Impacts of Sanitary Sewer Overflows and Combined Sewer Overflows on Human Health and on the Environment: a Literature Review

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Introduction

There are two types of public sewer systems used in the United States for collecting and conveying sanitary sewage, combined sewer systems (CSS) and sanitary sewer systems (SSS). Combined sewer systems collect and convey sanitary sewage and urban runoff in a common piping system. Sanitary sewer systems collect and convey sanitary sewage separately from urban runoff. In locations where SSSs exist, urban runoff is collected and conveyed in a separate storm sewer system (EPA, 2004). There are approximately 20,000 SSSs in the U.S. serving 147 million people and approximately 1,100 CSSs serving 43 million people (Meyland et al., 1998).

CSSs were built prior to 1900 and were originally designed to convey combined sewage directly to points of discharge, generally into adjacent water bodies. With the advent of sewage treatment, CSS discharge points were redirected to wastewater treatment plant intake points (EPA, 2004).

Out of economic necessity, wastewater treatment plants have limited hydraulic and treatment capacity. These plants are generally designed to accommodate diurnal peak sanitary sewage flows and loads, plus a limited additional hydraulic load resulting from wet weather sources. During wet weather events, hydraulic loads in CSSs quickly exceed the treatment and hydraulic capacity of treatment plants, necessitating diversion of part of the flow from the plant. Provisions for flow diversions around the treatment plant are designed into combined sewer systems. Some CSSs have temporary storage impoundments and all have direct discharge points to receiving water bodies. These direct discharges are called combined sewer overflows (CSOs).

Because wastewater treatment plants are designed to accommodate sanitary sewage flows and loads, all collected sanitary sewage in SSSs is processed through the treatment plant prior to discharge. Sanitary sewer systems are not designed with diversions around the treatment plant.

Unplanned discharges do occur, however, from SSSs. These unplanned discharges generally result from pipe blockages or component failures and when they occur are classified as sanitary sewer overflows (SSOs).

When either CSOs or SSOs occur, sewage is released to the environment. These releases have the potential to endanger public health and cause environmental damage because of the contaminants contained in sanitary sewage and urban runoff. Little evidence is available, however, about direct links between SSO and CSO events and significant environmental and human health impacts. The 2004 U.S. Environmental Protection Agency report to Congress (EPA 2004), which cites some evidence, stands as the only extensive and comprehensive study concerning CSO and SSO impacts on human health and the environment.

Human Health Impacts of Exposure to Sewage

Pollutants causing human health impacts – Sewage contains contaminants that can adversely impact human health from both acute and chronic exposure. The focus here will be on agents that cause adverse human health impacts as a result of acute exposure because chronic exposure to sewage is not expected in developed, industrialized societies. Although agents that can cause illness can be chemical, physical, or biological, illness is most commonly caused by exposure to biological contaminants – bacteria, viruses, and parasites. Illnesses resulting from exposure to pathogens contained in sewage fall under the classification of waterborne diseases.

Each year, since 1920, various federal agencies and ultimately, the U.S. Center for Disease Control (CDC) have been collecting data on waterborne disease outbreaks in the United States (CDC, 2002). The CDC reports that each year, thousands of Americans contract waterborne diseases. Of those waterborne disease infections, the vast majority are gastrointestinal. Symptoms include nausea, vomiting, diarrhea, and abdominal cramps. Although healthy people generally recover fully from waterborne gastrointestinal illnesses, infection can prove fatal to vulnerable groups in society such as infants, elderly, and immunocompromised individuals (Gerba et al., 1996).

The following table, excepted from *Review of Potential Modeling Tools and Approaches to Support the BEACH Program*, USEPA 823-R-99-02, 1999, provides a good summary of waterborne disease pathogens, the diseases they cause, and the symptoms experienced by afflicted individuals (EPA, 1999).

