



# Combined Sewer Overflow Technology Fact Sheet Retention Basins

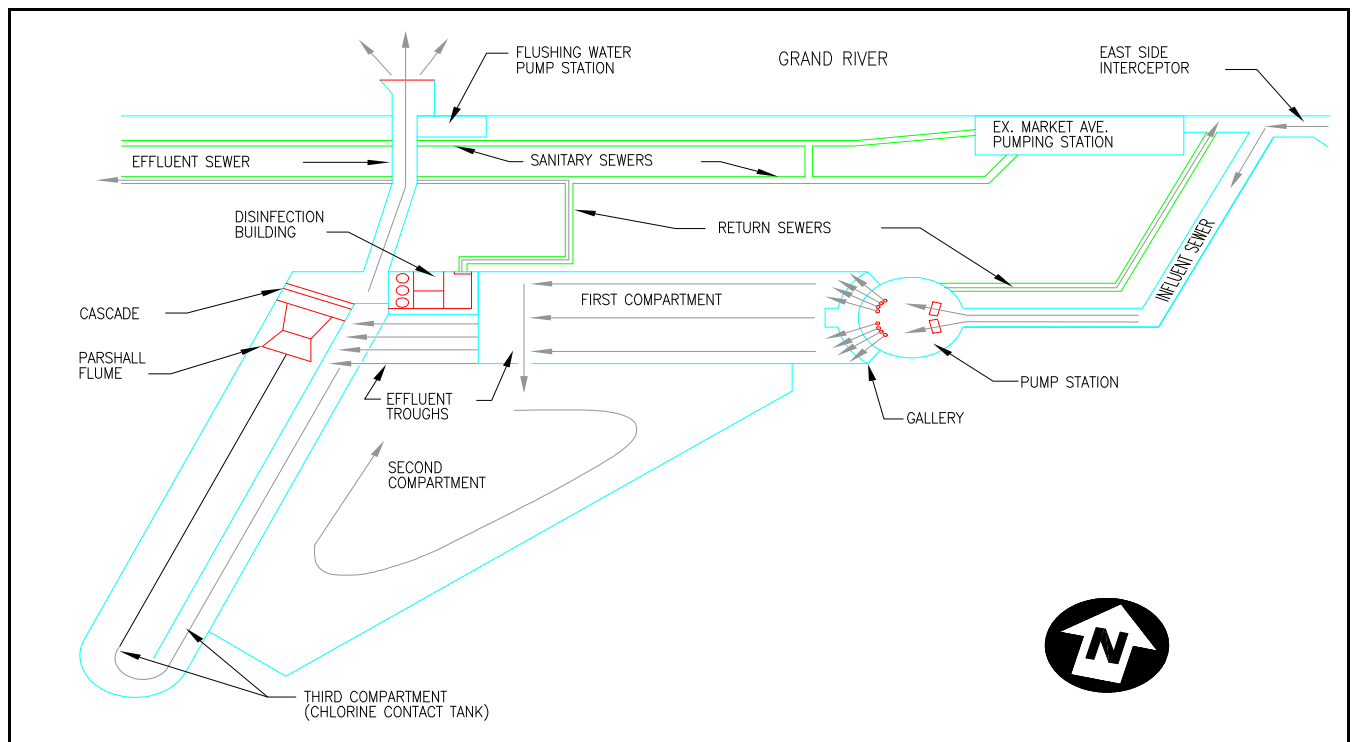
## DESCRIPTION

In older communities, where combined sewer systems are still common, storm water flows often exceed the sewer system's hydraulic capacity. Redevelopment of urban areas can also increase the impervious area in the sewershed, which, in turn, increases storm water flows to combined sewers.

Storage is often the best measure for attenuating peak combined sewer flows. Storage facilities have been used extensively for Combined Sewer Overflow (CSO) mitigation (Urbonas and Stahre, 1993; Field, 1997). Specific CSO retention methods include underground storage (e.g., tunnels), in-receiving water storage, and retention

basins (RBs). RBs may be built in-line or off-line. This fact sheet describes near-surface, off-line RBs.

