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Engineering Aspects of Waterborne Disease Outbreak Investigations

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INTRODUCTION

Two recent headline causing events have reinforced the concern about the spread of diseases through waterborne routes. These two events include the current cholera epidemic in the western hemisphere that has caused over 750,000 reported cases of cholera through April, 1993[1], and the more recent cryptosporidium outbreak in Milwaukee, Wisconsin where between 200,000 and 400,000 people had diarrhea during the time frame of concern. Although many of the disease cases can be contributed to other than the waterborne mode of transmission, the rapid spread and large number of illnesses are frequently the result of waterborne transmission. In both of these events, a breakdown in proper water treatment allowed the etiological agent to survive in and be transported by the drinking water, which in turn allowed for a rapid spread of the agent over large areas of population. Whenever an enteric disease outbreak occurs, or even when a small outbreak happens and drinking water is implicated, an investigation should take place to help determine if drinking water was a contributing factor. This investigation will attempt to overlay the epidemiological data collected by local, state, and federal health agencies, and any and all data available from the drinking water systems. These data will not be limited to water quality data, but will also include information about system operation, abnormal conditions (i.e. power losses or pipe breaks), and almost any other available information about the water system. In most cases, by the time drinking water is implicated, the disease outbreak is over or at least on a decline, therefore, the available data will depend on data records. This paper will discuss the types of information gathered in three cases studies from past suspected waterborne outbreaks and how these data were used to implicate water as a mode of transmission. This information should help those involved with future outbreaks with guidance to determine what types of information are useful in waterborne disease investigations (Figure 1).

DRINKING WATER IMPLICATED

In a suspected waterborne disease outbreak, drinking water will have been implicated as a carrier of the disease causing organisms. The implication that the water was suspect generally comes from the epidemiological data gathered by local, state, and federal agencies. A waterborne outbreak is normally defined as an acute illness affecting two or more persons with similar symptoms that is epidemiologically associated with ingesting of water or some other exposure to water intended for drinking.[2] By the time water is implicated in an outbreak, the conditions in water quality may have changed, and in most of the previous outbreaks, the etiologic agent was not isolated from the drinking water. The majority of waterborne outbreaks are not recognized, investigated, or even reported, and in only half of the reported outbreaks is the causative agent identified. Investigating waterborne disease outbreaks has been likened to "fire fighting--when an outbreak occurs, investigators rush to the scene, assess the damage, find its cause, correct the problem, and return the system to its normal state".[2] The investigators are normally trying to find the engineering solution to a breakdown in the system that normally protects us from waterborne pathogens (i.e. water treatment plants and distribution systems).

In fighting the fire (or conducting the investigations), the investigators must be prepared to work with any and all individuals, organizations, groups, and officials involved with the current outbreak. These contacts may include (but not limited to) local, state, and federal health agencies, water utility workers, local administration officials, state and federal regulatory agencies, the public, and even the press. In some cases, the investigating team may spend more time dealing with the many groups than actually doing the investigations. The investigators do need to remember that the water utility will probably need to be producing water during the investigation and the first order of business is to provide a safe water to their customers. The second concern is to determine what happened so that measures can be taken to prevent a future occurrence.

Another important factor in fighting the fires is to keep an open mind about what events may have occurred to cause the suspected waterborne disease outbreak. In the next section, three case studies are presented to highlight three different waterborne outbreaks investigations. Each of the outbreaks resulted from suspected contamination of the drinking water, but the method of contamination was significantly different in each case. The ability to keep an open mind allows the investigating team to look at many scenarios before attempting to make a judgment about what might have happened.

CASE STUDIES

Each of the three case studies presented in this paper will focus on a different method of contamination of the drinking water that resulted in diarrheal illnesses and in some instances deaths. The first case described is a contamination in a single facility, the second case describes contamination of a distribution system, and the third case discusses contamination that passed through a water treatment plant.

In Case Study I, 39 people in a residence hall for a hospital became ill over a three day period in July. The etiological agent was a blue-green algae, and drinking water was a suspected carrier.The drinking water supply for this building is connected to the municipal water supply. The water entering the hall passed through three pressure filter units plumbed in parallel and each one was approximately 5-6 ft in diameter and about 7 ft tall. When water was flowing through the filters, each filter had about 5 psi pressure loss across the filter indicating that media was present in each filter. The hall's service personnel indicated that the filters had not been backwashed for at least 10 years (that's how long the present service personnel had been there). The service personnel had been told that the filters were not in service any more.

