

Restoring Sediment Supply to Sustain Delta Marsh (Nisqually Delta)

Summary of the ESRP Learning Project. **“Assessment of vulnerabilities and opportunities to restore marsh sediment supply at Nisqually River Delta, west-central Washington, USA”.**

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Executive Summary

In 2009, the largest estuary restoration project in the Pacific Northwest recovered tidal connectivity across 308 hectares of historic tidal marsh in the Billy Frank Jr. Nisqually National Wildlife Refuge (Refuge) and Nisqually River delta important for regional salmon recovery (Figure 1). The project represented a critical step toward restoring juvenile salmon habitat that experienced ~80-90% loss over the last 100 years in response to diking and draining wetlands for farming, grazing and other land use activities. A common effect of these land uses has been land subsidence and so while several valued ecosystem metrics were restored in the Nisqually Delta in 2009, the delivery of sediment to recover and sustain marshes remains a concern. As of 2022, marsh development has been limited to select areas of high topography. This study integrated numerical modeling and comprehensive field measurements to compute the sediment budget of the Nisqually River delta and evaluate the fraction of fluvial sediment delivery to the delta that accumulates in the restored estuary today and that could be realized with additional distributary channel restoration under existing conditions and projected higher sea level and stream runoff.

Sediment delivery to the Nisqually River delta is constrained by a number of factors including trapping in Alder Lake at the base of Mount Rainier used principally for hydropower generation, flow restrictions along the Nisqually River including the I-5 corridor constructed on a causeway covering ~87% of the floodplain, and remaining levees and flow control structures associated with land use surrounding the delta. This study evaluated the hydrodynamics and sediment transport dynamics of the estuary to quantify the budget and flux of sediment to the 2009 Brown’s Farm restoration area under existing conditions. It also assessed the capacity for distributary restoration at one identified location near NR2 (Figure 2) to route and enhance sediment delivery under existing conditions and projected changes in sea level and stream flows to more efficiently establish grade suitable for expedited marsh development and resilience.

A numerical hydrodynamic-sediment transport model of the Nisqually River delta was constructed using Delft3D (Figure 3) and extensive measurements were made of physical oceanographic processes and sediment to evaluate the sediment transport pathways and mechanisms that operate across the study area. The model used best available data for boundary conditions including the 1m USGS Coastal National Elevation Data (Tyler and others, 2019) and observed marine water levels and stream flow from NOAA and USGS respectively. Sediment was included in the modeling with multiple size classes and transport properties

representative of the range in distribution observed in Curran and others (2016). Three different models following two general approaches were employed to evaluate sediment transport dynamics under existing conditions and projected future climate and land use change.

The first approach computed and tracked fluvial sediment delivery independent of other sources then subsequently, the total sediment transport including the contribution of bed

