Validation and Verification of Model Predictions for ^{131}I Transport in the Tidal Fresh Potomac River

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Abstract:

The 2011 Fukushima Daiichi nuclear reactor incident in Japan highlighted the importance of understanding and predicting the transport, dispersion, and fate of radioisotopes like Iodine-131 in aquatic systems. 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 in aquatic systems. It was successfully utilized by the U.S. Navy and DTRA in Operation Tomodachi, the U.S. Department of Defense response to the Fukushima Daiichi nuclear accident. Field deployment of the SHARC model highlighted the need for validation and verification of model results in dynamic coastal systems like estuaries, where physiochemical conditions change on fine spatial and temporal scales and influence the partitioning of reactive radioisotopes like ^{131}I between the dissolved, colloidal, and particulate phases and their cycling between the water column and the sediments. *Rose et al. (2013)* published data on activity levels and behavior of medically-derived, wastewater-sourced I-131 in the tidal-fresh Potomac River estuary near the outfall of the Blue Plains Advanced Wastewater Treatment Plant (BPWTP). These results provided an opportunity to validate and verify SHARC model predictions for I-131 transport, dispersion, and fate in the Potomac River. Comparison of SHARC model predictions to the field observations of I-131 activity published by *Rose et al. (2013)* confirm the baseline predictive capacity of SHARC in a dynamic estuarine system. Results highlight the need for better definition of radioisotope source input functions and higher-resolution hydrographic, bathymetric, and environmental data to improve SHARC model predictions in estuaries and coastal systems.

Study Area and Methods:

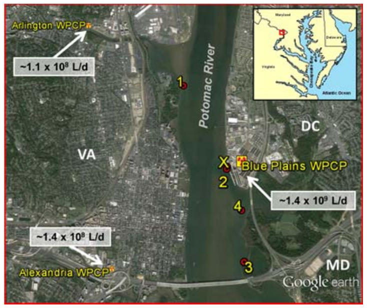

Figure 1. Google Earth view of the tidal-fresh Potomac River study area showing sampling locations for ^{131}I activity (X, 1-4) from *Rose et al. (2013)* and the locations of the Blue Plains, Arlington, and Alexandria Water Pollution Control Plants (WPCP). The average effluent discharge rate from each plant is also shown. These WPCPs service Washington, DC and parts of Montgomery and Prince Georges Counties in MD and Arlington, Alexandria, and Fairfax Counties in VA.

In February-November, 2009, *Rose et al. (2013)* collected surface water samples and sediments from the tidal-fresh Potomac River and measured medically-derived, wastewater-sourced ^{131}I activity. *Rose et al. (2013)* also measured ^{131}I activity in WPCP effluent from the 3 WPCPs that discharge into the Potomac River study area (**Fig. 1**). These field observations provided an opportunity to validate and verify System for Hazard Assessment of Released Chemicals (SHARC) model predictions for the transport, dispersion, and fate of simulated ^{131}I inputs to the tidal-fresh Potomac River.

SHARC Model Description and Approach:

SHARC was used to simulate inputs of 7.74 x 10^{-6} g (3.55 x 10^{10} Bq) of ^{131}I from the BPWPCP over a 10 day period under different flow conditions. Model runs included hydrographic data (winds tides, flow, and coarse bathymetry) and chemical constants specific to ^{131}I. The mass input for ^{131}I was based on average effluent ^{131}I activity concentrations measured by *Rose et al (2013)* and an average effluent discharge rate over the same period.

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Results:

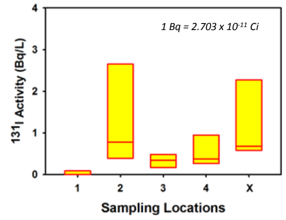

Figure 2. Box plot showing the range of surface water ^{131}I activities (Bq/L) measured by *Rose et al. (2013)* in the tidal-fresh Potomac River study area from February – November, 2009.

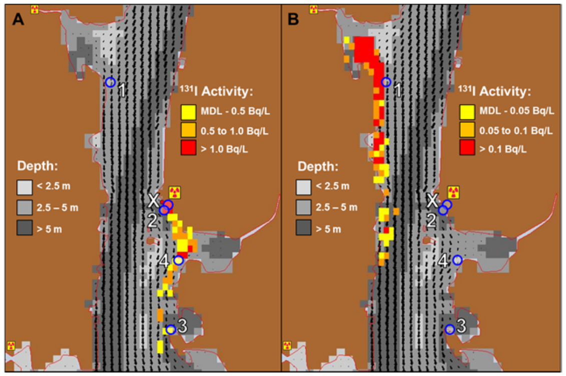

Figure 3. Example output of SHARC model simulations on day 10 at 12:00PM for an introduction of (**A**) 7.74 x 10^{-6} g (3.55 x 10^{10} Bq) of ^{131}I from BPWPCP over a 10-day period in October 2011 and (**B**) 7.74 x 10^{-7} g (3.55 x 10^{9} Bq) of ^{131}I from Arlington WPCP over the same 10-day period. The ten day introduction was chosen to allow equilibrium background activities to be reached in the Potomac River. The input from Arlington WPCP was reduced to 10% of the BPWPCP input to account for the lower capacity of the Arlington WPCP as compared to the BPWPCP . Arrows indicate flow direction at the time of model prediction and course bathymetry for the Potomac is shown in grey scale.

