These lecture materials are for the Marine Coastal and Delta Sustainability for Southeast Asia (MARE) (Project No. 610327-EPP-1-2019-1-DE-EPPKA2-CBHE-JP).

This project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the Commission cannot be made responsible for any use which may be made from the information contained herein.

Co-funded by the Erasmus+ Programme of the European Union

Topic 4

Sediment Transport & Coastal Morphodynamics

UNIVERSITI TEKNOLOGI PETRONAS
energising futures

Course Learning Outcomes

UTP

Upon completion of this course, students should be able to:

1. Evaluate the properties of offshore and near shore waves and establish design wave specification.
2. Assess currents and tidal processes.
3. Formulate sediment budget and perform shoreline evolution analysis.

Part 1
Littoral Transports

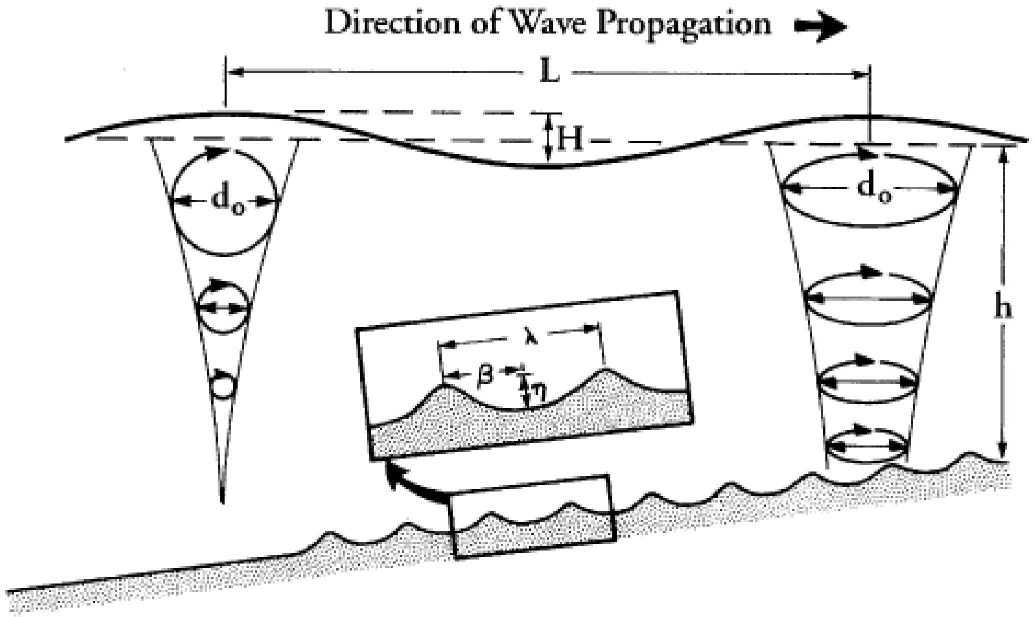
UNIVERSITI TEKNOLOGI PETRONAS
energising futures

LEARNING OUTCOMES

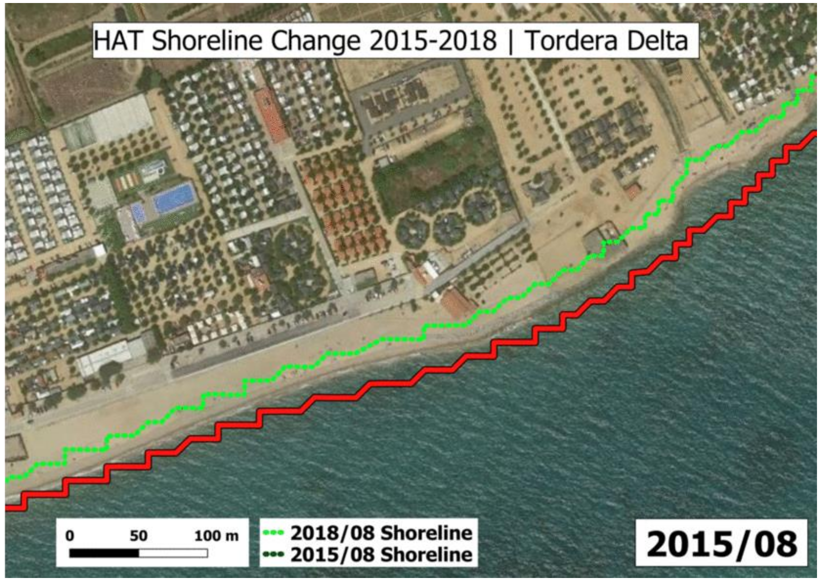
Upon completion of this topic, participants should be able:

- Distinguish factors affecting longshore transport
- Interpret and evaluate longshore transport behavior
- Estimate longshore transport magnitude and direction