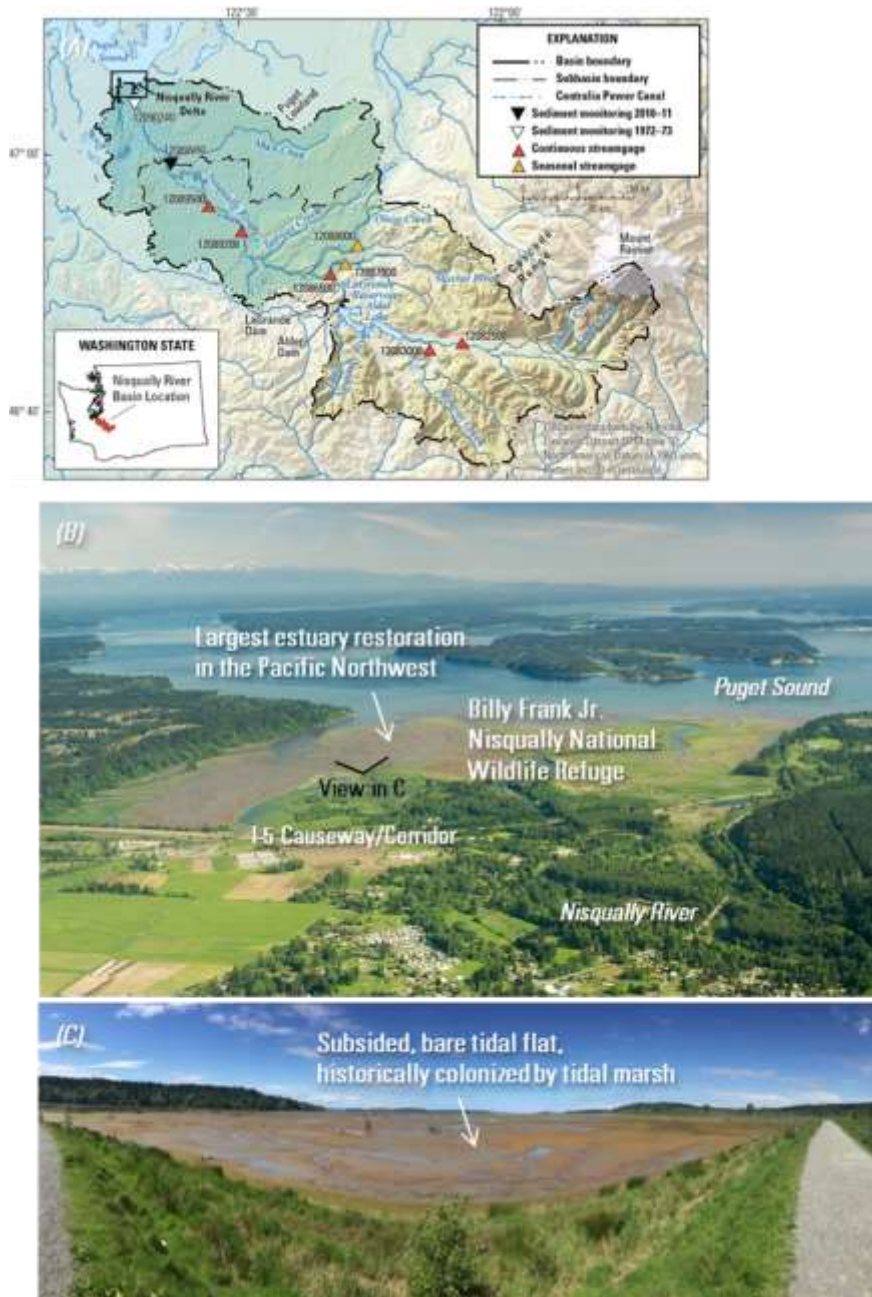


Figure 1. Map of the Nisqually River basin and location of the delta study area (A), and photographs of the Billy Frank Jr. Nisqually National Wildlife Refuge and Nisqually River Delta (B) and subsided, bare historic marsh platform (C) where sedimentation and marsh redevelopment remain a concern.

resuspension processes that redistribute existing sediment on the seafloor under existing conditions. The second approach implemented a schematized approach to evaluate the relative capacity of varying estuary distributary channel restoration alternative designs to convey sediment under existing and projected sea level and stream discharge. Three alternatives examined the influence of different potential distributary channel sizes, depths and degrees of connectivity across the delta relative to existing conditions to help answer the extent of additional restoration actions needed to restore sediment delivery.

