THE DEEP TUNNEL PLAN FOR THE BOSTON AREA

by

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INTRODUCTION

The New Boston demands a new approach to water pollution control. The whole metropolitan area needs to develop a community of thought and action in its approach to this matter. The polluted conditions of Boston Harbor waters, as well as those of tributary streams, are tragic reminders of our neglect.

The problem arises primarily because of the existence of combined sewers which discharge mixed raw sewage and storm water to the nearby waters nearly every time it rains. The State has been aware of this problem since 1907 when legislation (Chapter 485, Acts of 1907) was first passed for a program of separation. But the small amount of separation so far accomplished has had a negligible effect on the receiving waters. The New Boston can ill afford further neglect of its water environment.

At the 41st annual conference of the Water Pollution Control Federation held in Chicago recently, it was brought out by several speakers, including Walter Reuther, President of the United Auto Workers Union, that as the world about us becomes more and more complex, it becomes more and more true that no man is an island. Whether it is a paper mill in the timber lands of the north discharging white waters to a clear trout stream or whether it is a resident of Boston discharging sewage to a combined sewer system, the effects of these acts are felt by others.

In September 1967, Camp, Dresser & McKee completed a year and a half study on "Improvements to the Boston Main Drainage System" for the City.

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In this report, a Deep Tunnel Plan was proposed for the Boston Area to prevent the continued pollution of Boston Harbor and adjacent waters. This plan developed as a logical consequence of investigations into existing conditions and sewerage facilities in Boston, and the need for a genuine solution of the total water pollution problem.

About 100 years ago, the records tell us, health and odor problems became so bad in the Boston Area that a special commission was created to find a solution to the problems resulting from the discharge of sewage to open water at innumerable points along the streams and shoreline. Now, 100 years later, in an age of rocketry and atomic power, this problem persists.

By 1884, the Boston Main Drainage System was constructed. This system at that time was a far-sighted and progressive attempt to reduce and localize the nuisances created by sewage discharge. It consisted of 25 miles of main and branch intercepting sewers, a pumping station at Calf Pasture and an outfall sewer tunnel to holding tanks on Moon Island. This system was designed to collect dry weather flows of sewage plus a small amount of storm water and intercept the outlets then discharging sewage during dry weather to the Harbor. No attempt was made to collect wet weather overflows.

The Boston Main Drainage System formed the nucleus for the sewerage system of the entire metropolitan area for a number of years. As the suburban areas grew and developed, greater and greater sewage flows were discharged through the Boston system. About 1900, the M.D.C. North and South Sewerage Systems were constructed. In 1948 the M.D.C. constructed a primary treatment facility at Nut Island in Boston Harbor to treat flows collected from the South Metropolitan Sewerage District including part of Boston. Still later, the M.D.C. constructed a primary treatment facility at Deer Island to handle flows from the North Metropolitan Sewerage System including most of Boston. Only within the past year has the Deer Island facility been placed into operation.

Major efforts have been focused upon the disposal of sewage generated during dry weather periods. But it is ironic to note that, despite all of this attention, increasing sewage flows from rapidly growing population in the greater Boston metropolitan area have been and are outstripping all attempts made so far to reduce the pollution of Boston Harbor and adjacent waters from sewage discharges. All of the sewerage facilities so far constructed have been designed to collect and treat only dry weather flows plus a small increment of storm water.

STORM WATER OVERFLOWS

Coupled with the myriad problems associated with dry weather discharges of sewage, is a sleeping giant - the largely ignored problem of storm water overflows from combined sewer systems.

Why should there be such a storm water overflow problem, and why has it been ignored? First, storm water overflows contain disproportionately great quantities of polluting substances such as decomposable organic material and disease-producing bacteria and viruses. Second, the reason that the problem has been largely ignored appears to be the fact that not enough has been known of the significant effects of such discharges, and because the problem is so large, no solution was felt to be feasible until recently.

There is little doubt that much larger quantities of polluting substances are discharged to our watercourses through combined sewer outlets during wet weather periods than during dry weather periods of equal length. Studies in Buffalo have shown that 20 to 30 percent of the annual collection of sewage solids are settled out in the combined sewers and are then picked up and discharged through such outlets during relatively short wet weather periods. Even the runoff of surface water from city streets has been shown to contain extremely high counts of coliform bacteria. Studies in Buffalo have indicated not only that abnormally large quantities of solids and other polluting substances are discharged during storms, but that heavy concentrations may be discharged for many hours following a storm.

It has been common practice to design intercepting sewers with capacities of only 2 to 5 times the average dry weather flow of sanitary sewage. Thus, nearly every time it rains, or about 5 to 6 times per month on the average, sanitary sewage is discharged to receiving waters. This condition is typical for Boston combined sewers based on studies by Dr. Jack McKee in 1947.

For the Boston study, completed just one year ago, samples were taken during selected tide and weather conditions at several major outlets from the Boston combined sewer system. Analyses discussed hereinafter indicate that the waters of the Charles River Basin and principal beaches in the Boston area are definitely polluted.

BOSTON SEWERAGE SYSTEM

A few statistics are in order now to indicate the magnitude of the problem resulting from combined sewer overflows in the Boston area.

At the present time, there are over 250 miles of combined sewers in the City of Boston. Most of these sewers are located in the older sections of the City and were constructed prior to the 1890's. The outlets from these sewers, including regulators and tide gates, are typically in poor condition. These outlets as a rule are old and do not function effectively.

Of the approximately 20,500 acres of total sewered area in the City of Boston, it is estimated that about 7,000 acres (11.0 square miles) are served directly by combined sewers, and about 10,100 additional acres, now served directly by separate sewers and storm drains, discharge to combined sewers. The volume of flow discharged during wet weather periods from these outlets is considerable.

