Planned Facilities for Combined Sewer Overflows: Boston Metropolitan Area

Facilities to reduce the volume of combined sewer overflows into Boston Harbor include a deep tunnel storage system, a near surface storage facility and new storm sewers.

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Responsibility for correcting the aesthetic and water quality problems caused by the discharge of sewage from combined sewer overflows (CSOs) in the Boston metropolitan area is vested in the Massachusetts Water Resources Authority (MWRA). Created in 1984, the MWRA is a regional water and sewerage authority that provides wholesale water and sewer services to the Boston area. Its responsibilities previously belonged to the Metropolitan District Commission (MDC).

Combined sewers are present in four communities in the Boston metropolitan area: Boston, Cambridge, Chelsea and Somerville. Sewage outfalls that discharge CSOs are present in these communities' systems as well as in the MWRA system of major interceptor sewers. Although the MWRA does not own or operate the individual community sewer systems in its service area, it was asked by the federal Environmental Protection Agency (EPA) to take "responsibility" for controlling all CSOs within its service area. Because the problem of pollution from the CSOs had to be addressed as part of the general effort to revitalize the water quality of Boston Harbor, the MWRA agreed to the EPA's request.

After agreeing to take responsibility for CSOs, the MWRA immediately initiated a facilities planning effort to identify strategies to achieve CSO control. This planning effort was conducted by a team of consulting engineers. The plan was completed in September 1990 and was subsequently approved and adopted.

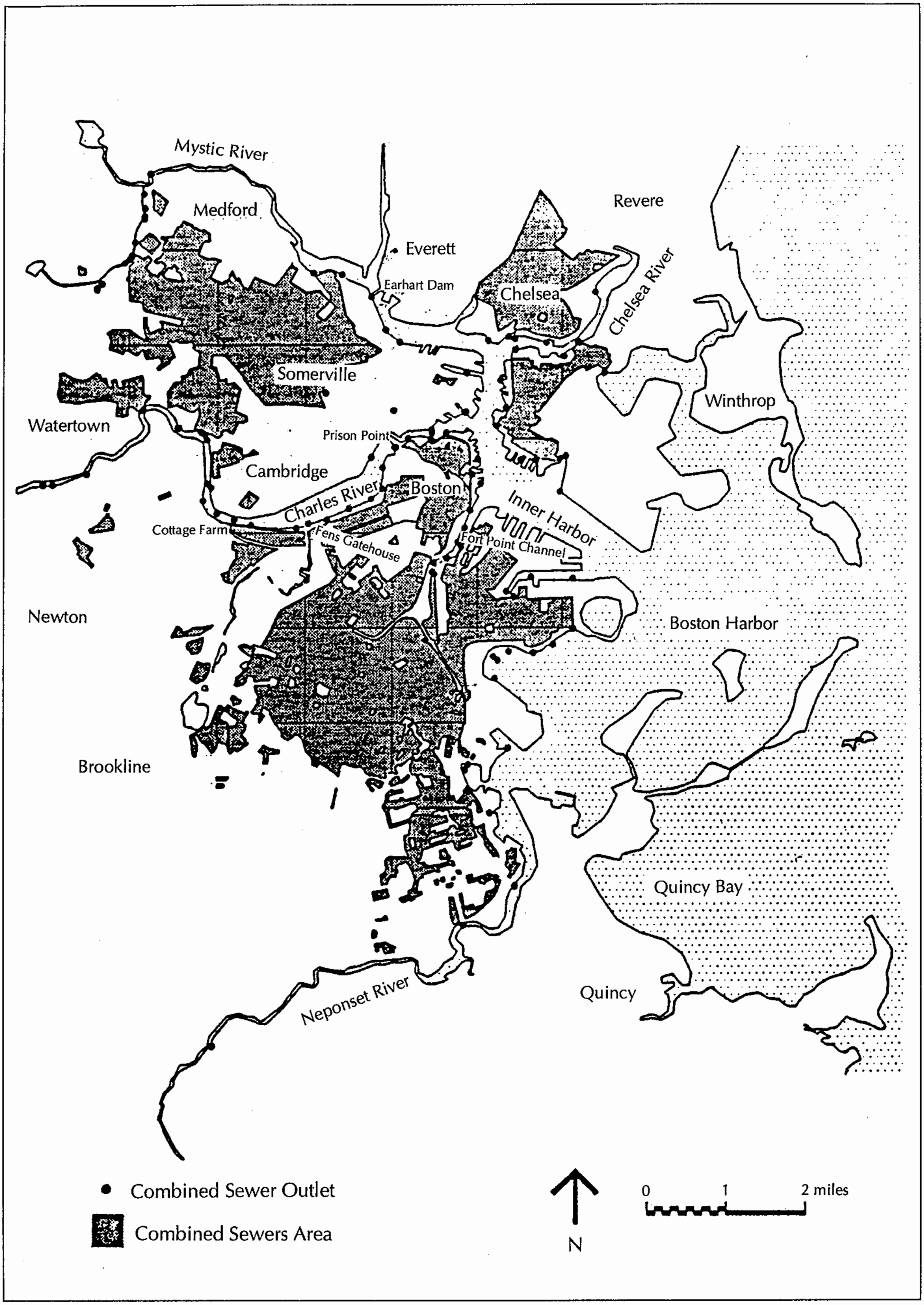

FIGURE 1. Combined sewer area and outlets for the Boston metropolitan area.