Pathogen		**Disease**	**Effects**
Bacteria	*Escherichia coli (enteropathogenic)*	Gastroenteritis	Vomiting, diarrhea, death in susceptible populations
	Legionella pneumophila	Legionellosis	Acute respiratory illness
	Leptospira	Leptospirosis	Jaundice, fever (Weil's disease)
	Salmonella typhi	Typhoid fever	High fever, diarrhea, ulceration of the small intestine
	Salmonella	Salmonellosis	Diarrhea, dehydration
	Shigella	Shigellosis	Bacillary dysentery
	Vibrio cholerae	Cholera	Extremely heavy diarrhea, dehydration
	Yersinia enterolitica	Yersinosis	Diarrhea
Protozoans	*Balantidium coli*	Balantidiasis	Diarrhea, dysentery
	Cryptosporidium	Cryptosporidiosis	Diarrhea
	Entamoeba histolytica	Amedbiasis (amoebic dysentery)	Prolonged diarrhea with bleeding, abscesses of the liver and small intestine
	Giardia lamblia	Giardiasis	Mild to severe diarrhea, nausea, indigestion
	Naegleria fowleri	Amoebic meningoencephalitis	Fatal disease; inflammation of the brain
Viruses	Adenovirus (31 types)	Respiratory disease	
	Enterovirus (67 types, e.g., polio, echo, and Coxsackie viruses)	Gastroenteritis	Heart anomalies, meningitis
	Hepatitis A	Infectious hepatitis	Jaundice, fever
	Norwalk agent	Gastroenteritis	Vomiting, diarrhea
	Reovirus	Gastroenteritis	Vomiting, diarrhea
	Rotavirus	Gastroenteritis	Vomiting, diarrhea

Exposure pathways – Individuals can be exposed to waterborne pathogens in a variety of ways. Pathogens can be ingested directly in contaminated drinking water or indirectly while swimming or diving in contaminated recreational waters. Individuals can also become infected by ingesting fish or shellfish caught in contaminated waters. Once the infecting agent enters a host, it reproduces and remains within the host until it is expelled or destroyed by the host's immune system. The resulting illness can last from days to weeks.

Sewage Overflows and Human Health Impacts

It is evident that sanitary sewage contains pathogenic organisms that, if ingested by people, will cause illness. It is further evident that waterborne disease outbreaks routinely occur in the United States. The question that remains: is there a direct link between waterborne disease outbreaks and sewage overflows?

To accurately answer that question requires controlled field studies set up to assess water quality conditions before, during, and after a sewer overflow event. The source of pathogens responsible for waterborne disease outbreaks must be identified by tracing its path back to its origin to determine whether its source was a sewer overflow.

Sanitary sewer overflows – sanitary sewer overflows are unplanned events that can occur at any time and location in a collection system. Because of the unpredictable and random nature of SSOs, it is nearly impossible to conduct a controlled study to definitively identify a SSO as the source of a waterborne disease outbreak (CERI, 1999).

In an extensive literature review and study conducted by EPA for a 2004 report to Congress, limited quantitative evidence was found of human health impacts attributed to specific SSO events. Factors that make it difficult to establish a cause and effect relationship between waterborne disease outbreaks and SSO events include the use of non-pathogenic indicator organisms in water quality monitoring, incomplete tracking of waterborne illness, and the presence of pollutants from other sources (EPA, 2004).

Waterborne disease outbreaks generally take several days to identify. An epidemiological investigation isn't initiated until enough afflicted individuals seek medical care for medical care providers to recognize a pattern that prompts testing and identifies a common pathogen responsible for the observed illnesses. After a common pathogen is identified, common behavioral patterns must be identified among the afflicted individuals to help identify the source(s) of the infecting pathogen. Once an infection source has been identified (e.g. drinking water, shellfish, swimming location), the path the pathogen took from the infection source to the infected individuals must be traced. By the time the epidemiological investigation has reached this point, several days or weeks have passed. Unless the pathogen source is continuous (e.g. agricultural runoff or an unidentified, long running sewage leak), it is unlikely that it can be definitively identified as the cause of the waterborne disease outbreak (EPA, 1999). Such is the case with SSOs because they are generally quickly identified and repaired and the spill contained and mitigated. At best, SSOs can often be implicated in a waterborne disease outbreak but not definitively identified as the cause. Following are summaries of published investigations of SSOs and waterborne disease outbreaks.

