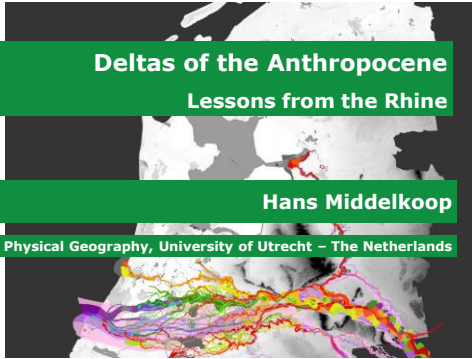
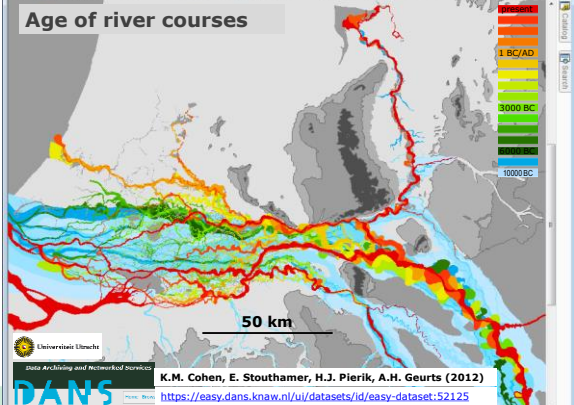


Department Physical Geography, University of Utrecht – The Netherlands

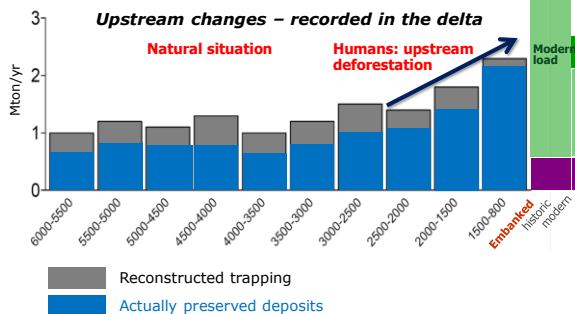


-



This geological cross-section illustrates the HST system from Rotterdam to Nijmegen. The vertical axis represents sea-level rise, ranging from -30 m to 10 m. The horizontal axis shows the distance from Rotterdam to Nijmegen, with a scale bar from 0 to 30 km. The diagram depicts various geological features and sedimentary layers, including the HST lagoon, TST estuary, and TST delta. Key features include the North Sea, HST barrier, and the buried paleovalley. The diagram also shows the tidal situation in the HST, with labels for tidal fresh waters, flood waters, and central drifts. The HST system is shown as a series of interconnected basins and channels, with the HST lagoon and TST estuary being the primary components. The TST delta is shown as a series of lobes extending from the TST estuary. The buried paleovalley is shown as a deep, narrow channel filled with sediment. The diagram is color-coded to show different sedimentary units, with green representing the HST lagoon, orange representing the TST estuary, and yellow representing the TST delta. The HST barrier is shown as a grey line separating the HST lagoon from the North Sea. The North Sea is shown as a grey area on the left. The HST system is shown as a series of interconnected basins and channels, with the HST lagoon and TST estuary being the primary components. The TST delta is shown as a series of lobes extending from the TST estuary. The buried paleovalley is shown as a deep, narrow channel filled with sediment. The diagram is color-coded to show different sedimentary units, with green representing the HST lagoon, orange representing the TST estuary, and yellow representing the TST delta. The HST barrier is shown as a grey line separating the HST lagoon from the North Sea. The North Sea is shown as a grey area on the left.

Historic load

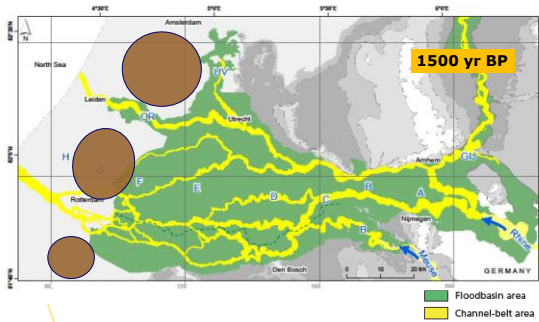


Holocene: Erkens & Cohen 2009
Modern: Ten Brinke 2000, Middelkoop et al. 2012

The map illustrates the geographical distribution of peat wetlands in the Netherlands, categorized into three types: **Peat wetland** (brown ovals), **Peat wetland** (green area), and **Peat wetland** (yellow area). The map also shows the **3500 yr BP** floodbasin area (green) and the **Channel-belt area** (yellow). Key locations marked include Amsterdam, Rotterdam, The Hague, and the North Sea. The Rhine and Meuse rivers are shown flowing into the North Sea. The legend at the bottom right identifies the floodbasin area (green) and the channel-belt area (yellow).

