Combined Sewer Overflow (CSO)

History

The contemporary incarnation of the combined sewer began in Europe in the 1840s when the cities of Hamburg and London began permitting discharge of sanitary wastewater into sewers that were originally designed to convey only surface runoff. The impetus was the swelling volume of water used by the increasingly ubiquitous water closet, which proved too much for existing privy vaults and cesspools (Burian 1999).

The mid 19th century in the United States also saw rapid urbanization. Urban area populations across the country more than doubled between 1840 and 1880, from 11 to 28%. Increased congestion and the advent of piped-in water supplies prompted the need to find more efficient, aesthetic and sanitary solutions for treating and disposing of sanitary waste water than backyard privies vaults and cesspool systems. Numerous municipalities had already built public sewer systems that relieved street flooding, but were not yet being used to convey sanitary wastewater. Eventually, though, odors and other unpleasant effects of backyard septic systems served as an impetus to find ways to transport wastes away from populated areas.

In the 1870s, Americans began to study European systems to determine whether to combine or separate the two systems. For urban areas where densities were high, the consensus by the end of the century was to combine them by conveying the waste through existing stormwater drainage sewers to receiving water bodies, where it was thought that there was enough dilution to render it harmless. Thus arose the practice of combining sanitary wastewater with stormwater in one pipe, or “combined sewer” (Moffa 1997).

Combined trunk or main sewers were often designed to convey sizable storms whose return frequency was as rare as once in ten years. Intercepting sewers, or interceptors, built for the purpose of diverting sanitary wastewater from the trunk sewer and ultimately from receiving streams to treatment plants, were commonly designed for two to four times the average dry-weather flow (DWF) rates. Because of these flow differentials, it became necessary to design structures (flow regulators) that would allow relief of flows or discharges into the interceptors when storm flow or wet-weather flow (WWF) exceeded their capacity. These discharges came to be known as “combined-sewer overflows” (“CSOs”) (Moffa 1997).

In the second half of the 19th Century, scientists such as Louis Pasteur and John Snow developed the science of bacteriology, they began to demonstrate the links between waste water discharges, polluted receiving waters and disease outbreaks. With these advances, the notion that dilution rendered waste water harmless became obsolete, and thus began a shift to treating waste water prior to discharge.

As urban watershed technology developed, financial and political constraints as much as health and environmental factors shaped how municipalities approached management and control and whether they separated or combined stormwater and waste water. Existing combined-sewer systems (CSSs) were retained in many cities because they provided a network for the centralized collection of human and industrial waste. Waste water treatment plants (WWTPs), however, were sized and designed to treat sanitary waste water only, not a combination of sanitary waste water and stormwater runoff or combined waste water. During dry weather flow (DWF) periods, the performance of CSSs was generally adequate, but during wet weather flow (WWF), the volume of sanitary waste water and stormwater runoff entering the CSSs often exceeded conveyance capacity, and as they were designed to do, overflowed directly to surface water bodies.

By the turn of the century, sanitary officials came to understand the hazards present in waste water, but it wasn't until the second half of the 20th Century that they began to grasp the serious water pollution threat posed by overflows. This was when scientific advances revealed the significant health and environmental hazards of untreated overflows of raw sanitary waste water and stormwater. Then they were recognized as major sources of pollution to receiving waters. Congress responded by passing the 1965 Federal Water Pollution Control Act (FWPCA), which acknowledged the need to regulate CSO output by authorizing funding for research, development, and demonstration of techniques to control them.

Early Studies

With FWPCA funds, the American Public Works Association (APWA) in 1967 conducted one of the first nationwide surveys to assess the extent of environmental problems resulting from CSOs in the United States. The survey found that CSSs were concentrated in three continuous regions: the Northeast, the Great Lakes region, and the Ohio River basin, and served more than 1,300 municipalities served and an estimated 36 million people -- twice as many as were served by separate sanitary sewers. Most CSOs were in communities with populations over 25,000, and combined, they served a total of 32 million people. Those in communities under 25,000 served about 2 million people.