CSO RBs capture and store some of the excess combined sewer flow that would otherwise be bypassed to receiving waters. Stored flows are subsequently returned to the sewer system during dry weather periods, when in-line flows are reduced and capacity is available at the treatment facility. RBs can be designed to control both flow rate and water quality. Figure 1 shows an example of a multi-stage CSO RB with treatment capabilities. This facility handles peak flows by routing them through a mechanical bar screen and then pumping them into the first compartment. The main function of the first compartment is to allow for



Source: City of Grand Rapids, Michigan, 1992.

**FIGURE 1 CITY OF GRAND RAPIDS-MARKET AVENUE CSO RETENTION BASIN**

primary settling and grit removal. If the flows continue to rise, the first compartment fills and then spills over into the second compartment. This compartment is designed specifically to store most of the overflow from the first compartment. Compartment two is also equipped with a floor wash system that flushes all settled sediments into a collection trough. If the flows continue to rise, the water spills over into a series of troughs where sodium hypochlorite is applied for disinfection. The flow is then routed to a contact tank in compartment three which eventually returns the water to the Grand River.

In addition to minimizing water quality impacts and attenuating peak flows, CSO storage eliminates or reduces sewer backups, improves the efficiency of existing treatment capacity, and improves effluent quality at the treatment facility (WEF/ASCE, 1992).

Near-surface storage in open or covered basins is the most common method of CSO retention. RBs may be placed online or offline from the combined sewer. Online RBs are connected in series to the combined sewer and retain excess flows when the inlet flow surpasses the outlet capacity. Off-line RBs are connected in parallel to the combined sewer and receive flows only during wet weather periods.

Off-line RBs are typically earthen basins or covered or uncovered concrete tanks. Covered basins are widely used because they provide better odor control and better safety conditions.

Off-line storage is more costly than online storage because parallel lines must be constructed and facilities for pumping the stored wastewater back to the sewer are usually required. However, off-line storage is required where head loss in the downstream sewer is a concern and sedimentation or other treatment methods are desired.

Offline RBs may be located at upstream or downstream locations in the combined sewer system. Advantages of upstream control include greater flexibility in selecting sites for facilities and more efficient control of flows to the downstream treatment facility. The primary advantage of downstream storage is that fewer facilities are

required, resulting in lower construction and operation and maintenance costs. It may be possible to minimize costs further if storage capacity is available at the wastewater treatment plant.

Primary concerns in CSO retention are:

- Managing flows to and from the retention basin.
- Preventing the combined sewage from becoming septic (or handling the wastewater after it has become septic).
- Removing accumulated solids and floatables.
- Disinfecting basin overflows to receiving waters.

CSO RBs have been designed to limit these problems. In offline facilities, flows are regulated by limiting the amount of flow that is diverted to the RB (Figure 1). The sidestream flow is regulated by a device located downstream of the diversion or at the basin's outlet. Many types of fixed and movable flow regulators may be used for CSO retention basins.

Average BOD concentrations of combined sewage are usually high enough to promote septic conditions if the wastewater is retained for an extended period of time. Therefore, the stored wastewater must be either aerated at the RB or returned to the sewer system in a timely manner.

Sedimentation treatment is often incorporated into the RB design. RBs may be compartmentalized so that the first flush flow can be retained in one or more tanks long enough to remove suspended solids, BOD, and nutrients, while the remainder of the flow is handled in subsequent compartments. In some cases, the discharged flow can bypass the primary sedimentation process at the wastewater treatment facility.

An RB can remove accumulated solids by inducing scouring or agitating the stored wastewater during discharge to the sewer, by flushing with a potable or

effluent water supply, or by using mechanical scrapers (WEF/ASCE, 1992). Flushing systems release a wave of water to sweep accumulated solids and debris to a disposal channel at the end of the basin.

