Boston's
Charles River Basin

AN ENGINEERING LANDMARK

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JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION • ASCE

VOLUME 67 • NUMBER 4 • SUMMER 1981

This is a special issue of the Journal containing a group of selected papers devoted to Boston's Charles River Basin and John R. Freeman's pivotal role in its establishment. It celebrates the American Society of Civil Engineers' designation in 1981 of the Charles River Basin as a National Historic Civil Engineering Landmark.

JOURNAL OF THE BOSTON SOCIETY OF CIVIL ENGINEERS SECTION

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AMERICAN SOCIETY OF CIVIL ENGINEERS

BOSTON'S CHARLES RIVER BASIN
an engineering landmark

Published four times a year, Autumn, Winter, Spring, Summer by the Society
80 Boylston Street, Boston, Massachustts 02116

Subscription price $10.00 a year. Single copies $2.50, except this special issue, for which see order form inside back cover. Orders must be accompanied by check. Members' subscriptions are part of their dues.

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BOSTON'S CHARLES RIVER BASIN

INTRODUCTION —

This issue of the *Journal of the Boston Society of Civil Engineers Section,* ASCE, had its origin in a modest plan to reprint the *Report of the Committee on Charles River Dam to the 1903 Massachusetts General Court,* including the report to that Committee of its Chief Engineer, John R. Freeman. The BSCE Section believed that by making this classic report readily available, and widely advertising the fact, it would be performing a great service, not only to *Journal* subscribers but to everyone involved in public affairs.

The report covers the comprehensive investigation of a major proposed public works project and its numerous significant impacts. Construction of a dam across the lower Charles River had been proposed many years before but was blocked by controversy. As a result of the Freeman investigation and report, the Commonwealth proceeded without delay to build the project, which ever since, has provided to Greater Boston its most distinguishing physical feature. The report is timeless in its clear presentation of controversial issues and of the engineering and scientific investigations and analyses applied to resolve them.

The plan to reprint the Charles River Dam report of 1903 did not occur by chance but was a result of the continual efforts of the BSCE Section's John R. Freeman Fund Committee to perpetuate the spirit of its benefactor's exemplary career. A happy series of events subsequently led to the more ambitious collection of papers herein assembled. First, the BSCE Section suggested to ASCE National that the society designate the Charles River Basin a National Historic Civil Engineering Landmark. The designation has been made and enthusiasm engendered by this event prompted the notion of a more elaborate publication than originally conceived. Next, a paper entitled *An Impact Assessment of the New Charles River Dam* by a group of seniors in the Department of Civil Engineering at MIT became available. The Committee then became aware of the large, indexed Freeman Collection in MIT's Archives and there unearthed John R. Freeman's draft of a paper (unpublished) on the Charles River dam investigation which he had delivered at a BSCE meeting in 1903. And, finally, we found in Deborah Cozort (a staff member of the MIT Archives) a needed catalyst and a major contributor to this publishing venture.

Hunter Rouse[1] called John R. Freeman "Probably the engineer who

[1]Hunter Rouse, *Hydraulics in the United States 1776-1976,* Journal of BSCE Section, ASCE, Vol. 63, 1976-1977; also published by the Institute of Hydraulic Research, The University of Iowa, Iowa City, 1976.

had the most profound and lasting effect on American hydraulics . . .". Almost 80 years after the fact, the current issue of the BSCE Section's *Journal* documents the difficult, but eventually successful, cooperative efforts of a broad cross-section of Boston area citizenry determined to perform a public good and the strong influence of a great civil engineer on these efforts. It should provide ideas and profound and lasting encouragement and inspiration to Americans and democrats everywhere who believe that public problems of all kinds can, and therefore should, be directly confronted and expeditiously solved.

The John R. Freeman Fund Committee

Lee Marc G. Wolman, David R. Campbell,
Harry L. Kinsel, Donald R.F. Harleman,
Lawrence C. Neale

ACKNOWLEDGEMENTS

Special assistance and support, cheerfully given by numerous individuals and organizations, have been essential to the accomplishment of this publication. In particular, the photographs made available by Captain Albert A. Swanson, Jack Maley and Julia Gianangelo of the Metropolitan District Commission; the liberal support of Chas. T. Main, Inc. in underwriting the extensive typing of Agnes Mace, the editorial efforts of Lee Wolman, and cover design work by Dick Peterson and Bob Santoro; the valuable suggestions of Al Kajander of Acme Printing Company; and the advice and encouragement of the Journal Editor, Ed Keane of Fay, Spofford and Thorndike, are gratefully acknowledged by the John R. Freeman Fund Committee.

View of Charles River Basin looking east; Cambridge at left, Boston at right, (MDC photo by Jack Maley, 1979)

John R. Freeman

JOHN RIPLEY FREEMAN AND THE HONEST DOUBTERS OF BOSTON: HOW THE CHARLES RIVER DAM WAS WON

By Deborah A. Cozort[1]

There are many examples of committees and commissions who have failed to convince the public of the merits of great engineering projects. The success of the Committee on Charles River Dam is rare and, in great measure, due to the efforts of John Ripley Freeman.[2] His classic *Report of the Chief Engineer to the Committee on Charles River Dam* is reprinted here as a tribute to his work. It also celebrates the designation of the Charles River Basin as a National Historic Civil Engineering Landmark.

This special issue of the *Journal of the Boston Society of Civil Engineers Section,* ASCE also contains Freeman's address on the project, delivered before the Society on June 24, 1903. A draft manuscript of the speech was discovered among Freeman's personal papers at the M.I.T. Institute Archives.[3] The manuscript is incomplete. Freeman's notes for the address indicate that it included a discussion of the chemist's report, temperature studies, and the examination of harbor currents. The address is so engaging and informative that the decision was made to edit it and include it in the *Journal.*

The papers printed here deceptively suggest that Freeman's meticulous analysis of the Charles River, the Basin and Boston Harbor was conducted in a calm, apolitical atmosphere. An examination of Freeman's correspondence indicates, on the contrary, that he and his survey teams faced problems familiar to contemporary civil engineers. Initially, the scope of the survey was underestimated, the Committee appropriation was inadequate, public sentiment on the dam was polarized, the Chief Engineer was overcommitted, a powerful lobby was actively working against a dam, and the deadline for the final report was unrealistic. When the survey was completed, the Chief Engineer even had

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[1]Archivist of the Scripps Institution of Oceanography in La Jolla, California; formerly Assistant Archivist, M.I.T. Institute Archives.

[2]Walter E. Spear, Freeman's principal assistant on the Charles River Dam survey and other projects, wrote an excellent biographical memoir on Freeman for the American Society of Civil Engineers, Trans., Vol. 98 (1933), p. 1471. It was reprinted in the *Journal of the BSCE Section,* Vol. 63, ASCE, No. 1 (April, 1976), p. 13.

[3]The Papers of John Ripley Freeman, 1827-1952 (MC 51), 120 record center cartons. In M.I.T. Libraries, Institute Archives and Special Collections. An inventory of the papers has been written with funding from the National Endowment for the Humanities. Copies can be ordered from the Institute Archives. The manuscript of the 1903 address can be found in Box 91, "Charles River Dam: Paper of BSCE."

difficulty collecting his fee.

John Ripley Freeman was forty-seven when asked to advise the Committee on Charles River Dam. He was already intimately familiar with the controversy and he knew many of the men who played principal parts in it. He had twenty-five years of civil engineering experience, ten of them working on hydraulics projects in New England. He was President and Treasurer of the Manufacturers Mutual Fire Insurance Company. He had served as Engineer Member of the Boston Metropolitan Water Board in 1895 and 1896, and his reputation as a hydraulician had more recently been enhanced by his exhaustive report on new sources of water supply for the Comptroller of the City of New York.

Freeman knew many of the men involved in the Basin controversy. Henry Smith Pritchett, Chairman of the Committee on Charles River Dam, was President of M.I.T., Freeman's alma mater. In fact, Freeman was an active member of the M.I.T. Corporation. Through M.I.T., Freeman also knew William O. Crosby, George L. Hosmer and William T. Sedgwick who were to assist him on the survey. Charles T. Main, an advocate of the dam, had been Freeman's classmate at Tech. The eminent civil engineer, Hiram F. Mills, Chairman of the Water Supply Committee of the Massachusetts State Board of Health, was Freeman's mentor. Mills was able to give Freeman an intimate view of the controversy and strongly supported the efforts of the Committee. Rudolph Hering, an expert witness for the opponents of the dam, was a colleague and friend.

Freeman did not seek the position of Chief Engineer for the Commission. He was quietly asked through a friend whether he would be interested in the assignment.[4] On February 9, 1902, he breakfasted with Henry S. Pritchett at the University Club in Boston and accepted the position. His compensation was established as sixty dollars for each day of seven hours,[5] and the appointment was confirmed in writing on March 7, 1902.[6]

The Charles River Dam appointment was not foremost in Freeman's mind when he accepted it. Pritchett initially conceived the role of the Chief Engineer as an advisory one which would certainly be completed at the end of the summer.[7] As Freeman later reminded Pritchett:

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[4]Edward Atkinson to JRF, February 7, 1902. In Freeman Papers, Institute Archives, Box 1, folder. 15.

[5]JRF diary, February 28, 1902. In Freeman Papers, Institute Archives, Box 1, f. 29.

[6]Henry S. Pritchett to JRF, March 7, 1902. In Freeman Papers, Institute Archives, Box 92, "Final Account, Charles River Dam."

[7]William O. Crosby to JRF, June 18, 1902. In Freeman Papers, Institute Archives, Box 18, f. 2.

> You had never intimated that extended field studies and surveys were to be part of the work. You had said that much of my work could be done by taking the papers and plans [home]. You had said that the Committee would want advice from other experts.[8]

Freeman had other, more pressing, matters on his mind in 1902. In addition to his full-time insurance work, Freeman served as Consulting Engineer to the New York Department of Water Supply, Gas and Electricity. He had received a lucrative offer to become Chief Engineer of the Department and spent time during the year consulting his colleagues to determine if he should accept the position. In July, the Secretary of War appointed him a civilian member of an army board on gun carriages. During trips to Washington, he met with friends in Congress to discuss an appointment to work on the planned canal in Panama. During the same year, Freeman wrote a report on the proposed Clarkesburg Reservoir near North Adams, Massachusetts. He supervised work on the dams of the Bee Tree Creek and North Fork branches of the Swananoa River in North Carolina, and wrote a report on water supply for the city of Asheville, North Carolina. Freeman also continued a long association with the St. Lawrence River Power Company and advised them on their hydraulics work. Freeman served on the boards of two banks and the Butler Hospital in Providence. He served on the boards of Brown University, the Massachusetts Institute of Technology, the Philadelphia Manufacturers Insurance Company, and Manufacturers Mutual Fire Insurance Company. Freeman also directed the construction of his new house in Providence, furnished it and plotted extensive gardens.

The most remarkable thing about Freeman's work in 1902 is that it was typical. He was a gloriously overworked engineer. He thrived for seventy-seven years on a diet of hasty conferences, insufficient data, exhausting travel, political obstruction and cost overruns. He often complained of ruinous hours, importunate committees, slow typists, and the effect of these upon his health, but his complaints were meaningless. When sorely pressed by a deadline, Freeman responded:

> It is true that I have led an exceptionally busy life and had many irons in the fire, but in the 27 years since graduation, I have only once *asked for* a job — that was then I began with Mr. Mills . . .[9]

[8]JRF to Henry S. Pritchett, September 28, 1903. In Freeman Papers, Institute Archives, Box 92, "Final Account, Charles River Dam."
[9]JRF to Henry S. Pritchett, September 28, 1903. In Freeman Papers, Institute Archives, Box 92, "Final Account, Charles River Dam."

It seems quite clear that even Freeman did not expect the report of the Committee on Charles River Dam to demand so much time. From its inception, the project was subject to unexpected delays. Freeman was engaged in February and planned to begin the work in April, but the work was postponed when Freeman's assistant, Walter Spear, contracted mumps. Spear recovered in May, but the report of the experts for the opponents had not been completed as promised.[10] Some work was underway in June, but the important survey of the basin was delayed far into July when the rebuilt survey boat was not completed on schedule.[11]

Time and weather became major problems in August, for the temperature study had to be conducted during the summer months, and the sewer overflow study required rain. Freeman warned Pritchett that overtime would be necessary if the survey teams were to complete their work in the summer, but he still felt confident that:

> . . . the work [will be] in an advanced state ready for some preliminary conclusions early in September, and [I] will do my best to have it rounded up by October 1st.[12]

Indeed, the work might have been finished by the fall of 1902 if Freeman had been content with the modest role of the Chief Engineer envisioned by the Committee. Freeman's motto, however, was "nothing is settled until settled right."[13] Throughout the spring and summer, he began to realize that a simple review of previous surveys and testimony was not sufficient. It would be necessary to collect new data to decide properly issues such as the alleged pollution of the basin and the navigation arguments of the opponents.

On May 26, 1902, Freeman urged Pritchett to authorize William Otis Crosby to study the geology of Boston Harbor and to investigate subsidence of the coast.[14] On August 9th, Freeman informed Pritchett that a

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[10]Joseph Lund to J.R.F., May 24, 1902. In Freeman Papers, Institute Archives, Box 18, folder 3. Said Lund, "It has proved almost impossible to get Prof. Porter and Mr. Hering to hand in their reports." Freeman did not receive Hering's report until August 7th.

[11] Walter Spear to J.R.F., July 16, 1902, in Freeman Papers, Institute Archives, Box 91, "Charles River Dam: Temperature, Sewer Overflow, Miscellaneous." The rebuilt boat was finally completed in mid-July but proved inadequate. Freeman bought a new boat in August. A rented steamer-yacht, the Eleanor, was used for some survey work in the Harbor, but she was run down by a schooner in November with the survey team aboard her. No one was hurt.

[12]J.R.F. to Henry S. Prichett, August 9, 1902, in Freeman Papers, Institute Archives, Box 7, folder 8, p. 319.

[13]J.R.F. notes for an address before the Boston Society of Civil Engineers, 1903. In Freeman Papers, Institute Archives, Box 91, "Charles River Dam: Temperature, Sewer, Overflow, Miscellaneous."

[14]J.R.F. to Henry S. Pritchett, May 26, 1902. In Freeman Papers, Box 7, folder 8, p. 117.

survey of the Basin would be necessary:

> From interviewing [the] Chief Engineer of the Harbor Commission, I found there was no reliable surveys or maps in existence showing present conditions in the Basin . . . We therefore arranged with Mr. George L. Hosmer . . . to take charge of a new survey of the Basin.[15]

On August 26th, he instructed Dr. Theobold Smith to expand the study of mosquitoes breeding along the River and to conduct a bacteriological analysis of the Basin.[16] By the end of August, Freeman noted:

> I have not got anywhere near to the bottom of the pollution question yet and am troubled at the time and labor required to uncover the facts.[17]

Members of the Committee on Charles River Dam also contributed to the expansion of Freeman's role. Richard Dana asked Freeman to investigate the "closed" gates of sewers during summer storms to determine sewage overflow. The Secretary of the Committee asked Freeman to consult with representatives of the railroad concerning the proposed Craigie Bridge site of the dam.[18] The Committee required Freeman to spend considerable time revising his report and that of the other experts, and later the Legislature asked him to refine his estimates of the cost of a dam and consider sites other than Craigie Bridge. Gradually, the deadline for Freeman's report was pushed further and further into the future.

Certainly, Freeman's first goal as Chief Engineer was to compile data concerning the issues raised by the opponents of the dam. As time passed, however, he felt increasingly responsible for the work of the entire Committee. Freeman's sense of responsibility was intrinsically tied to his view of the role of an engineer. He once remarked to his colleague William Crosby:

> My own rule has been not to allow myself to be used by a lawyer for the manufacture of testimony and not to go into a case unless I was well convinced of the merits and justice of the case and desirous of seeing the side that sought my services win.[19]

[15]J.R.F. to Henry Smith Pritchett, August 9, 1902. In Freeman Papers, Institute Archives, Box 7, folder 8, p. 322.

[16]J.R.F. to Theobold Smith, August 26, 1902. In Freeman Papers, Institute Archives, Box 91, "Charles River Dam Reports."

[17]J.R.F. to Hiram F. Mills, August 26, 1902. In Freeman Papers, Institute Archives, Box 7, folder 8, p. 366.

[18]Joseph W. Lund to J.R.F., June 2, 1902. In Freeman Papers, Institute Archives, Box 91, "Charles River Dam: Temperature, Sewer Overflow, Miscellaneous."

[19]J.R.F. to William O. Crosby, May 11, 1903. In Freeman Papers, Institute Archives, Box 7, folder 9, p. 459.

Eventually, Freeman undertook the supervision of the work of all of the Committee experts as well as that of the survey teams. He also identified and unified the tone of the experts' reports:

> At the time these reports were drafted, it was, of course, not known just how the Legislature and the public were going to receive this proposition, and I felt it was very desirable to set everything forth with such fullness that if the work ever had to be done over again, the next investigator could pretty nearly start where you left off; moreover, I felt that it was good business policy to set forth our investigations at such length that any legislator or good citizen, who was particularly interested, could see for himself that we had tried to study these questions thoroughly.[20]

It is a tribute to Freeman's quality of leadership that his scrutiny of the work of other Committee experts did not cause resentment. He noted in a letter to Hiram Mills that "Crosby submitted very nicely to this effort, although Clark . . . rebelled vigorously."[21] In the end, Freeman had the final editorial word on the reports of the experts. Since the report of the Committee on Charles River Dam was only thirty-seven pages, and the report of the Chief Engineer with appendices was five hundred and thirty-five pages, Freeman's control over the work of the experts gave him virtual control of the published report of the Committee.

Despite the expansion of the work and the delays, Pritchett was determined to have the report completed by January 14, 1903, as mandated by the Legislature, but on January 15th, Freeman wrote Hiram Mills:

> The Committee submitted its Report yesterday noon together with a statement that the Engineer's Report and the Appendices were *in the hands of* the printer. Literally, this may be understood that the printer has hold of one end while I have hold of the other end . . .[22]

Freeman did not turn his last proof sheet in until April.

Freeman was a painstaking engineer, but his thorough work on the survey was not entirely inspired by this trait. The Committee on

[20] J.R.F. to Louis F. Cutter, March 31, 1903. In Freeman Papers, Institute Archives, Box 7, folder 9, p. 348.

[21] J.R.F. to Hiram F. Mills, January 28, 1903. In Freeman Papers, Institute Archives, Box 7, folder 9, p. 145. Harry W. Clark, author of The Chemist's Report, Appendix No. 4, told Freeman, "Popularizing cheapens . . . and sometimes leads one to make statements more broadly than true science will allow . . ." See Harry W. Clark to J.R.F., December 9, 1902, in Freeman Papers, Box 91, "Charles River Dam Reports."

[22] J.R.F. to Hiram F. Mills, January 15, 1903. In Freeman Papers, Institute Archives, Box 7, folder 9, p. 88.

Charles River Dam faced a serious and well funded opposition which had already defeated one board favoring a dam. Although Freeman jests about the status of the Beacon Street opponents in his address before the Society, they were prominent men who understood politics.

The roots of the opposition in 1902 go back to 1894. Opposition to a dam in 1894 consisted of a powerful coalition of Beacon Street property owners and the Boston commercial community. This coalition was created by a committee of Beacon Street residents described by one of its members, the distinguished lawyer Louis S. Dabney:

> We got together and consulted, and appointed a committee. That committee was composed of the late Mr. George O. Shattuck, who died on the 4th of February, 1897, Mr. Charles Head and myself. When Mr. Shattuck died in 1897, he was succeeded by Mr. William Caleb Loring, who on September 7, 1899 was appointed a justice of the Supreme Court of Massachusetts; and he was then succeeded by Mr. Howard Stockton . . .[23]

This Committee consulted two engineers, Col. George E. Waring and Dwight Porter. The Committee was advised of several issues that supported their initial negative view of the desirability of a dam. One of these issues was the alleged untoward effect a dam might have on Boston Harbor and navigation. This issue alarmed a number of powerful business concerns whose commerce depended directly or indirectly on the Harbor. The Citizen's Association of Boston and the Associated Board of Trade, influential business associations in the city, joined the opposition.

The Beacon Street Committee knew how to press an advantage. They engaged two former governors of Massachusetts, John Davis Long and William Eustace Russell, to represent them before the Joint Board. The Board was helpless before such opposition, particularly since it had materialized so rapidly.

The Beacon Street Committee did not oppose the appointment of the Committee on Charles River Dam in 1901. They did, however, continue to oppose a dam and revitalized their committee by receiving the renewed endorsement of seventy-six residents of the water side of Beacon Street.

Several changes had occurred since 1894 that affected their organiza-

[23]*Evidence and Arguments before Committee on the Charles River Dam, Appointed under Resolves of 1901, Chapter 105. December 16, 1901 through January 1903.* Boston: Printed for the State by Wright and Porter, 1903, p. 309.

tion. George Waring, the sanitary engineer who had consulted with the Committee in 1894, had died of yellow fever in Havana in 1898. William Russell had died in 1896, and their other attorney, John D. Long, was serving in Theodore Roosevelt's Cabinet and was thus unavailable to represent them. The Committee had also suffered from bad press. The newspapers generally favored the dam and characterized the opposition as shortsighted wealthy men who had employed paid experts to defeat the dam.

These reverses were bad enough, but the Beacon Street Committee also faced a group of men favoring the dam whose wealth and social position perhaps exceeded their own. These were the petitioners to the Committee on Charles River Dam and included Charles W. Eliot, President of Harvard, Henry Lee Higginson, philanthropist and founder of the Boston Symphony Orchestra, James J. Storrow, and John F. (Honey Fitz) Fitzgerald. Not to be outdone by the opponents, the petitioners employed Boston hydraulicians Percy M. Blake and J. Herbert Shedd and retained the eminent counsel of Nathan Matthews, former Mayor of Boston.

The petitioners sallied forth to neutralize the Beacon Street Committee even before the Committee on Charles River Dam met to hear testimony. They explained their advocacy of the dam to the Boston press, they leafleted Beacon Street, they circulated petitions, and they collected seven thousand letters from citizens of Boston in favor of the dam. They were, in fact, determined that the issue of the dam would be settled. As James J. Storrow testified:

> This is the third or fourth commission that has dealt with this subject, and we will have more commissions, unless this committee takes up the subject and gives not merely a yes or no, but makes the matter sufficiently plain so that the ordinary citizen can understand it and be satisfied with the justice of the result.[24]

All of those in favor of a dam clearly understood that no dam would be built if the Beacon Street Committee could successfully mobilize the support it enjoyed in 1894. Its general strategy was to divide and conquer. The consulting engineers to the petitioners, Shedd and Blake, studied the Boston Harbor issue and discredited the statement that a dam would adversely affect harbor navigation. The Committee on Charles River Dam, through Freeman, successfully courted the Cambridge property owners who had opposed a dam in 1894. A.E. Pillsbury, counsel for the property owners and occupants of the Cambridge

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[24]*Evidence and Arguments* . . ., p. 153.

shore and the Broad and Lechmere canals, reached an agreement with counsel for the petitioners that his clients would no longer oppose a dam.[25] The Citizen's Association of Boston and the Associated Board of Trade also dropped their opposition to the dam.

When the smoke cleared, the Beacon Street Committee members found themselves alone in the field, and they were unhappy about it. They did, however, still have a number of influential members and a strong argument. They insisted that no one could prove, on the basis of evidence available in early 1902, that the dam would not have an adverse affect on the health, harbor and climate of the surrounding communities.

Thus, after the testimony before the Committee on Charles River Dam was completed, the fate of the dam was in the hands of Freeman. He had to prove that a dam would not have any ill effects. Always politic, Freeman referred to the members of the Beacon Street Committee as the "honest doubters." His personal opinion of them may not have been as sanguine. In his address before the Society, Freeman ridiculed the members of the Beacon Street Committee, but he saved his worse criticism for one of their consulting engineers, Dwight Porter:

> For an expert to do what a certain engineer friend of ours . . . did in the Charles River Dam case, leaves a very unpleasant odor, and I believe that every time that you or anyone of us enters a lay case as a partisan for hire, he dulls his keeness of perception of the truth and impairs his moral strength and his highest usefulness.[26]

The press joined Freeman in criticizing the motives of the Beacon Street Committee and, even thirty years later, these committeemen were lampooned by John Marquand in his novel, *The Late George Apley*.[27] The opponents were roundly defeated not only for the moment, but for all time. In parting, they criticized two portions of Freeman's work; his estimates of the cost of the dam and the appendix on the geology of the region.[28] Ultimately, they capitulated with some grace and withdrew their objections to the dam in exchange for some sanitary amendments to the enabling bill.[29]

Freeman was justifiably proud of his work for the Committee on Charles River Dam. It is a pity that his pleasure and that of the Com-

[25] *Evidence and Argument* . . ., p. 459.

[26] J.R.F. to William Otis Crosby, May 11, 1903, in Freeman Papers, Institute Archives, Box 7, folder 9, p. 459.

[27] John P. Marquand, *The Late George Apley*, New York: Grosset & Dunlap, 1936, pp. 122, 146.

mittee was spoiled by a dispute over the payment for his services. Henry Smith Pritchett, the Committee Chairman, felt that Freeman should not have billed the Committee for the work he had done after January 14, 1903, the expiration date of the Committee. Freeman disagreed — vehemently. "I propose to keep at that bill *until you and Mr. Dana comprehend the facts,*" said Freeman.

> A fee 50% greater than that charged would not have tempted me to put in the "strenuousity" that I did put in as the result of finding myself "up against it," and a desire to conscientiously find out whether the basin was likely to become foul and whether tidal sluices costing a quarter of a million, or conduits costing half a million, must be added. . .
> You will note from the time given that I devoted most of my Sundays to the work, and there are very few who could have put in the time that I did for so long a period without breaking down . . .[30]

Freeman finally settled for the payment of three-quarters of the fee he had submitted. His view of this compromise is not recorded. The disputed bill did, however, serve one good purpose. Freeman carefully culled his papers to document the bill for Pritchett and in so doing, he created a fascinating record of his work on the Charles River Dam project.

It is that record, housed now at M.I.T.'s Institute Archives, that enables us to present Freeman's view of the Charles River Dam project.

[28]The contention that the New England coast was subsiding sparked debates in several newspapers including the New York Times (June 23, 1903). One of Freeman's associates, however, suggested that the dispute was psychological rather than geological. "I have your report on the Sinking Condition of Boston," said Stephen Edwards:

> It contradicts all notions that Bostonians have of their own city and I fear that evén your scientific report will not convince them that their tendency is downward rather than upward.

S.O. Edwards to J.R.F., June 29, 1903, in Freeman Papers, Institute Archives, Box 91.
[29]See *Boston Herald,* February 15, 1903, "The Proposed Water Park."
[30]J.R.F. to Henry S. Pritchett, September 28, 1903, in Freeman Papers, Institute Archives, Box 92, "Final Account, Charles River Dam."

SOME PROBLEMS OF THE CHARLES RIVER DAM[1,2]

By John R. Freeman

The proposition to dam the tidal estuary of the Charles lying between Boston and Cambridge has been before this community and a subject of legislative inquiry, at one time and another, for more than forty years. The suggestion came naturally from a desire to avoid the offensive appearance and odors from portions of the large areas of mud flats uncovered at low tide. The earliest suggestion was somewhat vague as to details but proposed the control of the water level. This obviously involved some kind of dam, and the agitation of 1869 which reached the state of legislative inquiry involved a dam of height sufficient to flood the flats.

Half tide dams and full dams, salt water basins and fresh water basins have been proposed, and the proposed location has ranged all the way from Craigie Bridge to a point three miles up the stream near the foot of the narrow river and the head of the broad basin. Eminent citizens famed for public spirit and breadth of view have favored it. Other eminent citizens doubting its feasibility from a sanitary standpoint have earnestly opposed it. Mayor Matthews[3] at his inaugural in 1891 recommended the project in earnest terms saying:

> [W]e have in this basin the opportunity for making the finest water park in any city in this country, an opportunity which should be grasped before it is too late. The eventual solution of this whole problem should, I think, be an imitation of the plan adopted by the City of Hamburg under similar circumstances. We should dam up the stream at the narrowest point between Charlestown and Boston and lay out a series of boulevards along the basin thus created.

The Massachusetts Legislature of 1893 by Chapter No. 475 enacted that the newly established board of the Metropolitan Park Commissioners and the State Board of Health sitting as a Joint Board should investigate the sanitary condition and prepare plans for the improvement of the beds, shores and waters of the Charles River between Charles River

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[1]From a draft manuscript found among Freeman's private papers in M.I.T. Archives. Prepared for publication by Deborah A. Cozort, Assistant Archivist.

[2]The Annual Report of the Board of Government of the Boston Society of Civil Engineers, for the year 1903-1904, p. 2, cites that at the June 24, 1903 meeting the following paper was read: "John R. Freeman, 'Problems connected with the proposed Charles River Dam.' (Illustrated)".

[3]Mayor Nathan Matthews of Boston represented the Petitioners in favor of the dam before the Committee on Charles River Dam in 1902.

Bridge and the Waltham Line.

