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Project Summary

Predicting Toxic Waste Concentrations in Community Drinking Water Supplies: Analysis of Vulnerability to Upstream Industrial Discharges

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A study was conducted to predict toxic waste concentrations in community drinking water supplies along the Ohio and Kanawha Rivers between Charleston, West Virginia, and Cincinnati, Ohio, using QUAL-II, a water quality simulation model. Specifically, a toxics screening method was developed that can close the potential gap in the loop between water pollution control and water consumption. The project was a response to the lack of methods for identifying and assessing communities whose water supplies were vulnerable to excessive chloroform and synthetic organics resulting from industrial pollution and urban and agricultural runoff.

The most important factors to consider in identifying vulnerable communities are potency and persistence of the pollutants, amount and timing of discharge of pollutants, storage times of utilities, and relative location of point sources and community intakes.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

On February 9, 1978, the Environmental Protection Agency (EPA) proposed a regulation designed to protect the public health from organic chemical contaminants in drinking water (Federal Register, "Environmental Protection Agency Interim Primary Drinking Water Regulations," Vol. 43, No. 28, Thursday, February 9, 1978, pp. 5756-5780). Originally, the regulation consisted of two major parts:

A. A maximum contaminant level (MCL) that initially required water treatment systems serving populations greater than 75,000 to reduce trihalomethanes (TTHM) to 0.10 mg/L (100 parts per billion), and
B. A treatment technique regulation that required water systems serving populations greater than 75,000 to use GAC in the treatment process to remove synthetic organic chemicals unless a variance was granted.

Part A was promulgated as proposed on November 29, 1979; but Part B has been cancelled as proposed because of the wide concern over the impact of this regulation, especially regarding the procedure granting variances. Are those utilities within a specified number of miles downstream from industrial dischargers vulnerable and subject to the regulation? Or should utilities be granted a variance if fewer than a certain number of dischargers exist upstream from its intakes? This project uses a case study to answer these questions and to close the gap that potentially exists in this loop between water pollution control and water consumption.

Through the use of the methodology developed here, this study predicts which communities in the case study area will be vulnerable to (1) background levels of typical daily discharges, and (2) large, unexpected spills. Thus the report describes who is at risk, their relative levels of risk, and the main factors contributing to the risk.

QUAL-II, a water quality simulation model, was used 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. Though QUAL-II is less flexible than other models in simulating various flow scenarios and less sophisticated in modeling dozens of built-in parameters and biological and chemical transformations, the model exhibits a spatial organization that simplifies thinking and highlights critical variables such as the relative locations of utilities and dischargers and the time of travel.

Procedures

Determining the Case Study Area

Figure 1 presents the case study area, and Figure 2 schematically represents the waste loads, tributaries, and junctions involved in the water quality modeling. The contaminants were routed approximately 200 miles at various flow scenarios to account for seasonal variations in flow. The Kanawha River averages 25,000 cubic feet per second (cfs), and the Ohio River, 125,000 cfs. Time of travel during average flow is approximately 4.1 days through the case study area.

Identifying Existing Point Sources and Communities

The next step in the analysis was to provide an inventory and description of existing point sources and communities. To make a complete and thorough analysis of a community's vulnerability to water pollution, nonpoint sources of pollution as well as the point sources should be considered. But tremendous gaps often exist in the land use data, especially in watersheds involving various states and regional authorities, and thus any attempts to model runoff water quality are pre-empted. To simplify the analysis, only industrial dischargers and their wastes are considered in this paper, though various techniques could be used to model both municipal discharges and nonpoint run off.

Calculating Waste Stream Data for Industrial Dischargers

Typical waste stream data for each industry type was needed next. For this analysis, each point source was assigned a discharge value in parts per billion based on the best available control technology (BACT) for the relevant contaminants coming from each industrial production process. For modeling purposes, a general idea of a pollutant's persistence in the stream is required. Based on extensive calculations and literature reviewed, disappearance rates to account for processes such as volatilization were assigned to each pollutant (Maybey, W.R., et al., "Aquatic Process Data for Organic Priority Pollutants," Final Draft Report, Michael W. Slimak, Project Officer, Monitoring and Data Support Division, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, DC, July, 1981, pp. 409-434.)