In cases where CSO flows exceed the capacity of RBs, an overflow structure diverts the excess flows to nearby surface waters. Disinfection of RB overflows may be required to minimize the risk of pathogens being discharged to receiving waters. High-rate disinfection is often required to ensure adequate removal of pathogens from short-term, high volume overflows. The disinfection process must be adaptable to intermittent high flows with variable temperatures, suspended solids concentrations, and microorganism levels (Field, 1997).

## **APPLICABILITY**

Offline storage is a common structural CSO control because it is less costly and more easily adapted to site conditions than other structural approaches (e.g., storm sewer separation). Several municipalities, including Boston, MA, Atlanta, GA, Los Angeles, CA, Wayne County, MI, and Saginaw, MI, have constructed networks of offline retention basins to minimize CSOs. Other municipalities, including Richmond, VA, and Grand Rapids, MI, are using one or a few large RBs for CSO control.

The City of Richmond's RB has a storage capacity of 36 million gallons (MG). It is designed to capture the first flush of combined sewage for a one-month design storm. The basin includes jet aeration and momentum headers, which prevent the retained wastewater from becoming septic and keep solids in suspension. The stored combined sewage is pumped to the wastewater treatment plant within 48 hours after the end of each event.

Environmental assessments are required to evaluate the environmental impact of constructing and operating RBs. The results of these studies can influence the location and the design of facilities, and even the decision of whether or not to construct retention basins (Munger and Toll, 1996).

Experience has shown that public perception is an important factor in the design of CSO retention basins. Recent designs of CSO retention basins have incorporated aesthetic elements, such as parks or recreational areas, on top of covered basins, as well as more elaborate odor control systems (Wayne County, 1997; AMSA, 1994).

Offline retention basins are often used to manage CSOs after existing storage in the sewer system has been optimized. Offline RBs are usually implemented where online facilities are not practical (e.g., where head loss in downstream sewers is a concern) or some level of treatment is required.

Engineering design studies should evaluate subsurface soil conditions, depth of construction, constraints on use and access to the site, and environmental impact. Detailed evaluation should consider the means of disposal of screenings and residual solids, handling and storage of chemicals, capacity and routing of sewer/force main, and the need for a pump station.

## **ADVANTAGES AND DISADVANTAGES**

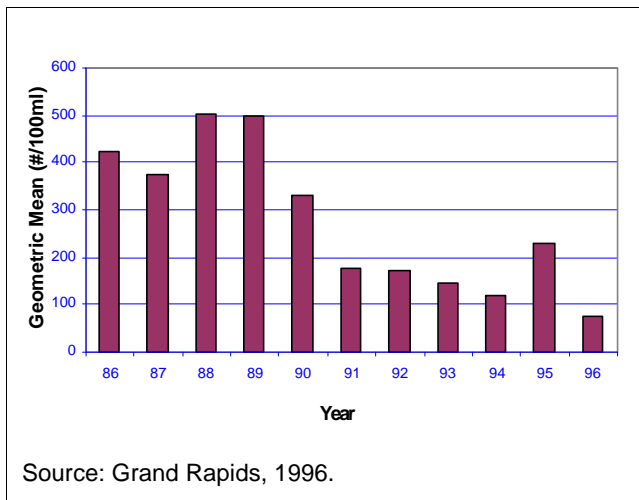
The primary limitations of CSO retention basins are their costs and the environmental impact of construction. Because retention basin construction can be expensive, other source control and sewer optimization measures should be implemented before considering the addition of storage controls.

Construction of large retention basins may require the destruction of sensitive habitats for terrestrial and aquatic life. Environmental assessments are generally required to select sites that will have the least impact on the environment and the public. In some cases, mitigation of unavoidable environmental impacts may be required.

Construction of RBs can have a significant impact on the environment. Environmental assessments are usually performed to identify sites and construction methods that will minimize damage to the environment and disturbance of the public. These assessments will also specify steps that can be taken to mitigate unavoidable environmental impacts.