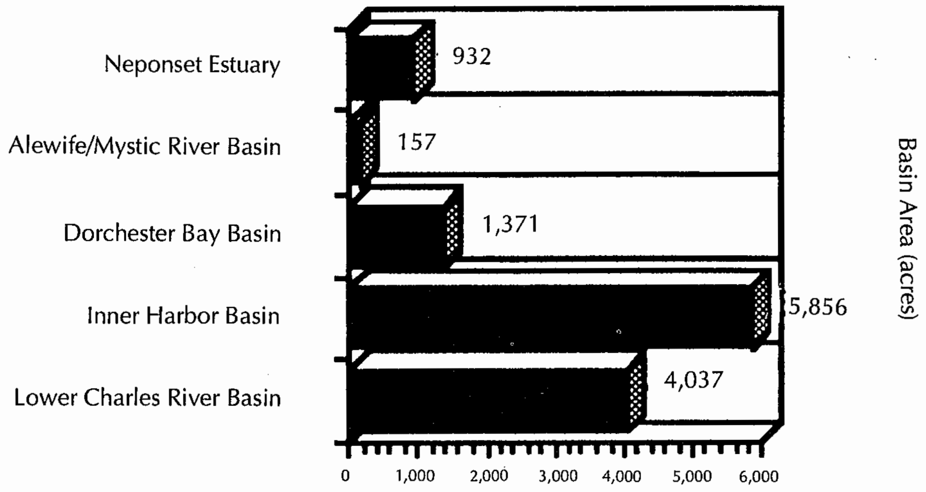

FIGURE 2. CSO area by basin.

Taken together, about 12,355 acres (almost 20 square miles) in the Boston area are served by combined sewers. These areas are almost entirely tributary to five different receiving water bodies or basins. The areas served by combined sewers and the locations of existing combined sewer outfalls are shown in Figure 1. The distribution of the area served by combined sewers according to the receiving basin is depicted in Figure 2.

Prior to about 1989, CSOs comprised an annual volume of 12,203 million gallons (mg). The distribution among the various basins is shown in Figure 3. The total volume discharged from

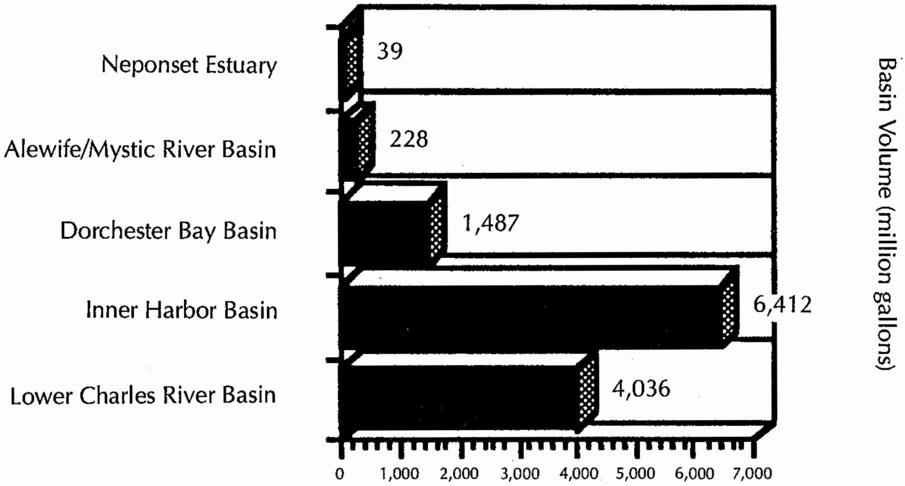

FIGURE 3. Annual CSO volume by basin before 1989.

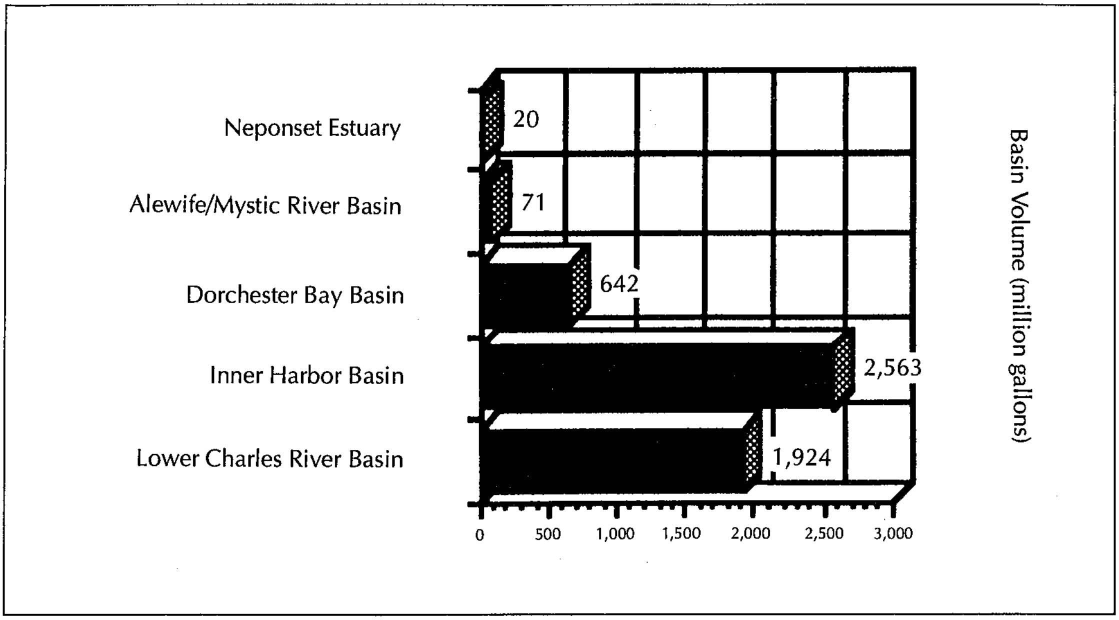

FIGURE 4. Annual CSO volume by basin after headworks improvements.