Determining Potential Impact on Public Health

To assess the potential impact on public health, simulated pollutant concentrations for each utility are compared with the Water Quality Criteria, which only suggest at this time the concentrations of various pollutants that could be harmful to human health. The Criteria take into account toxicity, carcinogenicity, or organolepticity (taste and odor) of the pollutants (Personal communication with Dr. Christopher T. DeRosa, EPA, Environmental Criteria Assessment Office, 1982).

The Water Quality Critera for toxicity and taste and odor indicate the general population would be affected by consuming water with a pollutant reaching the guideline concentration — for example, 3,770 μg/L of cyanide (a toxic), or 300 μg/L phenol (an odor-causing agent). A tenfold buffer is incorporated in the toxic and organoleptic standards to take into account the more sensitive or susceptible consumers such as those who are very young, old, pregnant, or ill. Thus segments of a population could be possibly affected by 377 μg/L and 30 μg/L of cyanide and phenol, respectively.

The carcinogenic data are estimates of incremental risks associated with exposures from suspected carcinogens in drinking water. For example, a person is assumed to be at the 0.00001 risk level of developing cancer in his or her lifetime by drinking 2 L of water with 6.6 μg/L of benzene daily. The only no-risk level for carcinogens is zero concentration. Risk is assumed to be linear, but promoters and synergism among the pollutants could actually increase the risk levels.

This analysis is to be undertaken for daily dischargers of industrial wastes. In the event of a spill or large accidental discharge, information regarding the storage time for each utility is also necessary. Storage time indicates how long a utility could operate if the intakes were closed to prevent the high concentration of pollutants from entering the system. This factor affects the vulnerability of a utility.

Creating Various Flow Scenarios

To assess the vulnerability of communities to daily discharges of toxic wastes, three scenarios were created to account for variations in flow. With the use of QUAL-II, the applicable priority pollutants discharged in the case study area (81 out of the 129 priority pollutants) were simulated at average, high, and low flows. Average flow was set at 125,000 cfs, high flow was 220,000 cfs, and low flow was 35,000 cfs. As the volume of water increases, so does the mean velocity in the river channel, thus reducing the time of travel.

For toxic and organoleptic pollutants, the flow scenarios are critical in determining whether a Water Quality Criteria has been exceeded. Because vulnerability to carcinogens is evaluated over years of exposure to pollutants in the drinking water, carcinogenic risk levels were initially estimated only at average flows. In the event of a spill, however, the flow characteristics can be important even to carcinogens, since very high concentrations of carbon tetrachloride, for example, can have an acute health effect. In addition, regulatory agencies may want to use higher- or lower-than-average flows to increase safety factors. As will be demonstrated later, and contrary to the conventional wisdom, low flows do not necessarily exhibit higher pollutant concentrations than high flows because of decreased dilution. Utilities can be vulnerable to different pollutants at different flows.

Results and Discussion

Organoleptic Pollutants

Only 2 of the 11 organoleptic pollutants simulated exceeded a level at which sensitive consumers could be affected by

