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Hydrodynamic & Morphodynamic Modeling of Alameda Creek's Sediment Transport to Evaluate Restoration Alternatives

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Summary

The Alameda Creek Flood Control Channel was dredged by the US Army Corps of Engineers (USACE) over 50 years ago. The intensive 10-year project channelized the lower portion of Alameda Creek to provide flood protection, but many issues have arisen since. In particular, the low-flow channel was not designed to move sediment to the San Francisco Bay, and now it requires continuous dredging to alleviate problematic sediment deposition.

Alameda County Flood Control District (ACFCD) has been investigating channel redesign alternatives for nearly a decade. The channel redesigns being considered are aimed at reducing sediment deposition while maintaining flood protection. Modifications to the originally trapezoidal channel geometry of Alameda Creek involve both the longitudinal slope and the channel cross-section. In 2015, the Danish Hydraulic Institute (DHI) performed a study and assessed sediment deposition, but there were limitations in terms of the area covered by the model and the considered channel redesigns.

The goal of this study is to provide a more comprehensive characterization of the hydrodynamics, sediment transport, and morphodynamics in the Alameda Creek. The results presented here provide ACFCD with an improved understanding of the current conditions and comparisons to possibilities for future sediment transport. Moreover, this work can be seen as a steppingstone for follow-up studies that connect Alameda Creek's local changes to more regional dynamics within San Francisco Bay's marshes, vegetation, wildlife, and mudflats as well as influences on hydrodynamics.

For this purpose, a Delft3D model was created and validated with observational data. It successfully reproduced hydrodynamics and morphodynamics, including water levels and discharge in the Bay and Creek, and morphological changes observed by LIDAR between 2006 and 2019, with some underestimation in cumulative depositional trends.

Seven scenarios were considered in the model application including three baseline variations: current situation without modifications; the original USACE design (from the 1970s) and the design proposed by the ACFCD. Additionally, four alternative scenarios were evaluated, varying in their starting elevations and transitions to deeper sections. These scenarios range from starting elevations of 3 ft to 8 ft.

In terms of hydrodynamics, the model shows that tidal amplitudes reach around 0.7 m (2.3 ft) at the confluence of San Francisco Bay and Alameda Creek and decrease going upstream the Creek thalweg. The proposed design shows the least amplitude reduction due to its deeper bed level with tides reaching around Dry Creek. However, alternative scenarios with shallower bed levels experience a larger decay in tides, especially near railroad passages where tidal propagation is notably hindered.

In terms of morphodynamics, the USACE design showed the highest sediment deposition rates and is strongly influenced by hard structures in the creek bed. The proposed design has lower deposition rates compared to the current situation, while alternative, shallower scenario designs result in higher deposition rates than the proposed design. Deposition

trends vary along the creek, with all scenarios indicating a net sediment deposition from the fish passage towards San Francisco Bay. The proposed design is most effective in reducing overall deposition (14 % less compared to the current situation), while deeper channel designs correlate with less sediment deposition.

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1 Introduction

The Alameda Creek Flood Control Channel is one of the largest streams in the San Francisco Bay Area (Figure 1). From 1965 to 1975, the lower 12 miles (downstream of the BART weir) of Alameda Creek's total 45 miles were diverted and channelized by the US Army Corps of Engineers (USACE). This substantial project was intended to provide flood protection for the neighborhoods of Fremont, Union City, and Newark. The creek was relocated, widened, and straightened the downstream portion of the creek, and it was rerouted to reach the bay more directly. These changes led to unintended consequences related to sedimentation, fish migration, and other natural processes that were disrupted.

Historically, the creek fed the tidal Baylands directly with sediment, nourishing this natural infrastructure over time. The new channel was not designed to preserve the essential sediment transport function that the natural creek provided. Now, sediment builds up in the low-flow channel, reducing flood storage capacity and requiring continuous dredging.

Figure 1: Overview and detailed map of the southern San Francisco Bay and Alameda Creek.

Alameda County Flood Control District (ACFCD) is exploring several configurations for redesigning the low-flow channel. Each of these would increase the sediment transport capacity resulting in less deposition while maintaining flood risk reduction and restoring many of the natural functions of the creek. All the proposed channel redesign alternatives lower the level of the trapezoidal bed to increase sediment transport rates in Alameda Creek.

Previous work by DHI in 2015 compared potential changes to sediment deposition for several configurations with an area of interest focused on the lower part of Alameda Creek, downstream of the Bay Area Rapid Transit District (BART) weir. Results showed similar sediment deposition trends for all alternatives three alternative channel widths, but there would likely be differences with a variation in exploring various depths. The analysis would also be more accurate if a larger extent of the channel was assessed and if variable tidal forcing conditions were included.

This study intends to determine if the alternatives can be further refined to minimize the depth and optimize the shape of the channel, while still retaining sediment transport capabilities. The depth and length are important because there is concern that, if the channel is too deep, there may be seepage from the nearby Quarry Lakes or the groundwater system in general. These lakes are crucial for recharging the aquifers, helping to maintain the local water supply. Water resources have been vulnerable to high demand coupled with severe droughts.

2 Summary of Approach

This study aims to increase the understanding of hydrodynamics, sediment transport, and morphodynamics across the lower portion of Alameda Creek for several design scenarios. In order to meet this objective, a model was developed, validated, and applied.

Figure 2. Overview of study approach.

The approach followed three steps (Figure 2). These steps are described in more detail in the outline below:

1. **Development.** We developed a model for hydrodynamics, sediment transport, and morphodynamics across the lower portion of Alameda Creek in the Delft3D Flexible Mesh modeling suite (Delft3D FM; Kernkamp et al. 2011). Delft3D FM was chosen since this is continuously being updated to include the latest scientific developments in coastal modeling.
    - The new model was created based on the San Francisco Bay-Delta Community Model (https://www.d3d-baydelta.org/ or Nederhoff et al., 2021).
    - Model settings from previous modeling (DHI, 2015) were used to limit calibration efforts of the sediment transport and morphology modeling.
    - The model was configured so that any future work can use it as a starting point. We ensured that possible follow-up model applications can be as broad as possible by providing open access and by using open-source software.
    - Information on the model setup and input data is described in Section 3.
2. **Validation.** We validated the developed model on different sets of measured data to test its accuracy and reliability.
    - Hydrodynamic validation focused on both water levels in the San Francisco Bay that are mainly tidally driven but also on the fluvial portion of the Creek.
    - Morphodynamic validation focused on the development of bed level cross-sections in the Creek and the cumulative deposition of material.
    - Sensitivity testing for both hydrodynamic and morphodynamic parameters provided insight into the relative impacts of the most important parameters on the overall computed system dynamics.
    - Specific details on the methods and results of the calibration and validation are provided in Section 4.
3. **Scenario Analysis**. The performed model simulations are used to answer several practical questions about Alameda Creek's alternative design scenarios. Information on the Model Application and Scenario Analysis are described in Section 5.

3 Model Setup and Input Data

3.1 Introduction

This Chapter describes the model setup and input data of this numerical modeling study. We first introduce the general model setup which focuses on the model domain and computational grid, the topo-bathymetry used, and various parameter settings. Subsequently, more information is given on the hydrodynamic boundary conditions, sediment transport model, applied simulation period, and bed level scenarios evaluated.

3.2 General Model Setup

3.2.1 Assumptions

The numerical model developed for this study was built using the Delft3D Flexible Mesh modeling suite (Delft3D FM). Since the impact of stratification of the water column is considered negligible (in terms of relevance to the applied research questions), the model operates in a depth-averaged 2DH mode (where H stands for the horizontal average over depth). This reduces the computational cost of the model while maintaining similar accuracy.

Wind-generated waves have not been incorporated into the model because the effects of local waves are deemed minimal. The assumptions on the role of stratification and waves align with the assumptions made by DHI in their 2015 study (Zyserman & Saleh 2015).

3.2.2 Model Domain

The model's domain encompasses the entire southern San Francisco Bay and extends to Alameda Creek up to the Niles Canyon, as depicted in Figure 3. The model grid generally employs curvilinear cells but resorts to triangular cells in the region surrounding the mouth of Alameda Creek. Grid resolution ranges, with the minimum being 350 m x 300 m in the Bay area and the maximum reaching up to 13 m x 4 m (approximately 42.6 feet x 13.1 feet) in Alameda Creek.

The starting point for the model's bathymetry is derived from the District LIDAR data from 2006. However, LIDAR misses some low points and was therefore manually deepened. Moreover, the dataset has been extended with USGS for the San Franciso Bay called Coastal National Elevation Database (CoNED; Danielson et al., 2016).

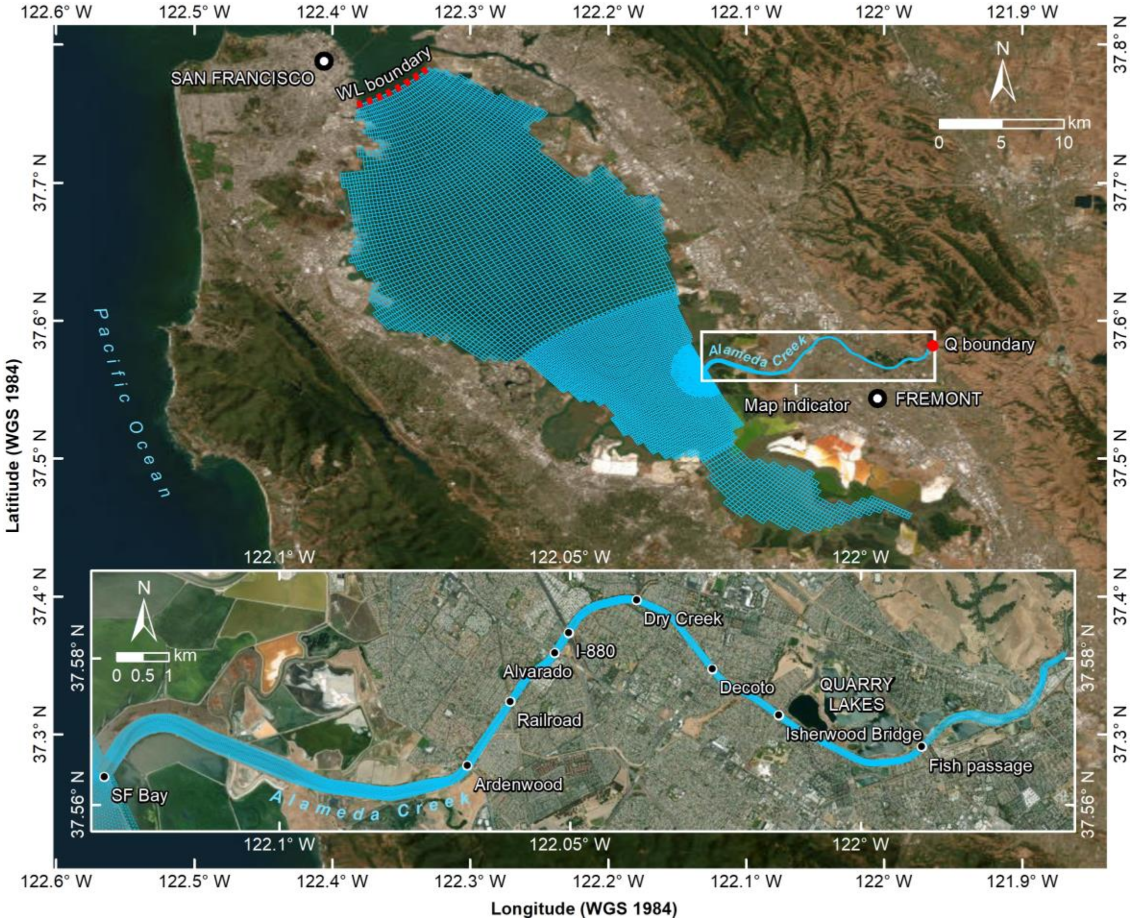

Figure 3. Overview and detailed map of the southern San Francisco Bay and Alameda Creek, indicating the computational grid of the Delft3D Flexible Mesh model applied in this study. The model grid covers Alameda Creek up to Niles Canyon.

3.2.3 Bottom Friction

Based on the findings of the sensitivity analysis performed for the hydro- and morphodynamic model (see Sections 4.2 and 4.3), a spatially varying bottom friction field is used. In the area of the highly vegetated banks of Alameda Creek, a Manning's *n* friction coefficient of 0.05 s/m$^{-1/3}$ is applied, while a smaller value of 0.02 s/m$^{-1/3}$ is applied in the unvegetated channels of Alameda Creek and in the whole southern San Francisco Bay. The bottom friction field was derived from both the 2019 LIDAR data as well as the 2019 satellite images of the study area. A sensitivity analysis of the friction was performed both in terms of hydrodynamics (Appendix 6.2A.1) and morphodynamics (Appendix 6.2B.2).

3.3 Hydrodynamic Boundary Conditions and Forcings

The Delft3D FM model is forced at two open model boundaries, i.e. the seaward boundary in the San Franciso Bay and the upstream boundary of Alameda Creek. At the seaward boundary, the model is forced by a water level time series, which is derived from a large-scale and highly accurate model developed by Nederhoff et al. (2021) through a process called nesting. The seaward water level boundary conditions contain tidal water levels and sea level anomalies that propagate from the Pacific Ocean into the bay.

Upstream of Alameda Creek, the model is forced by a measured discharge time series (source) at Niles (USGS #11179000). Moreover, the model incorporates daily water abstractions (sink) from Alameda Creek to Quarry Lakes (see Figure 3) as provided by Alameda County Water District (ACWD; personal communication; June 2023)

3.4 Sediment Model

The model considers three distinct sediment fractions:

- **Mud** (a combination of clay and silt, with a median particle diameter smaller than 0.063 mm and a settling velocity of 0.0001 m/s in both fresh and saline water, categorized as cohesive sediment),
- **Coarse sand** (with a median particle diameter of 1.4 mm, non-cohesive sediment), and
- **Medium gravel** (with a median particle diameter of 30 mm, non-cohesive sediment).

These three fractions represent the dominant sediment fractions in the bed of Alameda Creek between the rubber dam and the mouth, although the actual bed composition is much more heterogeneous according to the samples taken by Pearce & McKee (2009).