Erkens & Cohen 2009

Enhanced clay deposition from upstream



Humans in the delta

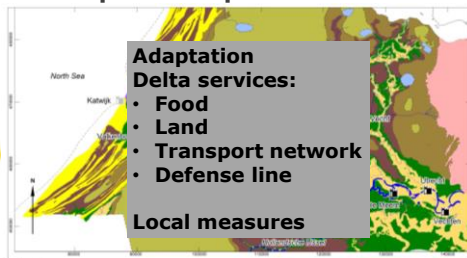
Prehistoric time
6000 – 2000 BP

Adaptation
Delta services:

- Food
- Land
- Transport network

Source: Arnoldussen & Van Zijverden, 2013

Adapted occupation: Roman Limes



Van Dinter et al., 2013

Land reclamation: drainage



Drainage: subsidence!

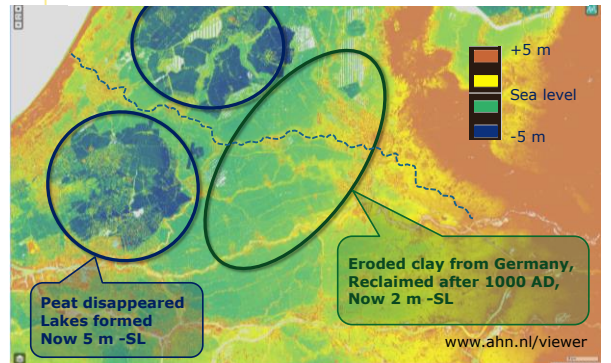
Peat mining, resulting in lakes

~1400 – 1800 AD

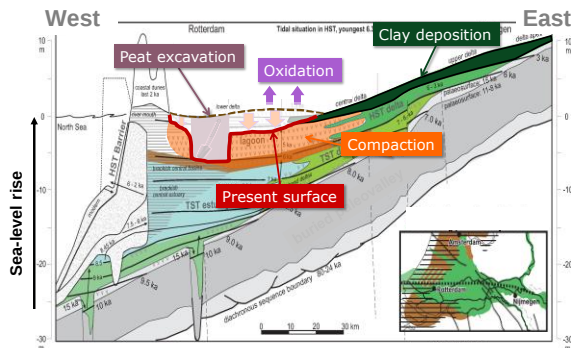
- Economic development
- Urban growth
- Need for fuel
- Over-exploitation



Lidar delta elevation: artificial surface



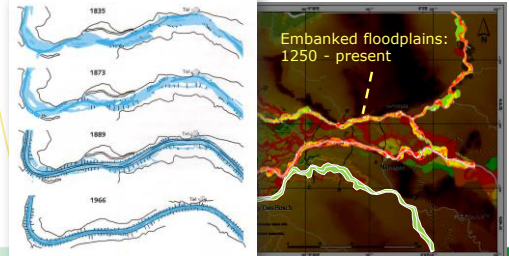
Longitudinal section delta wedge



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Embanked rivers in the delta

- Disruption of channel – floodplain connection
- No more natural avulsions
- Sediment deposition only along rivers and in estuary



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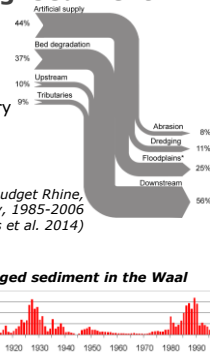
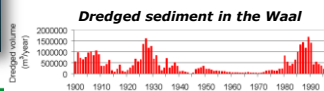
20th century engineering: sediment

- Upstream weirs trap sediment
- Excessive gravel dredging
- Result = reduced sediment delivery to the delta



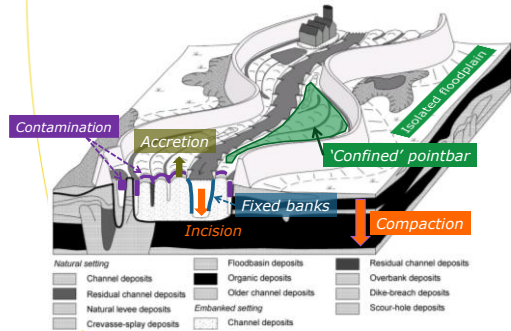
Weir at Iffesheim – Germany

Sand+gravel budget Rhine, mid-Germany, 1985-2006 (Frings et al. 2014)



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Man-made channel-belt architecture