The scientific investigation of the problems presented may fairly be said to have begun with the work of this Joint Board, notwithstanding their limited appropriation (their engineering expenses were only about $2,800.00). They outlined the main problems so completely that the more recent board has found reason to differ from them only in some of the details, such as means for removing the pollution from the basin and in proposing that the dam shall form part of a new Craigie Bridge instead of being located 600 feet up stream. [The] strong endorsement of the project given by these two boards . . . failed to [convince] all the honest doubters, and strong personal interests were aroused in opposition.[4]

It is considered by many that under the strong recommendation of the Joint Board of 1894 the Legislature would have authorized the work and the cities [would] have supported it, had not the project as then presented contained a proposal to fill a long strip of the tidal basin 300 feet wide in the shabby water-side of the Beacon Street houses. [The proposal would thereby have made] available a new tier of lots upon which residences might be built presenting a facade appropriate to a water park. [T] he sale of [these] lots would doubtless have paid the cost of the entire improvement, but the chief spokesman for the opponent[s], the eminent lawyer Mr. L. S. Dabney, a resident of the adjoining territory, says that [they] feared the unsanitary condition of a sewage pollut[ed] . . . . . fresh water lake, and would have opposed the project with equal vigor had the filling of this new tier of lots been abandoned.

A veritable howl of indignation arose from Beacon Street, and as the residents of that region are reputed to have money to burn, . . . intelligence, standing and great influence in the community, there were soon plenty of opposition and no lack of eminent counsel at work probing the scheme . . . and emphasizing the doubtful [pollution argument].

Meanwhile, the Park Commission and the State Board of Health said but little. They had investigated so far as a limited appropriation would permit. [They] had presented a carefully considered report and upon it they rested. The chief claims in opposition were first that the health of

[4]Freeman's manuscript characterized the boards as having ". . . added to the fame of Massachusetts throughout the length and breadth of this continent, one by the thoroughness and skill of its investigation, the other by breadth of conception and beautiful execution of its work." — ed.

[the] community would be endangered by the sewage polluted basin; second that malaria would be invited by increased dampness of the soil due to the elevation of the ground water; [third] that the cooling influence of the influx of [a] large body of salt ocean water twice a day would be lost; fourth that the navigation interests around the basin would suffer; fifth, that the commercial interests of Boston would be threatened and the shoaling of the main channels of its harbor [would be] invited by cutting off the scouring action of [the] tidal prism.

The Park Commission had already shown the desirability of the project, the State Board of Health had rendered its opinion on the sanitary questions involved, and so the Legislature naturally passed the harbor problem along to the State Board of Harbor and Land Commissioners, directing them by Chapter 85 of the Resolves of 1894:

> To inquire into the construction of a dam and lock in the tidal basin of Charles River, with special reference to interference with the tide water and its special effect upon the harbor of Boston — and a sum not exceeding $1,500.00 is allowed for the necessary expenses of such inquiry and hearing.

Naturally, with so limited an appropriation, the Harbor Commission did nothing in the way of scientific or practical inquiry through its own engineer but simply gave an opportunity for all persons desiring to be heard to present their views. Seventeen hearings were given and a thousand pages of printed testimony and argument recorded, but a small part of which was devoted to Harbor questions. The bulk of the testimony related to problems within the special province of the Board of Health and that of the Park Commissioners.

Expert testimony in opposition [to a dam, with respect to the sanitary issue] was presented by Professor [Dwight] Porter, George E. Waring, Jr. and Dr. Henry J. Barnes, and in favor . . . by F. P. Stearns, Albert F. Noyes and Prof. Sedgewick.[5] Marinden and Whiting of the Coast Survey [testified] on the harbor question. The burden of the defense rested on a few statements by Mr. Stearns. Eminent citizens appeared on both sides. President [Charles W.] Eliot [of Harvard], Henry D. Yerxa, E. D. Leavitt and Asa M. Tice were heard in favor [of the dam] while L. G. Burnham, President of the Associated Board of Trade, William H. Lincoln, [and] Captain Humphrey, Treasurer of the Boston Tow Boat Company, spoke earnestly of the impending danger to Boston Harbor. Eminent counsel, among them two ex-governors of Massachusetts,

[5]This is probably William Thompson Sedgwick, M.I.T. Professor of Biology.

appeared for the opponents while the city solicitors of Watertown, Cambridge and Newton argued in support of the proposition.

The State Board of Health and the Metropolitan Park Commission, as befitted their dignity, did not appear before the collateral branch of the Board of Harbor Commissioners to urge this project. Although Mr. Stearns, the chief engineer of the Joint Board, appeared by request, [he did not take] the time to prepare any special report, for those were the days when he was working to the limit of endurance on his report for the Metropolitan Water Supply. The fight was plainly in the hands of the opposition.

As already stated, the Harbor Commissioners had an appropriation of only $1,500.00, barely sufficient to pay the stenographer and the expenses of the hearing. They apparently did not feel called upon to make any investigation on their own account.

Their verdict was that a full and exhaustive investigation would have to be made before anyone could foretell with reasonable certainty what the effect of a [Charles River] dam would be. [They] concluded their report with the words:

> . . . in view of the incalculable injury which might ensue from [impairing] the usefulness of the harbor, we are unable to report in favor of the recommendations contained in the report of the Joint Board.

On the sanitary questions, the [Commissioners] stated that, in view of this conclusion, it was thought to be unprofitable to indulge in any discussion of the testimony. [They] ventured the statement that in view of the irreconcilable [testimony] of the experts, [the Commissioners were] unable to say that the conclusion of the Joint Board might not justify the experiment so far as sanitary objections were concerned.

A meritorious case failed from lack of investigation and presentation complete enough to satisfy the conservatives and the honest doubters. Victory rested with the opponents and almost nothing more was heard in public of the scheme for the next six or seven years. I have heard some of the foremost advocates of the project say within the past year that they were now not sorry for the defeat, that there had been developments in these eight years which favored changes in the original plans and now the time was ripe for doing a more perfect and beautiful work.

About two years ago the project was revived under the lead of Henry L. Higginson, philantropist and financier, foremost in many good works for the public good. [Higginson was aided by] Augustus Hemenway, likewise a lover of his kind, whose interest in wholesome recreation is shown by the name borne by the gymnasium of Harvard University. James J. Storrow, son of one of our foremost lawyers, himself a rising lawyer and financier, a lover of wholesome recreation who had pulled the stroke oar and been a coach of Harvard crew, and other public spirited citizens earnest in the belief that this great improvement should not wait longer, started upon a campaign of education and prevailed upon the Legislature of 1901 to appoint a Committee for a thorough investigation of all these questions.

The Governor and Council gave evidence of careful attention to the Harbor problem in the makeup of this Committee. [The Chairman was] Dr. [Henry Smith] Pritchett, President of [M.I.T.][6] . . . and recent[ly] superintendent of the U.S. Coast Survey. Colonel Samuel M. Mansfield [was] an officer of high rank in the U.S. Corps of Engineers [who had formerly been] in charge of the improvements in the channels of Boston Harbor [and the planning of] the new Broadsound Channel. In Richard H. Dana [they] found a man of the highest standing in the community who had already given largely of his time *pro bono publico* and in whom the citizens of both Boston and Cambridge would have great confidence.

The Committee [on the Charles River Dam] was directed in specific terms to investigate the desirability and feasibility [of the project.] An exceptionally wise feature of the [enabling] statute . . . authorized the expenditure of such funds [for] investigations as the Governor and Council might determine. The [Committee] began the investigation with a series of public hearings. [They] first asked the various municipal boards and commissioners of public improvements whether a dam would interfere with present or prospective public works, . . . thus wisely opening the question in its broadest terms.

The Street Commissioner of Boston presented maps showing the relation of the drainage and the sewerage system to the water level and the flow of the Charles. The Chief Engineer [of the] Metropolitan Sewage Board described the relation of these sewers to the Charles and the necessity of their overflow into the basin in time of storm. [He also] gave estimates showing the small extra cost of sewage pumping that would be caused by raising the overflow level. The City Engineers of Boston, Cambridge and Newton and the Town Engineers of Brookline

[6]Freeman referred to M.I.T. in his manuscript as ". . . what we believe to be the foremost scientific school of the country . . ." Freeman graduated from the Institute in 1876 and served as a member of its Corporation. -ed.

and Watertown described the relation of their sewers to the river. Some of these city officials admitted that a good deal of sewage now got mingled with the natural flow of Stony Brook and thus entered the Fens and the Charles. The City Engineer of Cambridge presented statements indicating that seven percent of all the sewage of Cambridge now found its way into the Charles. The faculty of Tufts College Medical School located near the Fens called attention to the discharge of large quantities of sewage into the Fens Basin. The Harbor Commissioners sent their engineer, but he confined his testimony to a statement of the construction work in progress and declined to enter into the premeditation of opinions on the Harbor question. The Commandant of the Watertown Arsenal, the Chairman of the Boston Park Commission and the Chairman of the Cambridge Park Commission each appeared and stated the relation of works under his charge to the proposed improvement.

Perhaps the most interesting statements were those from the State Board of Health and the Metropolitan Park Commission. The Chief Engineer of the State Board of Health presented a very full statement containing many statistics and computations and claimed that the upland Charles below the head of the proposed basin was more free from direct sewage pollution than any river of equal size in eastern Massachusetts. [He further claimed] that the sewage entering the basin of the Charles after the new high level sewer was completed would be utterly insignificant in proportion to the flow of the river and "could not be regarded as a menace to the health of those boating on the basin or living upon its boarders."

Mr. Las Casas, Chairman of the Metropolitan Park Commission showed how the [Charles River] estuary had been encroached upon from time to time until more than half its area had been filled. [He] also give a history of the park improvement along its shores and showed that nine-tenths of the toal shore line of seventeen miles around the proposed basin had now passed into public ownership. [He stated] that the Metropolitan Park Commission had not acquired its holdings in a haphazard manner for the mere purpose of making parks here and there but that each was part of a comprehensive plan and that, "the Charles River is the central feature of the Metropolitan Park System both as a waterway and as a parkway." [Mr. Las Casas] eloquently urged that the transform[ation of] this basin into a water park was a logical consequence of natural location and of the work already done and that any shortsightedness today would call for a heavy penalty in increased expenditure hereafter. This first stage of the hearings clarified the relation of all public works around the basin to the project in question.

The Massachusetts Civic League presented petitions in favor [of the dam] signed by five hundred residents of the crowded North End. President Eliot of Harvard made a strong plea stating that the project was in the interest of the people by the hundred thousands, that the dam was essential to . . . beauty and the sanitation of the valley with its extended low lands and marshes. The Roman Catholic Vicar General of the Archdiocese [and] the Episcopal Bishop of Eastern Massachusetts urged this park improvement on broad humanitarian grounds . . . Congressman Fitzgerald urged it as a representative of the crowded North End and John Shepard urged it as a resident of the Back Bay. Mr. Gamaliel Bradford and others living near the Charles opposed the project with equal earnestness and claimed that the whole scheme was merely an effort to provide the boating men of Harvard College with a better waterway for their races. There was plenty of other testimony both general and expert. Mr. Percy Blake presented a very full study of the problem on behalf of [project advocates], bringing out many facts to show that it was entirely safe from every standpoint. Mr. J. Herbert Shedd presented facts and figures showing that nothing unsanitary was to be feared and that the harbor surely would not suffer.

Professor Porter, on behalf of the opponents, presented a report in which he found against the dam on every point. [He] found that the Alster Basin of Hamburg was not a safe guide on sanitary questions because [it is] located 700 miles nearer the North Pole and in a cooler climate. [He said] that the foul Fens Basin was but a prototype of the proposed basin, that the remaining undredged mud flats are not large or particularly offensive, and that the shores not yet improved could be sloped and made attractive for a small sum. . . . [Professor Porter reported] that it was doubtful that the proposed basin would ever be largely used for pleasure boating and that skiffing upon it would be unsafe. [He advised] that the bathing at Captain's Island would no longer be sanitary or agreeable. [He noted] that the building of the dam would not prevent possible flooding of the marshes in extreme freshets and high tides, and that the constant level of the dam because of ice would injure the navigation. . . . [Professor Porter estimated] that the temperature of the basin water would be raised 8 or 10 degrees and the temperature of the breezes blowing over the basin would be materially warmer than now and less wholesome.

Mr. Rudolph Hering was strong in the belief that unless [special] arrangements were added . . . the basin as proposed would unquestionally have disappointing results [and] would probably be injurious to health and certainly to comfort. [He] insisted that the sewage now entering the basin must be excluded. He said, "most of the solid sewage will remain suspended or deposited nearer the shores and create conditions unworthy of a park."

In the twelve days of hearings the Committee [on Charles River Dam] accumulated a large and varied assortment of maps, statistical tables, blueprints, inferences and opinions - a mass of testimony that filled between three hundred and four hundred closely printed pages.[7] [The testimony would] doubtless have exceeded [the] thousand pages of testimony [accumulated by] the Harbor Commissioners had not the Chairman called a halt. On oral testimony in the form of question and answer which alone appears to have standing in courts of law, he stated with a positiveness that was refreshing that this slow and disjointed method was a waste of time. [He] urged that the expert testimony be presented in the form of written reports. Notwithstanding the violent protest of counsel, this course prevailed.

Distinguished counsel on both sides summed the various points, and on almost every important point the experts called by the proponents were diametrically opposed by the experts called by the opponents.

I was asked to review the testimony and get it into parallels and to aid the Committee in its construction. Then came my days of sorrow. To untangle this conglomeration of facts and opinions, to get opposing statements in parallel, to trace back the data on which they rested, to arrange all this in [a] form convenient for members of the Committee to weigh, and incidently to present some opinions of my own was no easy task particularly as it was desired that I also review the evidence of 1894. Reconciling the views of my friend Porter with those of my friend Blake or those of my friend Goodnough with the diametrically opposite opinions of my friend Hering was impossible. After tracing back their data, I shunned the responsibility of declaring which was making the shrewdest guess from the insufficient data.

For a time I almost began to envy those experts of the court room whose lawyer friends tell them what they are expected to prove. I began to sympathize with the Harbor Commissioners and wish that I might dodge a decision on the sanitary question and imply that Harbor shoaling was one of those things that no fellow could [predict].

It became more and more clear that insufficent exact reliable data

[7]***Evidence and Arguments before Committee on the Charles River Dam, Appointed under Resolves of 1901, Chapter 105. December 16, 1901 through January, 1903.*** Boston: Printed for the State by Wright and Potter, 1903. Actually, the volume is 553 pages with maps and illustrations. —ed.

was at the bottom of all of the difficulties. Many of the differences of opinion brought out both in the hearing of 1894 and of 1902 came from men of different points of view working from insufficient data. Many of the points in controversy, although now matters of opinion, could be made matters of fact by field work and measurements, by observation and experiment. I reported to the Committee [on the Charles River Dam] that I must put engineering parties into the field before presenting a report which would justify conviction.

The Committee responded nobly. Several engineering parties were put into the field. Some of the most eminent specialists that could be found were called in to assist us by further observation and experiment on some of the most puzzling questions. I never would have dared to undertake this work in addition to previous engagements had I realized what it would come to. Days of sixteen hours were the frequent rule and a man never had more loyal or willing helpers. Spear, Carter, Armstrong, Pierce, Ireson and others worked far into the night week after week without complaint, each earnest to help in getting our data into the best possible shape before the time appointed for a report. If there are engineers who see signs of imcompleteness in some matters as, for example, boring and ground water determination, or lack of scientific polish or elaboration in some of the special studies, we must ask to bear gently with us for the date for the report was fixed by law.

As in many another problem, the way cleared up as we advanced. It all looks clear and easy now, but I will confess that there were [difficult] weeks while I was studying the pollution and finding more and more from day to day and [I was] particularly [discouraged] after talking with some of my friends of the city engineering department whose ten or twenty years of acquaintence with the sewer system had made them fearful of anything more than a half tide dam. I was myself in doubt about the sweetness of a stagnant lake receiving occasional overflows of sewage.

We quickly used up our first appropriation. Dr. Pritchett [the Committee Chairman] went to the Governor and Council and told them where we were and what we were up against. If we stopped with the initial appropriation, the answer to the problems would be imcomplete. Additional funds were twice granted [and our work] continued. . . . In all of this engineering work we expended a little less then $30,000.00 leaving a little more than $20,000.00 for rent, lithography, printing and the expenses of the Committee and the secretary.

I believed at the time and still believe that this money was wisely spent. It appeared to me that a great case was on trial before the public and that the completeness of evidence, thoroughness of data, and quality of expert advice should [meet the standards of] eminent counsel in an important case. Judged by these standards our expenditures were moderate. The simpler problems of the Whitehall Pond case cost each of the contestants about $35,000.00, and I have repeatedly seen water diversion cases and the valuation of water works cost much larger sums.

Having in a long introduction thus told the story of the case, we will now discuss the investigation of some of its special problems.

Map of the Basin

As a starting point for several investigations we made surveys for a new map showing the depth of water in all parts of the basin from Craigie Bridge to the dam at Watertown, with contours of depth drawn at one foot intervals. The surveys of the lower half were in the charge of Instructor [George L.] Hosmer of the Institute of Technology during his summer vacation. The Metropolitan Park Commission helped us out in the survey of the upper half. This map gave us accurate data for the areas of flats uncovered at low tide, for computing the cost of dredging these flats. [The data] were also of use in our sanitary and biological studies, for [as a result of] dredging for the Cambridge embankments, filling portions of the Boston shore, and improving the margins further upstream, the bed of the river had undergone great changes since the previous survey. There was nothing connected with this survey which was in any way out of the ordinary and nothing about which I need take your time.

Remedies for Pollution

The problem of the pollution [of the Charles Basin was central to] the main question of whether or not a dam and basin were feasible and advisable. [Reports written by experts measuring the pollution were appended to the final report of the Committee on Charles River Dam.] The five appendixes containing these reports in condensed form covered more than 200 pages. [E]ach one of these appendixes might easily cover a paper occupying an entire session of this Society. To touch upon them in the time at my disposal, I must further consolidate the reports . . . and can therefore not go into details.

The two main questions about pollution are first, whether the amount was sufficient to produce offensive conditions, and second, how to dispose of it. We had lots of testimony on this subject and it was made up of opinions rather than fact of observation. The experts estimated the proportion of the sewage [which escaped into the Charles River] from one percent to seven percent of the entire amount from the adjoining thickly settled territory. It was stated by experts of high standing that the amount of the sewage to enter the basin could certainly be taken care of . . . by natural forces. [Other] experts of high standing strongly maintained that these overflows of sewage would shortly make the basin very abusive to sight, smell and health.

Professor [Dwight] Porter concluded that the condition of the proposed basin would shortly become very abusive and referred to the present condition of the basin in the Back Bay Fens as an illustration. Mr. Percy M. Blake reviewed sewer gauge records of Cambridge and other cities and records of rainfall. [He] found that the river flow was more than ample to dilute [the sewage] beyond notice and concluded that the present sewage overflow into the Charles could be cared for by the existing natural forces without any special salt water sluice and special marginal conduits. Mr. Goodnough presented a very complete study based on a theoretical discussion of the sizes of the sewers, the rainfall records and the pollution from each. [He] concluded that there was no danger of the basin becoming abusive.

Mr. Rudolph Hering stated

> . . . . . a theoretical computation of the amount of filth escaping from the overflows may be far from giving the true results regarding the expected quality of the water, for they deal with averages. I cannot agree to such a method of computation in this case.[8]

[He] concluded that the proposed basin would surely be abusive unless all overflow of sewage was prevented from entering it. The late Mr. George E. Waring in 1894 had reached opposite conclusions.

Mr. Stearns, you will remember, was exceptionally familiar with the Boston Main Drainage System having had an important share in its direction and subsequently been charged with its management for two years. [He] concluded in 1894 that no danger whatever was to be apprehended on sanitary grounds. [He noted] that, should objectionable waste by any chance appear, the basin could be temporarily flushed out with harbor water. [I]t must be borne in mind [however] that Mr. Stearns had reached this conclusion eight years ago, before Stony

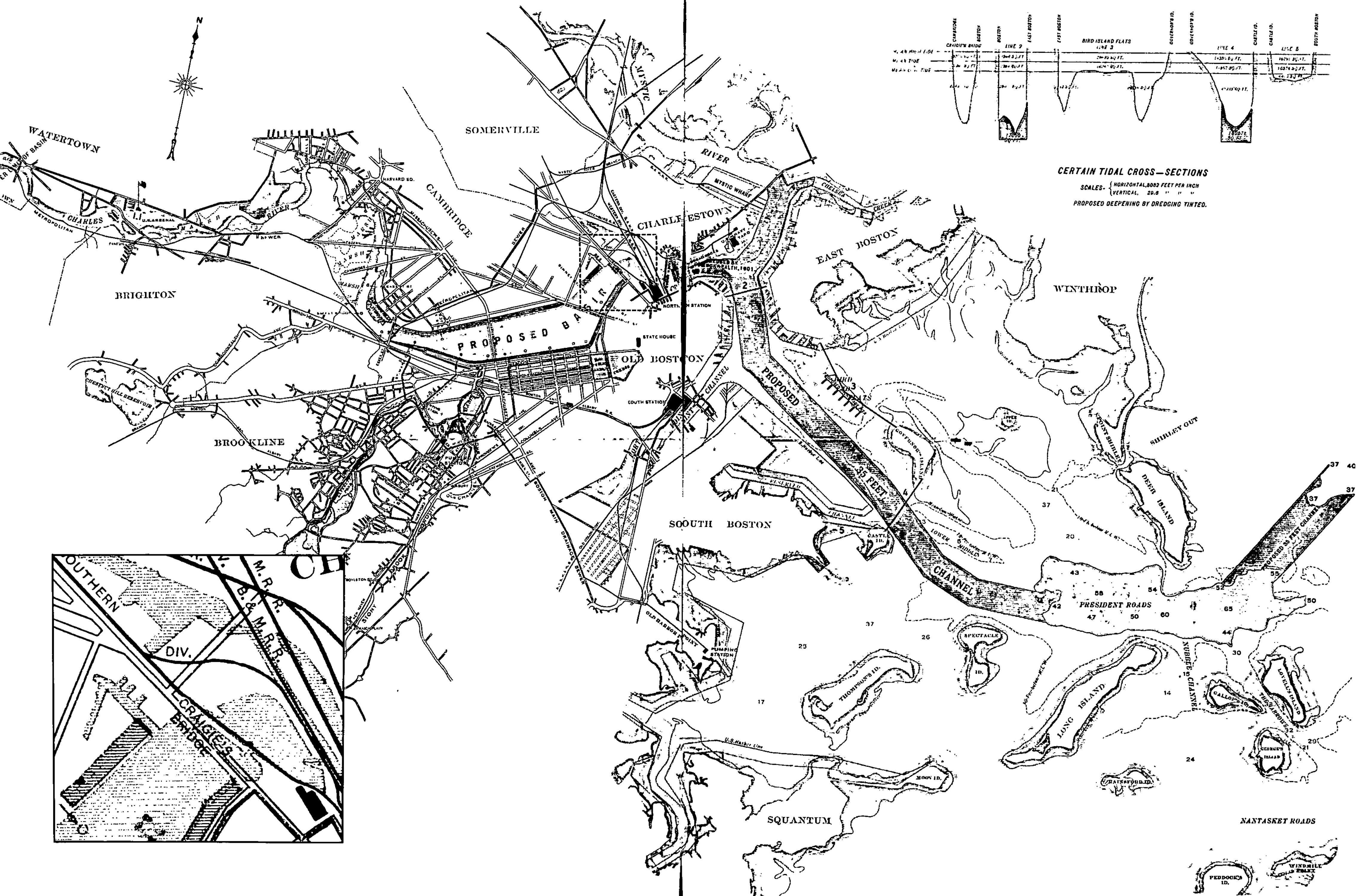
[8]Commonwealth of Massachusetts, *Report of the Committee on Charles River Dam Appointed under Resolves of 1901, Chapter 105, to Consider the Advisability and Feasibility of Building a Dam Across the Charles River at or Near Craigie Bridge.* Boston: Wright & Potter, 1903, p. 134.

Brook had reached its present condition of pollution.

Mr. Noyes in the hearing of 1894 had expressed entire confidence that the sanitary conditions would not be bad. Mr. J. Herbert Shedd, designer of the Providence sewers, was fully familiar with the conditions at the Providence Cove and in the Providence River and equally familiar with the conditions in the regions around the Charles River. From his previous engineering experience in Boston, [he] was confident in the belief that no abusive condition need be feared.

These were all men of standing, whose statements of fact and observations would be accepted implicitly by every man in this room and . . . would probably also have been accepted by the men on the other side. Obviously, we [had] to get down to the bed rock facts and get more facts. While there was much evidence presented, the main pieces of positive evidence were the statements of Mr. Hastings that the Cambridge clock gauges showed that seven percent of the entire sewage of Cambridge escaped into the river during storms. Dr. Henry J. Barnes recounted seeing with his own eyes large quantities of floating excrement at the outlet at the sewer overflow near Hereford and Beacon Streets after a sudden rain.

We set forth to become more familiar with the sewer overflow. [M]y assistant climbed down into each one of the seventy-five manholes, inspected its operative condition and obtained measurements from its float and swinging gate. [To] the extent that its opening could be observed and arranged for, we organized a sort of minuteman brigade. [We] divided the overflows up into districts so that whenever a heavy shower occurred these could be visited and measured and the quantity of water flowing through it approximately determined. This was not a very sweet or attractive job, but we got a good deal of valuable information. [We] found every one of these pieces of apparatus in good working order every time that we inspected them. [O]ur evidence that this apparatus did not fail to do the work that was expected greatly increased. We found, however, one of these in operation more elusive than "the Irishman's flea," and never until undertaking this investigation had I appreciated how quickly the rain gets into the sewers and how quickly the peak of the flood wave has passed. I soon found out that the only way to obtain positive information was by setting clock gauges maintained by Mr. Hastings in Cambridge which have been so much in evidence throughout this case, but here again we had difficulty for the clock and the record chart that will work beautifully in the office or in the open air rebels when put into the foul atmosphere in the sewer manhole. I came near having suspicions about the walking dele-



Portion of map from 1903 Report at reduced scale of about 1" = 5920'. Inset, lower left, shows area centered on Craigie's Bridge where dam was constructed. Inset scale, about 1" = 1500'.

Editor's Note

The Editorial Board decided it would be unnecessary and, in fact, unwise, for reasons of convenience and economy, to reproduce the 20 technical appendices, comprising 454 pages of text, included with the original Report. These appendices, each of genuine historic value, are listed, with subheadings, in the Table of Contents of the following reprint. The interested reader who would like to see any of them, but does not have access to the original Report, can obtain a copy, at the cost of reproduction and handling, from the BSCE Section office, 80 Boylston Street, Boston, MA 02116.

gate who looked after these clocks. Things conspired against us, for instead of having weather like we have had during the past two weeks, we had the most remarkable absence of rain storms during the time that I was most anxious to get observations of the overflow. But we kept at it, persistently hastening to the River every time it had begun to rain. In our gasolene dory I navigated rapidly to every overflow outlet and in some of these found an abundance of material going out which would not look well in the water park.

I soon reached the conclusion that the reason why Mr. Goodnough and others of our sturdy oarsmen who have been long familiar with the Charles River had not seen more of this kind of pollution, came from the fact that people seldom go a boating during a heavy rain. From conversation with the draw tender and others as well as my own inspection, I soon became convinced that a condition at times prevailed that [defied description] by any system of statistics. . . .

A Harvard professor described a mass of [sewage which he observed] floating by the outgoing tide, thickly covering the surface for thirty or forty feet in width and for a mile or more in length. [He] was confirmed in this statement by the assistant keeper. I myself once saw the Binney Street overflow discharge such a mass of this filthy material and saw such long streaks of it coming for half an hour at a time . . . that I concluded that the floating gate sometimes acts as a sort of skimmer to hold back and concentrate the floating pieces for a long time during the progress of a storm while the bulk of the sewage [runs] out into the Metropolitan sewer. [F]inally the pitch of water [runs] to the gate to such an extent as to belch a large mass of this material forth. Obviously, material of this kind seen floating about by a family boating party on the future parkway would destroy the relish of a trip even though a chemist might issue his certificate that the quality on the basin as a whole was too minute a percentage to trouble oneself about.

Although the manuscript for Freeman's speech ends here, his notes indicate that the speech as delivered included additional sections describing the Report of the Chemist, Harry Clark, and Freeman's study of Boston Harbor currents and temperatures. — ed.

Commonwealth of Massachusetts.

REPORT OF THE COMMITTEE

ON

CHARLES RIVER DAM

APPOINTED UNDER

RESOLVES OF 1901, CHAPTER 105,

TO CONSIDER THE

ADVISABILITY AND FEASIBILITY OF BUILDING A DAM ACROSS THE CHARLES RIVER AT OR NEAR CRAIGIE BRIDGE.

BOSTON:
WRIGHT & POTTER PRINTING CO., STATE PRINTERS,
18 POST OFFICE SQUARE.
1903.

Committee on Charles River Dam.

HENRY S. PRITCHETT.
SAMUEL M. MANSFIELD.
RICHARD H. DANA.

JOSEPH W. LUND, *Secretary.*
JOHN R. FREEMAN, *Chief Engineer.*

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INTRODUCTION.

