3D modelling of Saltwater Intrusion into the Haringvliet to support Evidencebased Policy Development

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3D modelling of Saltwater Intrusion into the Haringvliet to support Evidence-based Policy Development

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Highlights

- We use measurements and model results to explore stratified salt intrusion into the Haringvliet estuary.
- Wind conditions – and especially specific wind directions – dominate distribution of salt water intrusion.
- 3D simulations are indispensable in policy decisions regarding putting the 'Kierbesluit' into practice.

Overview

The Haringvliet estuary was once a vibrant ecosystem with a diverse range of species that included migratory fish such as salmon and trout. The construction of the Haringvliet sluices in 1970 as part of the Delta works has severely limited the migration of fish from saltwater to freshwater for spawning. The resultant loss of biodiversity has been extensive, with many species of plants and animals disappearing (Winter et. al, 2001). In recent years, Rijkswaterstaat has implemented a testing campaign to open the sluices during floods with the aim of promoting international fish migration and improving biodiversity. However, this results in an increase in salinity in the western part of the Haringvliet. To address this, the Kierbesluit decree stipulates that fresh water intake must be guaranteed east of the (imaginary) Middelharnis-Spui line, limiting the opening of the sluices to times when the river discharge is large enough to push back any intruding salt. This study – commissioned by Rijkswaterstaat – aims to use a validated 3D model of saltwater intrusion in the Haringvliet estuary to support evidence-based policy development on the management of sluice openings.

We used the D-HYDRO (DFlow-FM) modelling software to simulate the complex process of salt dispersion unique to the Haringvliet, with its deep pits, channels and intertidal shoals. The model (Tiessen, et. Al, 2023) used and further developed, consists of a horizontal unstructured grid with typical cell side lengths of 60 m and a combination of z- and σ-layers in the vertical with a typical thickness of 0.125 m (the combination of which makes the model particularly suited to simulating stratified flows in estuaries). The model was calibrated and validated against observational data, including water level, salinity, and current velocity data collected by Rijkswaterstaat, and was able to describe situations of both open sluices where saline water flows into consecutive deep pits, and closed sluices where salt is (or is not) stirred up from those pits and transported due to wind forcing.

Our scenario analyses show that salt water intrusion may occur beyond the Middelharnis-Spui line under east and south-east wind conditions. We also found that a combination of floodgate discharges and wind are the main forcing mechanisms that control the salt transport and mixing in the Haringvliet. Finally, scenarios have been applied to investigate for what rates of seawater inflow and outward floodgate discharges dynamic equilibria can be reached between incoming (during flood) and outgoing (during ebb) salt mass. These insights are used to develop management strategies for the sluice system and understanding the response of other semi-enclosed estuaries where such interventions are considered (e.g. the Lauwersmeer).

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Closed sluices

By defining scenarios we explore the various measures and operations that put the Kierbesluit into practice. Model simulations have shown that horizontal recirculation in the system as a result of specific wind conditions is a determining factor for the risk of salt transport eastwards towards the Middelharnis-Spui line. This has also been shown previously in analyses of observations (Kranenburg et. Al, 2023). The inclination of the salt water interface in pits and the overflow of salt water between pits during such wind conditions are key processes. See Fig. 1 for an example of eastern winds leading to eastern directed flow in the main channels, inducing inclination of the salt water interface.