In late December 1989 and early January 1990, 243 cases of diarrhea and four deaths occurred in Cabool, a small city in rural Missouri. A CDC investigation concluded that the cause of the illnesses was infection with E coli O157:H7, an antibiotic-resistant bacterial strain that had been identified in previous outbreaks spread by contaminated ground beef, raw milk, or person to person contact (Swerdlow et al., 1992). In the Cabool outbreak, the public water systems was identified as contamination pathway and SSOs were linked to the water system contamination.

The Cabool sanitary sewer system routinely experienced capacity related SSOs, which resulted in spills over water lines and into meter boxes. During the period of the outbreak, water distribution system construction work was occurring and it was concluded that the system was contaminated by contact with previously contaminated adjacent soils during construction activities (Geldreich et al., 1992).

In Ocoee, Florida, Hepatitis-A outbreaks in 1988-1989 were tied to capacity-related SSOs that flooded streets and exposed residents to untreated sewage. Residents of a trailer park that was routinely flooded when storm conditions caused power outages at a nearby lift station were exposed when they waded through sewage flooded streets to replace manhole covers after each storm. The initial infections were subsequently spread to the larger population by some of the infected residents who worked as food handlers (Vonstille, et al., 1993).

In July 1998, a lightning strike in Brushy Creek, Texas, incapacitated a wastewater lift station causing 167,000 gallons of raw sewage to spill into Brushy Creek. Within 11 days, 1,440 cases of Cryptosporidiosis were reported (TDH, 1998). The source of the infections was traced back to sewage contamination from the SSO of four of the five drinking water supply wells for the Brushy Creek community. Although the wells were 100 feet deep and encased in concrete, the aquifer was under the influence of surface water and the SSO contamination reached the aquifer.

Although other waterborne disease outbreaks have probably been caused by SSOs, positively linking cause and effect is very difficult. Because of the EPA investigators' belief that SSOs and CSOs are the cause of some waterborne disease outbreaks, a statistical approach was taken in the 2004 EPA report to Congress to estimate the number of CSO and SSO-caused waterborne disease outbreaks originating from recreational water activities. Available data for CSOs and SSOs affecting recognized beaches, average fecal coliform bacteria counts at affected beaches, number of exposed individuals, and rates of infection were compiled to generate a probable range of sewage overflow-caused illnesses. The projected annual range for SSO-caused illnesses at recognized beaches in the U.S. was 2,269 to 3,669 illnesses per year (EPA, 2004).

Combined sewer overflows – although combined sewer overflows are not desired, they are expected events. When wet weather-induced hydraulic loads exceed the capacity of a wastewater treatment plant, excess flow in the CSS is diverted around the treatment plant and directly discharged to receiving waters through a CSO outfall.

In researching possible links between CSOs and waterborne disease outbreaks for its 2004 report to Congress, EPA geo-referenced the locations of more than 90% of CSO outfalls in the U.S. and compared them to the locations for drinking water intakes. EPA investigated the 59 drinking water intakes in seven states that were identified as being within one mile downstream of a CSO outfall. In all cases, EPA investigators found that the drinking water agencies were aware of the upstream CSO outfall and that communication procedures between the water and wastewater agencies were in place (EPA, 2004). Based on these findings and on an absence of direct cause and effect data relating CSO discharges to specific human health impacts, EPA investigators concluded that, within the scope of their investigation, the "…assessment indicates that CSOs do not pose a major risk of contamination to most public drinking water supplies."

Combined sewer overflows regularly release untreated sanitary sewage into lakes, rivers, streams, bays, estuaries, and coastal waters of the United States. Those waters are used as drinking water sources, recreational waters, and habitat for fish and shellfish used for human consumption. EPA found varying levels of contamination with constituents found in sewage in many rivers, bays, estuaries, and coastal waters, but found an absence of data relating CSO discharges to waterborne disease outbreaks. CSOs are subject, however, to implication as sources of some outbreaks because of the commonality of contaminants found in sanitary sewage and impacting the environment (EPA, 2004).