But the pollution of the waterways in the Boston area is not the responsibility alone of the City of Boston. There are portions of at least four other cities and towns in the immediate vicinity of Boston which are served by combined sewers. These four are Brookline, Cambridge, Chelsea, and Somerville, which, together with Boston, we have termed the "regional area." There is a grand total of about 12,000 acres (18.8 square miles) served by combined sewers in the regional area. An additional 10,000 acres are now served directly by separate systems discharging into combined sewers, of which 5,000 acres can be diverted from combined sewer outlets. From the remaining total of 17,000 acres (26.5 square miles), over 300 outlets discharge to Boston Harbor, Charles River Basin, the Mystic River and the Neponset River. From the City of Boston systems alone there are 76 outlets from combined sewers.

Of the 76 combined sewer outlets, 14 have estimated capacities in excess of 100 million gallons per day each. The largest outlets are those discharging to Muddy Brook and the Charles River Basin, and to Fort Point Channel. The outlet to the Fens and the Charles River Basin is regulated by the Boston Gatehouse No. 2 which receives the flows from two 99-in by 126-in rectangular reinforced concrete conduits. So called "foul flow" channels carry the first flushings from a storm from the gatehouse to the M.D.C. Fens Gatehouse. The estimated capacity of this outlet is about 2,270 mgd or about 1,500 cfs.

The discharge to Fort Point Channel is now from the recently completed Roxbury Canal Conduit which eliminated 12 outlets. At its downstream end this conduit is a double 240-in by 186-in rectangular reinforced concrete box culvert with an estimated capacity of 2,240 mgd or just slightly less than for the Fens outlet. These estimated capacities do not reflect the restricting effect of high tide on discharge capacity, but are considered to represent capacities which may be realized under free discharge conditions with the installation of remedial measures such as the proposed Deep Tunnel Plan. It is, of course, evident that surcharging and backing up occurs during periods of high tide at the present time.

Because of the extremely poor conditions of the tide gates, regulators, and outlets, lower reaches of the principal sewerage system throughout the city are surcharged by tidewater on flood tides, and purged through outlets on ebb tides. It may be safely assumed that similar conditions exist in other municipalities in the Boston region served by combined sewer systems.

STANDARDS OF WATER QUALITY

There is no question that the waters of Boston Harbor and vicinity are in violation of the established water quality standards. Of particular importance in considering pollution due to overflows of mixed sewage and storm water, are the requirements of the water quality standards for solids and coliform bacteria. No sludge deposits or floating solids are allowable except for those amounts that may result from the discharge from waste treatment facilities providing appropriate treatment. The median coliform count shall not exceed a value of 700 per 100 ml or more than 2,300 for more than 10 percent of the time in bathing and shellfish areas.

During the course of the study, a very limited water quality sampling program was undertaken to provide evidence of pollution from discharges of mixed sewage and storm water. It was considered particularly important to obtain such evidence in waters used for recreation. Therefore, a series of eight grab samples was taken of water from Old Harbor (Carson Beach), Charles River Basin, Malibu Beach, and Tenean Beach.

Weather conditions during the period of sampling in October 1966, were generally dry but did include significant rainfall during the last two days of the sampling period. Grab samples were taken about 25 to 30 ft off-shore and in about 2 to 3 ft of water along beaches. They were analyzed for coliform bacteria by the M.D.C. Water Division Laboratory. Results of analyses are shown in Table 1.

Analyses revealed that the most serious pollution conditions existed in the vicinity of the Stony Brook Outlet and at the Berkeley Street Outlet in the Charles River Basin where coliform counts reached 800,000 and 130,000/100 ml respectively. Coliform counts during wet weather rose significantly at the eight sampling point locations with the exception of that at the Stony Brook Outlet which decreased but remained at a high level of contamination.

TABLE 1. WATER QUALITY IN VICINITY OF COMBINED SEWER OUTLETS

SAMPLING POINT LOCATION	*COLIFORM BACTERIA PER 100 ML. on Date Shown (October 1966)*								
	10/3	10/4	10/5	10/6	10/10	10/11	10/13	10/19	10/20
50 ft. West of Stony Brook outlet, Charles River Basin	—	10,000	180,000	440,000	500,000	700,000	800,000	45,000	38,000
Over Berkeley Street outlet, Charles River Basin	—	12,000	130,000	37,000	50,000	4,000	12,000	78,000	76,000
100 ft. West of "N" Street outlet, South Boston	600	140	320	680	500	220	770	1,800	1,400
50 ft. West of "K" Street outlet, L Street Beach	1,400	500	500	1,000	24,000	650	540	8,000	4,500
500 ft. Northeast of MDC Bathhouse, Carson Beach	2,000	3,800	2,200	1,500	1,100	80	1,400	3,000	2,600
300 ft. Northwest of Park Pavilion, at south end of Carson Beach	300	100	430	800	4,000	290	660	1,600	1,900
50 ft. North of Yacht Club, Malibu Beach, Dorchester	200	300	200	2,200	690	80	4,600	24,000	2,500
North end of Tenean Beach, Dorchester	500	400	700	280	240	260	1,000	20,000	2,100

NOTES: 1. Grab samples taken by Camp, Dresser & McKee
2. Laboratory analyses performed by MDC Water Division

At seven of the eight locations coliform counts exceeded 2,300 per 100 ml on at least one of the nine days on which samples were obtained. During the rainy period which occurred during the end of the sampling period, coliform counts exceeded 2,300 at all but two gaging points, those being located at the N Street Outlet in South Boston and at the south end of Carson Beach near the park pavilion. Since all sampling points were located in areas used either for recreational bathing, boating, or shellfish taking, significant hazards to health are presented by discharges of sewage and storm water.

