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THE PROPOSED CHARLES RIVER PROJECT

by
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(Presented at a meeting of the Hydraulics Section, B.S.C.E., and M.S.A.S.C.E., on January 30, 1974).

Introduction

The Charles River Project is the largest single construction project ever advertised by the New England Division of the Corps of Engineers. Final plans and specifications for this project were prepared by CE Maguire, Inc., Engineers-Architects. Bids were opened on February 7, 1974 for the project which consists of a dam, navigation locks and flood control pumping station at Warren Avenue in Boston.

The main purpose of the project is to maintain the Charles River Basin at an essentially constant level, in order to prevent flooding. However, many corollary benefits will also result from its construction. Improvements will be made to navigation and pollution control. A fish passage and park will be provided, and the areas adjacent to the extended water Basin will be enhanced.

The costs are shared federally by the Corps of Engineers (87 percent), and locally by the Metropolitan District Commission (13 percent). Upon completion, the project will be turned over by the Corps of Engineers to the Metropolitan District Commission for operation and maintenance.

Before this project reached its present status, many alternative solutions to pumping were proposed such as diking of banks, upstream flood storage, additional sluicing facilities, and prelowering in anticipation of floods. The feasibility and economic justification for the entire project were questioned.

The project was first investigated by the Metropolitan District Commission, then turned over to the Corps of Engineers. After a very thorough investigation the Corps of Engineers reached the same conclusion as the MDC; that the only positive means for control of flooding on the Charles is with a pumping station. It was also determined that the project is economically justified with a benefit to cost ratio of 1.4 to 1.0.

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History

In order to understand the flooding problems which exist today, we must look back in the history of the existing Charles River Dam to the time when Charles River Basin was a tidal estuary.

Tidal Estuary

The City of Boston in 1775 was a small peninsula about a mile wide and a mile and a half long, connected to the mainland by the narrow Roxbury Neck. The Back Bay, the Charles River Basin, and the Cambridge shore where M.I.T. is located today, were subject to daily tidal fluctuations.

In 1814 Mill Dam was authorized along the present alignment of Beacon Street, and was completed in 1821. A short cross dam was built between the Mill Dam and the present intersection of Massachusetts and Commonwealth Avenues to provide a two pool system of tidal power for the mills on the cross dam. Between 1834 and 1884 some 750 acres of Back Bay were filled with land brought in by railroad cars until the whole of the formerly tidal Back Bay became filled. Some 140 acres were also filled along the Cambridge shore below the Boston University Bridge, and an additional 500 acres upstream of the Boston University Bridge along both sides of the river. By 1902 the Boston and Cambridge shores, in back of retaining walls were completely filled in. Figure 1 shows the tidal conditions in the Charles River Basin along the Cambridge shore in 1902.[1]

Old Charles River Dam

The contract for the existing Charles River Dam, Locks, Sluices and Drawbridge was let in January 14, 1905 following detailed studies by the Committee on Charles River Dam under the supervision of John R. Freeman, Chief Engineer for the Committee.[2] John R. Freeman is a familiar figure in Boston because of his close association with the Boston Society of Civil Engineers, which included his establishment of scholarship and lecture funds. He was one of the greatest American civil engineers and his very thorough engineering report in 1903 was instrumental in establishing the Charles River Basin.

The site for the present dam was established at the Craigie Bridge between Boston and Cambridge. The dam and lock were placed in operation October 20, 1908 and the highway was completed January 27, 1910. One large lock was provided, 350 feet long, 45 feet wide and 18 feet deep at low water.

Hydrology and Hydraulics for Old Dam

The design of sluicing facilities was based on flood flow records for a freshet of February 1886 which was the largest flood up to that time for which records were available. Records were kept for discharge over the

Figure 1 — Charles River from Cambridge Shore in 1902.

dam at Moody Street in Waltham which was calculated at 3,968 cfs for 181 square miles of contributing area. The same unit runoff was applied for the remaining 57 square miles of drainage area downstream for a total of 5,212 cfs. This figure was felt to be conservative because, as Freeman noted: "The maximum rate of flow does not occur at Waltham until two or three days after the maximum rate of rainfall. The maximum rate of flow from the 57 square miles below Waltham, on the other hand, follows but a few hours after the maximum rate of rainfall and would have passed before the crest of the main flood arrived.[2]"

The sluices and other openings at the dam were designed for 5,700 cfs (10 percent in excess of the flood of February 1886) with continuous tides rising to elevation 113, and the Basin level rising to elevation 111 as indicated in Figure 2.[2]

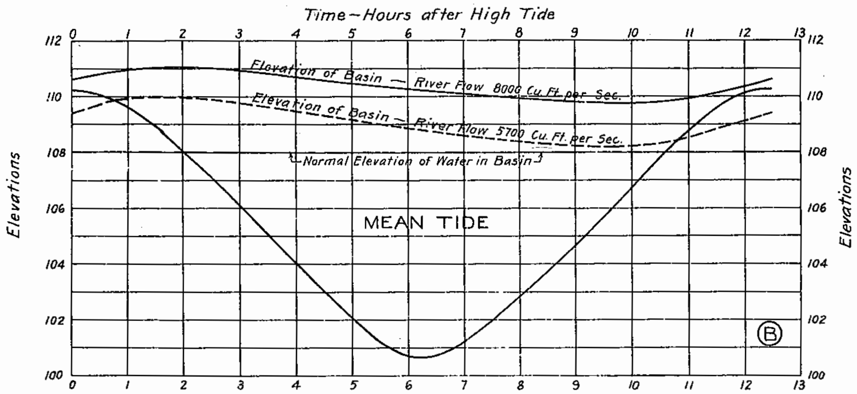


Figure 2 — Basin Levels for Design of Old Dam.

