DRINKING WATER SUPPLY MANAGEMENT:
AN INTERACTIVE APPROACH

JAMES A. GOODRICH

ROBERT M. CLARK

Drinking Water Research Division
Water Engineering Research Laboratory
Cincinnati, Ohio

ABSTRACT

In February 1977, a massive discharge of carbon tetrachloride into the Kanawha River in West Virginia threatened much of the Ohio Valley with contaminated drinking water potentially affecting over one million consumers. This episode heightened the awareness of consumers and decision-makers alike to the relationship between wastewater discharges and drinking water consumption. This article examined the results of a study motivated by the carbon tetrachloride spill and examined interactions between industrial discharges and drinking water consumption in surface water supplies. The mechanism used to study the wastewater discharge water supply intake interaction was a water quality/quantity simulation model, QUAL-II. QUAL-II was used to provide a framework to bring the diverse elements of mathematic modeling, fluid dynamics, organic chemistry and geography to create an interactive systems analysis approach that can have an impact on public policy in drinking water.

INTRODUCTION

In February 1977, a massive discharge of carbon tetrachloride into the Kanawha River in West Virginia threatened much of the Ohio River Valley with contaminated drinking water potentially affecting over one million consumers. This episode heightened the awareness of consumers and decision-makers alike to the relationship between wastewater discharges and drinking water consumption.

1

In this article the results of a study designed to examine the interactions between industrial discharges and drinking water consumption in surface water supplies is examined. The mechanism used to study the wastewater discharge water supply intake interaction was a water quality/quantity simulation model, QUAL-II [1]. QUAL-II was used to provide a framework to bring together the diverse elements of mathematical modeling, fluid dynamics, organic chemistry, and geography to create an interactive systems analysis approach that can have an impact on public policy in drinking water. QUAL-II, although less flexible in simulating various flow scenarios and less elegant in modeling dozens of built-in parameters and biological and chemical transformations than other models currently available, exhibits a spatial organization that highlights critical variables such as relative locations of utilities and dischargers and time-of-travel from discharge to intake.

A wide array of models are available and selection of the proper model is ultimately determined by the objectives of the user, data requirements, and data availability. In this case study, QUAL-II was used, but any model can be utilized depending on the user's desires. Important factors to consider when choosing a model and performing this type of analysis include: stream characteristics, potency and persistence of the pollutants, amount and timing of discharge of pollutants, storage time of utilities, relative location of point sources and water utility intakes, and model availability and support.

METHODOLOGY

The case study area selected for analysis includes communities that utilize the Ohio River as their drinking water source and the major industrial dischargers along the Ohio and Kanawha Rivers between Charleston, West Virginia and Cincinnati, Ohio. Figure 1 is a map of the case study area. Figure 2 schematically represents the case study area, including waste loads and tributaries included in water quality modeling. In the case study, the pollutants are routed over approximately 200 stream miles (322 km). Various flow scenarios are used to account for seasonal variations in flow. Average flow in the Kanawah River is 25,000 cubic feet per second (cfs) (708 cubic meters per second) and the average Ohio River flow is 125,000 cfs (3,538 m^3/s). The smaller tributaries were considered as point loads in the analysis. Table 1 displays the various flow conditions in the Ohio River and the average time-of-travel from the first discharger in West Virginia to Cincinnati, Ohio.