EVIDENCE OF SEDIMENT MOVEMENT



https://link.springer.com/referenceworkentry/10.1007%2F3-540-31079-7_183



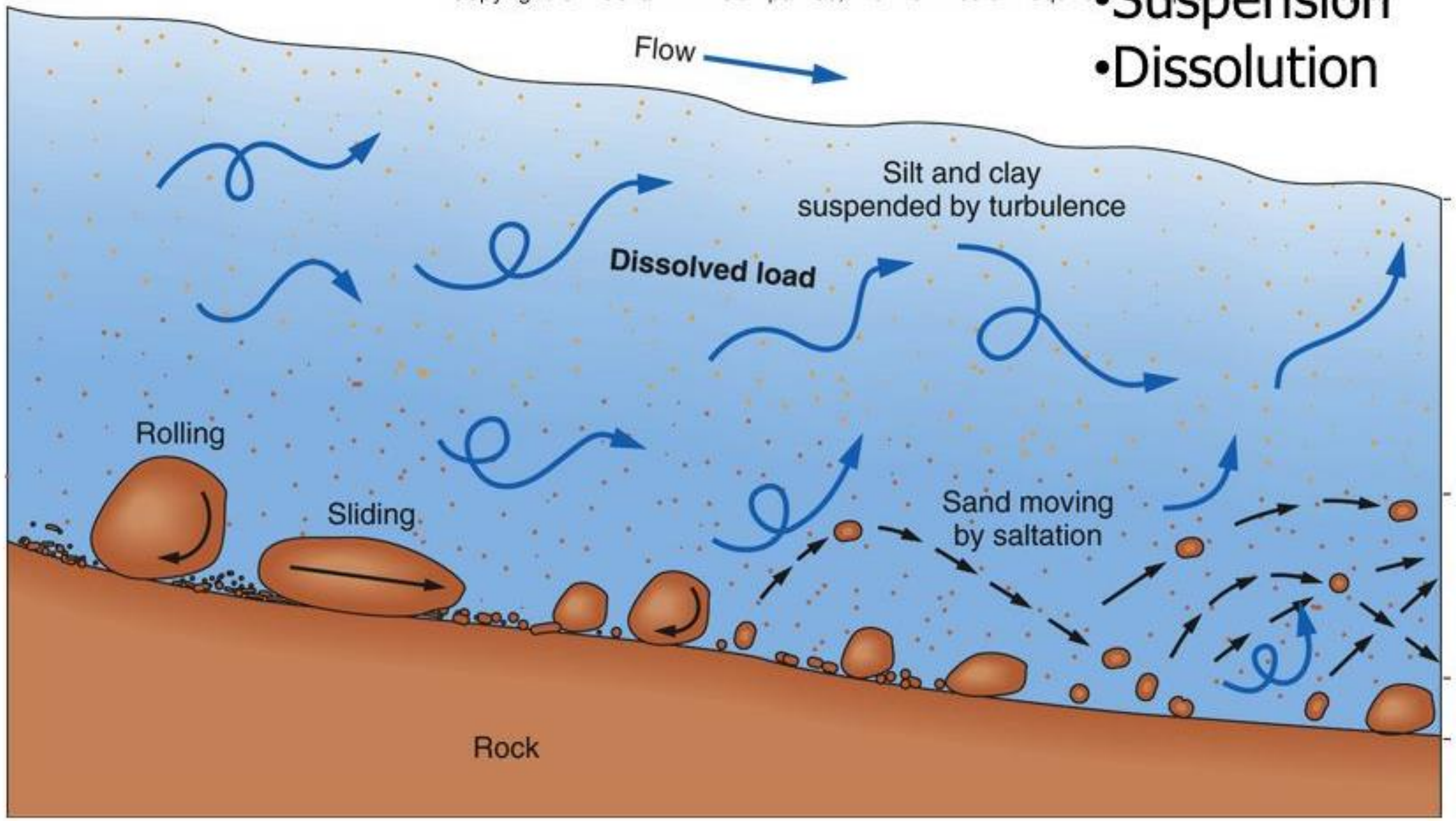
https://sentinels.copernicus.eu/web/success-stories/-/shoreline-changes

WHY ARE COASTAL LANDS & SEDIMENTS CONSTANTLY IN MOTION?

- **Breaking waves** move sand along the coast, eroding sand in one area and depositing it on adjacent beaches.
- **Tidal cycles** bring sand onto the beach and carry it back into the surf zone.
- **Rivers** carry sediment to the coast and build deltas into the open water.
- **Storms** cause deep erosion in one area and leave thick overwash deposits in another.
- **Wind** carries sand at the beach face to offshore.

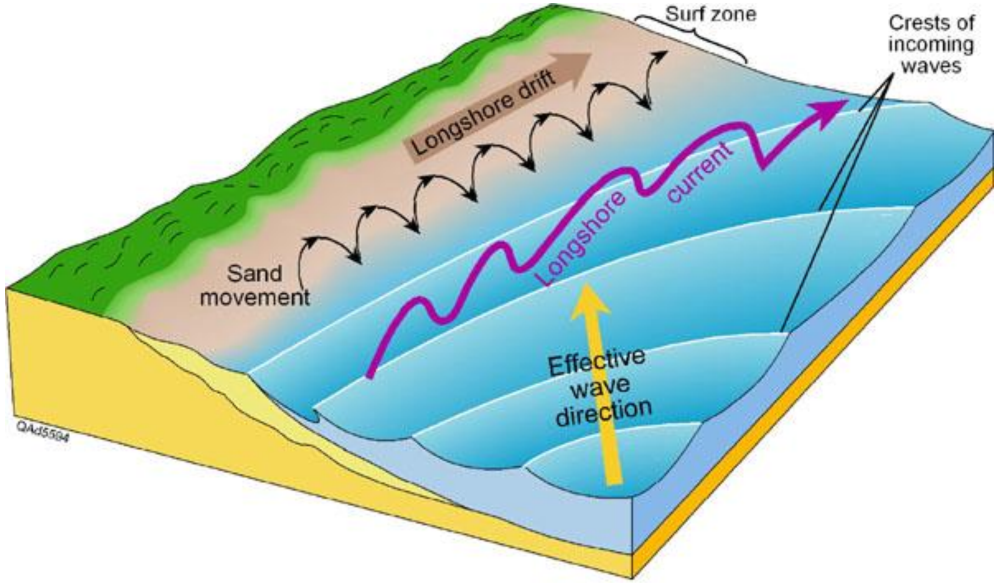
Sediment Transportation Modes

- Rolling
- Suspension
- Dissolution



https://slideplayer.com/slide/10102443/

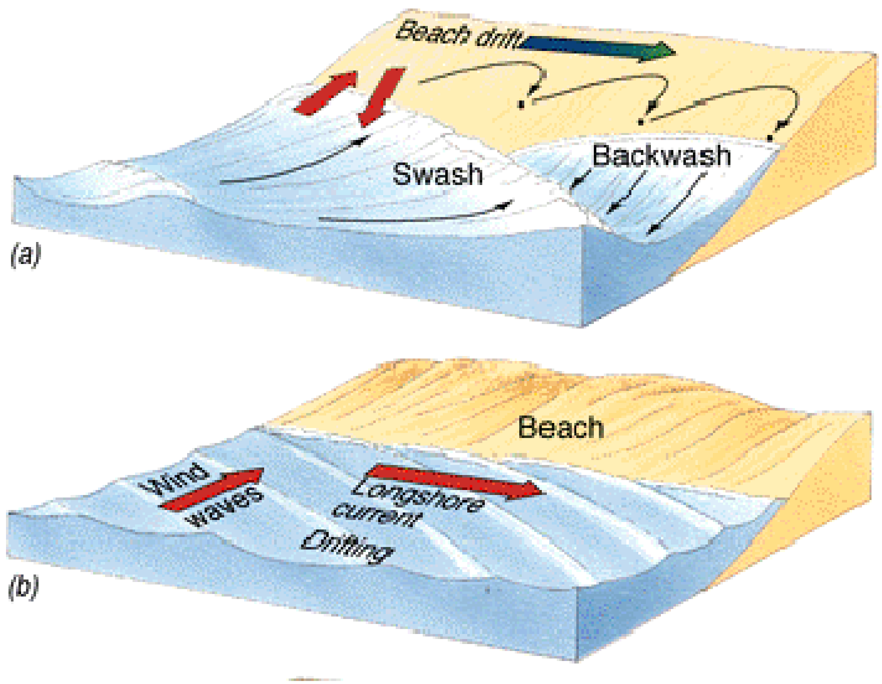
Alongshore Sediment Transport



- Littoral sediment transport (LST) is the transport of non-cohesive sediments, i.e. mainly sand, along the foreshore and the surf zone (approximately parallel to the shoreline) due to the action of the breaking waves and the longshore current.

