morphological changes in the Scheldt estuary and its consequences on hydrodynamics

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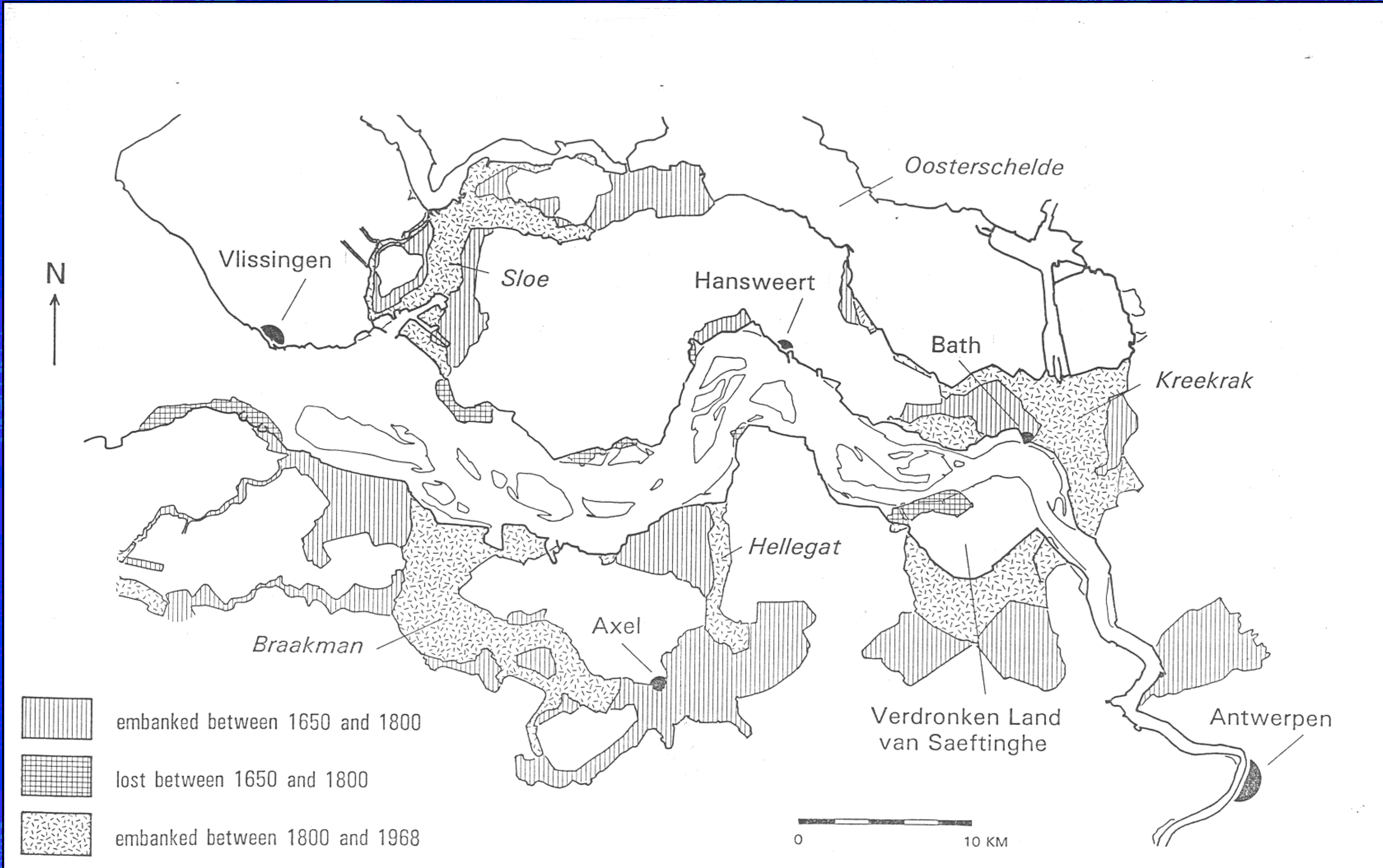
contents

- some historical development,
- development of primary tidal movement,
- sediment balance,
- morphodynamic processes, with emphasis:
  - tidal asymmetry, and
  - compound channels
- application to Scheldt estuary.

historical developments (1)

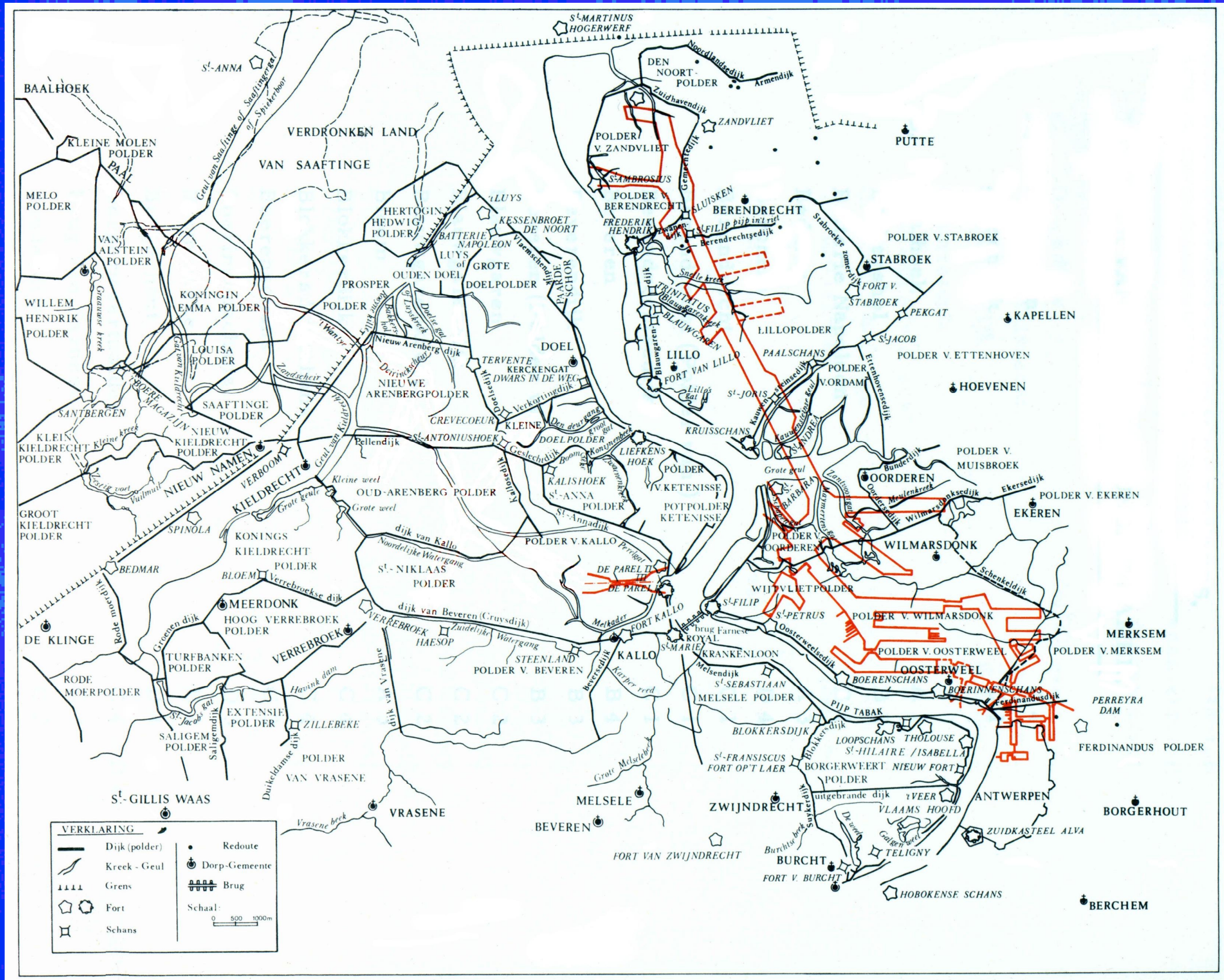
- reduction of Western Scheldt basin,
- reclamation along Sea Scheldt,
- controlled flood areas (GOG's),
- mean water levels