On one occasion during the sampling program, masses of grease balls and other debris were found littering the South Boston beaches. This condition apparently occurs fairly regularly with an east wind and a falling tide. Records in City Hall indicate that about 40 or 50 years ago, regular dredging operations were carried out in Old Harbor off-shore from Carson Beach to remove sludge deposits built up by discharges from major combined sewer outlets in the area.

To summarize the above, the overflow of mixed sewage and storm water from combined sewers into the waters of Boston Harbor and adjacent waters constitutes a serious hazard to public health and requires immediate corrective measures.

On May 20, 1968, the FWPCA held an enforcement hearing on water pollution of Boston Harbor. There can be little doubt that clean-up will be ordered.

A truly major investment is desperately needed not only to maintain even the present low level of water quality but to improve it for maximum usefulness and enjoyment. A partial solution will not be acceptable.

THE BOSTON DEEP TUNNEL PLAN

At the present time no projects have been constructed or planned which will significantly improve water quality in the Boston area. To date, overflows of mixed sewage and storm water have been treated as minor problems, and solutions attempted have been and are totally inadequate. Because of the extremely high counts of coliform bacteria, indicative of pathogenic organisms in sewage, no relatively small amount of reduction in either the frequency, quantity or duration of overflows will significantly reduce the pollution hazards.

The only solution worth the major effort required is one that would completely eliminate overflows. The proposed Deep Tunnel Plan for the Boston regional area appears to offer the best and the only feasible method for the elimination of overflows.

Simply stated, the proposed Deep Tunnel Plan involves the construction, under the city, of large tunnels in rock, into which all of the overflows can be discharged through vertical shafts. The tunnels will store and conduct the overflows to a point where they can be screened, chlorinated and pumped through a long ocean outfall and disposed of into deep waters of Massachusetts Bay.

In May 1966, a report titled "Proposed Deep Tunnel Storage Plan for Flood and Pollution Control" was submitted to the Metropolitan Sanitary District of Greater Chicago by the firms of Harza Engineering Company and Bauer Engineering, Inc. Since that time more detailed reports have been prepared and an extensive subsurface rock exploration program has been undertaken.

After a thorough review of the earlier Chicago plans, including discussions with the engineers involved, it was concluded that the basic concept of deep rock tunnels for storing overflows is most attractive and appears to offer possibilities that other methods do not. The concept of utilizing the underground as the natural resource which it is, has been coming more and more to the fore as tunneling technology improves, and as surface conditions become more and more congested.

The geologic formation of the Boston region lends itself to a deep rock tunnel concept. The M.D.C. for a number of years has been constructing deep rock tunnels for both its sewerage and water systems. For this study, samples were obtained of rock excavated during the construction of the Boston Main Drainage Tunnel from Columbus Park, South Boston, to Deer Island. In addition, the U.S. Geological Survey and the Boston Society of Civil Engineers have, over the years, compiled extensive records on rock beneath Boston. The data show that the most common rock beneath Boston is argillite, which is dense and suitable for tunneling.

Before recommending such a radical new method as the Deep Tunnel Plan, it was necessary to investigate it thoroughly and compare it with traditional methods of solving problems created by combined sewer systems. The three alternative methods studied were:

1. Complete separation of all sanitary sewerage and storm drainage systems in areas now served by combined sewers.
2. Construction of chlorination detention tanks at selected locations to receive flows from tributary combined sewerage systems of mixed sewage and storm water in excess of dry weather interceptor capacities, detain the flows to provide chlorine contact time for

disinfection and discharge chlorinated flows to nearby watercourses or to the harbor.

3. Construction of surface holding tanks at selected locations to receive flows from tributary combined sewerage systems of mixed sewage and storm water in excess of dry weather interceptor capacities, and discharge untreated flows to the dry weather interceptors following storms.

It was found that these three alternative methods are more expensive and disruptive of surface activities than the Deep Tunnel Plan. More important, these methods do not provide feasible complete solutions for the Boston regional area.

The Deep Tunnel Plan, as studied for the Boston regional area (Fig. 1 and 2), would cost an estimated 496 million dollars (including 66 million dollars for capitalized operation and maintenance) which is less than the alternative methods studied. This is equivalent to about $41,000 per acre of combined sewer area (12,000 acres), or $29,000 per acre of area tributary to combined sewer outlets (17,000 acres). Table 2 is a comparison of the costs of the Deep Tunnel Plan with the alternative methods.

TABLE 2
ESTIMATED COSTS OF ALTERNATIVE METHODS FOR THE BOSTON REGION

	Estimated Costs, Million Dollars		
Method	*Construction*	*Capitalized Operation and Maintenance**	*Total*
Complete Separation	550.0	34.0	584.0
Chlorination Detention Tanks	400.0	133.0	533.0
Holding Tanks	715.0	99.0	814.0
Deep Tunnel Plan	430.0	66.0	496.0

NOTE: Costs do not include replacement of existing storm drains or combined sewers

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* At interest rate of 4.00%.