After the water passed through the filters, it flowed into a surge tank that fed the main pump. The surge tank was not covered and the water was exposed to the basement area. The main pump then transferred the water to two roof storage tanks that fed the hall's distribution system by gravity (Figure 2). The two roof storage tanks (each approximately 5000 gallons) were housed in a penthouse area and were uncovered. A tarp was available for covering the tanks, but the tarps did not always completely cover the tanks. The water line from the basement pump was split into two lines and each line served one of the storage tanks. The influent to each storage tank was at the top of the tank and water free fell into the tank. The effluent lines from the tanks were located approximately 8-10 inches above the bottom of the tanks and the effluent from the two tanks were combined again before serving the hall's distribution system. The water depth in each storage tank normally varied from a low of 4-5 ft to a high of 7-8 ft.

Early in the morning (~1:00 am) on the day of the first diarrheal case, the water pump in the basement that pumps water to the roof storage stopped and roof storage tanks were drained by normal use. The pump was repaired and restarted at about 7:00 am. Because of the timing of the pump breakdown (just prior to the onset of the outbreak) the water supply was immediately suspect as a probable cause. The onset of the illnesses began on July 5 and continued through July 7. By the time the cases were reported and the pump problem noted, it was July 10 and clean water had been pumped through the building system for over five days. Fecal specimens taken from patients indicated that blue-green algae caused the illnesses. Water samples taken from kitchen taps and drinking water fountains were all negative for blue-green algae.

The penthouse area (where the storage tanks were housed) was not sealed from the outside and several windows were broken and no screens were available. There was evidence of birds in the penthouse with bird feces on the storage tank brim, on the pipes located above the tanks, and on the tarp that partially covered the one tank that still contained water.

Drinking water was the suspected source of contamination and the point where the contamination entered the water was likely the roof storage tanks. When the pump failure occurred, the water level in the tanks drained down to the bottom of the effluent line (approximately 8-10 inches above the bottom of the tanks). The bottom 8 inches of water in those tanks was a stagnant zone where normally the water moved either very little or not at all. This zone would not normally mix with the water above this zone and chlorine concentration in this zone would be very low. Because this zone would not have normal levels of chlorine and would not be flowing in normal conditions, this was a likely area for biological growth. When the pump was turned back on, the new water coming into the storage tank would mix with this stagnant water into the new water and thus distribute the stagnant water throughout the building. The bird fecal material and the birds using the tanks for drinking or swimming were a possible source of initial contamination.

The new water flowing into the storage tanks both flushed the tanks out and added fresh chlorine into the lower areas of the storage tank. The flushing action would be enough to reduce the algal concentration in the tank so that the later sampling for blue-green algae was negative.

In this example, the epidemiological data collected by the Centers for Disease Control could not completely rule out one other mode of disease transmission (a food route was suggested), but the scenario described above is considered the most likely route of exposure.

In Case Study II, a small town with a population of 2090 experienced an outbreak where 243 cases of diarrhea (85 cases were bloody diarrhea) were reported, and four deaths were recorded over a 35-day period. The epidemiological study implicated the drinking water system when it was observed that individuals living within the limits of the water distribution system (or those that frequently came into the area and consumed water) were 18 times more likely to become infected than those that lived just outside the limits of the distribution system, or those that drank bottled water.[3] The etiological agent identified in stool samples was <u>Escherichia coli</u> serotype 0157:H7. This <u>E. coli</u> had been identified in other outbreaks but had always been limited to hamburger or milk contaminations.

In this case, the engineering investigation did not begin until four weeks after the main impact of the outbreak. Prior to the engineering investigation, a boil water order had been issued for this community and the water utility began chlorinating the previous untreated well water before sending it out into the distribution system. An engineering investigation was requested to determine if a sequence of events could have taken place that would have caused the spread of the E. coli through the drinking water distribution system.

Since the investigation of the water system was conducted four weeks after the outbreak, the strategy for investigating the possible involvement of the water supply focused on the study of long term water quality data from the municipal wells and distribution system. A computer model was used to investigate the movement of water through the system. In addition, a general inspection of the drinking water supply system and operating practices was also conducted. In the course of the investigation, two major pipe breaks and numerous curbside meter replacements were done just prior to the onset of the outbreak and during the outbreak. The investigation also showed that the wells used by the community were in protected aquifers and the well heads appeared sound. This indicated that if contamination occurred, it had to have happened within the distribution system. The timing of the pipe breaks and meter replacements also helped to implicate drinking water in the outbreak. The municipal sewage and storm water collection systems were under designed for the capacity that was being transmitted and there were indications that the sewage system was prone to infiltration from storm water run off. The sewage collection system routinely overflowed during rain events and sewage products were visible around many manhole covers. One of the known sewage overflow areas was in the proximity of one of the major water supply pipe breaks and several of the meter replacements. Water utility personnel noted that in many of the meter replacements, water had to dipped out of the meter box before replacing the water meter.