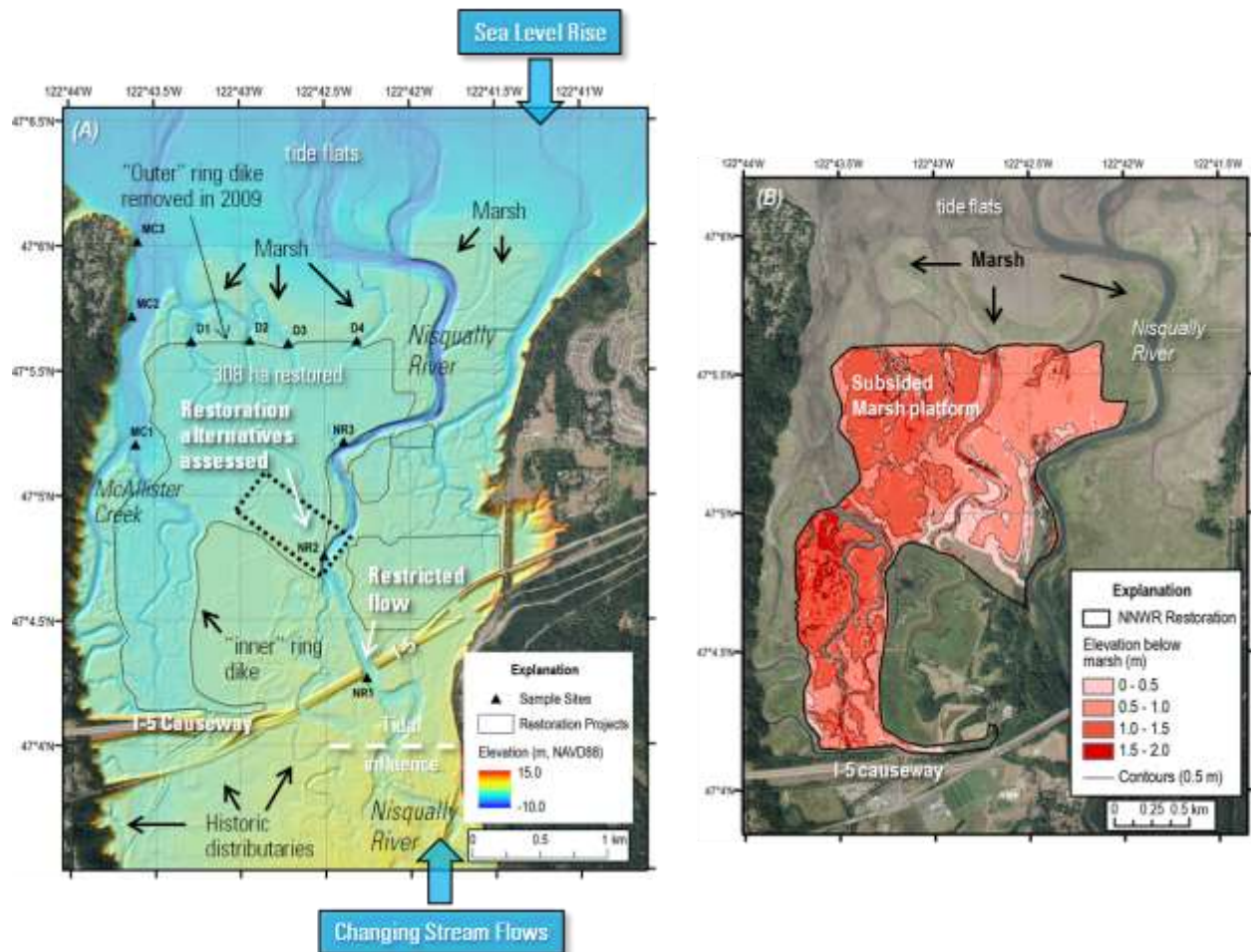


Figure 2. Maps showing the study area land surface elevations, sample sites, constraints and identified alternatives for recovering sediment (A) and the extent of subsidence below dominant marsh elevations with darker red colors indicating greater subsidence/more elevation to restore (B).

