The Deschutes Estuary Restoration Feasibility Study: development of a process-based morphological model

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Abstract
Continual sediment accumulation in Capitol Lake since the damming of the Deschutes River in 1951 has altered the initial morphology of the basin. As part of the Deschutes River Estuary Restoration Feasibility Study, the United States Geological Survey (USGS) is modeling how tidal and storm processes will influence the river, lake and lower Budd Inlet should estuary restoration occur. Understanding these mechanisms will assist in developing a scientifically sound assessment on the feasibility of restoring the estuary.

We are using a process-based sediment transport model, Delft3D, to simulate conditions prior to dam construction and the accumulation of sediment subsequent to dam construction. Potential changes in hydrodynamics and sediment transport after dam removal will also be modeled. Key components of the model include tidal currents, density-driven circulations, cohesive and non-cohesive sediment transport and bathymetric change. Model results will be compared to historical and recent field data consisting of bathymetric surveys and bottom sediment classification. Future modeling work will incorporate simulation of mud flocculation in the more saline Budd Inlet and integrate model results with expected biological changes due to a shift from a freshwater environment to a more brackish estuarine one if the estuary is restored.

Introduction
Situated below the Washington State Capitol campus in Olympia, WA, the Deschutes Estuary became Capitol Lake upon construction of the Fifth Avenue Dam in 1951. Prior to the structure, the estuary was a tidally-dominated system at the southern end of Budd Inlet, Puget Sound, that experienced a tidal range of ~5 m (15 ft) and received freshwater input from the Deschutes River. Since dam construction, an estimated 60 – 80% of suspended sediment transported by the river has been trapped by the lake (Entranco, 1984). Between 80 – 85% of the sediment input from the Deschutes River was delivered by flows that occurred only 8% of the time (Mih and Orsborn, 1974). Since the mid-1970s, several dozen studies investigating sediment removal, water quality and maintenance protocols have been conducted to preserve Capitol Lake. Portions of the lake were dredged twice (1978 and 1986) even as the shoreline was altered by the construction of various parks and highway improvements. In spite of these efforts, by 2004, lake volume had decreased by 28% and water quality was worsening due to plant growth and decay (Figure 1). Several state and municipal agencies were prompted to develop a long-term solution under the Deschutes Estuary Restoration Feasibility Study.

The goal of the feasibility study is to investigate returning tidal and estuarine processes to restore the lake to an estuary. Several restoration solutions have been proposed, including removal of the dam and widening the opening to Budd Inlet from the current 21 m (70 ft) to ~150 m (500 ft). A critical aspect of the study is to anticipate how the lake/estuary environs would change under different restoration scenarios, particularly sediment transport dynamics in the restored estuary. Key concerns include adjustment of the lake bed morphology, development of scour zones under bridges, deposition of eroded sediment in the Port of Olympia, coarsening or fining of habitat substrate and exposure of biological communities to saline or brackish water. Another question to be investigated is whether a restored estuary would stratify, altering circulation and affecting water quality.

To address these questions, the USGS is using Delft3D, a hydrodynamic and sediment transport numerical model developed by Delft Hydraulics. The model consists of several modules, such as hydrodynamics or ecological. Both sediment transport and morphology are integrated within the hydrodynamic module (Lesser, et al, 2004). The model can be forced using tides, river discharge (continuous or flood events), atmospheric pressure, wind and waves. Salinity and sediment grain size are input as constituents. For sediment transport, velocity and turbulence results from the hydrodynamics module are used to calculate advection and diffusion of the sediment. The resulting concentration and new distribution of the sediment are then incorporated into the hydrodynamic module and the velocity and turbulence are recalculated. This feedback cycle is repeated for the duration of each simulation. Up to five different sediment grain-size classes can be included and tracked in each model run. Delft3D can also be run either in a vertically-averaged two-dimensional or three- dimensional mode.

