Final Report

Enhancements to the ICPRB Potomac RiverSpill model

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submitted by

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I. INTRODUCTION

The Potomac River and its tributaries are the principal source of drinking water for the metropolitan Washington, DC area. The many road crossings and several pipelines for petroleum products across the basin provide opportunities for accidents or intentional introduction of toxic materials into the river that might contaminate downstream drinking water systems. In addition, failures or system overflows at wastewater treatment plants and combined sewer systems can introduce large pathogen loads into the river system.

In the mid 1980s the Interstate Commission on the Potomac River Basin (ICPRB) developed its Toxic Spill Model to estimate the travel time of spilled materials on the mainstem Potomac river and five major tributaries. Since then, ICPRB has been the agency designated by area water utilities to make forecasts of time of arrival of contaminants at water intakes. Recently, the EPA has funded SAIC to develop a version of its RiverSpill model specific to the Potomac river. RiverSpill offers features not found in the ICPRB Toxic Spill model, include a variety of graphical outputs, contaminant assessments based on a built in library of contaminant characteristics, and, most particularly, the ability to estimate travel time on streams throughout the basin (not limited to the Potomac river and five tributaries included in the Toxic Spill model). These features are sufficiently attractive that ICPRB is considering adopting the RiverSpill model for operational use during spill events. ICPRB, the community of water suppliers, and local governments are concerned, however, that travel time predictions by the RiverSpill model are consistent with predictions of the Toxic Spill model for the region covered by the Toxic Spill model. This report documents the results of the three objectives for this project:

A) - Implement at ICPRB the RiverSpill model as a replacement for the ICPRB model.

B) - Test RiverSpill features and in particular test its travel time predictions in comparison to the Spill model.

C) - Using the RiverSpill model, hold a “spill exercise” with participation by Washington area water utilities to demonstrate the new capabilities of this model (vis a vis the ICPRB model), and to test its application in advance of an actual emergency.

II) IMPLEMENTING THE RIVERSPILL MODEL AT ICPRB

ICPRB’s spill response plan is to have three staff members trained and equipped to run the spill model and provide travel time predictions to the water utilities and government agencies at any time. Having three staff members prepared to make an analysis provide redundancy to assure a timely response in the event of a contaminant spill at any time. Each person has a notebook computer with appropriate hardware and software so that calculations can be made and shared with relevant officials while away from ICPRB offices. To provide this three person coverage, existing resources were supplemented by purchasing one copy of ArcView 3.3 software and one notebook computer with funds from this project.

SAIC has developed a new version of RiverSpill, called ICWater, which is expected to be available for the mid-Atlantic states by the end of 2006. That model is an ArcGIS 9 application which does not run in ArcView 3. In anticipation of a transition to ICWater, three copies of ArcMap 9 were purchased also for this project. Transition to ICWater is discussed further later in this report.

The RiverSpill application was provided by SAIC on CD along with a manual. Successful installation required followup assistance from SAIC to solve undocumented requirements for computer hardware and operating system configuration. All of these problems were due to differences between computers used by the SAIC development team and computers in use at ICPRB. If RiverSpill and its successor ICWater are to be distributed to multiple agencies around the United States, it is recommended that, before a general release, SAIC test installation and program execution at "beta" test sites outside of SAIC. It appeared that ICPRB served that function with this version of RiverSpill.

Once installation challenges were resolved, and SAIC staff were conscientious in resolving each problem, RiverSpill was integrated into ICPRB's emergency response operations and program testing began. Testing focused on two aspects of RiverSpill: how comparable to the ICPRB Toxic Spill model are its travel time and peak concentration predictions, and what RiverSpill features provide a useful addition to the reports that ICPRB can provide to the utilities and government agencies.

To integrate RiverSpill into ICPRB spill response operations, the model was installed on three notebook computers. At least two of these computers travel with their users to home and on business travel at all times. State emergency management agencies know to contact ICPRB in the event of a contaminant spill on the Potomac River and its major tributaries, providing information on time, location, amount, and nature of the spill. Outside of normal business hours emergency messages can be left in a voice mailbox set aside for that purpose. When a message is left in that mailbox the ICPRB phone system begins sequentially calling the three ICPRB staff members "on call". It continues to call until one of the three answers. That individual is then connected with the voicemail message. Staff members on call have with them a notebook computer with the ICPRB Spill Model and RiverSpill installed. Prior to RiverSpill, the Spill Model would be run, providing predicted time of arrival of the leading edge, peak and trailing edge of the contaminant, plus the peak concentration, at selected points downstream from the spill. That information would be communicated to state emergency management agencies and downstream utilities by telephone and via the MWCOG RICCS system. One of the advantages of the RiverSpill model is that one can create and save maps showing the origin and downstream course of a spill. To take advantage of this capability, ICPRB has developed a password protected webpage on which information about a spill will be posted and agency and utility staff will be directed to access it there.

III TESTING RIVERSPILL TRAVEL TIME PREDICTIONS

(A) Background

The Toxic Spill Model is based upon a set of time travel dye studies conducted by the U.S. Geological Survey and Maryland Geological Survey in the 1960s and early 1980s on the Potomac river and five tributaries: Monocacy River, Shenandoah River, Antietam Creek, Conococheague Creek, and the South Branch Potomac River (K.R. Taylor et al, 1970; K.R. Taylor and W.B. Solley, 1971; A.R. Jack, 1984; K.R. Taylor et al, 1985; K.R. Taylor et al, 1986). In those studies a soluble dye was injected during approximately constant flow conditions and the time of travel of the leading edge, peak concentration, and trailing edge of the dye cloud to selected points downstream was measured. On each river dye travel time was measured at two or three flow levels. A method for predicting the travel time of a conservative, soluble, material during constant flow conditions based on the dye study results is described in each of these publications. The method is based on this relationship of stream flow (Q) and velocity (V)

$$V = a * Q^b \quad \text{[Eq. 1]}$$

or

$$\log(V) = \log(a) + b * \log(Q) \quad \text{[Eq. 2]}$$

Equation 2 describes a straight line relationship between log(V) and log(Q). Estimates for the coefficients log(a) and b can be determined by linear regression of observed Q and V from the dye studies. A method for estimating the peak concentration of contaminant clouds based on the "unit peak concentration" concept is described in K.R. Taylor et al (1985 and 1986). In these publications, time of travel and peak concentration problems are solved by selecting appropriate points on plots of travel time versus distance for reference flows or in tables of travel time values for reference flows.

The original Toxic Spill Model, developed in 1986, was a Fortran computer program that provided a numerical solution for travel time and peak concentration using the same techniques described by the USGS in the dye study publications (including modeling continuous spills using the Superposition method) and based on a and b coefficients computed from the dye studies field data (K. Hogan, et al, 1991). That model was re-written in 2002 as a Quattro Pro spreadsheet model. The computational method in the revised model is the same but there are slight differences in a and b coefficients in a few reaches[1]. The revised model added a simple graphical plot of travel times, added the ability to estimate concentrations of non-conservative substances, and enhanced the ability to model sewage spills. The revised model also is much faster and easier to use than the original model - a significant advantage when doing multiple model runs to explore spill scenarios. From 1986 to the present, the Toxic Spill Model, in its original or revised form, has been the tool used by ICPRB to advise water utilities and government agencies of the expected travel times of contaminants in the Potomac River and five major tributaries.

The RiverSpill model, developed by SAIC, is a computer program using geographic information system tools to connect points of interest to a stream network, calculate travel time and peak contaminant concentrations, and to display affected stream reaches and related points of interest on maps (W.B. Samuels et al 2006). As in the USGS dye studies and the ICPRB Toxic Spill model, in RiverSpill travel time calculations are based on the discharge:velocity relationship shown in Equation 1 above. In the national version of RiverSpill, coefficient b is assigned a constant value of 0.255 and coefficient a is calculated for each reach by

$$a = V_{av} / Q_{av}^{b} \quad \text{[Eq. 3]}$$

where V_{av} is average stream velocity for a reach

Q_{av} is average stream discharge for a reach

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[1]An examination of the original USGS/MGS studies revealed a few cases where the trailing edge of the dye cloud traveled faster than the leading edge. This is not possible under steady state flow conditions, probably indicating rising flows during the field study. In those cases an adjustment was made in coefficients so that the trailing edge did not move faster than the leading edge. This situation was most obvious on the South Branch.