- The littoral transport is also called the longshore transport (surf zone) or the littoral drift (swash zone).
- LST is induced by wave action at the surf zone, breaker zone and swash zone.
- When waves approach a shoreline at an angle, sediment will move along the shore in the direction of wave propagation; therefore, the alongshore transport take place.

ZONING OF LST



https://www.researchgate.net/figure/Describing-longshore-sediment-transport-from-the-web-Littoral-drift-Beach-drift_fig5_27667012

LST at a breaker zone

The breaking and broken waves stir up the bottom sediment into suspension (suspended load) and the sediment is transported by alongshore currents or any other currents present.

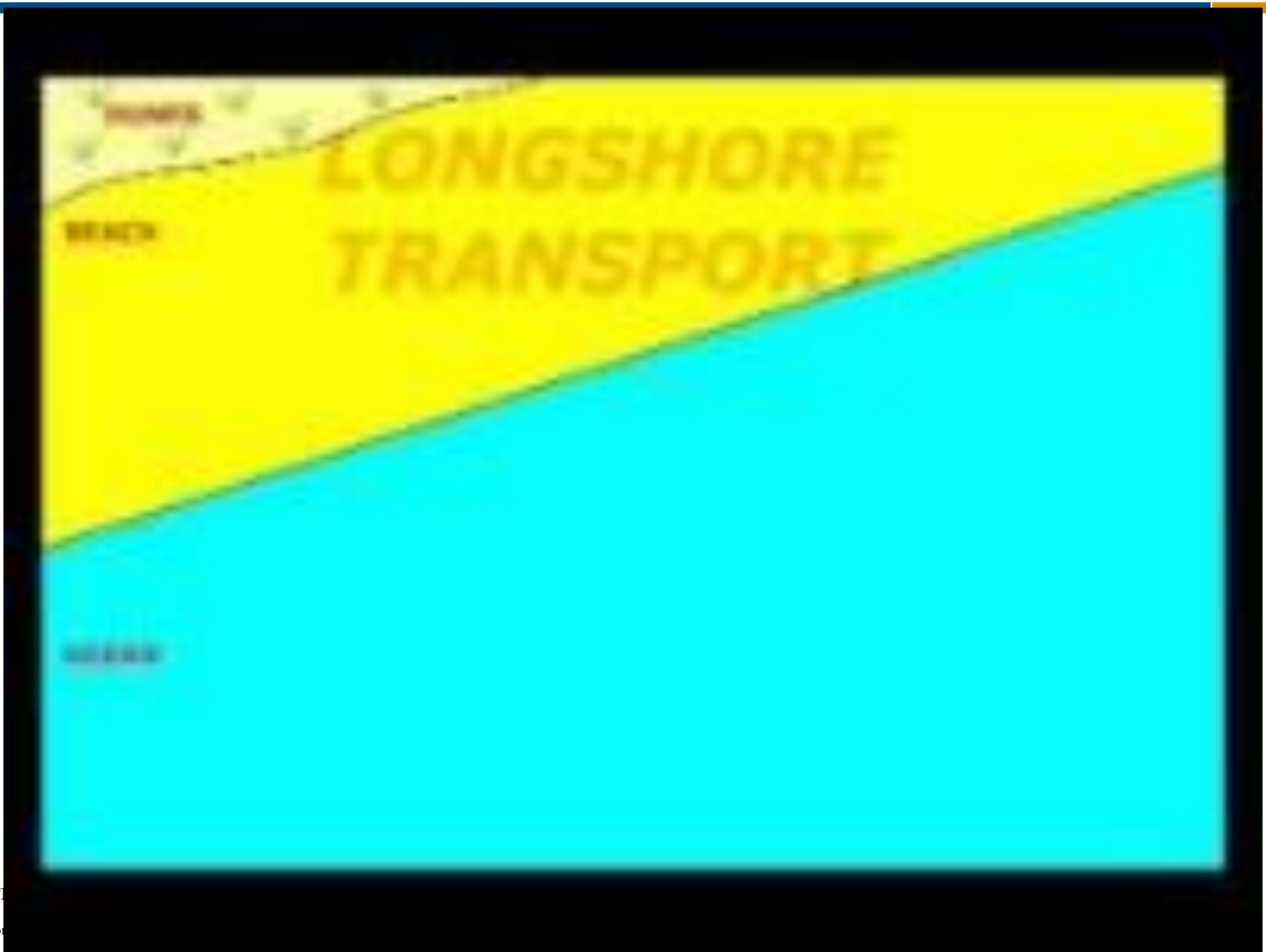
LST at a swash zone

A zig-zag motion of the sediment along the beach face (beach drifting) caused by the uprush and the backwash.