approximately 85 outfalls. On average, there were discharge events from one or more of these outfalls 70 to 80 times per year, or almost every time it rained. When improvements to system headworks and pumping facilities are completed as part of the Boston Harbor clean-up plan (a phase that is now largely finished), annual CSO volume will decrease more than 50 percent to about 5,220 mg. That new distribution by basin is shown in Figure 4. With an annual sewage volume from the same tributary sewer system of over 100 billion gallons, the approximately 5 billion gallons of CSO represents slightly less than 5 percent of the total volume (see Figure 5). The five largest CSO discharges that will remain after these headworks improvements are:

- Fens Gatehouse — 1,630 mg/yr
- Prison Point — 1,152 mg/yr
- Fort Point Channel — 399 mg/yr
- Cottage Farm — 293 mg/yr
- Earhart Dam — 231 mg/yr

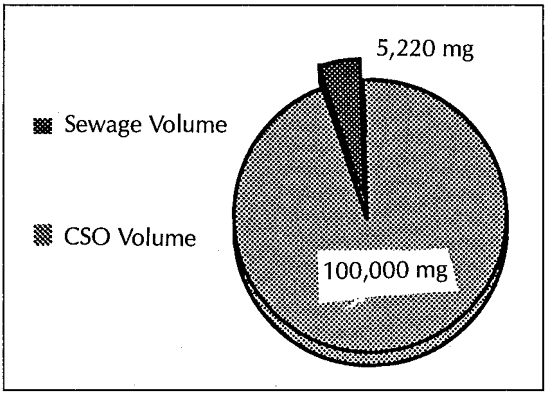

FIGURE 5. Annual sewage *versus* CSO volume after headworks improvements.

These five largest CSOs comprise about 71 percent (3,705 mg/yr) of the total overflows that will remain after the completion of headworks improvements. By contrast, after the CSO control facilities that are currently being contemplated for construction are completed,[1] annual CSOs will be decreased to about 876 mg. This distribution by basin is shown in Figure 6.

Facilities Planning for CSO Control

The CSO facility planning effort followed on the heels of earlier work that had defined the location, type of treatment and capacity of secondary treatment to be provided as part of the Boston Harbor clean-up effort.[2] As a result, the CSO planning proceeded in accordance with certain predetermined conditions.

Since the secondary treatment facility now

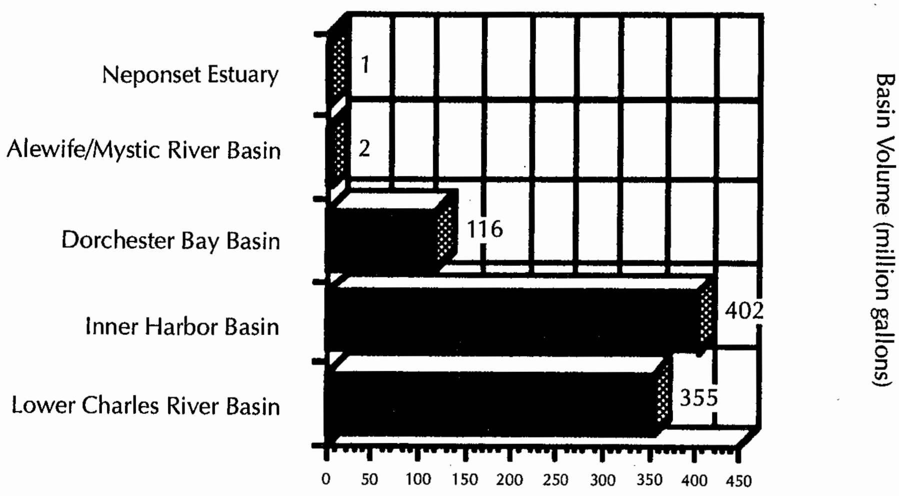

FIGURE 6. Annual CSO volume by basin after CSO facilities plan improvements.

under construction at Deer Island is designed to provide for the total capacity of its influent system, the CSO control stratagems should make full use of the capacity of that system prior to adding other control measures in order to alleviate any CSO that exceeds the intercept capacity.

In addition, the planning was conducted over a period of time during which the Massachusetts Department of Environmental Protection (DEP) was in the process of revising water quality standards and policies governing CSO control. Although standards and policies changed during the course of the planning effort, there was close and continuous coordination between the MWRA, the planning team, the DEP and the EPA. This cooperation ensured that the recommended CSO control plan was able to accommodate this "moving target."