In this version of RiverSpill, customized for the Potomac basin by SAIC, the coefficients a and b for each stream included in the USGS dye studies were adjusted to match those used in the Toxic Spill model (which were, in turn, calculated from travel time data reported for the dye studies). For other streams in the basin, coefficient b was assigned a constant value of 0.6851 and coefficient a was calculated using Equation 3 (SAIC, 2005).

As a successor to the Toxic Spill Model, RiverSpill has several attractive features. First, and most important, it calculates travel time for spills on any stream in the watershed whereas the Toxic Spill Model is limited to the Potomac mainstem and five tributaries. Second, it has the ability to store and display on maps many kinds of information that may be of interest. These include, in addition to water intake locations, road and railroad networks, political boundaries, wastewater discharge points, and hazardous waste sites. In addition to displaying locations, databases associated with these features can provide important information such as population served and emergency contact information for water intakes, and types of materials at hazardous waste sites. Third, RiverSpill also contains a library of information about biological effects and chemical behavior of contaminants and, where applicable, decay coefficients for non conservative substances. Fourth, RiverSpill has an “Upstream Trace” utility which, given a point where a contaminant detected, calculates the region upstream based on travel time that encloses potential source locations.

For application to the Potomac basin, ICPRB and local water utilities had one concern. They already have a travel time model calibrated to actual field data. Would RiverSpill yield similar travel time and peak concentration predictions as the Toxic Spill Model? If yes, then the other features of RiverSpill would recommend it as a replacement for the Toxic Spill Model. If the answer is no, then additional investigative work would be necessary to determine the cause of the differences.

(B) Comparing RiverSpill and the Toxic Spill models

The performance of the RiverSpill and Toxic Spill models was compared by running simulations of identical spill conditions with both models. Travel times and peak concentrations were calculated also using the graphs, lookup tables, and equations provided in each USGS/MGS dye study report (hereinafter referred to as the “USGS method”). Instantaneous spill scenarios were run on each of the tributaries and the Potomac mainstem. Continuous spill scenarios were run on Conococheague Creek for RiverSpill and Toxic Spill Model, and on the Shenandoah River for both models to mimic an example provided in the USGS report. Approximately 60 RiverSpill simulations, 20 Toxic Spill, and 20 USGS method simulations were run.

Each instantaneous spill simulation was of 1,000 kg HCl and the simulations were run at two flow levels that were approximately the same as flow conditions during the original dye studies. Table 1 provides the results of the instantaneous spill simulations. During the testing some particularly anomalous results were identified with respect to the calculation of travel time and peak concentration for continuous spills. These results were shared with SAIC who identified the source of the problem and provided a revised version of the RiverSpill model. All of the simulations were done with both versions of the model, but only revised RiverSpill results are discussed in this report.

Graphs in Figures 1 and 2 summarize results of the instantaneous spill simulations for Time to Peak and Peak Concentration. In these graphs the Toxic Spill model and RiverSpill model predictions are presented as a percent difference from the prediction derived from the USGS method. For each river there are two pairs of simulations. The first pair is a Toxic Spill model (ICPRB) and a RiverSpill (SAIC) simulation at a low flow and the second pair is for the two models at a moderate flow level. Exact flow levels are shown in Table 1. The percent difference from USGS method is calculated as

(USGS prediction - Model prediction) / USGS prediction

A negative percent difference means that the model predicted travel time or peak concentration is greater than the USGS prediction. Figures 1 and 2 compare Time to Peak (hours) and Peak Concentration (mg/l) at the simulation end point.

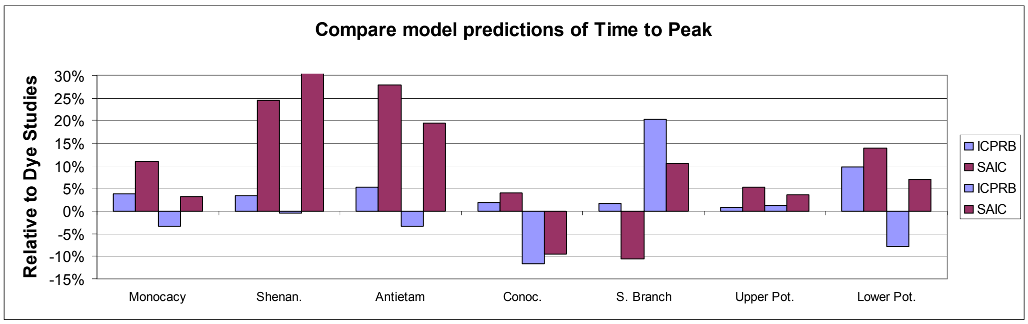

Figure 1. Comparing predictions of travel time of the peak concentration.

From Figure 1 it can be seen that the ICPRB Toxic Spill model predictions of travel time for the peak concentration is usually within 5% of the USGS method. The three rivers where differences are greater, Conococheague Creek, the South Branch, and the lower Potomac river, are reaches where an examination of the dye study travel time data along with the relevant streamflow records suggested to ICPRB that the assumption of a steady state flow condition was violated and adjustments were made in the Toxic Spill model to the coefficients a or b. The USGS method is such (interpolating flows and travel times from lines on a graph or from a lookup table) that agreement within about 5% is likely the best that can be expected. The results in this Figure show also that RiverSpill predictions are usually further from the USGS method predictions than the Toxic Spill model.

There is more variability in Peak concentration predictions, as shown in Figure 2. Since Peak concentration is a function of Leading Edge and Trailing Edge travel time, any variability in the estimates for those two parameters is amplified in the Peak concentration calculation. Still Toxic Spill model predictions are in most cases within 20% of the USGS method estimate, and the worst fit is a 40% difference on the South Branch moderate flow simulation. RiverSpill predictions are considerably further away from the USGS method estimates and in all cases except the South Branch low flow are worse than the Toxic Spill model estimates. The RiverSpill predictions are almost always higher than USGS method or Toxic Spill model estimates, suggesting a method bias that should be investigated.

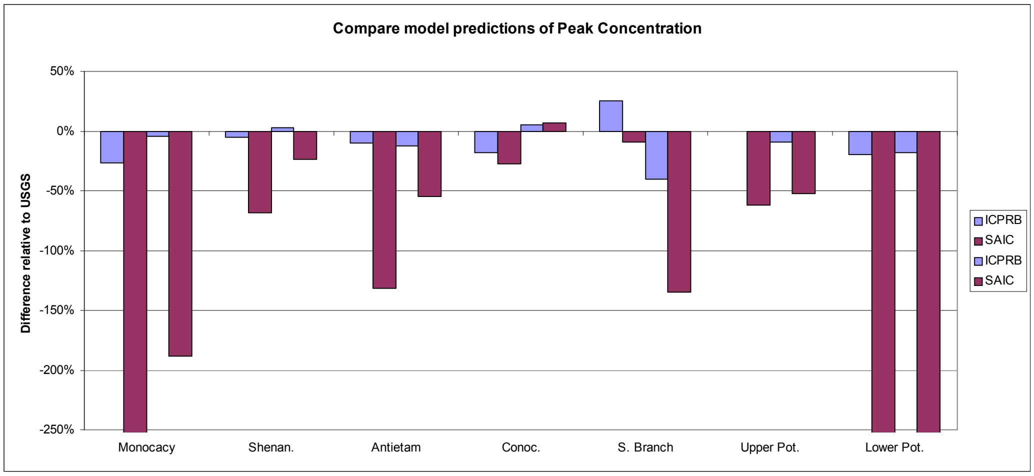

Figure 2. Comparing model predictions of peak concentration.

