



EGUsphere, referee comment RC1
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Comment on egusphere-2022-142

Anonymous Referee #1

Referee comment on "Modelling the impact of anthropogenic measures on saltwater intrusion in the Weser estuary" by Pia Kolb et al., EGU sphere,
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The manuscript presents results from a modelling study of how changes in bathymetry of the Weser estuary affect the salinity intrusion. The study evaluates four time periods and calibrates them separately to account for variability in data availability. The main result is that dredging has resulted in a modest increase in the salinity intrusion, but this is only apparent using comparable forcing conditions because the mean change in salinity intrusion is much less than the natural variability with river discharge.

Overall the manuscript is well written and contains appropriate citations. Separately calibrating the different time periods is a distinctive approach which makes sense if there are data available to support the model evaluation, but that may not always be the case. The results presented here are broadly consistent with similar studies, and it could be a valuable contribution to the literature on the topic of anthropogenic modification of estuaries. However, I have a couple of general comments on how the analysis could be clarified to examine the physical processes more substantively and make the results more broadly applicable.

- The approach of calibrating to multiple time periods results in different optimal friction parameters among the different periods. This is attributed to differences in along-estuary depth variability (Table 1), which is explained by differences in bathymetric data resolution. The differences among most of the years are quite modest (5-20%), and are much smaller than the "additional roughness" imposed to represent tidal damping (line 258) or the variation in the effective roughness (Table 3). Additional

analysis explaining this conclusion would be helpful. In particular, it's not clear how the variation in bathymetric data density (e.g., soundings from hydrographic surveys?) compares with the model grid resolution. The grid resolution is 50-250 m, and so the bathymetric data resolution would have to be lower than this to influence model results. It's also not clear whether the difference in effective roughness may instead be due to differences in sub-grid scale roughness, which is not represented directly in the grid regardless of the bathymetric survey density. The model uses a roughness parameter based on sediment characteristics (grain size), and this does not change among the years. There are certainly examples from other modified estuaries where changes in bed sediment characteristics directly affect the friction, and that would be a different mechanism than is suggested here. For example, fine sediment accumulation in the Ems reduced friction and amplified the tides (Winterwerp et al 2013), or removal of sand waves by dredging in the Columbia reduced friction and amplified the tides (Jay et al. 2011). Perhaps it is impossible to isolate the reason for the differences in calibration values among the periods, but a more thorough explanation of the proposed mechanism and assessment of alternative explanations would build confidence in the results. See below for related comments.

- Part of the analysis examines differences (which are small) in the exponential regression between salinity intrusion and river discharge. This has been done in previous studies, and presumably is meant to be linked with analytical expressions for salinity vs discharge based on different assumptions about the dominant salt flux mechanisms. For example, salt flux dominated by the estuarine exchange scales with $Q^{-1/3}$, whereas tidally dominated salt flux scales as Q^{-1} . Explanation of this in the text would help readers understand the motivation for examining the regressions. However, the idealized analytical frameworks don't necessarily apply to real estuaries with spatially variable bathymetry, and instead estuary shape can have a dominant influence on observed relationships with discharge. This makes it hard to link temporal variation in the exponent for Q to changes in salt flux mechanisms. Instead, it would be better to calculate salt fluxes directly in the model and quantify changes (if any) in the decomposed components (estuarine exchange vs tidal correlations). This could be particularly interesting for this system, as there is the suggestion that tidal processes are important for salt flux because the results mention that the salinity intrusion is greater during spring tides than neap tides. It likely also would require examination of the changes in tidal amplitude over time to aid in interpretation of the salinity dynamics. A previous study of the Hudson is referenced on changes in salt flux processes with dredging, but the Hudson is dominated by the estuarine exchange and not tidal salt flux. Deepening and reduction in friction with dredging generally increase tidal amplitude, which would tend to decrease the estuarine exchange flow but increase the tidal salt flux. The Weser could be an interesting and contrasting example to the previous studies as how the salinity intrusion responds to dredging in a tidally dominated system. It would be nice to see this aspect of the results explored in greater detail.

Additional, specific comments follow with line numbers.

[25] Perhaps “masked” rather than “outweighed” (unless there was a shift in the mean discharge that was compensating for the shift in the mean depth).

[48] “other drivers” of what?

[76] “Ems has successively become finer...” In the other cases (Hudson, Seine, Danshui), were changes in bed composition coincident with the changes in depth? If not, is there still need to recalibrate, presuming similar numerical grid resolution and bathymetric data (sounding density, which is the often case in systems with a long history of navigational use)? Could this include changes in bedforms with dredging (removal of sand waves)?

[78] The bathymetric data resolution has to be considered in conjunction with the bathymetry data and the model grid resolution. Is the assumption here that the grid resolution exceeds the bathymetry data resolution? Is that often the case? It seems like it would not be the case in most estuaries with data collected for navigational charts.

[80] “different calibrations...” Does this presume similar availability of observations (water level, salinity) for calibration? Is there a tradeoff where diminished availability of historical data to use in the calibration would degrade the confidence in the historical calibration to the point that it would be better to use the more robust and data-constrained modern calibration?

[89] “impact is larger...” impact of what?

[92] Are "anthropogenic measures" just dredging or does it include other modifications (shoreline reclamation/hardening, discharge regulation, etc)?

[123] "between Brake and Bremen..." Note distances from the mouth for context and to help with the interpretation of Fig 2.

[143] What are the values of the horizontal viscosity and diffusivity?

[164] "data were scarcer..." Can this be quantified by comparing the bathymetric sounding data density (if that's what was used) to the grid resolution for the different eras? It could be a range if spatially variable, but would be helpful for context particularly given the importance placed on the data density.