The elimination or reduction of CSOs can improve receiving water quality. As shown in Figure 2, fecal coliform concentrations in the Grand River below the CSO outfalls and wastewater treatment plant have exhibited a long-term decline. The improved water quality appears to be related to the 30 MG retention basin that came online in 1992. Additional information on the effects of CSO storage on water quality will become available when CSO long-term monitoring programs are fully implemented as part of EPA's CSO Control Strategy (U.S. EPA, 1994). Recommended performance measures for the National CSO Control Program are described by AMSA (1996).

## DESIGN CRITERIA



Source: City of Grand Rapids, Michigan, 1996.

**FIGURE 2 TREND OF FECAL COLIFORMS IN GRAND RAPIDS, MI**

The primary purpose of storage is to optimize treatment of the combined flow at the downstream wastewater treatment plant; therefore, RB design should be developed with consideration of the treatment capabilities of the wastewater treatment plant. The RB design should also ensure that stored wastewater does not become septic and accumulated solids and floatables are effectively removed. In some cases, RB overflows to receiving waters must be disinfected.

As with all CSO control approaches, the evaluation of CSO retention basins should start with a detailed

characterization of the sewer system, including a review of rainfall and sewer flow records, monitoring of selected CSO locations, receiving water quality monitoring, and mathematic modeling (Moffa, 1997). This information is used to establish a design standard such as the frequency of RB overflows to surface waters (e.g., one, three, or five times a year) or the percent reduction in CSO volume. The size of the basin may be based on data on rainfall intensity, duration, and frequency; standard design storms with a specified recurrence interval (e.g., one, five, or ten years); the chronologic record of rainfall; or a chronologic series of measured flows at the site (Urbonas and Stahre, 1993).

## Storage Volume

Several methods for calculating storage volumes have been summarized by Urbonas and Stahre (1993). One of the most common is flow route modeling. These models have become popular for calculating storage volumes because of their ability to simulate runoff under a variety of conditions. Commonly used models include EPA's Storm Water Management Model (SWMM); the U.S. Army Corps of Engineers' Storage, Treatment, Overflow, Runoff Model (STORM); and the Hydrological Simulation Program-FORTRAN (HSPF). Useful summaries of these models are given by Huber and Heaney (1980, 1982). SWMM is most commonly used to simulate urban runoff processes and combined sewer systems (EPA, 1985; James, 1993). In addition to estimating surface runoff, SWMM and other models can estimate pollutant loads in response to precipitation and surface pollutant accumulations.

## Basin Shape

Rectangular basins are the least expensive to construct and maintain. Circular and octagonal basins are more expensive to build, but are advantageous because they can be configured to self-clean settled solids.

## Inlet Type

The choice of inlet type will depend on whether the RB is designed to remove solids. If solids removal

is desired, the inflow velocity must be reduced (e.g., by using baffles) to prevent resuspension of settled solids. Alternatively, the inlet can be configured to create turbulence and circular flow to keep solids in suspension if sedimentation is not desired.

### Bottom Configuration

The bottom configuration of an RB can enhance cleaning of sand, silt, and other settled solids. Three types of bottom configuration are used for rectangular RBs: flat bottoms; parallel longitudinal grooves; and a single continuous groove. Flat bottoms are the easiest to construct, but require a mechanism for solids removal. Urbonas and Stahre (1993) suggest that flat-bottomed basins should have a minimum bottom slope of 3 percent and a width equal to one-half to two-thirds of the length.

A series of parallel, longitudinal grooves may be constructed to convey solids out of the basin; however, experience has shown that supplemental cleaning is occasionally required (Urbonas and Stahre, 1993). Basins with bottoms that have a single continuous groove can also be self-flushing.