In addition to recommending a series of largely non-structural actions termed "Best Management Practices," the planning team analyzed a large number of structural techniques for CSO control. These methods of controlling CSOs structurally consisted of:

- Sewer Separation: constructing new sanitary sewers and new storm drains.
- Storage: providing in-system, shallow off-line and deep off-line storage systems.
- Separate Treatment: implementing gravity separation treatment with disinfection, or vortex separation with disinfection.
- Stormwater Control: using roof storage, porous pavement, sumps and diversion.
- Miscellaneous Techniques: including flow slippage, bladders, polymer injection and source control via street sweeping and/or flushing.

The facility plan report contains a recommended CSO control plan for the entire combined sewer area. The facility plan recommendations for the basin areas are:

- Upper Charles River Basin — in-system
- Lower Charles River Basin — deep tunnel
- Inner Harbor Basin — deep tunnel
- Dorchester Bay Basin — deep tunnel
- Alewife/Mystic River Basin — off-line storage
- Neponset Estuary Basin — new storm drains

The plan proposes a deep tunnel storage system to serve the largest basins in the combined sewer area, and a near surface storage facility

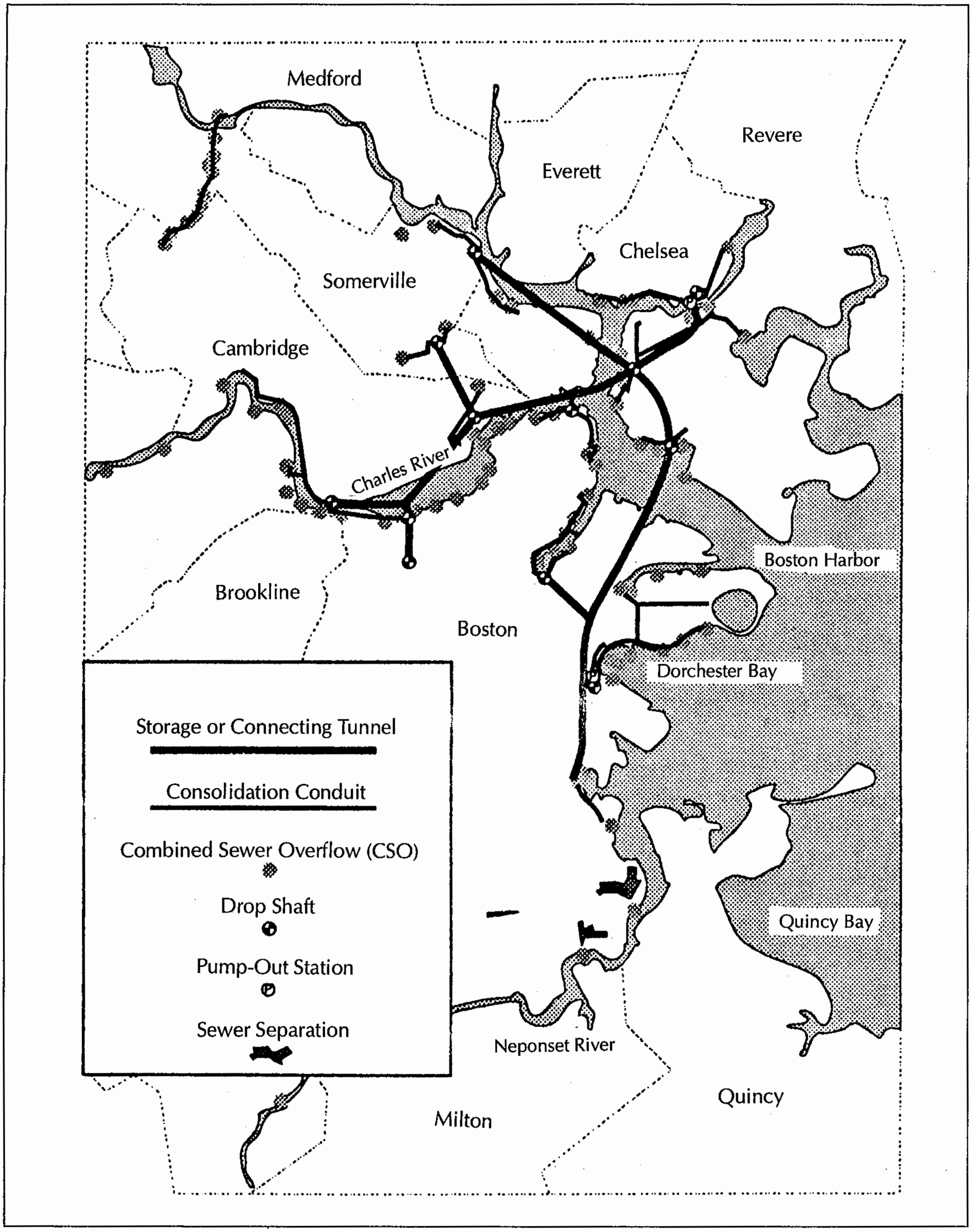

FIGURE 7. The location of the recommended CSO facilities.

for Alewife Brook. In the Neponset River Basin, the volume of storm water reaching combined sewers is relatively small, and a small number of new storm sewers were found to have the capability to reduce the volume of CSO discharge sufficiently to comply with the regulations. The locations for these recommended facilities are shown in Figure 7.

