David M. Lawrence
ENVS 691 Laboratory Exercise No. 2

ESTUARINE HYDRODYNAMICS

The hydrodynamics of a virtual river/estuary system were investigated using a simple spreadsheet model. The model's discharge and tidal inputs were obtained from actual river and estuarine data. Average annual and monthly discharge (m^2 s^{-1}) data for the Kennebec River at Bingham, Maine, were obtained from the National Water Information System (U.S. Geological Survey, 2012). Three variables where used for this model: average annual discharge (129 m^3 s^{-1}), highest average monthly discharge (May; 247 m^3 s^{-1}), and lowest average monthly discharge (September; 93.2 m^3 s^{-1}). One week's worth of hourly tidal data (height above mean low low water in meters) for Eastport, Maine—near the mouth of the Bay of Fundy—were obtained from (Center for Operational Oceanographic Products and Services, 2011).

Outputs were calculated for each of three river flow regimes (high, average, and low) for each model segment. Basin geometry and discharge data were used to calculate fluvial velocity (m s^{-1}), transit time (d), and age of water (sum of transit times; d), for each of 20 segments (10 riverine, 10 estuarine) in the model system. Tidal range data were used to calculate tidal volume (m^3) and tidal velocity (m s^{-1}) for each of the estuarine segments. Finally, energy ratio (%) was calculated for each of the 20 segments.[1] Results are presented in Figure 1.

The relationship between basin cross-sectional area [Figure 1 (a)] and fluvial velocity [Figure 1 (b)] are as expected from the Bernoulli effect: the greater the cross sectional area the lower the velocity and vice versa. Fluvial velocity slows as the estuary widens towards its mouth and is dwarfed by tidal velocity [Figure 1 (b)].

[1] For more detail on the methods, see Appendix A.

Other variable change as cross-sectional area and velocity changes. Transit times are faster and age of water increases more slowly in reaches with smaller cross-sectional areas. In reaches with larger cross sectional areas, the opposite is true. The effects are most noticeable in the estuarine portion where the estuary progressively widens (and its cross-sectional area increases) from its head to its mouth. The “aging” effects are much more prominent under low flow regimes [Figure 1 (c)].

The contribution of fluvial energy to the system drops rapidly from 100% in the non-tidal reaches to less than 10% in the first estuarine segment and 2% (in the high-flow regime) or less by the third (Figure 1 (d)]. In this estuarine system—modeled on the Bay of Fundy, known for the greatest tidal range on Earth (Garrett, 1984)—the massive exchange of water as tides move in and out dwarfs the volume of water contributed by the river even under high flow conditions.