As required by Resolves of 1901, chapter 105, this committee submitted its report to the Legislature on Jan. 14, 1903. The work of the committee and of its chief engineer and various experts up to that time had been devoted entirely to collecting information in regard to the feasibility and desirability of the general project, and a mass of data had been accumulated in reference to sewage overflow, harbor conditions and other matters involved in the determination of these general questions, which the chief engineer of the committee has necessarily been several months in reducing to form for publication.

As the mere construction of a dam at Craigie bridge in itself involved no serious engineering difficulties, the committee had made no studies for such a dam, but had largely relied on the reports of the Joint Board of 1894 as a basis for estimates of cost. After the hearings before the joint committee of the Legislature on metropolitan affairs and harbors and public lands, in January, 1903, Mr. Freeman, the chief engineer of the committee, at the request of the commercial interests upon Charles River, made various detailed studies of a dam having a lock with a depth of 18 feet over the sill at low water. The construction of so deep a lock necessitated abandoning the plan proposed by the Joint Board of 1894 of using the lock as a sluiceway, called for the insertion of special sluices, and somewhat increased the expense of the construction of the dam and lock. All these studies and estimates, together with more complete estimates of cost of the marginal conduits and embankment walls, are set forth in Appendix No. 19 to the report of the chief engineer, which presents six plans for a dam, at a cost varying from $983,800 to $1,549,250.

A dam with surface and drawbridge at grade 22, Boston base, will result in frequent interruption of street traffic over the dam, owing to the necessity of opening the draw for all vessels requiring more than 12 feet head room. On this account, with a view to less frequent obstruction of the highway, the chief engineer of the committee recommends a high dam, with a surface and drawbridge at grade 38.5, Boston base, which would allow the passage of tugs and mastless vessels without opening the draw. Studies for such a dam, both of solid masonry and with a steel viaduct, have been prepared, though it is probable that the former is preferable, as the cost of maintenance of a steel structure would offset the decreased expense of construction.

These later studies have resulted in some modification of the figures given on pages 12, 31 and 32 of the report of this committee.

The following is an estimate of the entire cost of the improvement, based on these later estimates: —

Item No. 1: —	
Dam, elevation 38.5, without catch-basins (estimate of John R. Freeman), ...	$1,425,000
Item No. 2: —	
Marginal conduit, Boston side, Leverett Street to Fens outlet, 11.5 by 10.5 feet (estimate of John R. Freeman),	500,000
Item No. 3: —	
Marginal conduit, Cambridge side (estimate of John R. Freeman), ...	88,000
Item No. 4: —	
Dredging Broad and Lechmere canals, and rebuilding walls (estimate of John R. Freeman and Percy M. Blake), .	100,000
Item No. 5: —	
Dredging in basin (estimate of John R. Freeman), . .	25,000
Item No. 6: —	
Embankment wall and filling, 100 feet wide, Cambridge Street to Fens outlet (estimate of John R. Freeman), 7,550 feet of wall at $20 and 378,000 cubic yards of filling at 60 cents, ...	378,000
Item No. 7: —	
Improvement of Back Street, rear of Beacon Street (estimate of Mr. Jackson), ...	31,350
Item No. 8: —	
Beacon Street sewer, Otter Street to Hereford Street (estimate of Mr. Jackson), ...	60,000

Item No. 9: —		
Extension of Stony Brook conduit from commissioners' channel to the Charles River (estimate of sewer division of street department),		$300,000
Item No. 10: —		
Dredging in Fens (estimate of John R. Freeman),		50,000
		$2,957,350
Of the total expense, Items Nos. 5, 8, 9 and 10 are for work which is demanded in case a dam is not built, and they amount to	$435,000	
Item No. 6, for the embankment from Cambridge Street to the Fenway, is already authorized by Acts of 1893, chapter 435, amounting to	378,000	
Item No. 1: the dam will take the place of Craigie bridge, which must be rebuilt in the near future. The estimate by the city engineer of the cost of a bridge 100 feet wide, with the draw at grade 38.5, Boston base, is	1,463,362	
If the dam is not built, there will be an additional expense in the construction of the wall between Cambridge Street and the Charlesgate East of $45 a linear foot, being the difference between the cost of the Charlesbank wall and of the wall necessary in case the basin is maintained at a constant level of grade 8 (estimate of Mr. Freeman), amounting to	341,000	
		2,617,362
Balance representing total *immediate* increased expenses charged upon the municipalities by this improvement is		$339,988
These figures are based upon one of the most expensive forms of dam, and do not include the future saving on the Metropolitan Park Commission work in the Charles River reservation, in case the dam is built and the water held at grade 8, which is estimated by that commission to be	$425,000	
Or the saving on the sea wall of the Cambridge Esplanade of	37,000	
Or the saving in construction of beach wall on the Cambridge Esplanade of	62,000	
Or saving in cost of filling in the Cambridge marshes of	100,000	
		$624,000

These figures do not include the estimates for dredging the flats in the river to grade — 5, Boston base, as has been suggested, which would entail a total expense of $1,016,945, it being very improbable that so extensive dredging would ever be undertaken; nor do they include the future saving in expense of construction of sea wall between the Fens outlet and the Essex Street bridge.

Taking into consideration the above amount of $624,000, which will be saved in the future to the municipalities bordering on the river, it appears that the treatment of the basin with a dam will effect a saving of $284,012, as compared with the expense of adapting the basin to public use without a dam.

BOSTON, June 1, 1903.

REPORTS

OF THE

COMMITTEE AND CHIEF ENGINEER.

FINANCIAL STATEMENT.

DECEMBER, 1901 — JANUARY 14, 1903.

Appropriation for expenses of committee,			$50,000 00
Stenographer and typewriting,		$1,095 92	
Rent and office supplies, electric light, postage, express, telephone and telegrams, advertising, etc.,		1,876 26	
Maps, plans, photographs, blue-prints,		3,516 92	
Wright & Potter: —			
Printing testimony,	$2,240 29		
Printing report, estimated,	3,500 00		
Printing miscellaneous matter,	111 94		
		5,852 23	
G. W. Field, biologist, report and expenses,		563 46	
Harry W. Clark, chemist, report, expenses and assistants,		1,743 31	
Lieut.-Col. W. A. Jones, United States Corps of Engineers, report and expenses,		673 85	
F. W. Hodgdon, C.E., report and expenses, Broad and Lechmere canals,		220 00	
R. A. Hale, report of flow of upland water, and expenses,		299 24	
Metropolitan Park Commission, for survey of upper basin,		915 82	
Louis F. Cutter, report on separate system of sewerage in Boston, and expenses,		393 22	
J. R. Burke, C.E., harbor survey map,		100 00	
Theobald Smith, M.D., report, assistants and expenses,		716 42	
X. H. Goodnough, sanitary engineer, report and expenses,		777 50	
Prof. W. O. Crosby, geological report,		400 00	
J. R. Freeman, chief engineer, apparatus, boat hire, carpenter work, clerical supplies, labor, etc.,		2,600 72	
J. R. Freeman, services and assistant engineers,		18,460 80	
J. W. Lund, secretary,		3,375 00	
Henry S. Pritchett, Samuel M. Mansfield, R. H. Dana, services and expenses of committee,		6,218 00	
			$49,798 67

Report of the Committee appointed under Resolves of 1901, Chap. 105,

TO CONSIDER THE

ADVISABILITY OF CONSTRUCTING A DAM ACROSS THE CHARLES RIVER BETWEEN THE CITIES OF BOSTON AND CAMBRIDGE.

To the Honorable the Senate and House of Representatives of the Commonwealth in General Court assembled.

Your committee, appointed to report as to the feasibility and desirability of a dam across the Charles River between Boston and Cambridge in the vicinity of the bridges known as Craigie bridge and West Boston bridge, respectfully submits the following statement of its conclusions, together with the reports of the engineers and experts employed by it. The evidence and arguments presented to the committee by those favoring or objecting to a dam are printed in a separate volume, which is submitted herewith.

The work of the committee and the scope of its investigations have been determined by Resolves of 1901, chapter 105, as follows: —

RESOLVE TO PROVIDE FOR THE APPOINTMENT OF A COMMITTEE TO CONSIDER THE ADVISABILITY OF CONSTRUCTING A DAM ACROSS THE CHARLES RIVER BETWEEN THE CITIES OF BOSTON AND CAMBRIDGE.

Resolved, That the governor, with the advice and consent of the council, be authorized and requested to appoint, not later than the thirty-first day of December, nineteen hundred and one, a committee, to consist of three or more suitable persons, one of whom he shall designate as chairman, to investigate and report upon the feasibility and desirability of constructing and maintaining a dam across Charles river between Boston and Cambridge, in the vicinity of the bridges known as Craigie's bridge and West Boston bridge. The committee may employ such assistance as may be necessary, shall give a hearing to all persons desiring to be heard upon the subject, and shall make a report of their doings, with such recommendations as they may deem proper, to the next general court. The committee may expend such sums in the performance of its duties, and shall be allowed such compensation, as the governor and council may determine. The whole expense of the committee shall be borne equally by the cities of Boston and Cambridge. The powers of the committee shall terminate on the making of their report. If the committee conclude that the proposed dam is feasible and desirable, they shall recommend a plan for apportioning the expense of constructing and maintaining it, between such cities and towns as will specially be benefited by it, and they shall annex to their report the draft of a bill in accordance with their recommendations. The provisions of this resolve shall be accepted by a majority vote of the city councils of Boston and Cambridge before any action can be taken thereunder. [*Approved June 13, 1901.*

Accepted by vote of the city councils of Boston and Cambridge, dated June 24, 1901, and July 3, 1901, respectively.

By Resolves of 1902, chapter 103, the time within which this committee is allowed to report was extended until the second Wednesday of January of the year 1903.

In accordance with the provisions of said resolve, this committee, between Dec. 16, 1901, and July 2, 1902, gave public hearings to all persons desiring to be heard, both in favor of and against the project; and since the close of the hearings, through its own engineers and experts, has investigated as fully as possible all the questions involved.

Your committee was soon convinced that a considerable time would unavoidably be employed in its investigations. When the question of a dam was before the Board of Harbor and Land Commissioners, in 1894, no funds were available to enable that Board to conduct independent examinations. Expert opinions of a widely diverse character were presented in the testimony before that Board, and its report stated: —

The evidence adduced at the hearing in favor of the plan, so far as it affected the harbor, was perhaps necessarily to a large extent desultory and inconclusive. That which was opposed to it was largely expert and other opinion, and recorded observations taken almost if not quite wholly from the reports and data on file in the office of this Board.

That Board made the following suggestion in reference to further investigations which it thought necessary before coming to any conclusion which would justify so radical and permanent a change: —

Bearing in mind that what is suggested to be done may affect the welfare of generations yet unborn for centuries to come, we are met at the outset with the question, What information is necessary to justify the conclusion that so permanent a change can be made without detriment? In order to answer this question understandingly and with certainty, knowledge on the following points is essential: —

1. The exact present condition of the harbor.
2. Just what forces are acting either to improve, maintain or in any way injure it.
3. What effect the proposed lock and dam will have upon these forces.

4. The causes of the shoalings that have from time to time occurred in the harbor, and the material of which they are composed.

5. Whether the natural bottom of the upper harbor is or is not abraded by the currents, and moved from place to place.

Comparative studies should be made of all the plans and records of all general surveys and examinations of Boston harbor and of similar harbors, and to supplement the information thus obtained by further surveys and examinations to cover the portions not sufficiently covered or not covered in sufficient detail, or not at all covered.

A series of observations of the currents should be made; as, since the current measurements were made, in 1861, large areas on the South Boston flats and in Charles, Miller's and Mystic rivers have been filled, and the deep-water channels in the upper harbor have been materially enlarged by dredging.

Physical examinations should be made, by borings or otherwise, and also microscopical and chemical examinations of the material composing the bottom of the harbor to a depth of several feet, especially where the soundings indicate that there has been considerable shoaling, in order to assist in determining the source and amount of all deleterious and foreign substances.

The foregoing data should be collected under the direction of a competent hydraulic engineer, with the assistance of an advisory board of engineers, before any conclusions can be formulated which would justify so radical and permanent a change as is contemplated in the proposed plan.*

Your committee has fully carried out the work thus indicated as a prerequisite to a satisfactory decision, and in the chief engineer's report and the appendices thereto will be found the observations which are here called for.

In addition to these evidently necessary inquiries, the committee has also made a large number of observations in order to settle other questions concerning which the expert opinions given in the evidence before it have differed.

This class of questions may be, perhaps, illustrated by one or two examples.

In the evidence presented for and against the building of a dam there was a wide difference of opinion as to the effect of the salt water in the present basin in cooling the air of the adjacent region during the hot season. One set of experts claimed that this basin was filled twice daily with cool sea water and had a marked influence in lowering the temperature of the air over the city; other experts doubted this effect. The committee dealt with this problem by placing a series of thermometers and thermographs extending from Boston Light to Norumbega Park; thermographs were also placed in different parts of the city. Simultaneous readings of all these instruments were obtained for a period extending through the two and one-half months of

* Report of Board of Harbor and Land Commissioners, 1894, pp. xv and xvi.

summer. The results of these observations were conclusive and final. They showed that the cooling influence of the basin upon the atmosphere of the Back Bay was practically zero.

Another question, and a most important one, concerning which the committee received varying testimony, was that of the quantity of sewage being emptied into the present Charles River basin. Into this subject your committee has endeavored to go with completeness, and an enormous amount of time and work has been spent upon it. As is shown in the reports of experts, and particularly in that of the chief engineer, the sources of pollution are more numerous, and the amount of sewage emptying into the Fenway and thence into the basin is greater, than had been supposed. The present Fenway basin is practically a cesspool; and, without any regard to whether a dam is built or not, this basin should be freed from the objectionable sewage now entering it. A simple and effective method of doing this is shown in the report of the chief engineer.

Similar questions, concerning the effect of a dam upon the health of the region, its effect upon the flow of tides, and many others, could be settled only by a careful and systematic study.

The committee has found it necessary to make extensive surveys. Among these are an accurate hydrographic chart of the Charles River basin, made upon a large scale, and showing with exactness the shoals which have accumulated, and which may need removal; a geological survey of the surroundings of Boston harbor; a survey of the region for the purpose of ascertaining the present sources of malaria, and those which might exist in case the dam were built; and, finally, a survey made from the stand-point of the biologist and bacteriologist. In addition, it has caused to be made a chemical examination of the river water and the material entering the basin.

All of this work has required time, but the committee felt assured that it was desirable to investigate fully all these questions, rather than to leave any of them in an unsettled state; and it believes that the results herein set forth are based upon examinations sufficiently full and accurate to afford safe conclusions. The committee desires to express its obligation to its experts and engineers, and particularly its appreciation of the services of its chief engineer, John R. Freeman, under whose direction the work has been carried on. The committee is also indebted to the Board of Metropolitan Park Commissioners for the completion of that portion of the survey of Charles River between Essex Street bridge and Watertown dam; and it desires also to express its appreciation of the assistance and cordial co-operation it has received from the members and officers of the Metropolitan Park Commission, the State Board of Health, the Metropolitan Water and Sewerage Board and the Board of Harbor and Land Commissioners; from the officers of the United States Engineers' office and the Navy Yard; and from the officials and engineers of the cities of Boston, Cambridge and Newton and the town of Watertown. All of these boards and officials have given the committee all possible assistance in its studies and investigations.

History of the Project.

The project of building a dam across the Charles River has been discussed since 1859. An act was passed in 1870 providing for the establishment of a Metropolitan Park Commission, for the purpose of improving the basin by a dam, as proposed by the late U. H. Crocker. This act was subject to acceptance by a two-thirds vote of the people of Boston, and was rejected, as only a majority vote was received.

In 1891 Hon. Nathan Matthews, then mayor of Boston, in his inaugural address recommended the creation of a water park out of the basin; and, in view of the private interests involved, suggested that the whole matter be considered by a State commission. The Charles River Improvement Commission was thereupon appointed, under chapter 390 of the Acts of 1891, for the purpose of considering what improvements could be made in the Charles River basin between the dam at Watertown and Charles River bridge at Boston, and submitted two reports, dated Feb. 21, 1892, and April 20, 1893, respectively. Both reports recommended embankments along the river. The second recommended more specifically the discontinuance of the railroad bridges, and their concentration in a new high-level bridge without a draw.

The Legislature of 1893, without acting on these recommendations, appointed a Joint Board, consisting of the Metropolitan Park Commission and the State Board of Health, with instructions "to investigate the sanitary conditions, and prepare plans for the improvement of the bed, shores and waters of the Charles River between the Charles River bridge and the Waltham line on the Charles River, and the removal of any nuisances therefrom." This Joint

Board reported in April of 1894, recommending the building of a dam and lock about 600 feet above Craigie bridge, by which a constant level in the basin would be maintained at about grade 8. The Legislature referred the report of this Board to the Harbor and Land Commission, with directions "to inquire into the construction of a dam and lock in the tidal basin of Charles River, as proposed by the Metropolitan Park Commission and the State Board of Health, sitting as a Joint Board, with special reference to interference with tide water and its effect upon the harbor of Boston."

After holding public hearings, in 1894 the Board of Harbor and Land Commissioners reported that: "This Board is powerless to say, on the imperfect information it has, what effect a dam, as proposed, would have upon shoaling in the upper harbor. Upon all the evidence within the knowledge of the Board, we are unable to find the consequences of building the proposed dam as at all certain of being foreseen; and, in view of the incalculable injury which might ensue from impairing the usefulness of the harbor, we are unable to report in favor of the recommendations contained in the report of the Joint Board." *

By chapter 531 of the Acts of 1898 the Legislature authorized and directed the Metropolitan Park Commission to construct and maintain a dam with suitable locks across the Charles River at or about St. Mary's Street. No action has been taken under this authority.

In 1901 the Legislature authorized the appointment of this committee.

The Present Condition of the Charles River below Watertown Dam, in Relation to the Park Systems of the Cities of Boston, Cambridge and the Metropolitan Park District.

The Charles River basin occupies the centre of the park systems of both Boston and Cambridge and the metropolitan district, and its banks have already been dedicated to the park purposes of these systems.

On the Cambridge side of the river, from Craigie bridge to Watertown dam, the banks of the river, with the exception of about one-half a mile† in a length of nine miles, have

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* Report of Board of Harbor and Land Commissioners, 1894, pp. xix, xx.

† Fifteen hundred linear feet are occupied by private interests of the Damon Safe Works, Coleman Brothers and Smith properties, between the Craigie and West Boston bridges; and the entrances to and properties upon Broad and Lechmere canals are also used for commercial and manufacturing purposes. The Hollingsworth & Whitney Paper Companies, Lewando and others occupy 740 feet in Watertown.

Cambridge embankment and flats from West Boston Bridge, July 11, 1902, at low tide.

Flats exposed at outlet of Hereford Street sewer, July 11, 1902, at low tide.

been dedicated to the public uses of the Cambridge and metropolitan park systems and the United States arsenal. This is exclusive of the wharves on Broad and Lechmere canals.

Of the beach construction, 5,240 feet are completed, and about 6,540 feet of beach and 2,500 feet of wall remain to be built.

On the Boston side of the river, from the Craigie bridge to the Watertown dam, the banks, with the exception of one mile of private ownership,* have been either occupied or authorized to be occupied for the public purposes of the Charlesbank (the proposed embankment in the rear of Beacon Street authorized by Acts of 1893, chapter 435), by the Bay State Road, and by the Metropolitan Park Commission.

The cities of Boston and Cambridge and the Metropolitan Park Commission have already spent $3,685,000 on these park improvements bordering on the river, and the high-level West Boston bridge, without a draw, is now being built between these cities at a cost of $2,500,000. This, as an architectural and engineering structure, will be in harmony with the general scheme of the use of the river as a park.

Necessary Improvements if no Dam is built.

The Charles River, between the Watertown dam and Craigie bridge, has a mean rise and fall of tide of 9.6 feet, with an extreme predicted range of 13.6 feet, which at times of easterly winds and freshet flow of the river may be increased to 15 feet. In case a dam is not built, it will still be necessary, in order to adapt the river to these park requirements, to dredge the unsightly and unsanitary flats in the lower portion of the river basin to a depth of five feet below mean low water. These flats are indicated upon the survey of the basin made under the direction of this committee. The amount and position of the excavations to be made are indicated in the report of the chief engineer, and their extent and appearance at low tide are shown in the accompanying photographs. In addition, certain changes in the sewage conditions, including separation of objectionable sewage from the Stony Brook channels, extending an overflow channel from the Commissioners' channel to the Charles River, and the interception of the sewage which comes from Beacon Street houses, should be effected ; the embankment and walls

* Costello's Wharf, Cousens' Wharf, 320 linear feet; Brookline Gas Company, 500 linear feet; the Brighton Abattoir, 3,400 linear feet; and the Newton & Watertown Gas Company and others, 1,200 linear feet. (Evidence of Mr. de las Casas, p. 24.)

from West Boston bridge to the westerly line of the Fenway should be built by the Board of Park Commissioners of Boston, in accordance with the provision of the Acts of 1893, chapter 435, with some amendments hereafter suggested; the unimproved banks of the river above the territory which is to be walled must be dealt with in a similar way to that adopted by the Cambridge and metropolitan park commissions above the Boylston Street bridge; and portions of the tidal marshes should be diked, as has been done by the Metropolitan Park Commission between the Boylston Street and Arsenal Street bridges. As the extreme rise and fall of the tide is about 15 feet, these works will be necessarily expensive. The estimated cost of this work above outlined is $3,914,000.*

After this work is completed, however, the river, as a tidal stream, will still for half the time present an unsightly and unattractive appearance. Its use by the public will be limited, and its possibilities as the main feature of the park system will be only partially utilized.

Considerations in Regard to a Dam.

Under the resolves of 1901, your committee is charged with the duty of reporting upon the question of improving these conditions by means of a dam. The resolve directs the committee to report upon three matters involved in the erection of such a structure: —

1. Its feasibility.
2. Its desirability.
3. In case of its feasibility and desirability, to recommend a plan for apportioning the expense of constructing and maintaining it between such cities and towns as will specially be benefited by it, and to annex a draft of a bill in accordance with its recommendations.

Feasibility. — Considered merely as an engineering project, there can be no question as to the feasibility of constructing a dam and of maintaining a basin above it at constant grade, even in times of freshet flow of the river,

* Cost of sea wall and 70-foot embankment, West Boston Bridge to Fenway, estimate of city engineer, 1894, for park department,	$684,000
Cost of work on Charles River Reservation by Metropolitan Park Commission, including beaching, diking and roads,	1,542,000
Cost of Stony Brook conduit from outlet of Commissioners' channel to river, street department, sewer division (Rep. City Doc. 1901),	300,000
Cost of intercepting sewer in the rear of Beacon Street,	60,000
Cost of dredging flats in the Charles River from the Craigie bridge to 500 feet below Watertown dam to grade —5, estimate by Percy M. Blake, civil engineer,	1,016,000
Cost of wall and beach yet to be constructed by Cambridge Park Commission,	312,000
	$3,914,000

and this without flooding the Back Bay districts and without obstructing the existing storm sewage overflows.

It will make the following report more clear if it is at once stated that the committee, early in its investigations, was led to believe that, whether such basin were fresh or salt, a dam, if built at all, must be high enough to keep out high tides, and that it must be supplied with a lock for the accommodation of river navigation.

Desirability. — The chief reasons for the construction of such a dam are to be found in the sanitary betterment of the region itself and in the value which such a basin would have in relation to the Boston, Cambridge and metropolitan park systems.

It would be a great addition to the attractions of the city, and would lend itself to a plan of improvement which in the long run cannot fail to make Boston one of the most beautiful cities in the world. The creation of such a basin would give the cities of Boston and Cambridge, practically without expense, an open park area of 1,000 acres, the lower portion of which is situated in the heart of the most congested metropolitan district. How much this basin will be used as a pleasure park, and particularly by the poorer inhabitants of the city, your committee feels itself unable to say. If the use of the Charles River Gymnasium, of the North End Park, of Jamaica Pond and of Franklin Field in the winter is to be taken as a criterion, the basin would be of immense benefit; and there is no reason why such use should not be made of it if rendered accessible and if the use of boats be made easy and cheap. The committee feels that, under reasonable conditions, it ought to become the scene, for at least four or five months of the year, of a great popular playground.

There is no reason why the Charles River below Watertown dam, with the water at a constant level of not less than grade 8, should not offer the same opportunity of use by the public both for a water highway and for purposes of pleasure and recreation which is furnished by the Charles at Riverside, the Thames at Henley and the Alster at Hamburg.

As metropolitan Boston grows passenger traffic ought to develop and reach large proportions on such a stream.

The accompanying photographs of the banks of the river, as improved by the Metropolitan Park Commission, show that with low tides the river at its best offers but little attraction to persons seeking recreation or pleasure upon it or in its vicinity. The currents are too swift for any boat except racing craft, and the view from the river is generally limited to high banks of rubble or mud. The pictures of the same stretches of the river at the Longfellow marshes and at Lemon brook, with the water at grade 8 and with low tide, show how largely its appearance is dependent on its tidal condition, and a comparison of the photographs of the Alster basin and river frontage at Hamburg with the present views of the rear of Beacon Street and the Cambridge Esplanade gives some idea of the way in which the neglected opportunities of the Charles River basin might be utilized both for the convenience and pleasure of the public and for beautifying the cities of Boston and Cambridge.*

There can be no question that a basin of clear water, held at a constant level, with attractive banks, is in every way desirable. The questions which your committee feels called to answer are: Can this basin be kept reasonably sweet and clean? Can it be maintained with advantage to the sanitary interests of those who live upon the river banks? Will such a basin be prejudicial to the great interests of Boston harbor, or to possible commercial interests in Charles River? And, if these questions can be answered in the affirmative, it then remains to determine whether all this can be done within a limit of cost consistent with a just public policy.

Sanitary Conditions.

The sanitary question is the most difficult, and in some respects the most important, involved in this inquiry, and upon it has been bestowed more time and labor than upon any other question, both by the chief engineer and by experts working independently.

This work has been done in the effort to ascertain, first of all, the quantity and character of sewage actually going

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* The Charles River above the dams is now crowded with pleasure craft in spring, summer and autumn, while below the dams little boating is seen except the racing boats, mostly college ones.

For the difference between swift, tidal waters with exposed flats on the one hand, and a basin of constant level with slight currents on the other hand, in fostering pleasure boating we are not without instructive examples.

After the construction of the half dam at Richmond on the Thames, in England, the use of pleasure boats increased. On the other hand, by the removal of the half dam on the Clyde at Glasgow, Scot., in 1879, on the mistaken theory that this would benefit the harbor by increasing the scour, "a good deal of damage was done to boating, then a popular pastime" (evidence, p. 457); while, on the rebuilding of the weir, lately finished, so as to prevent further damage to the harbor, it is predicted that it will "enable the citizens to enjoy the use of the river for boating."

The Dee Conservancy Board, at Chester, Eng., reported that the dam there, which keeps out the ordinary tides, would, if removed, "ruin the beautiful basin of almost still water, which is immensely enjoyed for boating" (evidence, p. 456).

We have another illustration right at hand. The Cambridge Casino, on the Charles River, near the foot of Hawthorne Street, was furnished with a boat house. At first the boats and canoes were used zealously, but the strong currents and the high, muddy banks, at all times below half tide soon discouraged boating, and later, boating practically ceased. The canoes were all removed, most of them to the upper parts of the river, with constant level and slight currents, though much farther from the owners' homes than the tide water at the Casino.

into the basin, the sources of this sewage and the possible means of its exclusion.

Next, the question of the deposits already made in the basin, from sewage which has been coming into it in the past, was investigated.

Following this inquiry, the experts and engineers of the committee took up the study of the question as to whether fresh or salt water permitted better sanitary conditions; the effect of each upon the bacterial life in the basin was studied, and examinations were made to test, in each case, prevalence of mosquitoes and the consequent effect upon inducing malaria.

These studies of a biological character were accompanied constantly by thorough chemical tests, so that the experts of the committee have endeavored by all scientific methods to study the problems involved in the formation and sanitary maintenance of such a basin from every point of view.

The results of these examinations are found in the series of reports made by the chief engineer and the several experts, and are printed as appendices to this report.

The Present Condition of the Basin.

In considering the question, the present sanitary condition of the basin must be borne in mind. There are in the basin to-day unsanitary conditions, which must be remedied even if a dam is not built.

The Fenway. — The influx of sewage into the Fenway has transformed this body of water from a water park into a drainage canal. The Fens were not offensive as long as Stony Brook discharged through its old channel, in accordance with the original plans of the park department, and the present conditions have been largely caused by the building of the new Commissioners' channel. The present conditions are a nuisance to the people living in the vicinity, and destroy the usefulness and beauty of the Fens as part of the park system. The objectionable sewage at present entering at various points in both the old and new channels of Stony Brook should be removed. The necessity for immediate relief is fully set forth in the report of the street department, sewer division, of the city of Boston for 1901, in which it is proposed to construct a 12-foot channel from the present Commissioners channel to the Charles River, at an expense of $300,000. While this solution of the difficulty will relieve the Fens, it will transfer the trouble to the river basin at the present outlet of the Fens.