Since there is no detailed documentation of the absolute sediment thicknesses in Alameda Creek, the model was calibrated with initial thicknesses varying spatially in the flow direction (but not in the cross-flow direction) between approximately 0.4 m and 1.2 m, which resulted in a realistic cumulative deposition in the creek, as shown in Section 4.3. In the area upstream of the rubber dam, the initial thicknesses were intentionally set to 0 m to avoid overestimating sediment deposition downstream.

The initial sedimentary composition in the model is derived from the sediment samples collected by Pearce & McKee (2009) from Alameda Creek. To establish this, the volume percentages of mud (clay and silt), sand, and gravel from the bed samples (not from low or high bar samples) provided in Table 2 in Pearce & McKee (2009) were multiplied by the total initial thicknesses. The sedimentary composition was linearly interpolated for each fraction between the sample points.

At the upstream boundary of Alameda Creek, there is a daily measured time series of the mud concentration at Niles (USGS #11179000; USGS source). However, since measured mud concentrations are not available for the entire simulation period from 2006 to 2019, gaps in the measured time series were filled using a linear correlation between the measured discharge and mud concentration in Alameda Creek, as shown in Figure 4. For the sand and gravel fractions, equilibrium sediment concentrations were applied at the upstream boundary, while at the seaward model boundary, equilibrium sediment concentrations were used for all sediment fractions.

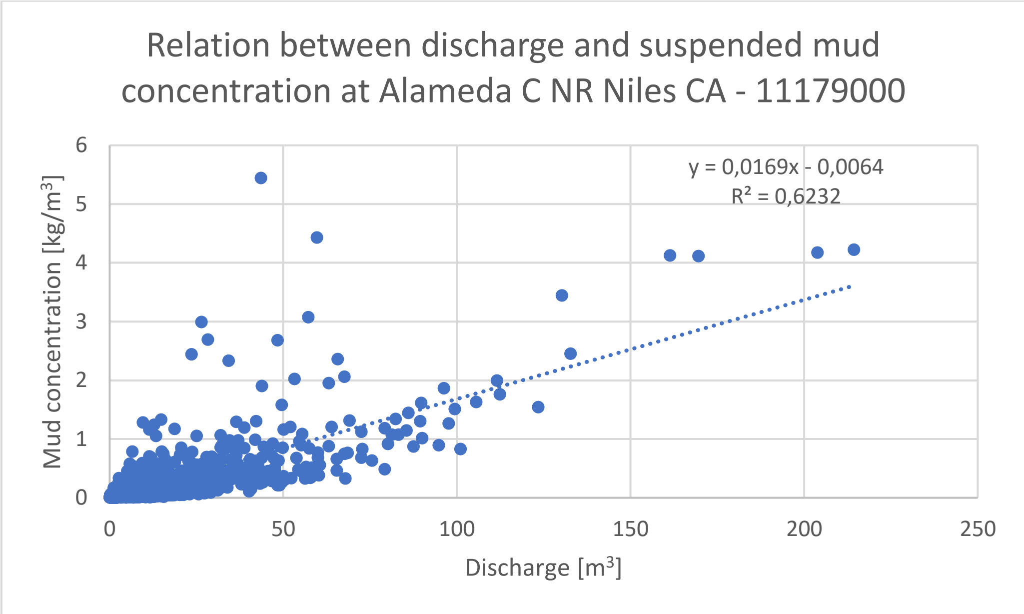

Figure 4. Correlation between the measured discharge and measured mud concentration in the period 1 January 2000 to 1 January 2023 at measurement station Niles #11179000. Based on the measured data, a linear correlation between both parameters was derived, which was used to fill gaps in the measured time series of the mud concentrations.

As was the case in the study by Zyserman & Saleh (2015), the sediment transport in the model was calculated using the transport formulation by Engelund & Hansen (1967). The validation is presented in Section 4.3 and presents that the formulation by Engelund & Hansen (1967) yielded reliable morphological modeling results, while – at the same time – reducing the computational cost of the model compared to the more complex transport formulations by e.g. van Rijn (1993) and van Rijn (2007). A sensitivity analysis of the importance of grain sizes can be found in Appendix 6.2B.3.

3.5 Applied Simulation Periods

The model was run with different approaches which are summarized below:

1. **Compressed time series:** 237 storm days based on Jan 2006 to 1 Jan 2019 with daily inflows and mean sea level.
2. **Brute force time series**: from 1 Jan 2006 to 1 Jan 2019 with **daily inflow** at Niles and variable water levels downstream.
3. **Brute force time series** (several specific years between 2006 and 2019) with a **15-minute inflow** at Niles and variable water levels downstream.

Approach 1, known as the "compressed time series", utilizes a squeezed time series method, which concentrates on specific periods when Alameda Creek is 'open' during high discharge conditions (discharge > 18.8 m^3/s or 700 cfs). The idea is to only simulate conditions when the rubber dams are not inflated, and most of the sediment gets mobilized and routed through Alameda Creek. This method is based on DHI (2015) and allows for a more efficient model run, as it focuses on a shortened simulation period (only 237 days for 13 years). The primary advantage is efficiency, permitting more simulations to be run in a shorter period. However, one significant limitation is that this method does not account for tidal influences, which can significantly affect the model's results (especially downstream). For efficiency reasons, this method has primarily been used for morphological model sensitivity testing (Appendix 6.2B). In order to allow for a direct comparison of morphological simulation results based on the compressed time series (Approach 1) with those based on the brute force time series (Approach 2; see below), all morphological model results are converted to a single-year.

Approach 2 utilizes a 'brute force' method of simulation, employing a continuous simulation technique with daily inflow at Niles. The primary advantage of this method is its comprehensiveness, as it takes into account all interactions, in particular tidal effects, providing a more holistic view of the system's dynamics. However, due to its detailed nature, this method takes the longest to execute (~30 days for Approach 2 versus ~2 days for Approach 1), making it difficult to run multiple times. This method has been primarily used for the model validation and application in order to provide the quantification after preliminary testing with the first approach (Sections 4 and 5) A sensitivity analysis on the the difference in morphologic response between Approaches 1 and 2 can be found in Appendix 6.2B.1.

Finally, Approach 3 also uses a 'brute force' method but introduces high-frequency discharge forcing by simulating a 15-minute inflow at Niles. This approach aims to capture the short temporal variations in flow conditions. This higher frequency approach may be particularly advantageous in scenarios where rapid changes in flow conditions are expected, for example, during storms. However, this method was only used for hydrodynamic model validation (Section 4.2) and sensitivity testing (Appendix 6.2A.2) since sediment concentrations were only available as daily averages and morphodynamic predictions were the focus of this study.

3.6 Model Output

High-frequency 10-minute outputs are saved across observation points and cross-section along the thalweg for detailed analysis. Low-frequency daily outputs are saved for the entire model domain including a running average of mean sediment transport. Moreover, an online Fourier analysis is performed on the computational results. This enables the generation of computed co-tidal maps and provides insights into the tidal amplitude and phases.

3.7 Evaluated Bed Level Scenarios

For the aim of this study (Sections 1 and 2), the model was run with different bed level scenarios. The starting point is the following three scenarios (see Figure 5):

1. The **current situation** is topo-bathymetry without any modifications.
2. The **USACE design** is largely a trapezoidal channel.
3. The **proposed design** was introduced in DHI (2015) and has a deeper minimum elevation compared to 1) or 2) and a low-flow channel with a depth of 9 feet, a width is 24 feet, and a slope of 1:3.

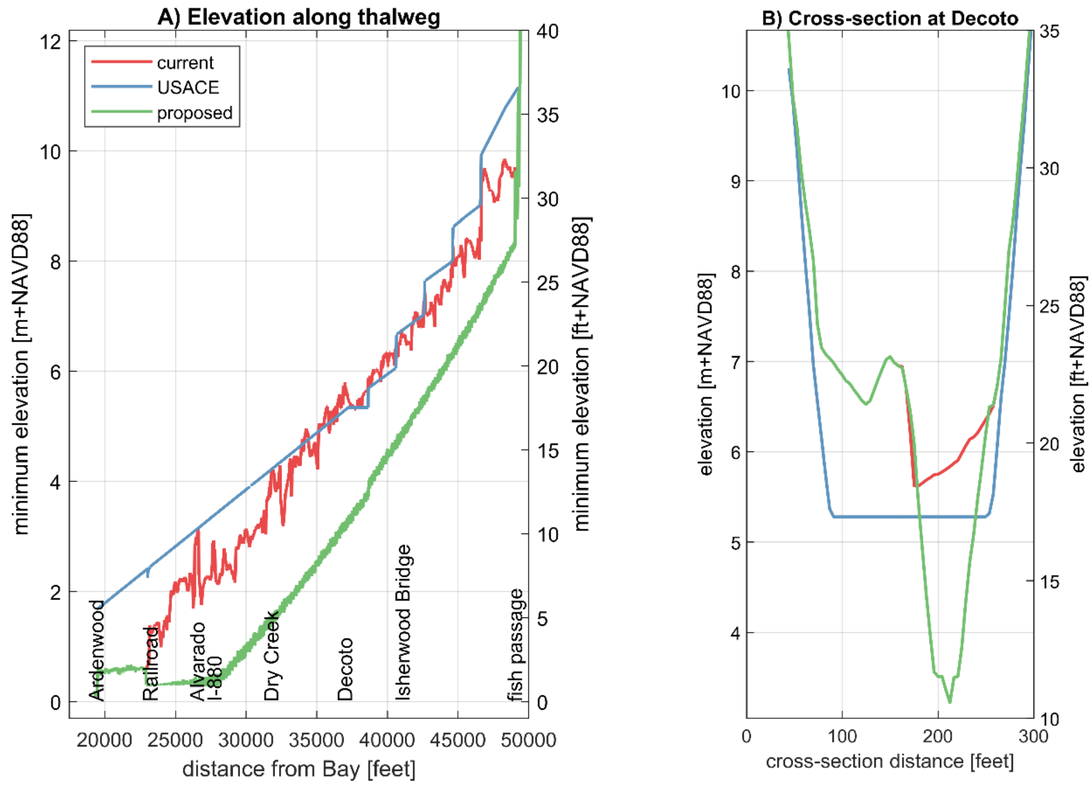

Figure 5. Three baseline scenarios were evaluated in this study. The left panel presents the minimum elevation along the thalweg of Alameda Creek from Ardenwood to fish passage. Right panel: cross-section at Decoto.

Moreover, four other alternatives were evaluated in the Delft3D FM model. All alternatives run with the proposed cross-section from the DHI study. For these alternatives, no topo-bathymetry exists and therefore an algorithm was written to create the necessary input files for Delft3D FM on the basis of the current situation.

4. **Alternative #1**: start at 3ft and linearly move upstream to the proposed design.
5. **Alternative #2:** start at 3ft and smoothly move upstream towards the fish passage
6. **Alternative #3**: start at 5ft and smoothly move upstream towards the fish passage
7. **Alternative #4**: start at 8ft and linearly move upstream to the proposed design

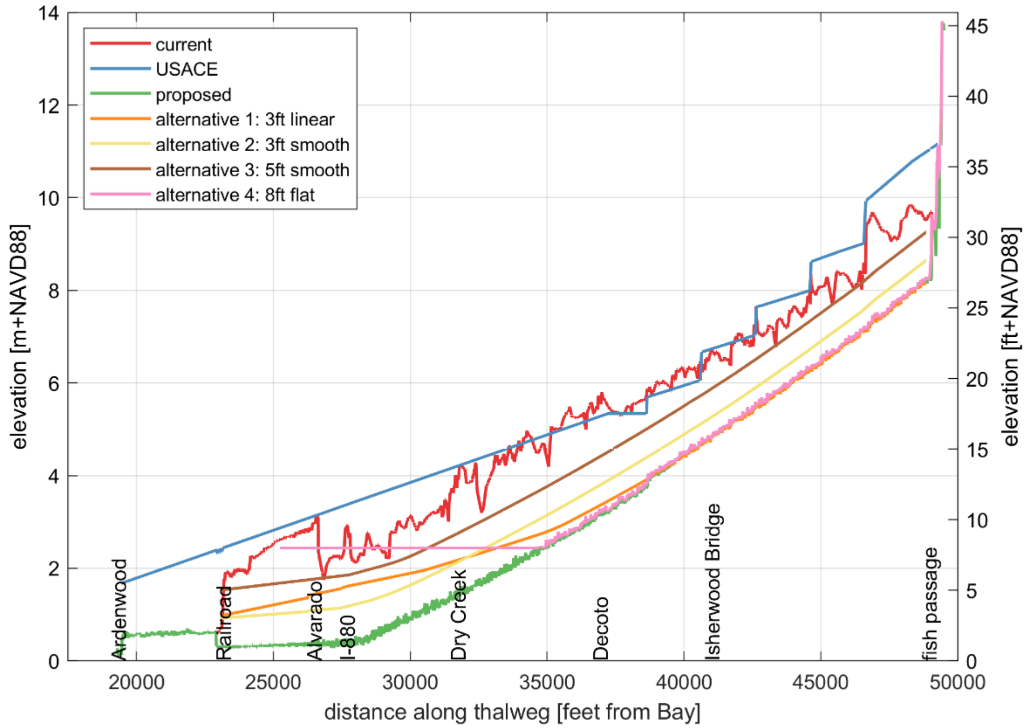

Figure 6. The 7 scenarios as evaluated in the Delft3D FM model include the three baseline situations from Figure 5

Table 1 provides an overview of the seven scenarios evaluated and their respective bed levels at four locations along the thalweg. Note that these are the minimum elevations at the start of the Delft3D simulation.

Table 1. Overview of 7 scenarios and their minimum elevation at the start of the simulation

		Minimum elevation [ft+NAVD88]			
#	Name	Railroad	Dry Creek	Decoto	Fish passage
1	current	9.8	13.1	18.4	31.3
2	USACE	10.2	13.8	17.3	36.0
3	proposed	1.0	4.6	10.2	27.0
4	Alternative 1: 3ft linear	3.0	7.1	11.0	27.0
5	Alternative 2: 3ft smooth	3.0	7.0	12.5	28.3
6	Alternative 3: 5ft smooth	5.0	9.0	14.5	30.3
7	Alternative 4: 8ft flat	8.0	8.0	10.5	27.0

4 Model Validation

4.1 Quality Assurance and Collaboration

During a workshop session on October 20th, analysts showed the model developments to the ACFCD team. They reviewed the methods and results for the calibration and validation of the model. The model application was conducted after the team agreed that the process was robust.