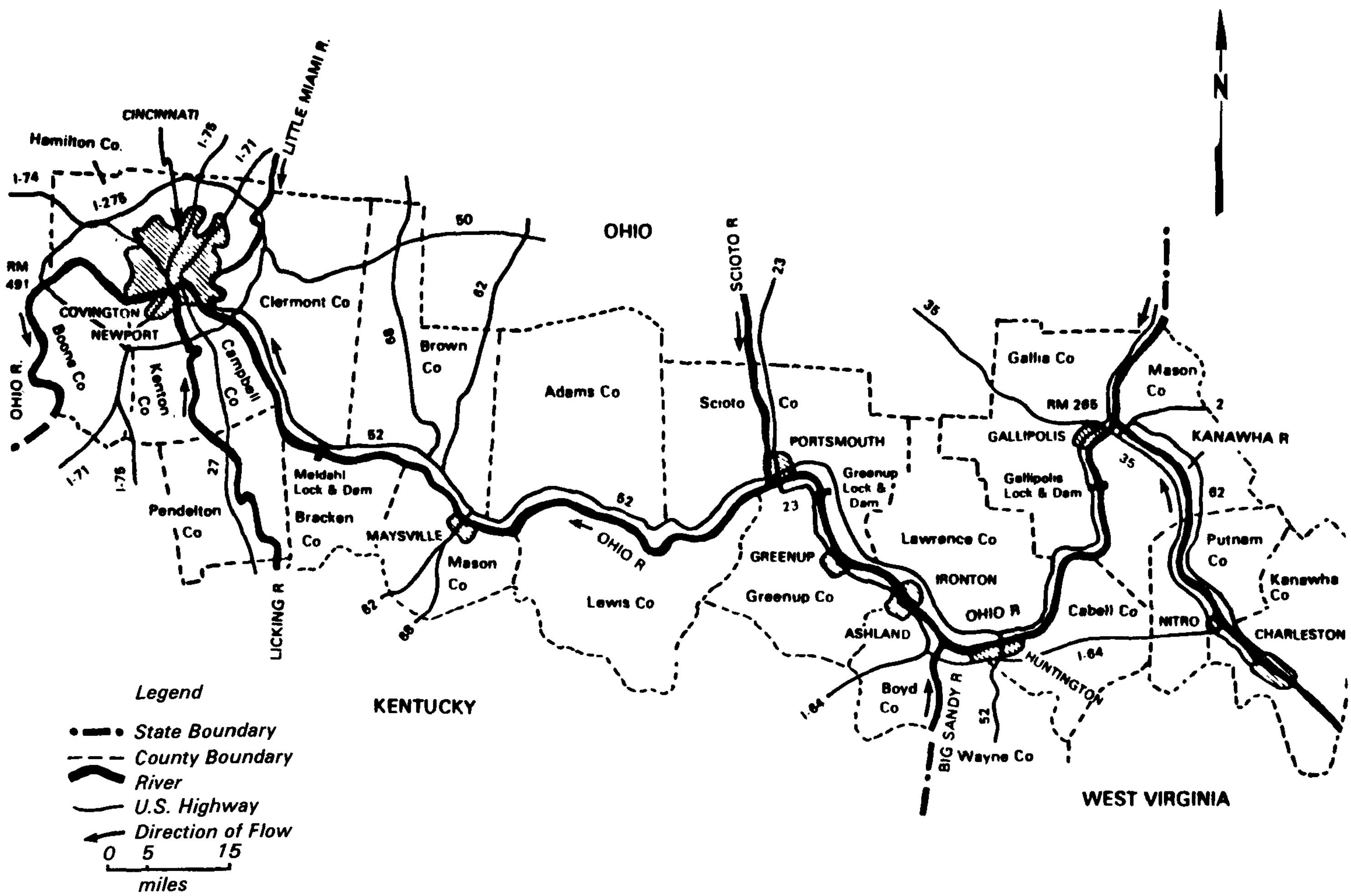

Figure 1. *Case study area.*

taste and odor problems. Those two pollutants are 2-chlorophenol and 2,4-dichlorophenol. Only during the low-flow scenario were these pollutants of any concern to the utilities. Though taste and odor problems are not dangerous, they often create greater response than do reports of possible carcinogens. Historically, aesthetic considerations have often been the basis for regulation rather than public health concerns.

