Response to Reviews

“Impacts of Human Modifications on Material Transport in Deltas”

Jayaram Hariharan, Kyle Wright, Andrew Moodie, Nelson Tull, and Paola Passalacqua

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Dear Editorial Team,

Thank you for handling the review of this manuscript. We have made a number of changes to the text and believe that as a result of these revisions the manuscript has been improved, and we express our sincere thanks to the editorial team and the reviewers for the time and effort they have put into this process.

Thank you,
Paola Passalacqua

Associate Professor
Department of Civil, Architectural, and Environmental Engineering
The University of Texas at Austin

Reviewer No. 1

1.00—*This article applies numerical modeling to explore particle transport and impacts on hydrological connectivity in river deltas due to common anthropogenic landscape modifications such as the construction of embankments or the dredging of channels. Findings from this work can help inform the use of engineering structures on delta landscapes with evidence of changes to hydrological connectivity and the need for more in-depth studies in regions of proposed structures. This article is well-written and should be published, as it will be of interest to engineers, coastal scientists, and potentially even policy and decision-makers.*

>> Thank you for taking the time to read and review our manuscript. We appreciate the support, and have made changes to the text to address the

comments made. Responses to each individual comment are provided below.

1.01—*In section 2.2.1,, it would be helpful to add a short statement summarizing what the three "looks" are from the approach of Shaw et al. (2008).*

>> We have revised the text of this sentence to be more consistent with the language of Shaw, Wolinsky, Paola, and Voller (2008) and reference their appendix explicitly. The revised sentence reads: "First, we identify the position of the deltaic shoreline using the opening angle method (Shaw et al., 2008) using the largest 3 view angles ($p = 3$ per Shaw et al. (2008) appendix), a threshold angle of 75 degrees, and an elevation threshold of 0.5 m below sea level to include the low lying shallow marine environment (Shaw et al., 2008; Liang, Van Dyk, & Passalacqua, 2016)."

1.02—*The Wax Lake Delta is mentioned several times throughout the manuscript as a natural system comparison for the model. The article could benefit from more discussion with specific similarities/differences to the Wax Lake Delta. This will help support that despite necessary reduced complexity often used in modeling analyses, that the model is valid and can be applied to natural delta systems. The Wax Lake delta is currently gaining land. So another question I have is what the implications of these model results are for deltas that are experiencing widespread coastal erosion or subsidence, instead of gaining land.*

>> Thank you for this suggestion. We have revised the text in Section 2.1 where the model is first described to make explicit the relationship and similarities between our model domain and the Wax Lake Delta, by adding the text: "These modeling parameters, in particular the input flow velocity (1 m/s), and resulting delta size (~ 41 km^2), are designed to be similar to the Wax Lake Delta (Liang et al., 2016), which has flow velocities of roughly 1 m/s (Shaw, Mohrig, & Whitman, 2013) and a cumulative areal island area of ~ 50 km^2 (Olliver & Edmonds, 2017). The model simplifies both the inflow discharge and basin depths as a constant values of 1,250 m^3/s and 5 m respectively. The real Wax Lake Delta in contrast has a variable discharge at the inlet, with an average value of 2,800 m^3/s, and a basin which grows deeper with distance from the river mouth (Wright, Passalacqua, Simard, & Jones, 2022)."

The second question about the implications on these results for deltas undergoing erosion is certainly interesting and is the subject of ongoing studies. In this study, as we do not morphodynamically evolve the delta system after imposing human modifications, we believe the results hold over short (decadal) timescales, but are not necessarily relevant over longer timescales where the island and channel morphology has time to change and adjust in response to the human modifications (see Section 4.4 on study limitations). So whether or not these results hold in eroding or subsiding landscapes is likely related more to the overall morphology of those systems. Systems with comparable morphologies should have similar behaviors over the short-term, with the above caveats about the dynamic evolution of the landscape for longer timescales.

1.03—*In lines 269-272, it could be useful to add a sentence or two about what the implications are for deposits and sediment storage on the delta vs. what material is flushed offshore.*

>> We have added text to this paragraph that states the following: "The deposition of sediment within the delta is key to land building (Kim, Mohrig, Twilley, Paola, & Parker, 2009). Channel properties are not the only factor controlling sediment deposition, a number of studies have shown that the type, structure, presence, and organization of deltaic vegetation can have substantial influences on the deposition of sediment within the delta itself (e.g., Nardin & Edmonds, 2014; Nardin, Edmonds, & Fagherazzi, 2016; Wright, Hiatt, & Passalacqua, 2018; Lauzon & Murray, 2018)."