### Outlet Type

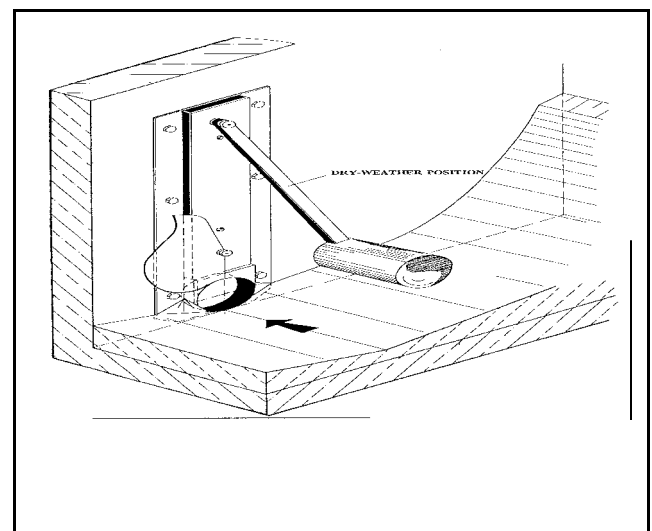
Outlet structures must be closely matched to the specifications of downstream facilities. It is usually desirable to maintain a constant outlet flow rate to minimize the effects on downstream structures. RB outflow can be controlled using a fixed outlet opening, a choked outlet pipe, adjustable gates, pumps, and special regulators. Fixed outlet orifices, flow-restricting pipes, and overflow weirs are often chosen to regulate the RB outlet flow because they have predictable hydraulic characteristics and are simple to design (Field, 1997).

Remotely controlled gates offer more direct control of the RB outlet flow. These outlets generally consist of a flow-monitoring system, movable gates that are adjusted by electrical, hydraulic, or pneumatic controls, and a data processing and control unit (Urbonas and Stahre, 1993). Coupled with the use of a model to estimate runoff from rainfall, this system can be adjusted the gate opening well in advance of high-flow events. However, gate

systems consist of many moving parts and require instrumentation, which can be expensive to operate and maintain.

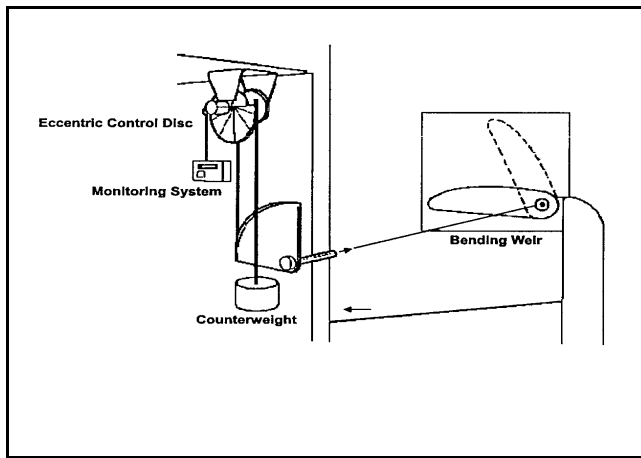
Pumps are used to regulate RB outflow where the topography does not allow gravity flow or more operational control is needed. The primary disadvantages of this system are the costs of operating and maintaining the pumps and the potential for pump failure.

In Europe, several self-regulating outlet systems have been developed for RBs, including float-activated gates, floating outlets, and bending weirs. A float-activated gate developed in Germany, called the Hydroslide™, restricts outlet openings during high flow events so that a constant discharge rate is maintained (Figure 3). A floating outlet is another self-regulating outlet. This outlet floats on the water surface and maintains a constant water depth at the RB outlet. The removal of surface water helps to trap settled solids in the RB. Bending weirs also operate automatically without the use of auxiliary power (Field, 1997). One type of bending weir used for RBs, called the Hydrobend™, is a bending flap controlled by a counterweight and an eccentric control disc. As shown in Figure 4, the disc is designed to balance between the forces of water pressure on the overflow face of the bending weir and the counterweight (GNA, 1996).



Source: GNA, 1996.

**FIGURE 3 HYDROSLIDE™ FLOW REGULATOR**



Source: GNA, 1996.

**FIGURE 4 HYDROBEND™ FLOW REGULATOR**

### Overflow Structures

RBs are usually equipped with emergency spillways or outlets. Spillways are sized to pass the maximum inflow under the worst-case condition of a clogged or non-operational outlet. Spillways should be located away from the RB outlet to minimize the loss of floatables that often collect near outlets (Urbonas and Stahre, 1993).