historical developments (2)



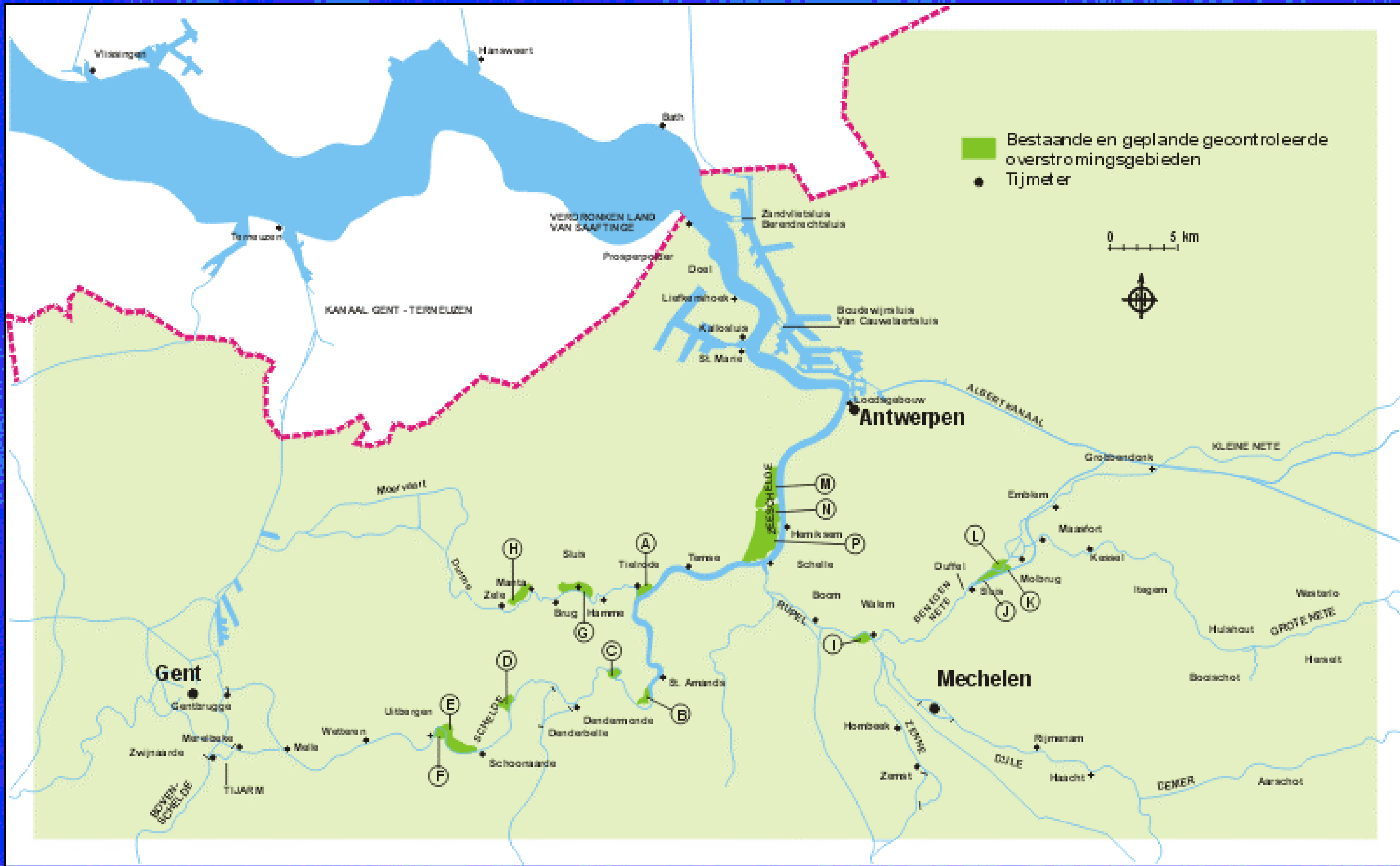
loss of tidal volume, after van der Spek, 1994

historical developments (3)