The first major step in the analysis is to provide an inventory and description of point and nonpoint sources of pollution. However, because of tremendous gaps in land use data, especially in watersheds involving various states and regional authorities it is almost impossible to model runoff water quality. While recognizing the importance of nonpoint and community dischargers in this analysis, only industrial dischargers and their wastes are considered.
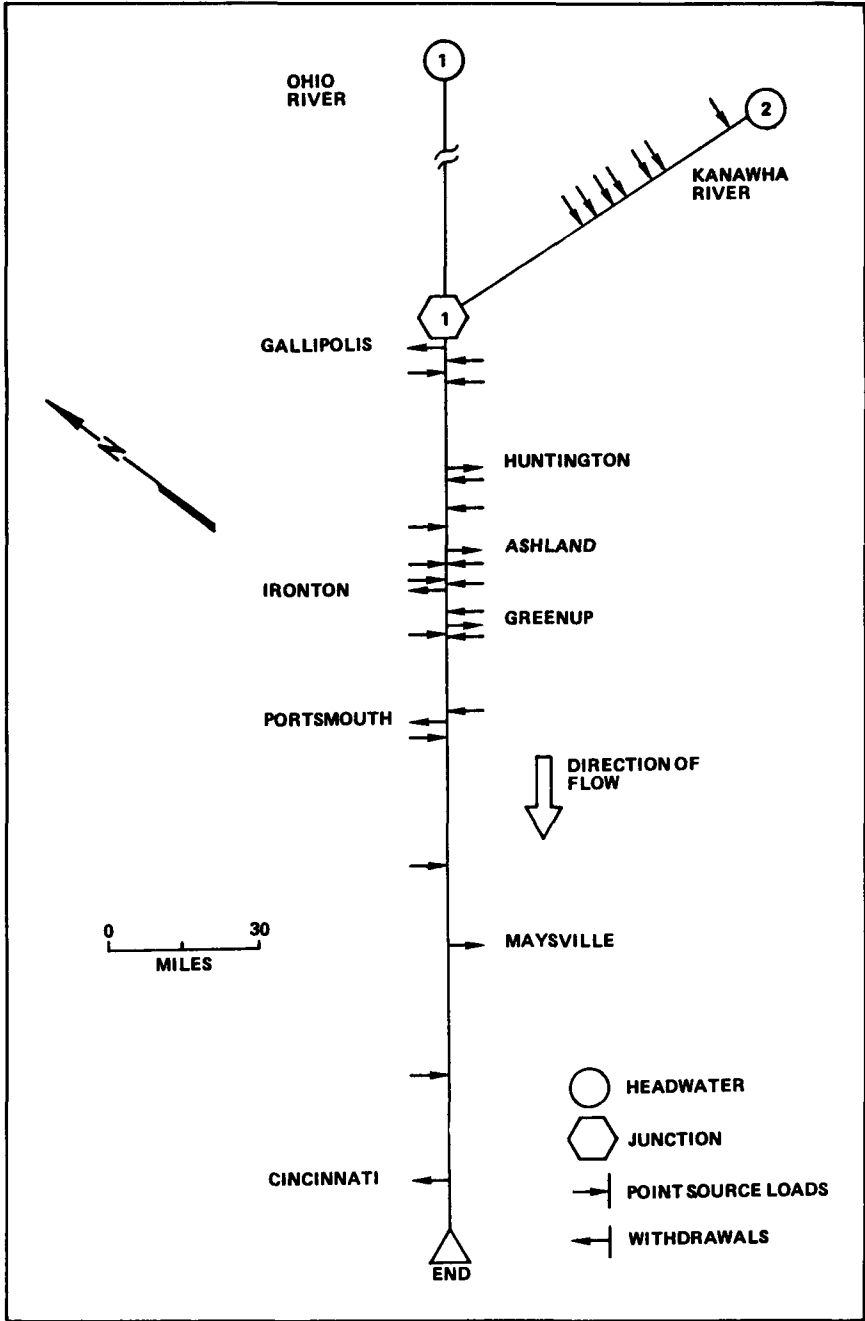
Figure 1. Case Study Area.

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Figure 2. Schematic of Study Area.

Table 1. Hydraulic Characteristics for Daily Discharge Scenarios
(Ohio River)

Scenario	CFS (X 1,000)	Time of Travel (Days)
High Flow	220.00 (6.2)	2.4
Average Flow	125.00 (3.5)	4.1
Low Flow	35.00 (.99)	15.0

(m³/s)

Table 2 lists the industrial dischargers including·Standard Industrial
Classification Codes (SIC Codes) 2812, 2819, 2821, 2856, 2868, and 3311 in
the case study area. These SIC Codes are divided into major groups and then
into industrial numbers. The river mile from the top-most point in the area is
given for each discharger along with the estimated volume. Major groups 28
and 33 were used to take into account a majority of the priority pollutants to be
modeled. Table 3 briefly describes the SIC Codes [2].

Table 2. Inventory of Major Industrial Dischargers in Case Study Area

	River Mile	Discharger Number	Industrial Discharge	SIC Code
Kanawah River	69.2	1.	3.87 (.11)	2869
	56.2	2.	15.48 (.44)	2869
	54.7	3.	4.33 (.12)	2812
	48.2	4.	8.92 (.25)	2869
	42.7	5.	50.62 (1.42)	2819
	42.7	6.	5.88 (.17)	2869
	42.6	7.	19.50 (.55)	2869
Ohio River	270.0	8.	.85 (.03)	2819
	280.4	9.	.45 (.01)	2821
	318.4	10.	118.19 (3.34)	2819
	320.0	11.	9.29 (.26)	3312
	325.0	12.	.33 (.01)	3312
	325.0	13.	15.48 (.44)	2812
	325.0	14.	66.19 (1.87)	3312
	322.2	15.	18.11 (.51)	2821
	336.5	16.	1.24 (.04)	2865

(m³/s)