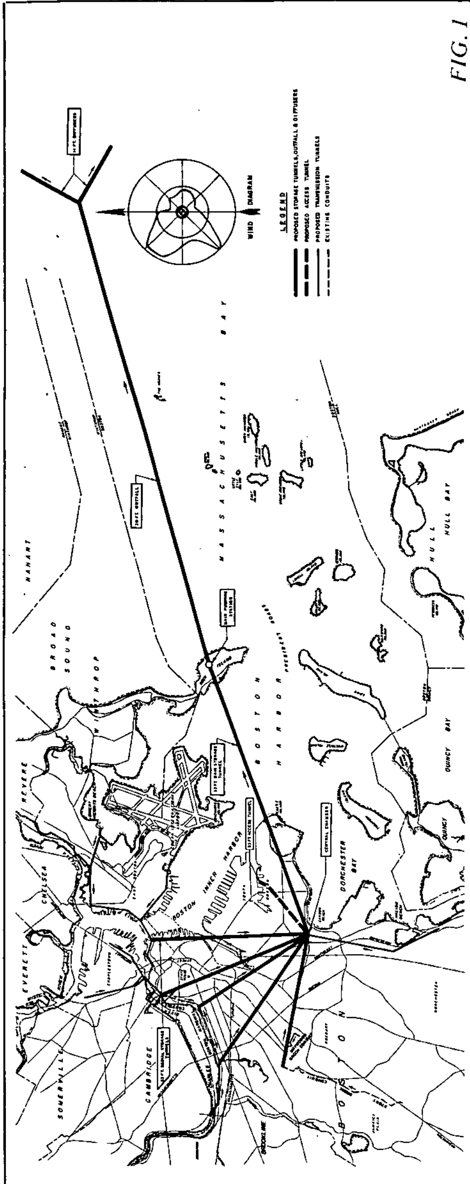


FIG. 1

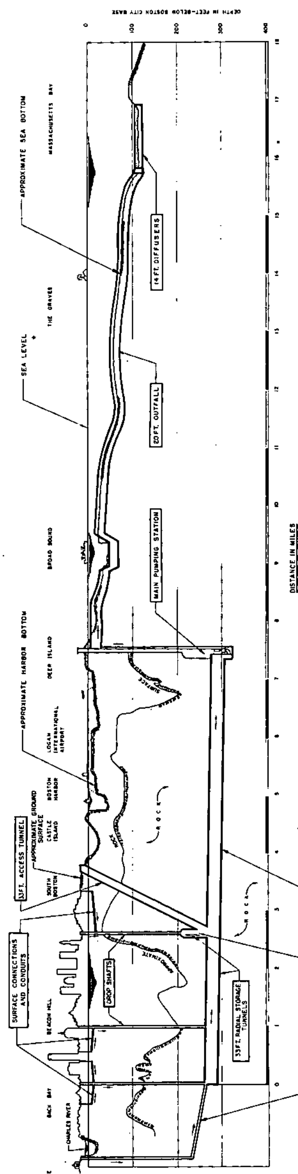


FIG. 2

FIG. 1 and 2. — PROPOSED DEEP TUNNEL PLAN — PLAN AND PROFILE.

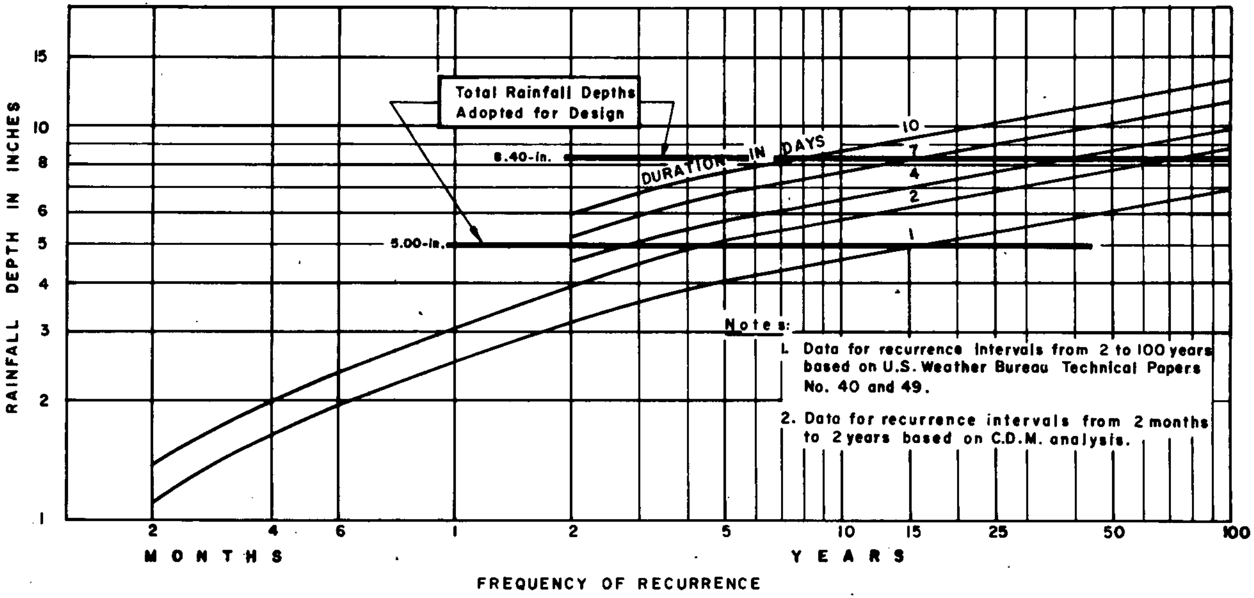
There are two unique features of the Deep Tunnel Plan. The first is the provision of storage of mixed sewage and storm water, particularly the use of deep rock tunnels to provide that storage. The second unique feature is is the provision of large pumping capacity to empty the tunnels and pump the waste waters to points of treatment and discharge. The provision of storage for mixed sewage and storm water is a new concept and greatly reduces the rates at which the waste waters must be pumped and treated.