Toxic Pollutants

Toxic pollutants that exceeded the Water Quality Criteria values at the utility intakes are listed in Table 1. During low-flow periods, the sensitive consumers of all the utilities would have been affected by cadmium. Ashland consumers would also be affected by mercury, and Greenup would have to deal with lead and chromium in addition to cadmium. The simulated concentrations of mercury exceeded the criteria guideline for all consumers at Ironton, Greenup, Portsmouth, Maysville and Cincinnati during low flow. Because of greater dilution of the pollutants at high flow, only mercury remains a concern to some of the utilities. During a high-flow period, mercury would affect only the sensitive consumers for the five utilities mentioned above. At average flow, cadmium and mercury exceed the guidelines for sensitive consumers at the same utilities except for Greenup. Throughout this analysis, mercury remains a problem at various levels for all flow scenarios. Simulated cadmium, lead, and chromium concentrations would affect sensitive consumers only during low and average flow scenarios.

Carcinogenic Pollutants

Analyses of carcinogenic pollutants proceed differently from the previous analyses for toxic and organoleptic pollutants. When assessing risks posed by carcinogens, no single value signifies that a health hazard exists for each pollutant. Rather, the Water Quality Criteria describe the carcinogenicity at the 1×10^{-5} risk level. These values can be used to calculate a community's expected death rate per pollutant per year. Table 2 ranks the utilities from most to least vulnerable, their river mile location, and the expected annual deaths attributable to carcinogens. Table 3 summarizes the vulnerability for different flow rates.

As expected, the overall number of expected deaths are lower at high flow because of the greater dilution of the pollutants at 220,000 cfs. Only Huntington and Ashland reverse positions in vulnerability at high flow. However, a few carcinogens do have downstream risk levels at high flow that exceed those at average and low flow. Through the total expected deaths are lower at high flow than at average and low flows, a few individual pollutants exhibit higher concentrations because of their disap-

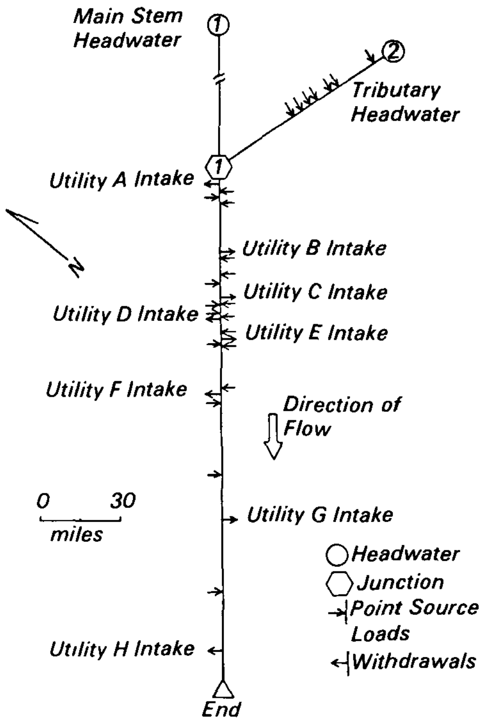

Figure 2. *Schematic of the study area.*

Table 1. *Summary of Toxic Pollutants Exceeding Health Guidelines*

	Average Flow		*High Flow*		*Low Flow*	
Utility	*10% Level*	*100% Level*	*10% Level*	*100% Level*	*10% Level*	*100% Level*
Gallipolis, Ohio	*None*	*None*	*None*	*None*	*Cadmium*	*None*
Huntington, West Virgina	*None*	*None*	*None*	*None*	*Cadmium*	*None*
Ashland, Kentucky	*None*	*None*	*None*	*None*	*Cadmium* *Mercury*	*None*
Ironton, Ohio	*Cadmium* *Mercury*	*None*	*Mercury*	*None*	*Cadmium*	*Mercury*
Greenup, Kentucky	*Cadmium*	*None*	*Mercury*	*None*	*Cadmium* *Lead* *Chromium*	*Mercury*
Portsmouth, Ohio	*Cadmium* *Mercury*	*None*	*Mercury*	*None*	*Cadmium*	*Mercury*
Maysville, Kentucky	*Cadmium* *Mercury*	*None*	*Mercury*	*None*	*Cadmium*	*Mercury*
Cincinnati, Ohio	*Cadmium* *Mercury*	*None*	*Mercury*	*None*	*Cadmium*	*Mercury*