4.2 Hydrodynamic Model Validation

The Delft3D model setup introduced in Section 3 was used to simulate the water years 2014 and 2017 (WY2014 and WY2017) to validate hydrodynamic predictions in San Francisco Bay and Alameda Creek. For this validation, we utilized a brute force simulation with a 15-minute inflow at Niles (Approach 3; see Section 3.5).

Model performance in the San Francisco Bay is strongly influenced by the source of the downstream boundary conditions. In this study, we nested the model in a large-scale model developed by Nederhoff et al. (2021). The model reproduces still water levels at Alameda (NOAA station #9414750) with an RMSE of 0.07 m (or 2.8 inches). Figure 3 shows an overview of performance regarding the instantaneous still water level, tidal water levels, and daily-averaged water levels. Moreover, tidal water levels at San Mateo and Dumbarton Bridges are reproduced with an RMSE of 0.11 and 0.15 m, respectively. Note that the model error does increase when going deeper into the estuary, but gives confidence that (tidal) water levels are reproduced well.

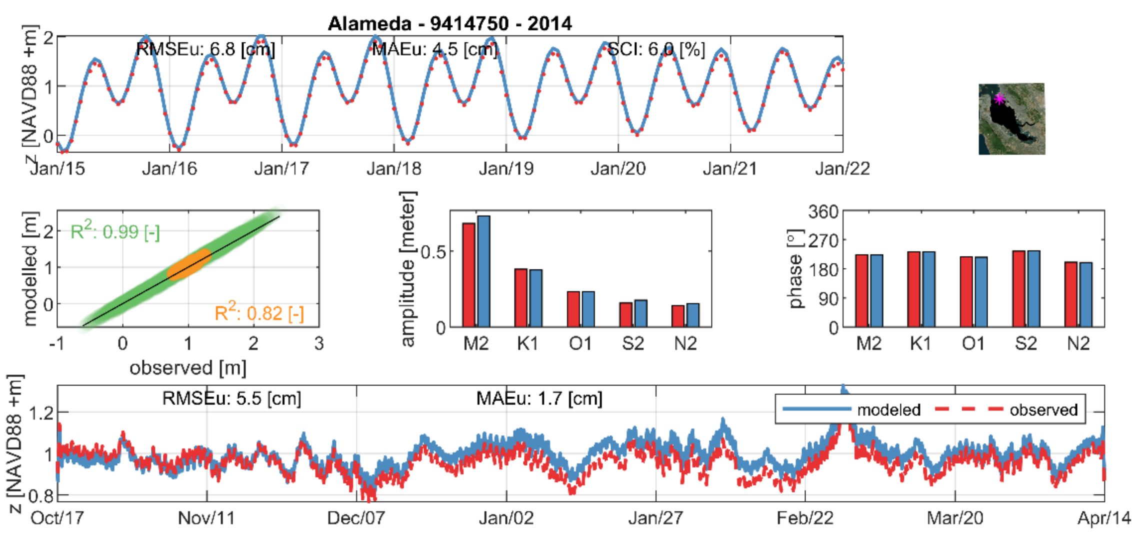

Figure 7. Overview figure of model skill. The top panel is instantaneous still water level. Left-middle middles show tidal (green) and daily-averaged (orange) water levels as observed and modeled. Right-middle panels show tidal amplitudes and phases as modeled and simulated. The bottom panel shows the daily-averaged water level.

Moreover, the hydrodynamic skill in Alameda Creek is determined at Fremont (#11179100) and Union City (#11180700) for the same period. Figure 8 presents observed and modeled time series of flow at Fremont (#USGS 11179100), which gives confidence that the model routes water correctly. Moreover, Figure 9 presents the predicted stage at the same station. Discharge values are reproduced with an RMSE of 6.6 m^3/s and 7.1 m^3/s at Fremont and Union City (#11180700). Stage levels are reproduced with an RMSE of 0.12 or 0.21 m for the same stations. Differences between the model and observations are noticeable, but this validation does give confidence that hydrodynamics in Alameda Creek are well captured.

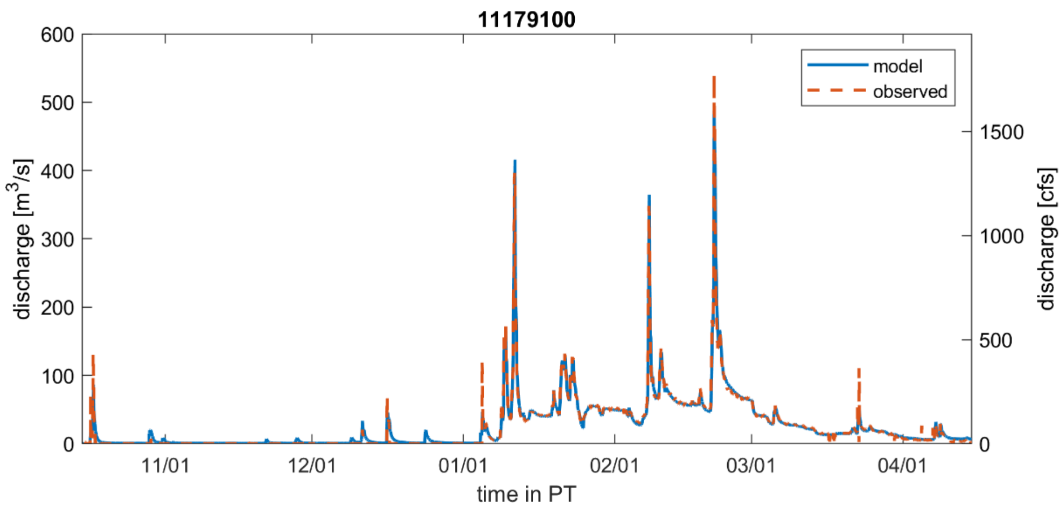

Figure 8. Time series of observed and modeled discharges at Fremont (#11179100) for WY2017

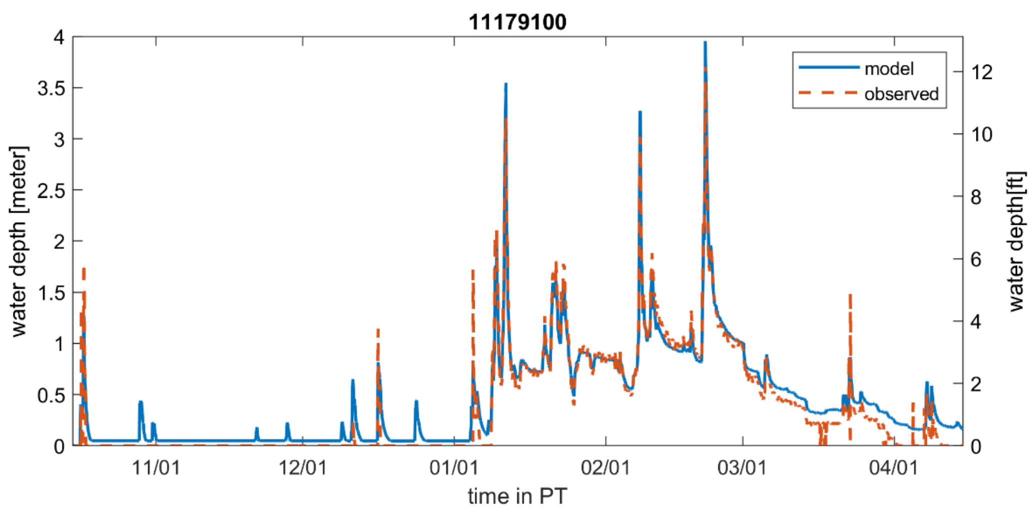

Figure 9. Time series of observed and modeled stage at Fremont (#11179100) for WY2017.

4.3 Morphological Validation

The morphological model was validated based on the comparison between observed and simulated sediment deposition volumes and bed level changes (bed level cross-sections) in Alameda Creek in the period from 1 Jan 2006 and 1 Jan 2019. For this validation, we used the model reference run with the brute force time series with daily inflow (Approach 2 described in Section 3.5), which reproduced the observed deposition/bed level changes most accurately. The robustness of the model concerning the applied time series (brute force vs. compressed times series; Section 2) and various model parameter settings is demonstrated in Appendix 6.2B. The observed sediment deposition volumes and bed level changes in Alameda Creek were derived from the differences between the measured 2006 and 2019 LIDAR beds (see Section 3.2).

Figure 10 shows the observed and simulated sediment volume change (i.e. erosion and deposition) per cross-section (i.e. for each cell row of the computational grid in cross-flow direction in cubic meters per meter per year or m^3/m/year) in Alameda Creek between the fish passage and the creek mouth. The observed LIDAR data indicates that almost the entire stretch downstream of the fish passage is characterized by sediment deposition in the period 2006–2019, although there are large variations in the deposition rate, the latter ranging from 0 m^3/m/year to a maximum of about 70 m^3/m/year. Significant erosion only occurs in the mouth area (up to ca. -32 m^3/m/year) and near the railroad (up to ca. 5 m^3/m/year).

The model generally reproduces the observed sediment deposition in the creek. Nevertheless, the model underestimates the sediment deposition i) between the fish passage and Decoto, ii) between the railroad and Ardenwood and iii) near the mouth. In contrast, the deposition is overestimated between ca. 12,000 feet and 6,000 feet upstream from the mouth. The colored dashed lines in Figure 10 show that the simulated sediment deposition in the upper creek is mainly associated with gravel and mud, while sand is eroded in this area. Most of this sand is accumulated further downstream between the railroad and Ardenwood, where the deposition of gravel and mud is less pronounced. The latter is even eroded in the area of the railroad. Downstream of Ardenwood, sediment deposition is almost exclusively associated with mud.

Figure 11 shows the observed and simulated cumulative sediment volume change (i.e. the sum of the volume changes per cross-section in cubic meters per year or m^3/year) in Alameda Creek. The figure emphasizes that the model underestimates the observed sediment deposition in the creek, except for the area between ca. 12,000 feet and 6,000 feet upstream from the mouth, where the slope of the red curve (model) is larger than the slope of the blue curve (observed data). At the mouth, the model predicts an average cumulative volume change of about 15,500 m^3 per year, while the LIDAR data indicates an average change of 22,000 m^3 per year. Figure 11 further confirms that gravel is merely locally redistributed with a small downstream trend depending on local availability and that sand is eroded in the upstream [part of the creek and is deposited again further downstream between the railroad and Ardenwood. Mud accumulates in the entire (illustrated) creek but is eroded in the stretch between the railroad and Ardenwood and near the mouth. These patterns can also clearly be seen in Figure 12, which shows the erosion and deposition of the three considered model sediment fractions along and across Alameda Creek and clearly indicates the different behaviour of three different sediment types.

In Figure 13, the initial and final bed volume of the three considered sediment fractions in the model of Alameda Creek (upper panel) as well as the corresponding change in volume (lower panel) are depicted. From the upper panel it becomes clear that gravel is the dominant sediment fraction in the upper creek at the start (2006) and the end (2019) of the simulation, while it is mud in the lower creek, which agrees with the collected sediment samples (Pearce & McKee 2009). The volume of gravel but particularly of mud increases during the simulation. The increase in gravel volume can be explained by gravel input from further upstream, while the mud volume increases due to both mud input from upstream and from the southern San Francisco Bay. In contrast to gravel and mud, no significant sand volume increase can be observed but especially a relocation of sand from upstream to more downstream regions. This is because sand is hardly available in the bed upstream of the fish passage and downstream of Ardenwood in the model (in line with the sediment samples taken by Pearce & McKee 2009).

Besides the observed sediment volume changes in Alameda Creek (see above), the model was also validated against observed bed level changes at individual cross-sections of the creek. Figure 14 shows a selection of bed level cross-sections from the upper, central and lower Alameda Creek. At all four cross-sections, the LIDAR data implies dominant deposition on the creek banks, while the channel depth is relatively stable (except for cross-section 1300, where, however, the 2006 LIDAR seems to underestimate the actual channel depth). This pattern is representative of the morphodynamics observed in most areas of the creek in the period 2006–2019. The model is generally capable of reproducing the observed bank deposition, although, the deposition is slightly underestimated at all four cross-sections. At the same time, the channel depths are relatively stable in the model as is observed in the data.

Finally, Figure 15 illustrates a skill diagram of the observed versus the simulated bed erosion and deposition in Alameda Creek. Generally, the observed and simulated bed level changes agree, although, the model shows a trend to underestimate the observed deposition in the creeks, as was already indicated by the validation figures above. The exact reason for this remains unclear since the underestimation of the total cumulative volume change was also observed in all sensitivity runs performed with the model (see Appendix 6.2B). However, since the observed deposition in the creek mainly occurs on the vegetated creek banks and the model systematically underestimates this deposition, the lack of vegetation in the model is likely a major reason for the underestimation of the observed deposition in Alameda Creek. Besides, inaccuracies i) of the 2006 LIDAR (which is missing several low points; see Section 3.2.2), ii) of the spatially varying friction field as derived from the 2019 LIDAR and satellite images and iii) of the assumed initial sediment availability in the creek bed may hold responsible for the discrepancy between the observations and the model.