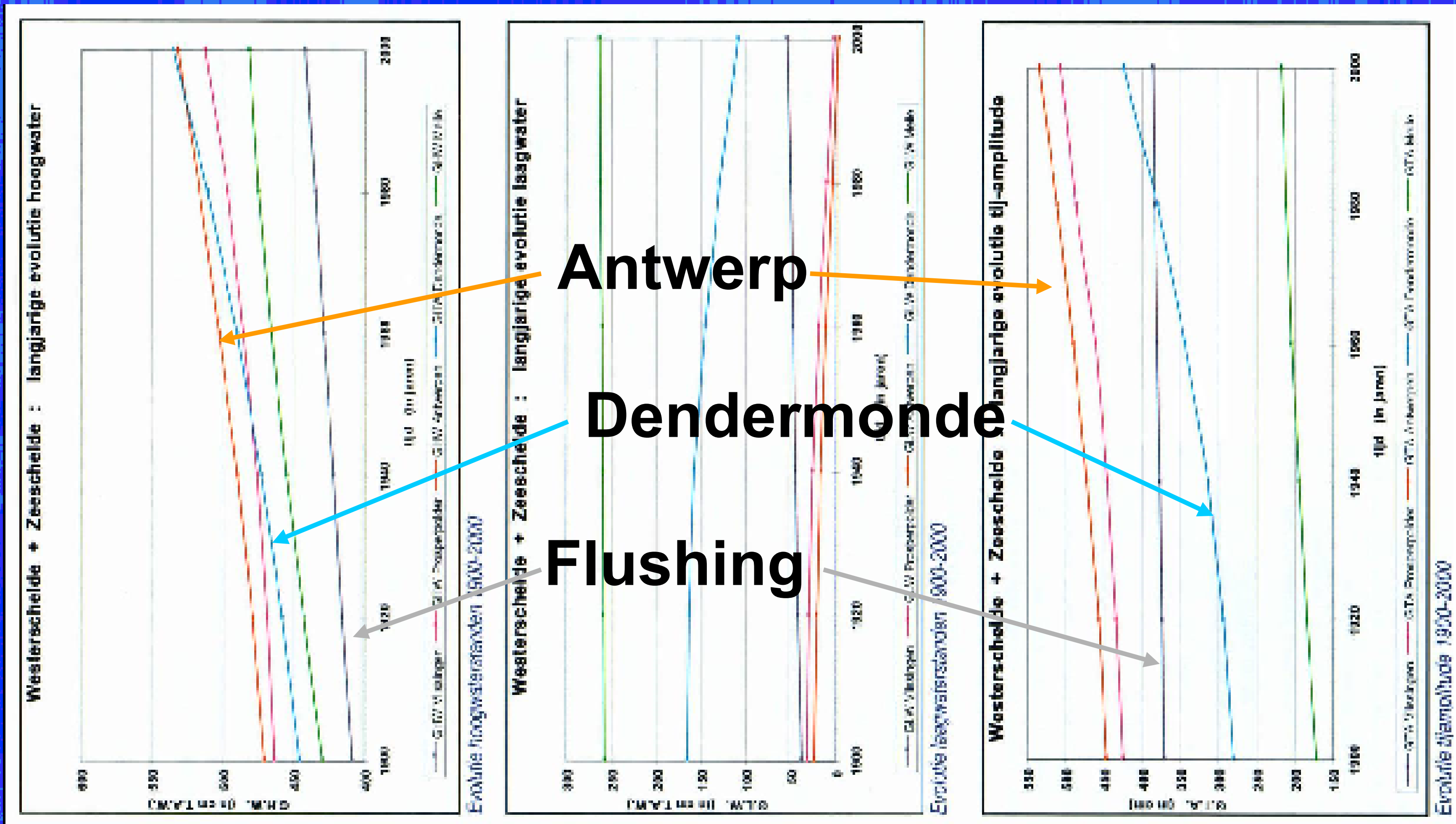
developments around Antwerp

historical developments (4)



controlled flood areas (GOG's) along Scheldt estuary (533 ha)

primary tidal movement (1)



evolution of HW **LW** **tidal amplitude since 1900**

primary tidal movement (2)

- considerable changes in tidal amplitude & water levels,
- also: increase in celerity tidal wave, hence a decrease in phase difference Flushing - Antwerp (next sheet),
- hence an increase in tidal volume (more efficient tidal filling),
- feed-back to morphological developments.

primary tidal movement (3)

station	time lag HW w.r.t. Flushing	time lag LW w.r.t. Flushing
Terneuzen	- 5 min.	- 2 min.
Bath	- 10 min. (~ 5 deg.)	- 11 min.

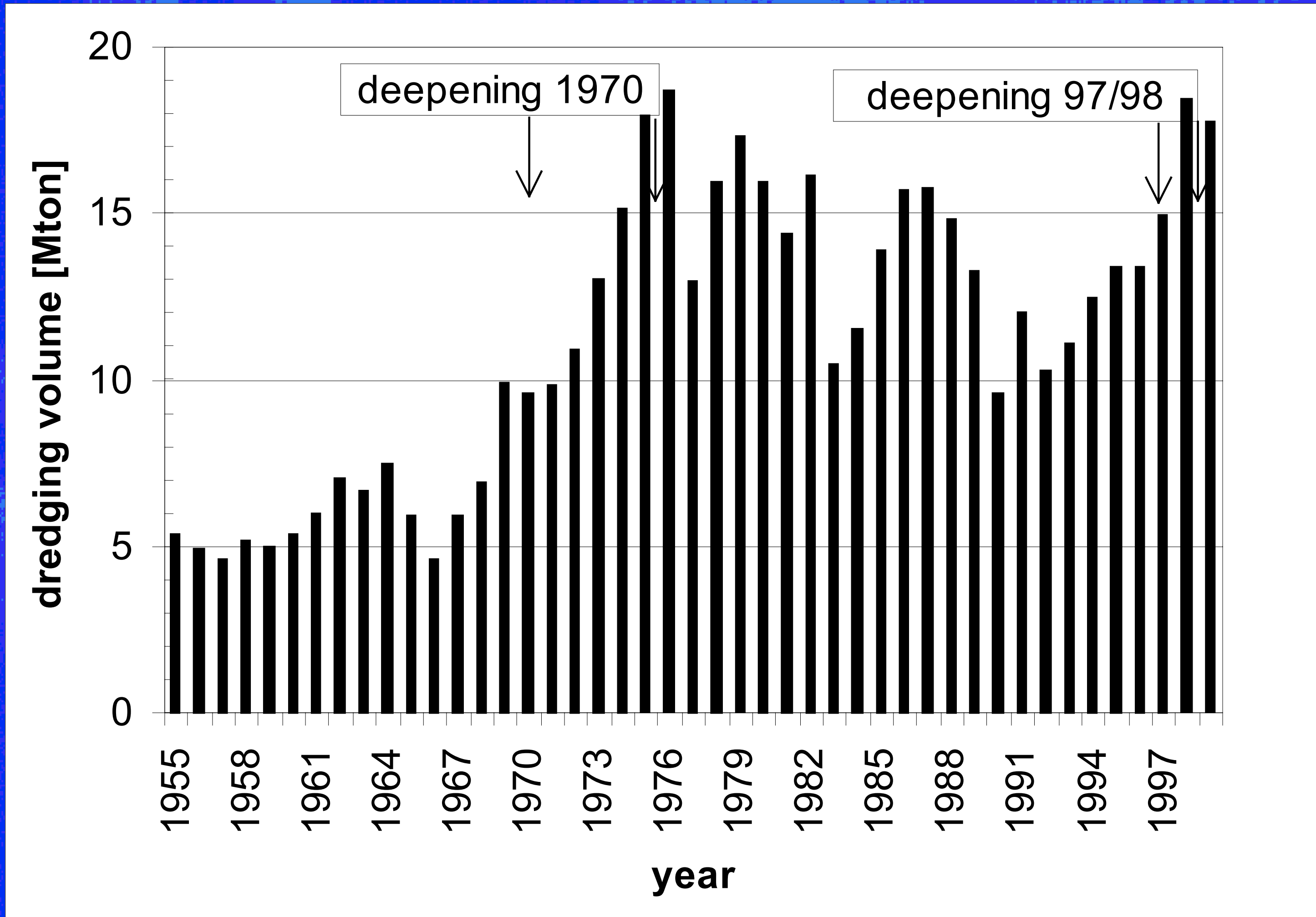
change in time lag water levels
wit respect to Flushing from 1960 to 1990
(MOVE report 1, 1997)