As can be seen in Table 1, the distances between equivalent points of interest on each stream differs between RiverSpill and Toxic Spill models. Whether the difference in distance estimates could account for the difference in travel time estimates was examined. The RiverSpill model uses the RF1 reach file to define stream channels and connect points. Stream reach lengths are determined by the RF1 database and intermediate points are interpolated by the ArcView application. The Toxic Spill model relies on river mile distances to many points provided by the USGS in the dye study publications, supplemented by additional points of interest for which river mile distances were mechanically measured by map wheel on topographic maps. Spot checking several stream reaches by map wheel has confirmed in every case the USGS distances. Figure 3 summarizes the differences in distance estimates between the two models by plotting the relative difference, {(RiverSpill - Toxic Spill) / Toxic Spill}, for the stream lengths in the spill simulations (from near the head to near the mouth of each tributary). As shown in Figure 3, the differences in all cases except Antietam Creek are in the vicinity of 5% . It is not known why the RF1 database distances for Antietam Creek are so different. In any case, these differences are not sufficient to explain the differences in model predictions of travel time.

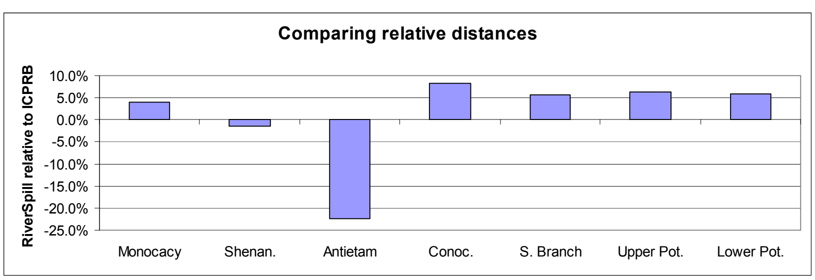

Figure 3. Comparing estimates of distances. Numbers < 0 indicate RiverSpill distances < Toxic Spill Model distances.

Table 1. Flows and locations for instantaneous spill simulations. Flow exceedence is the percent of days that flow at this gage is equal to or higher than the Reference flow. Distance refers to the distance in miles from the spill location to the end point. Distances used in the ICPRB model differ from those calculated by the RiverSpill model.

Tributary	Ref. gage	Ref Gage ID	Ref. Flow (cfs)	Flow Exceedence	Spill location	End Point	Flow, End Point	Distance (ICPRB)	Distance (RiverSpill)
Monocacy	Jug Bridge	1643000	94	95	Harney Rd. Bridge	C&O Canal Aqueduct	109	56.7	59
			551	40			640		
Shenandoah River	S. Fork, Front Royal	1631000	433	85	Hwy 664, Waynesboro	Hwy 340, Harper's Ferry	704	177.7	175.2
			1070	45			1790		
Antietam Creek	Sharpsburg	1619500	98	90	Hwy 60	Harpers Ferry Rd	98	35.5	27.55
			229	45			229		
Conococheague Cr.	Fairview	1614500	104	90	Hwy 58	C&O canal	112	21.05	22.8
			250	60			271		
S. Branch, Potomac R.	Springfield	1608500	122	95	Rt. 220, Petersburg	CORD 11	122	68.4	72.3
			1030	35			1030		
Potomac River	Pt Rocks	1638500	1690	90	Brunswick	WAD Great Falls	1995	39.9	42.4
			4120	60			4865		
Potomac River	Paw Paw	1610000	447	90	Cumberland	Dam #3	934	131.5	139.2
			906	70			1866		

Table 2. Results of instantaneous spill simulations.

ICPRB				RiverSpill				USGS Dye Studies			
LE (hours)	Peak (hours)	TE (hours)	Cpeak (mg/l)	LE (hours)	Peak (hours)	TE (hours)	Cpeak (mg/l)	LE (hours)	Peak (hours)	TE (hours)	Cpeak (mg/l)
383.4	481.2	705.1	0.583	378	445		1.851	408.0	500.0	815.0	0.461
95.3	111.1	152.6	0.557	89.4	104		1.536	95.0	107.5	155.0	0.532
526.8	607.4	730.0	0.143	408	475		0.229	542.0	629.0	756.0	0.136
259.2	293.4	340.0	0.141	134	155		0.179	258.0	292.0	337.0	0.145
106.7	122.8	175.9	3.015	70.9	93.4		6.3	107.7	129.6	184.0	2.734
59.9	66.6	84.4	3.644	39.9	51.9		5.0	57.4	64.4	85.0	3.234
55.7	65.2	90.2	5.291	42.1	63.9		5.73	62.3	66.5	103.0	4.484
31.5	36.3	48.6	4.412	23.9	35.6		4.35	28.3	32.5	44.5	4.656
266.3	305.8	404.2	1.215	281.0	344.0		1.772	264.0	311.0	367.0	1.627
61.8	71.0	91.6	0.665	66.1	79.6		1.109	75.0	89.0	117.0	0.473
91.0	99.1	119.7	3.571	82.1	94.8		5.73	91.8	100.0	120.7	3.545
52.5	56.4	67.3	2.839	47.9	55.1		3.944	51.4	57.1	67.6	2.594
430.5	527.7	742.3	0.702	439.0	502.0		2.575	465.0	584.0	838.0	0.587
299.4	353.9	494.0	0.661	269	305		2.256	264.0	328.0	460.0	0.559

(D) Assessment of continuous spills

Simulations of continuous spills were run on Conococheague Creek and on the Shenandoah River. Conococheague Creek was selected because the two travel time models were closer in their predicted travel times on this stream than elsewhere. The Shenandoah River was selected in order to recreate an example provided in Taylor et al (1986) and thereby provide a comparison with the calculation method described by the USGS.

Three spill simulations were done on Conococheague Creek: 1,000 kg instantaneous spill, a 4 hour spill at a rate of 1,000 kg/hr, and a 48 hour spill at a rate of 1,000 kg/hr. Spill origin was at the State Hwy 58 bridge crossing (lat 39.715N, long 77.79W). Streamflow at the Fairview reference gage was set to 250 cfs. The simulations followed the spill into the Potomac River down to the Rockville public water intake. The RiverSpill model estimates flow in all stream reaches based on a single reference gage, while the Toxic Spill model requires that tributary and Potomac river flows be separately input. In order to make these simulations as similar as possible, the same flow that RiverSpill calculated for Point of Rocks, 3,541 cfs, was used in the Toxic Spill model.

Spill simulation results are shown in Table 3 (A-D) and in Figures 4 - 6.

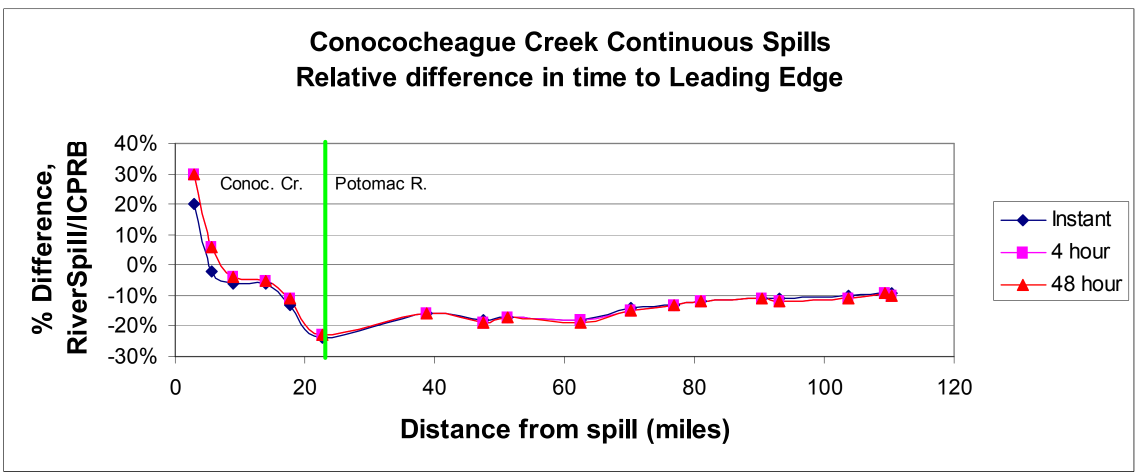

Figure 4. Conococheague Creek, relative difference in time to leading edge

In Figure 4 the relative difference between RiverSpill and Toxic Spill (ICPRB) model predictions of time of arrival of the leading edge of the contaminant cloud is shown as a function of distance from the spill origin. Relative differences less than zero indicate longer travel times (lower velocity) for the Toxic Spill model. Large relative differences in travel time close to the spill origin are not significant because the absolute differences in travel time are very small (less than one hour which, for the Toxic Spill model, is probably the approximate limit of precision). The plot shows that, after the first 10 miles, RiverSpill predictions of travel time are consistently 10-20% shorter than Toxic Spill predictions. Travel time predictions for all three simulations (instantaneous, 4 hour, and 48 hour) are the same, which is as it should be: the leading edge of continuous spills should be the same as for instantaneous spills.

