MODELING LONG-TERM PAH ATTENUATION IN ESTUARINE SEDIMENT, CASE STUDY: ELIZABETH RIVER, VA

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Abstract

Due to their slow degradation properties, hydrophobic organic contaminants in estuarine sediment have been a concern for risks to human health and aquatic organisms. Studies of fate and transport of these contaminants in estuaries are further complicated by the fact that hydrodynamics and sediment transport processes in these regions are complex, involving processes with various temporal and spatial scales. In order to simulate and quantify long-term attenuation of Polycyclic Aromatic Hydrocarbons (PAH) in the Elizabeth River, VA, we develop a modeling approach, which employs the U.S. Environmental Protection Agency's water quality model, WASP, and encompasses key physical and chemical processes that govern long-term fate and transport of PAHs in the river. In this box-model configuration, freshwater inflows mix with ocean saline water and tidally averaged dispersion coefficients are obtained by calibration using measured salinity data. Sediment core field data is used to estimate the net deposition/erosion rate, treating only either the gross resuspension or deposition rate as the calibration parameter. Once calibrated, the model simulates fate and transport PAHs following the loading input to the river in 1967, nearly 4 decades ago. Sediment PAH concentrations are simulated over 1967-2022 and model results for Year 2002 are compared with field data measured at various locations of the river during that year. Sediment concentrations for Year 2012 and 2022 are also projected for various remedial actions. Since all the model parameters are based on empirical field data, model predictions should reflect responses based on the assumptions that have been governing the fate and sediment transport for the past decades.

1. INTRODUCTION

The Elizabeth River, including its watershed, is a complex system with branches and tributaries, including a deep-water harbor used by the U.S. Navy and maritime industries. The watershed is approximately 600 km^2 and the highly industrialized, commercial and military activities and densely populated urban areas of the metropolitan Hampton Roads Region influence ambient water and sediment quality. Water and sediment within the river contain at least trace amounts of most pollutants and PAHs are found to exist in sediments in moderate concentrations throughout most of the Elizabeth River and to exist in extremely high concentrations in sediment in the vicinity of sites where creosote was historically used to treat wood for use in the marine environment.

PAHs, like many hydrophobic contaminants in aquatic systems, tend to get adsorbed with fine-grained sediments, which generally have large organic carbon materials. The processes mediating sediment transport within the aquatic system dictate the transport and fate of these particle-associated pollutants. In highly channelized tidal environments such as the Elizabeth River, fine sediment and associated pollutant transport and fate will be governed predominantly by physical processes. Consequently, to understand and model the processes controlling contaminant transport from Elizabeth River sediments to the water column, and from historically contaminated areas to lesser or nonpolluted sites, particles and associated contaminant resuspension and deposition must be evaluated quantitatively in the estuary along with likely mechanisms for physical transport.

2. MODEL CONFIGURATION AND CALIBRATION

In order to simulate and quantify long-term attenuation of Polycyclic Aromatic Hydrocarbons (PAH) in the Elizabeth River, VA (Figure 1), we develop a modeling approach, which employs the U.S. Environmental Protection Agency's water quality model, WASP (Ambrose et al., 1993; Figure 2), and encompasses key physical and chemical processes that govern long-term fate and transport of PAHs in the river. In this box-model configuration, freshwater inflows mix with ocean saline water and tidally averaged (steady state) dispersion coefficients are obtained by calibration using measured salinity data, namely,

$$V\frac{\partial S}{\partial l}=\frac{\partial}{\partial l}\left(D\frac{\partial S}{\partial l}\right) \tag{1}$$

where V is the net advection term driven by freshwater inflow, S is the salinity and l is the direction of 1-D segmentation from upstream to downstream. In Eq.(1), V is estimated based on both measured data and watershed numerical model. Using measured salinity along the river (Figure 3), we estimate the tidally averaged dispersion coefficient, D, from Eq.(1) (Figure 4).

Sediment core field data is used to estimate the net deposition/erosion rate, treating only either the gross resuspension or deposition rate as the calibration parameter, as shown in the following equation,

$$D_{NET} = D - R \tag{2}$$

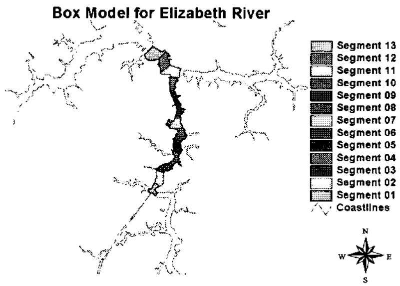
where D_{NET} is the net deposition rate obtained from the sediment core data, D and R are gross deposition and resuspension rate, respectively.

3. MODEL RESULTS AND DISCUSSIONS

Once calibrated, the model simulates fate and transport PAHs following the loading input to the river in 1967, nearly 4 decades ago. Sediment PAH concentrations are simulated over 1967-2022 and model results for Year 2002 are compared with field data measured at various locations of the river during that year (Figures 5 and 6). Simulated PAH concentrations are in agreement with measured data, spatial variations are in similar trend and magnitudes throughout the river stretch. In fact, the good agreement between the model and data is not surprising, but expected, since this dataset is used for model calibration for the gross sediment deposition or resuspension, as discussed above. Nevertheless, the agreement is important since this demonstrates that the model predicts PAH attenuation in sediment, with adequate accuracy, 35 years after the loading in 1967.