Shellfish living in waters contaminated by sewage spills and other sources concentrate the contaminants from the water in their bodies due to bioaccumulation (EPA, 2004). Consumption of contaminated shellfish was the confirmed cause of eight waterborne disease outbreaks in the U.S. from 1985-2000. The outbreaks resulted in 985 cases of illness. In all cited cases, the implicated contamination sources were land or marine based sewage disposal into waters used as fisheries. No direct cause and effect data were obtained to definitively identify the contamination source responsible for the disease outbreaks (CDC, 1982; CDC, 1990; CDC, 1993; CDC, 1995; CDC, 1996; CDC, 1997).

In response to the absence of data providing direct cause and effect correlation between waterborne disease outbreaks and CSOs, EPA investigators implemented an alternate approach to estimate the annual number of illnesses caused by recreational exposure to CSO discharges.   Available data for CSOs and SSOs affecting recognized beaches, average fecal coliform bacteria counts at affected beaches, number of exposed individuals, and rates of infection were compiled to statistically generate a probable range of sewage overflow-caused illnesses. The projected annual range for CSO-caused illnesses at recognized beaches in the U.S. was 845 to 1,367 illnesses per year (EPA, 2004).

Sewage Overflows and Environmental Impacts

EPA defines environmental impacts as circumstances that prevent designated uses from being attained. CSOs and SSOs can potentially have environmental impacts on five designated uses (EPA, 2004):

- Impede the ability of a habitat area to provide aquatic life support for desirable aquatic organisms
- Prevent a source water from serving as a safe drinking water supply with conventional treatment
- Interfere with a habitat's ability to support fish that are free from contamination
- Interfere with a habitat's ability to support shellfish that are free from contamination
- Prevent recreational use of water without risk of adverse health effects

Pollutants of concern in CSOs and SSOs that can have environmental impacts are oxygen-demanding substances, sediment, pathogens, toxics, nutrients, and floatables.

Sanitary sewer overflows – The unpredictable and random nature of SSOs makes them very difficult to monitor and study (Meyland, 1998). EPA collected a substantial amount of data on SSO events and was able to draw several conclusions about the nature, frequency, volume, and cause of SSO events. One important finding was that 72% of the 33,123 SSO events EPA evaluated reach a surface water (EPA, 2004).

The data EPA investigators evaluated were from reported SSO events that occurred between January 1, 2001 and December 31, 2003. The 33,123 SSO events were reported by 2,663 communities. The data were extrapolated into a national estimate and the analysis suggested that between 23,000 and 75,000 SSO events occur in the U.S. each year.

Of the 33,213 reported SSO events evaluated, 28,708 included estimated SSO volumes. The total reported estimated volume for the SSO events was 2.7 billion gallons over the three year study period. Extrapolated to a national estimate, three to 10 billion gallons per year are discharged to the environment by SSOs.

In 2000, EPA published the 2000 National Water Quality Inventory Report. A significant fraction of the nation's waters were assessed for the report and designated as either good or impaired. For waters that were assessed as impaired, pollutants and stressors were identified that contributed to the impaired status (EPA, 2002). Although the report did not cite CSOs and SSOs as a leading source of water body impairment, annual discharges even at the low end of the national estimate of SSO volume would lead to a conclusion that SSOs have an environmental impact. Following are selected summaries of published accounts of environmental impacts attributed to SSOs.

The North Carolina Department of Environment and Natural Resources (NCDENR) investigated and documented fish kills in North Carolina from 1997 to 2002 (NCDENR, 2003). Fish kills were attributed to SSOs, chemical spills, heavy rainfall, eutrophication, low dissolved oxygen due to unspecified causes, natural phenomenon (temperature and salinity effects), and unknown causes (EPA, 2004). Of the over four million documented fish killed in North Carolina during the six year study period, less than 10,000 were attributed to SSOs.