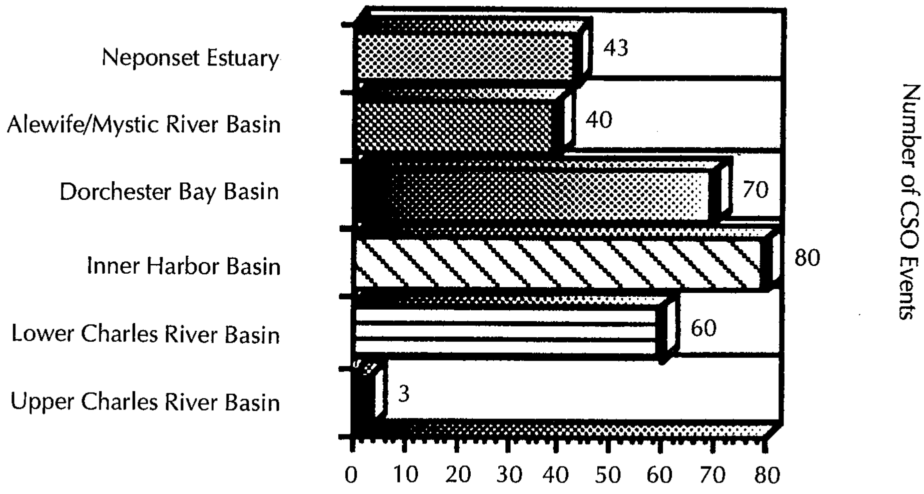

FIGURE 8. Overflow events by basin before 1989.

The level of CSO control that can be anticipated as a result of the recommended CSO control plan is illustrated in Figures 8 to 11. Figure 8 depicts the average number of annual CSO events during the time prior to 1989. Figure 9 illustrates the improvement that could be attained by making the headworks improvements.

In all basins, the annual number of CSO events is projected to be less than four after completion of the recommended CSO control plan. In addition to reducing the annual number of CSO events (after headworks improvements) from as many as 68 to less than four per

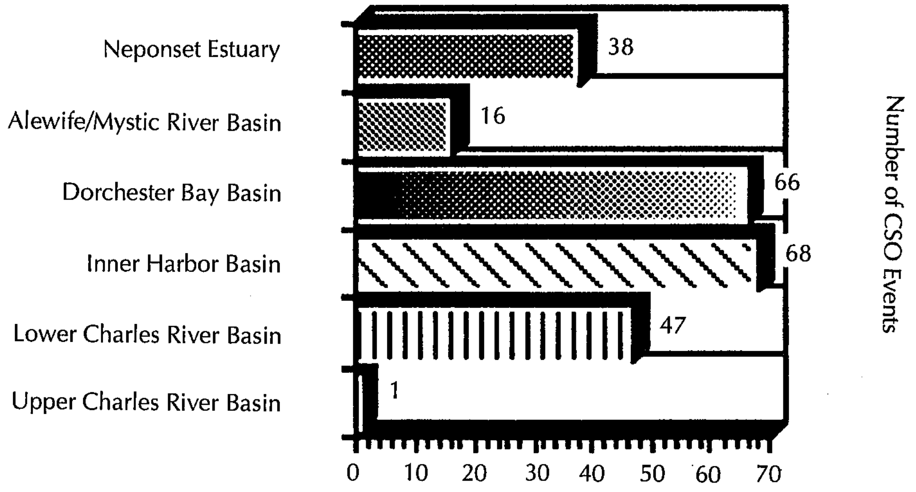

FIGURE 9. Annual overflow events by basin taking into account headworks improvements.

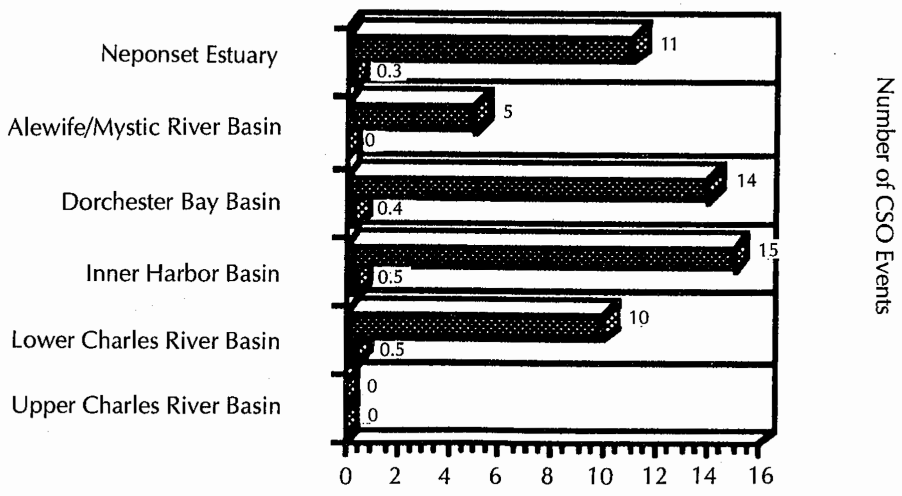

FIGURE 10. Summer overflow events by basin: top bar value for headworks improvements only; bottom bar value for CSO facilities plan construction.

year, the recommended facilities would even more drastically reduce overflow events during the summer recreation season. This reduction can be seen in Figure 10, which compares summer overflow occurrences without the construction of storage facilities (only headworks improvements is shown by the top bar value) and with the CSO facility plan construction recommendations (lower bar value). Figure 11 shows the volume of annual CSO that would remain to be discharged to the various basins after the planned construction is completed.