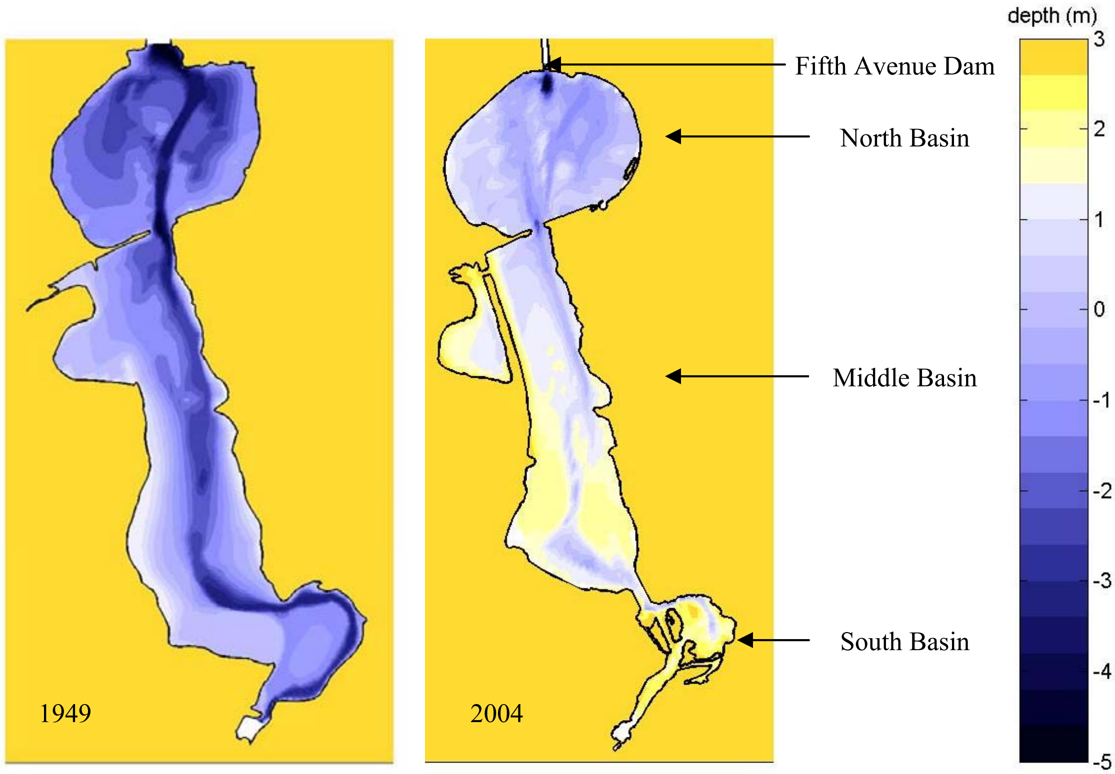

Figure 1. Bathymetric and shoreline change in Deschutes Estuary/Capitol Lake from 1949 to 2004. The Fifth Avenue Dam was built across the northern end of the estuary in 1951, roadway construction was completed in 1957 and portions of the lake were dredged in 1978 and 1986. Lake volume has decreased 28% in 55 years.

Application of Deflt3D to Deschutes Estuary Restoration

Modeling restoration of the Deschutes Estuary is occurring in several steps. First, a pre-dam model of the estuary was developed to establish how the historical estuary may have functioned (PREDAM). Second, a dam representing the 1951 structure was introduced and sediment was allowed to accumulate within the lake (LAKE). Third, details of each restoration scenario will be incorporated into specific restoration model runs. This paper describes work in progress and only the PREDAM and LAKE models will be discussed here.

For the PREDAM model, bathymetry was interpolated from a 1949 digitized contour map. Bathymetry for the LAKE model was complied from bathymetric and topographic surveys conducted by the USGS, Washington Department of Ecology and Washington Department of Fish and Wildlife in September 2004 and February 2005, respectively. Bathymetry and topography were converted to be in reference to mean sea level (MSL) and projected onto a curvilinear grid. Similarly sized model grids were used in the two models to cover the 3000 m long and 500 m wide area, with the PREDAM grid being slightly larger. The PREDAM model has more than 8100 active grid cells and the LAKE model has approximately 7500. The variation of the grid cell size is necessary to resolve the details of the flow in different areas of the model domain. For example, cells in the main channels are between 100 – 200 m^2 while cells on the mudflats range from 1200 to 3500 m^2.

Tidal constituents were extracted from NOAA tide gauge records at nearby Gull Harbor, Budd Inlet for forcing the PREDAM model. River discharge for both models was based on a USGS 57-yr stream gauge record from Tumwater Bridge just south of the mouth of the Deschutes River. Flood events (1-yr and 5-yr), mean high and mean low values were calculated from the stream gauge record. Wind data from Olympia weather records was also collected but has not yet been processed for inclusion as a forcing factor. Sediment grain size for Capitol Lake has been observed to range from clay to gravel, although no recent data has identified the exact size distribution.