In September 2000, an SSO occurred from a force main on the Camp Pendleton Marine Base in Oceanside, California. Over an eight day period an estimated 2.73 million gallons of sewage was spilled (EPA, 2004). Dissolved oxygen levels in the affected marine area dropped below 1 mg/L. Over 500 fish and shellfish deaths were attributed to the SSO.

In March 2003 a 102-inch diameter sanitary sewer line in Middlesex County, New Jersey ruptured, spilling sewage into residential areas and into the Raritan River. The 570 million gallons of sewage that spilled over a nine day period forced the closure of over 30,000 acres of commercial and recreational shellfish beds for six weeks

The California State Water Resources Control Board published a report of beach closures that occurred in California during 2000 as a result of bacterial standard exceedences CASWRCB, 2001). Beach closures are quantified as Beach-Mile-Days (miles of beach closed multiplied by the number of days of closure). Of the 1,091 Beach-Mile-Days of beach closures that occurred in California during 2000, SSOs were the attributed cause for 42% of the closures.

Combined sewer overflows – Combined sewer systems are primarily located in areas of the country developed prior to 1900. Only two communities in California, San Francisco and Sacramento, have combined sewer systems (EPA, 2004). As a result, CSOs, which are a significant source of wet weather-related sanitary sewage contamination of waterways in the eastern U.S., are much less likely to be a pollutant source in most of California. Of the 1,091 Beach-Mile-Days of beach closures that occurred in California during 2000, CSOs were the attributed cause for only 1% of the closures (CASWRCB, 2001).

Environmental impacts resulting from CSOs occurring in older U.S. cities and communities have been reported by many investigators. The following selected listing of documented impacts provides examples.

- PCBs in fish tissue extracted from fish in the Buffalo River in New York exceeded allowable FDA levels and PCB levels in the river often exceeded state water quality criteria. Investigators identified CSO discharges as a source of PCBs to the Buffalo River (Loganathan et al., 1997).
- Whole effluent toxicity testing was conducted by the City of Toledo, Ohio, on discharges from four CSO outfalls during wet weather events. Discharges from two of the outfalls were observed to contain acute toxicity agents and discharges from the other two outfalls contained chronic toxicity agents. In response, the city implemented wastewater discharge restrictions on industries during CSO events (EPA, 2004).
- Investigators studied a 12-mile long urban stream, tributary to the Ohio River in the Pittsburgh, Pennsylvania area, to assess the potential impact of the 26 CSO outfalls that discharge to the stream (Sykora et al., 1998). Number concentrations of two pathogenic protozoa, Cryptosporidium and Giardia, were measured in the stream during dry weather conditions and at the CSO discharge points during wet weather. The concentrations of Giardia cysts and Cryptosporidium oocysts were higher by more than two orders of magnitude in the CSO outfall than in the stream. The investigators concluded that the CSO discharges were a major factor in the presence of the two pathogenic protozoa in the urban stream.
- Several Connecticut beach communities preemptively close beaches following heavy rainfall, presuming that CSO, SSO, and stormwater discharges will occur and contaminate recreational waters (CTCEQ 2002).

Conclusion

Sanitary sewage contains constituents that can cause waterborne disease outbreaks and that can negatively impact the environment. It is the design intent of sanitary sewer systems and combined sewer systems to collect, contain, and convey sanitary sewage to treatment facilities and to prevent release of untreated sewage to the environment. However, either through unplanned releases due to blockages, equipment failures, or hydraulic overload, or to planned releases from CSO outfalls due to hydraulic overload, untreated sewage is released to the environment.

Because of the difficulty in definitively identifying SSOs and CSOs as the cause of waterborne disease outbreaks and environmental impacts, very few positive correlations have been made. However, a few SSO and CSO events have been positively associated with human health and environmental impacts. In many other cases, evidence suggests an association with CSOs and SSOs.

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