It appears that deep tunnel storage could be constructed that would handle the runoff resulting from a rainfall of 15-year frequency and 24-hour duration (total rainfall depth 5 in and 90 percent total runoff) and dispose of this runoff within a 2-day period without surcharging the tunnels. Fig. 3 relates depth of rainfall to duration and frequency. To dispose of the runoff over a longer period would entail a much greater increase in the cost of storage tunnels than could be compensated for by a decrease in the cost of the pumping station. If, on the other hand, the tunnels are permitted to surcharge, the runoff from a storm of about 8.40 inches in one day may be handled. This is the largest recorded storm ever to have hit Boston (Hurricane Diane), and the existing sewerage system generally would be unable to deliver flows in excess of this even if a greater storm should occur.

The existing M.D.C. Deer Island Treatment Plant was not designed to receive and dispose of storm flow of this magnitude. Based on Fig. 4, a discharge rate at the proposed Main Pumping Station on Deer Island of about 2,400 cfs (or 1,550 mgd) would be required to handle the runoff from a 5-in storm of 1-day duration. The design capacity, for treatment of dry weather flow, of the Deer Island plant is 343 mgd. Average daily flows already are reported to be approaching 300 mgd. The hydraulic capacity available for flows in excess of design dry weather flow is about 506 mgd.

With estimated 1985 average dry weather flow (343 mgd) entering the plant at the time of occurrence of the 15-year frequency storm, the total flow entering the treatment facilities would be about 225 percent of the maximum hydraulic capacity (849 mgd), and about 550 percent of the treatment plant design capacity. For a storm of 8.40 inches in one day, which would require a pumping rate of about 5,200 cfs (3,400 mgd), the existing treatment capacity would be overloaded by over 900 percent. Such overload conditions should not be permitted. Little or no BOD removal and solids removal at the Deer Island Sewage Treatment Plant could be obtained under these conditions, and all sanitary and storm flows would be discharged at Deer Island untreated except for minimal chlorination.

The possibility of providing large surface storage facilities covering



Notes:
1. Data for recurrence intervals from 2 to 100 years based on U.S. Weather Bureau Technical Papers No. 40 and 49.
2. Data for recurrence intervals from 2 months to 2 years based on C.D.M. analysis.