Table 3.   Inventory of SIC Codes in Case Study Area

Code	Title	
Major Group 28—Chemical and Allied Products		
2812	Alkalines and Chlorine	Establishments primarily engaged in manufacturing alkalies, chlorine, soda ash, caustic soda ash, and other basic inorganic chemicals.
2819	Industrial Inorganic Chemicals, Not Elsewhere Classified	Establishments engaged in manufacturing inorganic salts, chromium, magnesium, mercury, silver, nickel, and elemental flourine among many others.
2821	Plastic Materials, Synthetic Resins, and Nonvolnerizable Elastomers	Important products, include phenolic and other tar resins, vinyl resins, petroleum polymer resins, polyesters, and pthalic anhydride resins.
2865	Cyclic Crudes, Cyclic Intermediates, Dyes, and Organic Pigments	Important products of this industry include among many other derivatives of benzene, toluene, napthalene, anthracene, synthetic organic dyes, synthetic organic pigments, and coal tar crudes.
2869	Industrial Organic Chemicals, Not Elsewhere Classified	Important products not classified elsewhere include non-cyclic organic chemicals, solvents such as trichloroethylene plasticizers and esters.
Major Group 33—Primary Metal Industries		
3312	Blast Furnaces, Steel Works and Rolling Mills	Establishments primarily engaged in manufacturing ferroalloys, pig iron, and in hot rolling iron into basic shapes such as strips, bars, and tubing.

To assess potential public health impacts, simulated pollutant concentrations for each utility were compared to the water quality criteria that suggest concentrations of various pollutants that could be harmful to human health. These guidelines take into account toxicity, carcinogenicity, or organolepticity (taste and odor) of the pollutants.

Obviously many sources must be tapped to acquire the necessary data for this type of analysis. For example National Pollutant Discharge Elimination System (NPDES) permits, the Industrial Facilities Discharge File, Analytical

Reach File, and Pollutant Matrix File from EPA provide very important sources of information. Data from regional authorities and government sponsored reports are other sources that can be used to bring together an "analytical package" to address the public health impacts of industrial discharges on drinking water consumers. Many other data sources and/or water quality models can be incorporated into this process, but they are simply a tool to use as part of the total analysis outlined in this article.

As more data on the priority pollutants are gathered, the most important physical and chemical characteristics of toxic compounds that govern the fate of the pollutants can be identified and utilized to assign a more accurate decay rate, thus enabling the use of the more sophisticated models now being developed and tested. For the priority pollutants, this will probably involve direct photolysis and bioaccumulation in addition to volatilization [3].

Water Quality and Health Guidelines

Water Quality Criteria for toxicity and taste and odor are based on threshold limits at which the general population would be affected by consuming water containing a pollutant reaching that guideline. For example the criteria for cyanide (a toxic) is 3,770 μg/L; for phenol it is 300 μg/L (an odor causing agent) [4]. A tenfold buffer is incorporated in these standards to take into account the more sensitive or susceptible consumers such as the very young or old, pregnant or ill. Therefore, it is possible some small segments of a population could be affected by 377 μg/L and 30 μg/L of cyanide and phenol respectively.

Water quality criteria for carcinogens are based on a nonthreshold concept. For example, it is assumed that a person has a .00001 risk level of developing cancer in his or her lifetime by drinking two liters of water with 6.6 μg/L of Benzene daily. The only "no risk" level for carcinogens is zero. Although risk is assumed to increase linearly with concentration, promoters and synergism among the contaminants could actually increase risk levels beyond those given for a single carcinogen.

As mentioned earlier, three scenarios were created to account for variations in flow and the pollutants discharged (81 out of the 129 priority pollutants). The three flows were 125,000 cfs (3538 m^3/s), 220,000 cfs (6226 m^3/s), and 35,000 cfs (900 m^3/s). The average time-of-travel (Table 1) will vary with river flow.

For toxic and organoleptic pollutants, river flows are important as to whether a Water Quality Criteria is exceeded because of acute effects. Because of the chronic nature of carcinogenic exposure, they are evaluated over years of exposure to pollutants in the drinking water, and therefore carcinogenic risk levels were estimated only at average flows. In the event of a sudden spill, however, variations in flows can be important even to carcinogens since very high concentrations of carbon tetrachloride, for example, can have an acute health effect.

RESULTS OF ANALYSIS

Using the techniques and data discussed above an analysis of the organoleptic, toxic, and carcinogenic exposure of various utilities in the case study area was calculated. Each of these exposures is discussed in the following sections.