1.04—*Lines 284-291 seem a bit out-of-place. I think that a few additional sentences on how the model results can inform our understanding of salinity (particularly since saltwater intrusion can be a big issue for deltas) may strengthen the argument for the applicability of the model.*

>> While we appreciate the suggestion, following a comment made by Dr. Beemster (2.06), we have actually reworded these lines to be more cautious about the implications drawn from this work as this modeling is much simpler than what might be necessary to explain complex phenomena such as saltwater intrusion into deltas. We have revised this text to read: "While we do not model salinity, mixing, or density-driven flows directly in this work, we do simulate the transport of neutrally-buoyant, negatively-buoyant, and positively-buoyant material from the apex of the delta. These particle paths and visitation to islands (Figure 8) may thus be indicative of freshwater flow through the system."

1.05—*If possible, it could be useful to include quantitative estimates of changes in nourishment area and hydrological connectivity within the text.*

>> We have added Figure 6 which provides difference map quantifying the differences in flow velocities between different scenarios. We note that the box plots in Figure 7 provide a graphical depiction of the 0, 25, 50, 75, and 100th percentile values for nourishment area for each scenario. In Figures 8, 9, and 10 graphical information about particles visiting islands as well as the time material spends in the delta and within channels and islands specifically is available. As this is an idealized and generic study, we do not believe that providing additional specificity via direct quantification of the results will be of added value to the reader. This work is a more exploratory study that aims to offer broad guidance on the impacts of anthropogenic change on material transport in deltas rather than prescribing specific and precise values associated with those impacts.

1.06—*Figure 7: Difficult to quickly make out trends in the data. Consider adding a summary of trends to the figure caption.*

>> We have revised the figure caption (now Figure 8) to read: "Timeseries of the average percentage of particles to be within deltaic islands for the first 48 hours over which the particles are routed for each modeled scenario. Data is grouped by θ value, with **a)** $\theta = 0$, **b)** $\theta = 1$, and **c)** $\theta = 2$. In all of the

unsteady (tidal) scenarios (pale colors) the influence of the tidal signal is visible. For $\theta = 1$ and $\theta = 2$ the local maxima in the plots correspond to the flood tide peaks at hours 3 and 15. In **a)**, the natural topographies with 50% and 75% input sand fractions experience the highest fraction of particles visiting islands, while the poldered cases have the lowest values. In **b)** and **c)** higher input sand fractions correspond to higher fractions of particles entering islands, while the dredged topographies experience markedly low fractions of particles in islands across all time. Note that individual panels have different y-axis limits, in **a)** values near 80%, while in **b)** they only approach 15%, and in **c)** they only near 3%."

1.07—*Figure 8: Specify this figure is showing the exposure time in the whole delta system.*

>> This figure caption (now Figure 9) has been revised to read: "Exposure time cumulative distribution functions (CDFs) for the different scenarios calculated over the full delta extents (e.g., Figure 2d). Data is grouped by θ value, with **a)** $\theta = 0$, **b)** $\theta = 1$, and **c)** $\theta = 2$, with the **a-1, b-1, c-1** designations for zoomed in plots of the same data."

1.08—*Line 20: This sentence seems out of place and is not discussed elsewhere in the text. Consider adding another sentence here to summarize how connectivity impacts flora/fauna.*

>> We appreciate the comment but would like to highlight other lines in the introduction, e.g., L32-34, which explicitly describe the impacts of dredging on flora and fauna. Further references, e.g., L55-62, refer to site-specific studies conducted to understand the impacts of construction on the environment. As the work presented here is designed to assess the generic impacts of human modifications on material transport through deltas, we refrain from adding any additional text specific to flora/fauna as we do not model either in this work.

1.09—*Line 38: Awkward wording*

>> Thank you for flagging this, after another read we respectfully disagree and have left this sentence as-is.

1.10—*Line 44: How is hydrological connectivity significant and important for deltas?*

>> We have added a sentence here which reads "Hydrological connectivity in deltaic landscapes has been found to control nitrate removal (e.g., Knights, Sawyer, Edmonds, Olliver, & Barnes, 2021), affect water exposure time distributions (e.g., Hiatt, Castañeda-Moya, Twilley, Hodges, & Passalacqua, 2018), and via feedbacks with vegetation, influences sediment deposition and retention (e.g., Nardin & Edmonds, 2014)." to make clear the importance of hydrological connectivity in deltas.