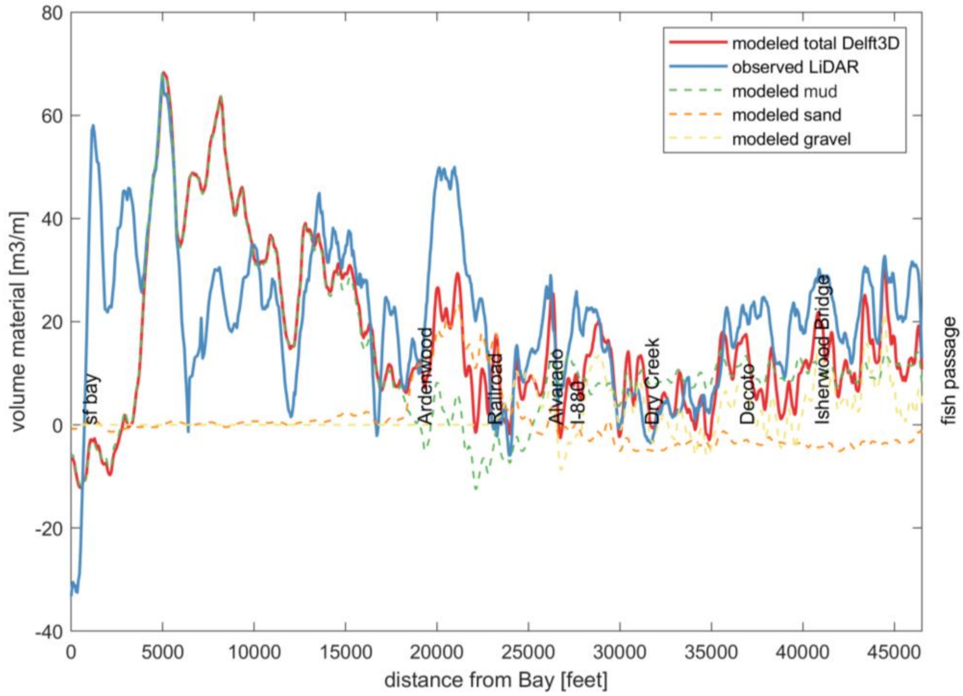

Figure 10. Comparison of the observed and the simulated (brute force time series – Approach 2) sediment volume change (i.e. deposition or erosion) per cross-section (i.e. each cell row of the computational grid in cross-flow direction) [m^3/m/year] in Alameda Creek in the period from 1 Jan 2006 to 1 Jan 2019 for the model validation.

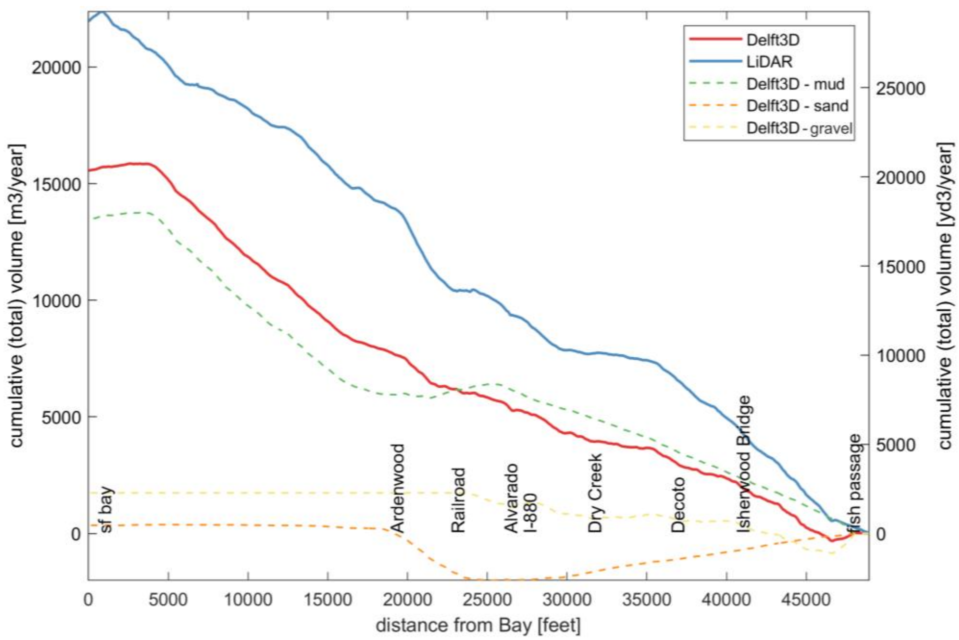

Figure 11. Comparison of the observed and simulated (brute force time series – Approach 2) cumulative sediment volume change (i.e. deposition or sedimentation) [m^3/year] in Alameda Creek in the period from 1 Jan 2006 to 1 Jan 2019 for the model validation. The dashed lines indicate the volumes per considered sediment fraction.

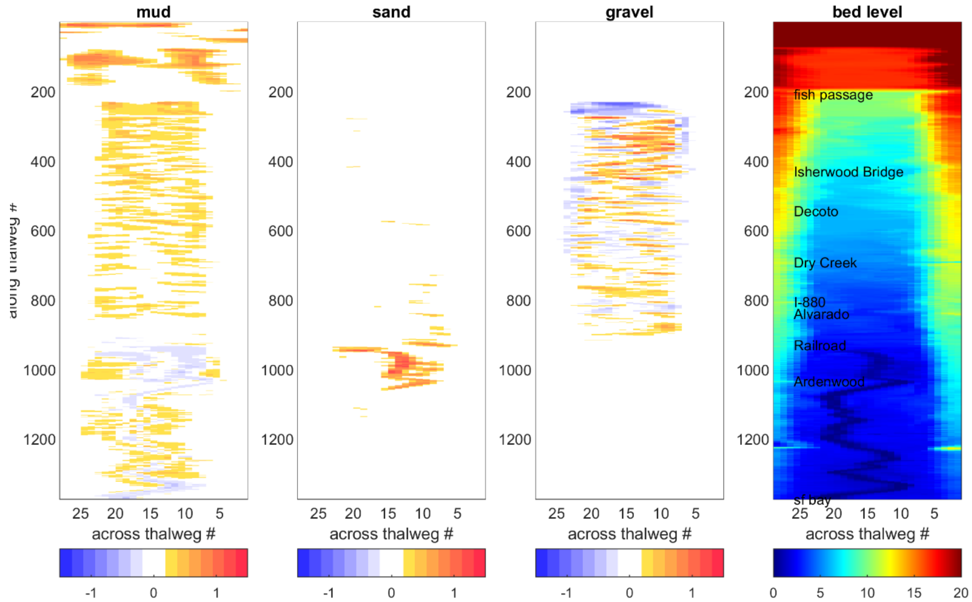

Figure 12: Simulated (brute force time series – Approach 2) erosion and deposition of mud, coarse sand, and fine gravel [m] in Alameda Creek in the period from 1 Jan 2006 to 1 Jan 2019 (left three panels) as well as final simulated bed level (right panel).

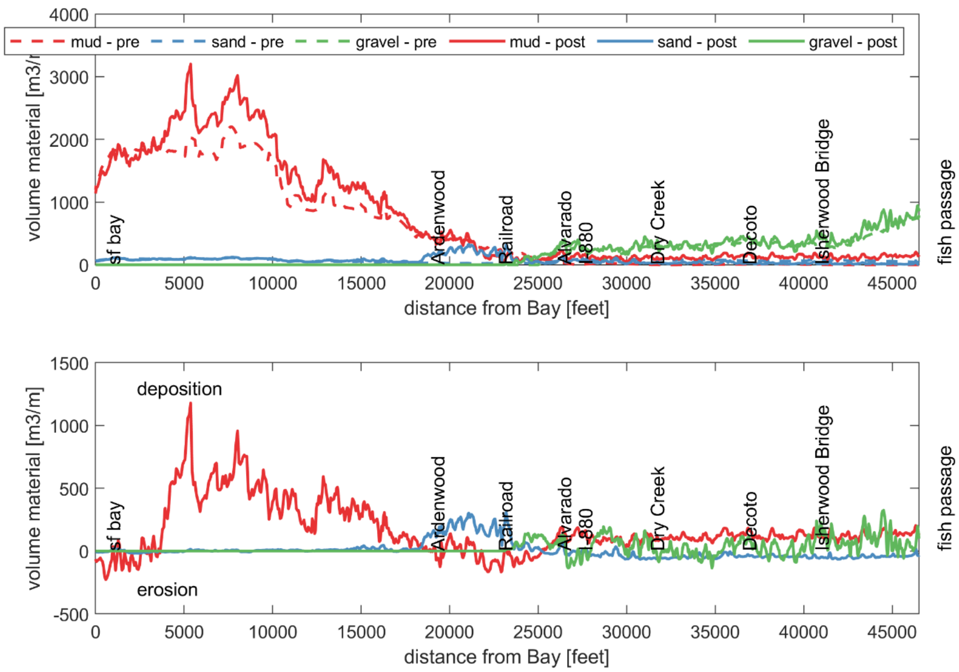

Figure 13. Upper panel: Initial (1 Jan 2006) and final (1 Jan 2019) volume of the three considered sediment fractions mud, coarse sand, and fine gravel in the model of Alameda Creek. Lower panel: volume change of the three considered sediment fractions in the model bed between Fish Passage and the mouth of Alameda Creek in the period from 1 Jan 2006 to 1 Jan 2019. All illustrated volumes are based on the simulated brute force time series (approach 2) and in m3/m.

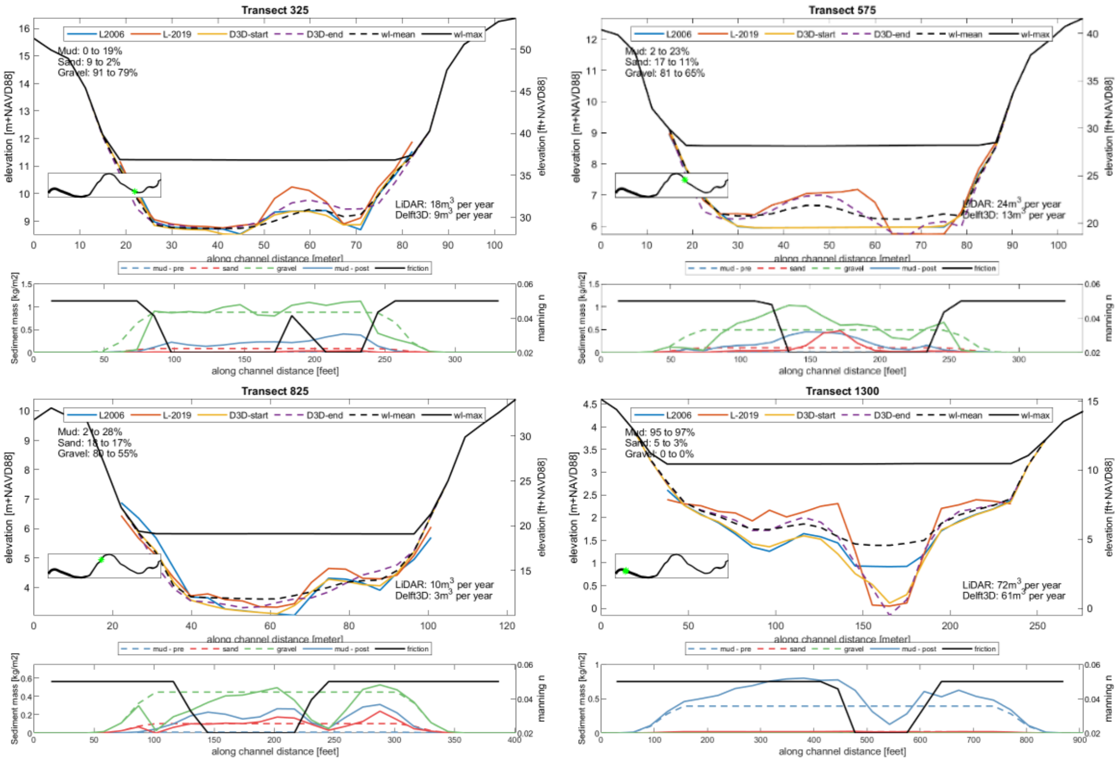

Figure 14. Observed and simulated brute force time series – Approach 2 bed level changes along various cross-sections of Alameda Creek between Fish Passage and Ardenwood in the period from 1 Jan 2006 to 1 Jan 2019. The locations of the cross-sections are indicated by a green dot in the overview maps of the creek on the left-hand side of each plot.

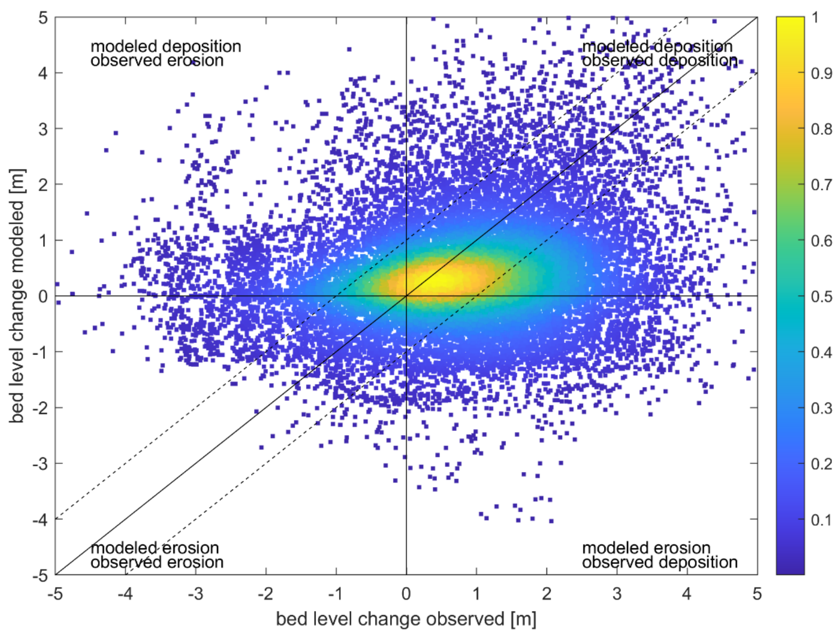

Figure 15: Skill diagram of the observed versus the simulated (brute force time series – Approach 2) bed level changes [m] in Alameda Creek in the period 1 Jan 2006 to 1 Jan 2019. The dotted line represents the bed level changes within 1 meter from the target.

5 Model Application: Scenario Analysis

The calibrated and validated hydrodynamic and morphological model was used to compare the effect that different bed level configurations had on the tidal water levels and computed sediment deposition volumes. For this, the same period and approach was used as for the validation of the model. Section 3.7 presents the seven bed level scenarios considered here.

5.1 Hydrodynamics

Figure 16 illustrates the variations in tidal amplitude for the different simulated scenarios. It shows that tidal amplitudes consistently reach approximately 0.7 m (2.3 ft) at the juncture of San Francisco Bay and Alameda Creek across all scenarios. However, as the tidal wave progresses inland through Alameda Creek, there is a noticeable reduction in amplitude. This decrease is attributed to factors such as friction, shallowing of the creek, and river flow dynamics.