Organoleptic Exposure

Table 4 summarizes organoleptic exposures for all three flow scenarios. A 10 percent level of exposure (10% of the standard) and a 100 percent level of exposure are considered. The 10 percent level is presumed to represent those sensitive consumers that could be affected and the 100 percent level accounts for the general population exposure.

Only 2-chlorophenol and 2,4-dichlorophenol of the eleven organoleptic pollutants, exceed a level where sensitive consumers could be affected by taste and odor problems. One can see that only during low flow periods would the utilities have to be concerned about taste and odor problems from the priority pollutants. Although taste and odor problems are not dangerous, they probably create greater public response than do reports of possible carcinogens. Historically, aesthetic considerations have often been the basis for water quality regulation rather than public health.

Toxic Exposure

Table 5 summarizes the exposure to toxic pollutants at the same three flow levels and at the 10 percent and 100 percent levels.

Table 4.   Summary of Organoleptic Pollutants Exceeding Guidelines

Utility	Average Flow		High Flow		Low Flow	
	10% Level	100% Level	10% Level	100% Level	10% Level	100% Level
Gallipolis, OH	None	None	None	None	None	None
Huntington, WV	None	None	None	None	None	None
Ashland, KY	None	None	None	None	None	None
Ironton, OH	None	None	None	None	2-chlorophenol 2,4-Dichlorophenol	None
Greenup, KY	None	None	None	None	2-chlorophenol 2,4-Dichlorophenol	None
Portsmouth, OH	None	None	None	None	2-Chlorophenol	None
Maysville, KY	None	None	None	None	2-Chlorophenol	None
Cincinnati, OH	None	None	None	None	2-Chlorophenol	None

Table 5. Summary of Toxic Pollutants Exceeding Guidelines

Utility	Average Flow		High Flow		Low Flow	
	10% Level	100% Level	10% Level	100% Level	10% Level	100% Level
Gallipolis, OH	None	None	None	None	Cadmium	None
Huntington, WV	None	None	None	None	Cadmium	None
Ashland, KY	None	None	None	None Mercury	Cadmium	None
Ironton, OH	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Greenup, KY	Cadmium	None	Mercury	None Lead Chromium	Cadmium	Mercury
Portsmouth, OH	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Maysville, KY	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury
Cincinnati, OH	Cadmium Mercury	None	Mercury	None	Cadmium	Mercury

During low flow periods, the 10 percent level for cadmium is exceeded at all the utilities. At Ashland, KY the 10 percent level is exceeded by mercury, and at Greenup, KY the 10 percent level is exceeded by lead and chromium in addition to cadmium. The simulated concentrations of mercury exceed the 100 percent level at Ironton, Greenup, Portsmouth, Maysville, and Cincinnati during low flow. Due to greater dilution of the pollutants at high flow, only mercury exceeds the 10 percent level (five utilities). At average flow, cadmium and mercury exceed the 10 percent level at Ironton, Portsmouth, Maysville and Cincinnati. Mercury tends to exceed the 10 percent level for most of the utilities at all flow scenarios. Cadmium, lead and chromium concentrations exceed the 10 percent level only during low and average flow scenarios.

Carcinogenic Exposure

Because no single threshold level has been established for carcinogens, this analysis uses a 1×10^{-5} risk level as a critical value. Based on this level, the expected additional death rate for an exposed population for a given contaminant is calculated. Table 6 ranks the utilities from highest to lowest in incremental death rate. As can be seen, the most down stream utility is not the utility most "at risk." Therefore, the concept that the utility with the most

Table 6. Summary of Vulnerability for Carcinogenic Pollutants
at Average Flow

Rank	Downstream Order	Utility	River Mile	Expected Number of Additional Deaths/ 100,000
1	5	Greenup, KY	334.7	6.47
2	6	Portsmouth, OH	355.5	5.01
3	7	Maysville, KY	408.4	2.99
4	8	Cincinnati, OH	462.8	1.56
5	4	Ironton, OH	327.0	0.20
6	2	Huntington, WV	304.3	0.19
7	3	Ashland, KY	319.6	0.18
8	1	Gallipolis, OH	365.8	0.02

discharges above its intakes is most vulnerable is not true. Vulnerability depends on relative locations of intakes and outfalls.