sediment balance (1)

- maintenance dredging:
  - Western Scheldt: about 13 Mton/yr
  - Sea Scheldt: about 2- 3 Mton/yr
- sand mining WS: about 3.5 Mton/yr
- sand import: about 1 Mton/yr (?)

so human interference is large

sediment balance (2)



maintenance dredging in Western Scheldt

morphodynamic processes

- tidal pumping,
- gravitational circulation,
- meandering thalweg,
- circulations in multiple channel system (ebb-flood channels),
- flooding and drying on intertidal areas,
- tidal asymmetry,
- compound channels.

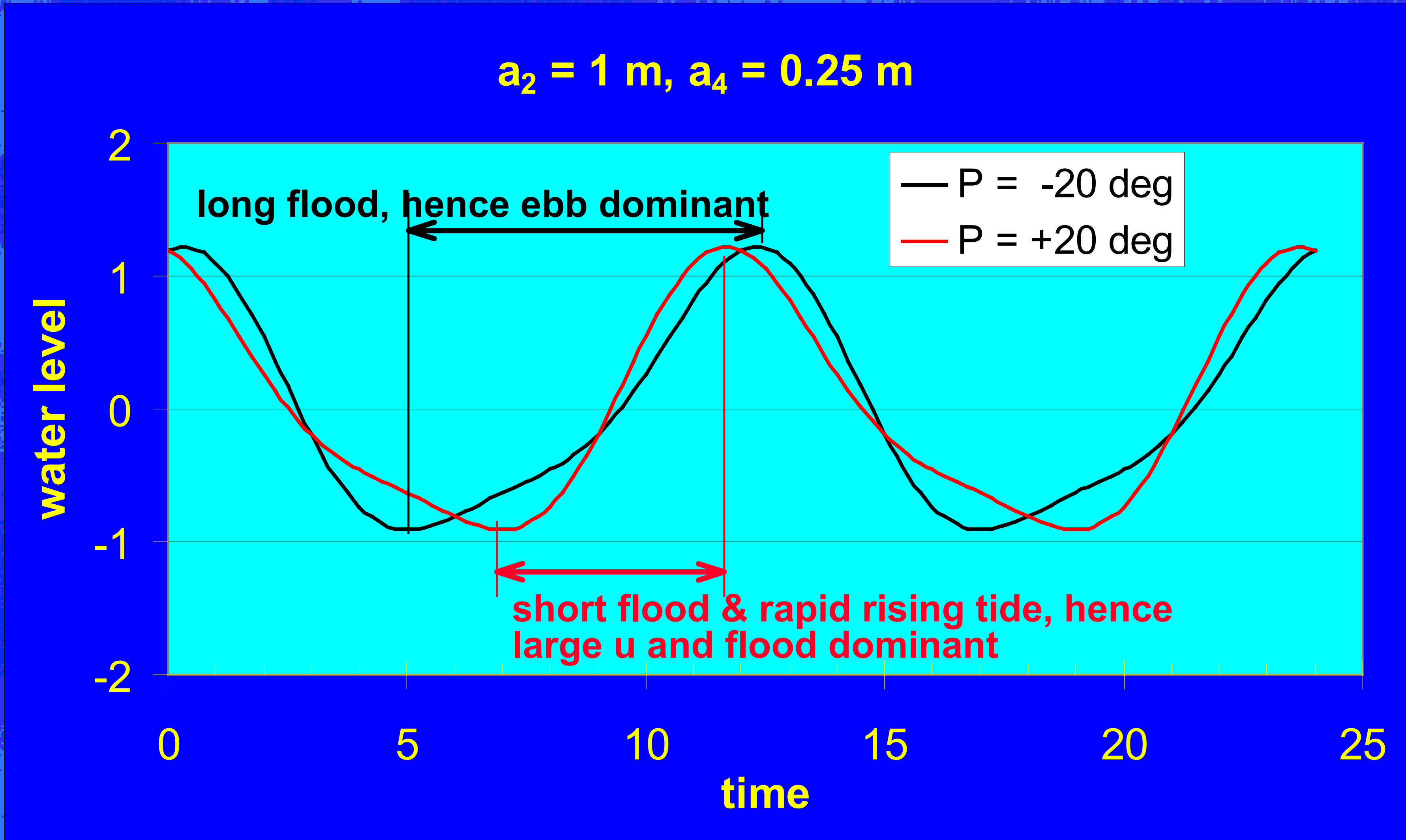
tidal asymmetry (1)