A study was made of more extreme condition with upland flow of 7,000 cfs, and with a high tide rising to elevation 114.5, and low tide rising to elevation 105.5. This actually occurred on November 27, 1898 during the Portland Tide, so named because the steamer "Portland" was lost in that storm. Under these conditions the Basin would reach a maximum elevation of 113.4. The conclusion reached was that: "The flood assumed is ⅓ greater than the greatest flood of record; and a coincidence of such a flood with such a series of tides is so remote a possibility as to be hardly worth consideration, although, even should it occur, it appears evident that no serious damage would be done."[2]

It must be emphasized that with tidal conditions upstream of the Charles River Dam there were no measurements of flow below the Moody Street dam, and tides of 113.4 had occurred several times per year.

The sluicing waterway area of some 909 to 951 square feet, depending on tide elevation, served adequately for many years to control the Basin levels. Between 1909 and 1954 the maximum Basin levels were controlled between elevation 109.0 and 110.2 in accordance with the intent of the design.

It wasn't until Hurricane Carol, on September 11, 1954, when the inflow reached a peak of 9,200 cfs, and the Basin rose to elevation 110.5 that any cause for concern was expressed. Flooding starts at about elevation 110.2; therefore damages were not excessive. However, Storrow Drive was flooded since its low elevation is 109.5 and the bank adjacent to it overflows at elevation 110.2. Since CE Maguire was working on the hydraulics of the proposed Chlorination Detention Station in the vicinity of Boston University Bridge, it was asked to take a second look at the then proposed elevation of 110.0 in the Basin for backwater through this proposed pollution control facility.

A brief evaluation led to the excellent records of Basin and tide levels which are kept in the Tower at the present Charles River Dam every half hour to the nearest .01 of a foot. The records of levels and the records for sluicing enabled the determination of a flood hydrograph for Hurricane Carol. Shifting the time of high tide with respect to rainfall led to the conclusion that with more adverse timing the Basin could have risen to elevation 112.5, and that we were faced with a very dangerous situation with respect to potential flood hazard. Some attempts were made to interest the Metropolitan District Commission in a more detailed study because of the potential hazard, but the matter was pretty much forgotten until Hurricane Diane in the following year.

Hurricane Diane 1955

Hurricane Diane, which occurred on August 18 and 19, 1955, had the highest rainfall in the Westfield, Massachusetts area with a total rainfall of about 20 inches. It was still a substantial storm in the Boston area with a total rainfall of about 12 inches. The tidal conditions were not unusually adverse with peak tide elevation of only 112.6. The rainfall exceeded 1 inch per hour for 4 hours and the Basin level rose to elevation 112.55 as shown in Figure 3, with a substantial amount of damage.[3]

As a result of this damage CE Maguire, Inc., together with Elson T. Killam Associates, was engaged to make a study of the Charles River Basin.[4] The joint venture recommended a flood control pumping station at the existing Charles River Dam to prevent recurrence of such flooding. They conducted a flood damage survey shortly after the flood.[5] Most of the damage was due to the back up through drainage systems discharging to the Basin and it followed the pattern of areas which were formerly tidal and had been filled in to create new land. Although Memorial Drive and Beacon Street are generally above elevation 115, 2½ feet above the flood level, some parts of Cambridge are as low as elevation 113 to 114. Many basements and basement apartments are at elevation 110.

M.D.C. Studies

Several detailed studies were performed for the Metropolitan District Commission in 1958 and 1959, following the completion of the first feasi-