Table 2. *Vulnerability of Utilities to Carcinogenic Pollutants at Average Flow*

Utility	*Vulnerability Rank*	*Downstream Order*	*River Mile*	*Expected Number of Cancer Deaths/100,000**
Greenup	*1*	*5*	*334.7*	*6.47*
Portsmouth	*2*	*6*	*355.5*	*5.01*
Maysville	*3*	*7*	*408.4*	*2.99*
Cincinnati	*4*	*8*	*462.8*	*1.56*
Ironton	*5*	*4*	*327.0*	*0.20*
Huntington	*6*	*2*	*304.3*	*0.19*
Ashland	*7*	*3*	*319.6*	*0.18*
Gallipolis	*8*	*1*	*265.8*	*0.02*

**Calculated rates.*

Table 3. *Vulnerability of Utilities to Carcinogenic Pollutants at Various Flow Rates*

Utility	*Expected Death Rate at Average Flow*	*Expected Death Rate at High Flow*	*Expected Death Rate at Low Flow*
Greenup	*6.47(1)**	*3.71(1)*	*19.77(1)*
Portsmouth	*5.01(2)*	*3.14(2)*	*10.42(2)*
Maysville	*2.99(3)*	*2.36(3)*	*2.35(3)*
Cincinnati	*1.56(4)*	*1.50(4)*	*0.56(4)*
Ironton	*0.20(5)*	*0.13(5)*	*0.46(5)*
Hungtinton	*0.19(6)*	*0.04(7)*	*0.44(6)*
Ashland	*0.18(7)*	*0.11(6)*	*0.40(7)*
Gallipolis	*0.02(8)*	*0.01(8)*	*0.07(8)*

**Figures in parentheses indicate ranking.*

pearance rates, allowing more decay at average and low flow during the longer time of travel. This result points to the usefulness of modeling the water quality parameters, since many pollutants are masked at various flow scenarios by the total expected number of deaths calculated. The expected death rates at Maysville and Cincinnati during high flow are greater than at low flow. Utilities at Huntington, Ashland, and Ironton also exhibit the same result for a few individual pollutants that have high disappearance rates and come from the Kanawha River. The decreased time of travel at high flow has not allowed for the pollutant to disappear. Thus utilities well downstream are at higher risk during high flow periods and consequently are at lower risk during low flow. Utilities closest to the outfalls would exhibit the expected risk levels — highest risk at low flow and lowest risk at high flow, regardless of disappearance rates.

A great deal of sensitivity exists between the factors of flow, pollutant concentration discharged, and disappearance rate. Figures 3 and 4 demonstrate the variability of pollutant concentrations at utilities based on the tradeoffs between flow, time of travel, and disappearance rate.

In those two figures, chlorobenzene and nitrobenzene are identically discharged from the same industries. However, chlorobenzene exhibits a high disappearance rate of 0.55/day, compared with 0.05/day for nitrobenzene. In Figure 3, one can see how the low-flow pollutant concentrations fall far below the average- and high-flow levels. The speed at which chlorobenzene travels downstream at higher flows does not allow for much disappearance to occur. As the time of travel increases, so does the amount of disappearance (thus the low concentrations of pollutant downstream during low flow). Figure 4 reinforces this concept because the curves do not cross over at various flow rates with the low disappearance rate. The concentration of nitrobenzene at each utility owes most of its decay to the dilution, not to its disappearance rate — hence the almost