FIG. 3 DEPTH OF RAINFALL VS FREQUENCY FOR BOSTON, MASSACHUSETTS

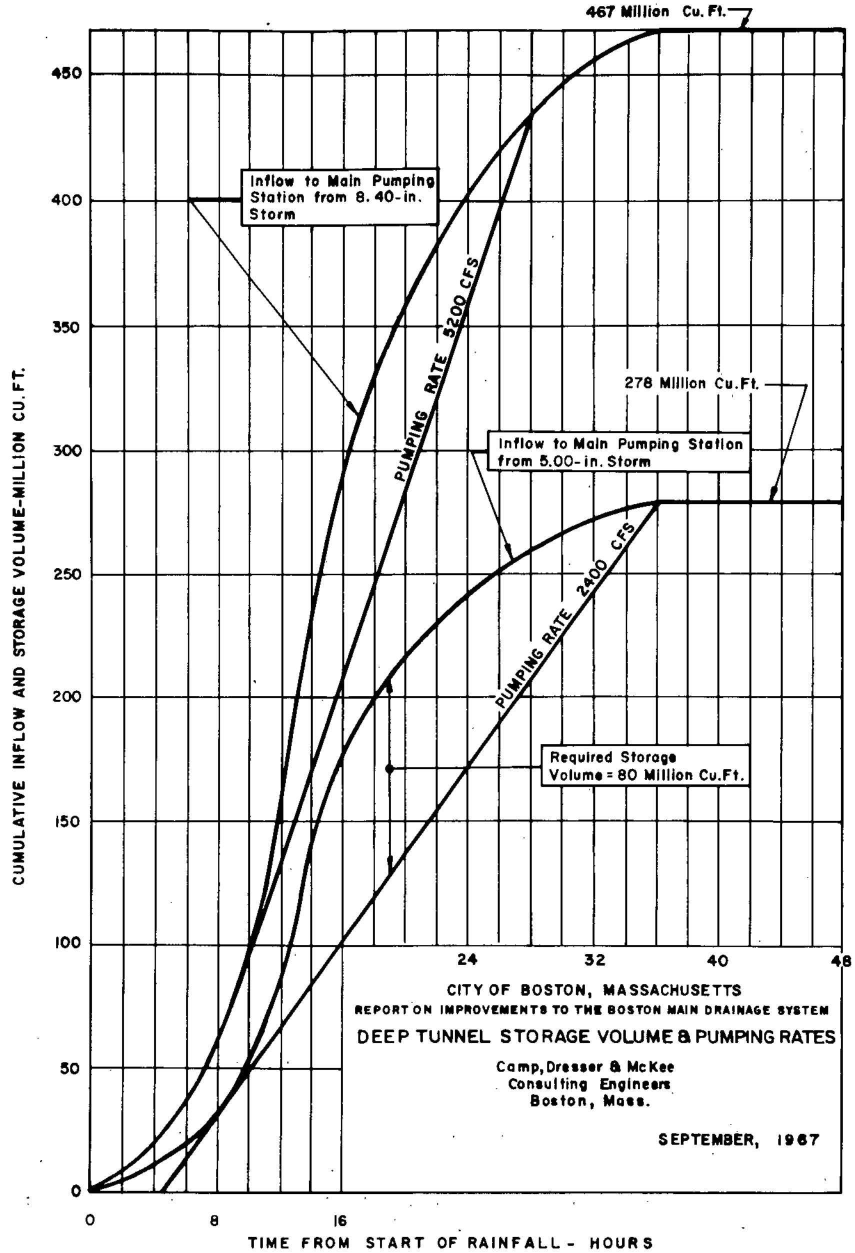

467 Million Cu. Ft.
Inflow to Main Pumping Station from 8.40-in. Storm
PUMPING RATE 5200 CFS
278 Million Cu.Ft.
Inflow to Main Pumping Station from 5.00-in. Storm
PUMPING RATE 2400 CFS
Required Storage Volume = 80 Million Cu.Ft.
CUMULATIVE INFLOW AND STORAGE VOLUME-MILLION CU. FT.
0
50
100
150
200
250
300
350
400
450
TIME FROM START OF RAINFALL - HOURS
0
8
16
24
32
40
48
CITY OF BOSTON, MASSACHUSETTS
REPORT ON IMPROVEMENTS TO THE BOSTON MAIN DRAINAGE SYSTEM
DEEP TUNNEL STORAGE VOLUME & PUMPING RATES
Camp, Dresser & McKee
Consulting Engineers
Boston, Mass.
SEPTEMBER, 1967

FIG. 4

most of Deer Island was considered as a means to reduce storm overloads on the existing plant, but this proved to be more expensive than the proposed outfall system.

The Deep Tunnel Plan consists of the following eight principal elements as shown in profile on Fig. 2:

1. Surface Connections
2. Drop Shafts
3. Transmission Tunnels
4. Deep Rock Storage Tunnels
5. Central Chamber
6. Access Tunnel
7. Main Pumping Station
8. Ocean Outfall

Surface connections would consist of interception chambers located on outlet conduits downstream of existing or proposed control chambers to divert dry weather flows to the present intercepting sewer system. Excess flows of mixed sewage and storm water flows would discharge via shallow conduits to the nearest drop shafts. Some principal existing conduits may require rehabilitation to serve this system.

Drop shafts, either vertical or inclined, would conduct flows from the surface connections to transmission tunnels or directly to the deep rock tunnels.

Transmission tunnels in rock would carry flows from drop shafts to the storage tunnels. These transmission tunnels are high speed tunnels up to about 10-ft diameter with velocities of perhaps 10 to 20 fps.

Deep rock storage tunnels. An underground reservoir would consist of a system of deep rock storage tunnels with equivalent diameters of about 33 ft in a radial pattern sloping gently to a central chamber located at Columbus Park, and a 33-ft diameter main storage tunnel extending from the Central Chamber at Columbus Park, beneath Boston Harbor, to a main pumping station at Deer Island. The design diameter of the tunnels would depend on the total required storage volume and the design pumping capacity of the main pumping station at Deer Island.

The total length of the five radial storage tunnels required is about 12.7 miles. Their locations beneath Boston are shown on Fig. 5. The main storage tunnel would be about 4.5 miles in length and would be approximately parallel to and on the south side of the existing M.D.C. Boston Main

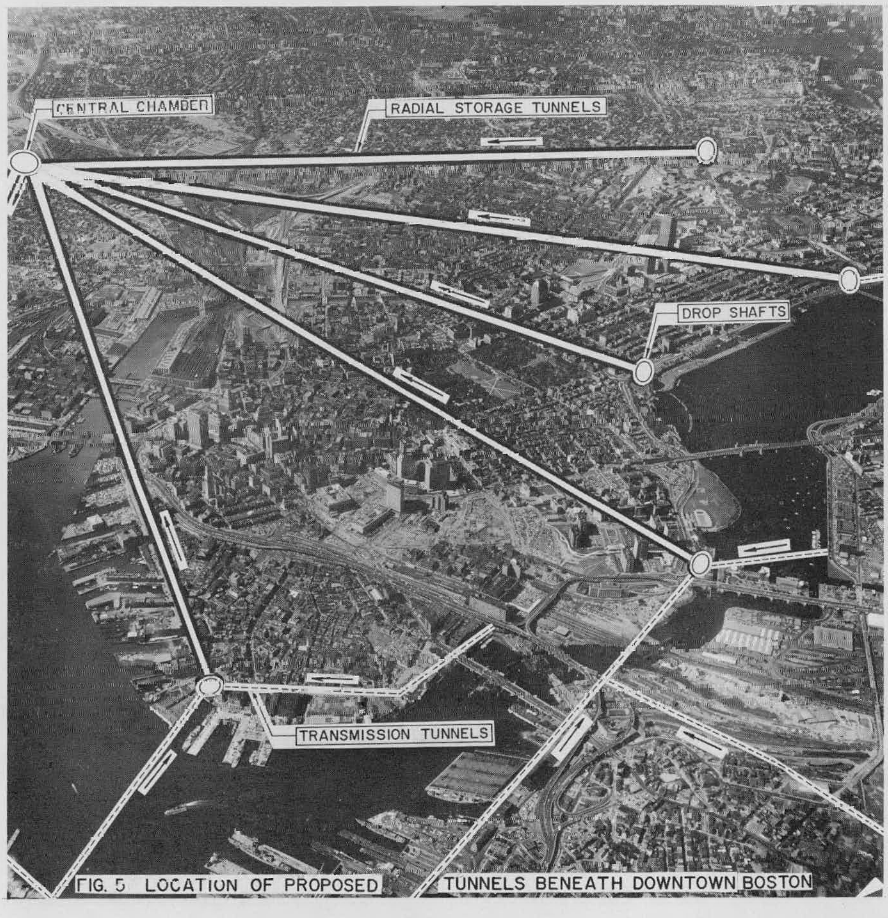


FIG. 5 LOCATION OF PROPOSED TUNNELS BENEATH DOWNTOWN BOSTON

Drainage Tunnel. The total length of storage tunnels is, therefore, about 17.2 miles. This length of 33-ft diameter tunnels would be sufficient to provide the required storage volume of 80 million cubic feet.