Circumstantial evidence strongly suggested that a break in the public health barrier concept did occur between sewage, storm water, and water supply. For example, six cases of bloody diarrhea were identified as having occurred prior to the first water main break but after 43 meter replacements on the system. Seven other cases were reported between the two water main breaks that occurred 3 days apart, with the remaining 72 cases identified within a week after the second break. This situation points to the possibility that E. coli 0157:H7 was prevalent for several weeks in the water supply.

A dynamic analysis of the movement of water under normal and pipe break conditions was simulated with EPA's Dynamic Water Quality Model (DWQM).[2,3] The model was applied to predict the movement of water flow and contaminant dispersion in the system under normal operating conditions prior to the breaks being repaired and hydraulic situations simulating recovery following the two repairs, or meter replacement. To simulate the break conditions, a conservative contamination level of 10^5 organisms per mL in a 0.6 L/sec flow for a period of 4-hours after break repair or meter replacement was used to simulate sewage contamination of the distribution system. Combining the patterns of organisms spread from both breaks provided an overlay of contaminated water (10-100 organisms per liter) that covered 85% of all household case locations (Figures 3,4). The model showed how rapidly the organisms would spread and how wide an area would be affected by the contamination occurring at the pipe breaks. (The pipe break areas were not disinfected after being repaired).

If sewage or surface water drainage was the origin for this pathogen, E. coli 0157:H7, then the question would arise as to why the organism and other coliforms were not detected in the contaminated water supply. It is important to note that no official monitoring of the public water supply was done during the 35 day outbreak period. One water sample was taken by a nonwater sampler and a certified laboratory analysis showed 22 total coliforms per 100 mL (no tests were done for fecal coliforms or E. coli). A follow up water sample was taken from the same location after chlorination was implemented and that sample was negative for coliforms.

The evidence strongly suggests that fecal contamination of the water system occurred in the distribution system and the movement of the water caused the rapid spread of the etiological agent. Water samples taken by EPA at the extremities of the distribution system (4 weeks after the outbreak) also showed signs of fecal contamination but the pathogen E. coli was not detected in the water system. Because of the elapsed time between the outbreak and the engineering investigation, the investigating team did not believe that water supply samples taken during the investigation would show E. coli 0157:H7.

In Case Study III, another small town (16,000 population) experienced several thousand cases of cryptosporidiosis and the drinking water system was implicated.[4] In this case, the engineering investigation concentrated on the conventional coagulation, sedimentation, and filtration surface water treatment plant. Earlier EPA laboratory and pilot plant research[5] had indicated that turbidity breakthrough, or passage of particulates, could be accompanied by protozoan cyst breakthrough. At this plant, turbidity was not routinely measured on each of the ten filter effluents, (only clearwell measurements were required) but were on a few occasions during the investigation. Analysis of the filtered water turbidity of each filter's effluent suggested that the practice of stopping and restarting filters (Figure 5) without backwashing resulted in higher than normal turbidity water passing through the filters (Table 1). This passage of turbidity would have also allowed passage of Cryptosporidium oocysts if the oocysts were present in the raw water. The water leaving the treatment plant had a turbidity of less than 1.0 NTU (and below 0.1 NTU on many occasions), and always had a chlorine residual present. Further investigation of the plant showed that the flocculation system was not performing optimumly, and modifications were suggested to improve flocculation which in turn would improve sedimentation and lessen the load on the filters.

Each of the three case studies described have shown a different source of contamination of the drinking water. Each outbreak required the investigative team to evaluate a different part of the water supply system as to what was the causing factor related to the drinking water system. Each of these cases also show that if the pathogen is known before the investigation begins, a probable path of contamination may be suggested. These three case studies are not meant to be all inclusive of the problems in investigating waterborne outbreaks, but are intended to be representative of waterborne outbreaks.

