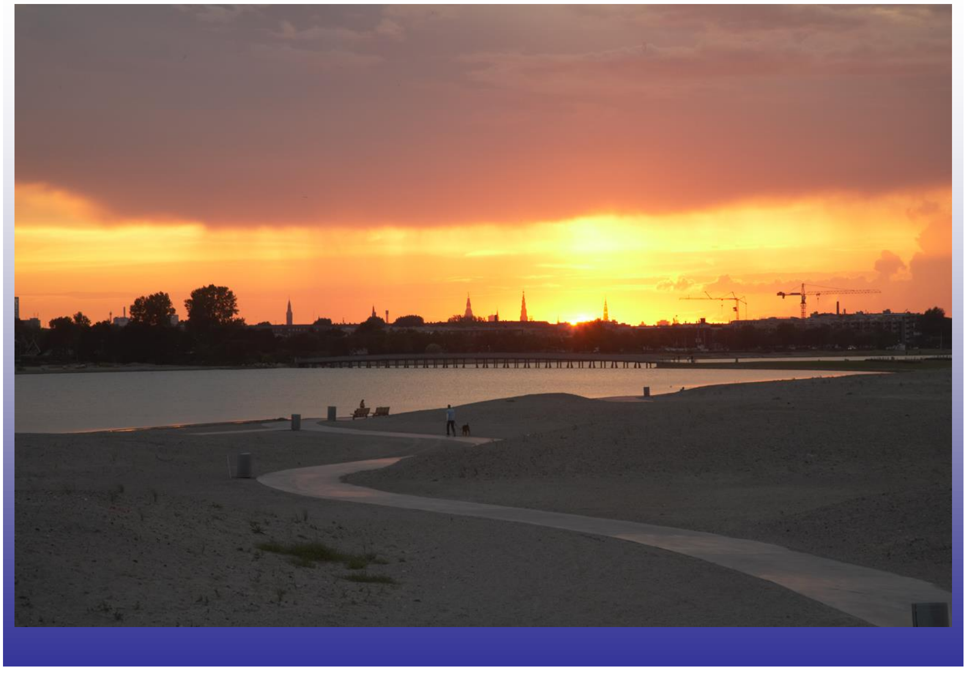
The average time for exchange of water in the lagoon is 24 hours (acceptable)

Currents along beaches acceptable









August 2005 – just after construction