1.11—*Line 47: "These environmental conditions lead to variations in morphology" is repetitive with the previous sentence*

>> We have re-worded this sentence to make the intended point which is that morphology can also influence hydrodynamics and sediment transport (in contrast to the previous statement which presents the inverse: external forcings shaping the morphology of a delta). We believe both points are important to make, and important to consider, when thinking about the dynamics of these systems and how to best manage them.

1.12—*Line 84: Figure 4 is referenced in the text before Figures 2 or 3*

>> We have re-ordered the figures so that their numbering matches their introduction in the text.

1.13—*Lines 228-229: Confusing sentence, consider rewording*

>> To improve clarity, this sentence has been reworded as: "Across the six model replicates per scenario, there is greater variability in the nourishment area of poldered topographies, than the dredged topographies (Figure 7). This result is consistent with the greater variability in polder areas compared to dredged channel areas (Tables A1 & A2); we do not normalize nourishment area values based on the area of the embanked island or dredged channel."

1.14—*Line 292: Specify if this finding is for every particle type (θ)*

>> We provide additional clarity and have revised this sentence to read: "Our finding that exposure times within islands are shorter than those within channels, for θ values of 1 and 2, is a counter-intuitive result (Figure 10), for which one possible explanation is related to the topographic delineation of channels and islands (Figure 2e)."

1.15—*Line 309: Run-on sentence*

>> We have split this sentence into: "For example, particles on the poldered topographies with $\theta = 0$ (positively-buoyant) appear to spend the least amount of time in the channels and islands. In contrast, it is the dredged topographies that have the shortest exposure times in the islands when the θ parameter is 1 (neutrally-buoyant) or 2 (negatively-buoyant, Figure 9)."

1.16—*Line 340: Missing year on the Wright et al. citation*

>> Thanks for pointing this out. We have fixed this citation.

1.17—*Line 341: This needs further explanation or support, since one of the findings in the text is that flow conditions do not seem to significantly influence particle behavior unless the landscape has been dredged (Lines 223-226).*

>> We have improved the clarity of our statement in Section 3.2 by specifying the conditions for which the particle behavior is influenced by changes in flow conditions. The revised paragraph now reads: "The flow regime has minimal influence on the total area nourished by particles in the natural and poldered scenarios. In the dredging scenario, however, the presence of tides consistently results in greater particle nourishment areas that the steady flow simulations. This result holds true across all sediment compositions and particle material

types when the main channel has been dredged (Figure 7).”

Reviewer No. 2 – Joris Beemster

2.00—*The manuscript explores material transport in human-modified deltaic landscapes through an exploratory model study. It examines how particles with varying buoyancies move through deltaic terrains generated by computer simulations. The study finds that both dredging and land reclamation reduce the nourished area, while exposure times for dredged or partially reclaimed deltas increase or decrease, respectively. Overall, the article is a valuable addition to the literature and fits well within the scope of Earth Surface Dynamics. It is also easily comprehensible. However, one main weakness is the limited discussion of the hydrodynamic results. I recommend accepting the manuscript with minor revisions. Below are my suggestions for improvement:*

Thank you for taking the time to read and review our manuscript. Below we provide responses to each review comment.

2.01—*The impacts of dredging and land reclamation on hydrodynamics considerable (e.g. Talke Jay, 2022), and despite the limited tidal range at the model boundaries, it would be beneficial to include a section in the results discussing the hydrodynamic response to these anthropogenic interferences. Currently, the hydrodynamic results are limited to one figure in the appendix, but dedicating a section to this topic could help explain some of the particle routing results and provide insight into the delta's morphodynamic response to dredging and land reclamation.*

>> We appreciate the opportunity to revise the text and include a figure and description of the hydrodynamics results. To this end, we have added Figure 6 and Section 3.1.

2.02—*The particle routing results provide valuable insight into the morphodynamic response to anthropogenic pressures, especially if they represent sediment transport pathways. However, the discussion of the future morphodynamic response is limited. It would be helpful to elaborate on the expected response based on the hydrodynamic and particle routing results.*

>> We have added Section 3.1 to discuss the hydrodynamic response to anthropogenic changes. As we do not simulate morphodynamics after introducing anthropogenic modifications, we have not added much text on those impacts, but there is some discussion of this topic (Section 4.4).