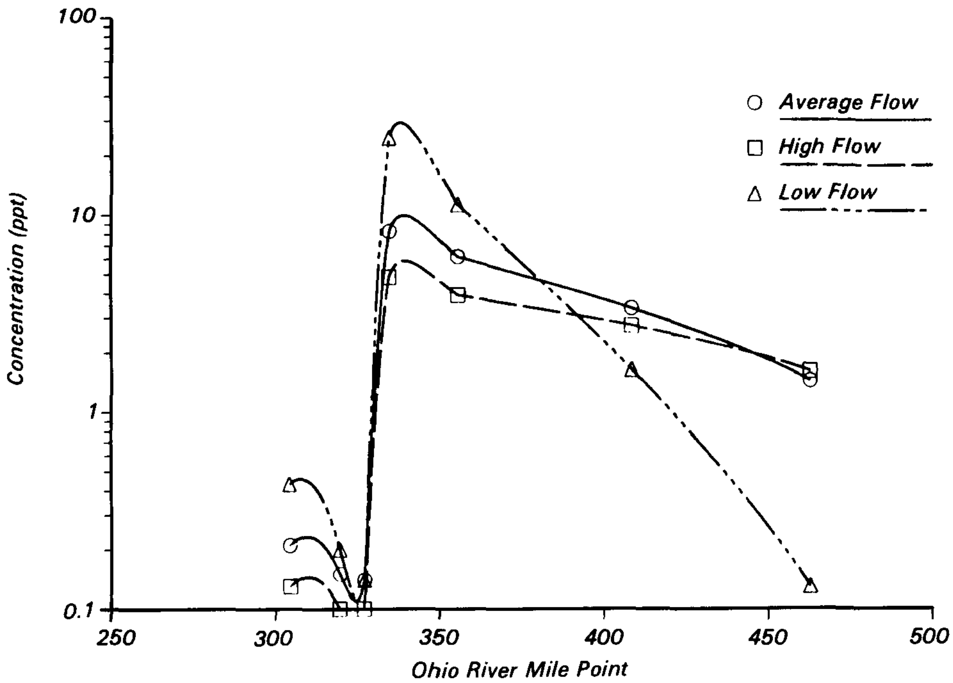

Figure 3. *Chlorobenzene concentrations at various flow rates.*

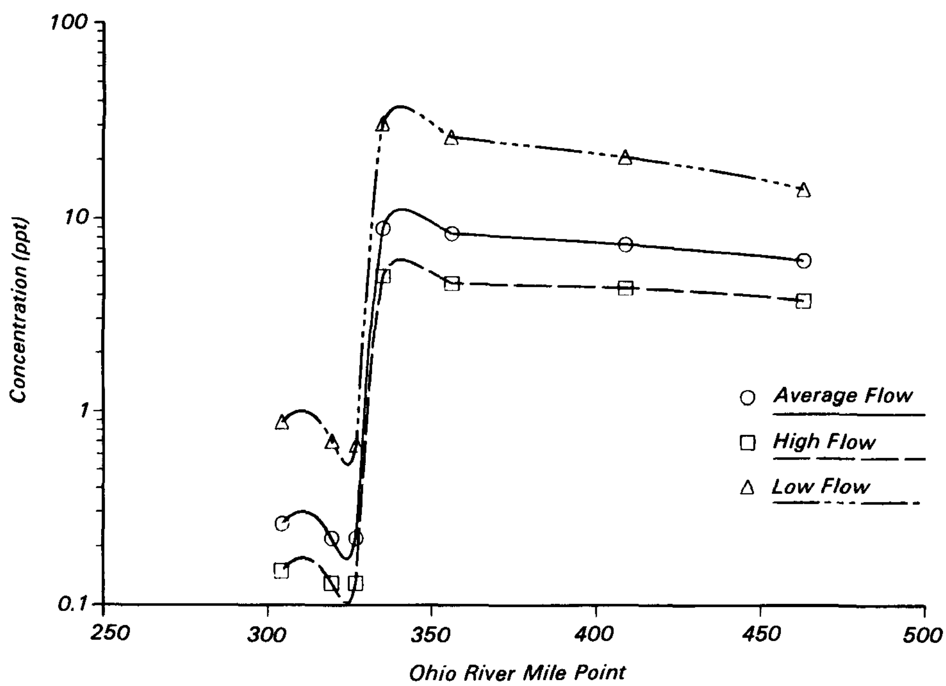

Figure 4. *Nitrobenzene concentrations at various flow rates.*

parallel curves in Figure 4 exhibiting the expected relationships. The low-flow curve begins to drop a bit more quickly than the high- and average-flow curves around the 450-mile point as the low disappearance rate begins to have an effect.