- overtides (e.g. M_4 vs M_2) because of non-linear processes (advection, friction):

$$\left(u_0 \cos(\omega t)\right)^2 = 0.5u_0^2\left[1+\cos(2\omega t)\right]$$

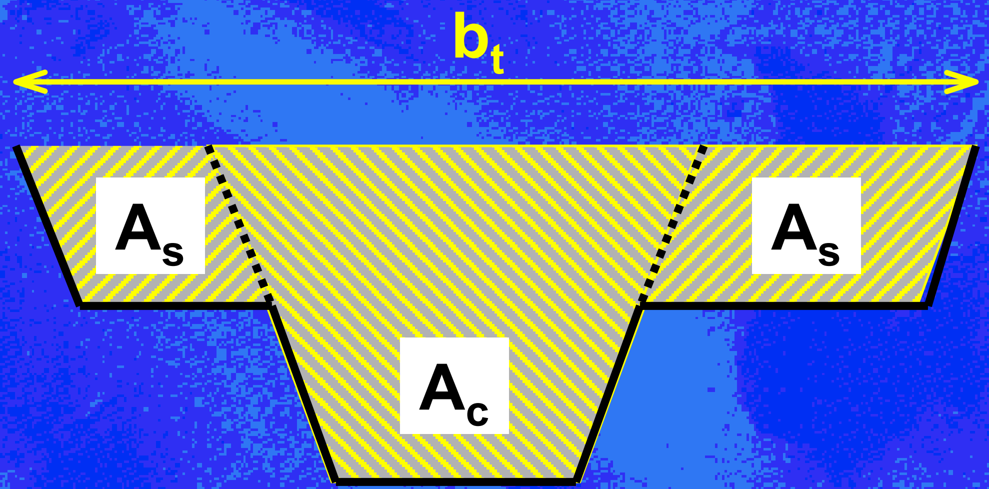
- relative amplitude ratio: $P = \left(2\varphi_2 - \varphi_4\right)_{II} - \left(2\varphi_2 - \varphi_4\right)_I$
- relative phase difference: $A = \left(\frac{a_4}{a_2}\right)_{II} \Big/ \left(\frac{a_4}{a_2}\right)_I$
- P > 0 $\Rightarrow$ flood dominant, P < 0 $\Rightarrow$ ebb dominant
- see example graphs next sheet
- for fine sediments: slack period

tidal asymmetry (2)



$$h = a_2 \cos\{\omega t\} + a_4 \cos\{2\omega (t-\Delta t)\}$$

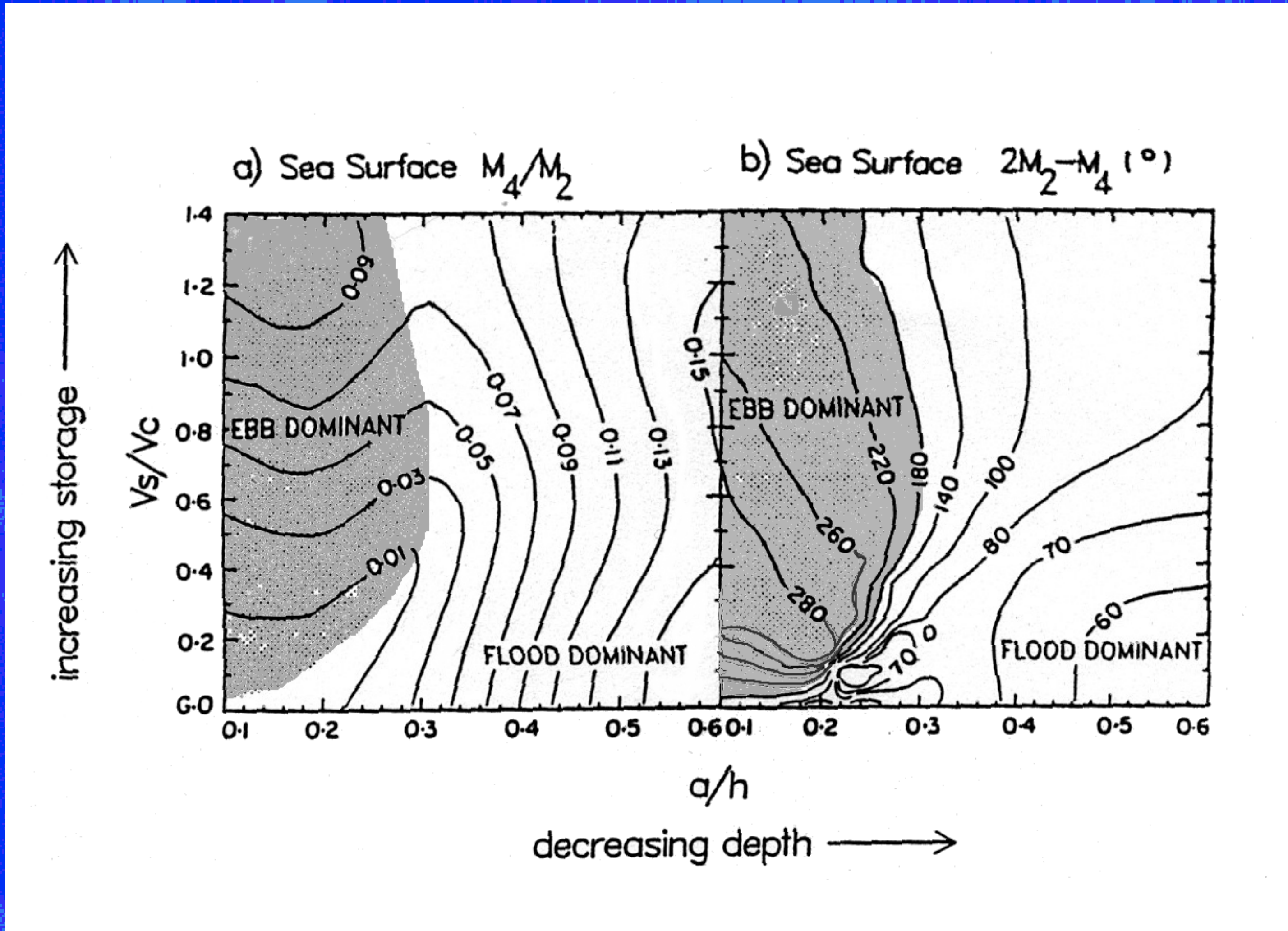
compound channels (1)