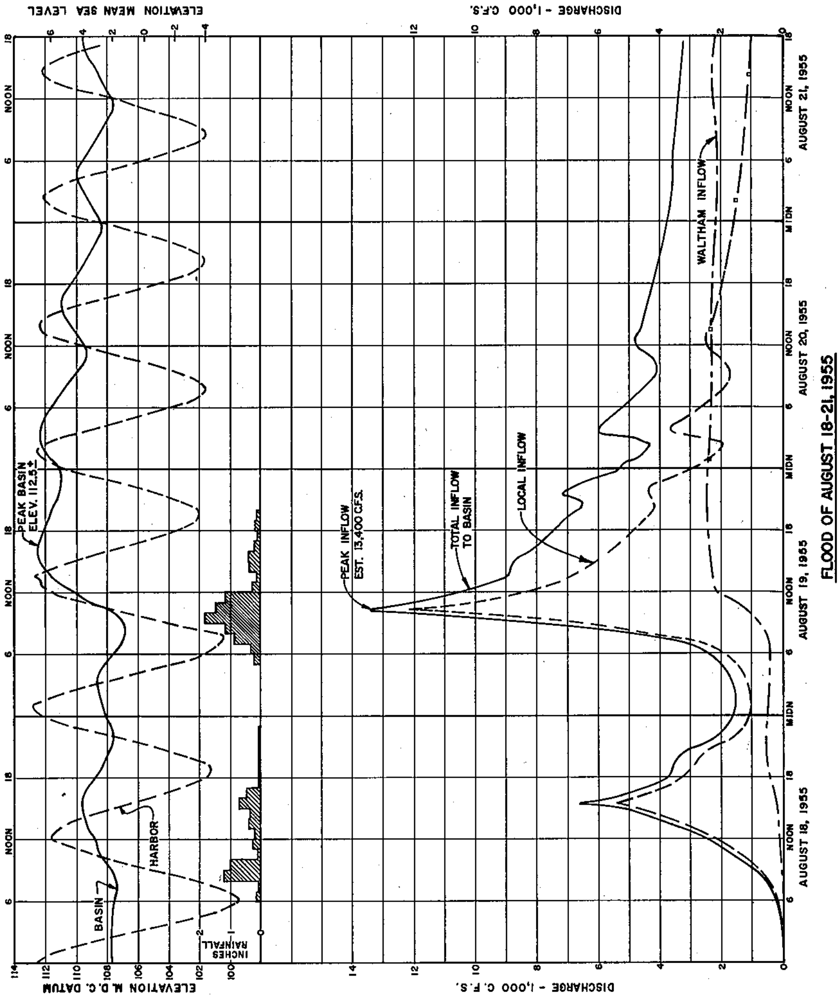


Figure 3 — Hurricane Diane Rainfall, Flows and Basin Levels.

bility study. An analog computer study was conducted by Dr. Henry M. Paynter in order to establish the criteria for pumping capacity.[6] Also a report was completed in 1959 on alternative types of pumping equipment in which CE Maguire recommended six vertical propeller pumps, with a total capacity of 8,400 cfs, driven by diesel engines.[7]

Another report in 1959 was concerned with commercial and recreational boating, stressing the importance of the increasing use of Basin and lock for recreational boating, and the declining use by commercial vessel traffic.[8] This report also recommended the construction of two small boat locks to reduce the waiting time for small boat users, sometimes up to two hours, and to reduce the intrusion of salt water into the Basin.

Site Selection

Alternative sites were first evaluated at the existing dam resulting in a preliminary selection of a site immediately downstream of the existing lock.[9] However, Hydraulic Model Tests, performed at the M.I.T. Hydrodynamics Laboratory, indicated considerable difficulty at this site due to cross flow from the lock resulting in vortices and in some instances surges.[10] Many runs were made with different pumping station orientations and various intake wall arrangements in order to minimize surging and vortex action. None of the arrangements was completely satisfactory.

At the same time borings were being taken at the site downstream of the existing lock. Suitable foundation material at this site is 90 feet below sea level, considerably beneath the bottom of the proposed structures, requiring the use of piles.

The unsatisfactory foundation and hydraulic conditions led the engineers to a new site, shown in Figure 4, at Warren Avenue where an old bridge had been abandoned and was in the state of collapse.[11] At this site suitable foundation material was 50 feet higher, near the level of the foundation of most of the structures.

Hydraulic Model Tests at the Warren Avenue site, also performed at the M.I.T. Hydrodynamics Laboratory, indicated that for the various arrangements of pumping station walls and station orientation investigated, even the worst arrangements at the new site were satisfactory and considerably better than the best at the existing dam.[12]

A recommendation was made to locate the project at the Warren Bridge site. A flood control pumping station, two small locks, a large lock and a highway bridge were included in the project. The highway bridge was for one-way traffic from Rutherford Avenue in Charlestown to Causeway Street in Boston.

Present Design Hydrologic Conditions

The Charles River has a drainage area of 307 square miles at Warren Avenue. The Lower Charles River Watershed, below Moody Street Dam in Waltham, has a drainage area of 58 square miles.

The Charles River Basin has a surface area of 705 acres between Warren Avenue and Watertown dam. The extension of the Basin to Warren Bridge has added 30 acres to the Basin area. However, since creation of the Basin by construction of the present dam, its surface area has been decreased by 101 acres due to filling.

The design flood hydrograph has a peak inflow of 15,500 cfs and exceeds 10,000 cfs for 6 hours. The flow at Moody Street Dam at Waltham is limited to a peak of 3,000 cfs due to river and dam restrictions. The design flood hydrograph is based on the inflow from Hurricane Diane, when a peak inflow of 13,400 cfs was reached, plus an allowance of additional 2,100 cfs for future increase in impervious areas due to further development of land area. The Corps of Engineers hydrologic studies were