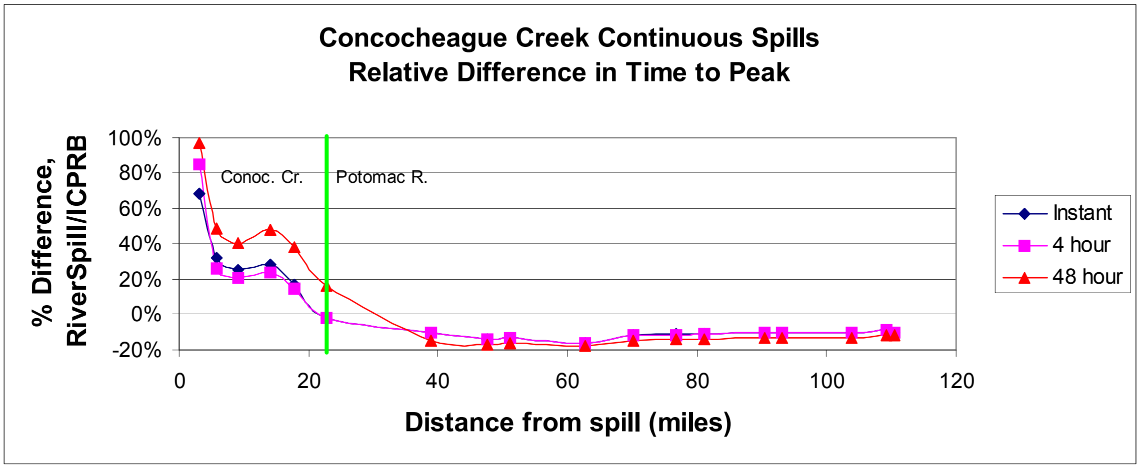

Figure 5. Conococheague Creek, relative difference in time to peak concentration

Figure 5 is similar to Figure 4 but plotting relative difference in travel time for the arrival of the Peak concentration. Here, the differences between RiverSpill and Toxic Spill models are generally the same as with the Leading Edge prediction, except in the case of the 48 hour spill. For spills of long duration, a stream reaches, and then stays at, a maximum concentration for a period of time. The change in RiverSpill prediction for the 48 hour spill suggests there may be an issue with the way in which RiverSpill identifies the beginning of the Peak concentration region for long duration spills.

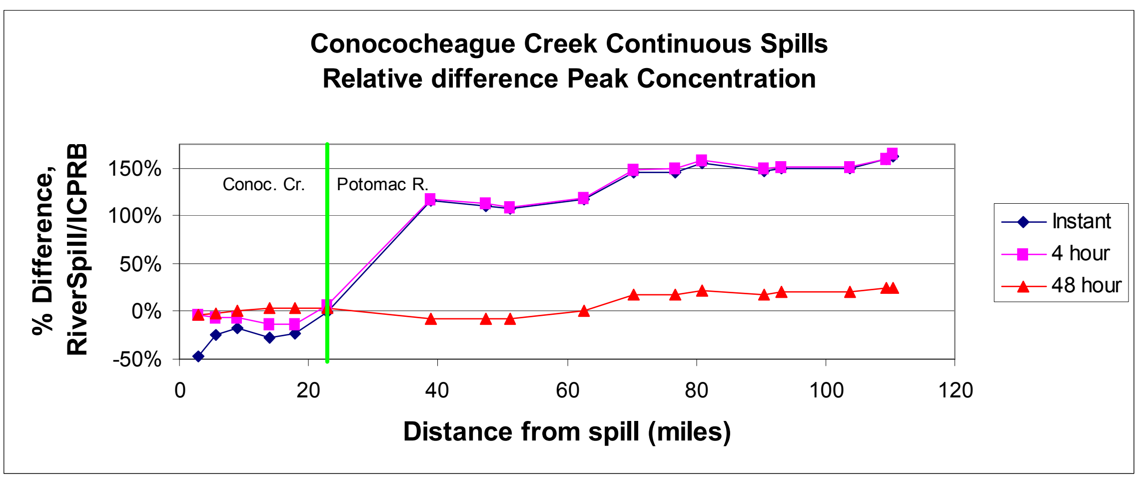

Figure 6. Conococheague Creek, relative difference in peak concentration

Figure 6 plots the relative difference between the models of predictions of Peak concentration. It is interesting to note that the difference in Peak concentration for the instantaneous spill flips from RiverSpill < Toxic Spill in Conococheague Creek to RiverSpill > Toxic Spill in the Potomac River.

It can be shown that, at any point where the duration of a continuous spill exceeds the time difference between leading edge and trailing edge of an instantaneous spill from the same spill origin, the peak concentration is simply the concentration at the spill origin multiplied by the ratio of flow at the spill origin over flow at the point of interest. In other words, for sufficiently long duration continuous spills, dispersion is no longer a factor and contaminant concentration is simply a function of dilution between the origin and the point of interest (see Jobson (1996)). This effect can be seen in Figure 6 for the 48 hour spill simulation where the difference between RiverSpill and Toxic Spill models is close to zero until 65 miles from the spill origin, while there are significant differences between the two models for the instantaneous and 4 hour spills. This plot reveals several insights into the RiverSpill to Toxic Spill model comparison. First, that RiverSpill is properly accounting for dilution effects (the increasing volume of water as the contaminant moves downstream). Second, it appears that the reason for the significant differences in Peak concentration for instantaneous and short duration spills is in the calculation of dispersion. Third, the slight differences between the two models in the 48 hour spill simulation in the first 65 miles is due to differences in how the two models estimate flow volumes away from the reference gage. In this case the differences are slight because the Toxic Spill simulation was forced to have the same flow at Point of Rocks as well as at the Fairview gage on Conococheague Creek.

A comparison of model performance with continuous spills was made also on the Shenandoah River because Taylor et al (1986) includes an example problem (pp 41-54). Thus, one can compare RiverSpill and the Toxic Spill model to the USGS method including time of travel calculations as well as peak concentration calculations for continuous and instantaneous spills. The continuous spill problem illustrated in Taylor cannot be reproduced exactly by RiverSpill or Toxic Spill because Taylor’s problem was for a spill with a varying rate of contaminant release, which neither of these models can simulate. However, the same spill release point and flow conditions were simulated and the series of calculations described in Taylor for calculating peak concentration for continuous spills was reproduced for a continuous spill at a constant rate. Taylor specified flow as an “80%flow duration level” which was described at 280 cfs for the gage at S. Fork Shen. R near Lynnwood and 465 cfs at the gage at S. Fork Shen. R. near Front Royal. Using more recent flow duration tables to determine the 80% flow duration level, flows for the Toxic Spill model were set at 84 cfs for the gage South River near Harriston, 300 cfs for the gage near Lynnwood, and 482 cfs for the gage near Front Royal. For the RiverSpill simulations, the reference gage was set to S. Fork Shen. R. near Lynwood, with flow at 300 cfs. RiverSpill simulations were tried also setting the reference gage to Harriston and to Front Royal. When these sites were selected as reference gages the flows on the stream reaches were significantly different than when Lynnwood was used. Simulations of two spills were done. The first was an instantaneous spill of 5,000 lbs (2,268 kg) at State Hwy 649 near Island Ford, VA. The second was a 25 hour spill, 200 lbs/hour, also at State Hwy 649. Simulation results are shown in Table 4 and Figures 7-9.