A_c (= V_c) = flow carrying cross section,
A_s (= V_s) = storage area, e.g. flood plains
b_t = total width

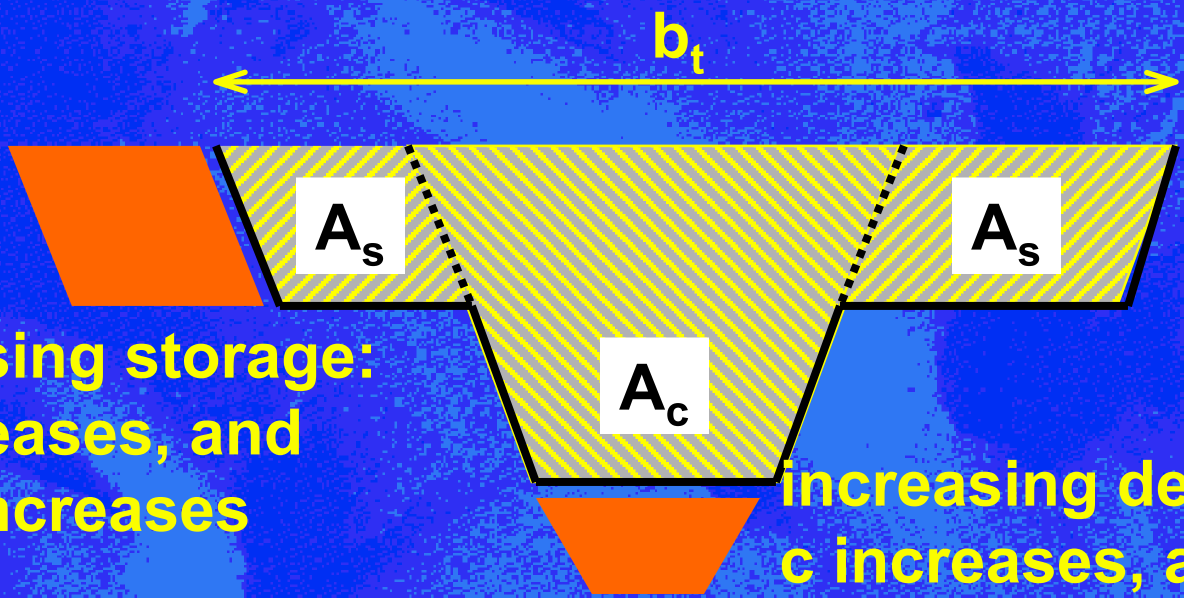
celerity tidal wave $c = \sqrt{A_c g / b_t}$

compound channels (2)



after Speer et al., 1991

compound channels (3)