LST within a surf zone

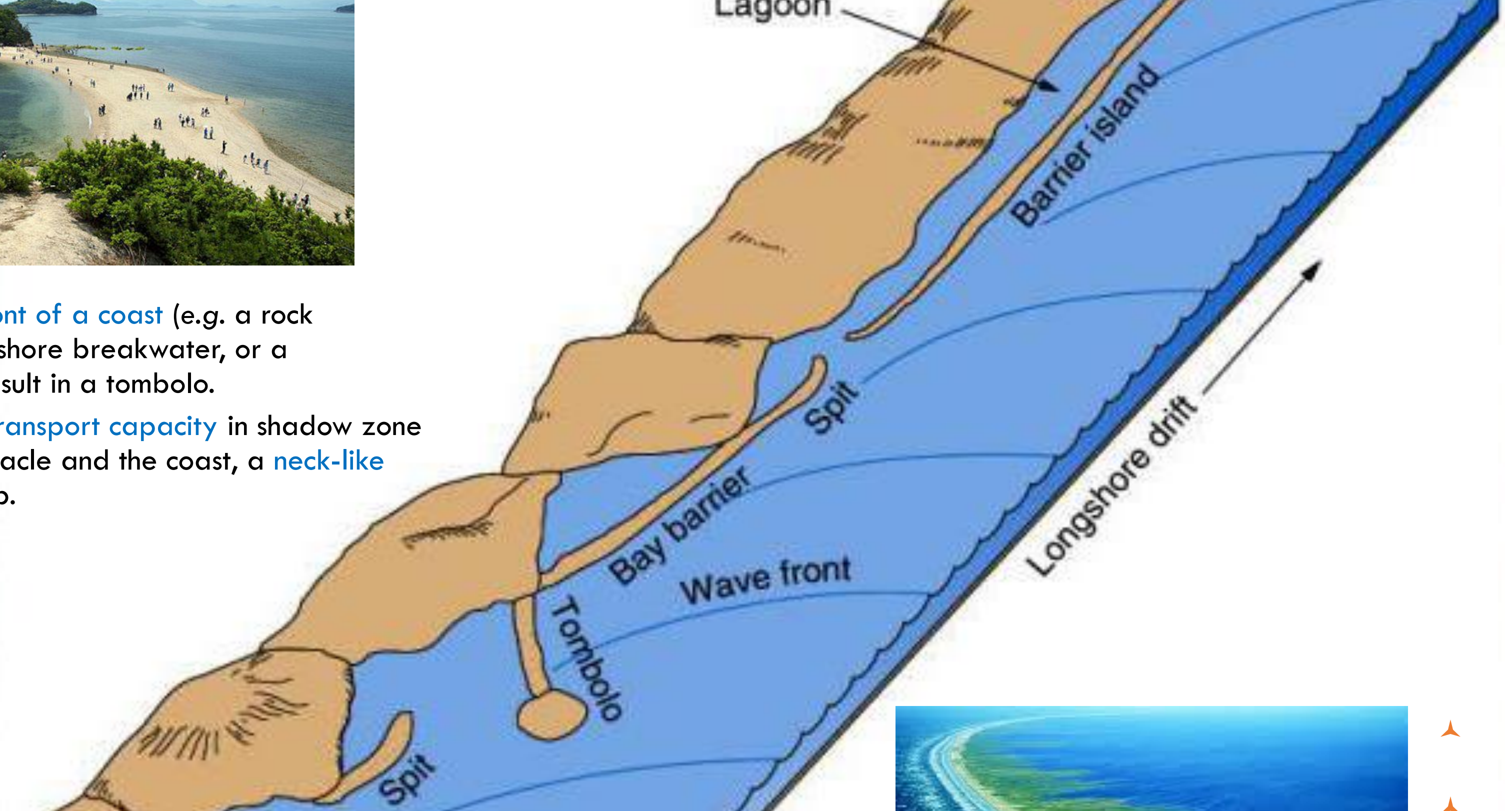
Bottom sediment (bed load) stirred up by the wave orbital motion is transported by the alongshore currents.

LONGSHORE TRANSPORTS



Typical Coastal Formations

- An obstacle in front of a coast (e.g. a rock formation, an offshore breakwater, or a shipwreck) can result in a tombolo.
- Due to reduced transport capacity in shadow zone between the obstacle and the coast, a neck-like shoal will develop.



- A spit is a coastal formation which points as a tongue into the sea.
- It is formed by a wave-driven current that transports sediment along a shore.
- Due to this longshore transport, the coast will be extended in the longshore direction where the shore abruptly ends.

- Barrier island is a bar essentially parallel to the shore and is detached from the mainland.
- The crest of which is above normal high water level.
- The barrier is formed at the edge of this foreshore where the waves break.

Measurement of Littoral Transport

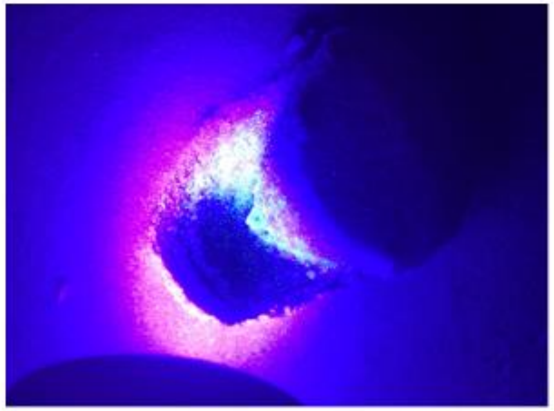
1. Tracer
2. Impoundment of sand at trapping structures
3. Acoustic/optical equipment

TRACER

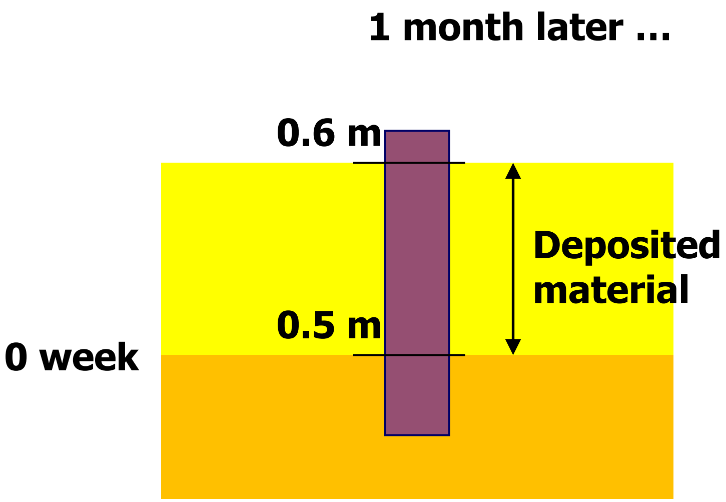
Measurement of Littoral Transport

- Measuring the differences in deposited volumes of sand
- Only for short-term tests, covering hours to weeks
- Risky : Tracers may be buried or lost
- Difficult measurement

Deployment of the tracer material on the Deer Island foreshore.