The Main Basin.

Direct sewage now enters from the houses on the water side of Beacon Strêet which should be cut out. There exist in the main basin large areas of flats covered with sewage mud, which are exposed at low tide, and which the Board of Health of the city regard as a "well-recognized public nuisance." These should all be dredged, if there is to be no dam. There is a discharge of the combined overflow sewage in times of storm from the sewerage systems of Boston and Cambridge which should be stopped or curtailed as soon as possible by the introduction of the separate sewerage system, already begun in Cambridge and officially recommended by the sewage division of the street department of the city of Boston in its report for 1901. There are numerous breeding-places for mosquitoes which ought to be removed.

Conclusions.

Basing its conclusions on the study of these conditions and on the reports of its engineer and special experts, the committee finds as follows: —

Fresh water, gallon for gallon, disposes in a normal manner of more sewage than salt water; the tendency of salt water is rapidly to precipitate sewage in sludge at the bottom.

For the proper disposition of sewage in water, it is essential that the water be well supplied with oxygen. This is accomplished by the contact of its surface with the air, and this surface water is carried down by the action of the waves and currents, and especially by the vertical movement caused by changes of temperature. Bodies of fresh, nearly still water are well oxygenated to a depth of 25 feet or more in ordinary summer weather, and to much greater depths with the autumn cold. No considerable part of the basin, with a permanent level at grade 8 or 9, would be over 25 feet in depth.

Letting in salt water under the fresh interferes with the vertical circulation necessary for oxygenation, and the salt water under the fresh soon loses its oxygen if any waste material is admitted into it.

Changing a fresh water basin into a salt from time to time interferes with the bacterial animal and vegetable growths, which effectively aid in taking care of and digesting sewage.

A comparatively still body of fresh water with animal and plant growths will dispose of a considerable amount of sewage admitted from time to time, and will tend to purify itself, even if no more fresh water is added.

Flats exposed at outlet of Fens Basin, July 11, 1902 at low tide.

Lechmere Canal, above Sawyer's Lumber Wharf, November 14, 1902.

Such a body of fresh water will dispose of more sewage if comparatively still than if in motion.

Most of the sewers in Cambridge and practically all in Boston carry both house sewage and storm water in the same conduits, which are called "combined sewers." These all connect with the intercepting sewers of the metropolitan system on both sides of the river leading into the lower part of Boston harbor; and in dry weather the metropolitan sewers take all the sewage, none of which goes into the basin with the exception of the sewers to the houses on the water side of Beacon Street, and some emptying into Stony Brook which find their way into the Fenway. The metropolitan sewers are not nearly large enough, however, to take both the house sewage and that very much larger body of liquid called the storm water in times of heavy rains and rapidly melting snows; and the surplus of this mixed storm water and house sewage, called the "storm overflow," is emptied into the basin, excepting when the storm water is small in amount.

The amount of house sewage that thus finds its way into the basin is not nearly as great as 7 per cent. of the total volume,* as contended by some authorities. Yet as found by careful measurement and observation it is not safe to assume that, at the dry season of the year, it is less than 3 per cent. of the total. This is somewhat more than supposed by other authorities. The sewers of Watertown, Newton, of parts of Brookline and of a fraction of Cambridge are on the separate plan, in which all rain water is turned into the natural water channels and there are no overflows of house sewage into the river.

Although the amount of fresh water coming over and through the Watertown dam is found by careful measurements to seldom average less than 70 cubic feet per second for the 24 hours in dry seasons, there is good reason to believe this is sometimes reduced to 30 cubic feet a second, for a month at a time, by storage in mill ponds while turbines are shut down.

The water coming over the Watertown dam is well supplied with oxygen, nearly colorless, and, except in the driest weather, nearly fit for a water supply; the only wastes polluting it, and which in dry weather somewhat diminish its purity, are chiefly from factories at Watertown and Waltham, and can be removed.

Notwithstanding the amount of sewage that enters the basin even at present, which our chief engineer estimates as

* The Cambridge sewer clocks have not been relied on as furnishing *final* data, for the reasons stated in the engineer's report.

equivalent to the constant discharge by a population of from 5,000 to 8,000 people, including that which comes from the Fens and from the Beacon Street houses, it is the unanimous opinion of the engineers and experts of the committee that a fresh-water basin, owing to its supply of oxygen and large area, would not affect injuriously the health of the inhabitants in the neighborhood.

Malaria is only spread from person to person by means of the *anopheles* mosquito. This mosquito breeds only in small pools of fresh or partially salt water; it does not breed in a large basin, with properly constructed shores open to the winds, and supplied with fish, even if the water is fresh. There are now, however, many breeding-places of this mosquito on the borders of and near Charles River, which have been located.

It is not true, as has been contended before the committee, that there is a large inflow into the Charles River basin of salt water direct from the ocean twice every twenty-five hours. A study of the currents shows that the water near Harvard bridge at high tide cannot come from the ocean direct, but at the best from the upper middle harbor as it was at the preceding low tide; and this is made up of what came from the Charles and Mystic rivers with the preceding ebb, mixed with what sea water stayed in the eddies and lagoons or was retained between the wharves from the high tide preceding that. A good deal more of the water making up the body of high tide at Harvard bridge comes from points still less remote. In short, the water in the estuary of the Charles surges back and forth day after day, and only gradually finds its way to the sea; the water at high tide near the Harvard bridge is on the average 8 degrees warmer than at Boston Light; when examined bacterially, it is not superior, if it is equal in purity, to the water at the same place at low tide when there is no sewer overflow going on; it is not as pure as the water coming over the Watertown dam.

Examined chemically, the high-tide water at Harvard bridge is somewhat better than the low-tide water; and the incoming sea water at Craigie bridge is about the same chemically as the water at the Watertown dam, except that the latter in summer weather is at present somewhat injured by certain factory wastes, which can be removed, as already stated.

It is not true, as contended, that the salt-water basin, as now existing, lowers the temperature of the air in the territory adjacent to it in warm weather. A most thorough and long-continued series of tests with recording thermometers has amply proved this. The substitution of fresh water would have no effect upon the temperature of the air, this being controlled by the direction and force of the prevailing winds. The water temperature would undoubtedly be raised from 3 to 4 degrees as shown by the engineer's report.

The level of the ground water in the Back Bay would not be raised by maintaining the level of the proposed basin at grade 8. The building of a tight wall with an embankment behind it, and the construction of a marginal sewer, emptying at grade 6, below the dam, into which some of the ground water could be drained in the immediate vicinity, would probably enable the basin to be maintained at grade 9, should it prove advisable, without interfering in any way with the ground-water level in the Back Bay. The old mill dam under Beacon Street was practically water-tight, and the ground level beyond it seems to be chiefly controlled by leakage into the sewers.

The combined sewers flowing from the Back Bay and from certain of the lower parts of Cambridge, in case of heavy rains during high tide, back up into and overflow the cellars of the houses to an extent that is a constant menace to the residents. If a permanent grade of 8 or 9 were maintained in the basin, this nuisance and danger to health would be removed.

The Fens basin furnishes no criterion for the condition of the large basin, nor of the Fens, if both were maintained as fresh-water basins at a permanent level, even under present conditions of sewer overflow. The Fens basin has far too little fresh water either in it or flowing into it in dry weather properly to care for the amount of sewage and waste admitted. The present circulation of salt water from the Charles River, as now established and carried on, is only about 30 per cent. of what the authorities supposed when they testified at the hearings; and this partially salt water stays under about 2 feet of fresh, loses all its oxygen and rapidly precipitates sewage sludge, which is in a state of fermentation with anaerobic bacteria, and emits nauseous gases. The condition is worse than if no salt water were admitted.

In the main basin the appearance during storm overflows is often worse than the reality, as the turbid fresh water floats over the salt in rather thin layers. If the basin were fresh, that condition would not exist.

With the introduction of the new high-level sewer of the metropolitan system on the Boston side, which will be finished in less than two years, the amount of sewage entering the basin will be much less than at present.

The Effect of a Dam on Boston Harbor.

In undertaking this study your committee found itself obliged to enter a wide field of investigation.

In the appendices to this report will be found, in the first place, a study of the geological character and history of the harbor and its present condition, explained from a geological point of view; secondly, a study of the supposed shoaling and of the existing currents, measured not only at the surface but at various depths, and especially near the bottom; and, lastly, a consideration of the problem from the point of view of modern engineers.

The work suggested by the Board of Harbor and Land Commissioners in their report of 1894 as necessary for a proper determination of the questions involved has been carried out.

First, it may be said that Boston harbor has no sand bars and hooks at its entrance, like New York harbor and almost all the other harbors farther south. The Broad Sound bar through which an entrance is soon to be dredged, is composed of clay, sand, gravel and boulders; and the sand beaches in Massachusetts Bay, both north and south, are in coves with rocky headlands. Arguments drawn from sandy harbors are, therefore, not applicable to that of Boston.

Sand from the submerged drumlins and the islands of the lower harbor, which were formerly being washed away into the surrounding water, but are now practically all guarded by stone structures built by the United States government, no longer comes in as formerly.

In going on with the study of this problem more in detail, the committee found itself face to face with a long-accepted theory of the maintenance of Boston harbor, which, in the end, it has felt obliged to reject.

This theory was accepted by the United States Commission on Boston Harbor, which, from 1859 to 1866, made ten reports to the city of Boston on this subject. The theory adopted was that of the so-called "tidal scour;" and under it improvement of the harbor should be so conducted as to maintain and even increase the tidal prism in reserve, the action of which was supposed to be necessary to maintain the depth of the channels in the harbor.

In 1866, when the last of these reports was made, Boston harbor was still a natural one, with practically no improvement by way of dredging. There were portions of the upper main ship channel which "had a least depth of 18 feet at mean low water, with a least width of 100 feet;" * and in 1894, when the Board of Harbor and Land Commissioners made its report, there were portions of the channel with a minimum depth of 23 feet and a least width of 625 feet.

The present project of the United States government, that of 1902, under which work is now being conducted and for which appropriations have been made, includes the making of a new entrance to Boston harbor across the bar of Broad Sound, 1,500 feet wide, with a minimum depth of 35 feet at mean low water, and a channel thence to the Navy Yard, with a minimum width of 1,200 feet and the same minimum depth.

For the future, Boston harbor will be an artificial one. The great extent of the dredging already done and proposed in the main ship channel, in comparison with the undredged area, is clearly shown on a map annexed. The natural conditions have been so altered by dredging that such equilibrium of forces as maintained the original channels has been entirely destroyed.

The modern steam dredge, the air drill and high explosives have so increased the efficiency and diminished the cost of labor that engineers can now accomplish more than could have been done in 1866. The shoaling, then feared, would no longer be an irreparable injury. The wealth of the community and the value of its commercial and wharf interests are so great as to have completely changed the relation of the harbor dredging to shore improvements.

While these considerations are quite enough to lead your committee to believe that it is no longer necessary to maintain the tidal reservoirs intact, yet it deems it its duty to consider further the original theory of tidal scour, as presented by the commission of 1859–66.

The commission of 1859–66 advanced the fundamental theory that: "Were these reservoirs [the basins of the Charles and Mystic rivers and Chelsea Creek] closed, the larger part of this main artery [the ship channel of Boston upper harbor] would in the course of time cease to exist, for it is but the trench dug through the yielding bed of the harbor by the passage to and fro of the river and tidal waters." (Tenth report, Boston City Document No. 50, 1866, p. 50.) This statement is quoted in the report of the Board of Harbor and Land Commissioners of 1894.

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* Report of Chief of Engineers, U. S. A., 1902, p. 98.

That fundamental theory, once adopted, naturally affected the conclusions of the United States Commission. That theory, however, we find to be wholly erroneous.

It is now clearly shown that the main channels of Boston harbor did not originate from the scour of the tidal waters, but are valleys eroded by the rivers in the broad, deep deposit of blue clay laid down near the close of the glacial epoch, when the land was higher than now, and since submerged during the slow subsidence of all this district. These rivers were then much larger than now, owing to the melting snow and ice on the retreat of the glaciers. In other words, the harbor channels are strictly what may be called a series of drowned valleys.

It is important to note that the conclusions of the United States Commission as to the scour in Boston harbor rested largely upon the experiments of the Dutch engineer, Dubuat, made in 1780. These experiments were carried on in a wooden channel 18 inches wide, with water less than 1 foot deep, and are of little significance when extended to large streams or large channels acting upon natural compact materials.*

The Board of Harbor and Land Commissioners, in the report of 1894, p. xvii, also seem to have followed the United States Commission, for they say: "From these [current observations] it appears that the velocities of ebb and flood currents rarely exceed 1 mile an hour between Boston and East Boston. According to Dubuat, a velocity of .15 of a mile an hour is 'sufficient to remove clay fit for pottery,' with which the stiff clays forming the natural bed of portions of the harbor are classed."

The velocity of currents necessary for erosion in natural conditions, as found by the engineer of the committee and by Mr. Hiram F. Mills, in actual practice are much greater than the velocities given by Dubuat.

In this matter we are not entirely dependent upon theory. The bottom of Boston harbor is covered with an average depth of from 6 inches to 5 feet of light, sandy mud. This appears everywhere excepting where dredging has taken place, showing that the currents are too feeble even to erode this softer material enough to leave bare the original hard bottom. The Board of Harbor and Land Commissioners, in their report in 1895, say:—

"Out in the harbor all the material dredged excepting the places at the mouth of the Charles River previously

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* Dubuat himself suggests this difference, which suggestion both the commission of 1866 and the Harbor and Land Commissioners of 1894 seem to have overlooked.

described in the report has been sand, clay, gravel or hardpan. The channels so dredged maintain their depths, and it has not been necessary to redredge them except in two cases. . . . In almost every case where dredging is done in the harbor, there is found on the surface a black deposit of varying thickness, but not exceeding one foot." (Sen. Doc. 303, 1895.)

It is important to note that tidal scour is an advantage only when under exactly the right conditions. There are well-known instances of harbors with little or no tide or river currents that have maintained their depths far better than other harbors with strong currents. Whatever is eroded from one place finds lodgment in another, and the place of settlement often turns out to be in some of the broader parts of the lower harbor, or at its mouth.

An instance of this appears in the case of the Clyde at Glasgow. The old weir or half dam in the upper reaches was removed in 1879 for the express purpose of benefiting the harbor by increasing the scour. It worked so badly and caused so much damage and expense that the weir has been rebuilt solely for the purpose of preventing the damage that was being done to the harbor by currents (see evidence, p. 457).

The Thames Conservancy Board predicted, about eight years ago, that the half dam, then about to be built at Richmond, and which would cut off a large part of the tidal prism, would result in serious shoaling below. That Board now states "Its effect upon the régime of the river as a whole cannot be said to be injurious" (see evidence, pp. 384, 385).

The Charles and Mystic rivers are not silt-bearing streams, and what little silt may be found in the lower Charles, from street wash and the like, will be kept out of the harbor by the settling basin formed by building the dam.

Mystic Lake, near the mouth of the Mystic River, is deeper than any part of Boston harbor. That it has maintained this great depth is clear proof of the small amount of silt that has come from the river.

The Board of Harbor and Land Commissioners, in their report of 1894, called attention to the apparent deepening of Boston harbor between 1835 and 1861, and the apparent shoaling from 1861 to 1892, during which period the tidal reservoir was so greatly reduced by the filling in of the Back Bay (pp. xvii, xviii, report of 1894).

That there has been no such shoaling is conclusively proved by borings which this committee has caused to be made, at places where this shoaling is supposed to have taken place; and the samples show the ancient mud, hereafter spoken of, at less than the average depth in Boston harbor, overlying the old clays dating from the end of the glacial period; and this notwithstanding that the tidal prism of the harbor above Governor's Island has been greatly diminished.

Geological observations show that the accumulated silt or sandy mud, so universal on the bottom of Boston harbor, is very ancient, covering in its growth climatic changes and changes in the level of Boston harbor shown by the presence of varieties of shells no longer living north of Cape Cod, and the interstratification of this silt with peat in the surrounding territory. That the process of accumulation is very slow is shown by the estimate that it has taken five thousand years to gather together from 2 to 5 feet, and there has been no tendency to wash any of this out to sea by the action of the currents at the bottom.

Another most important theory, on which the commission of 1859–66 based its report, is that of the "seaward gain" of the currents in the harbor. In the tenth report, p. 52, also cited in the report of the Board of Harbor and Land Commissioners in 1894, it is said: "A grain of sand would daily make two journeys, one up river, represented by 3.15 hours, in which velocity exceeded .3 mile per hour, the other seaward, by 5.18. The seaward gain is therefore fully in the proportion of 5 to 3; there is, then, at this point power sufficient to keep the channel free. . . . Except for the tides hurrying through this avenue to and from the basin above, the present good depth of water could not be maintained."

It is true there is a seaward gain of the currents as measured near the surface, though the proportion of 5 to 3 is not established by any current measurements recorded by that commission or that we find now, nor by any excess caused by the fresh-water flow of the river, called "back water," of which we now have accurate measurements not known to the earlier commission. But, measured from the bottom, where the erosion takes place, the gain is not seaward, but landward. This seems to be explained by the fact that, with a flood tide, the cold and heavier salt water dips under the warmer and brackish water and keeps nearer the bottom. (See chart of current curves in the appendices to the engineer's report.)

It is due to the United States commission of 1859–66 to say that at the time of their report physical data were very incomplete, the glacial theory had not been developed, and instruments of measurement were far less accurate than at present. It is not surprising, therefore, that this commission, reporting nearly forty years ago, should have been led into a wrong hypothesis as to the origin of Boston harbor.

Your committee has gone into this whole question with the conviction that no enterprise should be undertaken in Boston or vicinity that would affect in any unfavorable manner the future of Boston harbor. It believes that this great harbor is a vital factor in the commercial development, not of Boston and Massachusetts alone, but of the whole country; but it feels convinced that benefit rather than harm will come to the harbor from the erection of a dam, and that, should any shoaling occur, it will be small and of light material, and can easily be removed under the modern methods of dredging at small expense.

Commercial Interests.

The traffic on the Charles River in the delivery of coal and other material, either to wharves upon the river itself or upon the canals in Cambridge, is one that your committee feels should be preserved, whether this traffic is at present large or small, or whether it is increasing or diminishing.

The construction of a dam with a proper system of locks and with such dredging as is indicated below will, in the judgment of the committee, rather facilitate than hinder this traffic. The formation of ice in the winter will be a possible objection, and an estimate of the probable expenditure necessary to protect the annual traffic has been prepared.

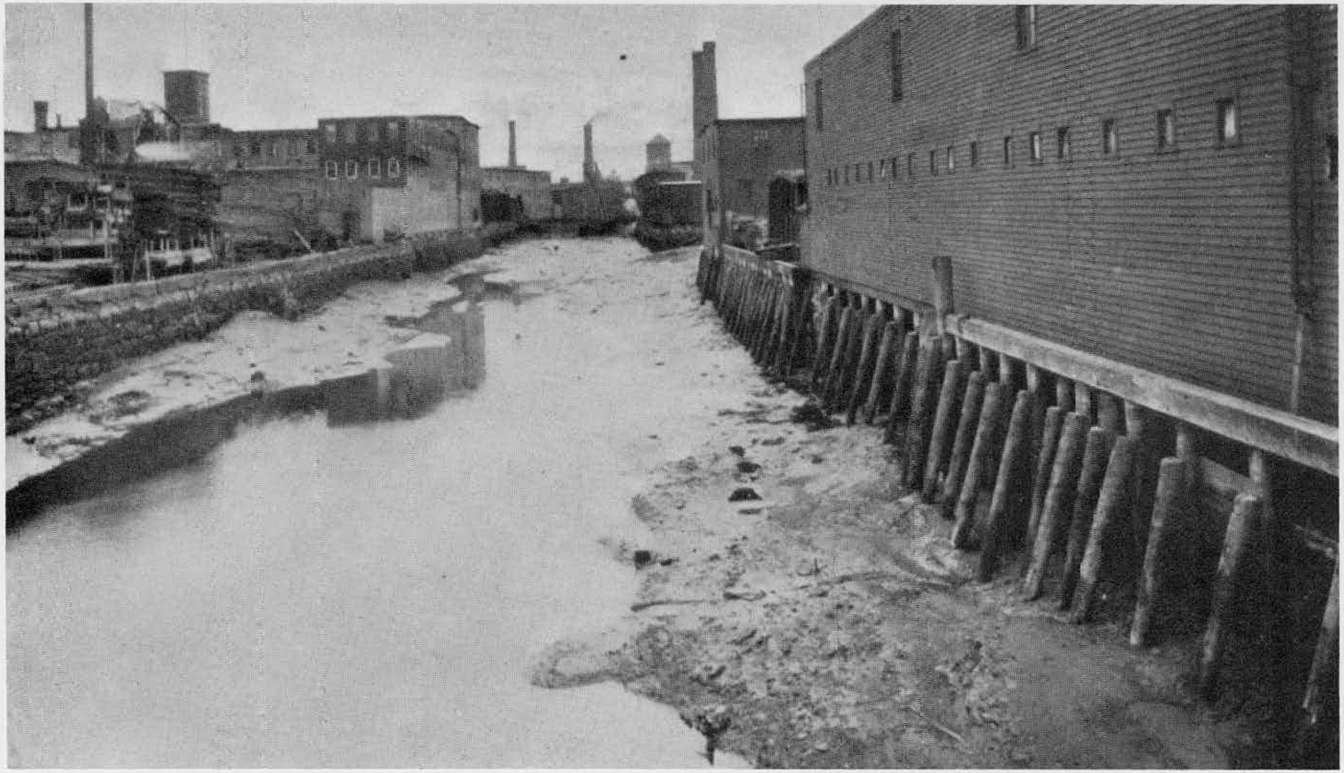
In view of the recommendation of the Craigie bridge as the site of the dam, the committee has considered the need of sufficient room for manœuvering vessels between that bridge and the Lowell Railroad freight bridge, immediately below. The evidence submitted to the committee is that a space of 320 feet is necessary, and the committee finds that the requisite space can be obtained by moving the Boston & Maine Railroad freight bridge slightly to the east, and recommends that 400 feet be secured, if practicable.

As the railroad company is under contract with the federal government to renew its present pile bridges with modern structures at an early day, the committee recommends that the railroad be required to locate their new bridges in such a manner as to give the requisite space.

Counsel for property owners on Broad and Lechmere canals have submitted to the committee a stipulation of certain conditions which they regard as essential, with reference to the size of the locks, dredging the canals, the maintenance of the sea-walls on the canals, and maintaining the canals free from ice in the winter. These conditions, so far as they refer to free maintenance of locks large enough to accommodate the largest vessels which will be used on the Charles, and the maintenance of access to the canals free from ice, should be complied with; and, in consideration of the possible future development of commerce, the committee would recommend locks of even greater width than those suggested by the engineers of the proprietors.

The Broad canal is owned by the proprietors of the banks as tenants in common under an agreement dated in 1806, by which they are authorized to maintain a canal at a depth of 9 feet, and they undoubtedly have certain riparian rights of access to tide water. Any act authorizing the building of a dam should contain a provision that the owners of private property on the river above the dam should recover damages for any injury occasioned to their property by reason of the construction of a dam and the consequent reduction of the water level. It is the opinion of the committee, and also of those interested in the river traffic whose testimony is before the committee, that the maintenance of a permanent water level at the elevation of mean high tide would be a material benefit to owners of wharf property above the dam.

If the basin is maintained at grade 8, Boston base, a depth equivalent to the present mean high water can be obtained by a moderate amount of dredging in the canals, and probably with comparatively small expense for strengthening the walls. The walls along these canals were in most cases built about twenty years ago, and in many places are ruinous, and must soon be rebuilt at the owner's expense. It is probable that the dredging of the canal to the depth called for by the owners at the wharves will result in many cases in causing these walls to fall in. The cost of dredging and rebuilding these walls and dikes, as might be called for under a strict construction of the owners' demands, is estimated by Mr. Hodgdon to be $331,735. In view of the benefit which these canals will receive by having a constant water level, and of the fact that walls will in many cases require rebuilding at an early date, the committee feels that the stipulation by the owners of these premises, if fully complied with, would place them in a much better position than they now enjoy. Dredging these



Broad Canal, between Sixth Street and Railroad, November 24, 1902.

Cambridge Esplanade, looking toward West Boston Bridge, July 11, 1902.

canals in the manner proposed by Mr. Hodgdon in his report, p 423, with the riprapping of the slopes, would leave the canals in as serviceable condition as they now are at mean high tides, and this can be done at an expense of $40,000, for work in the canals, which seems to the committee an equitable adjustment of the claim. A moderate amount of additional dredging in the basin would be required. The cost of this would not exceed $25,000. It was stated by counsel for the owners that $80,000 would probably cover the cost of their requirements. An examination of the photographs which accompany this report, showing the condition of these canals at low water, will give some idea of the limitations placed upon commerce in these canals under present tidal conditions.*

Recommendations.

The committee recommends that a dam be built, sufficiently high to keep out all tides; and that a fresh-water basin be maintained at a permanent level not below grade

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* The maintenance of a level at grade 8, Boston base, would be a reduction from mean high water level of 2.2 feet. Boston base is .64 feet below mean low water at the Navy Yard. Predicted high tides at Boston Navy Yard in 1902 ranged from 7.7 to 11.6 feet above mean low-water level, the mean rise of tide in Charles River being 9.6 feet above mean low-water level, which is a rise equivalent to grade 10.24, Boston base.

The owners of property on the Broad and Lechmere canals in their stipulations request that, in case a dam is built, these canals should be dredged so as to give them a *permanent* depth, with the water at grade 8, which would be from 1 to 2 feet deeper in the channels and from 4 to 7 feet deeper at the wharves than the depth which they have at present upon *spring* tides of 11 feet; and they also ask to be paid for the rebuilding of the walls, which may be necessitated by dredging for obtaining this increased depth. Spring tides of 11 feet occur monthly. The highest predicted tides of 11.5 feet in 1902 occur about four times during the year, and at such times, for a period of three or four days, the rise of the tide ranges from 11 to 11.5 or 11.6 feet.

The stipulation of the owners of property on Broad canal requests dredging which would give a constant water level "between the river and the Third Street draw, *to and at the wharves*, of 18 feet, between the Third and Sixth Street draws of not less than 14 feet, above the Sixth Street draw to the railroad draw of not less than 12 feet, and above the railroad draw of not less than 10 feet."

The owners of property on Lechmere canal stipulate for dredging which will give a constant depth of 18 feet up to Sawyer's lumber wharf and 14 feet above that point.

Under present conditions, with a spring tide of 11 feet, Broad canal, between the Charles River and the Third Street draw, has a greatest depth of 16.6 feet in the middle of the channel, with from 11.6 to 13.6 feet at the wharves; between Third and Sixth streets it has a greatest depth of 12.6 feet in the channel, with from 8.6 to 10.6 feet at the wharves; between Sixth Street and the railroad it has a depth of 11.6 feet in the channel and from 6.6 to 8.6 feet at the wharves; above the railroad it has a depth of 5 feet in the channel, and the canal is being used as a dump.

Lechmere canal, with a spring tide of 11 feet, has a depth of from 12.6 to 15.6 feet in the channel and from 10.6 to 11.6 feet at the wharves up to Sawyer's lumber wharf; above Sawyer's lumber wharf it has a depth of 12.6 feet in the channel, with from 10.6 to 11.6 feet at the wharves.

While owners may intend to dock vessels on spring tides, they cannot take advantage of this to its full extent, as vessels are often detained by head winds and otherwise, and the tides may be held below their predicted height by west winds or other causes.

The dredging stipulated for, nevertheless, calls for a constant depth which *is greater than that now existing upon spring tides of 11 feet, as follows:* Broad canal, between the river and Third Street, in the channel 1.4 feet and at the wharves from 4.4 to 6.4 feet; betweenThird and Sixth streets, in the channel 1.4 feet and at the wharves from 3.4 to 5.4 feet; between Sixth Street and the railroad, in the channel .4 of a foot and at the wharves from 3.6 to 5.6 feet; above the railroad, 4.4 feet. Lechmere canal, in the channel up to Sawyer's lumber wharf, from 2.4 to 5.4 feet and at the wharves from 6.4 to 7.4 feet; above Sawyer's lumber wharf, in the channel 1.4 feet and at the wharves from 2.4 to 3.4 feet.

These depths are taken from the soundings on Broad and Lechmere canals, as shown in map annexed to the engineer's report, and the tide ranges are taken from the tide tables of the United States Coast and Geodetic Survey of 1902.

8 or above grade 9. As this basin is to be used for park purposes, it is essential that the condition of the water should not only be harmless to health, but also that there should be no suggestion of sewage; that the water be as pure as reasonably possible, and thus both the factor of sanitary safety and the enjoyment of the water park be increased. Therefore, the committee recommends that certain changes be made in the present systems, which can be done at reasonable expense, and that the following changes be made conditions precedent to the building of the dam.