Table 7 summarizes the utilities in the case study area for the different flow scenarios, based on carcinogenic exposure. As expected, the overall number of expected deaths are lower at high flow due to dilution. However Cincinnati and Maysville risk levels decrease at low flow as compared to average and high flow due to carcinogenic exposure. This unusual effect is due to the tradeoff in disappearance coefficient effects and time of flow at the various flow scenarios. At high flows and short travel time, the dilution effect does not offset the

Table 7. Vulnerability of Utilities at Various Flow Scenarios for Carcinogens

Utility	Expected Deaths at Average Flow	Expected Deaths at High Flow	Expected Deaths at Low Flow
Greenup, KY	6.47 (1)	3.75 (1)	19.77 (1)
Portsmouth, OH	5.01 (2)	3.14 (2)	10.42 (2)
Maysville, KY	2.99 (3)	2.34 (3)	*2.35 (3)
Cincinnati, OH	1.56 (4)	1.50 (4)	*0.56 (4)
Ironton, OH	0.20 (5)	0.13 (5)	0.46 (5)
Huntington, WV	0.19 (6)	0.11 (6)	0.44 (6)
Ashland, KY	0.18 (7)	0.04 (7)	0.40 (7)
Gallipolis, OH	0.02 (8)	0.01 (8)	0.07 (8)

( ) Rank.

Table 8. Estimated Lifetime Risk of Death

One in 1,000,000 or 1×10^{-6}	One in 100,000 or 1×10^{-5}	One in 10,000 or 1×10^{-4}
Diptheria	Gas Gangrene	Electrocution
Acute Polio	Hemophilia	Fall Out of Building
Rubella	Hit by Bicycle	Hit by Falling Object
Vitamin D Deficiency	Lightning	Firearm Accident
Ricketts	Cataclysm	Excessive Cold
Hit by Train	Bites and Stings	Accidental Poisoning
Plane Crash		Fall from Ladder

lower amount of disappearance that has occurred. The concentrations of selected carcinogens at Maysville and Cincinnati are greater there during high flow than at low flow. Huntington, Ashland, and Ironton exhibit a similar result for pollutants coming from the Kanawha River.

Obviously the tradeoff between initial concentration, disappearance rate, and flow rate is very important in this kind of analysis and will be discussed in some detail in the next section. To place some of these risk levels in reasonable perspective, Table 8 is included and gives the estimated life time risk of death for various diseases and accidents [5].

TRADEOFF IN MODEL PARAMETERS

There is a great deal of tradeoff among the flow rate, initial concentration, and disappearance rate in this type of modeling effort. Figures 3 and 4 demonstrate the variability of downstream pollutant concentrations at three flow rates.

In those two figures, chlorobenzene and nitrobenzene are assumed to be discharged at identical concentrations at various points. However, chlorobenzene is assumed to have a high disappearance rate of .55/day compared to .05/day for nitrobenzene. In Figure 3, one can see that the low flow pollutant concentrations fall far below those at average and high flows.

The velocity at which chlorobenzene travels downstream during high flow conditions does not allow for much disappearance. As the time-of-travel decreases (high flow) the amount of disappearance decreases, thus the variations in concentrations of pollutant downstream. Figure 4 reinforces this concept for a pollutant with a low disappearance rate. Nitrobenzene is more nearly like a conservative pollutant and most of the decrease in concentration is due to dilution, not disappearance. At mile 450 one can see that concentrations at low flow drop more quickly than for high and average flows as the low disappearance rate begins to have an effect.
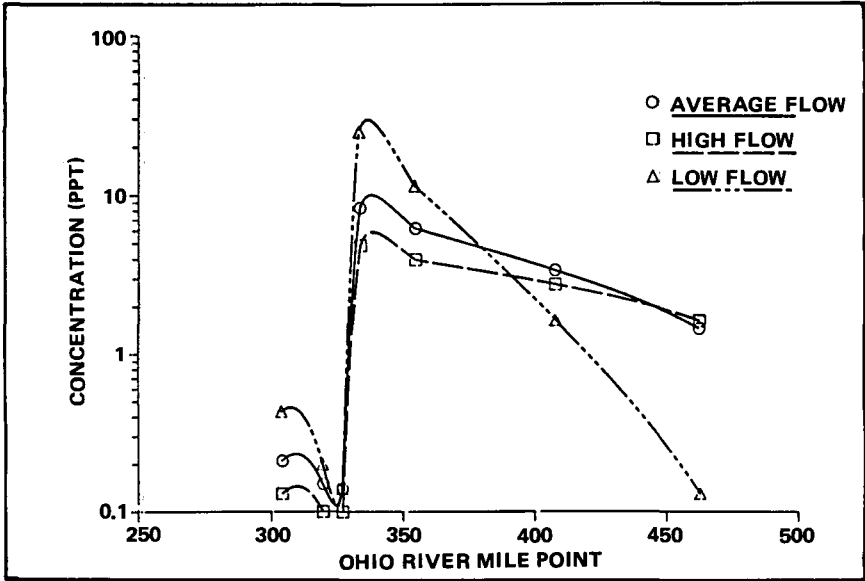
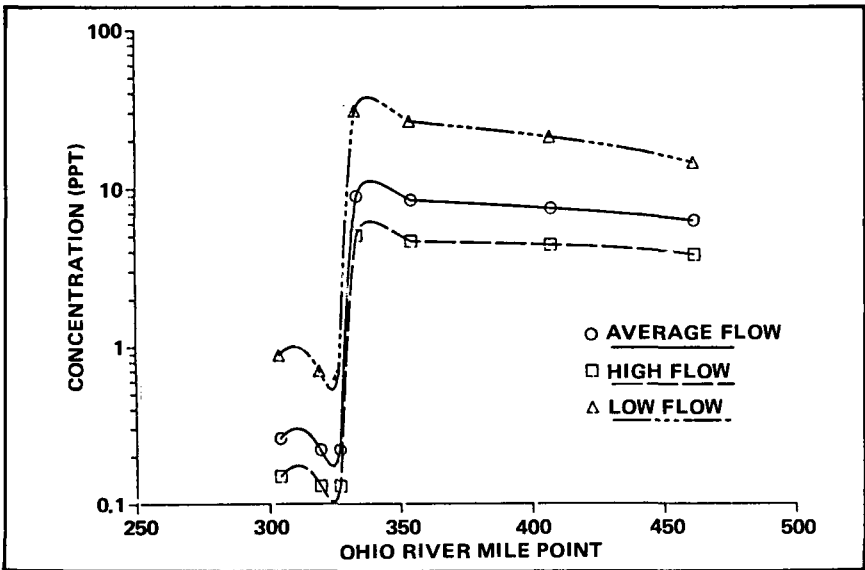Figure 3. Chlorobenzene Concentrations at Various Flow Scenarios.