OTHER AREAS OF CONCERN

In addition to the events investigated in the case studies presented, there are many other areas that should be considered in an outbreak situation. Some of these areas include making a complete inspection the treatment (or nontreatment) facilities based on visual observation and review of historical and current data records. This evaluation would include reviewing the source water quality, intake structures (and locations), the entire treatment train (operation and equipment), effluent water quality, and distribution system. This investigation should also include looking at abnormal conditions that include severe weather events, power loses, pipe breaks, fire demands, and even illegal dumping of contaminants. In the future, better reporting and new analytical techniques may help investigators to do a better job in tracking the causes of waterborne disease outbreaks, and to make recommendations that may help prevent future outbreaks.

There are two publications that are very good handbooks to help in waterborne disease investigations. These books are:

1. Methods for the Investigation and Prevention of Waterborne Disease Outbreaks, Edited by Gunther F. Craun, U.S. Environmental Protection Agency, Office of Research and Development, EPA/600/1-90/005a, September 1990. (Note: All participants of this Sunday Seminar will receive a copy of the above book).

2. Basic Need-to-Know on How to Conduct a Sanitary Survey of Small Water Systems, Learner's Guide for the Training Course, U.S. Environmental Protection Agency, Office of Ground Water and Drinking Water, January 1992.

Both of these books have chapters that deal with specifics on conducting treatment plant evaluations, watershed protection surveys, and distribution system analysis, and would be good guides to have on an investigator's desk.

REFERENCES

1. Cholera Epidemic in the Americas - Update #93-2, Diarrheal Diseases Section, Centers for Disease Control.

2. Methods for the Investigation and Prevention of Waterborne Disease Outbreaks, U.S. Environmental Protection Agency, EPA/600/1-90/005a, September 1990.

3. Geldreich, E. E., et al. Searching for a Water Supply Connection in the Cabool, Missouri Disease Outbreak of Escherichia Coli 0157:H7, Water Research, 26:8:1127 (1992).

4. Logsdon, G. S., et al. Trouble Shooting an Existing Plant, Presented at AWWA Annual Conference June 1988

5. Fox, K. R., Removal of Cryptosporidium in Laboratory and Pilot Plant Studies, in Advances in Filtration and Separation Technology, Vol 5, American Filtration Society, 1992.

TABLE 1. CASE STUDY III-- FILTER WATER TURBIDITY (NTU) (February 3)

	Clean Filters*				Dirty Filters		
	#1	#5	#7	#9	#3	#8	#10
6:19 pm	0.11	0.10	--	--	0.20	--	--
6:39	--	--	0.07	0.08	--	0.41	1.6
6:59	--	--	--	--	0.54	8.8	2.2
7:14	(Settled water at Filter #8 is 8.8 NTU)						
7:33					0.74	2.8	2.5
9:08					0.86	0.54	3.2
9:15	(Settled water at Filter #8 is 8.8 NTU)						
9:20	0.18	0.10	0.84	--			
9:35 pm			0.10	--			

The clean filter samples were taken from filters that had been recently backwashed and put on line. The dirty filters were filters that had been used for a short period of time, shut down, and then restarted without backwashing.