First. — That, in accordance with the recommendations of the engineer, all direct sewage and factory waste be taken out of the Stony Brook channel and out of the Charles River between Waltham and Craigie bridge; that the connection between the new Stony Brook channel and the old Stony Brook channel and gate house in the Fens be constructed, and that the old Stony Brook conduit be rebuilt, the cost of both being $347,000, or, in the alternative, that the 12-foot conduit recommended in the report of the sewer division of the street department of 1901, between the mouth of the Commissioners' channel and Stony Brook and Charles River, be constructed, the expense of which is estimated at $300,000. The committee also accepts the recommendation of the engineer that the Commissioners' channel of Stony Brook be extended to Forest Hills, and that the extension of the deep common sewer to Forest Hills be built.

Second. — That a marginal conduit be built, as described in the engineer's report, from the mouth of the Fenway, and preferably from the overflow outlet of the St. Mary's Street sewer, to a point below the dam. The structure recommended by the engineer is about 16 feet in width by 13 feet in depth, and would probably be sufficient to convey the entire flow of Stony Brook and the storm overflow from all of the neighboring sewers in all but the one or two worst storms of the average year except during the hours of extreme high water.

It would be provided with tide gates at its outlet, and in moderate storms its capacity would serve to store the flow entering until the tide had fallen. In heavy storms at extreme high water the surplus will overflow into the basin through numerous channels designed to diffuse the discharge at many points below the surface and to take their flow at or near mid depth of the conduit and thus reject the floating material and also the heavier particles.

It will be a simple matter at any future time to add a propeller pump at the outlet, operated from the same power plant which works the drawbridge and the lock gates, by which the marginal conduit can be discharged in the hours of extreme tide.

This marginal conduit should be constructed at the same time with embankment already authorized by statute in the rear of Brimmer and Beacon streets, thus saving considerable expense in construction. It would discharge below the dam. On the Cambridge side the overflow channel from Binney Street should, as proposed by the engineer of the committee, be continued below the dam, which is a distance of about 2,000 feet, with similar arrangements for discharge. This would take care of sewage overflow and street wash from 33 per cent. in area and 58 per cent. of the population of Cambridge, the sewage from which at present overflows into the Charles River above Craigie bridge. The marginal conduit on the Boston side connecting with the channel in the Fens would furnish a perfect gravity circulation of fresh water for the Fens in dry weather, the water flowing from the main basin into the Fens to the farther end of the channel and through it and the marginal conduit to a point below the dam whenever the tide outside is not above grade 6. In a similar way a gravity circulation for the Broad and Lechmere canals should be furnished by a connection with the Binney Street overflow conduit.

Third. — The existing deposits of sludge, which at present fill about one-quarter of the cubic capacity of the Fens intended to be filled with water, should be dredged, together with certain relatively small deposits in the main basin, mostly near sewer outlets, as detailed in the engineer's report.

Besides these three conditions which the committee deems essential, it recommends the following. The separate system of drainage for the Stony Brook valley and some other portions of Boston, as recommended in the report of the street department, sewer division, for the year 1901, should be begun and extended with reasonable rapidity, and on the Cambridge side the separation already begun should be extended, beginning with the upper reaches of the basin.

Salt water should not be admitted into the basin under the fresh water, as was suggested at the hearing, nor in any other way, unless under some unusual condition.

The banks of the basin should be so sloped and finished as to leave no small pools or shallow spots for the breeding of malarial or other mosquitoes; and the many breeding-places of these pests now existing near this great water park should be destroyed.

It is important to preserve the greatest possible water area; and, in building the embankment on the Boston side of the river, between the West Boston and Cottage Farm bridges, authorized under chapter 435 of the Acts of 1893, to be constructed 300 feet wide in the rear of Brimmer Street and 100 feet wide in the rear of Beacon Street, the surface of the river should not be encroached upon more than is necessary.

Your committee recommends Craigie bridge as the site of the dam for the following reasons: —

The borings indicate a good foundation there. This site continues the water park opposite the whole of the Charlesbank, and brings it nearer to the crowded portions of the North End of the city of Boston. The chief reason, however, for the location decided on, is that it will serve for a new bridge. The present Craigie bridge is old, and will soon have to be rebuilt. It serves as the only artery from East Cambridge and Somerville to Boston. It is near many of the large freight yards, is much crowded with heavy teaming, and many electric cars cross it. Blocks are frequent, and property would undoubtedly be improved in the neighborhood were a broader roadway supplied.

Character of the Structure recommended.

The committee refers to report of the chief engineer for a more detailed description of the structure which is recommended.

In brief, it is intended to serve both as a dam and as a bridge and to have substantially the construction recommended by the Joint Board of 1894.

That Board recommended a dam with a 100 foot roadway. We suggest that this width be increased by 30 feet in order to provide a space of from 15 to 25 feet in width along the up-stream edge, on which suitable seats can be placed, giving the inhabitants of the neighboring thickly-settled districts of Boston and Cambridge convenient opportunity to enjoy a view of the basin.

We also recommend a somewhat higher grade for the top of the dam near the lock and draw, similar to that proposed by the city engineer in bridge designs Nos. 3 and 4, and for the same purpose, namely: to admit tug-boats and barges without masts to pass the lock without interrupting the traffic over the bridge.

We recommend a lock 350 feet in length between gates of a clear width of 45 feet, with a drawbridge of 50 feet clear opening, with a depth over the sill of the lock of 13 feet at mean low water. It will be noted that these dimensions of the lock are considerably larger than those recommended by the petitioners or by the Joint Board of 1894. To increase them further would add an amount to the cost of construction and maintenance which appears out of proportion to the actual or prospective demands of navigation.

On examination of the various studies and plans proposed, including that of the Joint Board of 1894 on file in the office of the State Board of Health, your committee felt that it was not necessary to make fresh detailed drawings for construction, inasmuch as the drawings prepared for the Joint Board appear sufficient for the preliminary estimate.

Our engineer has reviewed these original drawings and estimates, and reports that he finds no recent developments which would lead to any material change except for the increased quantities, due to a somewhat larger cross-section of the stream at Craigie bridge and to increased width of the dam and its greater head room at the drawbridge.

Making ample allowance for these increased quantities, together with a margin for increased cost of building operations at the present time, we consider that these additional expenses will be covered by the addition of $590,000 to the estimate of the Joint Board, making the total cost of the dam, including roadway, drawbridge and lock, $1,250,000, or substantially the same as the cost of equivalent bridge No. 3 as estimated by the city engineer (exclusive of grade damages).

Cost.

The cost of a bridge will be about as much, or perhaps more, than the whole cost of the dam. The West Boston bridge is to cost $2,500,000, the Charles River bridge has cost $1,500,000. Four estimates have been made by the Boston city engineer for the cost of a new bridge to replace the Craigie bridge, the first being $864,430, the second $1,148,458, the third $1,463,362, and the fourth $2,044,687. The cost of the dam is stated by our engineer as follows: "The cost of the dam, including bridge and lock combined, would cost but little if any more than the equivalent bridge 100 feet in width."

As to the cost of the whole undertaking, the dam itself should not be charged to the basin improvement account, but should be charged to the same cities as would have to pay for a new bridge. The work required to be done in the Fenway should be charged wholly to the city of Boston; for that work, already recommended by Boston officials, should be done, even if a dam is not built. The construction of the embankment and filling in the rear of Beacon and Brimmer streets, already authorized by statute to be paid for by the city of Boston, should also be paid for by that city, excepting whatever excess of cost may be necessitated by the construction of the marginal conduit recommended by your committee. The cost of maintenance will be but little more than the cost of maintaining a drawbridge, which would fall in any case on the cities maintaining a bridge. For this reason no separate estimate is included.

The total cost of the recommendations of your committee, properly chargeable to the account of the improvement of the basin by a dam, will be: —

Marginal conduit on Boston side from Leverett Street to Fens outlet,	$500,000
Extension Fens outlet to St. Mary's Street,	200,000
Marginal conduit on Cambridge side,	150,000
Dredging of basin recommended by engineer,	25,000
Dredging Broad and Lechmere canals and rebuilding walls,	40,000
Keeping channels in and to Broad and Lechmere canals open from ice, capitalized,	100,000
General contingencies,	221,000
Total,	$1,236,000

The above does not include the extension of the Stony Brook conduit through Fens to Charles River.

As against this expenditure the following saving will be effected over the plans of improvement of the basin now in progress.

Saving on sea wall between Cambridge Street and St. Mary's Street,	$173,000
Saving on sea wall on Cambridge side,	112,000
Saving on grading on Cambridge side,	100,000
Approximate saving on Metropolitan Park Commission work for construction remaining to be done, in case water in the basin is held at grade 8, will be,	425,000
Total,	$810,000

From which it appears that the plan here proposed will entail an expense of only $426,000 above that of the treatment of the basin without a dam, and this without including the large expense necessary for dredging in case the basin is adapted for public use without the aid of a dam.* When in

* It is estimated by Percy M. Blake that the dredging below the Cambridge, River Street, bridge to grade —5 would cost $479,168; while the dredging above this bridge to the same grade would cost $537,777; total $1,016,945.

The engineer's estimate of the dredging necessary in case a dam is built is $25,000, in addition to the cost of dredging materials for dam and embankment which is included in the estimate of the cost of the dam.

addition to this the gain in public health, in increased commerce and in public pleasure are considered, the immediate carrying out of the work recommended would seem to be a measure of wise public policy and of economy as well.

Apportionment.

Your committee proposes to distribute the cost of the improvement of the basin proper, seven-twelfths to the city of Boston, three-twelfths to the city of Cambridge and one-twelfth each to the city of Newton and the town of Watertown.

The distribution of expense just suggested would assign the following amounts to the different cities and town respectively: —

Boston,	$721,000
Cambridge,	309,000
Newton,	103,000
Watertown,	103,000

Commission of Construction and Maintenance.

Your committee recommends, as a commission to have charge of the construction and maintenance of the dam, the mayors of the cities of Cambridge and Boston, and the Metropolitan Water and Sewerage Board *ex officiis*. The latter is composed of three members, one of them being the chairman of the State Board of Health. That commission has recently constructed some very large dams, involving much greater engineering difficulties than the dam proposed. It also has charge of the metropolitan drainage systems, and is now building large sewers much more difficult of construction than the marginal conduit and the continuation of the Binney Street sewer. It has in its employ also experts on the question of purity of water and the disposition of drainage. It would seem that no Board is better equipped for constructing this dam and maintaining the basin in good condition than the Metropolitan Water and Sewerage Board, with the help of the mayors of the cities of Cambridge and Boston and the city engineers, who will act under the control of the mayors of those cities.

The committee further recommends that the following amendments to existing acts be adopted: —

Be it enacted, etc., as follows:

SECTION 1. Chapter three hundred and forty-four of the acts of the year eighteen hundred and ninety-one, as amended by section one of chapter four hundred and thirty-five of the acts of eighteen hundred and ninety-three, is hereby further amended by inserting in said section one, after the words "thence running southerly by a straight line", the words "or a curved line"; and after the words, "to the point in Charles river", and before the words, "three hundred feet distant westerly", the words, "not less than one hundred feet nor more than"; and by inserting after the words "but no part of said wall shall be less than one hundred feet nor more than three hundred feet westerly from said commissioners' line"; and by omitting the word "straight", after the words "southerly and westerly from the aforesaid", and before the word "line"; so that said section one, as amended, shall read as follows: "*Section 1.* The city of Boston may, by its board of park commissioners, build a sea wall on the Boston side of the Charles river from the sea wall of its present park, situated between Craigie's bridge and West Boston bridge, to the sea wall of said river in the rear of Beacon street in said city, on or within the following lines: Beginning at a point in the south-west corner of the stone wall of the Charles river embankment, or Charlesbank, thence running southerly by a straight line, or a curved line, to a point in Charles river not less than one hundred feet nor more than three hundred feet distant westerly from the harbor commissioners' line, measuring on a line perpendicular to the said commissioners' line at its intersection with the southerly line of Mount Vernon street; but no part of said wall shall be less than one hundred feet nor more than three hundred feet westerly from said commissioners' line; thence continuing southerly and westerly from the aforesaid perpendicular line, on such lines, curved southerly and westerly from the aforesaid line, as said board of harbor and land commissioners shall approve, to a point one hundred feet or less distant from said sea wall in the rear of Beacon street; thence by a line parallel with said wall to the westerly line of the public park of said city, known as the Back Bay fens, extended to intersect said line parallel with said sea wall."

SECTION 2. Section three of said chapter four hundred and thirty-five of the acts of eighteen hundred and ninety-three is amended by omitting the words beginning, "The said city shall, in addition to the said dredging of material for filling", and ending with the words, "in their judgment is an equal improvement to the harbor of Boston"; and by inserting, after the words "and to the provisions of all general laws applicable thereto", the words, "but no compensation shall be required by said board from the city of Boston on account of said sea wall and filling"; so that said section three, as amended, shall read as follows: "*Section 3.* The material used for the filling authorized by said chapter shall, to such grade as shall be required by the board of harbor and land commissioners, be dredged from Charles River basin in such places and to such depths as the said board, having due regard to the requirements of navigation, the improvement of said basin and the quality of material suitable for such filling, shall from time to time prescribe. All of the filling, dredging and other work authorized or required by this act shall be subject to the direction and approval of said board and to the provisions of all general laws applicable thereto; but no compensation shall be required by said board of the city of Boston on account of said sea wall and filling. The filling, dredging and other work authorized by this act shall also be subject to the approval of the secretary of war and to all laws of the United States applicable thereto."

SECTION 3. This act shall take effect upon its passage.

Be it enacted, etc., as follows:

SECTION 1. That chapter five hundred and thirty-one of the acts of eighteen hundred and ninety-eight be so amended that the board of metropolitan park commissioners will have authority to build a bridge instead of a dam from Cambridge to Boston at the point therein prescribed for building a dam; and that the provisions of said chapter for the construction of said dam, as far as applicable, shall apply to the construction of said bridge.

SECTION 2. This act shall take effect upon its passage.

The committee submits the following draft of a bill:—

AN ACT TO AUTHORIZE THE CONSTRUCTION OF A DAM ACROSS THE CHARLES RIVER, BETWEEN THE CITIES OF BOSTON AND CAMBRIDGE.

Be it enacted, etc., as follows:

SECTION 1. The mayor for the time being of the city of Boston and the mayor for the time being of the city of Cambridge shall, with the metropolitan water and sewerage board, all acting *ex officiis*, constitute the Charles river basin commission.

SECTION 2. Said commission shall construct, maintain and operate a dam across Charles river, with a suitable lock, waste ways, etc., between Boston and Cambridge. Said dam shall be substantially at the present site of Craigie bridge. Said dam shall not be less than one hundred feet in width at the top, so built as to allow for a roadway of that width, with drawbridge over the entrance to the lock, and shall be of sufficient height to be capable of holding back all tides.

Said commission is authorized to apply for and take all necessary steps to obtain the approval of the secretary of war or other proper authorities of the United States for carrying out the purposes of this act.

Each member of said commission shall be paid his actual travelling expenses and all such other expenses as may be incurred by him in the performance of his duties under this act, as shall be allowed by the governor and council.

SECTION 3. As a condition precedent to the completion and operation of said dam, said commission shall carry out or cause to be carried out all the recommendations made by the committee on Charles river dam appointed under resolves of nineteen hundred and one, chapter one hundred and five, as amended by resolves of nineteen hundred and two, chapter one hundred and three, in its report of January fourteen, nineteen hundred and three, excepting as the same may be modified by said commission with the approval of the state board of health.

SECTION 4. The supreme judicial court or any justices thereof, and the superior court or any justices thereof, shall have jurisdiction in equity to enforce this act and any order made by said board in conformity therewith. Proceedings to enforce the same shall be instituted and prosecuted by the attorney-general, by the request of said board or any other party in interest.

SECTION 5. Said commission may allow damages to any wharf owners or others on account of the construction and maintenance of said dam, and said board may also dredge canals between Craigie bridge and West Boston bridge, and do such other dredging as they may deem proper in said basin; and may strengthen or rebuild wharves or other structures near said dredging; and they may provide for breaking channels through the ice in winter above said dam within the basin; and they may assess betterments for said dredging and strengthening or rebuilding of wharves, under the general law authorizing the assessment of betterments, with like remedies to all parties interested.

SECTION 6. Any person entitled by law to any damage for taking of or injury to property under authority of this act may appeal from the decision of said commission, within thirty days of said decision, to the superior court for the counties of Suffolk or Middlesex, on petition therefor; said damages to be determined by a jury, under the same rules of law, as far as applicable, as damages are determined for taking of lands for highways, under the provisions of law authorizing the assessment of betterments.

SECTION 7. To meet the expenses incurred under the provisions of this act, except for the annual repair and maintenance, the treasurer and receiver-general shall, with the approval of the governor and council, issue notes, bonds or scrip, in the name and behalf of the Commonwealth and under its seal, for a time not less than ten nor more than forty years from their respective dates, which shall bear interest at a rate not to exceed four per cent. per annum, payable semi-annually, and to be designated "The Charles River Basin Loan," and be issued as the governor and council shall direct.

The treasurer and receiver-general shall establish a sinking fund and apportion an amount to be paid each year, sufficient, with its accumulations, to extinguish the debt at maturity.

SECTION 8. So much of the debt in the preceding section as shall be caused by the construction of the dam itself shall be apportioned by said board on the basis of its being a substitute for a bridge among such cities as shall be directly benefited by its use as a highway, after giving a hearing to said cities, in such proportion as may seem best.

The cost of any work done hereunder within the fenway and the cost of the park in the rear of Beacon and Brimmer streets, as authorized by the acts of eighteen hundred and ninety-one, chapter three hundred and forty-four, as amended by the acts of eighteen hundred and ninety-three, chapter four hundred and thirty-five, shall be charged to the city of Boston. The annual payments for interest and sinking fund on so much of the debt as is provided for under this section shall be paid by the respective cities in proportion to their share of this portion of the debt charged to them hereunder.

SECTION 9. The annual payments for interest and sinking fund on so much of the debt as is not already provided for in the preceding section, together with the annual cost of maintaining, operating and repairing said dam and basin, and of other work done under authority of this act, and such dredging below the dam, if any may be required from time to time by the secretary of war, on account of the existence of said dam, shall be paid, seven-twelfths by the city of Boston, three-twelfths by the city of Cambridge, one-twelfth by the city of Newton and one-twelfth by the town of Watertown.

SECTION 10. The Boston park commission, duly authorized to construct said park in the rear of Beacon and Brimmer streets, shall construct said park in a manner to allow the commission herein established to build in the best and most economical manner the marginal sewer, as recommended by said committee on the Charles river dam, which shall be completed before the operation of said dam.

SECTION 11. The roadway on said dam within its limits, as determined by said commission, shall be surfaced or paved, policed and maintained by the cities of Cambridge and Boston; and all damages recovered in any action of law by reason of any defect or want of repair in any such roadway shall be paid by such cities equally.

SECTION 12. The Boston and Maine railroad shall remove its freight bridge next below said Craigie bridge, and shall rebuild the same further down, so as to allow a distance of at least four hundred feet in the clear between said bridge and the lower face of said dam, and shall remove the piles of said old bridge, all at the expense of said railroad company.

SECTION 13. No action shall be taken relative to dredging or to strengthening or rebuilding of wharves under this act, until the plans therefor have been duly submitted to the board of harbor and land commissioners, and received their approval thereon.

SECTION 14. This act shall take effect upon its passage.

HENRY S. PRITCHETT.
SAMUEL M. MANSFIELD.
RICHARD H. DANA.

BOSTON, MASS., Jan. 14, 1903.

REPORT OF JOHN R. FREEMAN, CHIEF ENGINEER.

HENRY S. PRITCHETT, LL.D., *Chairman, Committee on Charles River Dam.*

DEAR SIR: — The chief questions demanding consideration by your engineer, after the proposition and the evidence had been reviewed, appeared to be the following: —

I. In general, the benefits and disadvantages resulting from proposed dam.
II. Best type of dam, complete or half tide.
III. Best location.
  (*a*) Just above Broad canal.
  (*b*) Just above Lechmere canal.
  (*c*) At Craigie bridge.
IV. Most advantageous elevation of water surface; grade 8, Boston base, or higher. Effect on ground-water levels of neighboring territory.
V. Fresh water basin *v.* salt water; comparative advantages.
VI. Necessity for large tidal sluices.
VII. Present condition of Fens basin; analogy to proposed basin.
VIII. Quantity of upland water flowing into the proposed basin.
IX. Purity of this upland water.
X. Extent of the present pollution of Charles River basin; means of lessening this.
XI. Amount of pollution admissible without offence.
XII. Remedies for the unavoidable pollution.
XIII. Means for circulating water in Fens basin and Cambridge canals.
XIV. Lessening pollution of basin by extending separate system of sewerage.
XV. Effect of stagnation of water in proposed Charles River basin upon odor, appearance and character of water.
XVI. Effect of this stagnant fresh water basin on health; malaria.
XVII. Effect of lessening the tidal prism upon the shoaling of Boston harbor.
XVIII. Effect of dam upon navigation and commerce in Charles River basin, in Cambridge canals and in upper harbor.
XIX. Storm flood levels in proposed basin; frequency or probability of ever flooding the marshes after dam is built.
XX. Cost of dam and lock, with and without special tidal sluices.
XXI. Cost of marginal conduits for increasing cleanliness of waters of basin.
XXII. Cost of making good any injury to navigation resulting from dam.
XXIII. Cost of dredging foul sludge banks.
XXIV. Cost of shore line improvements.

The foregoing questions will be found discussed briefly under the corresponding numerals beginning at p. 64.

In order to secure data for the proper discussion of the above topics, I was led step by step into many extended investigations, and compelled to seek assistance from several specialists.

I have had these investigations reported in the form of a series of appendices, and have given the methods, the facts and their interpretation, all with much detail, because of this subject having been so many years before the public, and *in order that others may have full and convenient opportunity to judge of the adequacy of the new data secured and of the reasonableness of our conclusions.*

In accordance with your request I have carefully examined the evidence presented at the public hearings, and have given particular attention to the reports of studies by experts presented on behalf of the opponents. I have also carefully reviewed the evidence presented at the hearings before the Harbor and Land Commission in 1894 and the original report upon the improvement of Charles River by the Joint Board of 1894; also the series of ten reports made between 1861 and 1866 by the Board of Commissioners on Boston Harbor, and all reports made in connection with the public works of the metropolitan district suggested as bearing on the problems under discussion. In brief, I have sought earnestly to comply with your desire that these matters be reviewed so thoroughly and impartially that, whatever the conclusion, the question could be regarded as settled for a generation.

The Massachusetts Board of Harbor Commissioners in their review of the evidence of 1894 had urged strongly that certain matters be further investigated and more facts determined before final opinions were formed.

It became plain, early in these studies, while reviewing the evidence presented at the hearings of 1902, that a principal cause for sundry important differences in the opinions expressed regarding the desirability of the proposed dam lay in the inadequacy of the data of clearly proven facts, and the consequent recourse to assumptions made from different points of view. Therefore, with your approval, I made sundry investigations, which may be briefly outlined as follows: —

New Researches, and Data derived from them.

(*A*) *Surveys and Soundings of Basin.* — A new large-scale, contour map of the basin was prepared from new surveys and soundings, because it was found that the existing maps had been rendered worthless over a large portion of this area by the great changes in the bed of the basin made by dredging material to form the embankments for the Cambridge parks, for the speedway and for filling of large areas of private lands.

The wash of material stirred up by these operations, together with deposits from sewage and street wash, had also doubtless contributed to some shoaling in other parts of the territory in question.

This new map was desired as an aid in studying the requirements for navigation, for the purpose of estimating the cost of improving the muddy shores and marshes of the upper basin, and the cost of dredging several large, objectionable mud flats exposed at low tide, and for its aid in studying the biological conditions of the basin in case the dam was built and the water held nearly stagnant at constant level, because depth and light has a very material influence upon the growth of algæ and micro-organisms; and salt water in deep pockets becomes very foul and is displaced by fresh water very slowly.

(*B*) *Influence of Present Tidal Basin on Temperature of Air.* — A careful study was made of the influence of the present tidal basin upon the temperature of the surrounding air, both immediately over the water and for some distance back from the Boston and Cambridge shores. Ten self-recording thermometers were stationed at various representative localities, and ten other mercurial thermometers were stationed at other representative localities all the way from Boston Light to Norumbega Park, and read several times daily for a little more than two months. Great care was taken in the calibration of these thermometers, and also in locating them so as to obtain proper exposure.

The result of all these thermometric readings was to show that *the basin now cools the temperature of the air on the shores around the basin and at the street level over the middle of the basin by hardly more than a single degree Fahrenheit from 10 A.M. to 4 P.M. on the hottest days;* and it is proved by these very numerous and careful observations, beyond the shadow of a doubt, that the apparent coolness of the air on hot summer days near the present basin is almost wholly due to the wind, in very much the same way that the face is cooled by the motion of air from a fan.

Water Temperatures. — The temperature of the water was also observed several times daily, beginning the last of June and ending the middle of September, at Boston Light, Deer Island Light and at the drawbridges and at sundry other stations along the Charles River as far as Riverside.

From all these observations, it appears that *the average July and August temperature of the proposed fresh-water basin would not be warmer than the present tidal basin by more than three degrees Fahrenheit.*

Taking, for the mid-day temperature, the average from 10 A.M. to 4 P.M. *of the twelve hottest, sunniest days* between July 28 and Sept. 12, 1902, we found the

Sea water temperature at Boston Light,	62° F.
Harbor water temperature by mean of six stations,	65° F.
Estuary water temperature by mean of three stations,	70° F.
Upland water temperature by mean of four stations between Watertown dam and Riverside,	74° F.
Air temperature, Boston, mean of Weather Bureau, Institute of Technology, Harvard Observatory,	77° F.

From these observations the remarkable fact appears that *the salt water of the present tidal Charles basin in the warmest weather is only four degrees cooler at mid-day than the fresh Charles River water between Watertown, Waltham and Newton.*

Similarly, taking the mid-day temperature for *every* day throughout the summer, the difference would manifestly be less; and because the wide basin is deeper than the up-stream waters, and better exposed to wind and evaporation, the temperature of its water will probably be somewhat cooler than that in the shallow mill ponds up stream, and no reason appears why, with the pollution restricted by the means proposed, the warmth of the future basin should encourage a much more luxuriant growth of algæ here than the same (or a slightly higher) temperature does in the same water a few miles up stream.

(*C*) *Study of Fens Basin.* — The Fens basin, which certain persons have suggested was, in its present foul and offensive condition, a fair example of what the Charles River basin would become if the dam were built, has been studied from the stand-points of its history, its hydraulics, chemistry, biology, pathology, and, we venture to add, common-sense. These matters will be found set forth at considerable length in Appendix No. 3.

Its hydraulics are found very different from what was testified to at the hearings. The circulation of water found during the three weeks of our test was only about one-fourth part as great as had been supposed. The rise and fall at each tide was only about 9 inches, instead of 18 inches, and its regulating gates were found leaking so badly that 60 per cent. of the water admitted at high tide leaked back on the ebb without circulating through the basin. The present actual circulation brings in less new water each day than required for diluting the volume of foul flow that constantly enters it in dry weather.

The new Stony Brook channel has been allowed to become a channel for dilute sewage, and chemical analyses have shown a highly putrescent quality in the refuse which enters it from various sources.

The chemist finds the Fens water badly polluted by sewage, insufficiently diluted and mostly devoid of oxygen, and finds an offensive amount of putrefaction going on in the sludge deposits over its bottom.

The biologist finds the lower layers of water mainly devoid of aerobic organic life, its oxygen used up, and little opportunity for fresh aeration, because of the difference of specific gravity between the upper and the lower strata of water.

And, as a matter of common-sense, the continued admission of sewage into Stony Brook, transforming it, in a run of two miles, from the bright, clear country stream found just above Forest Hills, to a condition which one skilled observer has described as resembling "a long septic tank," and then passing it into a park and diluting it less than half as much as is easily possible with the means at hand, passes understanding. The present condition of this basin could be greatly improved at small expense.

We made soundings and borings over the entire area of the Fens pond to determine the depth and volume of the water and the depth and volume of the sludge requiring excavation. We find that it contains upwards of 50,000 cubic yards of foul sludge, and that there is one-third as much sludge as there is of water in this pond.

Historically, I find that the present continuously offensive condition began only in 1897, and followed immediately upon the turning of the dry-weather flow of the sewage-polluted Stony Brook into the Fens, this foul flow having been previously excluded; and about the same time a change was made in the method of renewing the water.

The comparison of the probable future condition of the fresh-water Charles basin to the present condition of the Fens basin is, in my opinion, based on a very superficial examination, and is unjust.

(*D*) *Pollution. Chemical Analysis of Water.* — A study of the present pollution in the Charles River basin, the Fens basin, and in the Charles River above the Watertown dam was undertaken by means of chemical analyses, over six hundred and fifty samples of water having been collected and analyzed during the latter part of the summer and the early fall. I called to our assistance, for this study, one who has had a practical experience in the chemistry of water pollution probably not exceeded by any one in this country, — the chemist of the Massachusetts State Board of Health. His report will be found in Appendix No. 4.

We have reason to be very grateful for the cordial response of the State Board of Health to my request for the aid of its corps of chemists in this work, and for the energetic work performed. There is probably not another laboratory in this country where we could have obtained so much assistance and such valuable assistance in so short a time.