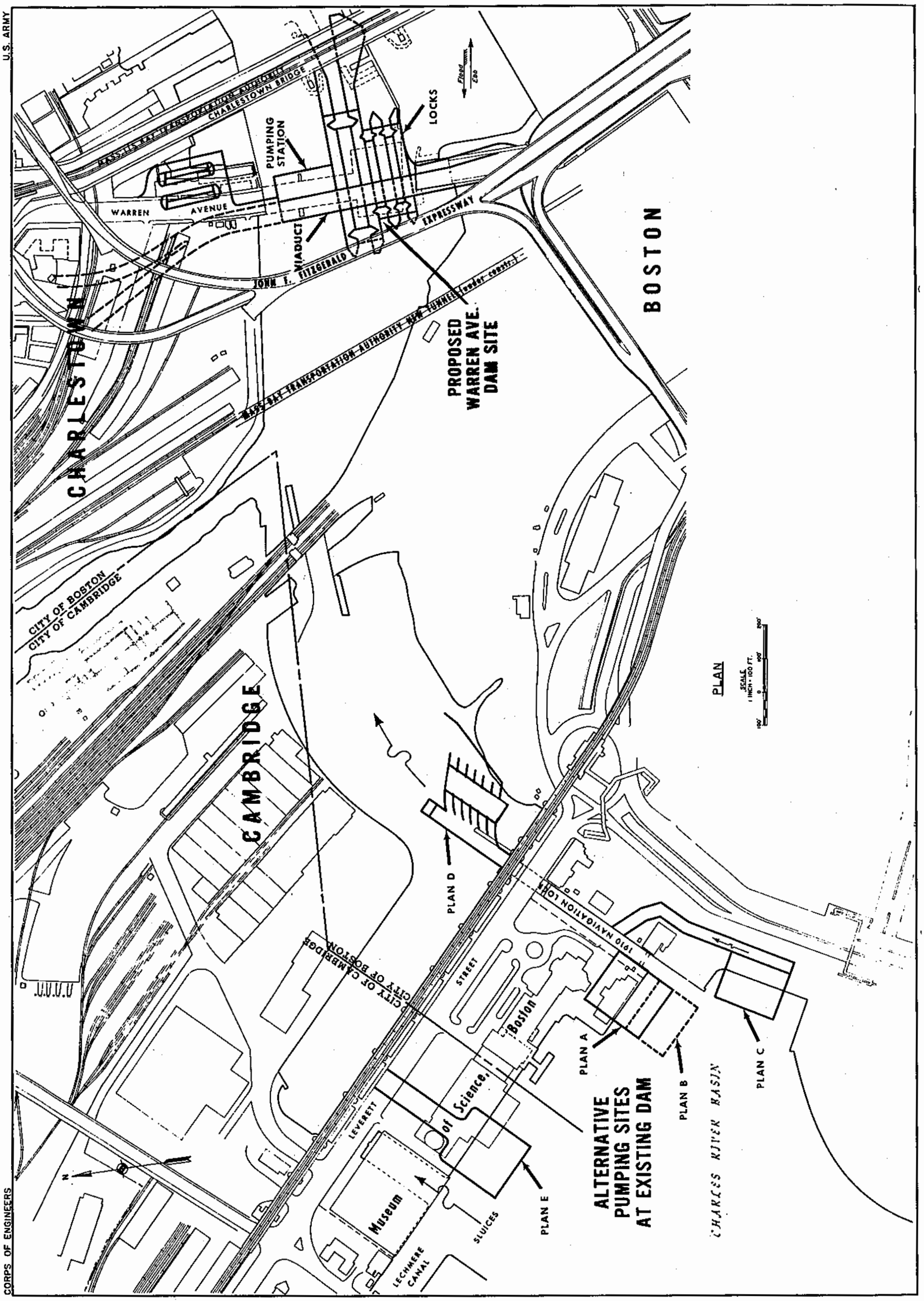


Figure 4 — Alternative Project Sites at Existing Dam and at Warren Avenue.

performed initially under the direction of Mr. E. Childs.

The Standard Project Flood has a peak inflow of 20,000 cfs. It was derived from a synthetic rainfall amounting to 10.43 inches in 18 hours as compared to 8.11 inches in 18 hours during Hurricane Diane. The rainfall loss was determined to be 2.63 inches for this period during Hurricane Diane, and was assumed to be the same for the Standard Project Flood. The rainfall excess, after deducting the loss, amounts to 5.48 inches of runoff for Hurricane Diane, and 7.80 inches for the Standard Project Flood during the 18 hour period. The design hydrograph and the Standard Project Flood are shown in Figure 5.[3]

The design tide has a high elevation of 113.0 and low elevation of 102.5. The high portion is below the 115.7 peak elevation reached during the Minot's Ledge Tide in April 16, 1851, and the low portion is below the 105.5 low elevation for the Portland Tide of November 27, 1898. The tides in the Boston area can sometimes rise 3 to 4 feet above predicted heights due to the northeasterly winds, and due to a drop in atmospheric pressure.

The design tide level of 113.0 is reached several times per year. An elevation of 114.0 is anticipated about once every 2½ years, and elevation 116.0 is anticipated about once every 100 years. The frequency of high tide levels is changing since the ocean level is currently rising at about a 0.6 foot rate per century.

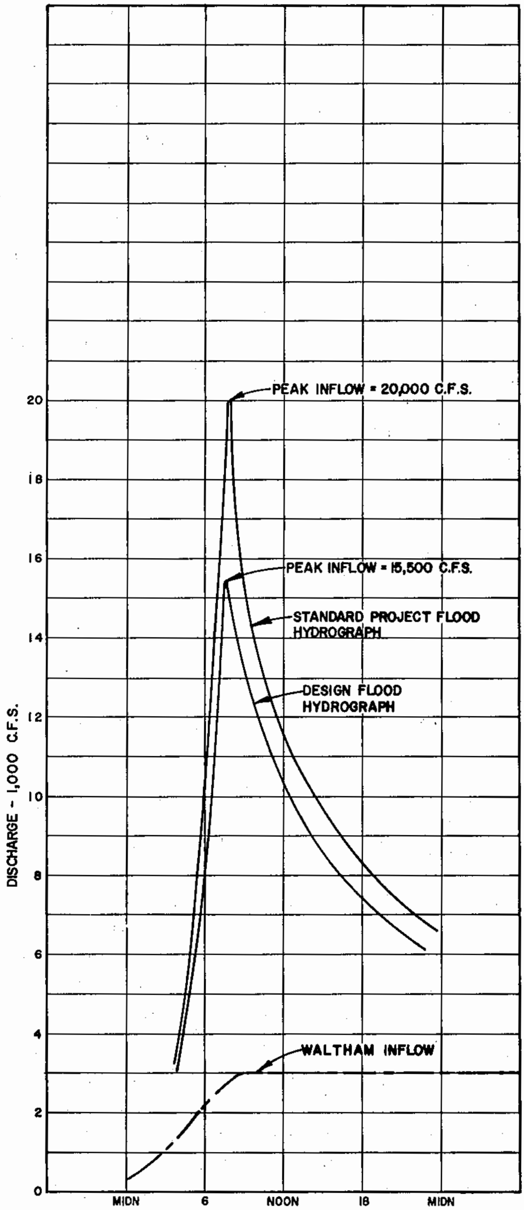
Under Project Design Flood conditions, and with a pumping rate of 8,400 cfs, the Basin would rise to elevation 109.6 as shown in Figure 6 and would cause no damage.[3] If one pump was inoperative, the pumping rate would be 7,000 cfs and the Basin would rise to elevation 110.5 causing a minor amount of damage. Damages start at about elevation 110.2 and at 110.7 are estimated to be only about $400,000.