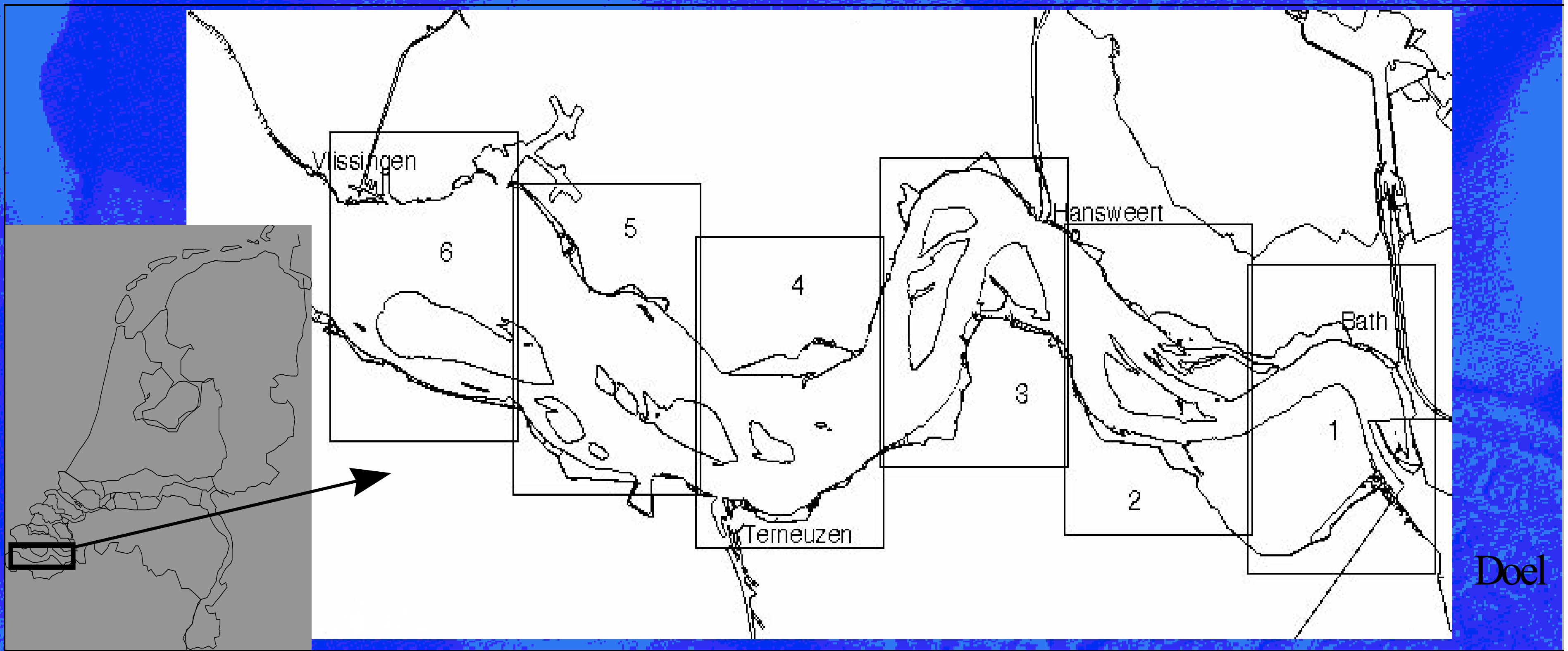


increasing storage:
c decreases, and
V_s/V_c increases

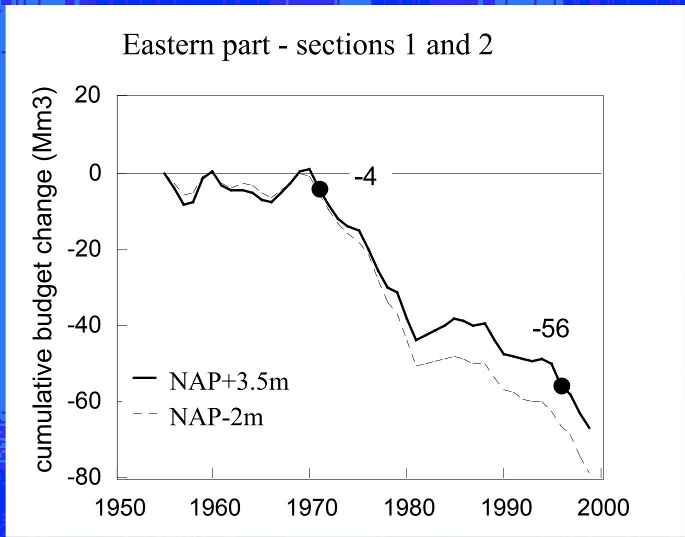
increasing depth:
c increases, and
a/h decreases

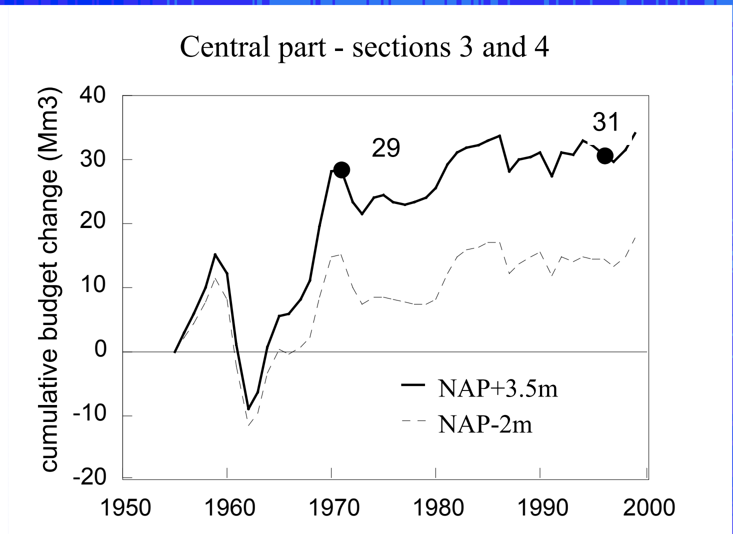
both changes lead to an increase in ebb-dominancy in tidal channel !!

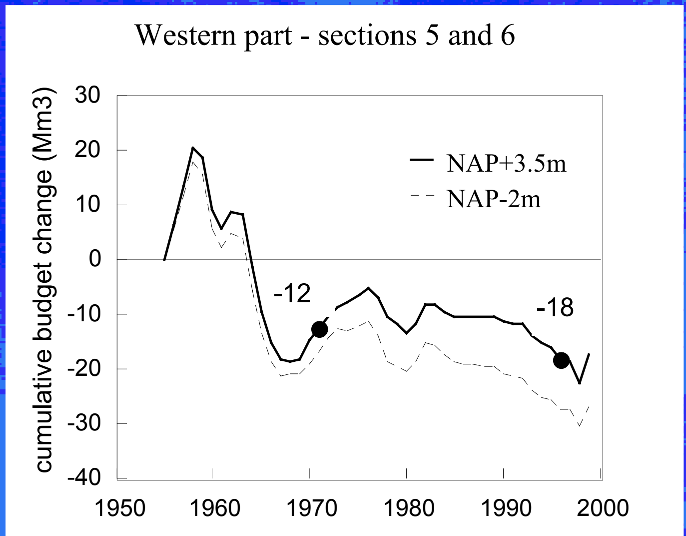
asymmetry in Western Scheldt (1)



asymmetry in Western Scheldt (2)