After I had observed the circumstances under which sewage sludge is deposited where the polluted fresh Stony Brook enters the salt basin of the Fens, I questioned whether the presence of salt in the water was not a disadvantage, by interfering with beneficent decomposition of impurities through organic life; and whether fresh water, with abundant life, might not receive a given amount of pollution with less chance of offence to sight and smell than salt water, and gave the more attention to this because of the presence of salt having been mentioned by many with approval, as if it were an aid to keeping the basins sweet and wholesome.

Therefore, sundry experiments were undertaken at the Lawrence Experiment Station of the Massachusetts State Board of Health, designed to increase our knowledge as to the comparative effect of dilution of sewage by salt water, brackish water and fresh water.

The results are very instructive, and show a decided superiority in fresh water, and a decidedly greater tendency to precipitate a sludge and give off offensive odors in salt water.

Certain other experiments were designed to show the difference in bacterial purification between water slowly moving and water at rest, which, taken with wide experience upon polluted water entering ponds and flowing streams, shows that stagnation in the proposed basin is not a condition that need be feared. "It is not running water, but quiet water, which soonest purifies itself," or most readily has its pollution disposed of by the activities of organic life.

Special studies have also been made with samples of the silt and mud from various parts of the basin of Charles River, with a view to learning its probable influence upon the purity of the water held above it. Bacterial counts have been made, under Mr. Clark's supervision, on a great many of these samples of water.

The chemist's conclusions will be found stated in great detail in the appendix devoted to his report. We may summarize the most important of those relating directly to the proposed basin as follows: —

(*a*) Although there are local pollutions, as a whole, the water of the present Charles basin gets well mixed in going through the bridge piles (soon to be removed), and is found to be fairly clean, with an abundance of free oxygen. The water of the Fens is overburdened with sewage, and its lower strata contain no free oxygen.

(*b*) Although the upland water, as it enters the basin in time of ordinary low summer flow, is somewhat discolored by dyes and factory washings, it always (except perhaps very rarely in extreme drought) contains an abundance of free oxygen, and it does not contain more organic matter than can be taken care of and rendered innocuous by the proportion of free oxygen contained, and such water if held stagnant in a pond would probably continually improve. This conclusion was reached after many experiments on incubation of this water, etc.

(*c*) The old and the new Stony Brook conduits continually discharge dilute sewage; Muddy River outlet is at times polluted; there are several places where the water is polluted by factory waste; and in time of storm considerable amounts of sewage overflow, also much street wash, enter the basin. But if all the pollution now entering were discharged into the nearly stagnant, fresh-water lake produced by the proposed dam, it is doubtful if this pollution would rob its water of all its dissolved oxygen and thereby lead to the generation of the offensive gases of putrefaction. It would probably be absorbed.

This conclusion was reached after an extended series of experiments by incubation of Charles River water containing various percentages of sewage. The chemist confirms this conclusion from a study of the analyses of the polluted Abbajona River water and the bettered condition of this water after storage in Mystic Lake, which was, until recently, used as a portion of Boston's water supply, and which has recently become a favorite resort for pleasure boating.

The turbidity and pollution from street wash and sewer overflow are now for a time mainly held as a thin layer at the surface, because of this fresh water being so much lighter than the salt, thereby exaggerating the appearance of pollution. With a fresh-water basin the same pollution would be at once more evenly diffused through the depths, and give less apparent defilement to the surface.

In case the proposed dam is to be built, in order to give the surface of the water a more attractive appearance, and as a safeguard against offence arising from the fact that the entrance of sewer overflows is intermittent, not uniform, the following improvements are recommended by the chemist: —

(*d*) The pollution now entering from the Beacon Street houses should be diverted into a sewer.

At least a portion of the pollution that now enters the basin through the Stony Brook channels should be excluded, particularly the highly putrescent brewery waste.

The outlets of polluting material from the abattoir and the starch factory near it should be more efficiently guarded.

It is possible, but not certain, that the dredging of a few of the present sludge banks in the Charles will be required.

(*e*) Better conditions would prevail for absorbing sewage pollution with the basin filled with still fresh water than if filled with still salt or brackish water. By an extensive series of experiments it is proved that salt water tends to a much greater precipitation of the impurities of sewage in the form of putrefying sludge than fresh water; and numerous other tests show that, when a given percentage of sewage is added to salt and fresh water under similar conditions, offensive odors arise much sooner from the salt water than from the fresh.

The salt water of the harbor, to begin with, averages containing less dissolved oxygen than the upland water which enters this basin, and this dissolved oxygen is found used up in the salt water to a greater extent in a given time than in the fresh.

This oxygenation is produced through bacterial agencies, and the quicker absorption of the free oxygen in the salt water, also the relatively greater number of anaerobic (or putrefactive) bacteria found able to live and work under salt-water conditions, leads naturally to the larger production of offensive odors.

In the fresh-water experiments, both with and without the bottom of the tank covered by polluted mud from the bed of the Charles, there were relatively more bacteria, but they were mainly aerobic, or bacteria effecting decomposition rather than putrefaction.

(*f*) The popular belief that running water purifies itself more readily than still water is fallacious. It is found to be the fact that with oxygen present, and equally good conditions for proper bacterial growth, the still water purification is fully as energetic.

(*g*) It does not appear probable that growths of algæ will cause trouble.

From the data given by Mr. Clark's report we have constructed the diagram inserted opposite this page, to exhibit the progressive decrease of the salinity of the present basin as we proceed up stream toward the Watertown dam.

(*E*) *Pollution. Bacterial Analyses of Water.* — Bacterial analyses, designed to exhibit the comparative degree of pollution in different parts of the Charles River basin, the Fens basin and in the water flowing in from above the Watertown dam, have also been made, under the direction of Dr. Theobald Smith. These observations were extended so as to lead to a clearer understanding of the degree of flushing received by the present Charles River basin under the ebb and flow of the tide; and they indicate, more fully than the chemical analyses, that the returning tide brings water that, while not very foul, is far from pure.

(*F*) *Malarial Conditions.* — The report of investigations relative to malaria, made at your request, form a separate Appendix, No. 1. The pathologist who made these studies has long been celebrated as a most skilful observer in this line of work. His researches for the United States government on the cause of the Texas fever are well known, and his recent call to direct the work of the newly established laboratory in New York for research on contagious disease is a testimonial to the esteem in which his work is held. I am told by competent authority that there is no man in America more competent to pass on these questions of effect of the proposed basin upon the health of the community by promoting or retarding conditions favorable to malaria. It is, therefore, most reassuring to learn that, following years of study on the origin of malaria, and after having repeatedly explored all parts of the adjacent territory, devoting a large part of his summer to this study, he reports: —

(*a*) "It is quite firmly established that the micro-organism of malaria which produces the well-known disturbances in the body by multiplying in the red blood corpuscles is transferred . . . by a certain species of mosquito."

(*b*) "The malarial microbe is a true parasite in all its stages. *It never exists free in the air or in the water or on vegetation*, but spends its life partly in the blood of man, partly in the organs of the mosquito."

(*c*) "All shallow pools in which water may stand for a portion of the year, and which are cut off from the permanent bodies of water so small fish cannot enter, may become breeding-places of mosquitoes, and should be filled up."

(*d*) "As regards the river itself, we may safely assume that the proposed basin will not become a breeding place for mosquitoes," if so treated as to contain abundant fish life, and if its banks are so treated as not to afford protection for mosquito larvæ from their natural enemies, the small fishes.

(*e*) Impurity or pollution of water, as in the present Fens basin, if made fresh water instead of salt, would tend to restrict the natural enemies of the mosquito, the little fishes, and, by greatly favoring the growth of fresh-water algæ, might eventually lead to the multiplication of *culex* and *anopheles* mosquitoes. "This necessarily implies the removal of all sewage from the Fens basin."

(*f*) "*In reviewing all the conditions likely to prevail in the future in and about the Charles River basin, there seem to be none which would tend to the increase of malaria* provided the suggestions made are carried out. In fact, the improvement of the banks and the territory beyond them *would be a great improvement on present conditions*, and tend to relieve those near the marshes of all mosquitoes now breeding in these places, *and perhaps remove the causes of malaria prevailing at the present time*, unless such malaria is due to bodies of fresh water beyond the immediate confines of the proposed basin."

(*g*) "Fresh water *v.* salt. The substitution of a fresh-water basin for the present tidal reservoir would not tend to intensify malarial influences, providing the present breeding-places of mosquitoes are properly dealt with. There would be a material improvement over present conditions, both as regards mosquitoes and malaria."

(*h*) "The introduction of salt water from the harbor will probably not be needed, and should be reserved as an artificial remedy for extreme unforeseen conditions."

(*G*) *The Unavoidable Pollution. Biological Studies.* — I soon came to believe that a hopeful remedy or means for taking care of such pollution of the water as may be unavoidable is its absorption by the activities of organic life.

I found it necessary to call in expert biological assistance for studying the conditions affecting microscopic and other life within the Fens basin and the Charles, both in its tidal estuary and above the Watertown dam, with a view to obtaining a clearer idea of what was necessary in order to establish biological equilibrium within the proposed basin; and for such light as a brief examination could shed upon the degree of pollution which could be admitted and absorbed by organic growth without causing offence; and for learning more about the probable result of changing from salt water to fresh water, and the results of an occasional flushing of the basin with salt water. This biological study was extended to cover an inquiry into the relative adequacy of salt water, fresh water and brackish water for supporting life, and for transforming and rendering harmless the impurities received.

The man called upon for this work had, after graduating at Brown some fifteen years ago, studied at Johns Hopkins, then at the celebrated biological laboratory at Naples, Italy, had continued these studies while an officer of instruction in biology in Brown University, and later as professor of biology at the Rhode Island Agricultural Experiment Station. While at the latter station he had given much attention to studying offensive conditions that had developed in the brackish Point Judith Pond, in which circulation of sea water had been cut off by natural causes. His report is given in Appendix No. 6, and brings out many interesting facts.

One important point brought out in this biological study of the Fens basin was *the influence on organic life of the prevention of aeration in the lower strata of water, where the specific gravity at the top of the water differs greatly from that below, thereby restraining vertical circulation.*

I have felt that the ideal toward which we should work in planning this large basin was that of a "balanced aquarium," and I greatly regret the lack of time for carrying these studies beyond the point merely sufficient for making sure that the proposed construction is safe, and that a fresh-water basin is best.

The investigations of the biologist show in brief, for *the special conditions of this problem:* —

(*a*) "The Fens basin . . . affords no fair or proper standard by which to judge the proposed Charles Basin."

(*b*) "Fresh water . . . will be better adapted for receiving sewage without causing offensive deposits or offensive odors than either salt or brackish water."

(*c*) "It appears probable that the organic life in the proposed fresh-water basin can assimilate the greatest amount of pollution that the engineers estimate it is likely to receive, without causing offence."

(*d*) "The occasional introduction of salt water into the basin should be avoided."

(*H*) *Pollution by Overflow of Sewage.* — The problem of the overflow of sewage mingled with storm water from sewers in Cambridge, Boston and the up-river towns, following heavy rains, has been studied with great care, and maps of these sewer systems have been compiled. Nearly every one of the fifty or more regulator gates controlling sewer overflows has been gone into and inspected. For several months I sought all opportunities for personally inspecting the overflows of sewage into the basin at low tide in time of storm. The new Stony Brook conduit, which receives the discharge of many sewer overflows, has been inspected repeatedly throughout its length, and the old conduit examined for a few hundred feet, or sufficiently to reveal its foulness.

This problem of estimating the quantity of sewage that may escape into the Charles River because of sewer overflows is one of extreme difficulty, — far more so than was anticipated; one reason is, that the sewer system of old Boston and Roxbury is extremely complicated, and contains many ancient sewers that were extended as the "made land" encroached upon the tidal flats and marshes, some of which are so outgrown and overloaded that in some of the small, old districts the extra flow of "washing day" is said to be almost sufficient to cause overflow.

All these matters will be found reviewed in much detail in Appendix No. 2.

We have reviewed and analyzed the Binney Street "sewer clock gauge" records in great detail, in order to learn their exact bearing upon the general problems of the amount of sewage overflow. We have also reviewed and analyzed all of the records of all the other sewer clocks, at the Bath Street, Lowell Street and Massachusetts Avenue district outlets, and also the records of the clock gauge in the Charles River valley sewer, and we have set several additional sewer clocks on outlets along the Boston sewer system, for comparison with the Binney Street records and the rainfall records.

We have also studied every one of the 77 sewer overflow districts individually, and compiled tables of population, impervious surface, etc., and have made estimates of the amount of sewage that each will probably contribute to the Charles after the new high-level sewer is finished and connected.

Speaking in general terms, I find: —

From the large and representative Binney Street district less than 3 per cent. of the total annual output of sewage enters the Charles, instead of the 7 per cent. assumed by several experts as the basis for their opinions; and during the six summer months, from May 1 to November 1, in which time alone could the overflow of sewage give noteworthy offence, *I believe it certain that not more than about 3 per cent. of all the sewage produced in all the territory tributary to the Charles in Boston and its suburbs will find its way into the Charles* after the new high-level sewer is put into use; and it appears certain that for twenty years to come, or as far as can be foreseen, this quantity will decrease. The tributary population, now about 300,000, will be decreased to not above 250,000 by diversion of flow from territory now tributary, on completion of the new high-level sewer two years hence; and the separation of sewage and storm drainage in future will without doubt progress fast enough to offset growth in population.

I believe that the amount of sewage entering the basin in the summer months would not exceed the amount that would be constantly discharged by a population of 7,500, perhaps not more than from 5,000, and I feel certain it could not possibly exceed that from a population of 10,000.

Experience on the discharge of sewage into other Massachusetts waters makes it appear entirely safe to say that a flow of less than 8 cubic feet per second of such water as now comes down over Watertown dam into this proposed "stagnant" reservoir will be ample to dilute and absorb the ordinary pollution from 1,000 persons without offence, if this pollution is well diffused through the water; and measurements of the river flow at Waltham make it certain that the summer flow, or for these six months, in all ordinary years, is more than sufficient for this degree of dilution of all the pollution that would enter if no marginal conduits are built.

Nevertheless, the intermittent character of the pollution and the storm flushing of concentrated filthy deposits and the added pollution due to street wash, with a population more dense in the future, have led me to propose marginal conduits, and these conduits are recommended also because of their utility in promoting circulation in the Fens and in the canals.

It further appears that the basin will be thoroughly flushed out by the flood waters every spring, and that the 458,-000,000 cubic feet of clean, fresh water that it will contain *could take care of the summer flow of sewage for three months with no inflow of fresh water whatever.*

This appears an ample factor of safety for extreme drought and for the almost complete holding of the river flow by the mills at Waltham, which has certainly occurred in times past for weeks at a time, and concerning which volume of river flow I have also made an extended investigation.

(*I*) *New Studies of Amount of Dilution required to make Sewage Inoffensive.* — Apparently the sanitary experts who made statements at the hearings regarding this had based their evidence concerning the permissible degree of pollution mainly upon certain statements and investigations that were first presented in the Report of the Massachusetts State Board of Health, 1890, special water supply volume, pp. 785–793. Those investigations are now twelve years old and did not rest on so many examples as are now available, and moreover contained a warning against discharge of sewage into ponds.

During the past ten years much additional knowledge of these matters has been obtained by the few skilled observers in this line, although very little that is new has been published.

Fortunately for present purposes, the Legislature of a year ago had directed the State Board of Health to investigate the discharge of sewage into rivers through the State, and a large quantity of new data had thus been obtained under the supervision of the chairman of its water supply committee, Mr. Hiram F. Mills, and its chief engineer, Mr. X. H. Goodnough. It is certainly beyond doubt or question that no set of men in the United States have had so broad an opportunity to study these matters intelligently during the past ten years as those connected with the Massachusetts State Board of Health. Therefore, it is with great pleasure that I report the yielding of Mr. Goodnough to my earnest request, and his laying aside of other work to collate the results of these observations in form for our use.

He finds that *many streams and ponds of the State receive, without offence or serious objection, a much larger quantity of pollution than that which can by any reasonable possi-*

bility enter the proposed basin, and in general the results of this broader experience fully confirm the conclusions set forth in the special water supply volume of the State Board of Health for 1890, p. 791, but define the limits with more precision, and add a new line of data on the pollution of ponds.

(*J*) *Flow of Water from the Upland Charles.* — We made continuous gaugings of the quantity of water entering the basin from the Charles River above Watertown dam, by means of a weir and a recording gauge, for two months, until stopped by ice and by pressure of other work. We made these gaugings because it was found that the use of the water by the factories at Waltham and elsewhere materially interferes with its uniform delivery, and that in severe drought the flow is sometimes nearly all held back by these mill dams for several weeks at a time. These investigations show that the supposed analogy to the observed flow of the Sudbury River, on which certain of the evidence presented at the hearings was based, fails badly at times.

I personally examined the water power records of the Boston Manufacturing Company for the past twenty years, and found many instances of holding back the flow, and Mr. George T. Jones, mechanical superintendent of these mills for the past twenty years, tells me that they have on several occasions held back so nearly the entire flow that the Waltham Bleachery, located next down stream, and which we find uses only about 10 cubic feet of water per second, has had to ask them to open the gates and let enough water flow to supply them. Finding that a thorough study would require more time than I could devote to this, Mr. Richard A. Hale, principal assistant engineer of the Water Power Company at Lawrence, who has had thirty years' experience in accurate water measurements, was engaged to study into this with all possible thoroughness. Mr. Hale's report and the results of our own gaugings are given in Appendix No. 16.

Our two months of daily gauging unfortunately did not include a period of extreme drought, and, although our observations were continuous night and day for two months, this period was too brief to serve for much more than the confirmation of other data. Our apparatus for this measurement has been turned over to the State Board of Health, that they may continue the gaugings for some years to come, as a part of their regular studies of discharge of the important rivers of the State.

(*K*) *The Flood Discharge of the Charles.* — Since certain statements made at the hearings of 1892 were calculated to cast doubt on the sufficiency of the estimate of flood discharge adopted by the Joint Board in 1894, Mr. Hale was also asked to continue the review that I had begun of the records of flood discharge at the mills in Waltham, which extend back many years, and to compute the quantity of flood discharge and confirm it by all records that could be obtained at the other factories, from Watertown to Newton Upper Falls; and to also study the conditions affecting flood delivery, — for these matters have a most important bearing upon the height to which water may rise in the proposed basin above the dam in extreme floods at time of high tide.

The investigation proves beyond a doubt that the Charles River is a very uncommon river, for this part of the country, in the slowness and moderation of its rise and the long duration of its run-off. This makes it much easier to take care of floods in the proposed basin, and the unquestioned fact that Stony Brook now has a quick water-shed, while the flood on the Charles responds very slowly to the rainfall, makes it certain that, under those conditions which produce extreme floods, the water from Stony Brook would have been nearly all delivered before the main flood from the upper Charles began to arrive, and shows that the extreme of a Stony Brook freshet will not be superimposed upon the top of a Charles River freshet, as was assumed, without justification, by some of those who testified on this subject at the hearings. I am satisfied that in the greatest flood of the past twenty-five years, "the Stony Brook flood," so called, the actual flood volume of the Charles was safely inside the estimates presented by Messrs. Stearns and Goodnough.

(*L*) *Dredging in Boston Harbor.* — In order that it might plainly appear to what extent the present navigation channels are artificial, I had Mr. J. R. Burke, assistant engineer, Massachusetts Harbor and Land Commission, compile a map showing all dredging up to date, from the records of the office with which he is connected, and also from the United States Engineer Office at Boston. This map will be found opposite p. 386, and shows that the important channels of the upper harbor are nearly all the production of the dredge, and it is also found in this connection that in all of this dredging, so far as can now be learned, the digging (except that near wharves and old sewer outlets) has been mainly in the original clay, which is found but thinly covered by mud or silt. *None of the dredging has been for digging out material that had silted up or shoaled an original main* *channel*, except, perhaps, some of that in the extreme upper harbor near the mouth of the Mystic River. *The channels of Boston harbor, once dredged, are found to retain their depth remarkably well.*

(*M*) *Measurement of Velocity of Harbor Currents.* — A new study of the currents in Boston harbor has been undertaken, and some hundreds of measurements made of the velocity of the water in various representative localities and throughout all stages of the tide, *close to the bottom*, for it is this bottom velocity that determines the question of scour or shoaling. A new determination of the distribution of velocity in vertical and horizontal planes at the three principal controlling sections for tidal currents has been made, at various stages of the tide, with the aid of special current meters kindly loaned to us, one by the United States Coast Survey, two others by direction of the Chief of Engineers. So far as could be learned, no investigations of this special subject had ever been previously made with such a degree of completeness or accuracy as would be considered necessary according to the standards of to-day.

As a result of our measurements, we find the bottom velocity is much smaller than the velocity given by floats near the surface, and inadequate in force to produce scour in the kind of material of which the bed of the harbor is chiefly composed. These measurements are described in detail in Appendix No. 11. One interesting feature of these current measurements was the discovery that much of the time pulsations were going on, which in their slow regular period could be likened to the long ground swell commonly found near the harbor entrance. The rise and fall of the rapidity of the click of the electric sounders which recorded the revolutions of the meter were nearly always apparent to the ear, and while we did not have the opportunity to study this subject fully, it appears that the velocity of the current on the swell of these pulsations may be increased fully 10 per cent., and the power of the current to scour thereby materially increased.

(*N*) *Geology of Boston Harbor.* — I felt that no study of the effect of a change in the tidal prism upon the preservation of the harbor would be adequate without fuller knowledge of the conditions which produced this depression or indentation of the coast line. Therefore, I requested the gentleman who, so far as I can learn, has studied the geology of the Boston basin in every part most profoundly for the past twenty-five years, who is now consulting geologist on the East Boston tunnel, and whose previous writings on the general geology of this region are a standard authority, to make this question of the origin and preservation of the harbor a special study, from the stand-point of the geologist. He was also asked to give particular attention to the character of the sub-strata in the immediate vicinity of the proposed dam site.

He has made an examination of all available records of the borings in different parts of the harbor and the adjacent estuaries; has personally examined the material now being dredged at Bird Island flats, etc.; and we have sought to compile a complete record of all known bed-rock borings, for foundations, elevator plungers, etc.

The geologist's report is given in Appendix No. 7, and will be found exceedingly interesting. His maps of contours of the bed rock and of the hardpan or bowlder clay cannot fail to prove of great value in many other engineering studies in and around Boston.

His conclusion is, that the surging back and forth of the tidal prism has probably done more to shoal the harbor as a whole than it has to deepen it, and that the *harbor is essentially a drowned valley*, a valley excavated by the meander of the larger streams flowing while the ice cap was melting at the close of the glacial epoch, probably ten thousand years ago and the valley afterwards submerged by the slow subsidence of this whole region, at the rate of perhaps only 5 or 10 feet in a thousand years, to the extent of from 30 to 50 feet, and of which actual subsidence there are many proofs. The reasonings and the conclusions are set forth in much detail in Appendix No. 7.

(*O*) *Borings in Silt Deposits in Harbor.* — We cut out 34 sample cores, from 2 to 4 feet in depth, or well down into the blue clay, of the material now forming the bed of the harbor at various representative localities, mainly in areas where a comparison of ancient soundings with modern soundings had indicated that shoaling had occurred. It has long been questioned by some of those familiar with hydrographic work whether the small differences in depth found in the main thoroughfares between the surveys of 1835–65 and 1888 were due to scour and shoaling, or due in part at least to errors of measurement; for all of these soundings were made rapidly for general purposes, obviously with no attempt at precision, probably with a light lead and a hemp line, from a moving boat, from an oscillating surface and partly in currents rapid enough to sway and belly out the hemp line in the 20 to 40 foot depth to a varying degree, according to the height and set of the tide.

It appears absolutely certain that wherever the hard blue clay free of shells is found, this represents the original floor of the harbor, and that this was deposited where it now lies thousands of years ago. Therefore, if we cut down into the blue clay and measure the thickness of the overlying silt and find this thickness smaller than the alleged shoaling, it is obvious that one at least of the two sets of old soundings compared must be in error.

For obtaining these samples I adopted the simple expedient of an 8-foot piece of 2-inch wrought iron pipe with a thin sharp end, on the outside of which was mounted a 30-pound ring of lead freely sliding up and down, and striking against a collar on the pipe, which weight, worked by a rope from the surface, was used like the ram of a pile-driver to hammer the pipe down into the harbor bottom. The apparatus was easily handled from an anchored scow and could be used in any depth of water. The pipe was provided with a valve at the top. A leather cup loosely fitting in the bottom of the pipe protected the top of the core, and the plug of hard blue clay secured the bottom of the core. A hard pull on tackle and davit drew the pipe out of the harbor bottom and brought it to the surface and on board the scow, when a piston was introduced at the top end of the pipe and the core pushed out on to a board for examination. Freezing weather stopped us in this work, but the cores obtained were from several different representative localities, and prove that the deposit of silt is thin, and tend to disprove the supposed shoaling shown by the soundings; for these sample cores generally show that the depth of soft material now found on top of the hard, original blue clay floor of the harbor is less than the supposed shoaling found by a comparison of ancient and modern soundings.

The decrease in tidal area caused by cutting off the Charles basin will be only 60 per cent. as great as the tidal areas previously cut off from the harbor by filling the flats; and, if shoaling naturally follows a reduction of tidal flow, it would have shown itself more conspicuously in these sample cores (see map opposite p. 379).

(*P*) We have given much attention to the navigation interests, and it has been sought to so plan the improvement that a great benefit to the manufacturing interests and the navigation interests should be obtained. These studies received a new impetus from the statements presented by Mr. Albert E. Pillsbury at the hearing of Oct. 10, 1902, on behalf of the owners of wharf properties along the Charles.

After reviewing his statements and revisiting the properties of his clients I came to feel that these requirements, if interpreted literally, might be construed to call for a much larger expenditure than Mr. Pillsbury and his clients had supposed. Moreover it appeared to me that they had underestimated or not allowed sufficiently for the manifest betterments due to ability to reach their wharves at any hour and to shift position at any hour, or the gain from no longer straining the hulls by allowing heavily loaded vessels to lie aground while the tide was out. Plainly this was a case demanding expert assistance, and I sought the advice of the man who has for more than twenty years been the engineer actually in charge of the investigations and constructions of the Massachusetts Board of Harbor and Land Commissioners, and was more familiar than anyone else of whom I could learn with the practical conditions of stability of dock walls in Boston harbor and the reasonable requirements of navigation in this particular region.

While it had appeared clear to me, from inspecting the walls all around the margins of the basin and from talking with disinterested parties, familiar with past and present conditions, that the shipping interest of the Charles basin is on the decline, and of comparatively small importance at present, and that part of the large tonnage shown during the past year or two has come from handling the large quantities of piles, lumber and granite required in the building of the Cambridge bridge, it nevertheless appears true that the keeping of the facilities for navigation opened and unimpaired may serve a very useful purpose, and be of great financial benefit to the citizens of Cambridge, Brookline, Newton and Brighton, by keeping water competition alive as a means of regulating railroad freights on coal and building materials.

Around the twenty miles of shore line that the Charles River basin and its canals present there is ample space for a great future development of manufacturing, without encroaching to any objectionable degree upon the utilization of the natural beauties of a large part of the shore line for park purposes; and with this prospective factory development there will come an increased commerce by water.

I would vigorously oppose the suggestion that factories are not wanted around this basin, by pointing out the plants of the Cambridge electric station and the University Press as examples of industrial architecture that need give no offence, and by the further suggestion that the natural location for factories is in situations like those along the Broad canal and the Lechmere canal, and that many other sites between Craigie bridge and the Watertown dam exist, eminently suitable for industrial development.

One chief requirement for a factory location is an abundance of fresh water for steam purposes and purposes of condensation. This matter was well set forth by the distinguished mechanical engineer, Mr. E. D. Leavitt, Jr., of Cambridge, in a letter presented with the evidence of 1894.

The water of the Charles would be entirely suitable for these purposes, thereby conserving the far more expensive supply brought in by the metropolitan water works.

We cannot now see far enough into the future to say what its industrial developments may be; but it is plain that it would be wrong to in any way impair the opportunities for this by limiting the benefits of free navigation, particularly since these can be secured with very small additional expense.

For example, the site of the lock is already deeper than necessary; therefore, it will add comparatively little to its cost if a depth over the sill sufficient for all ordinary coastwise traffic is provided. Second, the filling of the proposed esplanade will absorb the results of a large amount of dredging.

The present channel is very crooked and obscure. If the proposed new channels are built as near to the foot of the embankment walls as the economy and security of wall foundation will permit, this channel, although its edge be 40 feet away from the wall, will serve a very useful purpose in aiding in the preservation of the purity of the water in the basin, by bringing the main current, due to upland water, particularly in those seasons of the year when the flow of the Charles River is greatest, and the periods of sewage overflow most frequent and of longest duration, up close to the point where these overflows discharge.

It is a fact of hydraulics that the strongest current tends to follow the line of greatest depth; and by dredging the material for the embankments from channels near the margins, the strongest current will be brought close to the point where any pollution must enter the basin. In other words: Pollution will be most efficiently absorbed, if divided among many outlets, and it is simpler and better to bring the main current up near to the outlets of sewer overflow than to extend these many overflow channels beneath the basin out to the present main channel. With the adoption of marginal conduits, the overflows of storm water mingled with sewage from these conduits into the Charles will be so rare and so dilute that there is much less reason for inducing a current near the shore than if the marginal conduits were not to be built.