Table 3: Conococheague Creek continuous spill simulations.

	Flow (cfs)		Distance (miles)		Table 3A: Instantaneous Spill Results					
					RiverSpill			ICPRB Model		
Location	**RiverSpill**	**ICPRB**	**RiverSpill**	**ICPRB**	**Time to LE (hours)**	**Time to Peak (hours)**	**[Peak] (mg/l)**	**Time to LE (hours)**	**Time to Peak (hours)**	**[Peak] (mg/l)**
Sthwy 494	250	250	3.0	2.8	3.1	4.9	31.032	2.6	2.9	58.411
Broadfording Road	250	255	5.7	5.4	5.9	9.1	16.110	6.0	6.9	21.098
Mouth of Rush Run	250	260	9.0	8.4	9.4	14.4	10.244	10.0	11.5	12.286
UShwy 40	250	270	14.0	12.4	14.6	22.4	6.510	15.6	17.5	8.908
Kemps Mill Road	250	270	17.8	16.2	18.6	28.6	5.085	21.3	24.5	6.584
C&O Canal	250	271	22.8	21.1	23.9	35.6	4.348	31.5	36.3	4.412
Dam No. 4	2,274	2,006	38.8	36.7	67.9	83.6	0.331	81.2	92.6	0.153
Sharpsburg	2,274	2,023	47.5	46.4	76.1	92.1	0.323	93.4	107.2	0.153
Shepherdstown	2,274	2,026	51.2	48.4	79.4	95.9	0.317	95.9	110.2	0.153
Dam No. 3	2,409	2,148	62.6	58.9	104.9	123.6	0.265	128.2	146.4	0.122
Brunswick	3,449	3,470	70.2	66.2	117.1	135.9	0.177	136.5	155.2	0.072
Point of Rocks	3,541	3,541	76.8	72.5	125.6	144.6	0.170	144.1	163.4	0.069
Frederick County Intake	3,541	3,651	81.0	76.0	130.6	149.9	0.169	148.2	167.7	0.066
Whites Ferry	3,981	3,931	90.4	84.9	141.6	161.1	0.148	158.8	178.6	0.060
Leesburg PWS	3,981	3,987	93.2	87.9	144.9	164.4	0.147	163.4	183.5	0.059
Fairfax Water	4,221	4,178	103.8	98.1	160.1	179.9	0.137	178.9	200.2	0.055
WSSC	4,264	4,179	109.3	102.1	170.6	190.4	0.135	186.5	208.7	0.052
Rockville PWS	4,264	4,180	110.5	104.1	172.6	192.6	0.134	190.3	213.0	0.051

Table 3 (cont.): Comparison of model runs for Conococheague Creek continuous spills.

Location	Distance (miles)		Table 3B: 4 Hour Spill Results					
			RiverSpill			ICPRB Model		
	RiverSpill	ICPRB	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)
Sthwy 494	3.0	2.8	3.4	7.4	39.236	2.6	4.0	40.888
Broadfording Road	5.7	5.4	6.4	11.6	37.611	6.0	9.2	40.086
Mouth of Rush Run	9.0	8.4	9.6	16.6	31.745	10.0	13.8	33.632
UShwy 40	14.0	12.4	14.9	24.6	23.340	15.6	19.8	27.086
Kemps Mill Road	17.8	16.2	18.9	30.6	19.012	21.3	26.7	21.834
C&O Canal	22.8	21.1	24.4	37.6	16.559	31.5	38.5	15.621
Dam No. 4	38.8	36.7	67.9	85.4	1.291	81.2	95.1	0.593
Sharpsburg	47.5	46.4	75.9	94.1	1.261	93.4	109.6	0.593
Shepherdstown	51.2	48.4	79.1	97.9	1.237	95.9	112.6	0.593
Dam No. 3	62.6	58.9	104.6	125.6	1.041	128.2	148.7	0.475
Brunswick	70.2	66.2	116.6	137.9	0.696	136.5	157.5	0.281
Point of Rocks	76.8	72.5	124.9	146.6	0.669	144.1	165.7	0.269
Frederick County Intake	81.0	76.0	130.1	151.9	0.666	148.2	170.0	0.258
Whites Ferry	90.4	84.9	141.1	162.9	0.584	158.8	180.9	0.234
Leesburg PWS	93.2	87.9	144.1	166.4	0.580	163.4	185.8	0.231
Fairfax Water	103.8	98.1	159.4	181.9	0.539	178.9	202.5	0.215
WSSC	109.3	102.1	169.9	192.4	0.531	186.5	211.0	0.204
Rockville PWS	110.5	104.1	171.9	194.4	0.530	190.3	215.3	0.200

Table 3 (cont.): Comparison of model runs for Conococheague Creek continuous spills.

	Distance (miles)		Table 3C: 48 Hour Spill Results					
			RiverSpill			ICPRB Model		
Location	RiverSpill	ICPRB	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)
Sthwy 494	3.0	2.8	3.4	7.9	39.240	2.6	4.0	40.888
Broadfording Road	5.7	5.4	6.4	14.6	39.240	6.0	9.8	40.086
Mouth of Rush Run	9.0	8.4	9.6	22.9	39.240	10.0	16.4	39.315
UShwy 40	14.0	12.4	14.9	35.6	39.240	15.6	24.1	37.859
Kemps Mill Road	17.8	16.2	18.9	45.4	39.240	21.3	32.8	37.859
C&O Canal	22.8	21.1	24.4	56.4	39.240	31.5	48.6	37.720
Dam No. 4	38.8	36.7	67.9	111.4	4.314	81.2	131.6	4.699
Sharpsburg	47.5	46.4	75.9	119.6	4.314	93.4	144.4	4.682
Shepherdstown	51.2	48.4	79.1	123.1	4.314	95.9	147.0	4.677
Dam No. 3	62.6	58.9	104.4	150.1	4.072	128.2	182.5	4.061
Brunswick	70.2	66.2	116.4	162.4	2.844	136.5	191.4	2.440
Point of Rocks	76.8	72.5	124.9	170.9	2.770	144.1	199.6	2.366
Frederick County Intake	81.0	76.0	129.9	176.1	2.770	148.2	203.9	2.270
Whites Ferry	90.4	84.9	140.9	187.1	2.463	158.8	214.8	2.079
Leesburg PWS	93.2	87.9	144.1	190.4	2.463	163.4	219.6	2.051
Fairfax Water	103.8	98.1	159.4	205.9	2.323	178.9	236.0	1.933
WSSC	109.3	102.1	169.6	216.4	2.300	186.5	244.6	1.857
Rockville PWS	110.5	104.1	171.9	218.4	2.300	190.3	248.9	1.835

Table 4: Shenandoah River Simulations

Table	Flow (cfs)		Distance (miles)	
Location	River Spill	ICPRB	RiverSpill	ICPRB
Shenandoah	358	354	13.4	13.5
Grove Hill	358	357	29.4	21.4
U.S. Highway 211	358	381	35.3	36.4
Bixler Bridge	358	387	42.2	43.4
Bentonville	437	463	66.4	69.5
Front Royal Pump Station	437	487	80.9	84.9