Figure 4. Nitrobenzene Concentrations at Various Flow Scenarios.

SPILL EVENTS

Most spills are industrial in origin and occur within a plant due to untrained workers, carelessness, or lagoon-like failures following unfavorable weather. A large number of reported spills happened during transportation of industrial fluids. These include: barge accidents, train derailments, and truck collisions. Barge accidents, although less frequent then the others mentioned, are more threatening due to the volume and direct discharge into the river with little chance of material recovery [6].

QUAL-II was utilized to route a one-day, sixty-ton (54.4 metric ton) spill through the case study area from its entry into the Kanawha River. The tradeoffs between flow, magnitude of the spill, and the pollutant's disappearance rate are critical to downstream concentrations as in the daily discharge analysis. Figure 5 shows the simulated concentrations of carbon tetrachloride as it passes Gallipolis at various flows and an assumed .63/day disappearance rate. The peak concentration is not the only important statistic to be concerned within a spill event. The length of time it takes for a spill to pass a utility's intakes is also vital to a community's welfare. The shape of the curve of the spill as well as the peak must be considered in terms of how long a utility.will be forced to close its intakes and allow a spill to pass. A slow-moving spill although of lower peak and average concentration may pose a larger problem to a utility with limited storage capability than a more intense spill that passes quickly.

At high flows, the simulated spill would take almost two days to pass the Gallipolis intake. Average and low flow scenarios would require 3.5 and nine days respectively to pass. Although the peak concentration at high flows is large, Gallipolis has a two-day storage capacity and could close its intake and not be harmed. However, at average and low flows, the spill requires a longer time to pass and Gallipolis officials would need immediate and accurate information regarding the discharge in order to be able to decide when to close the intakes to reduce exposure to the pollutant.

Closing the intake at 1.5 days after the discharge and keeping it closed for two days during the average flow scenario would result in only very low concentrations of a pollutant being drawn into the intake. Since concentrations of the pollutant in the tails of the curve are in the parts per trillion range this should pose less of a health threat. During low flow conditions the intakes should be closed from the fifth to the seventh day after discharge to minimize exposure to the highest levels of the pollutant.

Another important factor that affects peak concentration and length of time for a discharge to pass an intake is the persistance of the pollutant. Figure 6 shows the simulated concentration of a pollutant with various disappearance rates at average flow. This figure could also represent three separate pollutants with varying disappearance rates under average flow conditions.