Under Standard Project Flood conditions, and with a pumping rate of 8,400 cfs, the Basin would rise to elevation 111.3, as shown in Figure 7, causing some damage.[3]

If there were no pumping facilities provided, then the Basin level would be governed essentially by the elevation of high tide level. For the design tide of 113.0, the Basin level would rise to elevation 113.0 with design flood inflow and to elevation 114.0 with the standard Project Flood.

The frequency of occurrence of high Basin levels with pumping and without pumping at present and in the future is shown in Figure 8.[11] With the proposed pumping capacity of 8,400 cfs, an elevation of 110.2, at which damages would start, will be reached about once every 150 years. Without pumping, Basin elevation of 110.2 would be reached once every 6 years now, and once every 3 years in the future.

Without pumping, a flood level of 112.5, during which damages are estimated at about 12 million dollars, would be reached every 40 years, and a flood level of 114.5, during which flood damages are estimated at 48 million dollars, would be reached every 150 years in the future.



STANDARD PROJECT FLOOD AND DESIGN FLOOD HYDROGRAPHS

Figure 5 — Flood Flow Hydrographs.

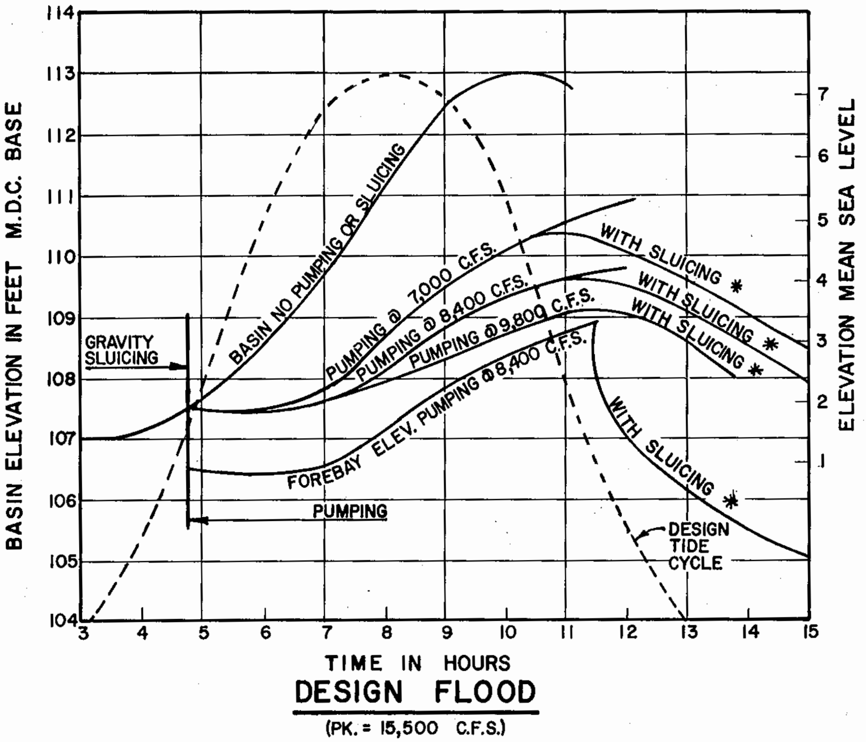


Figure 6 — Basin Levels During Design Flood.

The benefit of the pumping station is evident when we see that for once in a 100 year event, the pumping station will control the Basin level to elevation 109.0, without causing damages. On the other hand, without a pumping station, future Basin levels would be completely out of control with catastrophic flood damages.

Alternative Plans

Several plans were considered as alternatives to pumping by various interests. These were:

- Diking of banks.
- Upstream flood storage.
- Additional sluicing facilities.
- Prelowering in anticipation of floods.

These alternatives were considered by the engineers and discarded as being ineffective.

Diking of river banks is not practical because flooding occurs not by overbank flooding but through back up of drainage systems.

Upstream flood storage reservoirs are not practical because 84% of flood flow is from the areas adjacent to the Lower Charles River below

Moody Street Dam, as shown in Figure 9. Furthermore, during Hurricane Diane, the dam above Moody Street and other areas upstream were already very effectively storing flood flows to minimize damages downstream. It will, however, be necessary in the future to preserve areas for flood storage and conservation in order to avoid excessive flood damages upstream, and to avoid an increase in flood flows downstream. Today's flood flows are no longer as described by John R. Freeman in 1903 where the inflow from the upper watershed causes most of the flood flow. The engineers found that runoff from the lower watershed, below Moody Street Dam, is the major source of flooding.