	Table 4A: Instantaneous Spill Results								
	RiverSpill			ICPRB Model			USGS Example		
Location	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)
Shenandoah	25	38	6.566	25	39	13.365	37.0	40.0	15.0
Grove Hill	54	73	4.429	54	59	8.067	54.0	61.0	8.4
U.S. Highway 211	63	86	3.678	63	102	3.089	89.0	105.0	3.1
Bixler Bridge	74	102	3.019	74	148	1.650	121.0	152.0	1.6
Bentonville	137	176	1.753	137	222	1.063	187.0	229.0	1.1
Front Royal Pump Station	172	222	1.316	172	272	0.942	234.0	280.0	0.9

Table 4 (cont): Shenandoah River Simulations

Location	Table 4B: Shenandoah 25 hour Continuous Spill Results								
	RiverSpill			ICPRB Model			USGS Example		
	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)	Time to LE (hours)	Time to Peak (hours)	[Peak] (mg/l)
Shenandoah	27.4	52.1	2.482	35.8	45.6	2.620	37.0	45	2.71
Grove Hill	57.1	86.9	2.420	53.2	69.3	2.598	54.0	69.0	2.687
U.S. Highway 211	67.1	99.9	2.324	87.3	117.2	2.118	89.0	120.0	2.137
Bixler Bridge	78.6	114.9	2.164	118.5	162.0	1.366	121.0	166.0	1.363
Bentonville	143.1	189.1	1.465	182.2	235.9	0.932	187.0	242.5	0.925
Front Royal Pump Station	178.6	235.1	1.186	227.8	285.3	0.834	234.5	294.5	0.829

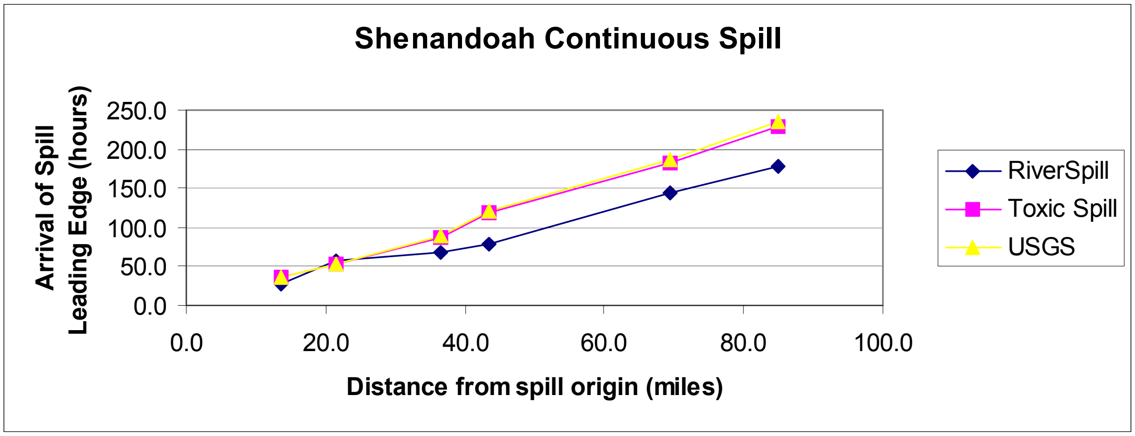

Figure 7: Shenandoah R. 25 hour spill travel time for leading edge

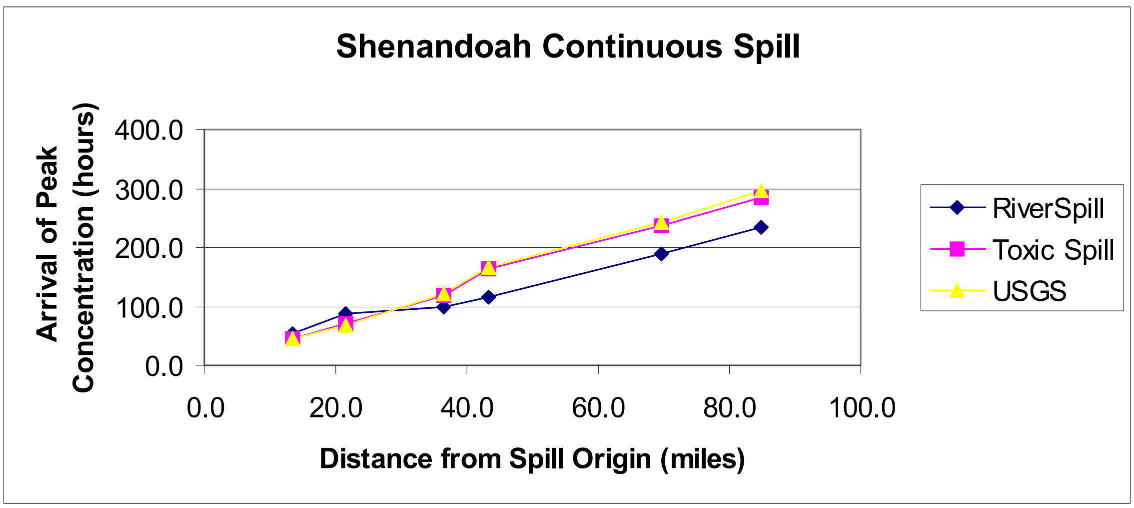

Figure 8: Shenandoah R. 25 hour spill travel time for Peak concentration

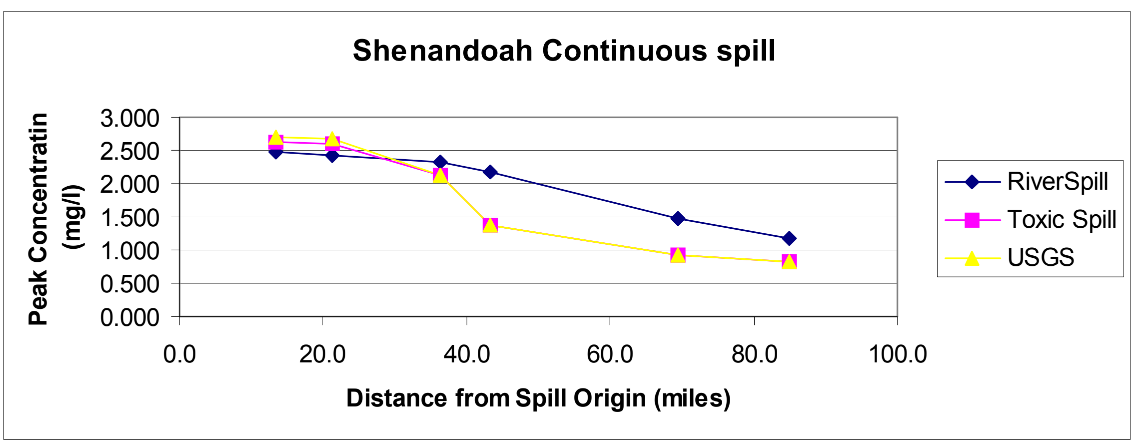

Figure 9: Shenandoah R. 25 hour spill Peak concentration

Shenandoah spill simulation results illustrated in Figures 7-9 and in Table 4 show that Toxic Spill model predictions and the USGS method are nearly identical. The comparison between RiverSpill and the Toxic Spill models reveals inconsistent results. In Table 4A it can be seen that, for an instantaneous spill simulation, the Leading Edge travel time prediction for the RiverSpill and Toxic Spill models are identical while, for Peak travel time, the incremental travel times between stations sometimes match and are sometimes far apart. The continuous spill simulation results shown in Figures 7-8 and in Table 4B show again that travel time predictions agree for some reaches and differ, sometimes substantially, for other reaches. Figure 9 shows the differences in Peak concentration between RiverSpill and Toxic Spill models which may be due, at least in part, to the travel time differences. RiverSpill's estimates of stream flow in the lower reaches was different than the Toxic Spill model estimates and will affect Peak concentration, but the flow differences are not enough to account for all of the difference.