[165] "the resolution of small-scale features such as bedforms in the different model topographies is not directly comparable". It seems like most bedforms aren't represented in the model grid with resolution of 50-250 m. For example, sand waves that are 1 m high and a steepness of 0.05 have a wavelength of 20 m. Perhaps clarify what is meant by "small-scale" and what types/sizes of bedforms?

[177] "Minor differences in depth variation do also occur between the individual model topographies" What does this mean?

[178] “the different resolutions of the underlying bathymetric data.” As noted above, it'd be useful to quantify this directly and report it relative to the model grid resolution.

[Table 1] The listed differences in roughness do not seem large – it seems like other than 2012 in the seaward section the values are essentially the same. Are the differences in roughness significant compared to the other sources of uncertainty in the data and model? This could be tested by smoothing the bathymetry to be comparable to previous years and seeing how the calibration changes.

[191] It seems like changes in the sediment composition could be a bigger effect than the small changes in the variance at the grid scale listed in Table 1. If dredging is removing sand waves or leading to finer bed sediment with increased deposition, then this would reduce the bottom roughness. Perhaps that has the same effect as is being implied by the changes in grid-scale roughness? The grid scale roughness of $\sim 0.15\text{-}0.3\text{m}$ variability over 50 m (Table 1) gives a bedform steepness of $0.003\text{-}0.006$, which is much less steep than the sand waves and other bedforms that would be subgrid scale and could dominate the roughness represented by z_0 .

[212] Did you quantify the "error" in the neural network salinity by comparing the model results to the observations? That could provide some context for interpreting the uncertainty in the periods without observations at the boundary.

[245] “An increase in potential energy anomaly indicates an increase in stratification...” Clarify that this assumes a constant water level η .

[257] Is the additional roughness spatially varying? Is it related to a physical parameter (e.g., mean depth, grain size, or distance along the channel, etc) or is it allowed to vary independently?

[260] Are the dunes and ripples not represented in the model grid because the van Rijn formulation does not match up with observed ripple size/steepness? Or is it that the grain size in the model does not match that in the real world? Please clarify.

[270] Omission of tributaries is mentioned as a reason for additional roughness, but is the presence/absence of tributaries different among the cases? If so, it seems that would not explain differences in the calibration among the periods?

[295] The result that the salinity intrusion is farther landward during spring tides seems notable, in that in many other systems where salinity has shifted with deepening the gravitational circulation dominates the landward salt flux, so salinity intrusion is maximum during neap tides. Perhaps this will be addressed in the discussion...

[342] The difference in exponent may be statistically significant (i.e., unlikely to be due to chance), but it is still really small (0.164 vs 0.145), so it perhaps it's not so important? Any difference in salt flux mechanisms associated with that small a change would be subtle, and it'd be hard to ascribe the differences in transport processes to the exponents alone. If that topic were of interest, diagnosing the salt flux mechanisms in the model directly would be the way to do it.

[342] This p-value should be reported as ($p < .001$) since it is not exactly 0 but rather 0.000 to three decimal places.

[387] "saltwater intrusion length is similar in the four scenarios." While the differences in salinity intrusion are smaller than in the case with different roughnesses, the trends are similar (1972 and 1966 similar and shorter than 2021 and 1981), and it seems inaccurate to say the four scenarios are similar.

[390] "less energy dissipation..." It would be valuable to diagnose this directly with analysis of the differences in tidal amplitude. Presumably, the roughness affects the tides, which then affects the salt transport. Showing the "why" of this response would clarify the physics and make it more transferable to other systems.

[414] "As expected..." Is it expected because of the river discharge? It'd be worth stating directly.

[417] "Through the increase of the landward relative to seaward volume transport and river discharge, saltwater intrudes further into the estuary." It's not obvious that this must be the case. If the volume transport scales with the tidal velocity and the difference between landward and seaward volume transport scales with the river discharge, then increasing the tidal velocities can have the opposite effect of reducing the estuarine circulation and mean stratification, thereby reducing the salinity intrusion. The salt transport in the Weser may be predominantly due to tidal processes rather than the mean circulation, but this should be explained, and the changes shown.

[443] "Therefore, the small difference between 1966 and 1981 cannot be clearly

attributed to a change in salt flux mechanisms.” This is repetitive of a previous section, and if the question is about changes in salt flux mechanisms then that should be analyzed in the model results directly.

[460] “However, models representing historical system states are often not calibrated” In the citations here, Ralston and Geyer compares their model with historical salinity data (Fig 6 and Fig 7), and Grasso and Le Hir and Liu et al. calculate model skills for their modern model configurations. Perhaps this should be recast to say that recalibration is only necessary 1) if the model grid does not capture changes in roughness that affect model skill, and 2) there are observational data to support a robust calibration?

[463] “We recommend...” Related to the previous comment, it is usually a lack of observational data that limits historical model calibration. What's the recommendation in that case? How do the "artificial surface irregularities" suggested to compensate for low resolution data relate to changes in topography at larger scales by dredging? One could imagine the irregularities being bigger (deeper channel=bigger sand waves) or smaller (maintenance dredging planes off big sand waves).

[486] What are the “analytical descriptions”? Is the suggestion that the variance from the power-law is greater for the Weser than for other systems? Or does it refer to the difference between -0.28 and -0.15 for the Hudson vs the Weser? That could reflect differences in transport processes and bathymetry between the systems, but does not necessarily mean that either is more or less "limited" in using this approach to characterize the relationship between discharge and salinity.

References

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