A series of 5 SHARC 10-day model simulations for an introduction of ^{131}I from BPWPCP different flow conditions were conducted and SHARC predicted ^{131}I activity concentrations were compared to those measured by *Rose et al. (2013)* in the Potomac River (**Fig. 2**). **Figure 3** shows examples of SHARC model simulation outputs for a 10-day introduction of ^{131}I from the BPWPCP (**Fig. 3A**) and Arlington WPCP (**Fig. 3B**). Hydrodynamic forcing and bathymetry constrain the BPWPCP plume to the eastern shore of the river. It is clear from the SHARC model simulation that the activities measured at sampling location 1 are not likely from BPWPCP effluent. Smaller inputs from the Arlington WPCP follow the deeper main channel of the Potomac along the western side of the river (**Fig. 3B**) and better explain the measured activities at sampling location 1. **Table 1** shows the range of ^{131}I activity concentrations measured by *Rose et al. (2013)* in surface waters of the Potomac River compared to SHARC predicted ^{131}I activity concentrations.

Table 1. ^{131}I activity concentrations measured by *Rose et al. (2013)* and SHARC predicted ^{131}I activity concentrations in surface waters of the Potomac River. Predicted ^{131}I activity concentrations are based on the average over a complete tidal cycle during 5 different flow conditions except for Location 1 which is based on 2 different flow conditions.

	Measured ^{131}I Activity (Bq/L)			SHARC Predicted ^{131}I Activity (Bq/L)		
Location	**Min.**	**Avg.**	**Max.**	**Min.**	**Avg.**	**Max.**
1	0.00	0.04	0.10	0.00	0.03	0.19
2	0.18	1.63	6.07	2.22	8.52	23.81
3	0.16	0.33	0.61	0.00	0.16	0.52
4	0.25	0.56	1.52	0.00	0.75	2.04
X	0.54	1.28	3.77	0.14	6.87	23.81

Discussion:

SHARC does an adequate job in predicting the presence of measurable ^{131}I activity at each location and the general (order of magnitude) range of values of ^{131}I activity concentrations measured by *Rose et al. (2013)* in surface waters of the Potomac River. (**Table 1**) SHARC tends to overestimate ^{131}I activity concentrations closest to the source (Location 2 and X). A particle-loss and settling rate of 0.05 m/day was used in all simulations. This may underestimate loss of ^{131}I to the sediments.

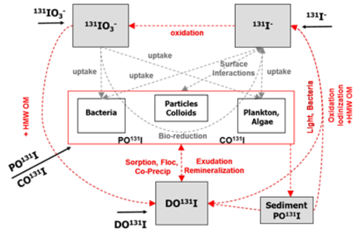

Figure 4. Cycling and partitioning of ^{131}I in aquatic systems (Modified after *Rose, 2011* and *Wong and Cheng, 2001*).

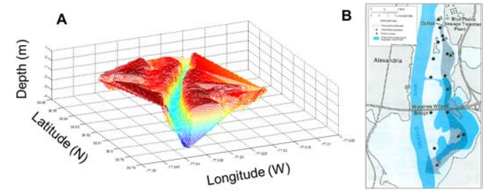

Figure 5. (**A**) High resolution bathymetry of the Potomac River study area (NOAA Hydrographic Survey H-9477, 1974) and (**B**) Blue Plains WPCP Plume Dye Study (USGS, Callender et al., 1984).

Discrepancies between SHARC predicted activities and activities measured by *Rose et al. (2013)* are a result of multiple factors: 1) hydrographic model resolution; 2) differences between model initial conditions and conditions at the time of sample collection (i.e. wind, tides, river flow); 3) complexities in the biogeochemical cycling of iodine (**Fig. 4**); 4) lack of high-resolution bathymetry (**Fig. 5A**). Previous research by *Rose et al. (2013), Smith et al (2008),* and others has shown that the biogeochemical cycle of iodine in aquatic systems is not well-understood. A Plume Dye Study by USGS (1984) concluded that the BPWPCP plume is influenced by (geo-)physical factors such as bathymetry, morphology, river and tidal flow, and wind speed/direction (**Fig. 5B**).

Conclusions:

- ***SHARC does a adequate job in predicting the dispersion plume for ^{131}I released into the tidal-fresh Potomac River.***
- ***Factors like fine-scale bathymetry and morphology and complex hydrodynamic forcing significantly influence radioisotope transport, dispersion, and fate in estuarine systems like the Potomac River.***
- ***There is a need to better understand the biogeochemical cycle of iodine in aquatic systems in order to predict ^{131}I fate and transport.***
- ***Detailed hydrographic, bathymetric, and environmental data is required to improve SHARC model predictions in estuaries.***

Acknowledgements: This work was funded by the U.S. Defense Threat Reduction Agency (DTRA). Special thanks to Richard Fry (DTRA); Matthew Ward, Mark Wholey, and Jennifer Cragan (Maritime Planning Associates), and Dr. Paula Rose (Department of Physical and Environmental Sciences, Texas A&M University - Corpus Christi).