Summarizing the results of these comparisons of travel time and peak concentration predictions by the two models to each other and to USGS dye studies, it appears that RiverSpill does not reproduce USGS dye study results as well as the Toxic Spill model. The magnitude and direction of the differences varies by stream, and apparently by reach, so it is not clear what the source of the problem is. Since the purpose of the Potomac customized version of RiverSpill was to reproduce dye study based travel times, it appears that a careful review of the travel time and dispersion calculations in the Potomac version of the RiverSpill model is needed. It should be pointed out that the dye study based predictions of travel time and peak concentration are not necessarily the "true" values. They are, however, empirically based and the accepted standard on the Potomac and major tributaries and will remain so until a compelling argument is made to adopt another framework.

(E) Single versus multiple reference stream flow gages.

As noted above the RiverSpill model estimates flow in all reaches downstream from a spill based flow at a single reference gage. Specifically, RiverSpill assumes the same ratio of current flow to mean flow in all reaches. Our experience at ICPRB suggested that this may not be a good assumption. The Potomac watershed is large enough that precipitation events frequently occur in one part of the basin only, so that the proportional impact on tributaries and on the Potomac mainstem is different. Rain in the upper basin may raise Potomac mainstem flow while lower basin tributaries remain at a relatively lower flow. Some method for estimating flows in ungaged reaches will always be necessary, but the Toxic Spill model can use flow input from at least one gage on each tributary plus four on the mainstem Potomac. The model **requires** at least a Point of Rocks flow for spills on the Potomac and at least one tributary gage plus Point of Rocks for spills on tributaries. Between reaches with gages, the Toxic Spill model assigns flows to ungaged reaches by assuming a constant ratio of flow to drainage area (not identical, but very close, to the method used by RiverSpill). To evaluate the frequency and magnitude of differences in flow between streams, a five year record (7/2001-7/2006) of daily stream flows was collected for ten gages and those records converted to Q/sq. mi. For selected pairs of gages the relative difference in Q/sq. mi. was calculated and the absolute value of those differences plotted in cumulative frequency diagrams. One of these diagrams is shown below in Figure 10 (the others are available on request).

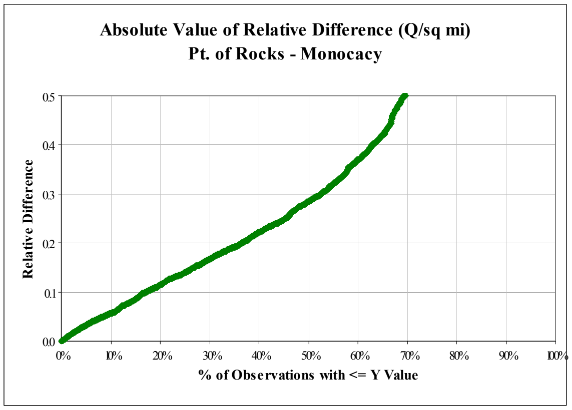

Figure 10: Cumulative frequency diagram of relative differences in flow at Point of Rock and at Monocacy Jug Bridge.

Figure 10 shows, for example, that on 70% of days, the relative difference between Point of Rocks and Jug Bridge Q/sq.mi. is 0.5 or less. This means, conversely, that on 30% of days the relative difference in Q/sq.mi. is greater than 0.5. This plot suggests, as did comparisons for other pairs of gages, that large differences in Q/sq.mi are common. This issue was discussed with SAIC staff, who responded that modifying RiverSpill or ICWater to use multiple reference gages would be a significant programming challenge.

(F) Features not tested

Several features of RiverSpill were explored but not thoroughly tested. These include spills on streams not part of the USGS dye studies and spills of non conservative substances (for example bacteria from a wastewater treatment plant overflow). It was decided that it would be too difficult to evaluate results from these spill simulations until the differences between RiverSpill and Toxic Spill for conservative substances on dye study reaches are resolved. The upstream trace capability was not extensively tested, but the problems RiverSpill has with travel time in a downstream trace will affect the upstream trace. On the basis of a few exploratory runs of the upstream trace, it appears that this capability may be a useful tool in source water protection efforts because it can identify the region within a specified travel time of water intakes.

(G) Transition from RiverSpill to ICWater

SAIC is developing a successor to the RiverSpill model named ICWater. ICWater promises improved graphic output options and an improved representation of the stream network with the NHD+ reach file database. ICWater apparently also will use a new algorithm for calculating dispersion. SAIC projects that a version of ICWater will be available for the mid-Atlantic region (including the Potomac basin) by the end of calendar 2006. ICPRB is interested in the graphic output capabilities of ICWater and will evaluate the model when it becomes available but, as with RiverSpill, a key requirement is that the travel time predictions be functionally equivalent to the USGS dye study results. It is not clear if funding has been provided to SAIC to make a customized version of ICWater for the Potomac.

IV. SPILL EXERCISE RESULTS

A spill exercise was held on May 16, 2006 involving water utilities in the metropolitan Washington area, all of whom withdraw water from the Potomac river. The objectives of the exercise were to test

a) communications procedures;
b) ICPRB internal procedures for running spill models, assembling information into reports, and posting information for utilities and government agencies to access;
c) test some of the reporting products that the RiverSpill model is capable of producing.

The spill scenario was a tanker truck that leaks 1,000 gallons (7,700 kg) of toluene into the Potomac River at Point of Rocks. The exercise plan was for ICPRB staff to run both travel time models, assemble relevant information into several documents, post those documents to a password protected page on ICPRB's website (www.potomacriver.org/spill/spillex.htm) , and to notify water utilities and government agencies using the MWCOG Regional Incident Communication and Coordination System (RICCS) system that a spill event had occurred and that information about the spill was available on the webpage. A conference call with utility and government agency representatives was held one week later to discuss problems and successes with this exercise.

Notification of utilities and agencies via RICCS was not as comprehensive as had been expected. During the post exercise conference call it was learned that at some utilities the appropriate person either did not get the spill alert message, or heard about it from another person rather than via a RICCS page. The problem appeared to be not so much with RICCS as with agencies making sure that the appropriate people are registered with the RICCS system. To enhance reliability in notification of utilities, in the future ICPRB will supplement the RICCS notification with phone calls directly to affected utilities and local governments. In coming months ICPRB plans to build a database of emergency contact numbers. The EPA SDWIS database provides a starting point for that database.

For this exercise about four hours was required for ICPRB staff to generate a time of travel prediction and post messages to RICCS and onto the website, considerably longer than is desirable. Four factors caused the long lead time before time of travel predictions were posted:

a) lack of familiarity with RiverSpill
b) time spent searching for other information about the toxicity and chemical behavior of toluene to supplement the information provided by RiverSpill;
c) time spent composing the RICCS alert message (the message must be extremely short to fit within limits set by pagers, while still conveying essential information) and composing the spill description information to post on the website; and
d) some difficulty uploading information on the ICPRB website.

In Appendix A is the report that was posted on ICPRB's spill webpage.

Regular practice should resolve the issue of familiarity with running either model and the difficulties in uploading text and documents to the webpage. The goal is for any ICPRB staff person tasked with being prepared to respond to a spill alert to be completely familiar with running either model and with the procedure for posting documents to the webpage. To reduce the time spent composing the RICCS alert message and the spill description posted on the website, sample text has been placed in the ICPRB Spill Operations document. It will be a much quicker operation in the future to edit the sample text as appropriate for a particular event, rather than compose something new. This text is likely to be refined with feedback from utilities and agencies following future spill drills. The question of how much information about a chemical ICPRB should post on its webpage generated considerable discussion during the follow-up conference call with spill drill participants. The library built into RiverSpill provides some information about toxicity and chemical behavior but it is possible to find additional information via WWW searches and consulting reference manuals. This research take time, however, and ICPRB may not have the expertise to determine which pieces of information are reliable and appropriate. A consensus recommendation from the spill drill conference call was that, in the future, ICPRB should quickly post basic description information about the spill (name of substance, time, place, and quantity spilled) plus travel time predictions to downstream intakes. Most of the time, contaminant travel times to downstream intakes are greater than 24 hours, so there is time for ICPRB to post supplemental information after an initial alert and web posting.