(*Q*) An investigation of the pollution of the waters of the Broad canal and the Lechmere canal was made, and conditions found which it was believed would make their appearance offensive after the basin was held at a constant level unless means for flushing or circulating the water could be found.

Although this matter was not touched upon in the evidence presented in 1894 or 1902, an inspection of these canals and their surroundings at low water shows that they now receive much pollution from oil, gas, tar waste, privy drainage, factory waste and stable drainage; and although much of this could be forced into the neighboring sewers, the waste that will naturally come to these canals from the shipping and from the factories along their shores appears to demand some further provision.

At each of a half-dozen inspections that I have made of Broad canal at low tide, I have noticed more of the iridescence and evidence of oil, tar and gas manufacturing waste in the outlet of Broad canal than at any other point on the Charles.

Fortunately it is found that very simple means can be provided, which appear certain to accomplish all necessary circulation and keep these canals at all times filled by an inward current of clean, fresh water from the basin, which shall be suitable for steam purposes, and of great service and economy to the factories already in this district and to the future factories which are likely to be built there, with the improved conditions for navigation.

The simple method proposed consists in utilizing a portion of the present Binney Street overflow conduit, which now stands idle 95 per cent. of the time, and which was originally built for a trunk sewer, but which, since the construction of the North Metropolitan Sewer system, has been used only for a storm overflow channel, and which runs conveniently near to the head of these two canals.

The connection at the head of each canal would consist merely of a cast-iron pipe, perhaps 48 inches in diameter, provided with a suitable adjustable weir and gate at its up-stream end, and a simple tide gate at its down-stream end, where entering the 9-foot Binney Street conduit.

I propose that a marginal conduit leading from the Binney Street sewer overflow channel be extended for a distance of about 2,000 feet beneath the parkway known as "The Front" down to a point just below the proposed dam site at Craigie bridge, crossing under the outlet of the Lechmere canal by means of a siphon, terminating just below the bridge in a sort of masonry catch-basin, having double tide gates at its outlet.

The present outlet from Binney Street into the basin would be reconstructed with an appropriate overflow weir, so as to retain the full advantages of the basin's water level at grade 8 or 9, for relieving the Cambridge storm drainage from the flooding of streets and cellars that now frequently occurs in storms at high tide.

One great advantage of this marginal conduit combined with the inflow weirs from the canals is that it serves the double purpose: first, of keeping out of the basin the pollution of this largest and perhaps dirtiest of the Cambridge sewer districts, with its street washings, sewer flushings and floating fæces; second, it affords a continual inflow and flushing of these two canals with clean water, with almost no expense for attendance and maintenance, and no expense whatever for pumping; and at the same time it will preserve all the advantages of relieving the Cambridge sewers in great storm flows occurring at high tide.

(*R*) An investigation of various methods for inducing circulation in the future Fens basin has been studied. The committee received a formal protest from the faculty of the Tufts College medical school, located a few hundred feet distant from the foulest spot in the Fens basin, to the effect that they feared the basin would become exceedingly foul if the circulation now produced by tidal action in the Charles were discontinued (evidence, p. 83). Mr. Blake had anticipated similar objections by providing for circulating the water by a pumping engine of the propeller type, which he estimated would cost $50,000,* and could be maintained for the yearly sum of $6,000. After considering the desirability of the south marginal conduit for sundry other purposes, it appeared that it could be made to co-operate in securing circulation in the Fens after much the same manner that I have proposed on the preceding page for the Lechmere canal, without any expense whatever for steam or electric power and at no expense for constant attendance of fireman and engine man.

* Evidence, Blake, p. 207.

For this purpose an intake near the Stony Brook bridge or near the Brookline Avenue gate house would be provided, consisting of a broad circular weir that could be closed when desired by a cylindrical gate, which, when open, would rise clear. This intake would communicate by a pipe, say 36 or 48 inches diameter, leading to the short new channel, by which the "foul flow" of the new Stony Brook channel is to be led into the old 7-foot conduit and thence into the proposed marginal channel. Automatic arrangements, similar to the sewer regulators, would be provided, by which the intake could be closed when rains or melting snows swell the flow of Stony Brook; or a similar arrangement can be attached to the Muddy River conduit near the Brookline Avenue gate house, if the marginal conduit is extended to St. Mary's Street.

This arrangement will permit of a broad open entrance from the Charles basin, by which canoes and boats can freely enter the Fens.

(*S*) At our request, the city engineer of Cambridge very kindly undertook new studies of their sewer system, with a view to developing an outline of a plan and determining the cost of the gradual abolition of storm overflows of sewage into the upper part of the proposed basin by carrying out the separation of sewage and storm water at a somewhat greater rate of progress than heretofore contemplated. Cambridge has already made much progress in this work of separation.

These studies are reported briefly in Appendix No. 14, and showed that the probable cost of constructing new sewers and drains for separating the sewage from the storm water in all that portion of Cambridge tributary to the Charles, and thereby excluding all of this pollution from the proposed basin, would be $767,783. The cost of changing over the house plumbing and drains for the 11,232 buildings within this area would probably add $100 per house, or $1,123,200, — a total of $1,890,983.

The Binney Street district alone would account for about $780,000 of the above, and the proposed Cambridge marginal conduit will answer all requirements for this Binney Street district, at a cost of only about $88,000. This leaves as the expense for separation of storm water and sewage in the remaining portion of Cambridge tributary to the dam about $1,111,000; but this work is not a "condition precedent" to the building of the dam.

(*T*) Studies have also been made in the Boston city engineer's office of a scheme for the progressive lessening of the discharge of sewage overflow in time of storm from the Boston main drainage system into the Charles basin, by separating the storm water and street drainage from the sewage, as had been already suggested in outline in the report of the sewer department for 1901, but beginning this work first on those districts where it would accomplish most in lessening the overflow of sewage into the Charles River. This work was placed in the hands of Mr. Louis F. Cutter, C.E., and is reported in detail in Appendix No. 15.

These investigations showed that the complete separation of sewage from storm water in those parts of Boston tributary to the Charles would cost about $4,705,000, while for the region west of the Fens, for which the reconstructed old Stony Brook channel would not serve as a surface water drain, the cost would be about $2,701,000.

Finally, it appeared that *both on the Boston side and on the Cambridge side the marginal conduit method of lessening the pollution was much quicker and more economical than the forcing of an early separation of all sewage from storm water*, and the conduits also serve for producing circulation in the Fens and in the Cambridge canals.

(*U*) We tried to repeat the ground-water level measurements of 1894 by utilizing the same pipe wells. We found only a few of them available, and a few ground-water levels were observed at such of the test wells mentioned in the report of the Joint Board as could be found. Further studies were planned, particularly in certain low districts near the Cambridge shore, and others above Exeter Street, and a well-boring apparatus suitable for this work was very kindly loaned us by the engineer of the Metropolitan Water and Sewerage Board, but the time proved insufficient, and it appears so plain to me from general principles that the proposed dam at grade 8 would not affect the present ground-water level injudiciously, and Mr. Stearns's reasons given on pages 26 and 27 of report of 1894 and in his evidence before the Harbor Commission are so clear and convincing on this point, that I was the more ready to defer this field work.

(*V*) The probability of the occurrence of a "Stony Brook flood" in conjunction with a "Minot's Ledge tide" was investigated, for in effect this had apparently been assumed in certain of the evidence presented as a means of showing that the storage space in the proposed basin, after drawing it down on the preceding tide, would not suffice to contain the largest flood and the worst conditions for which there were precedents.

From the United States Coast and Geodetic Survey and from the Weather Bureau I obtained all available records of exceptionally high tides and exceptionally heavy rainfalls. These records are not complete, and serve to show that the extreme tides commonly come from strong, long easterly storms, and that these are commonly accompanied by considerable quantities of rain; but no case has yet appeared where the very extreme conditions of tide and storm flood have come together; and from the theory of probabilities it is plain that the chances of a rainfall like that of February, 1886, being superimposed on a tide like that of April 15–17, 1851, are very remote, and, if it did come, need not be feared.

CONCLUSIONS.

As a result of the studies of the evidence presented at the hearings of 1902 and 1894, and from the new data described above, and for other reasons which will be stated in detail in the following pages, I have reached the following conclusions: —

I. *The Balance between Advantage and Disadvantage is unmistakably in Favor of Building the Dam.*

It surely does not threaten the preservation of the harbor. It surely does not threaten the public health, and, if certain present intolerable defects in the sewer system are remedied, there is no danger that the water in the proposed basin need ever become offensive, or its condition be like the present condition of the Fens basin.

Taking the whole year through, the navigation of the Charles basin and the Cambridge canals will surely be improved by the dam. There will be some increased trouble from ice and some moderate expenditure for dredging and for strengthening certain walls.

After including liberal allowance for the cost of marginal conduits to intercept street wash and intercept sewer overflows, and to provide circulation in the Cambridge canals and in the Fens (precautions not contemplated in the report of the Joint Board of 1894, and which I regard more in the light of insurance, or factor of safety, and as *a contribution to the luxury of cleanliness* rather than a distinct necessity) this whole great public improvement is wonderfully cheap.

Advantages v. *Disadvantages.* — The principal advantages are: —

1. The magnificent opportunity at comparatively small expense for replacing unsightly tidal mud flats and unclean muddy shores now having indifferent surroundings by a great water park, somewhat similar, in its lower, broader portions, to the Alster basin at Hamburg, Germany, and possessing, in its upper, narrower portion, the advantages for wholesome recreation now found on the Charles River near Riverside; all near to the great centres of population and convenient of access to people of moderate means and limited leisure, requiring neither long walks nor long rides on street cars before it can be enjoyed.

2. A probable large increase in valuation of the marginal lands, now in private ownership, up stream from Harvard bridge, consequent upon the basin being made more attractive.

3. The lessened expense for development of the 16½ miles in length of park lands upon the margin of the Charles River already acquired by the Metropolitan Park Commission and the municipalities bordering the river, or otherwise dedicated to public or semi-public use, because of lessening the amount of filling and diking of the marshes and guzzles; the lessening of the amount of dredging or cleaning, and gravelling of muddy slopes within the tidal range on some long reaches up stream from Soldiers' Field; and on other long reaches bringing the possibility of clean, walled shores within reasonable cost.

4. The holding of the basin at a constant level between grade 8 and 9 instead of the present frequent rise to grade 11, and *restricting the highest necessary storm level to grade 11 at high tide, in the greatest storm of half a century*, instead of the occasional tides of 14 feet, and with an extreme record of 15.67 feet above Boston base, *would give improved sanitary conditions* throughout portions of the Back Bay district of Boston and throughout portions of Cambridge by lowering the extreme flood level in the present sewer and storm-water drains, and thereby give almost *absolute relief from liability to such overflows of sewage into cellars and over certain low territory as are reported to now not infrequently occur* during extremely heavy rainfalls at high tide.*

5. This constant water level at grade 8 or 9 will prevent the uncovering of large areas of foul-smelling and unsightly mud flats near Harvard bridge and other large areas of mud flats immediately below the dam at Watertown, and will prevent the uncovering of muddy or slimy banks and guzzles along the narrow portion of the river for nearly the entire distance up stream from Captain's Island to the centre of Watertown.

These areas lying above grade 0, Boston base, or uncovered at extreme low tide, are colored brown on the accompanying large contour maps of the present basin and the maps of the Cambridge canals.

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* On page 19 of report on prevention of floods in valley of Stony Brook it is stated that during a period of eighteen years there were 41 tides which rose above 13.14, city base; 19 tides which rose above 13.50, city base; 8 tides which rose above 14.00, city base; 3 tides which rose above 14.50, city base; 1 tide which rose above 15.60, city base.

The portion of the river above Watertown Arsenal is not ordinarily uncovered down to the mean low-water grade of 0.64, Boston base, because the water of this long channel has not time to drain out completely between tides, and because throughout most of the year the flow of upland water is sufficient to cover the bed of the stream, but in extreme drought in hot weather these up-river flats may become very offensive to sight and smell.

6. A lessening of the probability of malaria and a lessening of the mosquito pest will naturally follow the construction of the proposed dam, because of the obliteration of their breeding places after the better drainage of the marshes that will be rendered feasible through the construction of the dam.

The *anopheles* mosquito, which recent research has proved to be the chief and probably the sole agent in the dissemination of malaria, now breeds in stagnant pools along the upper portion of the proposed basin, and the *culex*, or non-malarial mosquito, breeds in the small pools in the present poorly drained marshes.

If a dam is built as proposed, it will be a simple, inexpensive matter to so change the contour, elevation and drainage of the sloping banks that almost every one of these pools of fresh or brackish water, in which mosquito larvæ now find safe shelter from their natural enemies, will no longer exist.

7. The full dam, as proposed, will prevent the flooding of a broad extent of marsh land in Brighton, Watertown and Newton, under the highest tides of every month, as now, for the high water at ordinary spring tides of each month averages 11.64. The average elevation of these marshes is about 10.7.

8. The constant water level at grade 8.0, Boston base, or perhaps 0.5 or 0.75 foot higher, will give improved conditions for navigation by coal-laden or other shipping, after merely dredging out from appropriate places the amount of material required for filling the marginal embankment authorized by the Acts of 1893. Mean high water in the lower portion of the Charles basin is probably very slightly lower than at the Navy Yard because of the resistance of the pile bridges. In the upper portion of the Charles basin the tide rises slightly higher than at the Navy Yard, by reason of the momentum of the current and the narrowing channel. These differences anywhere between Essex Street and Craigie bridge are hardly more than an inch, and for the basin as a whole the height at the Navy Yard may be used with sufficient accuracy for present purposes.

Mean high water, according to determinations of about twenty-five to thirty-three years ago, is now commonly reckoned at $0.64 + 9.8 = 10.44$, Boston base.

If the basin level is grade 8.5, about 2 feet of the depth for floating barges or schooners to their berths *during the hour of extreme high water, under mean rise of tide*, would be lost; while, if found feasible to maintain basin at grade 8.75 or 9.0, the loss of depth over the shoals would be correspondingly less. But, on the other hand, the tide does not reach so great a height as 10.4, Boston base, on about half of the days of the year, and the alternate tides of each day materially differ in height. The tide curves for four representative months — May and June, when the carrying of building material is probably most active, and September and October, when the coal trade may be assumed to be the heaviest — are given below; and by comparing this diagram with the maps of the two Cambridge canals, it will be seen how very short the available time now is in which a coal schooner of average depth can be berthed, and how great the saving in demurrage would be if the dam is built and a moderate amount of dredging done.

That the consideration of mean high tide as the present working level for navigation tends to obscure the facts and tends to exaggerate the real injury will be seen by reference to these diagrams of tidal range; for, *during the low neap tide periods, the tide does not now rise above grade 8, by the mean low water datum, for about a week at a time.*

By the United States Coast Survey tables of predicted tides at the Navy Yard, Boston, it will be seen that, in May, 1902, the tide did not rise above grade 8, mean low water datum (corresponding to 8.6, Boston base), in the hours of daylight, during the entire week between May 22 and May 29, and again during the neap-tide period, for about a week from June 17 to June 24, 1902, the day tide did not rise above grade 8, mean low water. The same is true for the week from Sept. 9 to Sept. 16, 1902; and also for five or six days from Oct. 8 to 13, 1902. And, in my opinion, *the gain from constant level at grade 8.0 or 8.5, in freedom to move in and out at all hours and in avoiding the severe strains that a heavily laden boat now receives while lying on the mud while the tide is out*, as shown in the photograph opposite this page, *fairly offsets the loss.* Nevertheless, as material will have to be dredged for filling the dam and the embankments, I would recommend that the additional expense be incurred by taking a part of this filling material from the Cambridge canals and from the channels in the main basin.

9. The constant level at grade 8.0 or 8.5 will permit a form of dock wall construction that will be more economical for the improvement of shipping facilities than can be obtained under the present mean daily tidal range of about 10 feet rise and fall, and the spring tide range of 12 to 13 feet rise and fall.

For a section of this wall, see p. 419 of Appendix No. 12.

Because of the constant level, only about 9 feet in vertical height of stone wall is required along these canals, or just height enough to expose a fire-proof and imperishable face to the weather, whereas, under present conditions, the custom has been to build these canal walls about 14 feet high.

10. There will be some gain in economy of power because of the cheap and generous supply of fresh water for steam and condensation made available to the electric stations and other steam plants, present and prospective, at sundry sites within a thousand feet of this sixteen miles of shore line of the Charles River, including the Broad and Lechmere canals, convenient for cheap coal. This feature was presented forcibly at the hearings of 1894, p. 653, by the distinguished mechanical engineer, Mr. E. D. Leavitt.

11. It can be easily proved, as shown by Mr. Blake's evidence, 1902, and by Mr. Stearns's estimate in the report of the Joint Board of 1894, that the cost of the dam, together with the cost of the auxiliary structures rendered necessary by the dam, will be far less than the expense of removal of the present exposed mud flats by dredging, the filling of the guzzles and other depressions of the surface, and the extra cost of protecting the shores by embankment walls, bulkheads, riprap, gravel beaches or other treatment under the present monthly range of 12 to 13 feet in the tide. The predicted normal tide rises frequently to grade 11, city datum, and in easterly storms frequently comes up to grade 13, and has once been up to grade 15.6, city datum. Notes on a number of extreme tides will be found in Appendix No. 18.

The height of the principal sea walls on Charles River in Boston is 15.0, and in Cambridge 15.5.*

* The Charlesbank wall, which is probably the best of the Charles River sea walls, of coursed granite (built in 1885-6) is 13.1 feet high from bedstone to capstone inclusive, and is built on piles and platforms, at an average cost of about $65 per lineal foot. The presence of ledge and trouble about short piles added some to its cost. On the other hand, there was some saving by the use of stone from old walls, and in comparison with to-day the cost of labor is higher, while stone and cement are cheaper, so the cost can still be used as a fair guide for a wall of equal quality.

The coursed granite wall between Cambridge bridge and Harvard bridge, and now extending up stream from Harvard bridge, built in 1888, has top at elevation 15.5 and bottom at elevation — 2.0, Boston base, and rests on gravel filling without piles; has a riprap front slope. This has cost about $30 per lineal foot.

Disadvantages.

The only important disadvantages that would result from this dam appear to be: —

First. The extra cost (if any) of the dam and its auxiliary structures above the cost of the structures that will be required for sanitary and other reasons, if no dam be built.

(It appears that, taking account of the present condition of Craigie bridge; the dredging of foul mud banks; the improvement of the Fens required regardless of the dam; the necessity for filling and diking and draining marshes; the absolute necessity of improving the dirty banks of the upper portions of the estuary, the method of improvement by means of the dam and its auxiliary structures will cost the least of any efficient method of treatment that can be devised.)

Second. The loss of interest involved in an earlier expenditure for the separation of sewage from storm water than would otherwise be demanded.

(It does not appear that any part of the cost of remedying the present unsatisfactory conditions from sewage in the Fens basin or of removing the defilement from the two Stony Brook channels is properly chargeable to the dam. Neither should the cost of a sewer for the Beacon Street houses be charged against it, nor the connection to sewers of sundry privies and stable drains, now emptying openly or leaching into the basin and the Cambridge canals. The work of separation of sewage from storm water was begun in Cambridge two years ago, and the report of the Boston sewer division for the year 1901 strongly recommends that a similar work be begun in Boston, purely on sanitary and economic grounds, almost without regard to the Charles basin. This work of improving the sewers of Boston and Cambridge must be done sooner or later, although no dam be built. The building of the dam will merely stimulate an earlier and more energetic carrying out of the work.)

Third. The greater interference to navigation by ice on a fresh-water basin, in comparison with the present salt-water basin, and possibly, rarely, some increased trouble with ice in the part of the harbor near the railroad bridges below the dam.

Fourth. The compensation or damages that will doubtless be asked for by those owning wharves.

Fifth. Some very small increase in the cost of dredging out certain deposits of gravel for purpose of sale. (This will be far more than offset to the owners by the market afforded for this gravel in the dam.)

Sixth. A very small increase in total amount to be pumped at the pumping stations of the Boston main drainage and the metropolitan sewerage, due to the larger average quantity of storm water that will be stored in the main sewers after that lying below grade 8 can no longer drain into the Charles at low tide, and must, therefore, drain down through the regulator gates into the metropolitan sewers after the storm is over, and immediately be pumped.

I have had a very complete estimate made of this possible storage in the Cambridge system connected with Binney Street, the largest system of all, and find this will involve only a comparatively insignificant expense.

Seventh. The need and cost of flushing the Broad and Lechmere canals. (This has been provided for by means hereinafter described, and, in this respect, the arrangements proposed in connection with the dam will relieve the present unsatisfactory dirty condition of the Broad canal, due to oil sleeks on the basin that come from gas works and from asphalt roofers' waste, and that which comes from storm wash of streets and dirty yards.)

Eighth. The need and cost of special means for circulation in the Fens basin, now produced by the tide. (This can be done better than now by the marginal conduits elsewhere described in this report. Much less circulation will be required than now, after the "foul flow" of Stony Brook is removed from the Fens by the connection of the new "commissioners' channel" with the old 7-foot channel.)

II. *Full Dam* v. *Half-tide Dam.*

I have given careful consideration to this because of the half-tide plan having been favored by certain men whose opinions are entitled to great respect.

I have come to the opinion that the improvements which are most desirable can be accomplished very much better by a dam of full height than by a half-tide dam.

It appears that much more than half of the advantages for pleasure boating and for park development, with neat, attractive water margins, free from wetness, slime and mud, possessed by a basin with slight current, at constant water level, would be sacrificed by a half-tide dam.

For half the time tbe objectionable current would be as strong as now. For half the time the upper half of the slope would be as unsightly as now, and there are some dangers to life connected with pleasure boating controlled by a half-tide dam, due to boys in boats or canoes coming too near the overfall, or to direct attempts to run the rapids while fall was moderate.

The benefits of the constant water level near grade 8.0 or 9.0 in preventing the flooding of the marshes, in draining the mosquito-breeding pools and in lessening the height of storm discharge from sewers and drains would be wholly sacrificed by a half-tide dam.

The Back Bay cellars and Cambridge cellars would continue to be flooded by the backing up of sewage in severe storms at high tide, just the same as now.

A half-tide dam would not properly cover the broad areas of objectionable mud flats in Watertown (see map of upper basin); and, indeed, the rise of the tide, as now, to grade 10.4 (saying nothing about the frequent rise to about grade 12, Boston base) would keep these marshes, guzzles and shores wet and slimy; and its fall to grade 5.2 would uncover many acres of slimy, muddy slopes and flats, mainly in Brighton, Cambridge, Watertown and Newton.

Indeed, so far as now seen, the only substantial advantage presented by a half-tide dam is: —

1. It would secure the covering of the mud flats near Harvard bridge and the dirty strips of flats exposed at low water along the present embankment walls.

2. It would prevent uncovering the unsightly, bad-smelling bottom at the upper ends of the Broad canal and the Lechmere canal.

3. The daily flushing of the Charles basin with salt water would have nearly the same effect as now, and permit the separation of storm water from sewage to make slower progress, and permit delay in providing a sewer for the houses on the north side of Beacon Street.

4. It would afford to the shipping the same flood tide depths as now, during the week of spring tides, and would prevent some of the grounding with the ebb tide that now occurs.

In brief, it would deprive Newton, Watertown and upper Cambridge of the benefits that it brought to Boston and Cambridgeport.

III. *Location for Dam.*

The best location for the proposed dam is plainly at the present site of Craigie bridge; and a little forethought and ingenuity in planning the prosecution of the work here will lessen the cost by rendering a temporary bridge during construction unnecessary. Every foot gained in the length of the pool below the dam would be of advantage in manœuvring barges, tugs or other boats before or after passage through locks, more so perhaps with the larger commerce of the future than with that of to-day, therefore all increase of width should be crowded to the up-stream side.

One reason for location at Craigie bridge is the desirability of including the largest practicable area within the basin, so that the storage available for flood discharge shall be a maximum.

A second reason is that economy of operation of the drawbridge, the lock, the sluice gates and the possible future propeller pumps at the outlet of the marginal conduit for receiving sewer overflows and street wash can be gained by serving all of these from one power station and under one superintendent.

But the chief advantage of the location at Craigie bridge is that *the cost of the dam itself can be wholly saved to the cities* of Boston and Cambridge and Somerville by utilizing it as the substructure for a new bridge.

The present Craigie bridge is an old structure. I find by inspecting it from above and from a boat beneath that the marks of decay are very apparent, and it is plain that it must soon be rebuilt, regardless of what is done about the future water level of the basin. The present standards of municipal engineering and architecture would probably not tolerate another plain, crude, pile-and-stringer structure like the present, which is simply a restoration or patching up of the bridge of 1808, and the large and increasing traffic over it demands more width.

Some testimony upon the cost of each of the three modern bridges built across the Charles during the past few years was presented at the hearings, from which it plainly appeared that the cost of a modern bridge, including piers and abutments and draw-span, would be considerably greater than the entire cost of the dam, with its regulating gates, wasteways and lock; and the steel bridge would be much less permanent in character than the dam, and, therefore, subject to greater maintenance charges than the dam, by reason of rusting, repainting, repairs and allowance for ultimate renewal.

In order to obtain more definite information upon this question of cost of bridge *v.* dam, the city engineer of Boston was requested to prepare a definite estimate of the cost of the new bridge soon required.

He prepared approximate estimates based on three different designs, as follows, and stated that "the general condition of the [present Craigie] bridge is poor and nearly beyond repair :" —

For a steel girder, deck bridge, 70 feet wide, stone piers and abutments, steel draw of double retractile type, roadway grade 23.0, head room at draw above mean high water 7.5 feet,	$864,430
For steel bridge, same type, 100 feet wide,	1,148,458
Same as last, with more head room (23 feet above mean high water), grade at draw 38.5,	1,463,362
Ornamental steel bridge with stone piers, same width and grade as last,	2,044,687

For these estimates in detail, see Appendix No. 13.

The estimate of Mr. F. P. Stearns, chief engineer for the Joint Board of 1894, of the cost of a dam 100 feet in width, "located 600 feet above Craigie bridge, where the river is not more than 1,100 feet wide," including lock, power house and all appurtenances, was $660,000.

The estimate of Mr. Percy M. Blake, C.E. (evidence, p. 238, bottom of page), — made for the proponents in January, 1902, for a similar dam, located at Craigie bridge, without the tidal sluices (which Mr. Blake did not recommend and which I believe are unnecessary), and with a width of 120 feet "made to serve the purpose of a bridge," — was $1,075,000.

I have prepared estimates for three different types of dam, described in Appendix No. 19, and find that the cost of dam complete with deep lock, sluices, spillways, drawbridge, pavements and all necessary accessories, will be anywhere from about $1,000,000 to about $1,550,000, according to the elaborateness of the type of structure adopted. From an examination of the site, from knowledge of the substrata derived from borings at the site of the old Lowell freight bridge a few hundred feet down stream, and from the studies of the geologist, I am satisfied that the construction at this point is entirely feasible; and, all things considered, including depreciation and repair, the dam and bridge and lock combined would probably cost but little, if any, more than the equivalent bridge 100 feet in width.

IV. *Elevation of Water Surface.*

The requirements of navigation and of landscape effect make it desirable that the level be as near the present mean high-water level as practicable.

If grade 9 is permissible, instead of grade 8, this gain of a foot in height, by lessening the depth of dredging required in the Cambridge canals and near to wharf walls in other parts of the basin, would greatly lessen the danger of undermining those walls during the process of dredging, and perhaps would make it practicable to make the base secure by sheet piling, or other means, and so to a large extent render unnecessary any such general, immediate rebuilding as is set forth in Appendix No. 12.

Grade 8 was the grade that had been established for the Fens basin some years before as the most suitable, under the conditions then existing. The reasons for the fixing of the water level of the proposed Charles River basin at grade 8, Boston base, by the Joint Board in 1894, are quite fully stated on pages xiv–xv, also on pages 26–28 of their report.

One reason was to avoid flooding the up-river marshes; another, to favor the existing sewer systems; another, to make it easier to depress the railroad in Cambridge, for the separation of grades; perhaps the main reason was to make sure of not raising the ground-water level.

It appeared that the existing ground-water level *in the filled lands* adjacent to the proposed basin, except as controlled locally by sewers, was at slightly below grade 8.0. This, moreover, appeared to be about the natural elevation of the water table in this region a short distance back from the shore. The lowest cellar level permissible under the city ordinances is grade 12, four feet above this height.

It must be remembered that, at that time although only nine years ago, the immediate cause of malaria had not been discovered, and more importance was given to mere dampness of the soil as an unsanitary condition than would be attached to it to-day. That certain of the most famous seaside health resorts, located in a climate warmer than that of Boston, have ground water nearer the surface than this, appears by the statement of Lieut.-Col. W. A. Jones, Appendix No. 8, p. 374.

The recommendation of the Joint Board was safe and conservative in that the level recommended for the basin would make the level of the ground water no higher afterward than before the dam was built.