The depicted tidal amplitudes represent *average* values calculated over the period from 2006 to 2019. The tidal amplitude is based on M2, the largest lunar constituent related to the direct gravitational effect of the Moon on the tides. This period for the model simulation allows for the morphological development of the bed and encompasses varying conditions in Alameda Creek, ranging from high to low discharge. These varying conditions significantly impact tidal propagation. For example, notice the shallowing for the different bed level scenarios in the bottom panel of Figure 16 which affect tidal propagation upstream.

At Ardenwood tidal amplitudes diminish to around 0.5 m, marking a 30 % reduction over a span of 20,000 ft. It is at this location that variations between different bed level scenarios become apparent. For instance, the scenario featuring the USACE design shows a notable step in the bed level, leading to a rapid decline in the M2 tidal amplitude. In contrast, the proposed design scenario, characterized by the deepest bed level among all evaluated options, exhibits the least reduction in tidal amplitude. Nevertheless, even under this design, a continued decrease in tidal amplitudes is simulated as one moves further upstream.

Comparatively, the alternative scenarios explored in the study all demonstrate more pronounced reductions in tidal amplitude than the proposed design, owing to their relatively shallower bed levels. The railroad passage acts as a significant obstruction in all scenarios, leading to a marked decrease in tidal amplitude. However, under the proposed design, tides can propagate upstream to Dry Creek. In scenarios 1 and 2, which both feature a bed elevation of around 3 ft at the railroad passage, tidal propagation extends up to the I-880. Conversely, in the less deep scenarios 3 and 4, with bed elevations of 5 ft and 8 ft respectively, tidal movement is halted at the railroad passage. The tidal propagation from scenarios 3 and 4 looks quite similar to the current situation where tides also do not pass the railroad.

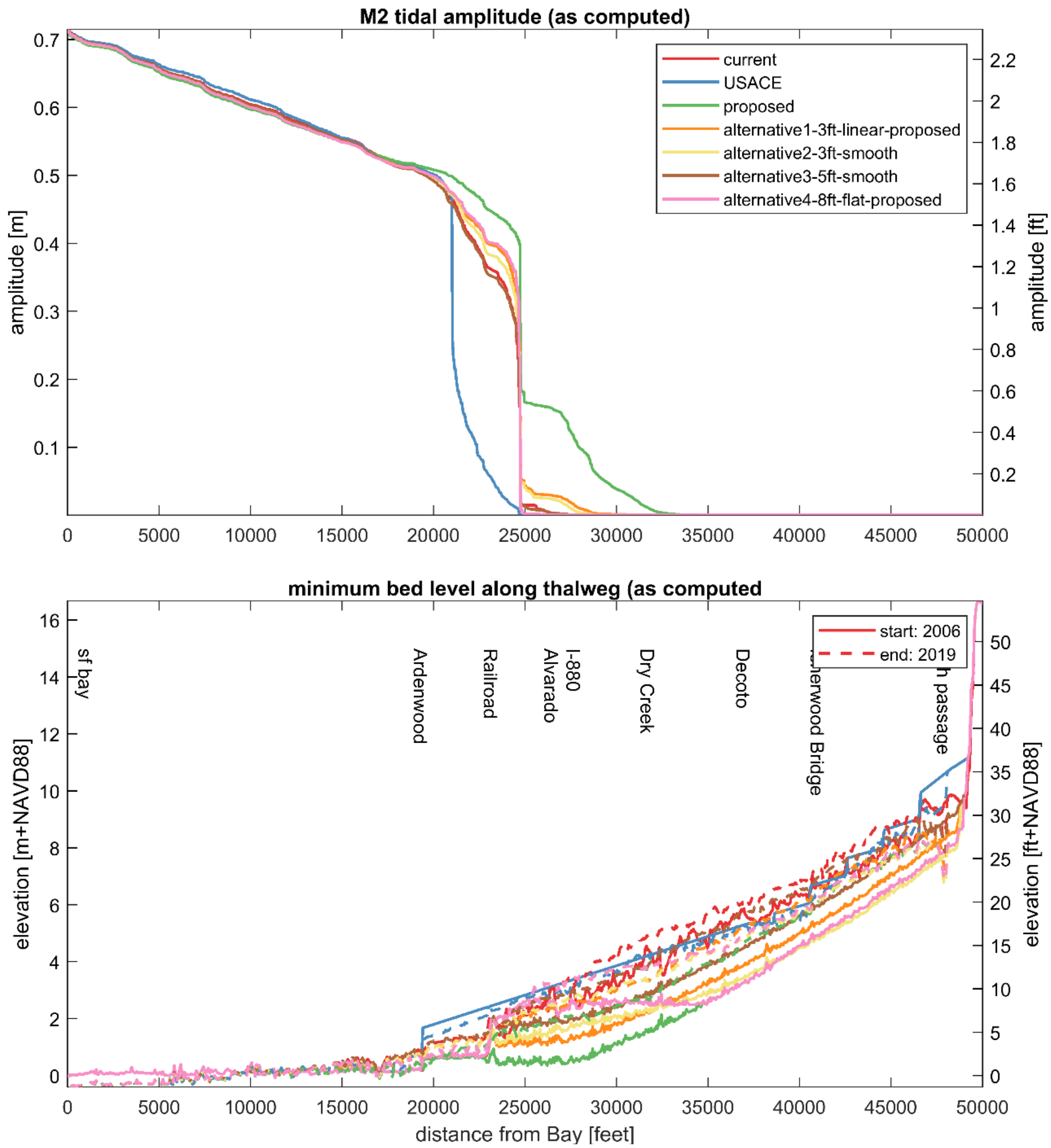

Figure 16. Comparison of the tidal propagation across Alameda Creek for the different scenarios. The upper panel shows the Delft3D computed M2 amplitude. The bottom panel shows the relative minimum bed level elevation at the start of the simulation.

5.2 Morphodynamics

Figure 17 displays the variations in sediment volume change, encompassing both erosion and deposition, for each cross-sectional cell row of the computational grid along the thalweg of Alameda Creek, from the fish passage to the creek mouth. The data progresses from upstream to downstream (depicted from right to left in the figure). In all scenarios, erosion is initially observed near the fish passage, followed by deposition up to the Alvarado area. The average rate of sediment deposition between Alvarado and Isherwood Bridge ranges from +6.6 to +11.2 m^3/m/year with the USACE design showing the highest and most variable rates. The variability is primarily attributed to the presence

Deltares

of hard structures or steps in the profile. The proposed design results in a lower rate of deposition compared to the current situation, while the four alternative designs exhibit, on average, higher rates of deposition – between 5 % to 85 % higher than the proposed design.

Between Alvarado and Ardenwood, significant differences are observed across scenarios due to the substantial impact of the railroad on computed hydrodynamics and sediment transport. Downstream of Ardenwood, towards the San Francisco Bay, all scenarios demonstrate first a consistent depositional pattern until 5000 ft from the San Francisco Bay around +50 m^3/m/year after which compute an erosional trend, averaging around 20 m^3/m/year. The bathymetry and thus instantaneous morphodynamic results in this section are relatively similar across all scenarios.

Figure 19 compiles these instantaneous cross-sectional results to present the total cumulative volume of sedimentary material (mud, sand, and gravel) deposited in Alameda Creek. All scenarios indicate an overall increase in deposition from the fish passage towards the San Francisco Bay. Along the thalweg, the proposed design shows the least cumulative deposited volume, whereas the USACE design results in the highest. The proposed design effectively reduces the maximum total deposition across Alameda Creek by 12 % (from 11,732 to 10,328 m^3/year). The four alternative designs yield higher deposition rates, ranging from 3 % to 14 % more than the proposed design. However, more significant local differences are also noted. For instance, between Dry Creek and the fish passage, the current scenario results in a deposition of 3,867 m^3/year, compared to 2,618 m^3/year in the proposed design – a reduction of approximately 48 %. The four alternative designs result in deposition volumes ranging from 2,843 to 4,669 m^3/year for the same stretch of the creek.

Overall, the proposed design is the most effective in minimizing deposition across Alameda Creek, as shown in Table 2. Among the four alternative designs, a clear trend emerges: deeper channel designs correlate with less simulated deposition. For example, alternatives 2 and 3, starting at 3 feet as opposed to the proposed design's 1 foot+NAVD88 (see Figure 6), yield very similar volume changes per cross-section and cumulative depositional values, which are 9 % (up to Dry Creek) to 3 % (maximum for the entire thalweg) higher than the proposed design. The design starting at 5 feet (alternative 1) results in 30 % to 8 % more deposition for the values evaluated at Dry Creek or the maximum along the thalweg. Alternative 4, starting at 8 feet, leads to deposition rates similar to the current situation, though locally higher in some areas. The difference between alternatives 1 and 2 is limited (orange and yellow lines in Figure 18) indicating that the specific shape of the profile is less relevant compared to the depth.

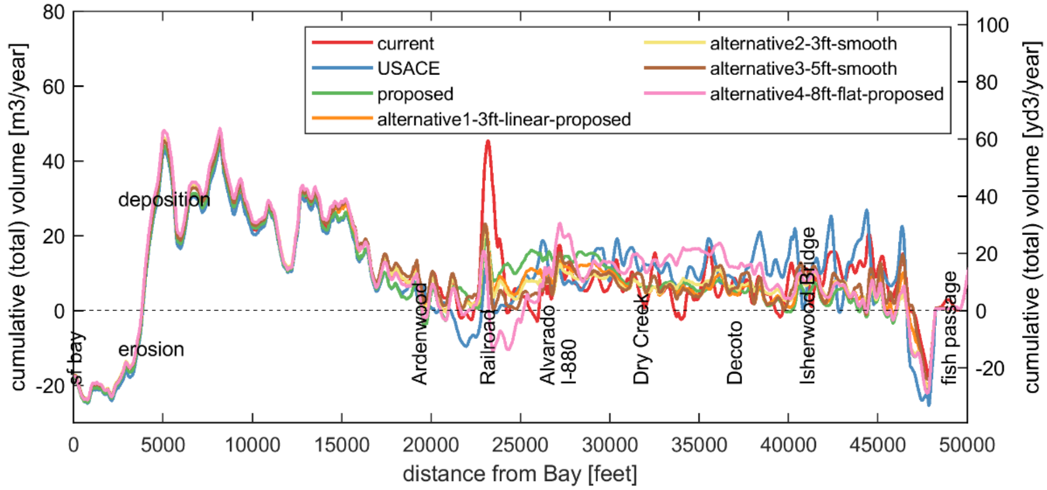

Figure 17. Comparison of the the simulated (brute force time series – Approach 2) sediment volume change (i.e. deposition or erosion) per cross-section (i.e. each cell row of the computational grid in cross-flow direction) [m³/m/year] in Alameda Creek in the period from 1 Jan 2006 to 1 Jan 2019 for the scenario analysis. The different colored lines indicate the different scenarios.

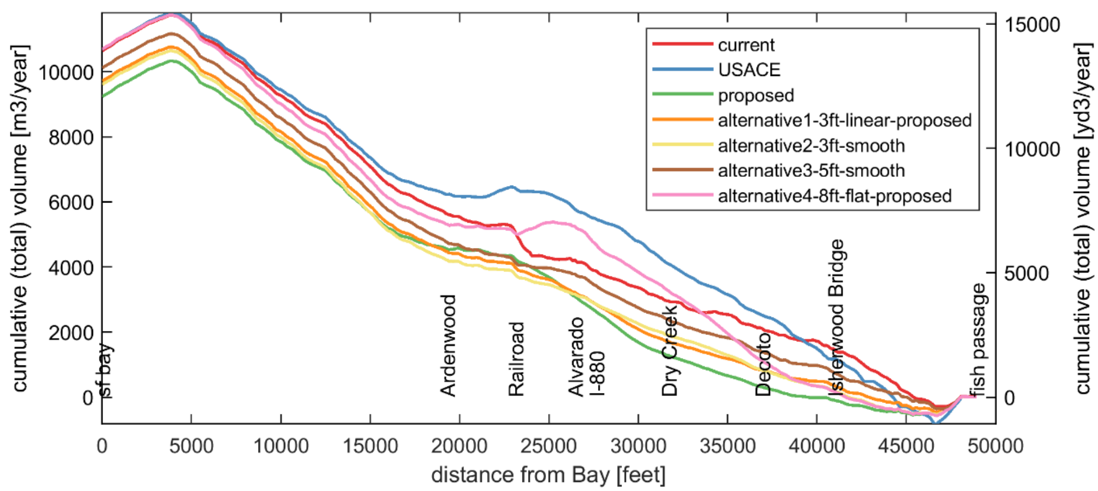

Figure 18. Comparison of the simulated (brute force time series – Approach 2) cumulative sediment volume change (i.e. deposition or sedimentation) [m³/year] in Alameda Creek in the period from 1 Jan 2006 to 1 Jan 2019 for the scenario analysis. The different colored lines indicate the different scenarios.

Table 2. Breakdown of the computed effects for the scenarios evaluated.

	Cumulative deposition from fish passage until Dry Creek		Cumulative deposition across Alameda Creek from fish passage untill the SF Bay	
Scenarios	**Volume [m^3/year]**	**Relative to proposed**	**Volume [m^3/year]**	**Relative proposed**
current	3,867	148 %	11,732	114 %
USACE	5,466	209 %	11,814	114 %
proposed	2,618	100 %	10,328	100 %
Alternative 1: 3ft linear	2,843	109 %	10,757	104 %
Alternative 2: 3ft smooth	2,850	109 %	10,640	103 %
Alternative 3: 5ft smooth	3,410	130 %	11,164	108 %
Alternative 4: 8ft flat	4,669	178 %	11,740	114 %

6 Conclusions and Recommendations

6.1 Conclusions

In this conclusions chapter, we will synthesize the key findings of this study. This study focused on improving understanding of hydrodynamics, sediment transport, and morphodynamics in Alameda Creek's lower portion under various design scenarios.

A model was developed using the Delft3D Flexible Mesh suite. The domain covered the southern San Francisco Bay and Alameda Creek up to Niles Canyon utilizing detailed topo-bathymetry. The model was forced with tidal downstream boundary conditions and upstream observed discharge time series. Additionally, the model accounted for three sediment fractions (mud, sand, and gravel) that were simulated with the Englund-Hansen sediment transport formula and also accounted for in the bed composition.