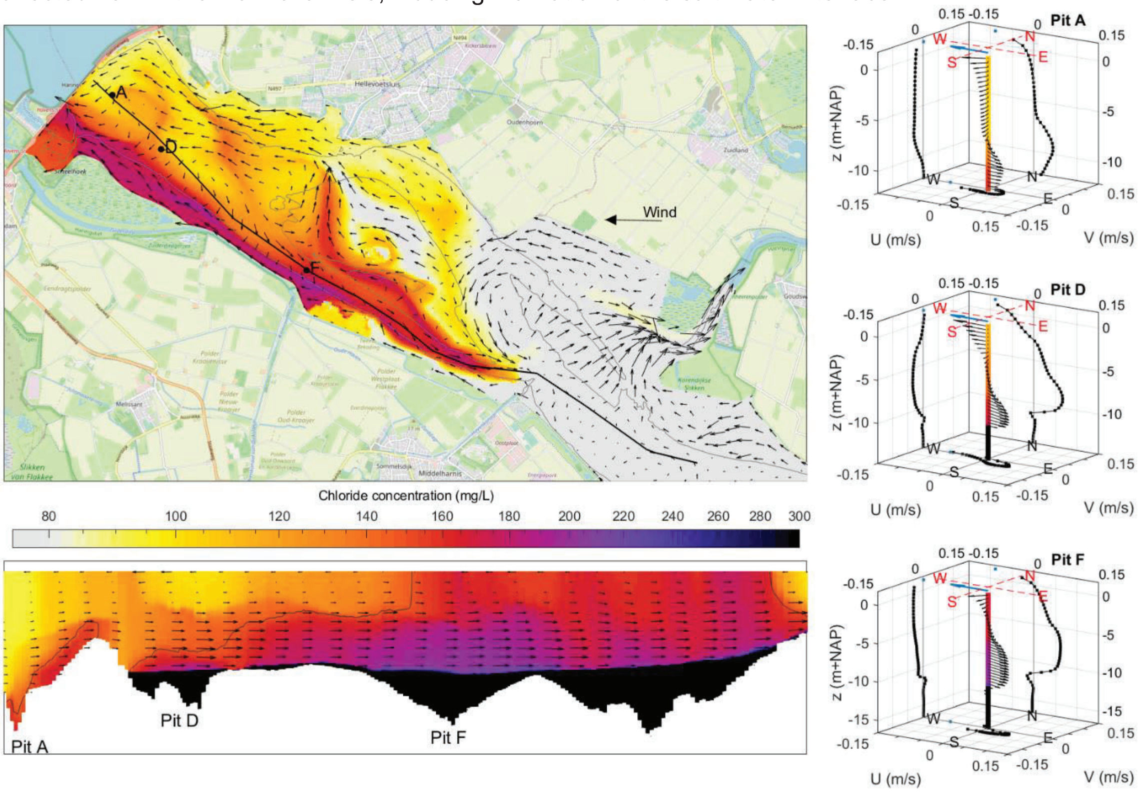

Fig. 1: Snapshot in time of wind driven circulation with closed sluices. Top left: mean chloride concentration and mean velocity in arrows in the part of the water column above -4m+NAP. Bottom left: cross section of chloride concentrations and velocities along Pits A, D and F. The location of the cross section is indicated in the top left plot with the black line. Right: vertical velocity profiles of flow in designated locations, with chloride concentration in the coloured dots.

Open sluices

Measures to push back the salt towards the sluices or to contain the salt in the pits are examined. The challenge is to find a dynamic equilibrium between incoming (during flood) and outgoing (during ebb) salt mass, see Fig. 2 for an example of influx of salt water during a period with open sluices.

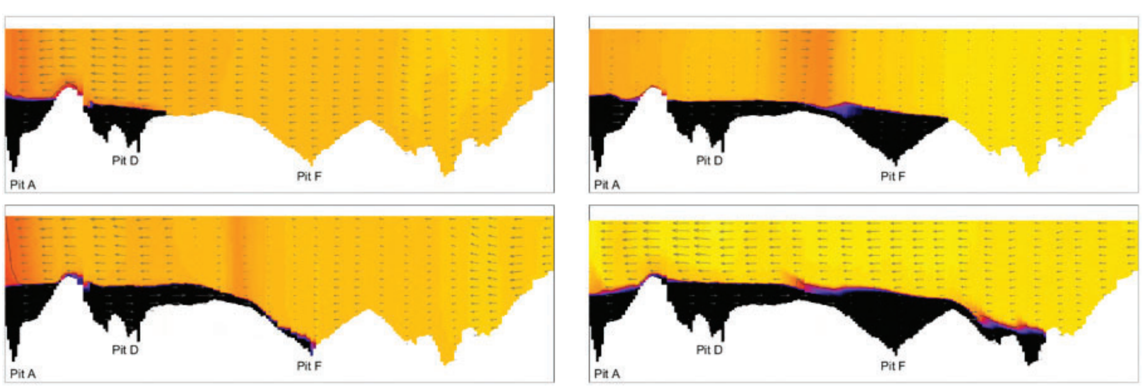

Fig. 2: Snapshots in time of saline water (black) entering the Haringvliet, during a period with open sluices during both flood and ebb flow. The location of the cross section is indicated in the top left plot in Fig. 1.