As can be seen in Figure 6, as disappearance decreases, not only does the peak concentration increase, the time-of-passage increases. A worst-case
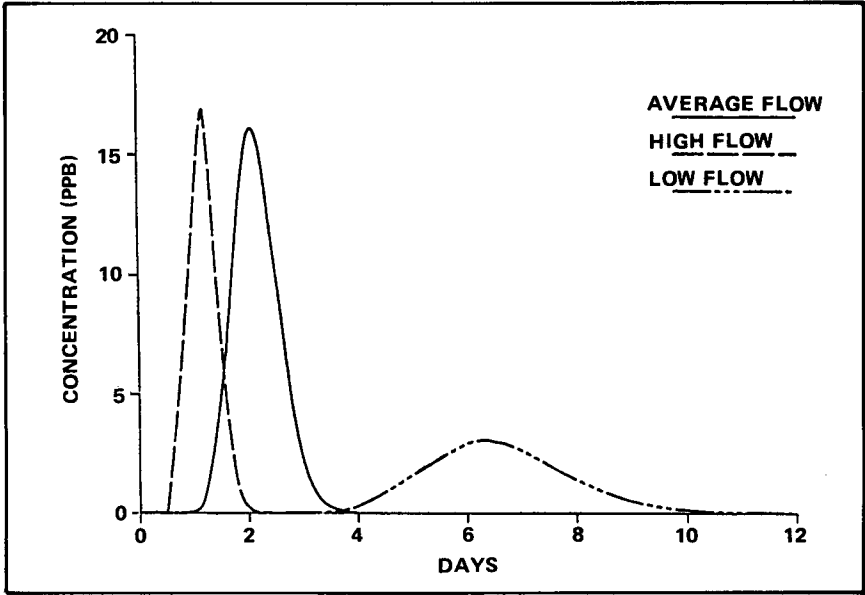
Figure 5. Carbon tetrachloride concentrations at Gallipolis, Ohio during various flow scenarios.
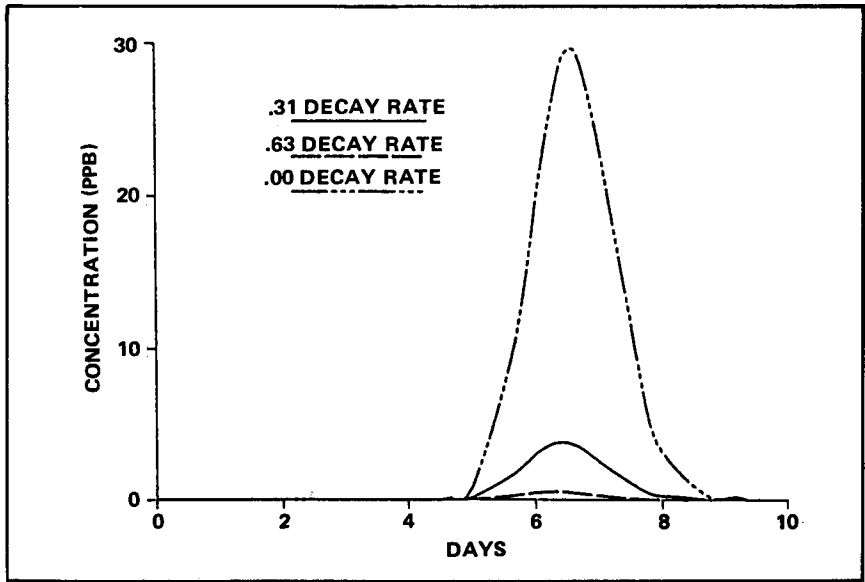

Figure 6. Priority pollutant concentrations at Cincinnati, Ohio with various decay rates.

scenario would include a nondisappearing or conservative, highly toxic pollutant, discharged during a low flow period. However, the slower time-of-travel would allow time for downstream utilities to take precautionary measures, possibly even altering treatment techniques temporarily to mitigate the health hazard should utility storage be inadequate to serve the community. Emergency conservation and public education of the situation could be instituted to stretch available supplies. A utility would be wise to have such a contingency plan developed to ensure quick and accurate implementation.

Table 9 summarizes the arrival time, leave time, the number of days with contamination, the peak concentration, storage time, and day of the peak concentration to each utility during a spill episode simulated by QUAL-II. A sixty-ton discharge is assumed to have occured during low flow with disappearance rate of zero. All the times listed in the table represent the number of days after the discharge occurred.

Health Implications

As can be seen in Table 9, the pollutant discharge takes two to three weeks to pass completely by each of the utilities. Utility storage time is shown in the last column. The peak concentrations are well in excess of most levels given in the water quality criteria guidelines for chronic exposure to priority pollutants. However, this exposure would only last a few days whereas the chronic exposure risk level is typically defined as low exposures exceeding six months.