### Disinfection

In some cases, RB overflows may be disinfected to prevent the discharge of pathogens to surface waters. Chlorine gas ( $\text{Cl}_2$ ) or sodium chloride ( $\text{NaCl}$ ) is commonly used for wastewater disinfection. However, these disinfectants can react with ammonia ( $\text{NH}_3$ ) in the combined sewage to form chloramine compounds, which are toxic to aquatic life. Chlorine dioxide ( $\text{ClO}_2$ ), a more rapidly-acting disinfectant, does not react with  $\text{NH}_3$ . It may be necessary to dechlorinate the RB overflow to eliminate the potential for instream toxicity due to chlorine.

### Operational Control

CSO retention basins are operated to minimize overflow and maximize the capacity of the sewer system and treatment facility. Three levels of operational control may be practiced:

- Local (closed-loop) control of regulators, gates, or pumps.
- Regional coordination of several local controllers.
- Global control of multiple components, including rainfall and flow data recorders, telemetered controllers for regulators, gates, and pumps, and a computer system for overall system control.

The City of Grand Rapids (MI) uses a global CSO monitoring system that consists of sewer level sensors, a bridged telephone network and telemetry system, and a PC-based data acquisition and processing system (Spykerman, 1996).

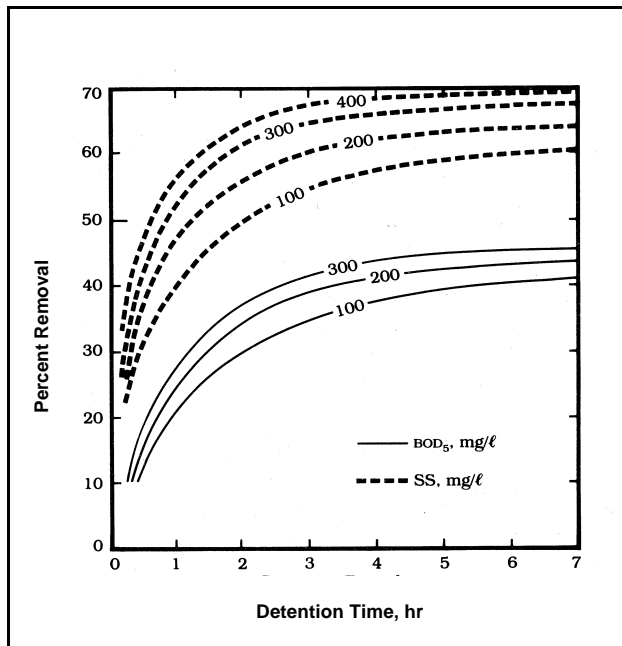
### PERFORMANCE

CSO retention basins can significantly reduce or eliminate CSO volumes. Construction of a 30 MG retention and treatment basin by the City of Grand Rapids (MI) helped to reduce CSO discharge volumes by about 90 percent (Grand Rapids, 1995). Similar results have been achieved at other municipalities.

Concentrations of coliform bacteria, suspended solids, nutrients, and BOD can be reduced in RBs designed to induce sedimentation. Estimated removal rates of  $\text{BOD}_5$  and suspended solids are determined by the detention time and overflow rates (based on average daily flows). Figure 5 shows the average percent removal of  $\text{BOD}_5$  and suspended solids for municipal wastewaters. However, the solids characteristics and settling velocities of CSOs vary by site and it is recommended to develop a settling velocity distribution for each site (Field, 1997). Chemicals can be added to improve solids removal by coagulation (Adams, *et. al*, 1981).

### OPERATION AND MAINTENANCE

Basins, especially those with covered compartments, are subjected to extreme conditions, including high humidity, corrosive gases, and sludge deposits. Operation and maintenance requirements can be reduced through appropriate



Source: Steel, 1960.