The model was able to reproduce the water levels in the San Francisco Bay and the creek discharge and stages when forced with a 15-minute observed discharge time series at Niles with a root-mean-square error of 0.06 to 0.21 m (3 to 8 inches). Morphodynamics were also well resolved for validation of the change between 2006 and 2019 as observed by LIDAR measurements. In particular, computed morphological change at cross-sections showed good agreement with observed changes. Moreover, the cumulative depositional trend along Alameda Creek was fairly well resolved, albeit underestimated locally between the fish passage and Decoto, between the railroad and Ardenwood, and near the mouth resulting in a total underestimation of ~30 % of the entire Alameda Creek.

The focus of this study was to evaluate the redesign alternatives proposed by the Alameda County Flood Control District for the low-flow channel of Alameda Creek. In particular, seven scenarios were considered. The three main scenarios assessed were: 1) the current situation without modifications; 2) the USACE design, characterized by a largely trapezoidal channel and 3) a proposed design with a deeper minimum elevation (locally 1 ft), featuring a low-flow channel. Additionally, four alternative scenarios were evaluated, varying in their starting elevations and transitions to deeper sections. These scenarios range from starting elevations of 3 ft to 8 ft and all at a similar low-flow channel. The analysis of these scenarios provided valuable insights into the potential impacts of different channel designs on the area's hydrodynamics and sediment transport.

Tidal amplitudes at the San Francisco Bay-Alameda Creek juncture reach on average 0.7 m (2.3 ft). However, as tides move inland of Alameda Creek, a significant reduction in amplitude occurs due to factors like friction, creek shallowing, and river flow dynamics. Over the 2006–2019 period, these conditions, including varied creek discharge levels and bed morphological changes, significantly influence tidal propagation. Tidal amplitudes decreased to approximately 0.5 m at Ardenwood regardless of the bed level scenarios evaluated. The USACE design caused the strongest decline in amplitude due to a step in the bed level, whereas the proposed design with the deepest bed level shows the smallest reduction. Alternative scenarios, with shallower bed levels, exhibited greater amplitude reductions. The railroad passage consistently acted as a restrictor, but under the proposed design, tides can progress upstream to Dry Creek. In scenarios with bed elevations of around 3 ft at the railroad passage, tides reach up to the I-880, while in shallower scenarios, including the current situation, tidal movement ceases at the railroad passage.

The analysis of the various scenario runs revealed strong morphodynamic change in the Alameda Creek. For all bed level scenarios, near the fish passage, erosion occurred, followed by consistent sediment deposition up to the Alvarado. The observed bed level changes between 2006 and 2019 indicated that the average deposition rate between Alvarado and Isherwood Bridge fluctuated between +6.6 to +11.2 m^3/m/year. The proposed design leads to a reduced rate of sediment deposition compared to the existing conditions. In contrast, the four alternative designs show, on average, an increase in deposition rates, ranging from 5 % to 85 % more than that of the proposed design. Significant differences in morphologic change were noted between Alvarado and Ardenwood, largely due to the influence of the railroad. Downstream of Ardenwood, towards the San Francisco Bay, the scenarios consistently showed first a depositional trend reaches +50 m^3/m/year after which the trend reversed to an erosional in the order of -20 m^3/m/year.

Across all scenarios, a net deposition was computed from the fish passage towards the San Francisco Bay. The proposed design was found to be the most effective in minimizing deposition throughout Alameda Creek, reducing the maximum total deposition by 12 % compared to the current scenario. The four alternative designs resulted in higher deposition rates. This study indicated a clear pattern: deeper channel designs correlated with reduced sediment deposition. For example, alternatives with deeper starting points showed lower cumulative depositional values compared to shallower designs. This trend was evident in the comparative analysis of deposition rates across different design scenarios.

6.2 Recommendations

Building on the insights garnered from this work, this section aims to outline pragmatic and forward-looking recommendations for the modeling of the Alameda Creek Flood Control Channel focusing on hydrodynamics, sediment transport, and morphology.

The data that informed the initial and validation conditions for both the bed level and bed composition deserves further attention. In particular, while LIDAR 2006 and 2019 provided a complete surface and thus a bed level estimate for the entire study area that was deemed of higher accuracy than several cross-sectional data for 2000–2009 than previous studies used. However, especially in LIDAR 2006, the bottom of the channel is not well represented, which limited the trustworthiness of the observed morphological change. Additional data, both in time (e.g. multiple time stamps) and including additional bathymetric surveys would be beneficial for our understanding of the morphology in Alameda Creek. Moreover, the bed composition was based on a limited number of boring logs from Pearce & McKee (2009) without any additional information on variation in depth. More detailed data on the bed composition both in space and depth will be beneficial to provide initial conditions for the modeling.

Throughout this study, forcing conditions were selected based on availability and consistency. This resulted in the usage of daily discharge to ensure consistency between sediment concentrations that are only provided daily in the morphological runs. However, sensitivity testing revealed a large response in the computed stage whenever using a 15-minute or daily discharge time series. Hence, it deserves the recommendation to explore a method to downscale sediment transport concentrations to the same 15-minute temporal resolution to have one model simulation that can be used for extreme water levels and sediment transport predictions. Moreover, inflow into Alameda Creek was only based on observed discharge at Niles including a simple abstraction rate based on reported abstraction rates into the Quarry Lakes. However, for long-term continuous simulations, a water balance of Alameda Creek might provide additional insights into missing processes that determine inflow (e.g. precipitation) at outflow (e.g. percolation and evaporation).

Testing with different friction values showed a large sensitivity in the computed stage relative to the absolute friction value used and bed level variations cross-channel between, for example, the channel and the banks due to friction gradients. In this study, satellite images were used to (statically) detect channels and vegetated banks. It deserves a recommendation to explore the use of the Dynamic Vegetation Module (e.g., Willemsen, et al. 2022) especially when redesigning channels. Ecosystems are known to have rapid geomorphological developments and their dynamics result from a two-way interaction between ecological and physical (hydrodynamic and morphodynamic) processes. Accounting for these variations over time might increase model skill. Lastly, sensitivity testing showed a strong response to the settling velocity of mud. An increased morphologic skill could be obtained when either calibrating with and/or having field data to fine-tune settling velocities.

The railroad passage has been identified as a critical point that substantially affects flow and sediment transport. Therefore, it warrants a more detailed and targeted study to better understand and mitigate its impact on the creek's overall functioning. The first step in this expanded investigation should be the collection of more comprehensive bed composition data at and around the railroad passage. In addition to bed composition data, it would be beneficial to conduct a series of targeted hydrodynamic simulations focusing specifically on the railroad passage area.

Seven bed level scenarios were evaluated, with the four alternatives all based on the proposed cross-section from the DHI study. This investigation revealed a marked sensitivity in sediment transport capacity to the depth of the channel using this specific cross-section. However, it did not explore other potential cross-section configurations that might yield similar sediment transport capacities. Given these findings, it is recommended that any future studies should expand the scope of the investigation to include a variety of cross-section designs.

Lastly, the current study utilized a depth-averaged model and while it provided valuable data on tidal amplitudes and general hydrodynamic behaviors, it cannot inherently resolve vertical variations that are critical for understanding and predicting saltwater intrusion patterns. It is therefore recommended to consider further research using a three-dimensional (3D) model to more accurately capture and analyze complex phenomena such as salt intrusion.

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A Sensitivity Analysis Hydrodynamics

A.1 Friction Variations

The river stage (or water depth) in Alameda Creek is sensitive to friction because this parameter is critical in determining flow velocity. In this study, we utilized a lower friction value of 0.020 s/m$^{-1/3}$ in the channel and a higher value of 0.050 s/m$^{-1/3}$ on the banks to mimic the effect of vegetation. A higher Manning's value signifies a rougher channel, translating to slower flow velocities and potentially higher river stages, while a lower value implies a smoother channel with faster flow velocities and potentially lower river stages. Figure 19 shows the sensitivity of 5 friction variations to the computed stage during WY2017. We varied the friction value from 0.023 s/m$^{-1/3}$ (uniform friction) to 0.060 s/m$^{-1/3}$ (the highest value used). The computed river stage almost increased by 1.5 m (~5 feet) depending on the friction value used. Discharge in Alameda Creek is not sensitive to friction variations.

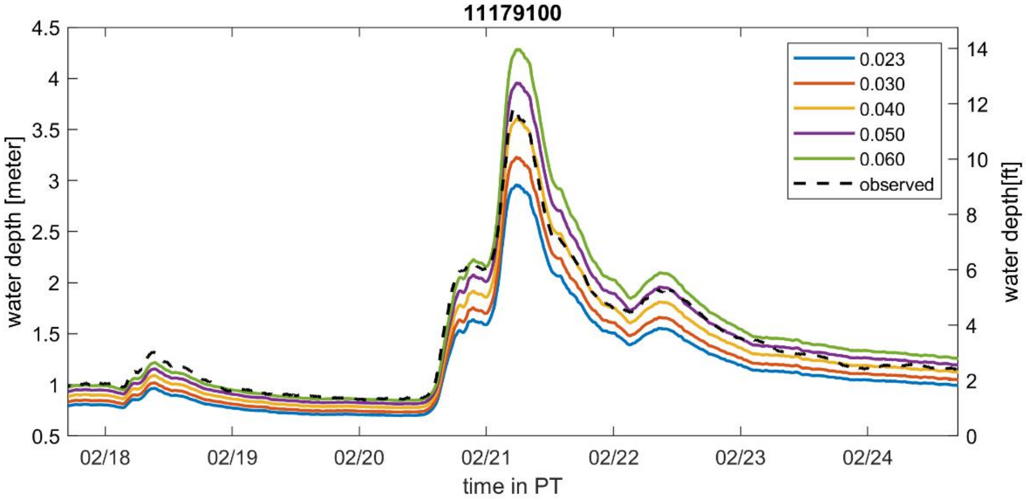

Figure 19. Time series of observed and modeled stage at Fremont (#11179100) during the peak stage of WY2017. Modeled stages are reproduced with a range of simulations testing the sensitivity of friction values used.

A.2 Daily versus 15-Minute Discharge Data

For the hydrodynamic validation, we utilized a brute force simulation with a 15-minute inflow at Niles. However, for the morphodynamic validation and scenario analysis we used daily inflow conditions. This approach was selected to maintain consistency with the daily-averaged sediment concentration data, as using different temporal resolutions could introduce inaccuracies in the model's predictions. The sensitivity to forcing the model with 15-minute inflows or daily averaged is presented in this paragraph.

Both discharge and stage are very sensitive to the temporal resolution applied. Figure 20 presents the stage as observed and computed by Delft3D at Fremont. The Delft3D forced with a discharge boundary with a temporal resolution of 15 minutes can capture quite well the high discharge events. A model forced with daily discharge follows a similar pattern but misses the high-stage peaks. In particular, an underestimation of up to 1.5 m (5 feet) was found. A similar pattern, albeit slightly less extreme, can be found for the discharges.

This sensitivity analysis indicates that particularly river stage, and to a lesser extent discharge, is quite sensitive to the temporal resolution. This finding underscores the need for caution when interpreting stages computed by Delft3D with daily discharges, as these are likely to be underestimations. Our analysis underscores the importance of high temporal resolutions in hydrodynamic modeling to ensure accurate predictions for events.

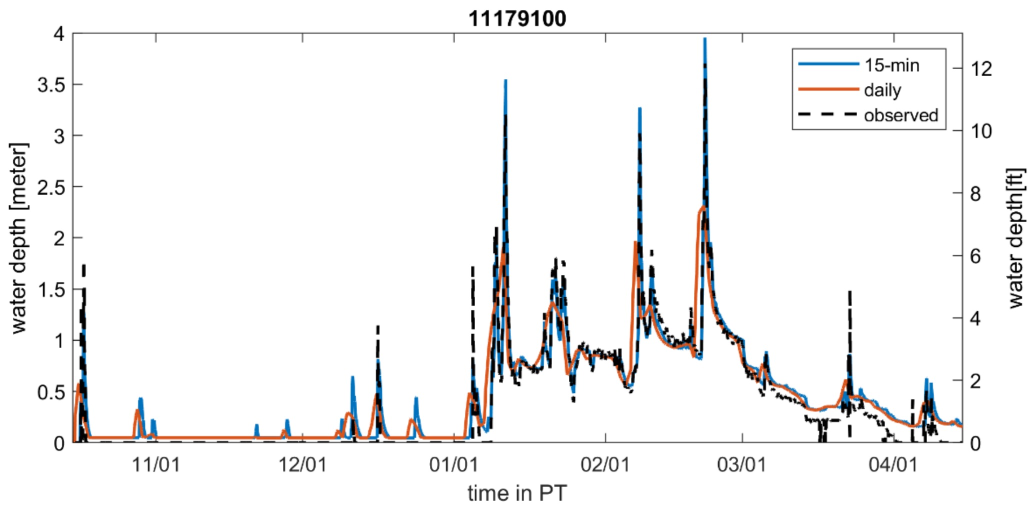

Figure 20. Time series of observed and modeled stage at Fremont (#11179100) for WY2017. Modeled stages are reproduced with either a 15-minute time series or daily inflow conditions.

B Sensitivity Analysis Morphodynamics

B.1 Importance of Model Approach: Brute Force versus compressed Time Series

This section discusses the morphological model sensitivity with regard to the applied brute force time series (used for the validation of the model; Section 4.3) versus the compressed time series (used for testing various model parameters and the model calibration)

Figure 21 illustrates the simulated sediment volume change (per cross-section and cumulative) and the skill diagrams for the validation model run (brute force times series) and the compressed time series run. The compressed time series run shows very similar patterns of the volume change per cross section (top panels of Figure 21) as the brute force run but underestimates the observed deposition more clearly. This is particularly the case in the downstream part of Alameda Creek, i.e. in the tidally influenced and mud-dominated area. The cumulative volume change (central panels of Figure 21) demonstrates that in this area, clearly less mud is deposited compared to the brute force run (due to the missing tide in the compressed time series approach), while the deposition of sand and gravel in the more upstream area is comparable in both model runs. The right bottom panel of Figure 21 indicates a good general agreement between the observed and the simulated bed erosion and deposition also for the compressed time series run and emphasizes that the underestimation of deposition is slightly more pronounced compared to the brute force run (left bottom panel).