Additional sluicing facilities are helpful only under certain tidal conditions. For the most critical conditions, when flood inflows occur with tide level above the Basin level, sluicing is not possible. Sluicing facilities could be built all the way from the Boston to the Cambridge shores, but as long as tide conditions are adverse the sluices would not do any good. During the design hydrograph inflow, the Basin level would rise at a peak rate of about 2 feet per hour no matter what sluicing facilities were provided if no pumps were provided. Since the tide is higher than the Basin for about 4 hours,

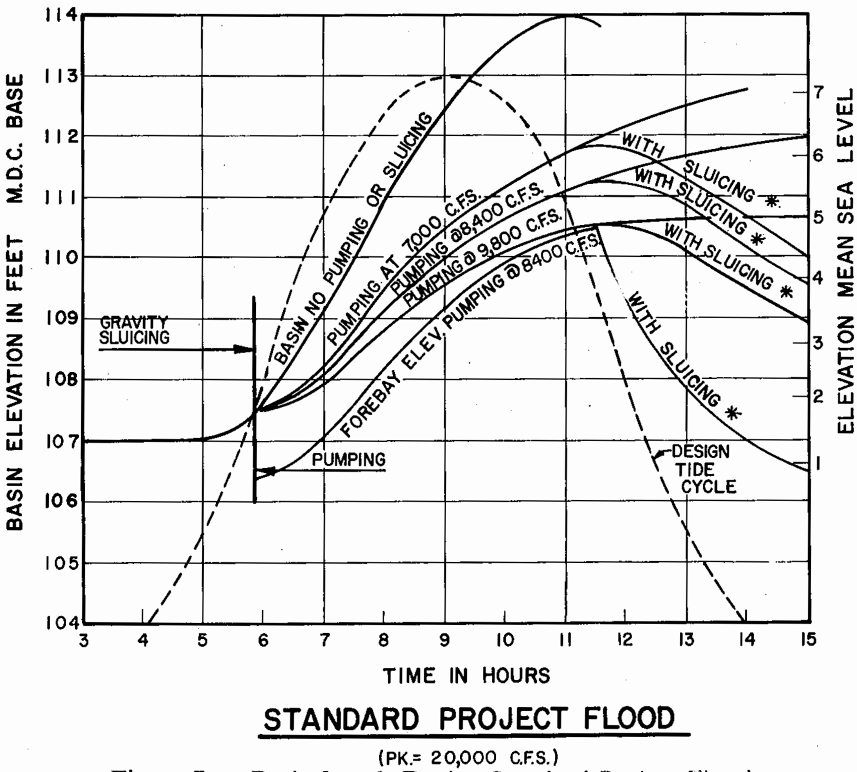


Figure 7 — Basin Levels During Standard Project Flood.

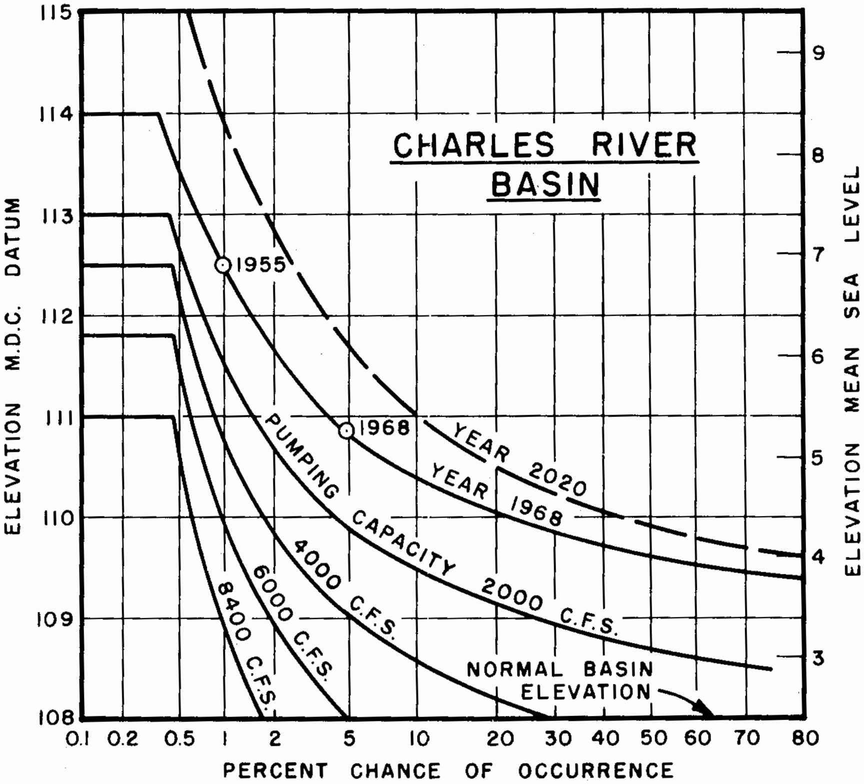


Figure 8 — Frequency of Occurrence of High Basin Levels.

sluicing facilities are of no consequence for the most critical tidal conditions.

Prelowering the Basin to elevation 106.5, 1½ feet below the normal Basin level, is considered to be practical. Dropping the Basin to elevation 106.5, rather than 107.5, would reduce the peak Basin rise without pumping under the Standard Project Flood with design tide only a small amount from about 114.0 to 113.8.