The emphasis in discussing the vulnerability of communities to the pollutants discharged for both spills and continuous discharges may lie somewhere between chronic and acute exposure. This exposure is called subchronic and is defined in rodent studies as extending between two weeks and more than ninety days [7]. This type of exposure may occur following a massive spill or succession of spills that may take many days to pass a utility's intake. Also, during seasonal periods of sustained low flow, pollutants of low disappearance

Table 9. Priority Pollutant Discharge Simulation (60-ton spill at low flow)

Utility	Arrival Time (Days)	Leave Time (Days)	Days with Contamination	Peak Day	Peak Concentration (µg/L)	Storage Time (Days)
Gallipolis, OH	2.67	16.99	14.32	7.51	288.92	2.0
Huntington, WV	4.51	19.98	15.47	10.02	209.29	.12
Ashland, KY	5.34	21.14	15.80	11.18	173.35	1.0
Ironton, OH	5.84	21.97	16.13	11.85	169.41	2.5
Greenup, KY	6.34	22.64	16.30	12.51	165.84	2.5
Portsmouth, OH	7.35	24.13	16.78	13.84	149.12	1.5
Maysville, KY	10.35	29.25	18.90	17.49	136.37	1.0
Cincinnati, OH	14.00	34.50	20.50	21.97	111.39	3.0

rates may increase to levels comparable to a spill. During these periods small spills may take on greater significance.

PREDICTING PEAK DOWNSTREAM CONCENTRATIONS

Using the results from extensive computer simulation runs, a model was developed for the case study river basin to predict concentration within a stream reach. The peak concentration of a spilled pollutant at a utility can be predicted by the following equation ($N = 296$).

$$\text{Peak} = .74268 + .04236 \times \text{Init} \times e^{-K \times \text{TOT}} \quad (R^2 = .93) \qquad (1)$$

Peak = peak concentration of the pollutant in ppb,
Init = initial concentration of the spill in ppb,
K   = disappearance rate of the pollutant in 1/day,
TOT = time-of-travel of the pollutant to the utility in days.

The peak concentration may vary substantially if a large tributary enters at the beginning of a reach and is not accounted for. To use equation (1), spill and flow information must be available to the utility manager, most of which may or may not be supplied by a regional authority. Although there is little actual empirical information regarding the fate of the priority pollutants as they travel downstream, given that the pollutant is known, it should be possible to know whether the pollutant is conservative, or highly volatile or subject to some other process affecting its disappearance rate. Having this information the manager could then make several calculations incorporating a range of disappearance rates. In this way, the utility manager would have a general idea as to when the spill will reach the utility and if the level of concentration will require extra water treatment or closure of the intakes. The equation was derived from QUAL-II simulations for the case study area, but similar analyses could be applied to other river basins.

CONCLUSIONS

There is a growing awareness of the important interactions between toxic waste discharges in surface waters and their impact on the location and management of water supply withdrawals. To properly study these interactions it is necessary to bring together data from many sources and to study them in a spatial context. Such an analysis has been performed in this article using available information in conjunction with the existing analytical tools.

The methodology employed in this analysis emphasizes human health considerations as a controlling factor in toxic waste discharges and looks at a river basin in a manner similar to the "Bubble" concept now being used in air quality regulations. The revised NPDES regulations recently proposed by EPA

states that no permit shall be issued to a new source of discharger if it will cause a violation of the water quality guidelines. NPDES permit limitations are established on water quality standards, but very few specific organic compounds (toxics) are written into these permits. In order for the NPDES permitting to be effective, specific organic compounds should be included that are indicative of each industries' particular discharge. The burden of proof would be on the permit applicant and that there is sufficient remaining pollutant loading capacity to cover the new discharge.

As water quality criteria guidelines are developed, refined, and possibly become law, the methodology developed in this article would be directly applicable to the fulfillment of the regulations. Although a particular industry would only be interested in simulating the effects of a few relevant pollutants, the downstream utilities would be concerned with the total pollutant load of all upstream discharges. The techniques presented here lend themselves readily to this kind of analysis.

This study points out that one cannot make "snap" judgements concerning the behavior of discharges. For example, because of the interactions between disappearance coefficients, time-of-passage, and river flow scenarios one cannot always easily predict the concentration effects of a given pollutant. Pollutants with high disappearance coefficients discharged at high flow (short travel time) may have higher concentrations at a given downstream point then when discharged at lower flows (long travel time). There is no easy intuitive way to make these estimates.

Another application of this methodology is the addressing of water treatment strategies and sizing of facilities. Various pollutants with differing characteristics and loadings can require substantially different treatment steps. The proper sizing and choice of technology to provied safe drinking water is highly dependent on identifying the type and level of contaminants in the source of supply.

It is necessary to draw attention to the gap between water pollution control and water consumption. Because the number of toxic and carcinogenic pollutants are great and their impact on human health is important, a method to assess the vulnerability of communities to these pollutants in the drinking water is necessary.

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