Validation and Verification of Model Predictions for ^{137}Cs Fate and Transport in the Tidal Fresh Potomac River

Midshipman 1/C Samuel J. Kelly, USN, Class of 2013; Advisor: CDR Joseph P. Smith, Dr. Andrew Muller

Abstract:

The 2011 Fukushima Daiichi nuclear reactor incident in Japan highlighted the importance of understanding the transport, dispersion, and fate of radioisotopes like ^{137}Cs in aquatic systems. Estuaries are often highly urbanized, resulting in a high probability for releases of radioisotopes into these systems. Predicting the transport, dispersion, and fate of radioisotopes in dynamic estuarine systems is especially challenging. The System for Hazard Assessment of Released Chemicals (SHARC) is a chemical modeling tool developed by RPS ASA, Inc. for the U.S. Defense Threat Reduction Agency (DTRA) to predict the transport, dispersion, and fate of chemical, biological, and radiological agents like ^{137}Cs in aquatic systems. Cesium-137 is not normally found in easily-measureable levels in the environment so chemical proxies with known input functions and reactivity similar to ^{137}Cs may be used to validate SHARC model outputs in estuaries. In this study, field measurements of Rubidium in the tidal-fresh Potomac River estuary by the outfall of the Blue Plains Advanced Wastewater Pollution Control Plant (BPWPCP) were used to validate and verify SHARC model predictions for ^{137}Cs dispersion and transport. Results show that SHARC does a good job in predicting the general plume for ^{137}Cs released into the tidal-fresh Potomac River but factors like river flow and fine-scale bathymetry and morphology significantly influence transport, dispersion, and fate. Detailed hydrographic, bathymetric, and environmental data is required to improve SHARC model predictions in estuaries.

Study Area and Methods:

Figure 1. Google Earth view of the tidal-fresh Potomac River study area. Markers denote the sampling locations for 21JUL11 (blue square), 10MAY12 (yellow circle), and 16NOV12 (red diamond). The BPWPCP is highlighted in the upper right hand corner. Note: Stations BPPR X/XA indicate the BPWPCP outfall site. Stations BPPR 1/1A, approximately 4 km north of BPWPCP outfall, were used to represent Potomac River background (not shown).

Figure 1 shows the Potomac River study site. *In-situ* data on water column parameters (temp, conductivity, pH, turbidity) were collected using a Hydrolab Quanta and surface water samples were collected for metals analysis (Rb, Gd) by High Resolution Inductively-Coupled Mass Spectrometry. Results of field measurements were compared to SHARC model runs simulating inputs of ^{137}Cs to the Potomac River (**Fig. 2**).

Figure 2. (**A**) MIDN 1/C Baker and MIDN 1/C Kelly (USNA Physics) collecting surface samples from a small boat on the Potomac River, 16NOV12. Samples were also collected from the Potomac River on 21JUL11 and 10MAY12 by faculty and Midshipmen of the USNA Oceanography Department. The System for Hazard Assessment of Released Chemicals (SHARC) is a waterborne chemical modeling tool developed made by RPS ASA, Inc. for DTRA.

Results and Discussion:

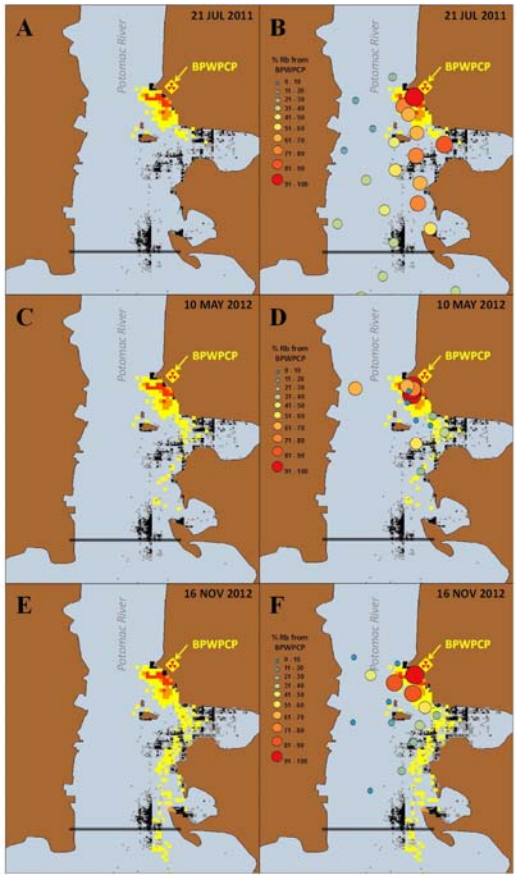

Figure 3. Output of SHARC Model runs simulating an input of 50 kg of ^{137}Cs from BPWPCP to the Potomac River: (**A**) 11-21JUL11; (**C**) 01-10MAY12; (**E**) 06-16NOV12. Red denotes highest, orange denotes moderate, and yellow denotes lowest ^{137}Cs aqueous activities. Black denotes highest and grey denotes lowest ^{137}Cs sediment activities. Results of measured % Rb from BPWPCP plotted against SHARC model outputs for: (**B**) 21JUL11; (**D**) 10MAY12; (**F**) 16NOV12. Measured Rb concentrations were normalized to background river concentrations (BPPR1/1A) and expressed in terms of % Rb from BPWPCP, with 100% assumed to be the measured Rb concentration at the BPWPCP site (BPPR X/XA) at the time of sampling.

Figure 3 shows a comparison of SHARC model outputs to field measured % Rb from BPWPCP in discrete surface water samples. In all SHARC simulations, the ^{137}Cs plume shows higher activities closest to the BPWPCP outfall and decreasing activities with distance from the source. Plume dispersion away from the source is variable by date, likely due to differences in meteorological, hydrological and environmental conditions. Field Rb observations tend to compare well with SHARC predictions closer to the BPWPCP outfall but not as well away from the source.

Results and Discussion (cont…):

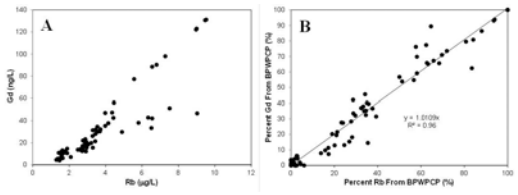

Figure 4. (**A**) Comparison of [Rb] and [Gd] at sample points near the BPWPCP in the tidal-fresh Potomac River and (**B**) Comparison of % Rb and % Gd from the BPWPCP outfall given background concentrations at the same points.

Rubidium was chosen as a proxy for Cs because they are in same group (Group 1) on the periodic table and should behave similarly in the environment. Gadolinium is a known wastewater tracer (Hartel et al., 2007). **Figure 4A &B** shows a comparison of measured [Rb] to [Gd] and normalized % Rb and % Gd from BPWPCP. The strong linear relationship between normalized % Rb and % Gd from BPWPCP suggests Rb is a effective tracer for the BPWPCP plume.

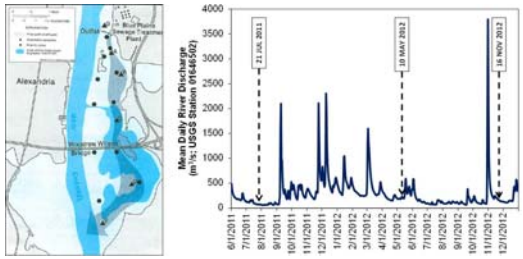

Figure 5. Blue Plains WPCP Plume Dye Study (USGS, Callender et al., 1984) and USGS Stream Flow for the Potomac River over the time period of the study.

A Plume Dye Study by USGS (1984) concluded that the BPWPCP plume is largely influence by (geo-)physical factors such as bathymetry, morphology, river and tidal flow, and wind speed/direction. The SHARC outputs are a function of the quality of data defining these factors. It can be seen that river flow conditions leading up to each sampling date were drastically different. This could partially explain the differences between modeled results and observed proxy results between dates (**Fig. 5**).

Conclusions:

- ***SHARC does a good job in predicting the dispersion plume for ^{137}Cs released into the tidal-fresh Potomac River.***
- ***Factors like river flow and fine-scale bathymetry and morphology significantly influence radioisotope transport, dispersion, and fate.***
- ***Detailed hydrographic, bathymetric, and environmental data is required to improve SHARC model predictions in estuaries.***

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