The storage tunnels would be about 300 ft below the surface. The required depth is controlled by the location of the rock surface along its profile. The invert of one radial storage tunnel (from near Ward Street) and the main storage tunnel are proposed to be slightly below that of the existing M.D.C. Boston Main Drainage Tunnel to permit dewatering the existing tunnel if required.

The probable method of construction of these tunnels, if constructed at the present time, would be by the drill and blast method, according to opinions of contractors experienced in tunnel work. The access tunnel sloping at about 8 percent grade from the ground surface to the central chamber at Columbus Park was proposed as an efficient means for access to the work area during construction for easy transportation of the muck to the surface for disposal either as fill in the immediate area or on barges for disposal elsewhere. The length of the five radial storage tunnels under Boston would be such that the transportation of the muck from the tunnels to the surface poses no unusual tunnel construction problems.

The sides and top of the tunnels would probably not have to be lined except where unstable rock was encountered, or where rock bolts would be needed for stability. Cost estimates of the deep storage tunnels include 25 percent of the tunnel length fully lined, 75 percent of the tunnel length with paved invert only, and 40 percent of the tunnel length supported by rock bolts. Inverts of tunnels excavated by conventional drill and blast methods would be lined with concrete to assist in the operation and maintenance of the tunnel system, and also to provide a relatively smooth surface on which the contractor's trucks could operate.

Considerable research on rock boring machines (moles) with rotary cutting heads in diameters as large as 36 ft is being done in this country and in Europe. Moles are now being used to excavate sewer tunnels in rock in Chicago. It appears likely, that in the next five to ten years, the excavation of hard rock by rock boring machines will become routine. If the proposed tunnels can be economically constructed by such machines, the interior of the tunnels will, of course, be of circular cross section and be quite smooth eliminating, in general, the need for concrete linings or inverts.

It is important to note that the development of rock boring machines will probably reduce excavation costs for rock. The estimated costs of tunnels excavated by boring machines, within a few years, may be substantially less than those of tunnels excavated by drilling and blasting methods. The cost of the rock tunnels contained in this report is based on conventional present-day methods of drilling and blasting with paved inverts throughout and full concrete lining where conditions require it.

A central chamber would be located in rock at Columbus Park with sluice gates, tunnel ventilation and control facilities. The size of the chamber might be about 400 ft long, 100 ft wide and 100 ft high to permit access and water passage.

Access tunnel. A sloping 33-ft diameter access tunnel would extend from the central chamber at Columbus Park to loading piers which would be located in the vicinity of the Reserved Channel in South Boston. Its purpose would be to provide access during construction, and later for maintenance and inspection purposes. Excavated rock could be hauled by barge for ultimate disposition.

A main pumping station would be located in a rock chamber at Deer Island with control building, power supply and chlorination facilities, etc., in a surface structure.

The location of the main pumping station would be to the east of the existing M.D.C. sewage treatment plant on Deer Island. It would consist of a circular chamber some 180 ft in diameter excavated in solid rock by the drill and blast method. The station would have design capacities of 2,400 cfs at a total head of about 350 ft with required operating horsepower of about 110,000, and 5,200 cfs at a total head of about 200 ft with a maximum required horsepower of about 150,000 with the tunnels surcharged.

It appears that eight vertical, single-stage, single-suction pumps would be required. Six of these pumps would be 60-in units, each with a capacity of about 380,000 gpm (550 mgd) when driven at a speed of 400 rpm by a 25,000 horsepower, 4,000 volt synchronous motor. Several of these pumps would be provided with variable speed drives, and six pumps together would be able to handle all design flows reaching the station. The two additional pumps would be 42-in units, each with a capacity of about 90,000 gpm when driven at a speed of 360 rpm by a 9,000 horsepower, 4,000 volt synchronous motor. These two pumps would serve as standby units and be used to dewater the suction well and tunnels after the main pumps are shut down.

The station would be provided with ventilation and control equipment and surge, access, and discharge shafts. Provision would be made for hypochlorination facilities, and electric power would be provided to operate the pumps and appurtenant facilities. It is assumed that all electric power requirements can be furnished from commercial sources. However, consideration was given to the possibility of generating power at Deer Island and selling power in excess of station demands. The possible use of high-capacity gas turbine generators has been examined and appears to have promise. Detailed cost analyses will be necessary to determine the most economical method of providing the necessary power.

It is not possible at the present time to consistently predict with accuracy the intensity, duration or volume of rainfall which will occur for any given storm. As a result, it would not be possible to fully foresee the maximum pumping rate which might be required for a given storm. Therefore, the pumps would be operated individually, following the storm development as closely as possible. This procedure would tend to minimize the possibility that the storm might develop so rapidly that the tunnels would become filled earlier than anticipated.

Ocean outfall. A 20-ft diameter subaqueous ocean outfall pipe would extend about 45,000 ft generally east-northeast into Massachusetts Bay, terminating in two 14-ft diameter diffuser pipes, each about 5,800 ft long.

The reinforced concrete pipe would be laid on the bottom of the bay in a trench sufficiently deep to prevent movement of the pipe. It would be buried where it crosses beneath the main ship channel.

In the absence of detailed studies of ocean currents in Boston Harbor, preliminary design of diffuser pipes was based on similar studies conducted on the West Coast. The diffuser pipes would have internal diameters of about 14 ft and be of reinforced concrete with flexible joints. The diameter of the 600 diffuser nozzles required would be 7 in, with a spacing on each side of the diffuser pipe of about 19.2 ft. The total length of the two diffuser pipes would be about 11,600 ft. The diffuser pipes would be located at approximately right angles to prevailing currents in the area, and would be located at about 110 ft below mean sea level as shown on Fig. 2.