Extreme prelowering of the Basin to lower elevations, such as elevation 104.5, as an alternate solution to pumping to control the Basin level rise is not very effective for the following reasons:

1. Reduced area of the Basin at lower elevations. The Basin has a surface area of about 600 acres of elevation 104.5 as compared to about 1,200 acres at elevation 114.5.
2. Increased gravity inflow to the Basin from adjacent drainage systems with lower Basin level.
3. Decreased gravity outflow from the Basin to tide as the Basin level drops. With the low design tide at elevation 102.5, it would be diffi-

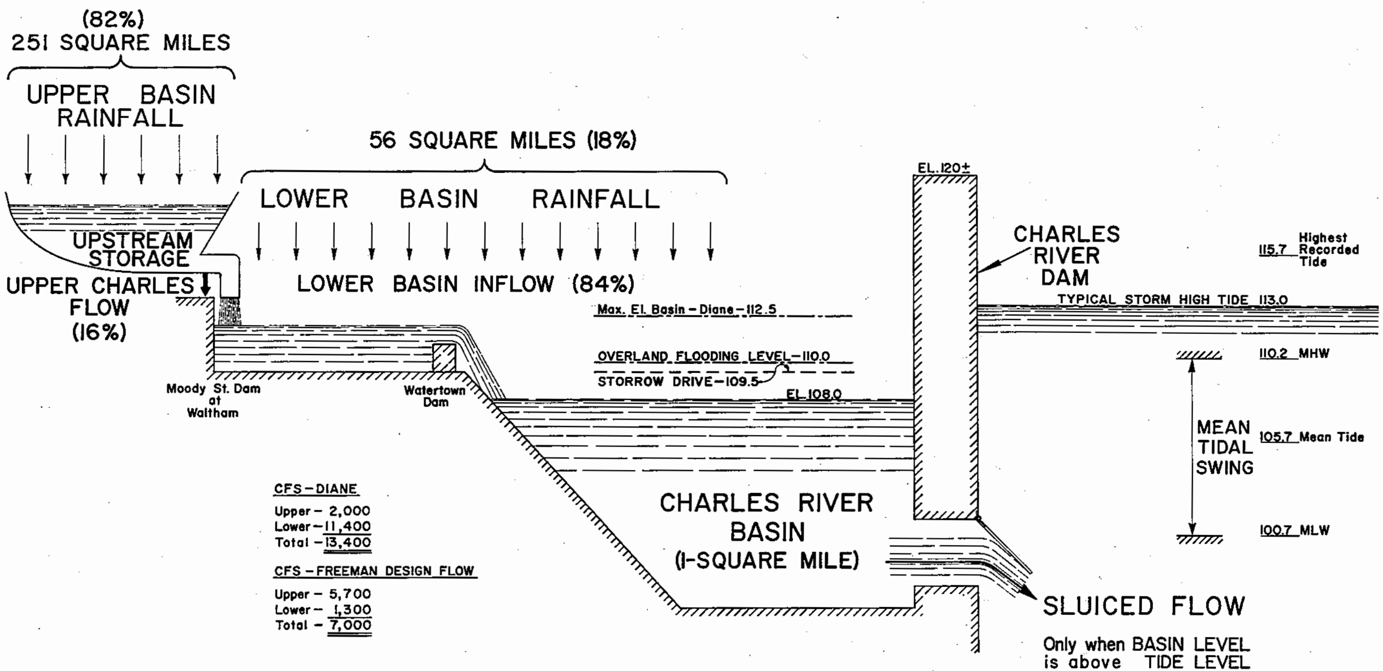


Figure 9 — Schematic Representation of Charles River Basin.

cult to drop the Basin to elevation 104.5.

4. Increased time during which flood inflow must be stored because the time during which tide will be higher than the Basin is extended.

Dropping the Basin level from 106.5 to 104.5 would reduce the peak Basin level rise without pumping under Standard Project Flood with design tide only a small amount from about 113.8 to 113.5. Basin levels could go higher under more adverse high tide conditions. Also under adverse tide conditions, the low tide can be at elevation 105.5 rather than 102.5 and it would not be possible to prelower much.

Dropping the Basin level below 106.5 to 104.5 would interrupt industrial water use, stop production of electricity at power plants which depend on cooling water, and would ground many boats which would be seeking safe refuge before a storm.

It was the engineers' conclusion, therefore, substantiated later by the Corps of Engineers, that adequate positive control of Basin levels required a flood control pumping station.

The conditions upon which the gravity sluicing facilities were designed by John R. Freeman are very different today and the change could not have been anticipated. Increase in population and construction of paved areas and drainage systems increased and speeded up the runoff from the watershed below Moody Street Dam. The fast high runoff from urban areas adjacent to the Basin, rather than the slow upland flow must now be the prime concern. The total flow has jumped from 7,000 cfs to 20,000 cfs.

Furthermore, the Basin area was 15 percent larger in 1910 than at present. Today's highly developed area is now very sensitive to small changes in Basin level as compared to the small population that was accustomed to the previous tidal conditions. It can no longer be said that with elevation 113.4 no serious damage would occur.

Proposed Facilities

Final plans and specifications were completed for the Metropolitan District Commission in April 1964. Because of the controversy relative to the need of the project and because of funding problems, the project was turned over by the Metropolitan District Commission to the Corps of Engineers.

The Corps of Engineers substantiated the need of the project and provided the major portion of the funds. The project was redesigned in accordance with the Corps of Engineers criteria, including new criteria for seismic considerations.