The APWA survey revealed that:

- Combined sewers represented about three-quarters of all overflow sources
- Over two-thirds of total overflows discharged into flowing streams, about one-third into lakes and tidewaters.
- Most overflows from combined sewers occured on industrial land, followed respectively by residential, recreational and commercial; treatment plant overflows occurred most often on industrial land, followed by vacant land; and pumping station overflows occurred predominantly in residential and industiral areas.
- Industrial waste discharged into the sewer systems represented the equivalent of an additional 69 percent of the total population reported in the survey.

The survey concluded that “active programs to eliminate or minimize the volume and strength of overflow wastes are impeded by the high costs of such projects," and that the jurisdictions surveyed lacked "necessary information required to evaluate the extent and effect of the problem. Its recommendations included further research to: better inform community officials of the importance of the problems, determine the quantity and quality of overflows, the relative extent and detrimental effects of the problems on receiving waters, and to enable communities to take steps to remedy the problems. (APWA 1967).

Early research by the US Environmental Protection Agency (US EPA) estimated that approximately 15,000 overflow points existed in about 1,100 communities serving a total population of 43 million. Since then, as more information has become available, communities made changes to their systems, causing estimates of number of CSS and CSO discharge points to fluctuate.

By 1994, the US EPA had reported that individual CSOs discharged an average of 50 to 80 times per year, resulting in the delivery nationwide of about 1.2 trillion gal of raw sanitary waste water, untreated industrial wastes and stormwater runoff into receiving waters each year (US EPA 1994). Still located predominantly in the Northeast and Great Lakes regions, three-fourths of CSSs are currently in only eight states: ME, NY, PA, WV, IL, IN, MI, and OH (US EPA 2001). In 2001, a US EPA review of NPDES files revealed 859 active CSO permits, which included descriptions of 9,463 permitted CSO outfalls in 32 states nationwide.

Consequences

The consequences of CSOs were specifically recognized in the National CSO Control Policy (US EPA 1994), which stated:

> *CSOs consist of mixtures of domestic sewage, industrial and commercial wastewater, and storm runoff. CSOs often contain high levels of suspended solids, pathogenic microorganisms, toxic pollutants, floatables, nutrients, oxygen-demanding compounds, oil and grease, and other pollutants. CSOs can cause exceedances of water quality standards. Such exceedances may pose risk to human health, threaten aquatic life and its habitat, and impair the use and enjoyment of the Nation's waterways.*

In many regions, precipitation events of as little as 0.10 in. can cause substantial stormwater (SW) drainage into CSSs, and multiple CSO events occur each year (Lijklema and Tyson 1993). Localized impairments to water quality have been well documented by some communities.

The relatively low flow characteristics of combined sewers during DWF periods, when municipal wastewater and infiltrated groundwater alone are carried, encourages settling and buildup of solids in the sewer lines until a surge of flow caused by a rainstorm purges the system. Studies in Buffalo, NY have shown that 20 to 30% of the annual collection of domestic wastewater solids settle and eventually are discharged during storms (Field and Struzeski 1972). As a result, a large residual sanitary pollution load over and above that which is normally carried is discharged over a relatively short interval and often results in what is known as a “first flush” phenomenon. This can produce shock loadings detrimental to receiving water life.

Aside from the raw domestic and industrial wastes carried in the overflow, non-sanitary urban runoff alone is a significant contributor to the overflow pollution load. As the storm runoff drains from urban land surface areas, it picks up accumulated debris; animal droppings; eroded soil; tire and vehicular exhaust residue; air pollution fallout; deicing compounds, pesticides, PCBs, fertilizers, and other chemical additives; decayed vegetation; heavy metals; and many other pollutants. A study of a 1,067-acre drainage basin in Durham, NC showed that the annual biochemical oxygen demand (BOD) contribution attributable to surface wash from storms was approximately equal to the contribution of the secondary treated sanitary effluent, and the chemical oxygen demand (COD) was estimated to exceed the amount expected in the raw sanitary wastewater from a residential area of the same size (Field and Struzeski 1972). Other studies have found that 40 to 80% of the total annual organic loading entering receiving waters from a city is caused by WWF, and that during a single storm event, WWF accounts for about 95% of the organic load as well as high loads of heavy metals and petroleum hydrocarbons (Field and Turkeltaub 1981).