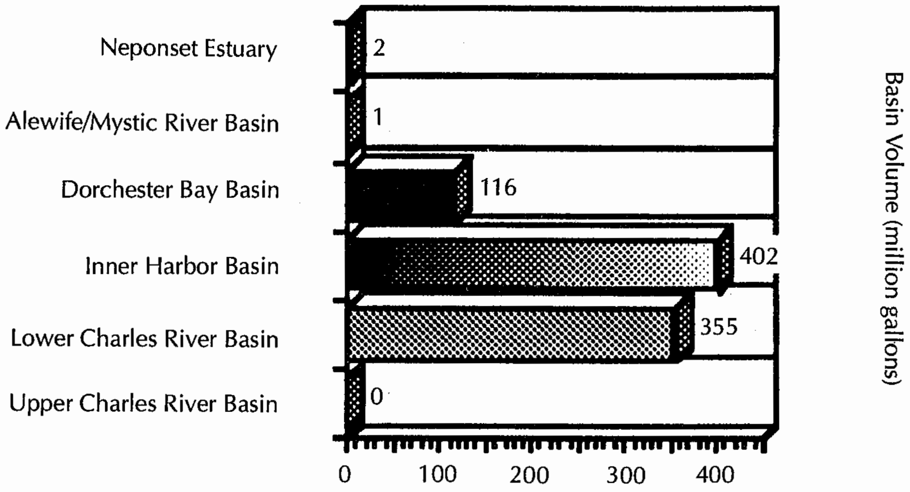

FIGURE 11. Annual CSO overflow volume by basin after planned construction.

Deep Tunnel Storage System

The proposed deep tunnel storage system would serve most of the combined sewer area, linking Boston's Inner Harbor, the Lower Charles River Basin and Dorchester Bay with a shared storage tunnel. During storm events, diversion structures would redirect combined flows into consolidation conduits for transport to drop shafts that would introduce the flow into the tunnel system. After a storm ends, based on available treatment capacity, two pump stations would pump the stored flows to the two existing MWRA headworks facilities that, in turn, would direct it to the Deer Island Wastewater Treatment Facility.

The proposed storage system has a capacity of 315 mg. Surface facilities and drop shafts add 27 mg, making the total available storage in the tunnel system 342 mg. The storage tunnels have a total length of 85,730 feet (16.2 miles), consisting of 69,480 feet (13.2 miles) of main storage tunnel and 16,250 feet (3.1 miles) of connecting tunnels. All tunnels have a finished diameter of 25 feet. This diameter is dictated by the geologic conditions governing the project area, which mandate a maximum economical bore of 27 feet in the type of rock that is expected to be encountered. Tunnel depth is anticipated to range from 390 to 425 feet below mean sea level. This depth is dictated by the elevation of bedrock in the area, a minimum tunnel slope of 0.1 percent (1 foot per thousand feet), and the design criterion that there be a minimum of four tunnel diameters of undisturbed bedrock above the tunnel crown. Excavation is expected to be accomplished largely by tunnel boring machine; however, some drill-and-blast mining is anticipated.

Pump stations are located so that over 93 percent of the entire tunnel volume could be drained by either pump station. Thus, even if one of the two pump-out stations were to be inoperable for a significant period of time, the tunnel could still be dewatered. A wedge of stored volume would remain in the tunnel branch leading to the inoperable pump-out station. The pump-out stations, consisting of three nominal 50 million gallons per day (mgd) pump units, would provide a maximum capacity of 150 mgd.

Flow enters the tunnel system via vertical shafts referred to as drop shafts. Vortexing drop shafts would be utilized in all but two locations. They are preferred because hydraulic studies reveal that they dissipate energy more effectively, entrain less air and cause far less stripping of volatile organic carbon than direct plunge shafts. These features become increasingly important as the depth of drop shaft increases. The terminal velocity of water falling 400 feet directly downward would be greater than 160 feet per second, possessing substantial kinetic energy. When this energy is released on sudden deceleration, the water could severely erode the splash zone and release significant quantities of volatile compounds. In contrast, a vortexing drop shaft introduces flow into the drop shaft in a tangential manner. This design feature causes the flow to adhere to the shaft circumference and swirl downward in a spiral fashion, losing energy to surface friction and promoting a gentle entrance into the drop pool beneath the shaft's lower end.

Water Quality Benefits

One of the more interesting facets of the facility planning effort was determining the degree of CSO control needed in order to conform to Massachusetts DEP water quality standards and CSO control policy. Near the end of the planning period, the DEP proposed upgrading both the Charles River and the Inner Harbor water quality designations from Classes B and SB to higher Classes A and SA, respectively. In doing so, the DEP proposed that these waters need not meet the high standards for Class A waters continuously, but rather that a very limited number of quality excursions to a lesser quality could be permitted annually. This water quality policy was termed a "partial use" designation. Initially, the DEP suggested that under this partial use policy, perhaps about four excursions could be permitted annually. Using a combination of mathematical models that generated overflow volume and water quality impacts generated by varying storage capacity and that linked storage capacity to cost, the facility planning team was able to demonstrate the impacts on cost and water quality associated with varying numbers of CSO events per year.