V. SUMMARY OF FINDINGS

1) Basic installation and operation for RiverSpill and its successor application, ICWater, should be tested at non SAIC "beta" test sites before a general distribution of the software. Testing by users other than the development team is more likely to discover problems because the developers will use standardized hardware and are likely to exercise the software in consistent patterns that will miss some problems.

2) In order to maintain proficiency, ICPRB staff should, on a regular basis, practice procedures for A) running models (RiverSpill and the Toxic Spill Model), B) posting information on the spill webpage, and C) contacting appropriate agencies via telephone and RICCS. In addition, the list of emergency contact numbers should be updated on a regular, perhaps annual, basis.

3) In order to maintain proficiency regular spill practice exercises should be held involving government agencies and water utilities. These exercises will familiarize agency and utility staff with procedures for accessing information about spills and with the strengths and weaknesses of spill travel time predictions. Regular exercises will enable agencies and utilities to make sure that appropriate individuals are being notified, and will provide opportunities for evaluating and improving the amount and kinds of information about spills being provided by ICPRB.

4) Comparative testing confirmed that the ICPRB Toxic Spill model is reasonably consistent with the USGS dye study results, but the RiverSpill model generates significantly different travel time and peak concentration predictions. Although one cannot say that the procedure used in the USGS dye study publications (and mimicked in the Toxic Spill Model) is known to provide "true" estimates of travel time, travel times based on the dye studies are the accepted point of reference for the Potomac River and its major tributaries. The algorithms used in the RiverSpill model need to

be modified so that its predictions are roughly equivalent to those of the Toxic Spill model before RiverSpill can be relied upon as a replacement for Toxic Spill. With respect to tributaries that were not included in the dye studies the issue of whether, and how, to modify current RiverSpill algorithms is complex and may require extended discussion and testing by ICPRB, SAIC, and possibly the USGS.

5) The new ICWater application uses a different method for estimating travel time and peak concentration than does RiverSpill. Before ICWater is adopted by ICPRB as the tool to use during spill events, it will have to be tested and possibly modified to match Toxic Spill model results.

6) One characteristic of the RiverSpill model approach (ICWater shares this characteristic) is that stream flows throughout the region of interest are set to a uniform ratio of current flow to mean flow based on a single reference gage. This may be a reasonable assumption in a small watershed but, as shown above, the Potomac basin is too large and diverse for this assumption to hold. The utility of the RiverSpill and ICWater models would be much improved if they were modified to enable multiple reference flow gages.

7) User interface recommendation: Have the model remember input values from a previous run so that one can quickly make another run modifying only 1-2 parameters. More often than not, multiple model runs are made for one "event", varying a few parameters such as flow, level of concern, spill amount, etc.

8) RiverSpill has several features that commend it as a replacement for the Toxic Spill model once the travel time issues are resolved. Among these are:

- Ability to generate maps showing the region affected by a spill and time-concentration plots for intakes of interest;
- Ability to display on maps features of interest such as water intakes, wastewater treatment plants, risk management plan sites, road and railroad crossings (road layer not provided by SAIC for RiverSpill, but can be separately obtained);
- Built in library of information about many contaminants;
- Ability to model spills on any stream in the basin.

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APPENDIX A: Spill information report posted on website for May 16 spill drill

ICPRB Spill Report - Spill Drill 2006
May 16, 2006
Interstate Commission on the Potomac River Basin

Information

This is an exercise. This is not a real spill but a simulated event.

Maryland Department of Environmental reports that there was a spill of toluene from a tanker truck at the Route 15 bridge (at Point of Rocks, MD). The spill began at 12:00 noon on May 16 and lasted for about an hour but is now contained. It appears that most of the toluene in the tanker was spilled and drained directly into the Potomac River. The tanker has a capacity of 1,000 gallons. This exercise simulates a 1,000 gallon tanker truck containing Toluene and spilling its entire contents.

Toluene is a "LNAPL" (Light non-aqueous phase liquid), which means it is sparingly soluble in water and less dense than water. The spill model assumes complete solubility of the spilled material.

Release information:
Agent Name: Toluene
Agent type: chemical
Agent half-life[1]: 22 days
Initial Mass (kg): 7,700
Level of Concern (Safe Drinking Water Standard)[2]: 1 mg/L
Release location (lat, long): 39.313 N, -77.630 W
Stability in water: 0.07 % soluble
Comments: Benzene-like odor[3]

ICPRB Predictions
(Actual travel times and peak concentration may differ – the spill model assumes complete solubility and Toluene has low solubility. See model run assumptions for additional information.)

Intake	Hours after spill			Peak Conc. (mg/L)
	Leading Edge	Peak	Trailing Edge	
County of Frederick water intake	11	11.5	12	9.8
Town of Leesburg	22	24	26	4.9

[1] (from Riverspill model, SAIC) Howard, P. H., R. S. Boethling, W. F. Jarvis, W. M. Meylan, E. M.Michalenko, Handbook of environmental degradation rates, Lewis Publishers, 1991

[2] Source: www.epa.gov/safewater/contaminants/dw_contamfs/toluene.html
[3] (from Riverspill) Deininger, R. A. Constituents of concern: The threat of chemical and biological agents to public water supply systems, Appendix F in PipelineNet User's Guide, SAIC 2000a

FW intake	32	36	38	3.7
WSSC intake	37	42	46	2.7

Model assumptions

The results from the USGS time of travel studies and corresponding ICPRB Spill model must be interpreted with caution. The USGS provides an excellent discussion of the limitations of the assumptions and limitations of the dye tracer studies, and the circumstances in which the time of travel analysis can be applied in the field. These limitations are paraphrased below (Taylor et al., 1986)

The river flow during the dye studies was that of generally slowly decreasing flow. Precipitation events introduce a flood wave, or unsteady flow conditions, into the river. The effect of unsteady flow on the movement of a discrete particle of water is indeterminate by dye-tracer studies and procedures to handle such a situation were beyond the scope of the USGS studies. When a significant flood wave is present in the system added uncertainty will be introduced in the results. Because the dye tracer studies are undertaken at essentially steady flow conditions, the Spill model is best utilized when flow is neither rapidly increasing or rapidly decreasing. As flow conditions change, the Spill model should be run iteratively in order to assess the effect of changing flow conditions and to determine the most current discharge information.

Two velocities were determined for associated river flow levels for each dye tracer study river reach segment. In interpolating and extrapolating the study results to assess travel times at other flow levels, a log-linear relationship was assumed. In reality, the relationship may be slightly curvilinear, but at least three measurements would be necessary to assess the curvilinear relationship.

Complete lateral mixing was assumed in development of the concentration attenuation procedures developed by the USGS. However, these conditions are not continuously maintained because of large inflows of water from major tributaries to the Potomac. When lateral mixing is incomplete, the estimate of contaminant concentration may be higher than that actually experienced.

All calculations of contaminant concentration assume a conservative substance. In other words, it was assumed that there was no evaporation of the substance, nor was any bound to sediments and removed from the water column as the contaminant moved downstream. In actual situations, physical, chemical, or biological processes could decrease the concentrations as compared to that predicted by the travel time model.

The dye study method incorporates the use of a dye that is completely soluble. The behavior of immiscible or floating substances cannot be determined by the techniques presented in the USGS report.

The dye tracer studies measure the travel time of a dye injected at several points across the river. An actual spill is unlikely to occur in this manner. More likely, such a spill would occur at a river tributary or shoreline. Travel times at a river bank are generally slower than that of the main river, so the travel times of a spill under these circumstances will generally be slower than that predicted by the model. Also, the contaminant would likely be concentrated on one side of the river. The distance required for complete lateral mixing can be substantial, in particular for rivers with a large width-to-depth ratio.

The USGS studies that were used in the Spill model describe a minimum of two travel time analyses (dye studies) for each river reach at different flow rates. These studies provide information for the interpolation and extrapolation to travel times corresponding to a wide range of flows. Some caution is warranted in extrapolating beyond the flows used to calibrate the Spill model. The flows used to calibrate the Spill model for the Potomac reaches were at the 10th and 40th percentiles.

References:

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