Many CSOs discharge to receiving waters in heavily populated urban areas. Their impacts include (but aren’t limited to) adverse human health effects, beach closures, fish survival effects, shellfish bed closures, aquatic life toxicity, and aesthetic impairment. Waterborne transmission is a common and fast way of spreading infectious agents to a large part of the population. Disease outcomes associated with waterborne infections often include hepatitis, gastroenteritis, as well as skin, wound, respiratory, and ear infections. Although in general waterborne diseases are considered to be a result of ingestion of contaminated water, they may also be contracted through inhalation of water vapors and eating contaminated fish and shellfish.

Urban WWFs add significant amounts of toxic materials to sediments in receiving water bodies. In recent years, contaminated sediments have emerged as a major ecological and human health issue throughout the US. Their direct acute and chronic toxic effects and contaminated sediments are a continuing source of persistent bioaccumulative toxic chemicals. Short-term effects on aquatic life can result from a change in constituent concentration in the water column. Long-term effects can result from accumulation of settled solids and nutrients in the receiving water bottom, or benthic, layer and the groundwater.

In addition to human health and habitat impacts, CSOs can seriously impair the aesthetic quality of receiving waters. Although aesthetic upsets are not directly related to human health risks, they have important socio-economic impacts on the affected area and provide a very important performance criteria for control technologies. The pollutants of concern and the principal consequences of CSO are summarized in Table 1 (US EPA 2001).

Table 1. Pollutants of Concern/Consequences of CSOs (US EPA 2001)

Pollutants	Principal Consequences
Bacteria (e.g., FC, E. coli, enterococci) Viruses Protozoa (e.g., *Giardia, Cryptosporidium*)	Beach closures Odors Shellfish bed closures Drinking water contamination Adverse public health effects
Trash and floatables	Aesthetic impairment Devaluation of property Odors Beach closures
Organic compounds Metals Oil and grease Toxic pollutants	Aquatic life impairment Adverse public health effects Fishing and shellfishing restrictions
Biochemical oxygen demand (BOD)	Reduced oxygen (O2) levels and fish kills
Solids deposits (sediments)	Aquatic habitat impairment Shellfish bed closures
Nutrients (e.g., nitrogen (N), phosphorus(P))	Eutrophication, algal blooms Aesthetic impairment
Flow shear stress	Stream erosion

Several assessments of water-body use impairment attributed to CSOs were published in the late 1980s and 1990s. For example:

- The National Resources Defense Council (NRDC) (1992) in its "Testing the Waters" reported:

  High levels of bacteria, primarily from sewage spills and overflows (CSOs, sanitary *sewer overflows (SSOs), and breaks in sewer lines or septic systems) are responsible for more than 2,433 beach closings and advisories per annum .*

- The National Oceanic and Atmospheric Administration (NOAA) (1992) reported that CSOs are a major cause of contaminated shellfish beds and fish kills. NOAA estimated that between 10 and 20% of harvest-limited shellfish acreage, amounting to nearly 600,000 acres, was attributable to CSO.

- The Center for Marine Conservation (CMC) summarized CSO public health risks as follows

  The primary health issue associated with CSOs is the risk of exposure to disease causing bacteria and viruses. Combined-sewers contain human waste that can carry pathogenic organisms. Activities involving water-exposure to these contaminants through swimming or other contact can lead to infectious disease. Some of the common diseases include hepatitis, gastric disorders, dysentery, and swimmer's ear. Other forms of bacteria found in untreated waters can cause typhoid, cholera, and dysentery. Human health is also impacted when fish or shellfish that have been contaminated by combined-sewer discharges are consumed (CMC 1992).