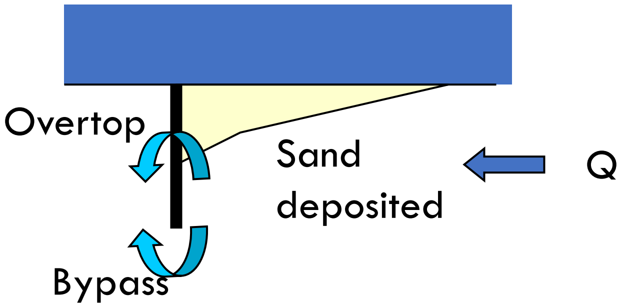


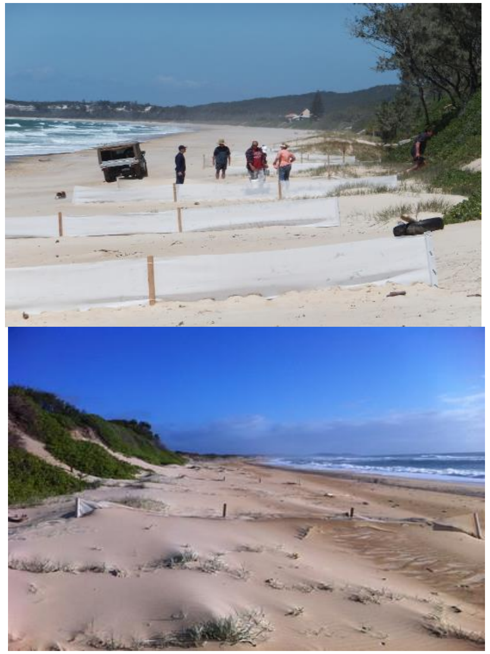
Detection of the tracer material in the field using a blue light / UV torch.

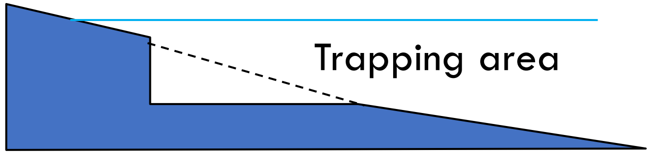


Impoundment of Sand at Trapping Structures

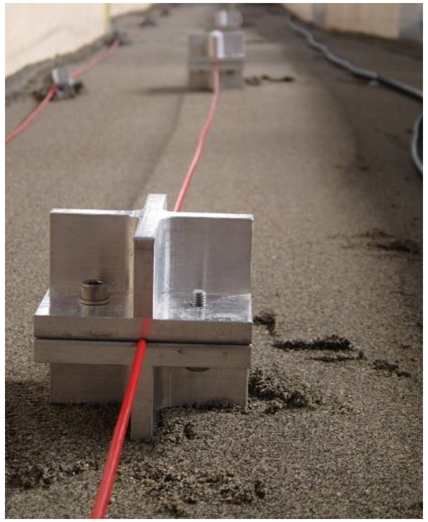
- Breakwater, groyne or large trapping areas dredged out is built.
- Extensive bathymetric surveys need to be made at frequent intervals.
- Results are quite inaccurate as sand may bypass by tidal currents or overtop (during major storm) the structures







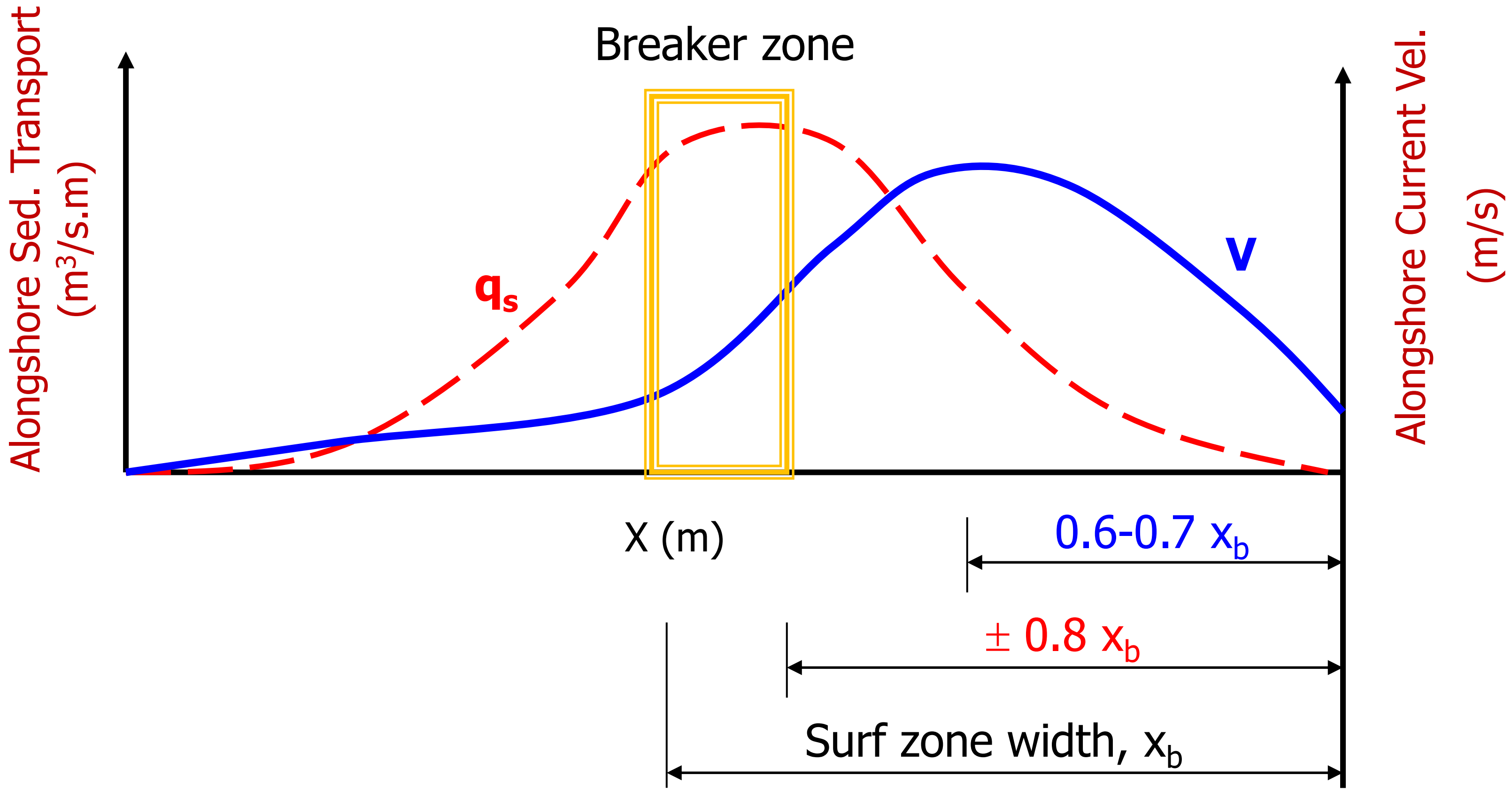
- To measure suspended sediment concentrations quite accurately
- Short-term tests
- Expensive method



CONCLUSION

The measurements of sediment transport rate are difficult and expensive yet contain large uncertainties.