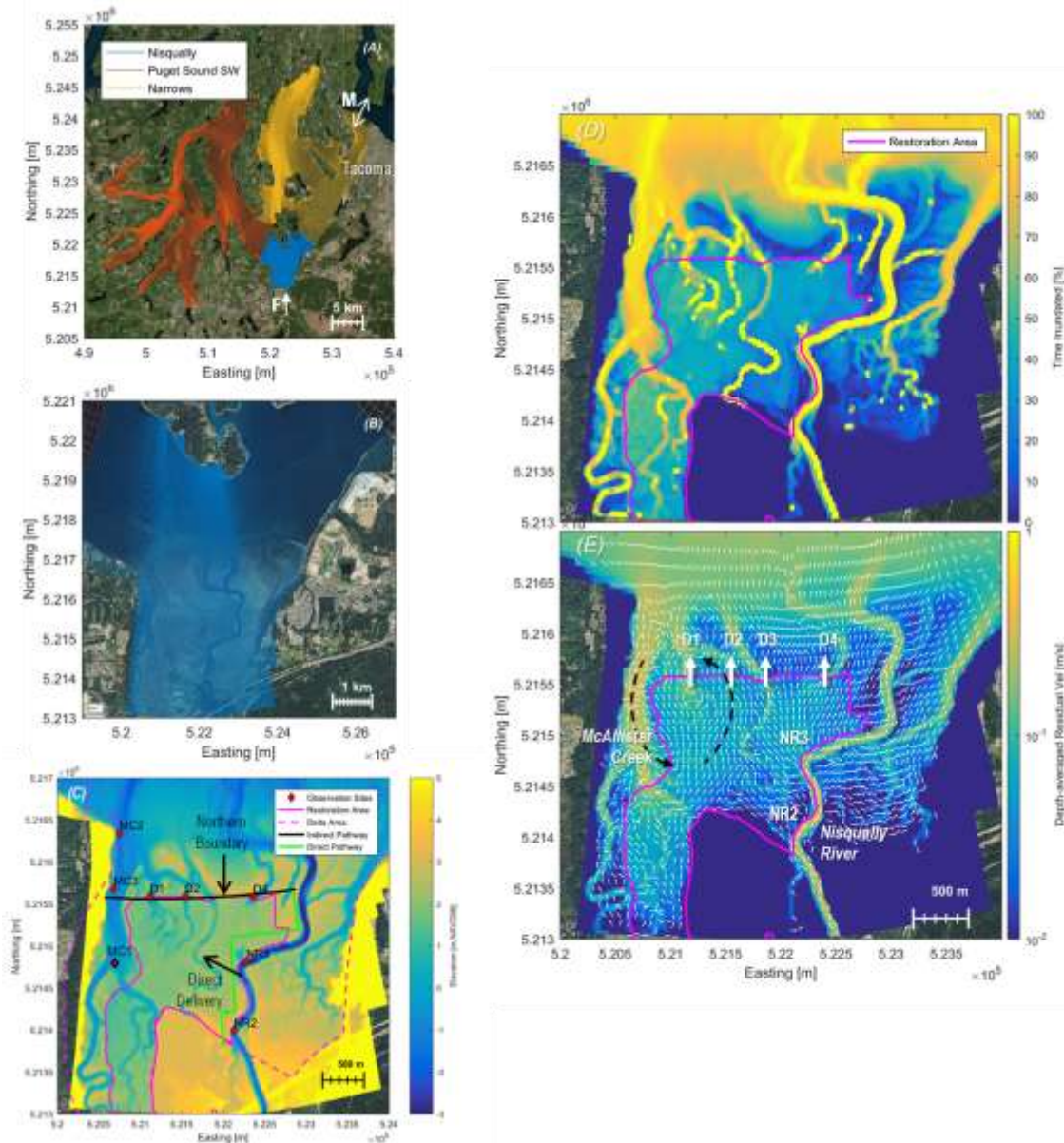


Figure 3. Maps showing model domain (A), nested high-resolution Nisqually estuary model (B) and location of model transects to quantify direct fluvial sediment delivery and indirect transport from resuspended and redistributed sediment principally across the Northern boundary to the restoration area, and model results of tidal inundation (D) and mean transport (E) including flow directed north from river and four estuary channel inlets relative to net flow south through McAllister Creek.

The model shows that the mean flow is directed offshore away from the restoration area through the Nisqually River and restored estuary channel inlets whereas net flow is directed into the restoration through McAllister Creek. Results of modeling the suspended fluvial sediment separately from all sediment in the system including sediment on the bed across the estuary, revealed that direct fluvial delivery to the restoration is high during large river discharge events but relatively low relative to the amount delivered by the river. High winds

and waves lead to significantly greater flux of sediment into and out of the restoration area across the old (removed) ring-dike along the northern boundary, than the river during period of low to moderate fluvial input. The total amount of sediment computed to flux into and be retained in the restoration area accounting for fluvial, tidal and wave processes ranges 14–32% of the fluvial sediment load delivered to the delta below Alder Lake (Figure 4). The composition of this material is primarily mud. Remaining concerns with this sediment regime is that fine material may be less resistant to post deposition erosion by waves and export out of the restoration and it is suspected that recovering subsided grade for marsh development will be slower with fine material than coarser, denser sand and larger materials.