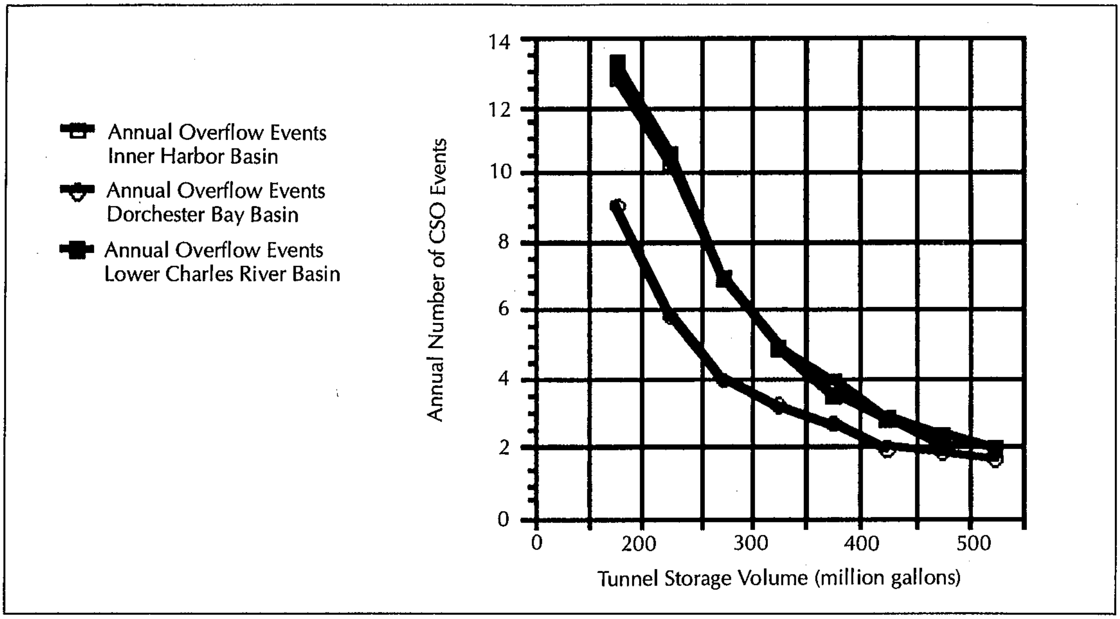

FIGURE 12. Deep tunnel system performance (in terms of volume) *versus* CSO event reduction.

Figure 12 demonstrates the relationship between storage tunnel performance and tunnel volume for each of the three basins served in terms of CSO event reduction, by basin, as a function of overall tunnel volume. Note that in the range of about 14 through six overflow events per year, the relationship to tunnel volume is nearly linear. However, once overflows are reduced to about four per year, each succeeding reduction requires greatly increased tunnel volume.

In Figure 13, the element of capital cost is

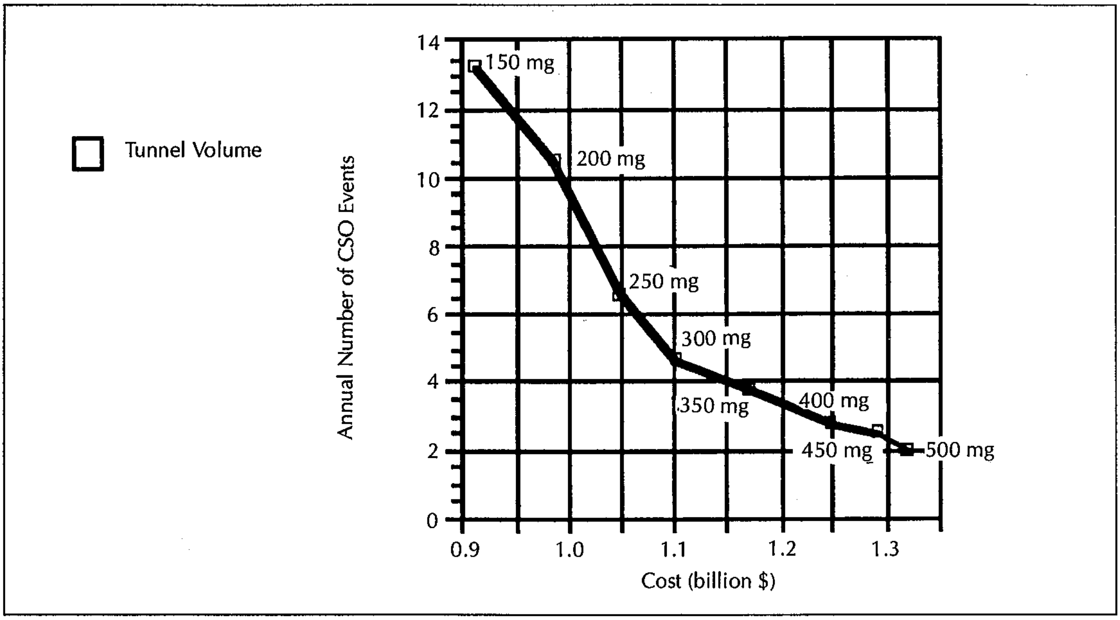

FIGURE 13. Capital cost *versus* CSO event reduction.