Distribution of littoral Transport Within the Surf Zone



Total Sediment Transport in the surf zone, Q_s

$$Q_s = \frac{K(1+e)}{16\gamma^{\frac{1}{2}}(s-1)} . g^{\frac{1}{2}} H_b^{\frac{5}{2}} \sin 2\theta_b$$

(Unit: m^3/s)

K = f (tan α, γ, sediment characteristics, etc)

= 0.77 for $H_{b,rms}$

= 0.32 for $H_{b,s}$

e = Ratio of the deposited sediment

γ = Breaker index = H_b/d_b

s = Specific gravity = ρ_s/ρ

For a relatively **flat beach** with fine to medium quartz sand (0.2 – 0.6 mm):

- $1/(1+e) = 0.6$
- $\gamma = 0.8$
- $s = 2.65$

Total Sediment Transport in the surf zone, Q_s:

$$Q_s = \frac{K(1+e)}{16\gamma^{\frac{1}{2}}(s-1)} . g^{\frac{1}{2}} H_b^{\frac{5}{2}} \sin 2\theta_b$$

(Unit: m^3/s)

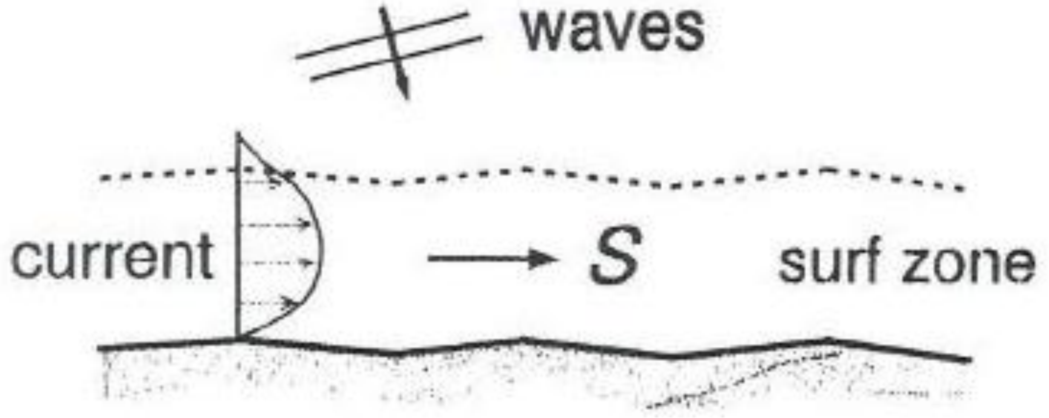
$$Q_s = 0.056 g^{\frac{1}{2}} H_{b,rms}^{\frac{5}{2}} . \sin 2\theta_b$$

$$Q_s = 0.024 g^{\frac{1}{2}} H_{b,s}^{\frac{5}{2}} . \sin 2\theta_b$$

CERC Formula

- Developed by Coastal Engineering Research Centre (CERC), US Army Corps of Engineers
- For straight sandy beach with a slope of 1:100 and sediment size of 200 micron, facing an open ocean (no mud or gravel)
- For wave generated current only with no tidal current effects
- Very simple (lack of 'physics')
- Alongshore sediment transport, S

$$S = VC$$



V = Longshore current velocity
C = The concentration of sand stirred up by waves and alongshore currents

Modified CERC Formula

US Army Corps of Engineers combined the longshore current formula of Longuet-Hinggins with some calibration constants leads to the following formula:

$$Q_s = AH_b{}^2 n_b c_b \sin\phi_b \cos\phi_b \rightarrow Q_s = \frac{1}{2} AH_b{}^2 n_b c_b \sin 2\phi_b$$

(Unit: m^3/s)

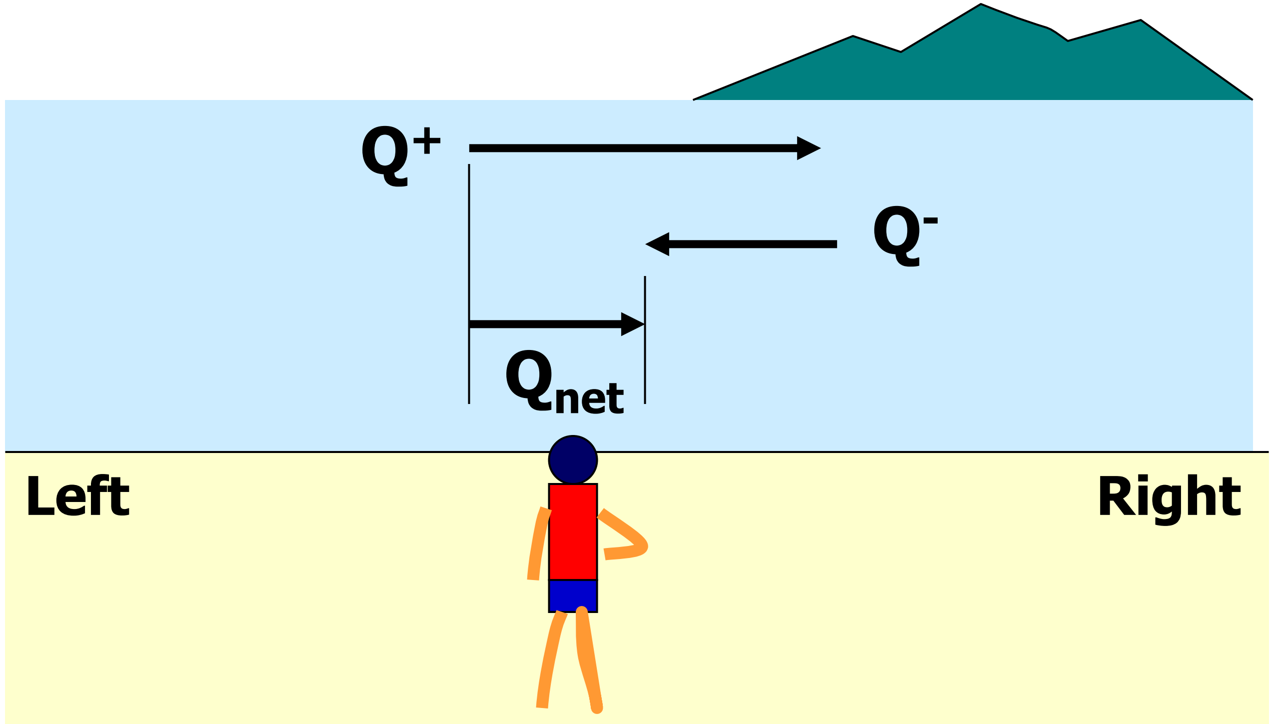
in which:

- H_b - breaker height
- c_b - wave-celerity at the breaker line
- ϕ_b - breaker angle
- n_b - wave number at breakerline (is approx. 1)

Shore Protection Manual (SPM)	A = 0.050
The Netherlands	A = 0.040
Kamphuis (1990)	A = 0.012
Reasonable range	A = 0.02 – 0.08

SEDIMENT TRANSPORT RATE & DIRECTION

Sediment transport from the LEFT sector



Sediment transport from the RIGHT section

Gross Sediment Transport, $Q_{gross} = Q^+ + Q^-$

Net Sediment Transport, $Q_{net} = Q^+ - Q^-$

If Q_{net} = +ve (left to right); Q_{net} = -ve (right to left)

PROBLEM

The table below shows the percentage occurrence of significant breaker heights and angles on a sandy coast. Estimate the littoral transport.