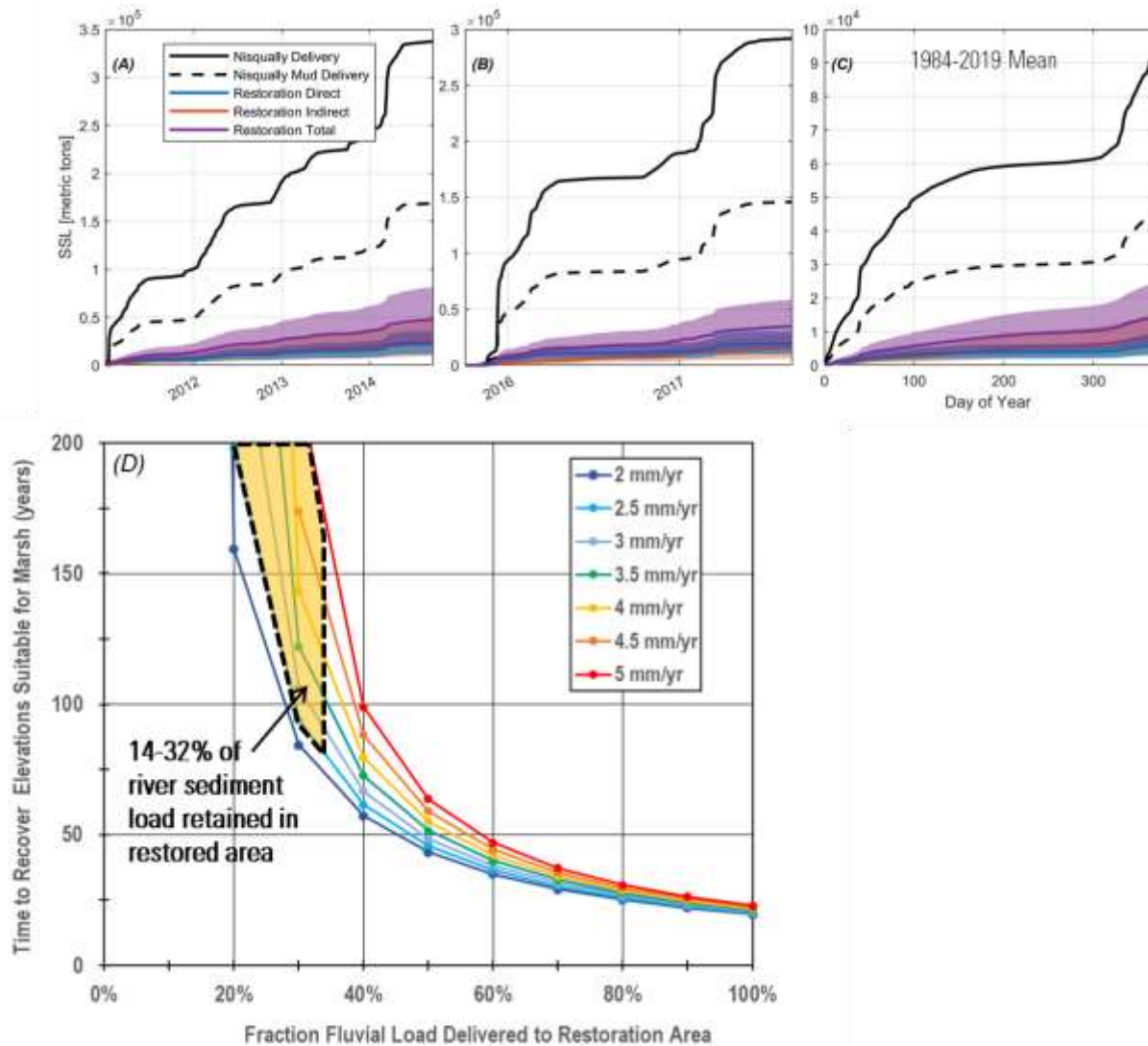
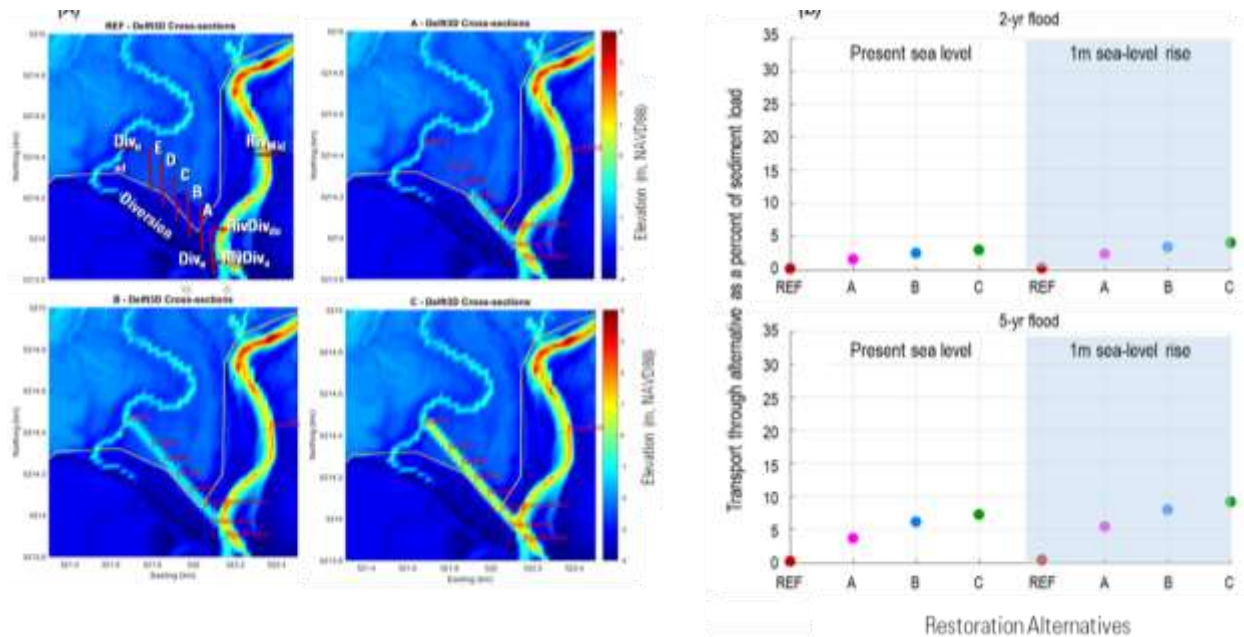