Preliminary results

As the PREDAM and LAKE models are still being evaluated for sensitivity and accuracy, results should be considered preliminary.

In the PREDAM model, circulation is dominated by tidal forcing through the opening to Budd Inlet. A main channel splits North Basin roughly in half, meanders slightly from the east side to the center and back to the east of Middle Basin before entering South Basin. In South Basin, the channel follows the eastern bank around the basin before meeting the river. Two constrictions to flow exist: the opening to the inlet and a railroad trestle dividing North Basin from Middle Basin. The highest velocities are found in the estuary during both ebb and flood stages at these two points. Low tides expose much of the bed as mudflats. Flooding tides fill the estuary similar to a river overtopping its banks rather than as a tidal wave filling each basin in succession (Figure 2a). The main channel absorbs the incoming flow until capacity and then spills across the mudflats of all three basins simultaneously. During slack high tide, opposing circulation cells develop off the main channel in the North Basin with the western cell spinning clockwise and eastern cell counterclockwise (Figure 2b). The ebb tide, in contrast, drains the estuary in stages. The shallow western side of Middle Basin dries first leaving the main channel on the eastern side filled with water. South Basin drains through this channel and when emptied, the remaining water in Middle Basin exits. Finally North Basin empties, leaving some residual water in the main channel (Figure 2c). At low slack tide, the discharge from the Deschutes River determines the depth of water in the main channel. The difference in how the flood and ebb tides behave may have an impact on restoration strategies.

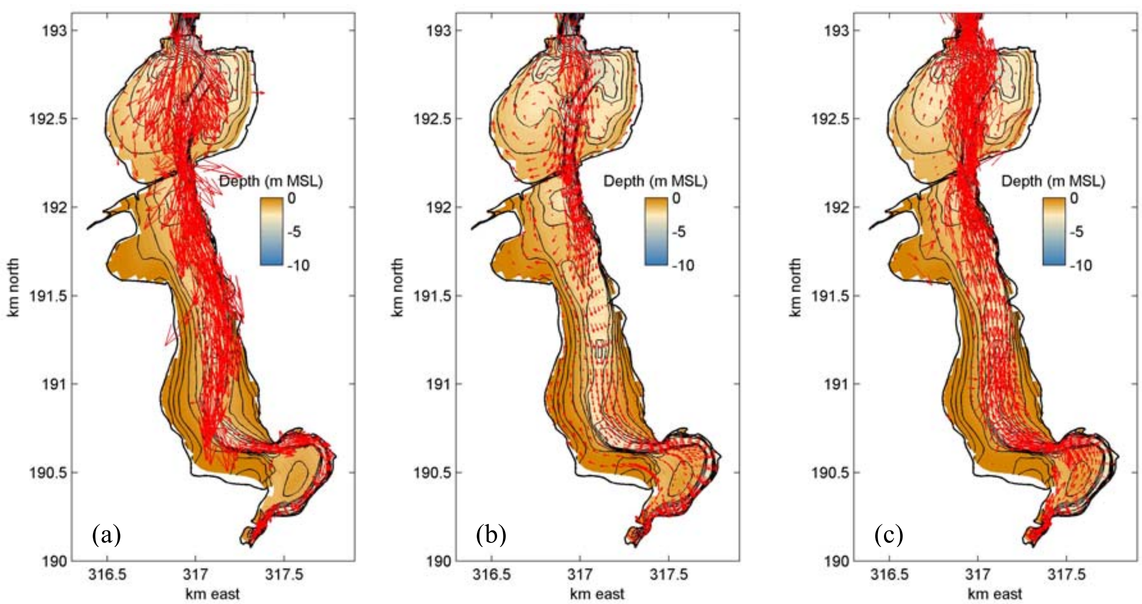

Figure 2. Circulation and tidal velocities in the PREDAM model at (a) flood tide, (b) high slack tide and (c) ebb tide. Black contour lines are isobaths and red vectors are tidal velocity. Increased velocities are seen for the two points of constriction in (a) and (c) while opposing circulation cells in North Basin can be identified in (b).