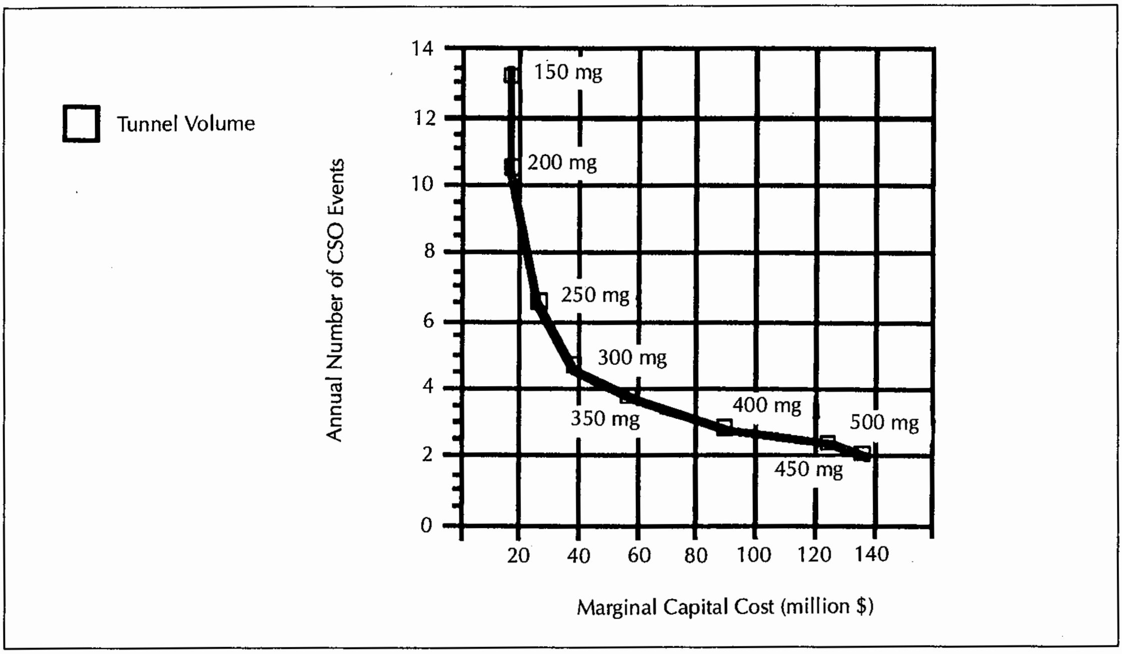

FIGURE 14. The marginal capital cost of CSO event reduction.

added to the information in the previous figure. Figure 13 portrays the capital cost of the system as a function of CSO event reduction. In the case of this figure, the number of events plotted corresponds to the maximum number of overflows expected in any basin (generally, the Inner Harbor Basin).

Figure 14 presents the curve that represents the first differential of the information plotted on Figure 13. It shows the rate of change of the slope of the cost curve and, therefore, portrays the incremental or marginal cost that would be incurred as a function of each succeeding event reduction. This marginal cost information indicates that in the range of event reduction between 14 and about ten per year, the cost for each event reduction is about the same as for the previous step. Beyond that point, each incremental reduction in the number of events incurs an ever increasing capital cost. The results clearly indicate that it would not be cost effective to provide storage capacity sufficient to reduce overflow events beyond the four per year level called for by the DEP. This marginal cost analysis was an important factor utilized by the DEP in obtaining EPA approval for their partial use standard.

Another interesting facet of the planning is that implementation of the deep tunnel could optimize water quality benefits that are associated with CSO control. This optimization is possible by prioritizing the availability of storage capacity for those discharges that most adversely affect recreational water use.

The recommended CSO control plan includes an operating plan that prioritizes the storage availability for the Charles River Basin (heavily used for water-dependent recreational activities) and Dorchester Bay (the location of most of Boston's salt water bathing beaches). Reservation of tunnel storage capacity for these water bodies can be accomplished by closing drop shafts serving the Inner Harbor area prior to the time that the tunnel is actually full, thus effectively reserving remaining volume that could be used to store added flow from the more critical water use areas. Through utilizing computer simulation, it was determined that the optimal closure (of Inner Harbor drop shafts) would occur when the overall tunnel system was about 80 percent filled.

Summary

The proposed CSO control facilities were devised based on planning-level engineering studies and the use of extensive water quality monitoring and mathematical modeling. Although improvements other than CSO control have been incorporated into the models and other analytic tools used in the planning work, additional refinements and water quality information will necessitate some changes in the overall program for CSO control. It appears likely that the modeling activity has overpredicted the volume of overflow for some of the existing overflow points, particularly the Inner Harbor, and has possibly underpredicted volume for at least one outfall in the Lower Charles River Basin. The MWRA is currently pursuing a flow monitoring study that meshes tidal schedules with the stormwater model. This type of study would more closely approximate how the overall system would behave, thus optimizing the size and location of the tunnel system.

Estimated costs for the recommended CSO plan are $1,223 million. Estimated annual operation and maintenance costs of new facilities to be constructed under the plan are $3.03 million. Estimated annual operation and maintenance costs of existing CSO facilities kept in use are $0.2 million.

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REFERENCES

1. "Final Combined Sewer Overflow Facilities Plan and Final Environmental Impact Report," prepared by CH2M Hill for the MWRA, September 28, 1991.

2. "Secondary Treatment Facilities Plan," prepared by Camp, Dresser & McKee for the MWRA, Boston, 1988.