2.03—*In Figures 1, 2, and 3, a diverging colorbar is used, and it would be advisable to set the divergence point to a relevant elevation. What is the value of this middle point, and is it a relevant elevation? If not, I recommend setting the value to mean sea level or mean low water.*

>> The middle point is set to a value of -0.5 m, following previous studies

using this modeling approach that also identify land pixels as those with elevations above -0.5 m (Liang et al., 2016; Lauzon & Murray, 2018). This is consistent with the approaches described in Sections 2.2.1 and 2.5 to define the shoreline, as well as the island and channels. For clarity, the colorbars have all been updated with labels at the divergence points (Figures 1, 3, and 4).

2.04—*In lines 120-121, the authors discuss the morphological closing and erosion operation. Could you explain what these operations entail and why the erosion operation is applied twice? Additionally, it is unclear why this is necessary if no further morphological evolution will be simulated following land reclamation.*

>> We regret the lack of clarity provided in these lines and would like to make it clear that the morphological operations are not taking place on the topography, but rather the representative maps of channelized pixels and island pixels as shown in Figure 2. The morphological closing operation is a morphological dilation, followed by a morphological erosion (Serra, 1982), resulting in the removal of "noise" or individual pixels. When conducted on the binary representation of channelized pixels, the morphological closing serves to remove individual land pixels present in the middle of channels, which for small channels may mean reduced connectivity. As the goal is to identify the largest continuous island, it is important to ensure that the channel structure is captured, and we found that this process helps ensure the connectivity of the channels is accurately represented. The two erosion operations are performed on the binary map representing the largest continuous island. We performed two morphological erosion operations with a square structuring element with connectivity equal to one (only connected on its 4 sides). This would have been equivalent to performing a single morphological erosion with a larger structuring element. The overarching purpose of the erosion, however, was to ensure the area identified as the embanked island, and thus artificially raised to simulate the embankment, was not within the channel. In fact this process was done to ensure the definition of the "island" to be raised would be at least 1 if not 2 pixels from the active channel, as the translation from the rectilinear grid to the unstructured triangular mesh creates opportunities for single-pixel interpolation that risked unrealistic or unstable conditions at the channel boundary. Instead, by doing these morphological operations we were able to maintain a semblance of a channel bank and retain confidence that our hydrodynamic simulation would not have unrealistically steep channel boundaries. In an effort to improve the clarity of the text, we have revised the text about morphological operations in Sections 2.2.1 and 2.2.2.

2.05—*In line 155, the authors mention that the simulation captures two tidal cycles. While this may be sufficient given the limited tidal range, it is common for hydrodynamics to require more than two cycles to converge. It would be helpful to ensure the reader that the hydrodynamics have indeed converged, e.g. by mentioning the difference in tidal amplitude or high water level within the delta for the second and third cycle.*

>> We have done a comparison of water levels over two sets of 25 points

in and near the modeled deltas between hours 23.75 and 24 for the steady flow scenario, and hours 10 and 22; 10.5 and 22.5; 11 and 23; 11.5 and 23.5; 12 and 24 for the tidal flow scenario. The difference in water stage across all 18 modeled scenarios for the steady flow simulations between hours 23.75 and 24 (Figure R1B) was $\mathcal{O}(10^{-5}$ m). For the tidal flow scenarios the difference in water stage between the five pairs of comparison points (Figure R1C) was also $\mathcal{O}(10^{-4} - 10^{-5}$ m). We calculate these differences over two different sets of 25 random points (Figure R1A), and get consistent results. The text in Section 2.3 has been amended to state that these tests were conducted and to describe the results.

2.06—*In lines 284-287, the authors assume that the traces indicate where freshwater would flow in a system influenced by density differences. However, density-driven flows can be complex and also significantly impact freshwater flow. Therefore, it is advisable to refrain from this assumption and simply state that particle visitation by positively buoyant particles might indicate freshwater flow.*

>> We appreciate this comment and despite our efforts to avoid doing so, we agree that in this case our language overstepped the bounds of this study and its findings. We have revised this text as suggested to read: "While we do not model salinity, mixing, or density-driven flows directly in this work, we do simulate the transport of neutrally-buoyant, negatively-buoyant, and positively-buoyant material from the apex of the delta. These particle paths and visitation to islands (Figure 8) may thus be indicative of freshwater flow through the system."

2.07—*In section 4.3, the transport differences due to material properties are discussed. It would be interesting to provide an indication of what types of particles the behavior of the positively, neutrally, and negatively buoyant particles represent. For instance, negatively buoyant particles might represent bedload transport, neutrally buoyant particles could resemble suspended load transport, and positively buoyant particles might represent plastics.*

>> Thank you for making this suggestion, we have added some text to this effect in Section 4.3: "For example, positively buoyant materials might represent flotsam, neutrally buoyant material could be suspended sediment, and negatively buoyant material may be more akin to bedload, three materials which occupy different vertical positions in the water column, and therefore will not follow the same transport paths."