θ_b / H_b - m	-15^o	-10^o	-5^o	0	5^o	10^o	15^o
1	1	4	2	25	7	12	5
2		1	1	20	5	3	
3			1	3	3	1	
4				2	1		

LST WITHIN THE SURF ZONE

For a relatively **flat beach** with fine to medium quartz sand (0.2 – 0.6 mm):

- $1/(1+e) = 0.6$
- $\gamma = 0.8$
- $s = 2.65$

Total Sediment Transport in the surf zone, Q_s:

$$Q_s = \frac{K(1+e)}{16\gamma^{\frac{1}{2}}(s-1)} . g^{\frac{1}{2}} H_b^{\frac{5}{2}} \sin 2\theta_b$$

(Unit: m^3/s)

$$Q_s = 0.056 g^{\frac{1}{2}} H_{b,rms}^{\frac{5}{2}} . \sin 2\theta_b$$

$$Q_s = 0.024 g^{\frac{1}{2}} H_{b,s}^{\frac{5}{2}} . \sin 2\theta_b$$

SOLUTION

$$Q_s = 0.024 g^{\frac{1}{2}} H_{b,s}^{\frac{5}{2}} . \sin 2\theta_b$$

(Unit: m^3/s)

For practical units of m^3/year

$$Q_s = 0.024 \times 9.81^{\frac{1}{2}} \times 60 \times 60 \times 24 \times 365\ H_b^{5/2} \sin 2\theta_b$$

$$= 2.371 \times 10^6\ H_b^{5/2} \sin 2\theta_b \quad m^3/year$$

For each value in table 7-1 the annual transport rate will be

$$Q_s = 2.371 \times 10^4\ p\ H_b^{5/2} \sin 2\theta_b \quad m^3/year$$

where p is % occurrence of a given H_b, θ_b combination.

θ_b / H_b - m	-15^o	-10^o	-5^o	0	5^o	10^o	15^o
1	1	4	2	25	7	12	5
2		1	1	20	5	3	
3			1	3	3	1	
4				2	1		

SOLUTION

θ_b / H_b - m	-15^o	-10^o	-5^o	0	5^o	10^o	15^o
1	11.9	32.4	8.2	0	28.8	97.3	35.6
2		45.9	23.3	0	116.4	137.6	
3			64.2	0	192.5	126.4	
4				0	131.7		

$\Sigma Q_{s1} = 185.9\ (m^3/year) \times 10^3$ $\Sigma Q_{sr} = 866.3\ (m^3/year) \times 10^3$

updrift $Q_{sr} = 8.66 \times 10^5\ m^3/year$

downdrift $Q_{s1} = 1.86 \times 10^5\ m^3/year$

gross $Q_{sg} = (8.66 + 1.86) \times 10^5$

$= \underline{\underline{10.52 \times 10^5\ m^3/year}}$

net $Q_{sn} = (8.66 - 1.86) \times 10^5$

$= \underline{\underline{6.80 \times 10^5\ m^3/year}}$

Queen's Formula (Khamphuis, 1991)

Longshore sediment transport, Q_{LS} (m^3/yr):

$$Q_{LS} = 6.4 \times 10^4 H_{sb}^2 T_p^{1.5} (\tan\beta)^{0.75} D_{50}^{-0.25} (\sin 2\theta_b)^{0.6}$$

H_{sb} = Significant wave height at breaker point (m)
T_p = Peak period of the wave spectrum (s)
β = Beach slope
D_{50} = Median grain size (m)
a_b = Wave angle of breaker point

Valid for the following conditions:

- No tidal current is present
- Straight beach, no groyne fields or offshore breakwater present
- Plane beach, no complicated breaker-bar system

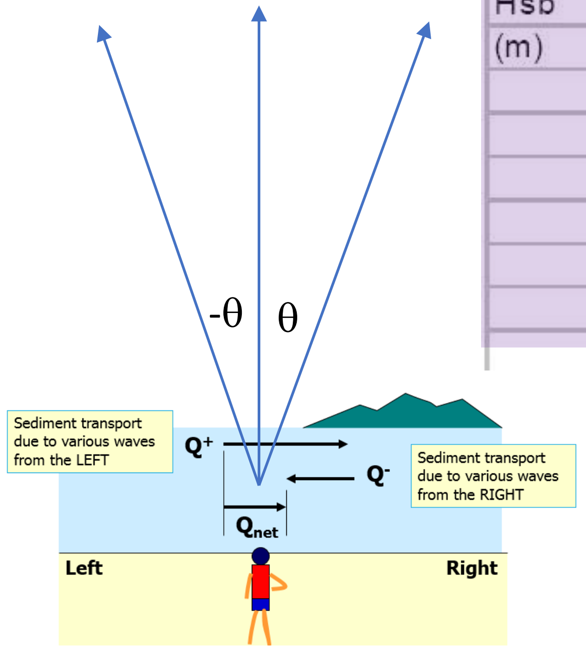
PROBLEM

Using the analyzed wave climate data given below, estimate the net longshore transport rate for a natural beach with a beach slope of 1 in 100 and D_{50} grain size of 0.4 mm, using the Queen's formula.