Besides the sediment volume changes along Alameda Creek, both the brute force and compressed time series also yield comparable bed level changes at individual cross-sections of the creek (Figure 22). The main difference between both model runs is that the creek banks show slightly less deposition in the case of the compressed time series, which is in line with the observation that this time series results in a stronger underestimation of the observed creek deposition than the brute force time series.

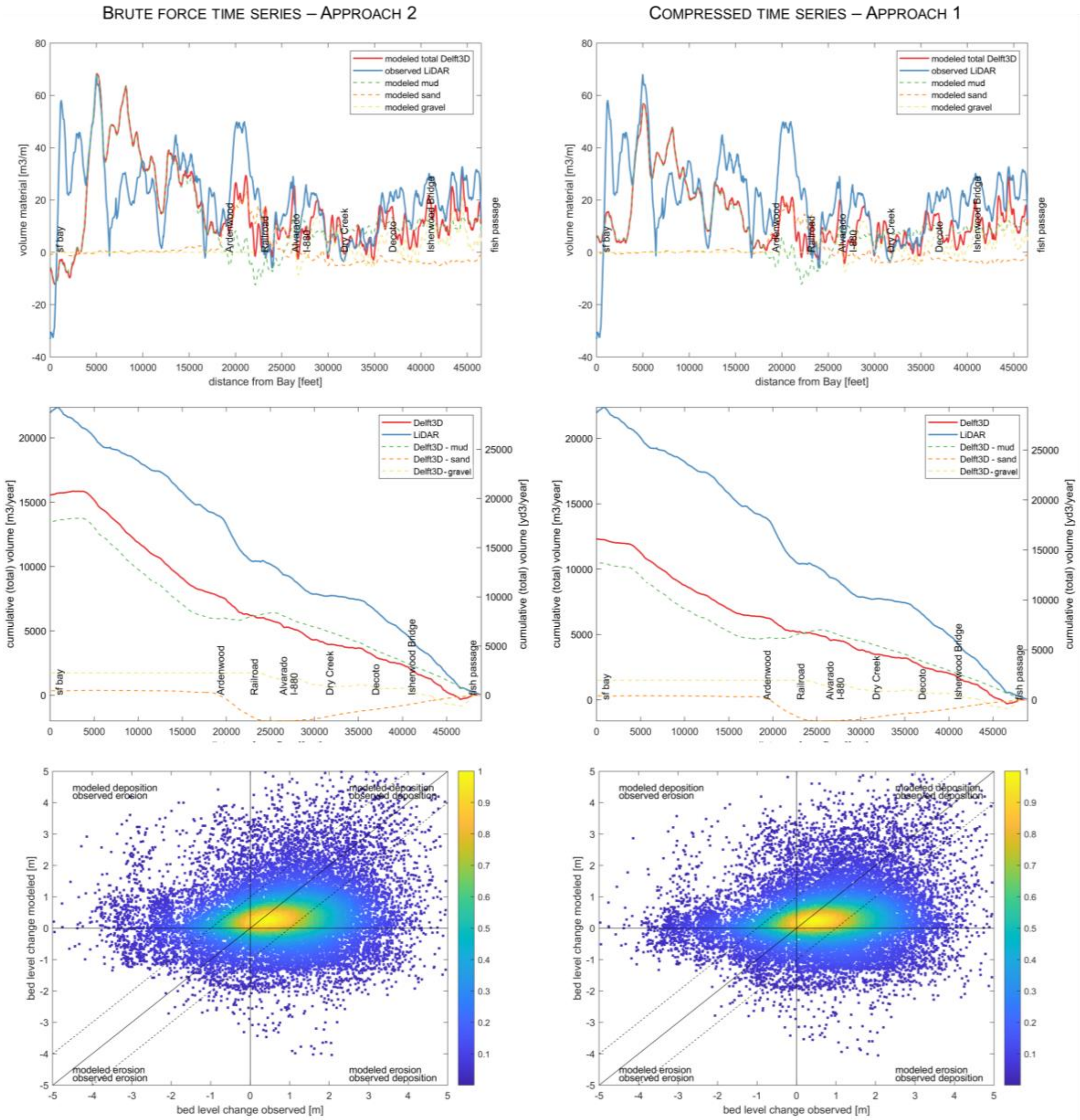

Figure 21. Top: Comparison of the observed and the simulated (brute force time series – Approach 2 versus compressed time series – Approach 1) sediment volume change (i.e. deposition or erosion) per cross-section [m³/m/year] in Alameda Creek. Center: Comparison of the observed and simulated (brute force time series – Approach 2 versus compressed time series – Approach 1) cumulative sediment volume change (i.e. deposition or sedimentation) [m³/year] in Alameda Creek. Bottom: Skill diagram of the simulated (brute force time series – Approach 2 versus compressed time series – Approach 1) versus the observed bed level changes in Alameda Creek.

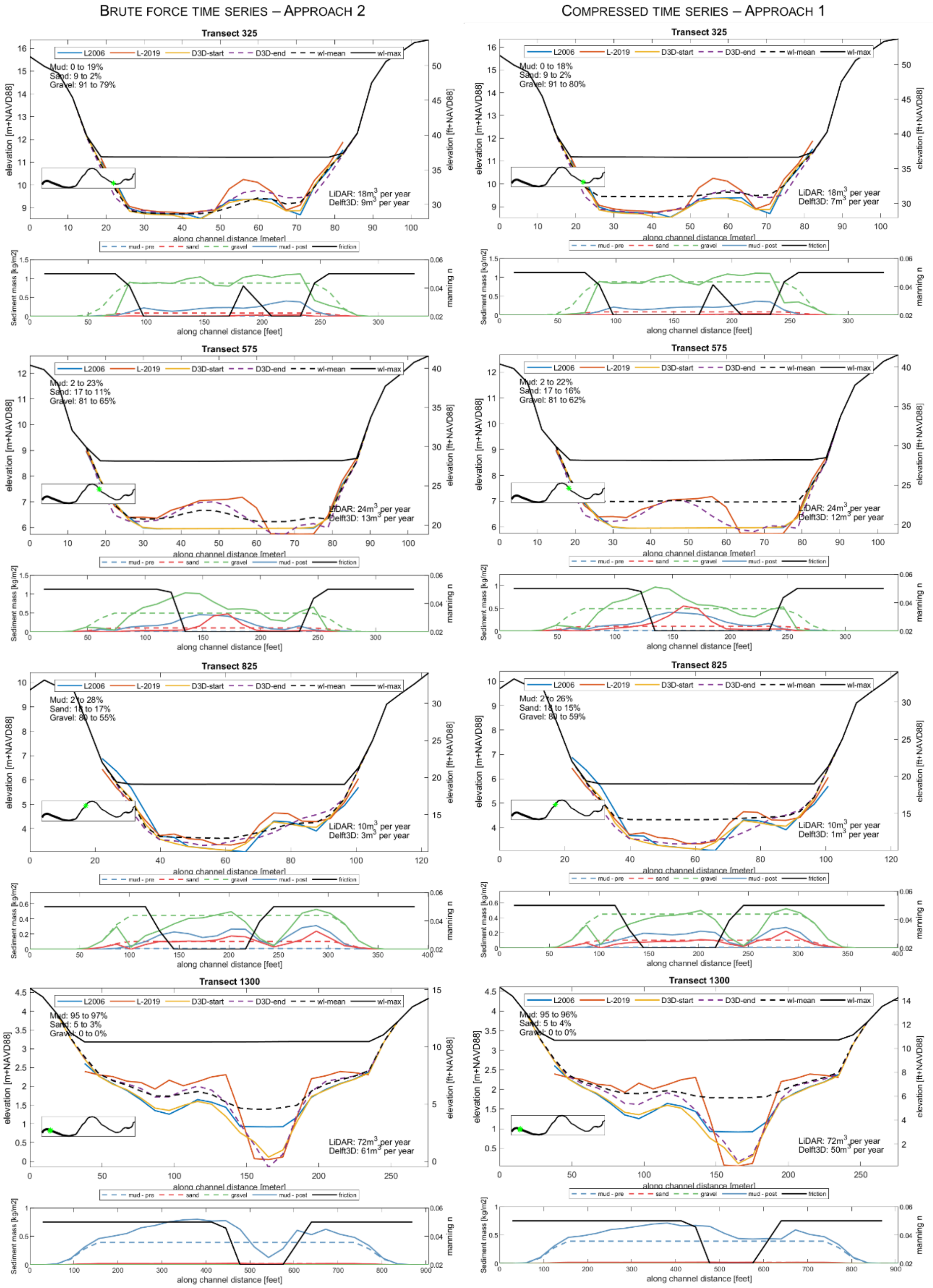

Figure 22: Observed and simulated brute force time series (Approach 2; left panels) and compressed time series (Approach 1; right panels) bed level changes [m] along various cross-sections of Alameda Creek between the fish passage and Ardenwood. The locations of the cross-sections are indicated by a green dot in the overview maps of the creek on the left-hand side of each plot.

B.2 Friction Variations

Figure 23 displays the cumulative sediment volume change in Alameda Creek based on different bottom frictions applied in the model. Generally, the simulated cumulative volume change in the creek is relatively robust against the different bottom frictions applied in the compressed time series runs. The only exception is the case where the friction in the channel is increased from 0.02 s/m$^{-1/3}$ to 0.03 s/m$^{-1/3}$ (Run 031), which causes a significant decrease in the volume change/deposition. The simulated bed level changes along individual cross-sections are more sensitive to the different applied bottom frictions, which is demonstrated exemplarily for cross-section 575 (located in the central Alameda Creek near Dry Creek) in Figure 24. In particular, a uniform bottom friction (Run 030) results in unrealistic bed level profiles, that hardly show a differentiation between the channel and the banks at the end of the simulation. When increasing the channel friction (Run 031) or decreasing the bank friction (Run 032) – meaning that the friction gradient between the channel and the banks decreases – the bed level profiles in the creek become more flattened as a result of less deposition on the banks and more deposition in the channels. An increased bank friction (Run 033), however, has a minor impact on the bed level profiles.

Table 3: Overview of various model sensitivity runs based on the compressed time series – Approach 1 and different settings for the applied bottom friction, sediment fractions, and sediment transport formula.

Run ID	Friction [s/m$^{-1/3}$]		Sediment Fractions		
	Channel	Banks	Settling Vel. Mud [m/s]	D50 Sand [mm]	D50 Gravel [mm]
020 (Ref)	0.02	0.05	0.0001	1.4	30
030	0.03	0.03	0.0001	1.4	30
031	0.03	0.05	0.0001	1.4	30
032	0.02	0.04	0.0001	1.4	30
033	0.02	0.06	0.0001	1.4	30
038	0.02	0.05	0.00005	1.4	30
039	0.02	0.05	0.0002	1.4	30
041	0.02	0.05	0.0001	0.8	30
034	0.02	0.05	0.0001	2	30
040	0.02	0.05	0.0001	1.4	15
035	0.02	0.05	0.0001	1.4	60

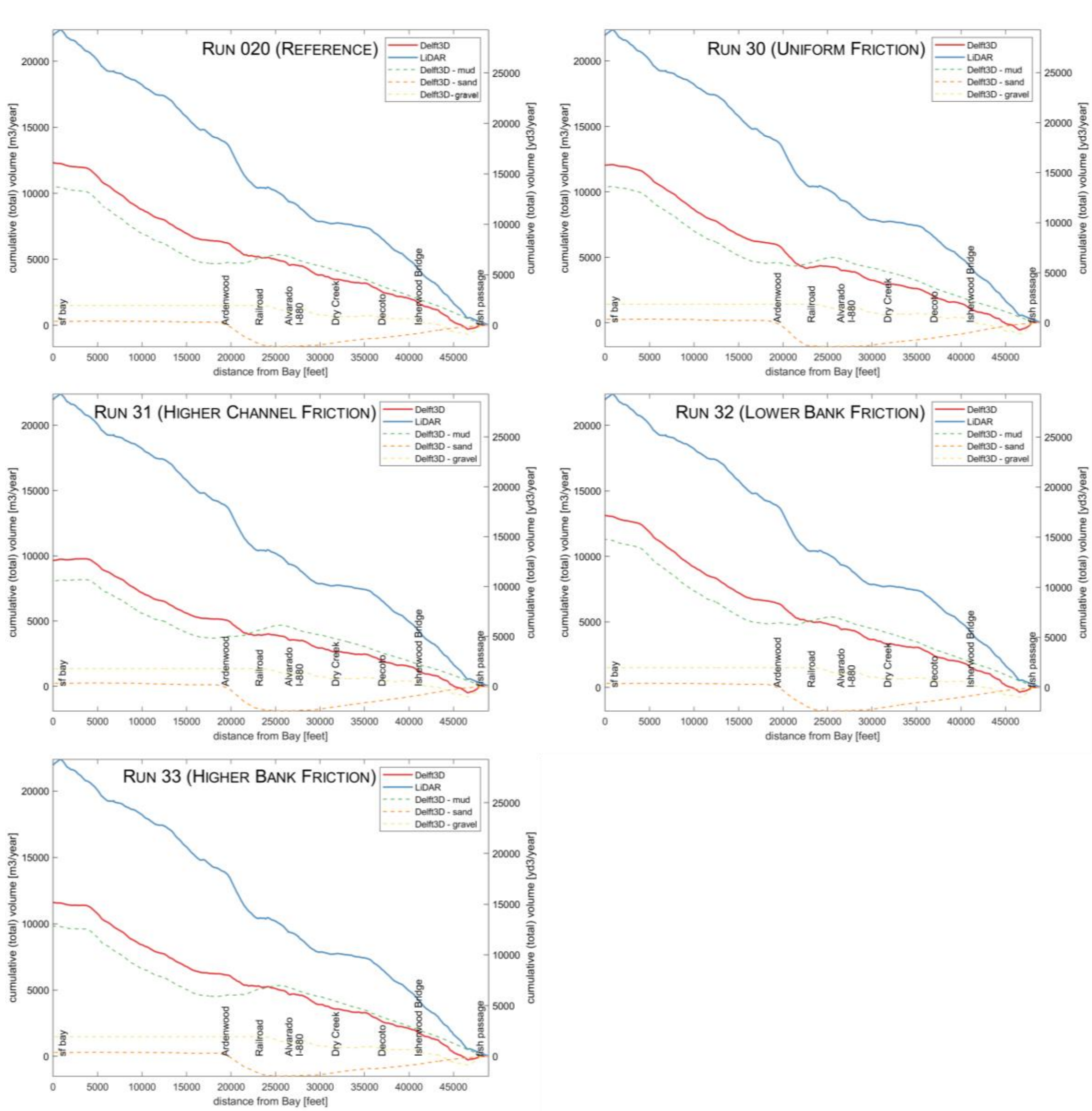

Figure 23: Comparison of the observed and simulated cumulative sediment volume change (i.e. deposition or sedimentation) [m3/year] in Alameda Creek. The simulated volume change is illustrated for the (compressed times series) reference run and corresponding sensitivity runs using different bottom frictions according to Table 3.