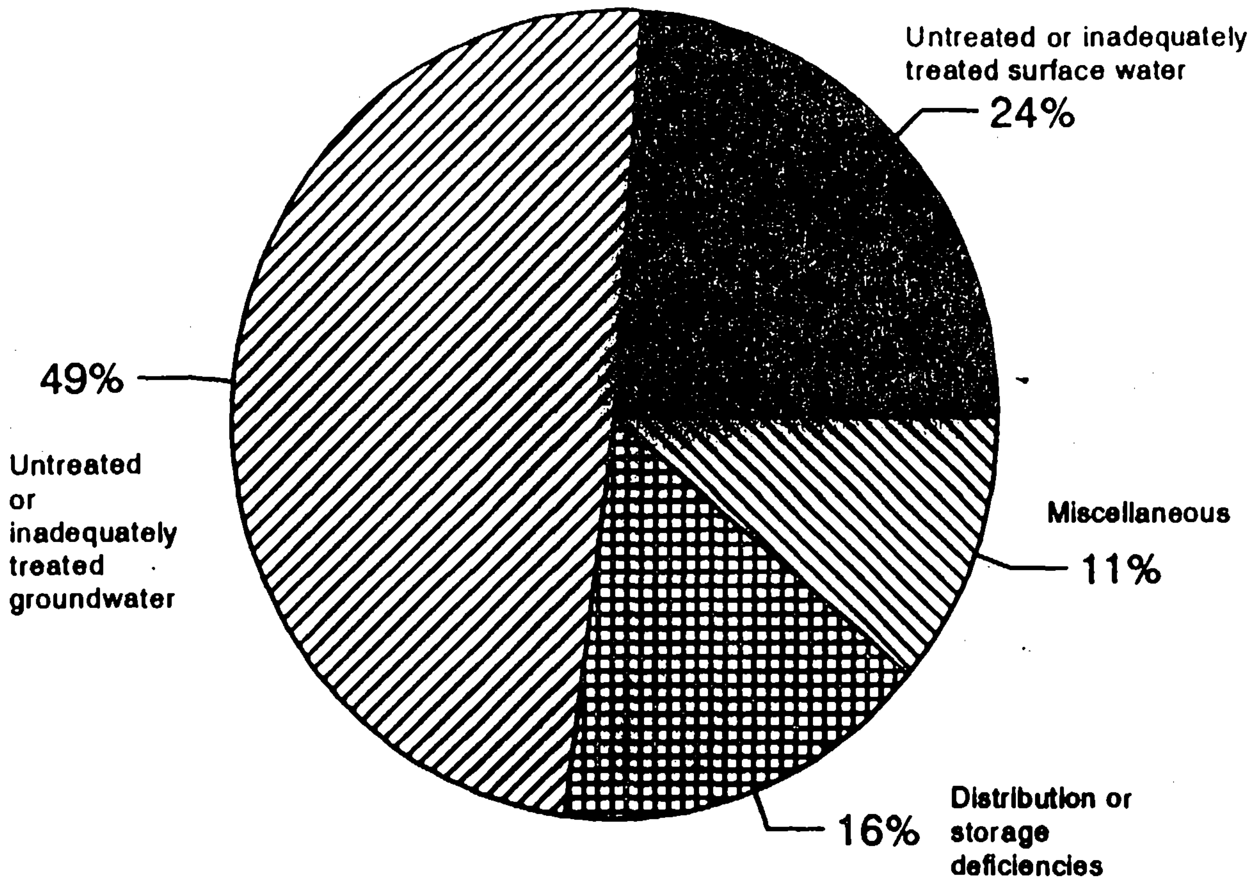


Figure 1. Causes of 502 waterborne disease outbreaks, 1971-1985.