Figure 4. Plots of the total, direct and indirect delivery of sediment and mud by the Nisqually River and to the restoration area for the period 2011–2014 (A), 2016–2017 (B) and mean of 1984–2019 (C) showing the amount retained in the restoration area ranging 14–32% of the fluvial load delivered by the river. Plot showing the time to recover marsh grade associated with the rate of sediment delivery ranges 85–200+ years for present and range of projected rates of sea level rise.

At the rates of sediment delivery determined by the study, it is expected to take more than 85 years to fill the subsided marsh platform to an elevation suitable for extensive marsh development (Figure 4). Roughly 18 years is needed if the entire fluvial sediment load of mud and sand could be directed into the central subsided region of the restoration area.



Modeled sediment conveyance capacity was found to be relatively low in all alternatives with the greatest potential for transport associated with Alternative C that required the largest and most extensive channel excavation to establish full connectivity between the river and tidal processes of Leschi Slough, a principal historic channel. Even so, only 5–10% more sediment was computed to be routed to the restored area only during large stream flows like the 2- and 5-yr floods that are relatively uncommon. The combination of high stream flow and 1 m of sea level rise expected by between 2070 and 2100 may result in an additional 2–5% of sediment delivery. Observations were used to help answer that the system is relatively well mixed during larger stream flows and high waves such that restoration approaches like notching levees are unlikely to achieve desired sediment recovery given the already low potential for flux. The overall low potential for sediment delivery in the areas studied is thought to be due to the relatively low hydraulic gradient that is insufficient to move the desired quantity and type of sediment for accelerated recovery.

This research points to the need for adaptive management higher in the estuary where restored distributary channel connections to the river have greater capacity to deliver a larger proportion of the river load and where processes associated with delta progradation may enhance retention. The results also indicate that additional strategies including sediment augmentation beyond what is available in the river below the trapping effects of Alder Lake may be important to accelerate the recovery time and promote positive feedbacks to sedimentation that marsh vegetation can provide.