Spill Events

Accidental discharges occur in every conceivable place and manner. QUAL-II was used to route a 1-day, 60-ton spill through the case study area from its entry into the large tributary. The trade-offs between flow, magnitude of the spill, and the pollutant's disappearance rate are critical to downstream concentrations as in the daily discharge analysis. Table 4 lists the simulated concentrations of a conservative pollutant as it travels downstream at low flow. The peak concentration is not the only important statistic to be concerned with in a spill event. The length of time it takes for a spill to pass the intakes is also vital to a community's welfare. A slow-passing spill, though of lower concentration, may pose a larger problem to a utility with limited storage capacity than a very high concentration of a pollutant that passes quickly.

At high flow, the spill would take only 2 days to pass Gallipolis. Average- and low-flow scenarios would require 5.5 and 14.32 days, respectively. Gallipolis has approximately 2 days of storage available and could close the intakes and not be harmed during high flow. 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 to be able to decide when to close the intakes and reduce the exposure to the pollutant. Proper timing of the closure during the peak of the curve could reduce the health risk immensely.

A worst-case scenario would include a nondisappearing, highly toxic pollutant discharged during a low-flow period. Such a case would not be a total disaster, however, since the slow time of travel would allow ample time for downstream utilities to take precautionary measures, possibly even altering treatment techniques temporarily to mitigate the health hazard should storage volumes 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.

Conclusions

This study examines a functional region that serves as the source of drinking water for more than 1.1 million people, even though it is only a portion of a watershed. The potential risk posed to communities results from the gap that exists between public health considerations and water pollution control strategies.

The main contribution of this research has been the development of an interactive systems analysis approach that can affect public policy on drinking water. Recent investigations suggest that much technological manipulation of the environment produces new hazards and ameliorates old ones, and that effective means for coping with these events call for a sensitive understanding of natural phenomena as altered by man's actions. To study these interactions, it was necessary to collect for the first time a myriad of data and procedures and place them in an areal framework that can address problems between man and his environment.

The water quality simulation model, QUAL-II, was the mechanism that brought together diverse elements of mathematical modeling, fluid dynamics, epidemiology, organic chemistry, and geography. In addition, QUAL-II has traditionally modeled only the typical parameters such as BOD, DO, temperature, etc. In this analysis, QUAL-II was used to go a step further in simulating toxic pollutants. First order decay coefficients were calculated from other sources and inserted into the model to estimate the fate of priority pollutants.

Thus the issue of vulnerability is not a clear-cut matter of looking for the most downstream utility or simulating pollutants at an average flow. Very detailed information on flow probabilities, pollutant characteristics, industrial discharges, and location are needed.

Table 4. *Priority Pollutant Spill Simulation (60-ton spill at low flow)*

Utility	Arrival Time (days)	Leave Time (days)	Days with Contamination	Peak Day	Peak Concentration (µg/L)
Gallipolis	2.67	16.99	14.32	7.51	288 92
Huntington	4.51	19.98	15 47	10.02	209.29
Ashland	5.34	21.14	15 80	11.18	173 35
Ironton	5.84	21.97	16.13	11.85	169.41
Greenup	6.34	22.64	16 30	12.51	165.84
Portsmouth	7 35	24.13	16.78	13.84	149.12
Maysville	10 35	29.25	18 90	17 49	136.37
Cincinnati	14.00	34.50	20.50	21.97	111.39

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The complete report, entitled "Predicting Toxic Waste Concentrations in Community Drinking Water Supplies: Analysis of Vulnerability to Upstream Industrial Discharges," (Order No. PB 84-206 531; Cost: $14.50, subject to change) will be available only from:

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