2.08—*Sections 3.2 and 3.3 are named after the figures they discuss. However, it would be preferable to use section headers named after the topic rather than the tool used to present the results. Timeseries and distributions are tools to get to the result and not the results themselves.*

>> We appreciate this suggestion and have changed the section headers to "Particle Island Visitation" and "Particle Exposure Times" for Sections 3.3 and 3.4 respectively.

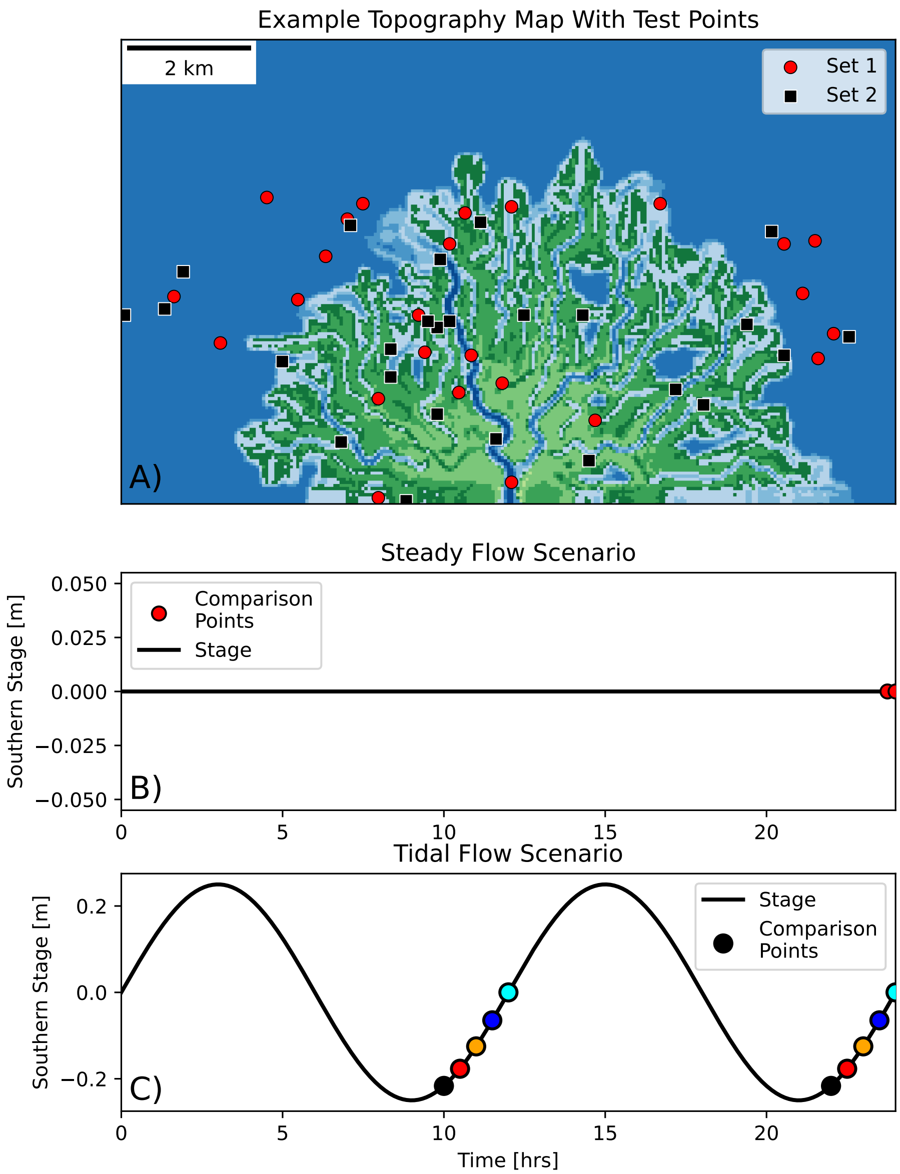

Figure R1: **A)** Example model topography with two randomly sampled sets of 25 points used to test the change in stage over `ANUGA` model time. **B)** The steady flow scenario southern stage over time with hours 23 and 24 identified for which stage at points in **A** are compared. **C)** The tidal flow scenario southern stage over time with the five pairs of time points used for comparing stage values at the locations identified in **A**.

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