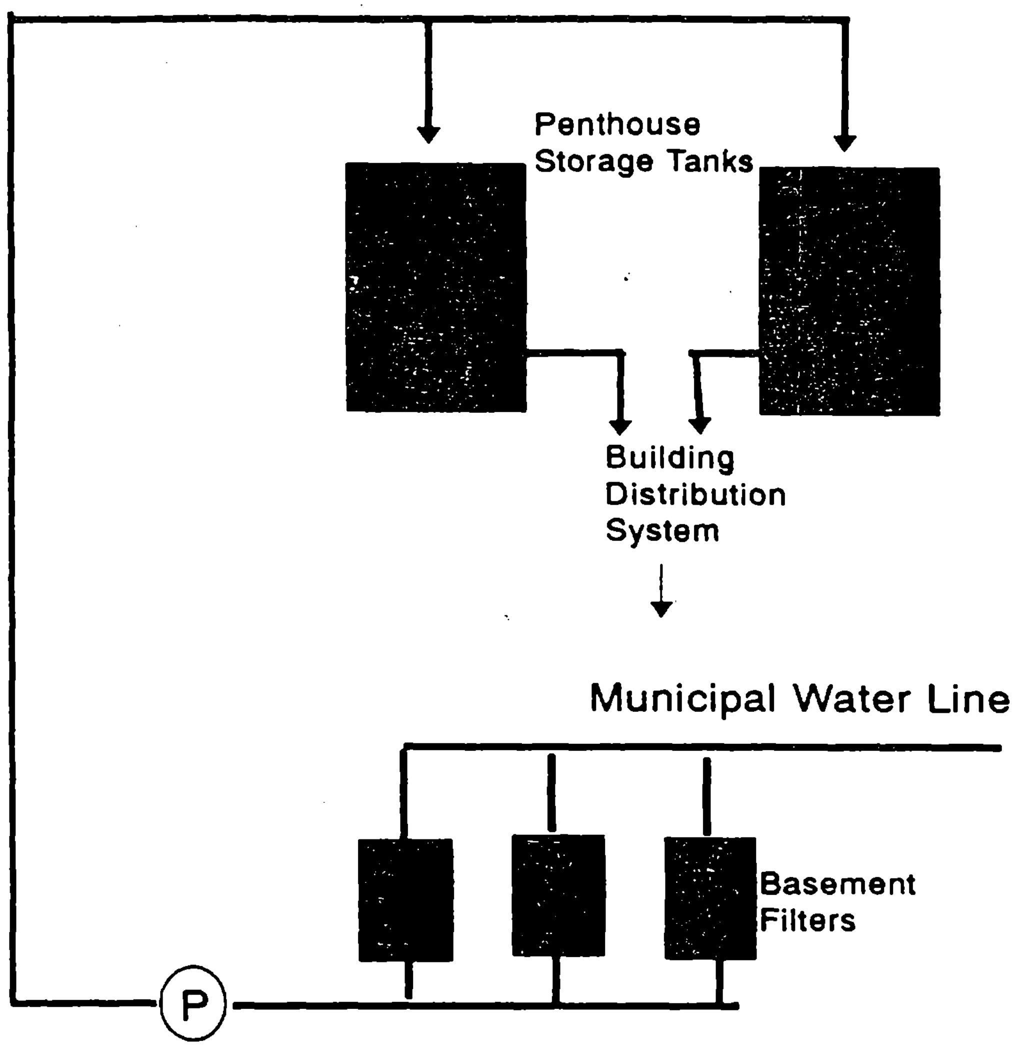


Figure 2. Building Schematic (Case I)

