Conclusion

The residual circulation in the bay appears to be a mix of classical two-layer flow over the deeper regions, tapering toward a transverse structure near to the edges. The major avenues for flushing (and the lowest residence times) are the deep navigation channels running approximately north-east to south-west through the bay from the eastern lobe of the head of the bay to the mouth. Residence times in these areas are short, on the order of a month, while outside this region, particularly near the bay edges, in the western lobe of the head of the bay, and near persistent eddies, residence time increased dramatically to over five months. The Eulerian approach captured the overall structure of the variation in residence time over the bay during the period studied in the TMDS. The spatial distribution of residence time, however, is considerably smooth, as compared to the Lagrangian distribution, and the spatial structure in some areas of the bay is oversimplified.

Bounds on residence time over the entire bay can be derived from the various simulations where the forces on the model domain were varied. The lower bound is given by the simulation where the river inflow was artificially increased, suggesting that during times of high river input and frequent wind events (e.g., a wet winter season) the bay-wide residence time could be as short as roughly two months. The upper bound of 9 months on residence time occurs under relatively dry, windless conditions (e.g., calm dry summer to fall) such as for the modeling scenario where the wind stress was set to zero during the relatively dry fall to winter of 1990-1991. The much longer residence times of the harmonic tide only case is probably too stringent a restriction on the forcing to be a realistic least upper bound. These scenarios also provide for a ranking of the contribution of the major forces that influence the residence time in a bay-wide sense. Removing the wind forcing and the sub-tidal setup led to the biggest change in bay wide residence time compared with the baseline case, indicating that this is the most important component. Removing the river input ranked a close second in importance and these two scenarios, wind and river input, could easily be ranked the other way if the double mean river input case is considered. The sub-tidal influence alone was least important in changing the bay-wide residence time. The structure function that evolved out of these scenarios also indicates that the residence time is two orders of magnitude more sensitive to alterations in the forcing at lower residence times than at higher ones. This implies that subtle changes in the river input or weather (wind and sub-tidal influences) could have large effects in bay-wide residence times when those times are less than about 7 months.

This dissertation has tested the hypothesis that a modeled Lagrangian particle tracking method can define bounds on the residence time in an estuary. The two method approach, Eulerian (concentration based) and Lagrangian (particle tracking), is more informative than either method alone. The Lagrangian method captures the structure in more detail than the Eulerian. However, both methods are actually only approximations, and are most likely end members to a true solution. The bounds on bay-wide residence time have been established and the structure of its variablity described. The Eulerian spatial distributions identify 4 distinct regions in the bay, with respect to unique residence time, and dominant controlling forces. The Lagrangian spatial distributions show more detail in each of these sub-regions, and thus indicates how the relative residence time varies spatially within these regions.

Future studies

Possible directions for future research include:

1) A sensitivity analysis of the Markovian diffusion in the particle tracking subroutine is needed. At present, particles have a small random walk dispersion component that assumes a uniform particle dispersion. The magnitude of the dispersion has been derived from two-dimensional (surface) drifters and closely agrees with real surface drifters in the bay. A three dimensional test has been conducted and analysis has been performed indicating that the effect of varying this parameter is to homogenize the particles in the vertical, which lengthens residence time in high flow areas. However, no data has been collected to give a magnitude to this parameter. A passive tracer release in the bay for calibration of this parameter should be performed.

2) A test of the sensitivity of these results to the number of initial particles should be performed to optimize the initial particle number to the study being conducted.

3) The model open boundary concentration is fixed at zero at the mouth of the bay, and particles are trapped at the open boundary in this research. This constraint does not allow for particles or concentration to exit the bay and then re-enter. A larger model domain is needed to test the influence of re-entry on residence time.

4) The bay geometry should be altered in the model (e.g., remove causeways) to check the hypothesis that these features play a significant roll in increasing residence time.

5) Future data collection in the bay should provide time series for salinity, velocity, and freshwater input from the major river sources. The model velocity calibration is the most difficult to achieve, because of the location (in the deep ship channels) of the instruments that have been deployed. The ship channel is a sub-grid feature to the model, even the finer grid of the TMDS does not resolve this feature. A random scatter of current meters would lend more confidence in the ability of the model to capture the flow field across the bay. Time series of accurate salinity data is a difficult measurement to make in the estuarine environment due to bio-fouling. It is however a key component in the model validation and should be made at as many sites in the bay as possible. At the least, the existing PORTS stations should collect water temperature and salinity. Finally, the river freshwater

input to the bay potentially has large errors, owing to the fact that not all rivers are gaged. Of the gaged rivers, the recording locations are substantially upstream from the bay. Thus there are substantial un-gaged areas of the rivers that are not accounted for in the river input data.

6) Instantaneous plots of particle position in the bay show particles grouped in strings, clumps, and filaments that are reminiscent of a chaotic flow structure. Spatial distributions of Lyapunov exponents should be derived to investigate the importance of chaotic mixing in residence time.