REFERENCES

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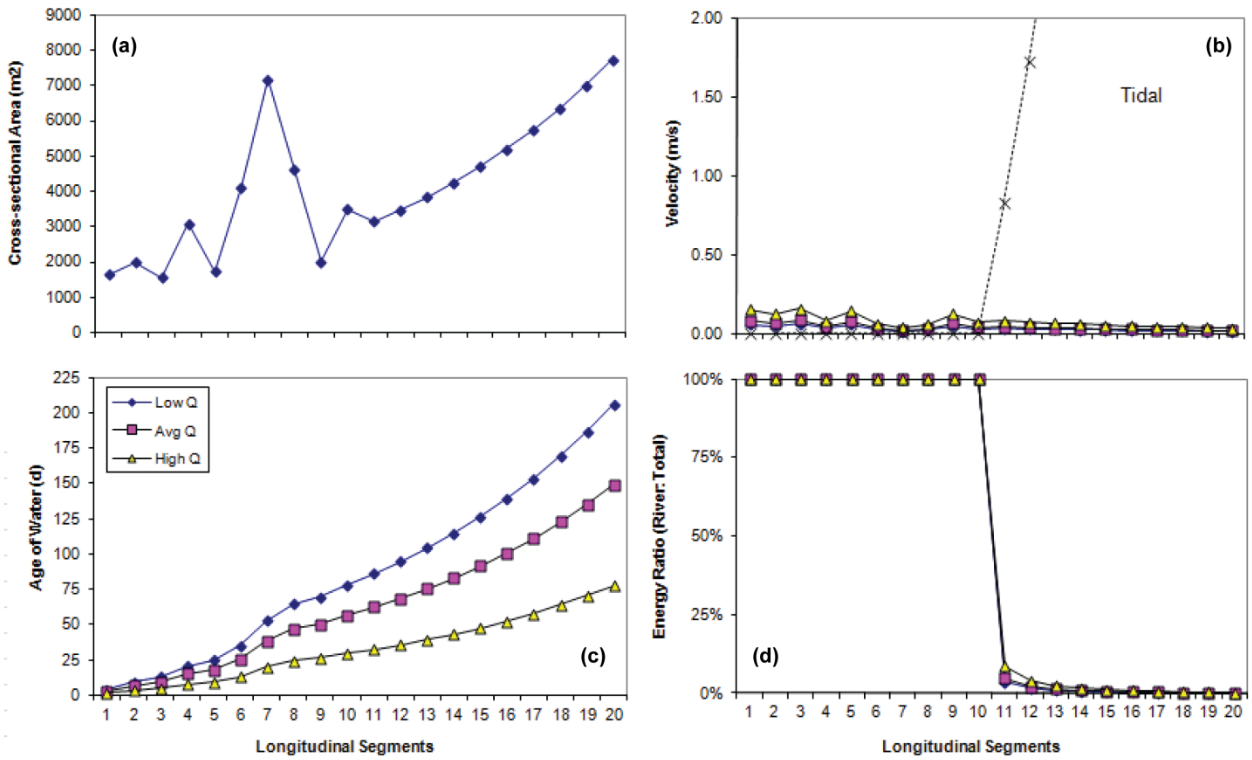

Figure 1. Results of a model of river and estuary hydrodynamics. Each plot shows basin parameters or predicted values per longitudinal segment of the river/estuary system. Segments 1 through 10 represent non-tidal portions of the river. Segments 11 through 20 represent the estuary. The plots are: (a) cross-sectional area, (b) riverine and tidal velocity, (c) age of water, and (d) percentage of riverine contribution to total system energy. Riverine phenomena in plots (b), (c), (d) are given for high-, average-, and low-flow regimes.

Appendix A. Methods

The hydrodynamics of a virtual river/estuary system were investigated using a simple spreadsheet model. The system was divided into twenty 20-km-long segments, with the first ten segments representing the non-tidal portion of the river and the last ten segments representing the estuary. The geometry (width and depth in meters) of each river segment was determined randomly, with width limited to a value between 200 and 1,000 m and depth limited to between 3 and 10 m. Estuarine geometry changed linearly, with the dimensions of the final riverine segment setting initial conditions for the first estuarine segment. Width of each estuarine segment increased by 30% over its predecessor; depth of each estuarine segment decreased by 15%. For each segment, cross-sectional area (m^2) was calculated by multiplying width by depth.

Flow and tidal parameters were obtained from actual river and estuarine data. Average annual and monthly discharge ($m^2\ s^{-1}$) data for the Kennebec River at Bingham, Maine, were obtained from the National Water Information System (U.S. Geological Survey, 2012). Three variables where used for this model: average annual discharge (129 $m^3\ s^{-1}$), highest average monthly discharge (May; 247 $m^3\ s^{-1}$), and lowest average monthly discharge (September; 93.2 $m^3\ s^{-1}$). One week's worth of hourly tidal data (height above mean low low water in meters) for Eastport, Maine—near the mouth of the Bay of Fundy—were obtained from (Center for Operational Oceanographic Products and Services, 2011). From the hourly data, the tidal range was calculated by subtracting average low tide from average high tide.

The discharge and tide data were used to calculate model outputs for each flow regime (high, average, and low). Fluvial velocity ($m\ s^{-1}$) was calculated by dividing discharge by cross-sectional area. Transit time (d) was calculated by dividing segment length by velocity. Age of water (d) was calculating by summing the transit time for the current and preceding segments.

For the estuarine segments of the model, tidal volume (m^3) was calculated by multiplying tidal range by segment length and width. Tidal velocity ($m\ s^{-1}$) was calculated by dividing tidal volume by cross-sectional area. Finally, energy ratio (%) was calculated by dividing fluvial velocity by the sum of fluvial and tidal velocities.