Figure 3. Dynamic Simulation of Contaminant Introduced at First Break

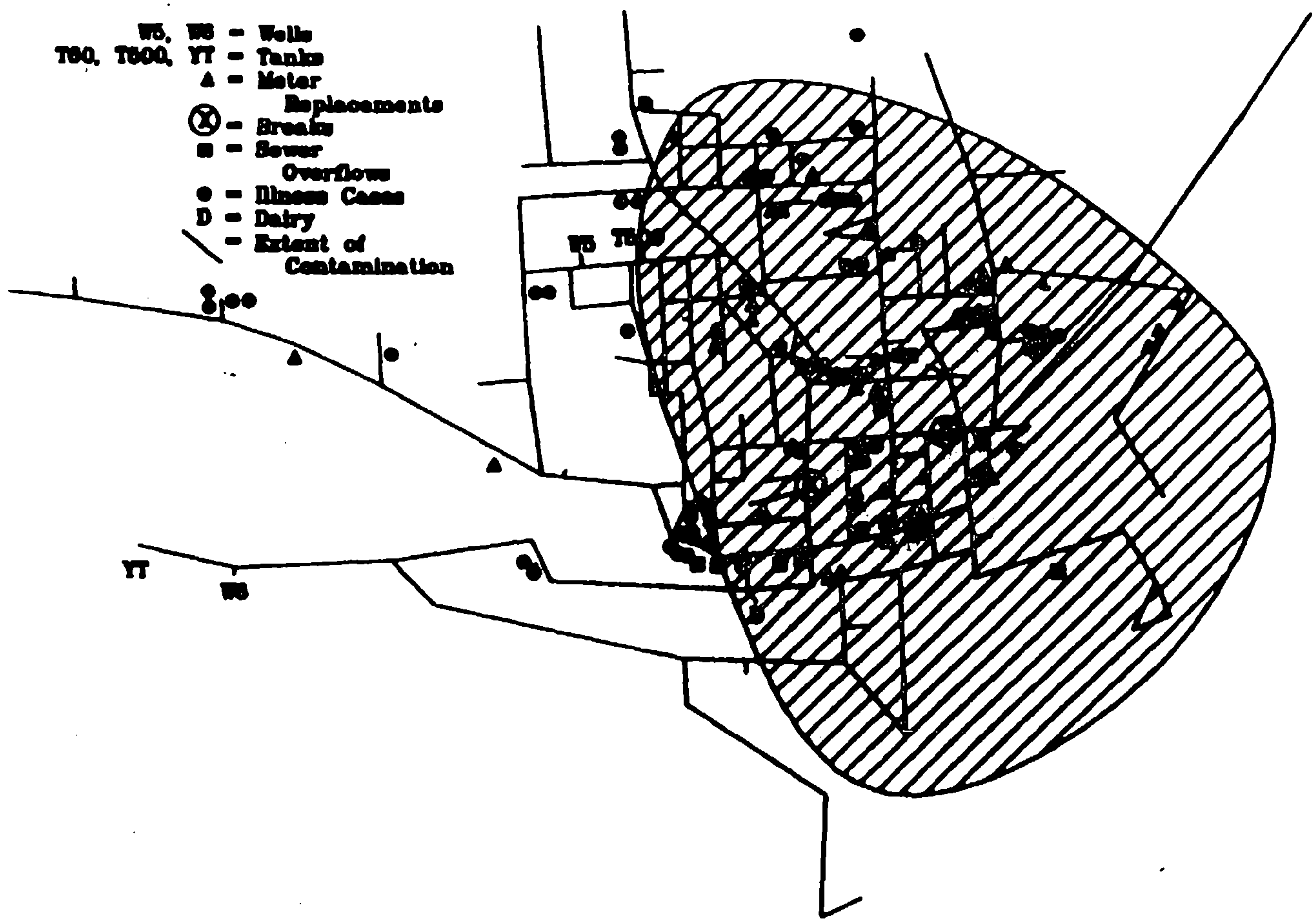
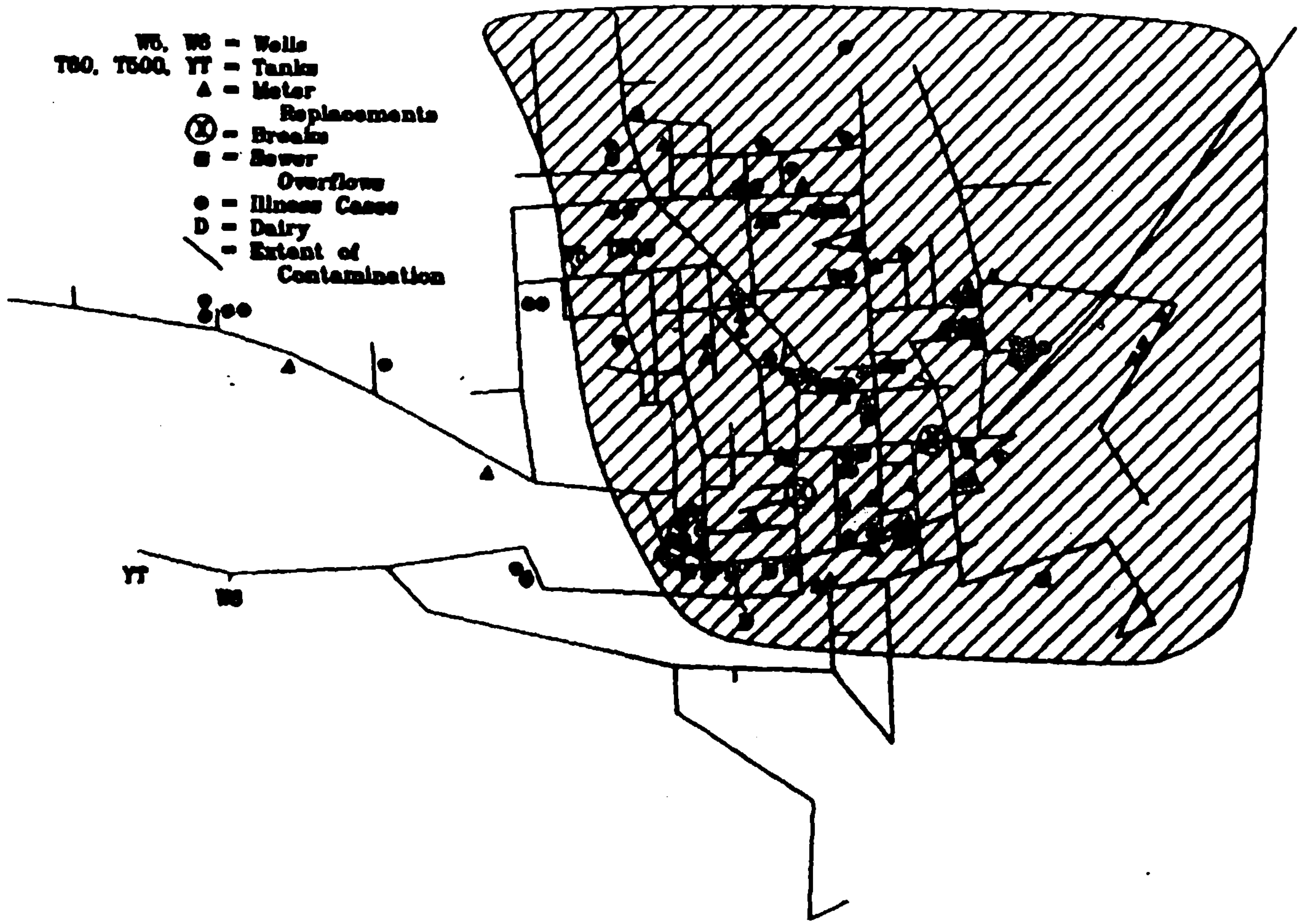


