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Using an idealized network model as the physical module for a salt intrusion serious game

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Introduction

Salt intrusion is a growing problem in many deltas around the world. During periods with low river discharges, salinity upstream in a delta increases and affects freshwater availability, ecology, and other delta functions. For example, in the Rhine-Meuse estuary (the Netherlands), brackish water can reach drinking water intakes about 40 km from the estuary mouth during droughts. Salt intrusion is likely to become more severe in the context of climate change, as a result of sea level rise and a lower river discharge during droughts.

The challenges with salt intrusion for the Netherlands are addressed in the Salti Solutions research program. Within this program the Delta Management Game offers an interactive environment where policy-making stakeholders can experience salt intrusion management and experiment with adaptation and mitigation strategies in the Rhine-Meuse estuary. As a serious game, the goal is for players to *"learn by taking actions and by experiencing their effects through feedback mechanisms that are deliberately built into and around the game"* (Mayer, 2009, p. 825).

A particular design challenge for serious games is simplifying the environmental system and sufficiently representing the relevant physics, while offering exploratory and experimentation through (near-)instant, interactive feedback. The physical module for salt intrusion in the Delta Management Game should be able to deal with, among others, changes in bathymetry (e.g. depth or width of waterways, adding a sill) of the estuary in the game, while offering relatively quick feedback.

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Here, we addressed this challenge by developing a game demonstrator as a proof of concept, which uses the idealized network model of the Rhine-Meuse estuary and simplifies the estuary geometry to a regular grid.

Idealized network model

The physical module in the serious game is an idealized network model, which builds forth on the work of Biemond et al. (2023). This model solves the dominant physical balances for flow and salinity in an estuarine channel network. For the Rhine-Meuse estuary, 21 channels and 13 junctions are used.

Preliminary analysis has indicated that water levels, flow and salinity in the Rhine-Meuse estuary can to a satisfactory level be reproduced by the model. The runtime of the model is in the order of one second for a day simulation time, which meets the requirement of near-instant feedback required for the serious game. Moreover, the model setup allows for adjustments to geometry and forcing conditions.

Abstracting the Rhine-Meuse estuary

To use the idealized network model in the game, the physical system and its behaviour should be abstracted in such a way that it balances its playability with its representation of reality (Harteveld, 2011). For this, we looked to abstract the Rhine-Meuse estuary by transforming the relevant waterways captured in the network model to a regular grid. This way, players can apply adaptation or mitigation measures on different grid cells, while showing effects on the estuary system scale. To develop the demonstrator of the Delta Management Game, we extended the physical board used in The Virtual River Game (den Haan et al., 2020), which is a 143-cell hexagonal grid. We drew an equal number of polygons on a map of the Rhine-Meuse estuary to include the sea boundary at the Rotterdam Waterway, the Haringvliet, the river boundary to include the Hollandse IJssel, and downstream sections of the Lek, Waal and Meuse. We shaped the polygons in such a way that these aligned with either waterways or land and that each polygon shares the same neighbours of the hexagonal grid. This way, each polygon covering real-world coordinates has a corresponding hexagon in game-world coordinates. We subsequently mapped in which polygons the waterways in the network model are located and drew a corresponding network of waterways on the hexagonal grid. To do so, network junctions in specific polygons were positioned as midpoints of the corresponding hexagon. As a last step, we reprojected the real-world coordinates of the network model output locations of each waterway to the waterways drawn on the hexagonal grid. The result is an abstracted, grid-based representation of the Rhine-Meuse estuary, where chloride concentration output of the network model is transformed to game-world coordinates (Figure 1).

Integration

We present a proof of concept of the use of an idealized network model of the Rhine-Meuse estuary to include salt intrusion modelling in the Delta Management Game. The presented approach can be used with a different salt intrusion models and different grid layouts, making it suitable for game design and adaptable for finding the balance between the systems representation of reality and its playability.

Next steps

A next step in the development of the Delta Management Game is to evaluate the developed proof of concept with policy-making stakeholders. The evaluation goal is, among others, to determine a suitable grid layout that represents relevant estuary locations and offers in-game measures on these locations that adequately represent real-world policy options.

Another improvement is the inclusion of the recently released updated climate change scenarios and associated Rhine and Meuse discharge scenarios (Buitink et al., 2023), to include future climatic conditions in the game.

The proof of concept furthermore includes the working output interface between the model and game, visualizing chloride concentrations on the grid-based estuary. Further development of the grid as input to the network model is possible, e.g. that by changing the geometry of a grid cell the bathymetry of the corresponding waterway in the model is updated.

Finally, additional physical processes like storm surges can be added to the idealized network model.

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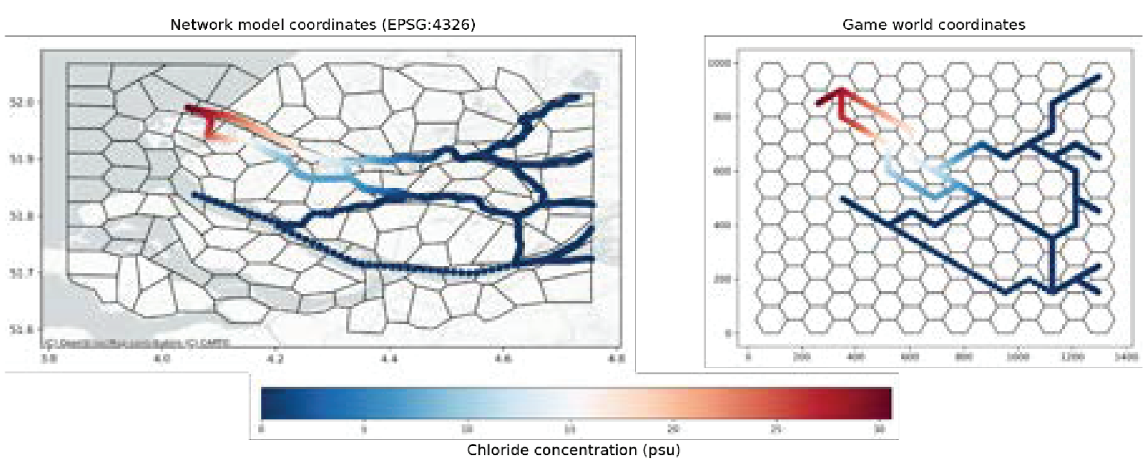

Figure 1. Chloride concentration values on one timestep at the Rhine-Meuse estuary network model output locations (left) and at their reprojected location on the hexagon grid-based game world (right).