- Referencing the US EPA's harbor study program and its own Beach Cleanup Results (CMC 1991), CMC also provided documentation on floatables and aesthetic impairment due to CSOs:

  Although only one percent of debris found by the U.S. EPA's Harbor Studies Program and 4.9 percent of the items found in the National Beach Cleanup Results constituted medical, drug and sewage-related debris, these wastes were more common in eastern cities that have [combined-sewer systems]. New Jersey and Massachusetts had five times the national average of sewage-associated wastes, comprising 2.8 and 2.6 percent respectively of total trash found. New York and Rhode Island had a significantly higher percent as well (1.6 and 1.1 percent respectively). The Harbor Study found CSO related wastes such as condoms, tampon applicators, fecal matter, grease and food in New York City waters. In Philadelphia, the plume from two CSO discharges was seen to contain condoms, tampons, and fecal matter (CMC 1992).

- The State of NJ reported in 2001that prior to CSO floatables control, CSOs caused or contributed to hundreds of days of ocean beach closings each year. The control of floatables in CSOs and SW discharges has reduced the average annual days of ocean beach closings by more than 95% (US EPA 2001).

Under the CWA, Section 305(b), the US EPA prepares biennial national water quality assessment reports to Congress. The US EPA's 1998 National Water Quality Inventory identified the local impacts of CSOs as often being intense and highly visible and a major source of water quality impairment. Findings of the study are summarized in Table 2 (US EPA 1998).

Table 2. Water Body Ranking by CSO Impairment (US EPA 1998)

Water Body Type	Rank of CSO as Source of Impairment (Out of 20)	1994 Impairment
Estuary	12	CSOs accounted for 5% of impairment (527 mi2)
Ocean Shoreline	8	CSOs accounted for 11% of impairment (43 shoreline mi)
Great Lakes Shoreline	10	CSOs accounted for 3% of impairment (172 shoreline mi)
Rivers and Streams	Not ranked in top 20	Not a leading source of impairment

References

APWA (1967). Problems of Combined-sewer Overflows. U.S. Department of Interior, Federal Water Pollution Control Administration, Water Pollution Control Series, WP-20-11, December 1, 1967.

Burian, Steven J., Stephen J. Nix, S. rocky Durrans, Robert Pitt, Chi-Yuan Fan and Richard Field. Historical Development of Wet-Weather Flow Management. Journal of Water Resources Planning and Management 125 (1): 3-13 (1999)

Center for Marine Conservation (1992). Sewage Treatment: America's Pipe Dream - A Report on Combined-sewer Overflows. Center for Marine Conservation, Washington, DC.

Field, R. and E. J. Struzeski (1972). "Management and Control of Combined-sewer Overflows." Journal Water Pollution Control Federation, 44 (7), 1393-1415.

Field, R. and R. Turkeltaub (1981). "Urban Runoff Receiving Water Impacts: Program Overview." Journal of the Environmental Engineering Division, EE1, February, 83-100.

Lijklema, L. and J. M. Tyson (1993). "Urban Water Quality: Interactions between Sewers,Treatment Plants, and Receiving Waters." Water Science and Technology, 27(5), 29-33.

Moffa, P. E. (1997). Control and Treatment of Combined-sewer Overflows. Van Nostrand Reinhold, New York, NY.

NOAA (1992). The 1990 National Shellfish Register of Classified Estuarine Water, U.S. Department of Commerce, Rockville, MD.

NRDC (1992). Testing the Waters: A Study of Beach Closures in Ten Coastal States, New York,NY.

U.S. Environmental Protection Agency (1994). Combined-sewer Overflow (CSO) Control Policy, Federal Register, 59 (75) 18688.

U.S. Environmental Protection Agency (1995). National Water Quality Inventory: 1994 Report to Congress, EPA 841-R-95-005. U. S. Environmental Protection Agency, Office of Water, Washington, DC.

U.S. Environmental Protection Agency (1998). Clean Water Action Plan: Restoring and Protecting America's Waters. U.S. Environmental Protection Agency, Washington, DC.

U.S. Environmental Protection Agency (2001). Report to Congress: Implementation and Enforcement of the CSO Control Policy. EPA 833-R-01-003, U.S. Environmental Protection Agency, Washington, DC.

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