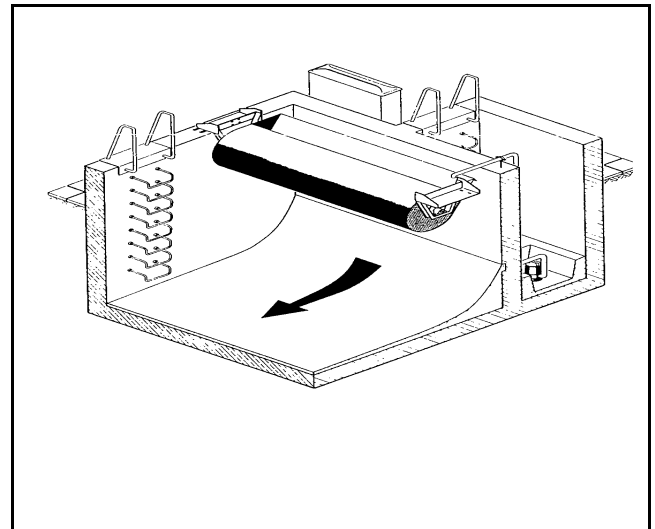
**FIGURE 5 PERCENT BOD<sub>5</sub> AND SUSPENDED SOLIDS REMOVAL FOR VARIOUS OVERFLOW RATES VERSUS DETENTION TIME IN TREATING MUNICIPAL WASTEWATERS**

planning and design (e.g., using corrosion-resistant materials and providing adequate ventilation). However, routine inspection and maintenance remain necessary to ensure proper operation of the basin.

Sediment removal systems include traveling bridge nozzles, fixed nozzles, mechanical mixers, and water flushing systems. Studies have shown that flushing systems are the most efficient and cost-effective (Novac and Grande, 1992; Parente, *et al.*, 1995). Two types of flushers have been widely used: a flip gate flusher such as Hydrosel<sup>TM</sup> or Hydrass<sup>TM</sup>, and tipping flushers (Field, 1997). The Hydrosel<sup>TM</sup> system operates by discharging water through a hydraulically operated flap gate. The gate creates a flushing wave that sweeps settled solids and debris from the basin floor (GNA, 1996). More than 300 Hydrosel<sup>TM</sup> units are used in Europe for cleaning CSO storage tanks (Field, 1997).

As shown in Figure 6, the tipping flusher is a cylindrical vessel that is placed above the maximum water level on the back wall of the retention basin. The vessel fills with water up to a pre-determined

depth, and then the vessel rotates on a center axis, spilling the water into the basin and creating a flushing wave. Tipping flusher units have been used in North America since the early 1990s.



Source: GNA, 1996.

**FIGURE 6 TIPPING FLUSHER UNIT**

Access must be provided for basin cleaning and for removing blockages from the outlet and spillway. Walkways are also recommended for inspection of spillways, outlets, and the interior of covered basins (Urbonas and Stahre, 1993). Monitoring information is essential for operational control and future design considerations; therefore, the water level in the basin should be recorded.

## COSTS

Storage and treatment of CSOs is structurally intensive and costly, and should be used only after CSO sources have been controlled and sewer use has been optimized. Costs of CSO controls for selected communities throughout the U.S are summarized in Table 1. The cost of basin construction can also be estimated from standard cost curves like those provided by Lager, *et al.* (1977).

As shown in Table 1, capital costs for CSO retention basins are significant. Before implementing CSO controls, a cost-benefit analysis should be done to compare the costs of the controls to the anticipated benefits of improved water