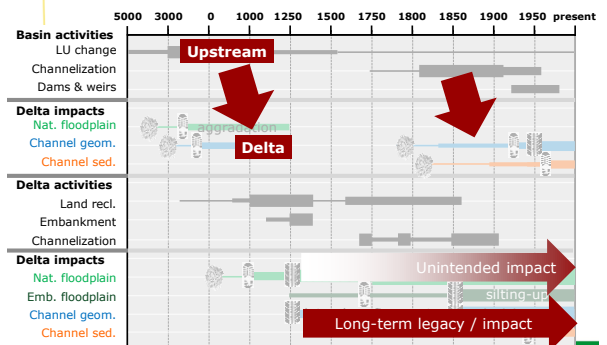
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Sediment dynamics

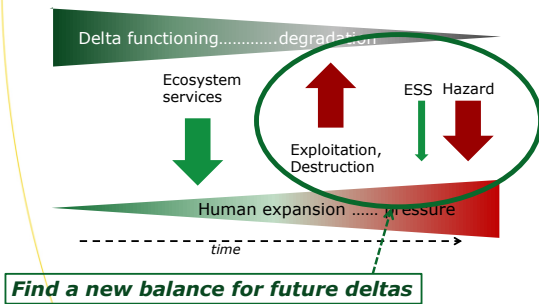
	Natural delta	Present Rhine
Total deposition suspension load	2 – 3 Mton/yr	2.5 Mton/yr
Main depo zones	Flood plain	Channel
Avulsions	Large-scale shifts in deposition areas	No change
Pacing in sediment dynamics	Channel belt life cycles Erosion, deposition reworking	Flood pulses only
Residence/preservation	Downstream increase Half lives: $10^2 - 10^5$ yr	Waal before normalisation: ~90% reworked 'Reworking' to date: Floodplains = clay excavation Channels = dredging

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Impacts across scales



What happened – the challenge



Solutions? - Pilots in the Rhine delta



Scientific challenges

Understand the physical system:

- Causes and mechanisms underlying the problem
- Longer-term and larger-scale impacts of measures
- Options for sustainable restoration

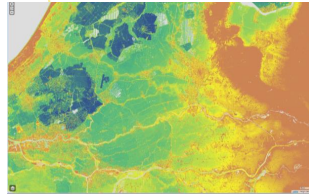
Understand the societal system:

- The problem is 'new' and not well incorporated in current governance / legislation
- Who has the problem, who caused it, who solves it?
- Conflicting interests across spatial scales and time
- Identification of adaptation capacity and options

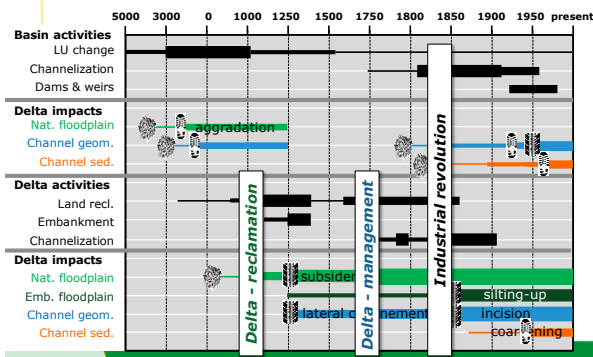
Integrate natural and human sciences
Apply this to deltas of the world



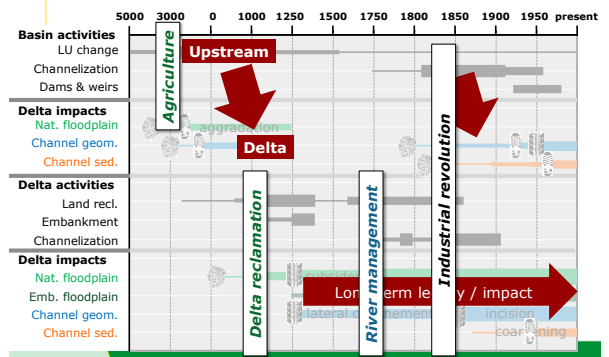
Thank you!



Synthesis – Rhine delta



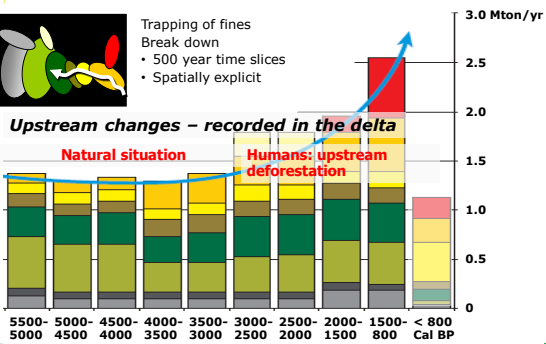
Synthesis – Rhine delta



High-stand sediment trapping



Trapping of fines
Break down
• 500 year time slices
• Spatially explicit



Erkens (2009)