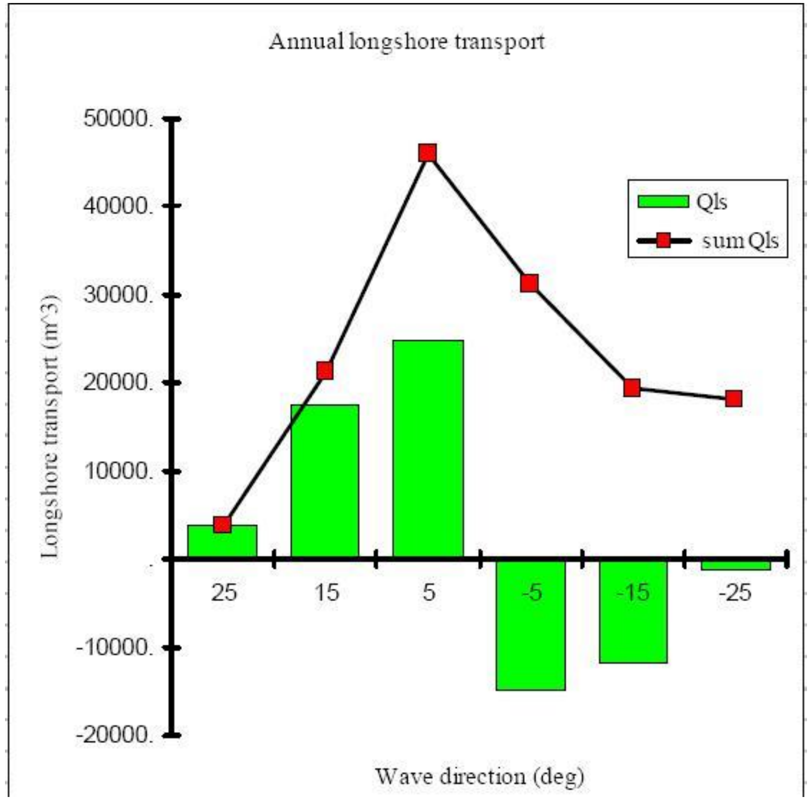
Hsb (m)	Tp (s)	Theta(b) (deg.)	Frequency (%)
0.8	4.5	25	5
1.2	5.5	15	10
1.5	6	5	15
1.3	6	-5	12
1.1	5.5	-15	8
0.5	4	-25	5

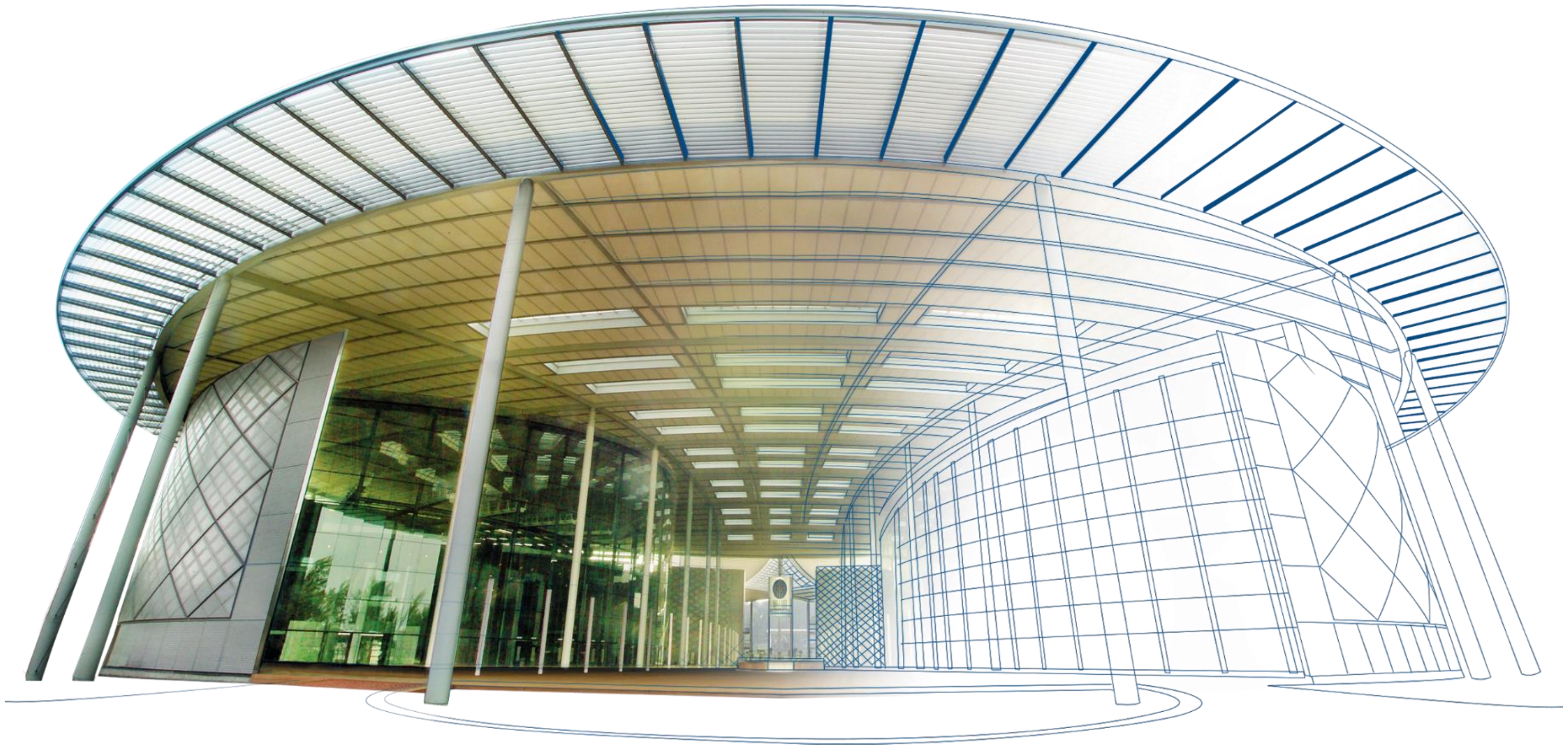
SOLUTION

$$Q_{LS} = 6.4 \times 10^4 H_{sb}^2 T_p^{1.5} (\tan\beta)^{0.75} D_{50}^{-0.25} (\sin 2\theta_b)^{0.6}$$



m	D50 (mm)				
0.01	0.4				
Hsb	Tp	Theta(b)	Frequency	Qls	sum Qls
(m)	(s)	(deg.)	(%)	(m^3/annum)	
0.8	4.5	25	5	3725.5	3725.5
1.2	5.5	15	10	17536.9	21262.4
1.5	6	5	15	24829.5	46091.9
1.3	6	-5	12	-14919.8	31172.2
1.1	5.5	-15	8	-11788.7	19383.4
0.5	4	-25	5	-1219.6	18163.8
			55	18163.8	





THANK YOU

Get Connected with

UTP
UNIVERSITI TEKNOLOGI PETRONAS

Scan the QR code or go to *https://bit.ly/2Ra323b*

www.utp.edu.my | UTPOfficial