The architectural features were changed at the request of the Metropolitan District Commission and the Architectural Review Board. The buildings were changed from precast concrete to brick, as shown in Figure 10. A facility was added for MDC patrol boats as well as a walkway, and an area for public viewing. Parking and park areas were expanded and now include the site of Paul Revere's landing. The Engineering Division of the Metro-

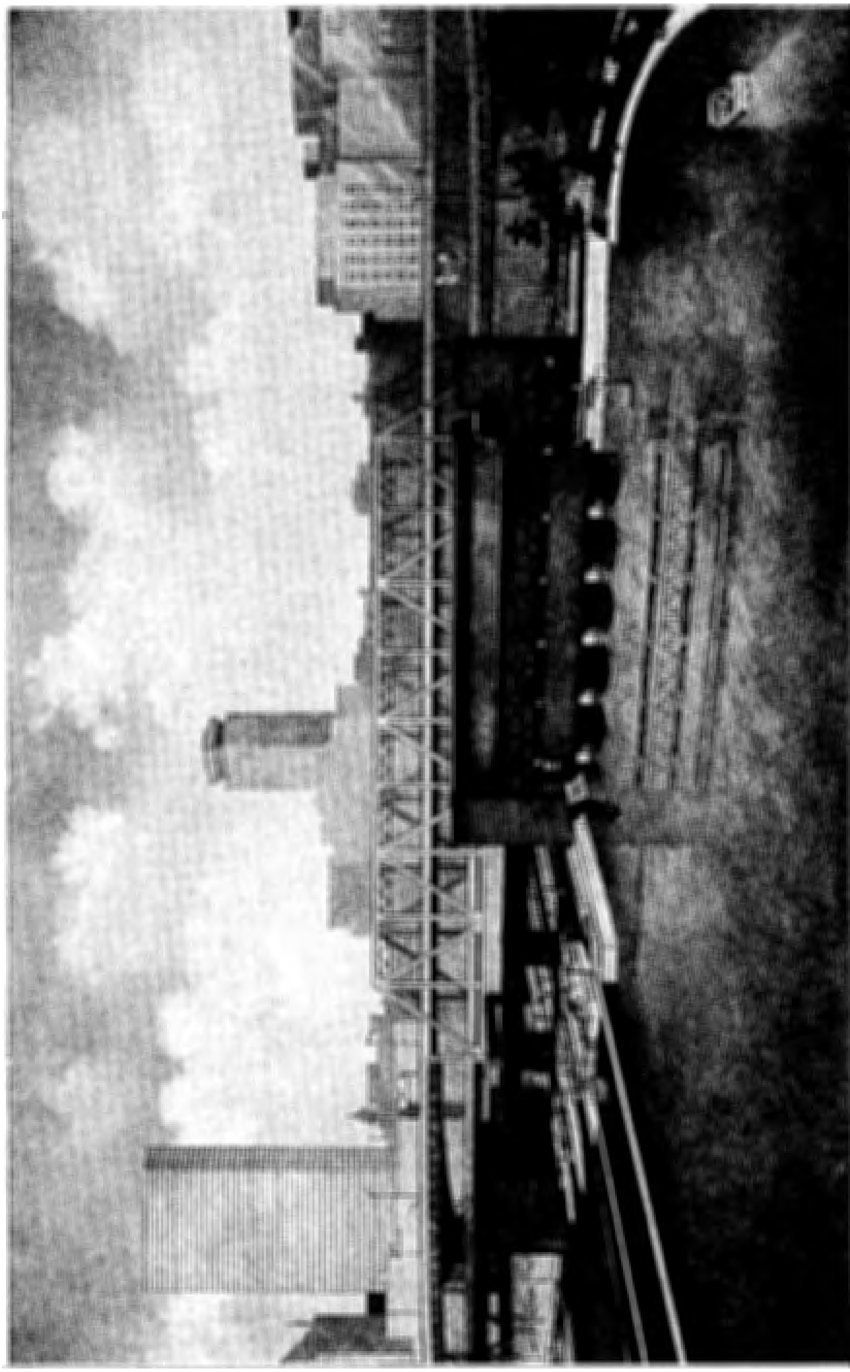


Figure 10 — Rendering of Proposed Project.

politan District Commission under the direction of Mr. F. Bergin is presently designing Charles River marginal conduits and a treatment facility to eliminate pollution in the area between the existing dam and the proposed dam, and to reduce pollution in the Charles River and Boston Harbor.

Postscript

Subsequent to the presentation of this paper on January 30, 1974, the New England Division of the Corps of Engineers received and opened bids for the construction of the Charles River Project on February 7, 1974. The low bidder was J. F. White Contracting Company with a bid of $34,957,250. The construction period will be limited to 45 months with scheduled completion in 1977.

The writer has had charge of the detailed enginering work on this project during the initial stages and its supervision during later design stages. The project managers for the Corps of Engineers were Mr. C. Ciriello during the report stages, and Mr. G. T. Sarandis during the preparation of final plans and specifications under the supervision of Mr. J. Leslie. The project manager for CE Maguire, Inc. was Mr. J. Lukacz, Jr., and Mr. E. Dunn provided engineering supervision. The project manager for the Metropolitan District Commission during early stages was Mr. A. Sulesky. During later stages Commissioner John Sears and Mr. F. Bergin provided MDC cooperation and assistance.

Acknowledgment is hereby made by the writer for the assistance and cooperation of the Metropolitan District Commission, the New England Division of the Corps of Engineers, special consultants and fellow members of the staff of CE Maguire, Inc.

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