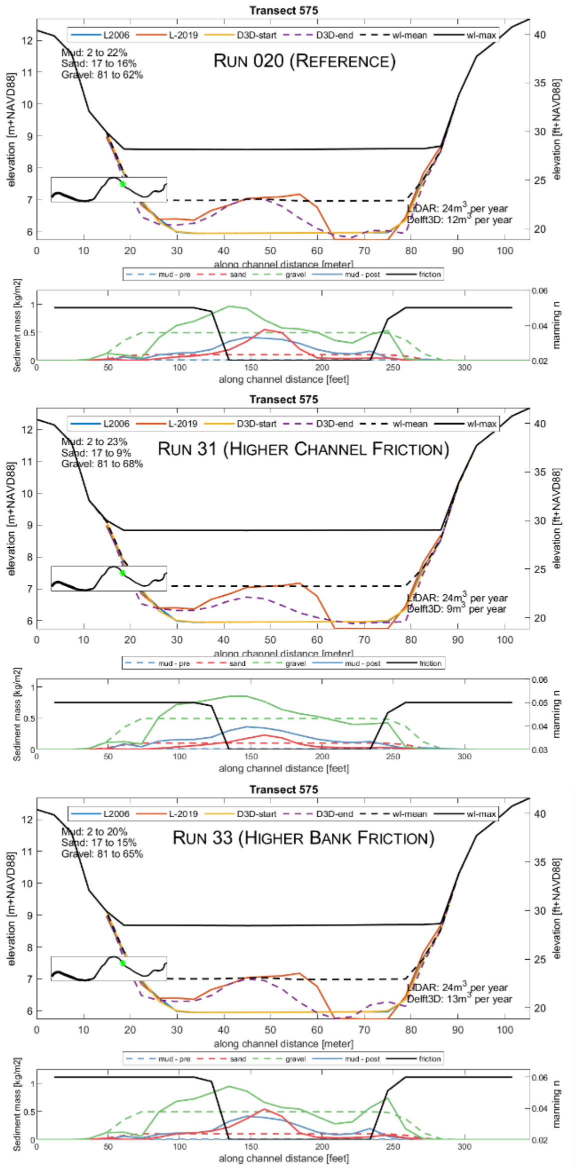

Figure 24: Observed and simulated bed level changes [m/year] along cross-section 575 located in the central Alameda Creek near Dry Creek. The simulated bed level cross-sections are illustrated for the (compressed times series) reference run and corresponding sensitivity runs using different bottom frictions according to Table 1. The locations of the cross-sections are indicated by a green dot in the overview maps of the creek on the left-hand side of each plot.

B.3 Grain Size Variations

In Figure 25, the cumulative sediment volume change in Alameda Creek based on different mud settling velocities/sand and gravel grain sizes in the model are illustrated. The simulated cumulative volume change in the creek is highly sensitive to the applied mud settling velocities. A lower settling velocity (Run 038) results in significantly less deposition in the creek since less mud accumulates in the creek. Accordingly, a higher settling velocity (Run 039) leads to more deposition in the creek and a relatively close match with the observed deposition (at least in the current case of the compressed time series). Using a finer sand fraction in the model (Run 041) has a minor impact on the total cumulative volume change in the creek, however, this results in significantly more erosion of sand in the upstream part and more deposition further downstream (relocation of sand due to increased mobility of finer compared to coarser sand). A coarser sand fraction as well as a finer and coarser gravel fraction hardly affect the simulated volume change in Alameda Creek.

The simulated bed level changes along individual cross-sections are generally sensitive to the different mud settling velocities/sand and gravel grain sizes (Figure 26). While a smaller mud settling velocity results in systematically less deposition on the creek banks, a higher mud settling velocity leads to more deposition on the banks and unrealistic (mud) accumulation in the channels. In contrast to the mud settling velocities, the impact of different sand and gravel grain sizes on the bed level profiles is spatially highly variable in the creek and does not follow a systematic pattern.

Table 4: Overview of various model sensitivity runs based on the compressed time series – Approach 1 and different settings for the applied bottom friction, sediment fractions and sediment transport formula.

Run ID	Friction [s/m$^{-1/3}$]		Sediment Fractions		
	Channel	Banks	Settling Vel. Mud [m/s]	D50 Sand [mm]	D50 Gravel [mm]
020 (Ref)	0.02	0.05	0.0001	1.4	30
030	0.03	0.03	0.0001	1.4	30
031	0.03	0.05	0.0001	1.4	30
032	0.02	0.04	0.0001	1.4	30
033	0.02	0.06	0.0001	1.4	30
038	0.02	0.05	0.00005	1.4	30
039	0.02	0.05	0.0002	1.4	30
041	0.02	0.05	0.0001	0.8	30
034	0.02	0.05	0.0001	2	30
040	0.02	0.05	0.0001	1.4	15
035	0.02	0.05	0.0001	1.4	60

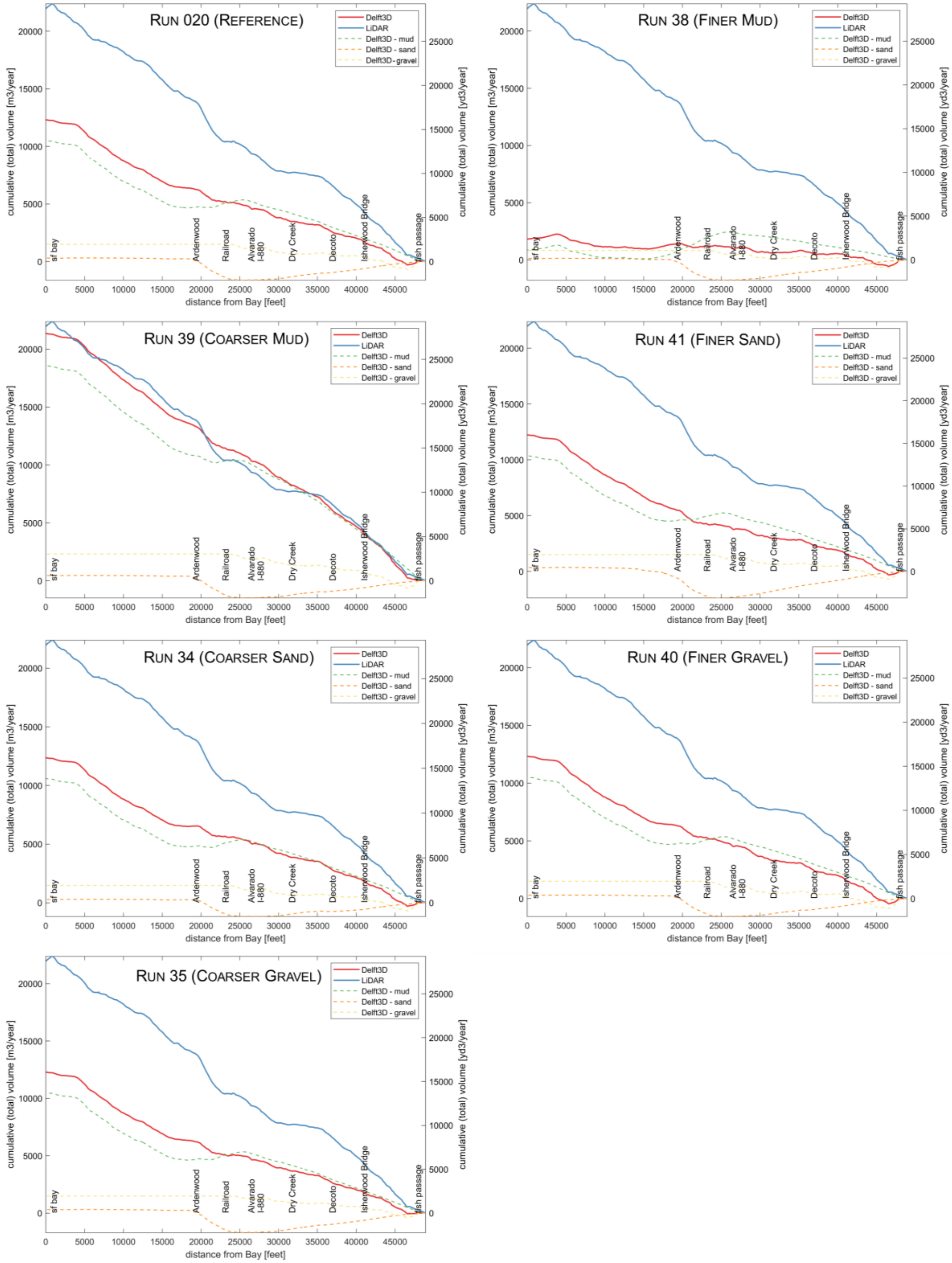

Figure 25: Comparison of the observed and simulated cumulative sediment volume change (i.e. deposition or sedimentation) [m³/year] in Alameda Creek. The simulated volume change is illustrated for the (compressed times series) reference run and corresponding sensitivity runs using different settling velocities for mud/grain sizes for sand and gravel according to Table 4.

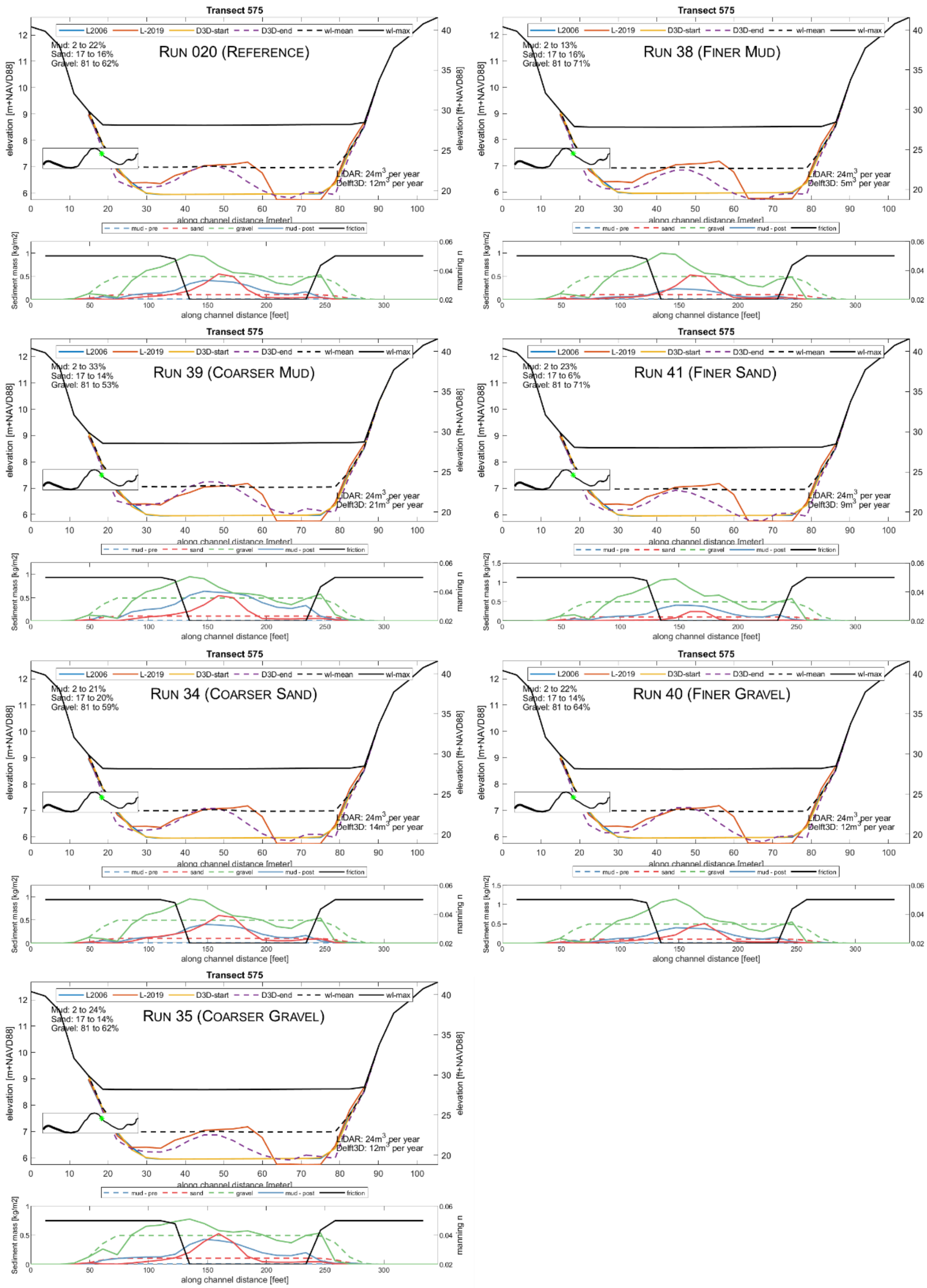

Figure 26: Observed and simulated bed level changes [m/year] along cross-section 575 located in the central Alameda Creek near Dry Creek. The simulated volume change is illustrated for the (compressed times series) reference run and corresponding sensitivity runs using different settling velocities for mud/grain sizes for sand and gravel according to Table 4. The locations of the cross-sections are indicated by a green dot in the overview maps of the creek on the left-hand side of each plot.

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