**TABLE 1 COSTS OF CSO RETENTION BASINS FOR SELECTED MUNICIPALITIES**

| Municipality              | Retention Basin                  | Year Constructed   | Basin Capacity (MG)   | Covered/ Uncovered    | Type of Facility   | Construction Cost  | O & M Cost    | Design Criteria                              |
|---------------------------|----------------------------------|--------------------|-----------------------|-----------------------|--|--|---------------|--|
| <i>Grand Rapids, MI</i>   | Market Avenue RB                 | June 1992          | 30.5                  |                       | offline  | \$30 million   | \$40,000      | 10 yr-1 hr storm                             |
|                           |                                  | First Compartment  | 10.68                 | covered               |  |  |               |  |
|                           |                                  | Second Compartment | 16.68                 | uncovered             |  |  |               |  |
|                           |                                  | Third Compartment  | 3.14                  | uncovered             |  |  |               |  |
| <i>Richmond, VA</i>       | Shockhoe RB and Diversion System | ~1988              | 41                    | covered and uncovered | hydraulic retention, sediment return to sewerage system, no disinfection | covered: \$1,077,900 <sup>2</sup><br>uncovered: \$343,900 <sup>2</sup> | \$500,096     | 1 month design storm, 7500 cfs first flush   |
| <i>Oakland County, MI</i> | Acacia Park                      | 1997               | 4.5                   | covered               | offline with sedimentation and disinfection capabilities                 | \$13.9 million   | \$207,000     | 30 minute detention for 1 year/ 1 hour storm |
|                           | Birmingham                       | 1997               | 9.6 (includes tunnel) | covered               | offline with sedimentation and disinfection capabilities                 | \$35.6 million   | \$370,000     | 30 minute detention for 1 year/ 1 hour storm |
|                           | Bloomfield Village               | 1997               | 10.2                  | covered               | offline with sedimentation and disinfection capabilities                 | \$28.9 million   | \$500,000     | 30 minute detention for 1 year/ 1 hour storm |
|                           | North Shore                      | 1984               | 24                    | covered (underground) | transport/ storage box <sup>3</sup>                                      | \$69.08 million  | not available | 4 CSOs/ year <sup>4</sup>                    |
|                           | Mariposa                         | 1992               | 0.7                   | covered (underground) | transport/ storage box <sup>3</sup>                                      | \$10.17 million  | not available | 10 CSOs/ year <sup>4</sup>                   |
|                           | Sunnydale                        | 1991               | 6.2                   | covered (underground) | transport/ storage box <sup>3</sup>                                      | \$19.29 million  | not available | 1 CSO/ year <sup>4</sup>                     |
|                           | Yosemite                         | 1989               | 11.5                  | covered (underground) | transport/ storage box <sup>3</sup>                                      | \$19.16 million  | not available | 1 CSO/ year <sup>4</sup>                     |

1 includes operators, time, supplies, chemicals, parts, and utility charges

2 costs adjusted to 1994 costs

3 CSO discharges from transport storage facilities receive flow through treatment with weirs to settle solids and baffles to skim floatables

4 Transport storage facilities were designed in conjunction with pumping and treatment facilities to meet annual average CSO criteria specified in NPDES permits; local sewers tributary to the transport/storage boxes are designed for the 5 year storm



quality. For example, King County, WA is currently performing a CSO assessment to identify the water quality benefits of CSO controls and to determine the most effective method for improving water quality (Munger and Toll, 1997).

Novac and Grande (1992) surveyed the costs of various methods for cleaning CSO storage basins. Tipping flushers had less capital and operation and maintenance costs than traveling bridge nozzles, fixed nozzles, and mechanical mixers. The average capital cost for tipping flushers was \$19.59 per cubic meter of storage (\$14.96 per cubic yard of storage), compared with \$51.66 and \$52.44 per cubic meter of storage (\$39.45 and \$40.04 per cubic yard) for traveling bridge nozzles and fixed nozzles (adjusted to 1998 costs). Parente, et al., (1995) determined that Hydrosel<sup>TM</sup>, a flushing gate system, would be cost-effective compared to tipping flushers and spray methods. Capital and operation and maintenance costs were \$109.38 and \$0.08 per square meter of area (\$91.44 and \$0.07 per square yard) for Hydrosel<sup>TM</sup> versus \$164.08 and \$0.12 per square meter of area (\$137.17 and \$0.10 per square yard) for tipping flushers (adjusted to 1998 costs).

Capital and operating costs for high-intensity chlorination systems are described by Field (1997). A system with short chlorine contact times and intense mixing is more economical and can be as effective as a conventional process with longer chlorine contact times (Field, 1997).

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