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ESTUARINE SENSITIVITY TO NATURE-BASED SALT INTRUSION MITIGATION MEASURES

Gijs G. Hendrickx, Delft University of Technology, g.g.hendrickx@tudelft.nl
José A. A. Antolínez, Delft University of Technology, j.a.a.antolinez@tudelft.nl
Peter M. J. Herman, Delft University of Technology / Deltares, peter.herman@deltares.nl
Stefan G. J. Aarninkhof, Delft University of Technology, s.g.j.aarninkhof@tudelft.nl

INTRODUCTION
All around the world, deltas are among the most densely populated and heavily utilised regions, where crucial functions, such as freshwater availability and safety against flooding, strongly relate to the natural dynamics of the system. Therefore, a thorough understanding of the estuarine system is crucial, especially when developing nature-based solutions for safeguarding these essential functions for today's society as well as future generations.

METHOD
To better understand the effect of different estuarine parameters on salt intrusion, an extensive sensitivity analysis has been executed based on an idealised estuary layout. The idealised estuary is parametrically designed using thirteen parameters that represent both boundary conditions and geometric features, such as river discharge and water depth. Subsequently, the Delft3D Flexible Mesh (DFM) model has been used to determine the salt intrusion, allowing the exploration of a wide range of estuary layouts.

To constrain the high computational costs of this exploratory study, adaptive sampling based on machine learning has been used such that samples in the input space are selected to maximise the expected explained entropy of the output space. In consequence, the selection of samples in the input space that is run with the DFM is based on the system's response, i.e. the salt intrusion.

At last, the data is post-processed by (1) fitting a regression model to gain insight into the sensitivity of the salt intrusion length to the various input parameters by analysing the regression coefficients; and (2) training a neural network that provides a quick, computationally cheap model that allows for exploring the whole input space. This easy-accessible neural network is open-access (Hendrickx, 2022) and a web-API is coupled to this neural network to enable low-key access to the model (Figure 1).

RESULTS: SENSITIVITY ANALYSIS
The sensitivity analysis shows a major dependence of the salt intrusion length on the river discharge and water depth, in line with previous studies. In addition, increasing the width of the tidal flats and reducing the width of the channel reduce salt intrusion, indicating that the enhancement of tidal flats is a potential nature-based solution to mitigate salt intrusion. Conversely, increasing the bottom friction seems to have limited impact on the salt intrusion length, although one would expect that the resulting vertical mixing induced by the bottom shear stress would have a larger impact.

Furthermore, a strong multivariate dependence of the salt intrusion length to a subset of input parameters due to nonlinear interactions has been found. Thus, in different estuarine configurations, different subsets of input parameters become dominant factors in determining the salt intrusion length. To grasp these nonlinearities in an accessible and efficient analysis framework, the aforementioned neural network has been trained (see *Method*).

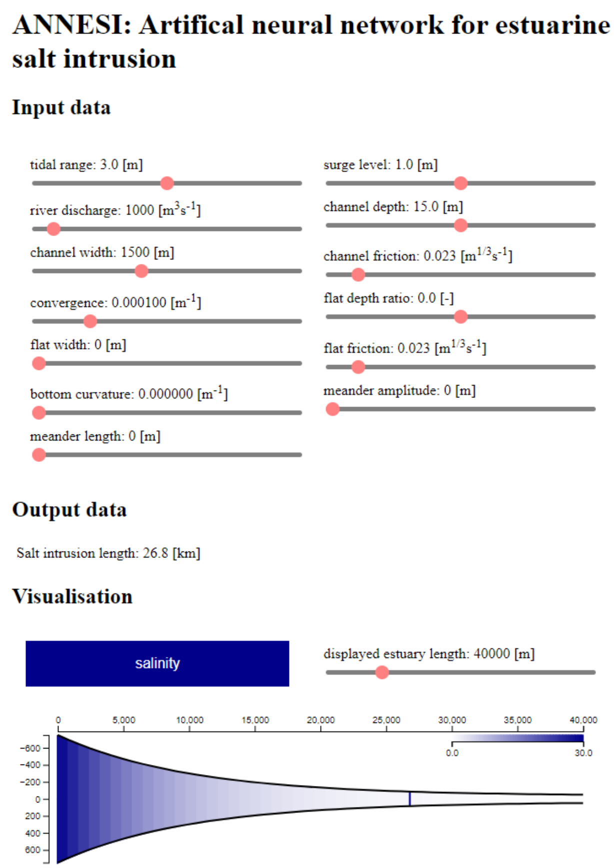

Figure 1 - Snap-shot of the web-API providing an easy-to-use interface of the neural network.

NATURE-BASED SOLUTION: SHALLOWING
Based on the sensitivity analysis and literature, a nature-based solution to mitigate salt intrusion in the Port of Rotterdam has been investigated (Iglesias, 2022). This investigation addressed what shallowing the New Waterway would mean for the stakeholders in the area. Here, the stakeholders were represented by two water-intake points, and one terminal of the Port of Rotterdam

relatively far landwards (namely the Koole Terminal). The hypothesis that shallowing would be beneficial for the water-intake points by reducing the salt intrusion length but disadvantageous for the port by limiting the vessel's draught was tested. The salt intrusion was determined using a hydrodynamic model of the Port of Rotterdam (OSR-model), and the port logistics were simulated using OpenTNSim (Bakker et al., *in prep.*).

Results show that reducing the water depth from 16.4 to 14.5 m has negligible effects on the port logistics, while substantially reducing the hindrance of the salt intrusion events at the water intakes (Figure 2). Nevertheless, further reducing the water depth would lead to exponential growth in the waiting time of vessels. These results highlight the importance of an integral evaluation of multivariate effects and interests related to nature-based solutions to mitigate salt intrusion. Although this case study was very much simplified compared to the real configuration of the Port of Rotterdam, its results are conceptually illustrative of the possibilities of nature-based solutions to mitigate salt intrusion.

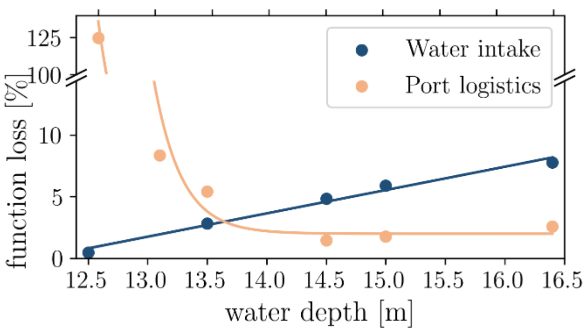

Figure 2 - Stakeholder function loss (y-axis) due to changes in water depth (x-axis). Water intake: days per year salinity exceeds the safety threshold (150 g Cl^{-} m^{-3}); port logistics: vessel waiting time as percentage of its maximum allowable waiting time (11 hours). (Data from Iglesias, 2022.)

REFERENCES

Bakker, van der Werff, de Jong, and van Koningsveld. (*in prep.*). An agent-based port accessibility model driven by real hydrodynamics: an AIS-based validation for the Port of Rotterdam.

Hendrickx. (2022). ANNESI: An open-source artificial neural network for estuarine salt intrusion. *4TU.ResearchData*. Software. DOI:10.4121/19307693.

Iglesias. (2022). *A systematic tool for the assessment of nature-based solutions to mitigate salt intrusion*. MSc thesis, Delft University of Technology.