Sediment concentrations are further projected for another 10 and 20 years, namely, for Year 2012 and 2022, for two remedial actions: no action (Figure 7) and clean-up Segment 15 with concentration reduced to 15,000 ppb (Figure 8). It is shown that, with no action taken, reduction of PAH concentrations is a very slow process. Reduction of sediment concentration down to 15,000 ppb at Segment 15 has only the local effect; concentrations in the adjacent segments barely are affected

In conclusion, a box model is developed to simulate the fate and transport of PAHs in sediment in the Elizabeth River, VA over the period of 1967-2022. This modeling approach is based on the assumption that physical processes, including transport in the water column and settling and resuspension between the water-sediment interface have been governing the PAHs in sediments. The model is calibrated by using the data measured at various locations in 2002. Once calibrated, the model is used to predict natural dispersion, and re-contamination for two remedial options, including no action and clean-up of the hot spots. Since all the model parameters are based on empirical field data, model predictions should reflect responses based on the assumptions that have been governing the fate and sediment transport for the past decades.



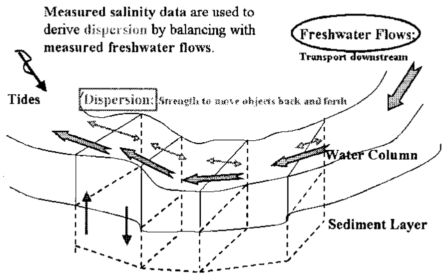
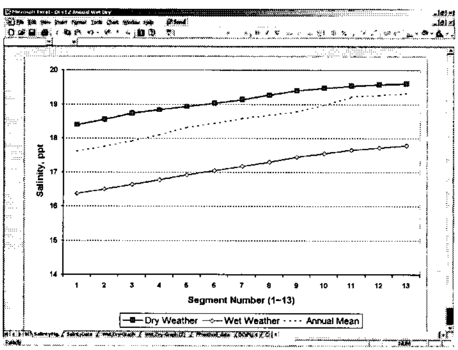


Fig. 1 Elizabeth River and Box Model Grid

Fig. 2 Mixing Between River Flow and Tides



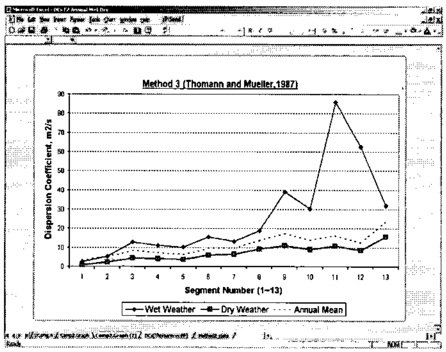


Fig. 3 Salinities Measured in the River

Fig. 4 Estimated Dispersion Coefficients

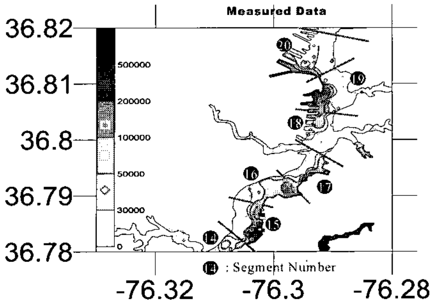


Fig. 5 Measured Data in Year 2002

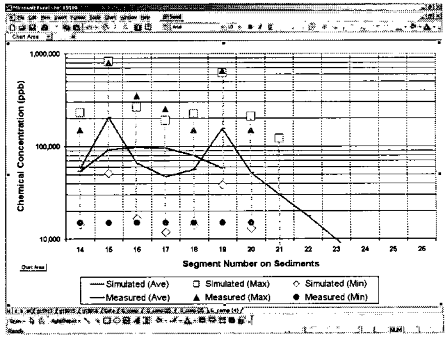


Fig. 6 Model-Data Comparison for Year 2002

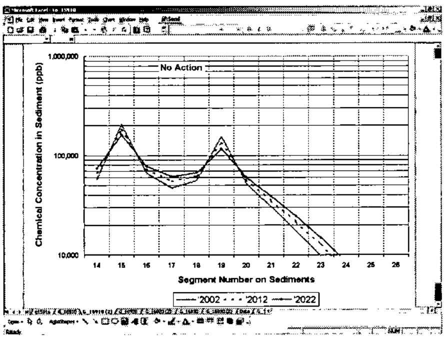


Fig. 7 Projected Concentrations for No-Action

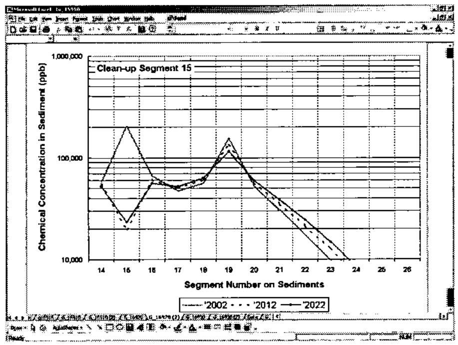


Fig. 6 Projected Concentrations for Clean-Up of Segment 15

REFERENCE

Ambrose, R.B., Jr., Wool, T.A. & Martin, J.L., 1993 The Water Quality Analysis Simulation Program, WASP5; Part A: Model Documentation U.S. Environmental Protection Agency, Center for Exposure Assessment Modeling, Athens, GA.