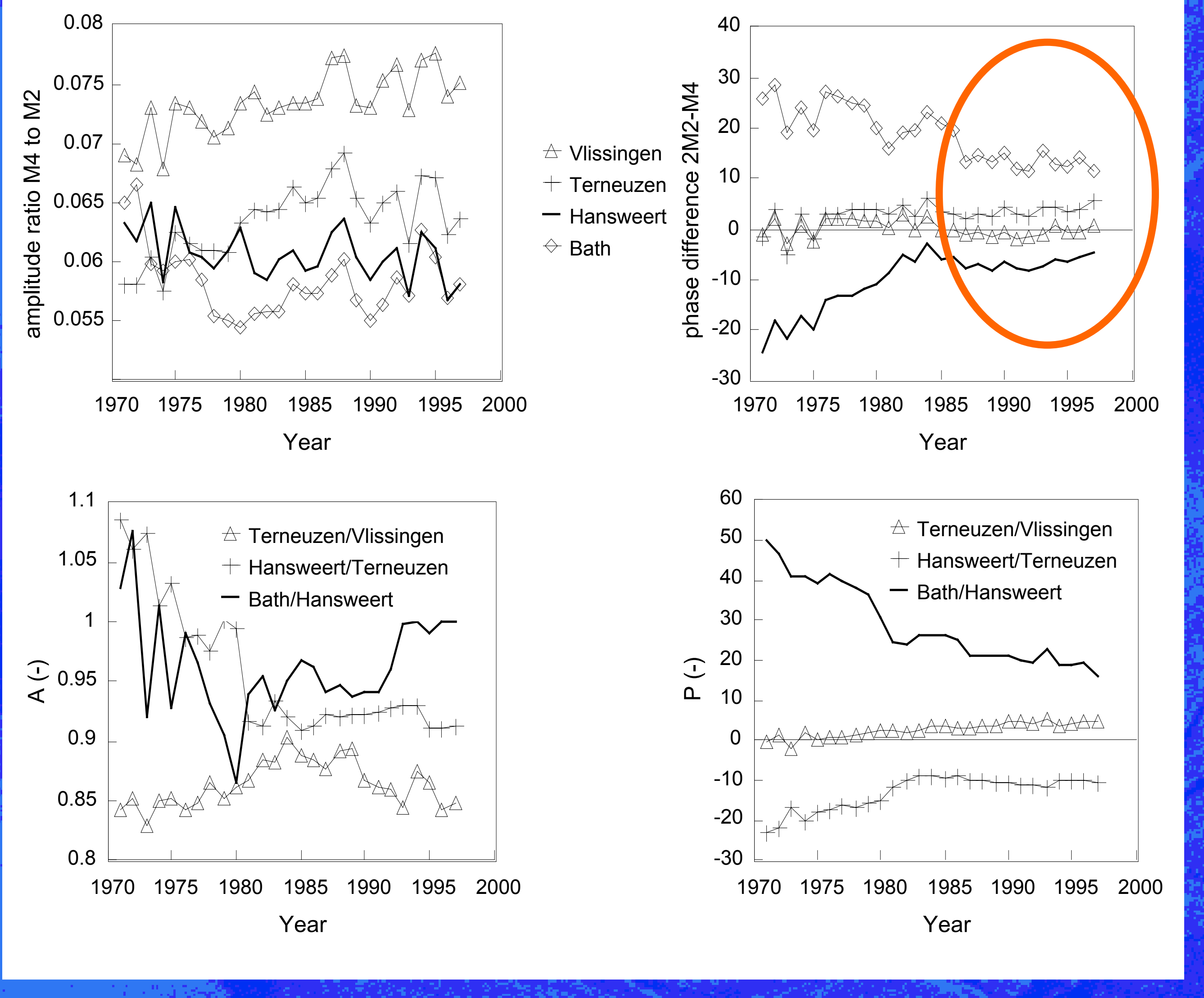




morphological development:

evolution of sediment volume in WS shows large erosion in eastern part and accretion in central part

asymmetry in Western Scheldt (3)

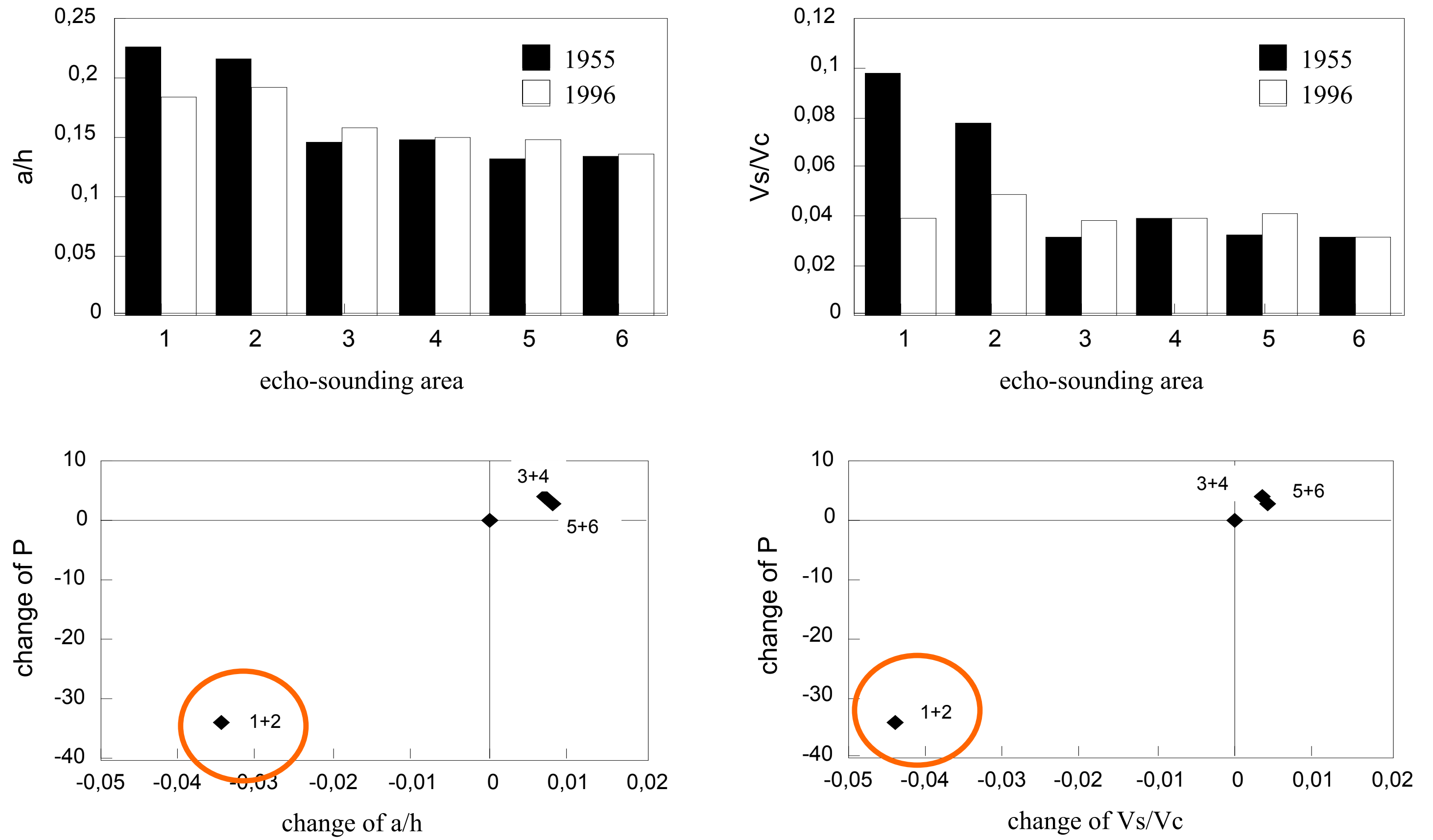


large changes in eastern part:

at Bath: less flood dom.

at Hansweert: less ebb dom.

asymmetry in Western Scheldt (4)



development in bathymetry (hypsometry) has strong effect on tidal asymmetry

conclusions (1)

- large natural and human-induced developments of Scheldt morphology,
- strong increase in high waters and tidal amplitude, probably as a result of widening and deepening of the channels,
- large-scale feed-back to morphological developments because of more efficient tidal filling (though changes in tidal volume could not be measured because of accuracy),
- historical morphological changes have affected tidal asymmetry strongly, and are reasonably understood,

conclusions (2)

- this does not imply that interaction tidal asymmetry - morphology is fully understood,
- in particular: sequence

  horizontal asymmetry ⇒

  vertical asymmetry ⇒

  residual flow

  not yet fully understood,
- however, analysis of tidal asymmetry is strong tool for sustainable management of the estuary:

developing the Scheldt estuary through sustainable management