Figure 4. Dynamic Simulation of Contamination Introduced at Second Break



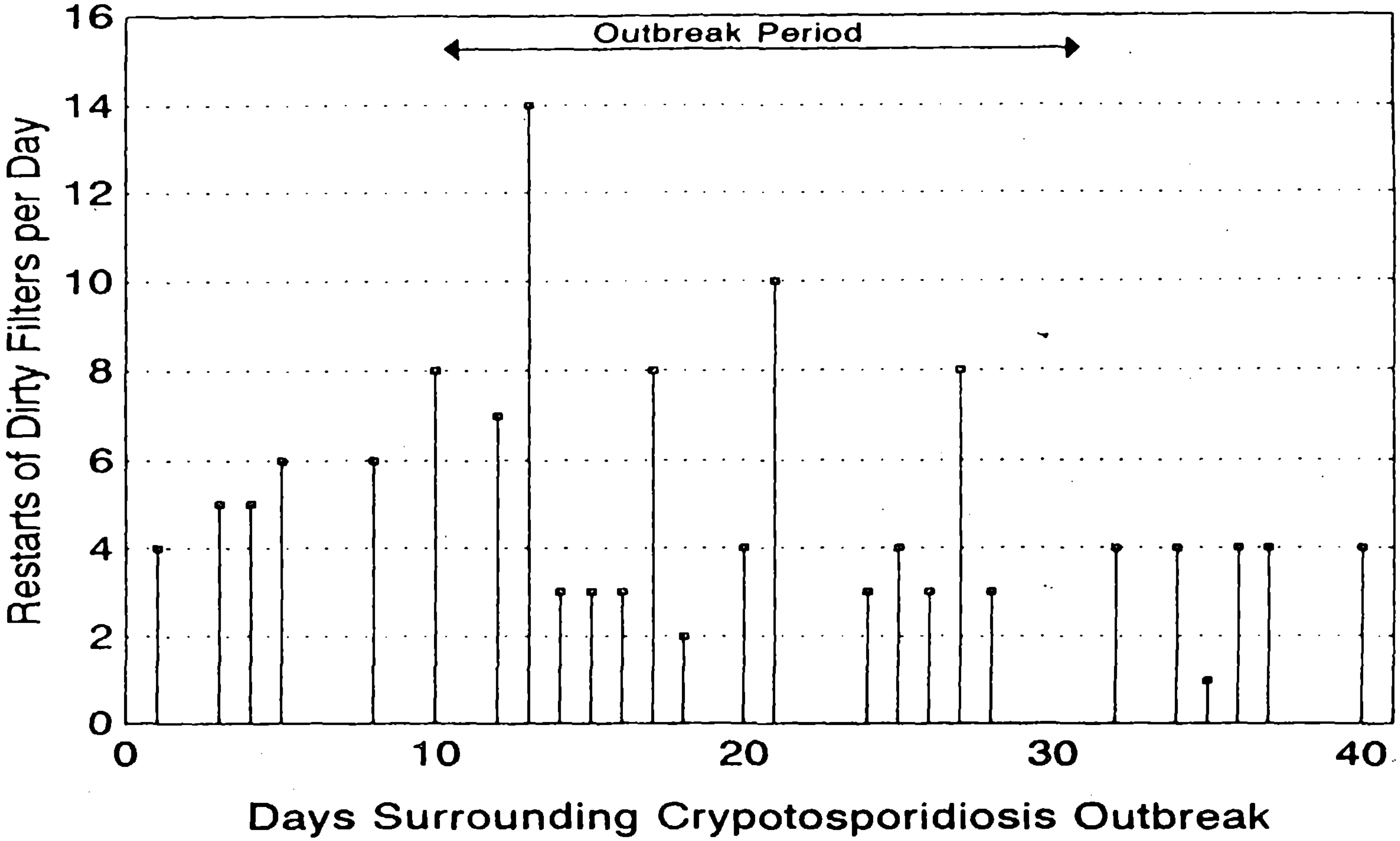


Figure 5. Filter operation surrounding the outbreak (Case III)

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16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

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