With a pumping rate of 2,400 cfs and a water depth of about 110 ft at the diffusers, an estimated minimum dilution ratio of about 200 parts of ocean water to 1 part of waste water would be achieved in the rising plume of waste water, discounting the dispersing effect of ocean and tidal currents.

The sewage would be diluted to varying degrees with storm water in the tunnels and outfall before it enters the dispersion field. It is, therefore, reasonable to expect dilution ratios to vary from 200 to 1 early in a storm to perhaps 6,000 to 1 during later periods, with consequent reduction in the concentration of bacteria, viruses and other polluting substances of between 99.50 percent and 99.98 percent, even without chlorination. This is a much greater reduction than can be achieved by conventional "complete" treatment. Natural die-off of bacteria and viruses in ocean water has not been allowed for, but should further reduce the concentrations.

In order to provide positive kill of bacteria and viruses, it is proposed that a 30 ppm chlorine dose be applied year-round to protect recreation and shellfish interests. This dose, applied to the flow within the outfall pipe, is considered adequate and is, therefore, recommended. With a velocity in the pipe of 7.5 fps (at a pumping rate of 2,400 cfs), the proposed outfall would provide over 1-½ hours contact time.

Calculations show that the dispersed field of waste water would remain submerged below the surface most of the time because the estimated limiting height of rise of the plume would be less than the ocean depth above the nozzles, thus preventing the formation of "sleek" areas. Under certain conditions, particularly during periods of low sea water temperatures, the plume might reach the surface. In the event that some material should float to the surface, prevailing winds from the northwest and southwest could be expected to carry it out to sea.

Land areas should not be affected by the intermittent discharge of mixed sewage and storm water at the diffusers. The nearest land area is Nahant, some 5.5 miles from the proposed diffuser pipes. From Marblehead the distance is 6.3 miles, from the tip of Nantasket Beach 6.8 miles, and from Cohasset 8.9 miles.

It has been recommended that the City of Boston adopt the Deep Tunnel Plan. It is suggested that it be adopted also by Brookline, Cambridge, Chelsea, and Somerville as the only feasible means of jointly eliminating pollution resulting from overflows of mixed sewage and storm water from combined sewers.

ADVANTAGES OF TUNNEL PLAN

Advantages of the Proposed Deep Tunnel Plan for the Boston regional area are:

1. The Deep Tunnel Plan provides a complete regional solution to the problem of handling mixed sewage and storm water and for water pollution abatement. Most important, it can be accomplished with present technology.
2. The Deep Tunnel Plan is adaptable to serve any conceivable development of Boston or the regional area in the future.
3. The Deep Tunnel Plan is the most economical means for eliminating overflows to the surrounding waters and can accept all surface runoff from the urban area. Possible future requirements for the disposal of storm water runoff would pose no problem.
4. The estimated total cost of the Deep Tunnel Plan is less than for alternative methods, including complete separation, and may become relatively less expensive in the future.
5. The Deep Tunnel Plan would involve very little valuable land area.

6. Construction of the Deep Tunnel Plan would not cause interference with traffic or surface activities.
7. Construction of the Deep Tunnel Plan would permit the efficient draining of all areas that now flood during heavy rains.
8. The Deep Tunnel Plan provides the means for disposing of all mixed sewage and storm water well out to sea away from any inhabited areas. The use of the outfall might be considered by the M.D.C. for disposal of treated sanitary sewage.
9. The main section of the deep storage tunnels would parallel the M.D.C. Boston Main Drainage Tunnel and have lower inverts to permit dewatering the existing M.D.C. sewerage system.
10. The large quantity of rock (some 5.5 million cu yds) excavated from the tunnels during construction would be available at low cost for fill in connection with the expansion of Logan International Airport, site development for the proposed 1976 World's Fair, or other fill operations in and around Boston Harbor.

A number of additional studies will be necessary preliminary to any detailed design. Among these are:

1. More extensive subsurface exploration.
2. Oceanographic studies.
3. Effects of discharges on marine biology.
4. Economic study of power generation and/or purchase.
5. Optimization of design, perhaps by computer, to obtain the most economical design of the deep tunnel system.

SUMMARY

The Deep Tunnel Plan for the Boston regional area would cost about 496 million dollars (including capitalized operation and maintenance costs), whereas the cost of separation would be about 584 million dollars. The cost advantages of the tunnel plan may increase in the future as tunneling technology advances. The Deep Tunnel Plan would prevent any discharge of mixed sewage and storm water into the Charles and Mystic River Basins and Boston Harbor, and would convey all these wastes after chlorination for dispersion about 9 miles out in the ocean.

Any solution of the combined sewer problem will be very costly, and it does not appear reasonable to expect any community to implement a solution without substantial grants-in-aid from the Federal Government.

In order to bring this matter forceably to the attention of the Congress for action, the major metropolitan areas should cooperate in presenting the matter to the Congress. For maximum effectiveness, Boston, Brookline, Cambridge, Chelsea and Somerville should join in a cooperative effort to request assistance from State and Federal Governments to accomplish real pollution abatement in the Boston area.

CONCLUSION

The New Boston needs a new approach to water pollution control. Past efforts, despite their cost, have failed to significantly improve water quality in and around Boston. The Deep Tunnel Plan for the Boston region provides a long overdue opportunity to eliminate pollution from the waters of the Boston area and to provide a more healthful and enjoyable environment.

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