Salinity in the PREDAM model is determined by the discharge of the Deschutes River. Mean low flow (2.8 cms or 98 cfs) and mean high flow (23 cms or 812 cfs) were calculated from the stream gauge record and holding all other parameters constant, the PREDAM model was run with the differing river flows. Due to the large tidal range, almost all of the water is removed during ebb tides leaving the river flow as the sole source of water for the estuary. The amount of water delivered during low river flow at low slack tide does not provide enough freshwater to push the residual salt water from the main channel. Hence, when the flood tide returns with more saline water, the estuary retains a high salinity. The North Basin and most of Middle Basin do not receive significant amounts of freshwater and remain near or above 30 ppt while South Basin becomes brackish (~15 ppt) at high slack tide. This is contrasted by high river flows, which deliver an order of magnitude more freshwater. The higher river flow fills the main channel with more freshwater so that during flooding tides, more mixing occurs in the three basins. The North and lower Middle Basin become brackish (~15 ppt) and upper Middle and South Basin remain almost fresh (~2 ppt) at high slack tide. The connection between salinity levels and river flood events has not yet been examined, but based on the extreme difference for the mean high and low flows, a supposition can be forwarded that during river floods, the estuary may be entirely freshwater even at high slack tide.

For present-day sediment transport, a 1-yr flood event lasting 10 days was conducted on the LAKE model for sediment grain sizes (64, 125, 250, 500 μm) in the water column and on the lake bed (Figure 3). In the LAKE model, alterations of the shoreline and sedimentation have added a third constriction to the flow under the Interstate-5 bridges, dividing Middle and South Basins. The flow is complicated further by three islands in the South Basin that developed from deposition and were colonized by vegetation. Focusing on the 125-μm fine sand simulation, erosion of the channel in the South Basin occurs initially as the river flood builds. Sedimentation rapidly builds a subaqueous deposit of sand on the eastern edge of the channel. When the flood peaks, a pulse of sediment enters Middle Basin through the Interstate-5 constriction and settles across the main channel in southern Middle Basin. The location and thickness of the flood deposit may be modified by other forcings, such as wind and waves, which have yet to be incorporated into the model.

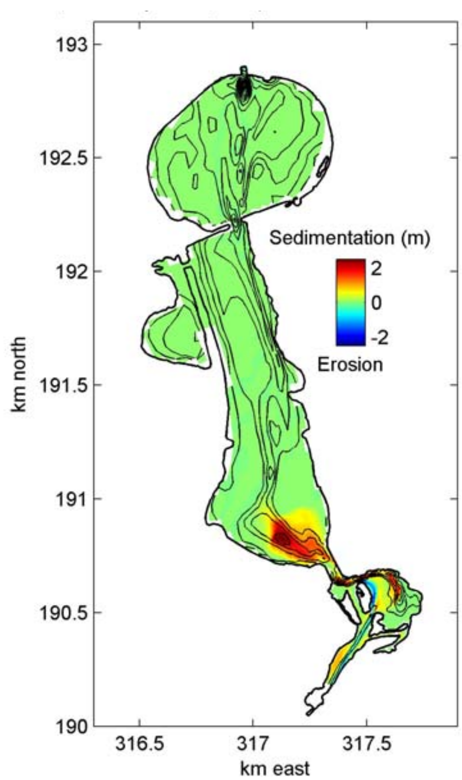

Figure 3. Sedimentation (red) and erosion (blue) for 125-μm fine sand during a 1-yr flood event in the LAKE model. Erosion occurs in the main channel in South Basin and under the Interstate-5 constriction. Deposition is seen on the eastern bank of South Basin and in the main channel of southern Middle Basin.

Future Directions

Before models specific to restoration scenarios can be constructed, vital details still need to be addressed. First, the grain size distribution on the lake bed will be quantified from 73 surficial grab samples collected in February 2005. A sediment map of the lake will be produced that can guide modeling of appropriate sediment size classes. Second, wind and waves will be included as forcings in the LAKE model to investigate impacts on resuspension and distribution of sediment, particularly the fine grain size classes. Once the sediment distribution and additional forcings are investigated, the restoration scenarios, such as removal of the dam or a partial estuary/lake system, can be modeled. The need to model the estuary in three dimensions to incorporate vertical mixing and stratification will also be examined. Model results will be used by managers, decision makers and the public to debate the merits of a restored Deschutes Estuary.

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