There are some conspicuous advantages in raising the basin level above grade 8, perhaps even to grade 9, and it is, to-day, a fair question whether a higher level than grade 8, Boston base, is not permissible. *The including of marginal conduits in the recommendations and estimates presented herewith will add to the safety in raising this water level.*

The feature now mainly controlling or limiting the height of the water appears to be the possible increase of dampness in cellars; and the lowest permissible level for a cellar bottom, according to the Boston ordinances, is grade 12.

The test wells and other investigations of the chief engineer of the Joint Board led him to conclude (p. 27, report of 1894) "for the Back Bay region of Boston *the height of the ground water is controlled for the most part by leakage into the sewers* and not by the height of the water in the Charles River."

I had hoped to find time to sink similar pipe wells for testing the level of the ground water in various parts of Cambridge near the river and the canals, and in the upstream territory along the narrower portions of the river; but, as already stated, the reasoning on this subject advanced by Mr. Stearns in the hearings before the Harbor and Land Commissioners appeared so conclusive that, in order to give time for other investigations, this work was deferred to the last, and finally had to be left undone.

I do not share the fears mentioned by certain of the experts in the recent hearings that the basin at grade 8 would seriously affect the inland water table, but consider that Mr. Stearns's general propositions regarding the influence of the basin level upon the ground-water level are almost sure to be applicable along the shores of the basin, viz.: —

(*a*) That natural ground-water level is nowhere materially below grade 8 except where lowered locally by drainage of sewers; and conversely, that a basin at grade 8 will not materially raise the present level of the ground water.

(*b*) That the leakage into the sewers controls this level of the ground water, a little way back from the shore, much more than does the water level in the Charles.

The capillary attraction, or the height to which wetness will rise in a porous earth, is almost entirely a question of the fineness of the material. The filling up and grading of the Back Bay lands was done almost entirely with a *loose, moderately coarse, open-grained gravel, in which capillary action would suck up the water or the dampness but very little, probably not over an inch or two;* and with the water of the basin at grade 9 there is no reason to think that the three feet then intervening between the water table and the cellar bottom, in the region close to the basin, would be insufficient. Farther away from the basin the sewers would mainly control the ground-water level.

Raising this basin level from 8.0 as formerly proposed to 9.0 as now suggested would not increase the flood level at high tide, for it is assumed that, in case of great storms, the basin would have been previously lowered or held down to grade 8. The Charles is slow to rise, and it is a matter of record that *in the great Charles River flood of 1886 the peak of its flood did not come along until about two days after the peak of the Stony Brook flood had passed.*

The marginal metropolitan sewers built since the report of the Joint Board of 1894, and the marginal conduits now proposed, also will have material influence in preventing a rise of the ground water behind them.

I am, therefore, led to recommend that it be made permissible to establish the ordinary constant water level at any point between grade 8 and grade 9, as further investigations may determine to be best; and recommend that the spillway be designed with changeable flashboards, so that practical test may be made on the ground-water level, after the dam is built, by first holding the basin at grade 8 for a few weeks and then at grade 9 for a few weeks or months, suitable pipe wells to be previously driven and observed under various conditions, spring and autumn.

V. *Fresh-water Basin* v. *Salt-water Basin. Comparative Advantages.*

Many persons have the idea that a salt-water basin is more healthful, and that the mere presence of salt in the water of the basin would tend to prevent or retard the decay of any putrescent matter that might enter it. The statements of Dr. H. O. Marcy (see report of evidence at hearings of 1894, pp. 27, 30) reflect the prevailing view.

In order to meet this, the proponents at the hearings of 1902 gave much attention to the feasibility of providing large tidal sluices in the dam.

I had some predisposition to favor a clean salt-water basin on anything like equal terms, particularly after having observed the pleasure of the children bathing and learning to swim at the Captain's Island playground; but a preliminary study soon led me to conclusions so different from the popular view, as expressed above, that I requested the pathologist, the biologist and the chemist each to take up this question from his own field of view, and to make his investigations independently of his associates. *Each of these experts independently reported that, in his opinion, the fresh-water basin would prove the better.*

If absolutely pure ocean water could be had in the Charles and kept free of pollution, a different conclusion might have been reached; but this is plainly impossible, and the varying quantity of upland water precludes a brackish basin of the constant salinity requisite for the best development of marine life.

The chemist, Mr. H. W. Clark, in order to answer this question of the comparative merits of fresh and salt water, undertook several lines of experimental work, which will be found described in some detail in Appendix No. 4. The principal results were as follows: —

(*a*) It was found that, temperature and other conditions being equal, *salt water holds somewhat less oxygen in solution than fresh water*, and therefore, volume for volume, fresh water can receive the greater volume of pollution without the exhaustion of this oxygen, if bacterial life is of equal vigor in each case (p. 272).

(*b*) Several lines of experiments were undertaken for determining the effect of mixing various definite percentages of sewage with fresh water and with salt water, the aim being to learn how large a percentage of sewage could be mixed with each, under various conditions and for different lengths of time, without exhausting the oxygen primarily present in this water and without producing odors from putrefaction (p. 270).

The first series of experiments were made with the mixtures in large, tightly stoppered bottles, which were "incubated" and maintained at a constant temperature of 80 degrees F. for five days, in order to give very favorable conditions for decomposition. The simple test of smelling of the respective samples, from time to time, gave strong presumptive evidence in favor of the fresh water; but, as a means of accurate demonstration, careful measurements of the percentage of oxygen remaining in the water of each test bottle were made frequently, because it is when the free oxygen originally dissolved in the water becomes nearly or quite exhausted that putrefaction with its offensive odors chiefly begins.

In every case and with all the various percentages of mixture it was found that the oxygen disappeared very much more rapidly in the salt water than in the fresh water.

Other similar tests were made, in which the test bottles were left unstoppered, in order that the surface of the water might be open to the air and free to absorb new oxygen from it. The open bottles did not develop such offensive odors as the closed bottles, but *the odors from the mixture with salt* *water were in all cases decidedly the worse;* and in general, throughout the variety of experiments performed on comparative mixtures of sewage with fresh water and with salt water, it was found that while when first mixed the faint sewage odor was most noticeable in the fresh water, this odor generally became less, while with sea water mixtures the odor invariably grew worse with time (see pp. 272, 291, Appendix No. 4; also p. 342, Appendix No. 6).

Another series of experiments was made on the comparative merits of salt water and fresh water for taking care of the pollution found in certain of the mud banks of the Charles. Equal quantities (2 grams) of the polluted mud from the Charles were shaken up with equal quantities (½ gallon) of fresh water and salt water in stoppered bottles, which were then incubated at a constant temperature of 80 degrees F. for five days, after which portions were siphoned off for dissolved oxygen determinations.

This experiment was made in duplicate, salt and fresh, with 9 different samples of mud taken from the most polluted mud banks of the Charles and the Fens. *In every case the incubation in sea water exhausted more oxygen than incubation in fresh water, and also exhausted a larger proportion of the oxygen originally present.*

A period of reincubation was then tried on the same samples, by adding one gram more of the respective samples of mud to each bottle aerated again, stoppering and incubating for ten days at 80 degrees F. After ten days the quantity of dissolved oxygen remaining in each sample was tested again, and it was found that in every case a larger proportion of the oxygen was exhausted from the salt water than from the fresh. The odors of the various samples of water were noted after the first incubation and also after the second incubation, and *in every case the salt water had the most offensive smell.*

The lesson from this series of experiments is plainly that the polluted mud flats of the Charles and of the Fens are more likely to rob the water immediately over them of this dissolved oxygen, and more likely to give rise to offensive odors, if the basin is filled with sea water than if it is filled with upland water.

The chemist also prepared a series of laboratory tests in glass tanks 18 inches deep for comparing the bacterial growths in sea water over polluted mud, and in fresh water over the same kind of polluted mud, all mud being taken from the bed of the Charles River. Some of these experiments were continued four weeks, test samples for bacterial counting being frequently taken. It was found that of the anaerobic growths, which are the ones which produce putrefaction, the greater number occurred in the sea-water tanks, both in the water and in the mud, and the greatest exhaustion of oxygen occurred in the sea water.

My observations upon the deposition of sludge going on continually in the outlet of the new Stony Brook channel and an examination of the vast foul sludge banks now found in the salt Fens basin, and also observations upon some of the smaller sludge banks that now exist near certain of the sewage outlets along the salt Charles basin, prompted a request that the chemist investigate the effect of salt in the water upon throwing down any suspended pollution or turbidity to the bottom as a sludge.

The results of these experiments are briefly reported on pages 286, 287 of Appendix No. 4, and are particularly well shown by the photographs of the samples compared.

It was found that the presence of salt in the water had a strong influence as a precipitant of such matters as Charles River mud and sewage pollution; and, while the effect of this precipitant would be to make the surface water of these large basins more clear, it at the same time concentrates the polluting particles into sludge banks, which are less easily acted upon by those bacteria or other growths which produce inoffensive, odorless decomposition, and in these concentrated mud banks there must be more of a tendency to putrefy.

In the present condition of the Fens basin and its sludge banks, with bubbles arising from them, may be found a most instructive example of the way that sea water acts upon polluted fresh water.

The biologist also made some experiments on the effect of mixing the same proportion of sewage with upland water and with salt harbor water. These are very briefly described on pages 341, 342 of Appendix No. 6. He found that "*under identical conditions, sewage introduced in fresh water was less offensive than when introduced into water from the Charles estuary or the harbor.*"

The biologist admittedly approached this question of the fresh-water basin *v.* a salt or brackish water basin with some bias in favor of a basin containing a considerable percentage of salt water mixed with the fresh water, expecting, from some of his previous experiments, that a brackish-water basin would support the maximum quantity of organic life, and that therefore its contents would absorb or devour a maximum pollution, or plant food, without the production of offensive odors; but soon after beginning his studies he reported unsurmountable obstacles to the success of this brackish-water plan.

(*a*) That the sea water entering the harbor from off Boston Light, being largely from the cold northern ocean current, was more nearly sterile than the warmer water of points south of Cape Cod, with which naturalists had made the most observations and experiments; and that therefore this water from Boston harbor would be less immediately available for absorbing the impurities and rendering them innocuous, through appropriate bacterial action.

(*b*) That the varying rate of flow of upland water would make it well-nigh impossible to preserve the uniform degree of salinity necessary for the most favorable growth and activity of organic life; that, with violent changes of salinity, many of the beneficent low forms of life would be killed off.

(*c*) That it was not practicable to secure such thorough mixture of the fresh upland water with the salt harbor water as to avoid differences of specific gravity which would prevent vertical circulation, and thus prevent water in the lower layers of the basin from coming into contact with the air, whereby their dissolved oxygen could be renewed.

The biologist found his main field for demonstration in the Fens basin itself. In the contents of this basin, which are about three-quarters salt harbor water, he found that, notwithstanding the motion of circulation is more rapid than it would be in the proposed Charles basin, the salt-water layers remained beneath the fresh-water layer; that vertical circulation and reaeration of the lower layers of the water were thereby cut off, and that these deeper layers were devoid of oxygen, and populated almost solely by the anaerobic or putrefactive bacteria, and would in warm weather continually give off hydrogen sulphide and other foul-smelling gases (see p. 326, Appendix No. 6).

The pathologist (p. 113, Appendix No. 1) reports that the malarial mosquito breeds most freely in fresh water, rarely in salt or brackish water, — which would appear an argument in favor of a salt-water basin; but, after carefully weighing the probable results of changing the Charles from a salt-water estuary to a fresh-water basin of constant level, and after making many bacterial tests of the quality of the harbor water, he concluded (p. 129) that "*the introduction of salt water from the harbor will not be needed, and should only be reserved as an artificial remedy for extreme, unforeseen conditions.*"

As a result of these carefully formed expert opinions, and from conference with other engineers who have had opportunity for observing the effect of sewers discharging into salt water; and from the reported fact that a marked difference is noted in the odors arising from the man-holes of the Boston main drainage and metropolitan sewers to which some proportion of salt water has been admitted, in comparison with the man-holes of the common sewers that receive no salt water; and from such investigations as I have been able to make upon the formation of the present sludge banks in the Charles basin and in the Fens; and from the broad common-sense view that any such varying percentage of salt as would of necessity follow the varying inflow of fresh upland water must interfere with the activities of organic life; and that, of necessity, an imperfect mixture with different specific gravities at the top and bottom would bring defective vertical circulation, and therefore defective oxygenation, and that from this there would of necessity follow a tendency to putrefaction, with its offensive odors, — *the conclusion has been reached as clear, beyond doubt or question, that the fresh-water basin will be very much better, under the circumstances; and that by means of a marginal conduit and other means proposed for lessening pollution, this water at Captain's Island and other future points available for bathing can be kept cleaner and more wholesome than it is to-day, even on an incoming tide.*

As stated on p. 47, and also on p. 145, Appendix No. 2, it appears more hopeful to absorb, devour and render the entering pollution inoffensive by means of the activities of organic life, very much as manure or plant food is absorbed in the garden, than to salt this water, and thus precipitate, concentrate and defer the oxidation of the impurities.

VI. *Necessity for Large Tidal Sluices.*

That these are unnecessary for preserving the sanitary condition of the water of the basin is practically settled by the answer to the last question; and proof that the storm flood sluices included in the present design are ample to prevent the basin from rising to a dangerous or inconvenient height, will be presented later.

That there is no necessity for a tidal sluice as a means for preserving the tidal scour of the channels of the harbor is shown by the statements to be found in Appendices Nos. 8, 9, 10 and 11.

These large tidal sluices, if of the design presented on pp. 272, 273 of the evidence of 1902, would be subject to rapid corrosion, possibly accelerated by electrolytic action under the influence of fresh or brackish water on one side and salt water on the other; and the expense of maintenance and renewal, as well as their great original cost, makes it desirable to omit them.

It will be found that the sluices provided by the Joint Board of 1894, and also the storm sluiceways provided under the present plans, are ample to change the water in the basin, should it ever become necessary because of too luxuriant a growth of algæ.

VII. *Present Condition of Fens Basin. — Analogy to Proposed Charles Basin.*

Appendix No. 3 is devoted to a study of the facts on which the answer to this question depends. On pp. 41, 42, there has already been given a brief summary of the results of the investigations concerning the present condition of the Fens basin. It was found foul and offensive, but the cause was plainly the continuous pollution of Stony Brook by brewery wash, dry-weather sewage and the overflow from the sewers flushed out in time of storm. A deep, wide-spread deposit of foul sewage sludge now covers nearly the whole bottom of the Fens basin, and has filled up 25 per cent. of its total volume, and the deposit is still going on.

The recent distinctly offensive conditions began with the extension of the new Stony Brook conduit up stream in 1897, in a way that *brings the continuous discharge of polluted fresh water of the brook into the salt-water basin of the Fens.* This precipitates much of the pollution in the form of a sludge on the bottom of the down-stream mile of this conduit, and within the Fens basin.

The lighter fresh water mostly floats on top of the heavier salt water; the salt water remains at the bottom; its dissolved oxygen quickly becomes exhausted; the beneficent aerobic bacteria cannot work in it; the sludge is left to the action of the anaerobic bacteria, which produce putrefaction and lead to the evolution of foul-smelling gases. Such are the conditions that now prevail in the Fens.

The Fens basin presents no true or reasonable parallel to the Charles basin as now proposed, because: —

1. The proportion of pollution entering the Fens to the water contained therein is larger than that entering the Charles as a whole.

2. The removal of a large part of this present pollution is proposed to be made a "condition precedent" to the building of the dam.

3. It is not proposed to reproduce the salt-water conditions of the Fens in the future Charles basin.

4. The aeration of the broad, exposed Charles basin, under the influence of the wind, would be much greater than that of the narrow, sheltered Fens basin.

The biologist, who was asked to give careful attention to the analogy between the Fens and the proposed Charles basin, reported (p. 316, Appendix No. 6): "The Fens basin . . . affords, in my opinion, no fair or proper standard by which to judge the proposed Charles basin." And again, on p. 330, he states, in substance, that the conditions in the proposed basin will be so superior to those in the present Fens basin that little real similarity will exist.

VIII. *Quantity of Upland Water.*

This is fully discussed in Appendix No. 16. We have no good reason to suppose that, under ordinary conditions, this will be very different from the estimates already made by Messrs. Stearns, Blake and others, which were based on assuming the flow per square mile of water-shed to be the same for the Charles as for the Sudbury; but in summer droughts the flow will often be less than this, because of interference with natural flow by holding back the water in the large mill pond of the Boston Manufacturing Company at Waltham.

It is found that the Charles is a river of remarkably uniform flow, and that the freshets on it are exceptionally slow, and small in extreme height, as compared with nearly all other New England streams. The rise comes slowly, is not high, and takes a long time in running past.

IX. *The Purity of this Upland Water.*

This was carefully investigated by the chemist, and a series of analyses upon it will be found on pp. 242–248 and 252–254 of Appendix No. 4.

Many samples of this water were collected and analyzed during September, October and November, some of them at times of a moderate drought, when, because of the factory wastes being nearly constant, the relative pollution is larger than at times of larger flow.

An abundance of free dissolved oxygen was found in the water at all times, and this shows its large capacity to support the microscopic life, — bacteria, diatoms, algæ and minute crustaceans, — through the life and activity of which the polluting material is absorbed, rendered harmless, and made available as a food supply for plants and fishes.

The proportion of organic matter shown by analysis in this upland water at nearly all times is no larger than found in some fairly satisfactory public water supplies; but in times of drought the pollution and discoloration from the dye houses, and other factory wastes, is very noticeable, and there are times of small flow when no water is flowing over the factory dams in which the concentration of street dust and floating rubbish, skimmed off and concentrated in the pools immediately above the factory dams, give an unsightly appearance to small areas. Although the dye-house wash water is sometimes alarming in appearance, the analyses show that the actual quantity of deleterious matter in it is very small. The high coloring matter becomes quickly diffused.

There is a good opportunity at most of these factories to divert any really foul flow of wash water into the main metropolitan sewer, and the wash from wool-scouring at the factory at Bemis is reported to be largely diverted into the sewer at present.

Incubation tests were made on many samples of this upland water, by exposing the samples of water, in large, stoppered bottles, to a temperature of 80 degrees F. for five days. Some samples reported on p. 270 of Appendix No. 4 were collected at a time when the flow of the river was exceptionally low (September 22, probable flow, about 35 cubic feet per second), at about the close of one of the dryest and warmest periods of the present year. These tests showed that, although this water contained, at most, dissolved oxygen to only 30 per cent. of saturation, and in some cases much less, in only a very small proportion of these samples was there present sufficient impurity of an easily oxidized nature to exhaust the oxygen in this severe test.

Bacterial examinations were made of many samples of this upland water (see pp. 281, 285, Appendix No. 4; also p. 123, Appendix No. 1). The number of bacteria per cubic centimeter of the water was found decidedly less than the average number of bacteria in the Merrimack water at Lawrence.

The biologist also gave careful attention to the quality of the upland water (see Appendix No. 6, p. 335), and found this favorable for its remaining nearly stagnant in the proposed basin during long periods if need be, and also found that the proportion and kinds of micro-organisms contained in it were favorable for the disposal of considerable quantities of pollution.

The biologist reported orally that this upland water was nearly always found in excellent condition, and that the large volume of storage contained in the proposed basin would so dilute any relatively high discoloration or pollution during summer droughts as to make it unnoticeable.

The quality of this upland water was also investigated carefully by the sanitary engineer (see Appendix No. 5, pp. 308, 309). He finds that the considerable pollution received near the head of the stream in Franklin and Milford is nearly all absorbed, and disappears during its sluggish flow through many miles of sparsely settled country; so that, when the river water reaches Newton Upper Falls, near the intakes of the Brookline and Newton water works, the water is clean and well suited for domestic use. At Newton Upper Falls a few small factories pollute it, and a slight increase of organic matter is found in the analysis of samples from near the intake of the Waltham water works. Below the Waltham dam some more factory wastes enter.

The chemist sums up the results of his analyses of this upland water by saying (p. 289): "This water is low in color, practically odorless, and, with the exclusion of some of the wastes entering below Waltham, would be suitable for a public water supply, as far as organic matter is concerned;" and that, with stagnation in summer in the proposed basin, the continual oxidation would cause the quality of this upland water to continually improve.

X. *Present Pollution of the Charles River Basin, and Means of lessening this.*

The obtaining of a reliable estimate of the quantity of polluting material was found to be the most complicated, puzzling and difficult of all of the subjects investigated; and the importance of this matter to the whole plan was such as to forbid leaving the subject until the conclusions were established within reasonable limits beyond possibility of mistake. In Appendix No. 2 it has been sought to describe, in the briefest intelligible form, the scope and methods of the investigation and their results.

The pollution is, beyond doubt, now greater than it was expected to be in 1894, after the completion of the north metropolitan sewer; mainly because of admitting the dry-weather flow of Stony Brook directly to the Fens, and because the sources of pollution in the Stony Brook valley have rapidly increased.

The recent investigations have brought to light a serious cause of offensive pollution in the flushing out of deposits and accumulations of filth from sewers by the rush of flood water in time of storm; but the percentage of the total sewage which escapes in time of storm into the Charles basin and its tributaries through the sewer overflows is found to be only about half as great as seemed probable from the evidence presented at the public hearings of 1902 (3 per cent., instead of 7).

After a very exhaustive examination into the conditions under which the sewer overflows discharge their surplus of mingled sewage, street wash, roof water and surface drainage into the Charles and its tributaries in time of storm, it was concluded (see table inserted at p. 183, Appendix No. 2; also p. 50, engineer's report) that, under present conditions, but allowing for the changes soon to be brought about by the completion of the high-level sewer, the amount of this sewage overflow will surely not exceed the ordinary constant sewage flow from a population of 10,000, and will perhaps be not more than half this. The most probable equivalent population is about 6,000 to 7,500. It is to be constantly borne in mind that the actual discharge is intermittent and not well diffused and therefore would be more difficult to deal with than the same quantity discharged at a constant rate; but, on the other hand, the diagrams at p. 188 of Appendix No. 2 show that this overflow discharge comes mainly in the cool months, before pleasure boating begins.

The proposed marginal conduit at Binney Street will, in ordinary storms, divert about 18 per cent. of this pollution; and that on the Boston side, if carried only to the Fens outlet, will, in moderate storms, divert about 50 per cent. more; and, after the marginal conduit has been extended to St. Mary's Street, perhaps 15 per cent. additional, in all moderate storms.

After the new high-level sewer is put into use, the Charles River valley sewer will be no longer backed up from the Boston main sewerage, and will have a surplus capacity for some years to come, save on comparatively rare occasions. Therefore, under the plans now proposed, the only pollution entering the basin will be the street wash, and the overflow from sewers in the west end of Cambridge, the discharge from which will become less as the separate system is gradually extended. In severe storms, and for two or three hours at high tide, the marginal channel cannot carry all the overflow, and some dilute sewage will continue to be discharged into the basin; but at such times the upland water available for dilution will also be increased.

The probable extension of the separate system in Boston will tend to lessen frequency of overflow, and a greater rainfall will be required before overflow occurs. This gradual improvement will offset any increase due to increased population, and the improvement of the two Stony Brook channels and the removal of the sewage now entering them will lessen the chance of a nuisance at the outlets of the marginal conduits, just below the proposed dam.

The means for lessening the present pollution are obvious and simple, and relief from a part of this pollution is already in sight, regardless of the proposed dam: —

(1) The pollution of the new channel of Stony Brook will be greatly lessened by the projected progress of this channel up stream during the next two years, and by the simultaneous construction of the large low-level sewer which is being built in combination with this Stony Brook conduit. This new sewer can at once take in the brewery waste and much sewage that now defiles the brook, and at the same time will provide for the probable future rapid increase of sewage in this region.

(2) The new high-level sewer now under construction, and which will be completed two years hence, will greatly lessen the quantity of sewage overflowing.

(3) A sewer will probably soon be constructed for the Beacon Street houses, so that they will no longer discharge their sewage directly into the basin.

(4) A careful sanitary inspection should be made along the tributary streams, and the privy drainage and factory waste, gas works waste and oil in condensation water should be diverted into sewers.

(5) The old Stony Brook conduit should be improved by diverting considerable sewage which now enters it into the sewers; and the present tumbledown structure, with its roughness and hollows, in which the sewage sludge finds lodgment, could be replaced by a smooth, clean, modern structure, designed primarily for the interception and conveyance of storm drainage from the streets and catch-basins.

(6) The dry-weather flow of Stony Brook that now comes down through the commissioner's channel into the Fens should be diverted by a short piece of conduit into the old 7-foot by-pass channel, leading now into the Charles River, but in future into the proposed marginal conduit.

This short and comparatively inexpensive piece of conduit should have been built five or six years ago, and would have prevented a large part of the recent defilement of the Fens basin.

(7) The sludge banks that have accumulated in the Fens should all be dredged out so as to give the original depth of 8 feet of water over all parts of the basin, excepting its steeply sloping banks.

From the plan of soundings given in Appendix No. 3, it will be found that the present volume of sludge may amount to 70,000 cubic yards; but, since there is some uncertainty in these measurements as to the dividing line between sludge and the original mud bottom, I have conservatively estimated this quantity as not less than 50,000 cubic yards.

This dredging could probably be most cheaply done after the completion of the dam and the opening of a broad passage way between the Fens basin and the Charles basin, through which scows could pass, since by this means the twice handling of material could be avoided; or it would be possible to remove it now in substantially the same manner that was followed in the dredging of 1895, by means of a hydraulic dredge, from which it could be discharged into the 7-foot channel, and again intercepted and redredged from the bed of the Charles near the Fens outlet, or flushed down through the marginal conduit and dredged out below the dam.

(8) There are three sludge banks in the Charles basin, each of comparatively small area, and probably in no case more than 2 or 3 feet in average depth, from which it may be advisable to dredge the sludge. These are located (1) near the outlet of the Binney Street sewer, (2) near the outlet of the Fens basin, (3) at the starch factory drain near the Brighton Abattoir. These can doubtless be cheaply removed while securing filling for the proposed marginal embankment, since the chemist's analyses show that the percentage of organic matter in the mud forming these banks is so small that they can doubtless be utilized for filling if deposited in a place where they will be deeply covered.

XI. *Amount of Pollution Admissible without Offence.*

The studies of the biologist, of the chemist and of the sanitary engineer were particularly directed to obtaining the fullest and most up-to-date information on this point that was possible in the time available.

Within the past five or ten years there has been a great advance in exact scientific knowledge concerning the means by which, in nature, manure or pollution is made available for plant food; and, while we are doubtless as yet only at the beginning of knowledge in these matters, some of the limitations as to admissible pollution are becoming well understood, and the debatable ground is being continually narrowed.

The biologist (Appendix No. 6, p. 316) says: "It appears to me highly probable that it" (the proposed Charles basin, containing 458,000,000 cubic feet of fresh water, of the quality now found above Watertown dam, refilled in hot weather at least once each one hundred days, and having a surface of 1.27 square miles favorably exposed to sun and wind) "can assimilate the assumed amount of sewage" (equivalent to the continuous ordinary flow from 10,000 persons), "together with the present, and probably the future, amount of street wash, without causing offence."

The following are other quotations from the biologist's report bearing on this question: —

"Just as by experiment in a balanced aquarium the amount of vegetation necessary to balance an excess of plant food could be added, so in the proposed Charles River basin a growth of algæ would soon become established sufficient to care for such polluting organic material as now comes over the Watertown dam or is likely to enter with the street wash" (p. 340).

And, as to danger from excessive growths of algæ, which by their decay would produce malodorous or unsightly conditions, such as have happened not infrequently in certain storage reservoirs for water supply, he states (p. 339) that, with care given to lessening the pollution and with conditions favorable to the life of organisms that browse on the algæ, trouble from this source appears extremely improbable, although remotely possible.

"While it is true that pollution of water by nitrogenous substances directly promotes the growth of aquatic plants, these same plants do much to justify their existence by producing oxygen (and thus tending to check putrefaction) and by assimilating the nitrified polluting material" (p. 331).

"It is probable that proper precautions may avoid the likelihood of an excessive growth of algæ, which might, in dying, become offensive."

The chemist concludes, as the result of his season's work: —

"It is exceedingly improbable, in view of the results of the experiments given, that all the wastes now entering the basin would, under any circumstances, rob the still fresh water in the proposed basin of its dissolved oxygen" (p. 290).

An extreme outside estimate of the amount of pollution entering the proposed basin at the present time during the six dry, warm months, would not exceed in quantity that contained in the continuous flow of sewage from a population of 10,000 (p. 50, also Appendix No. 2, table following p. 183). Assuming the average per capita quantity of sewage of average composition is 100 gallons (for, although the quantities of liquid found flowing in the sewers of the metropolitan district average more nearly 150 gallons (see Appendix No. 2, p. 171–174) a large part is ground water), and calling the population 10,000, it follows that the equivalent of not more than $10,000 \times 100 = 1,000,000$ gallons per day of ordinary sewage is discharged into the Charles basin under present conditions. The basin contains about 3,435,000,000 gallons of water; therefore thirty days' run of the quantity of sewage estimated on this extreme hypothesis would amount to less than 1 per cent. of the contents of the basin.

The marginal conduits will immediately lessen this quantity, the completion of the high-level sewer will lessen the frequency of overflow along the Charles valley sewer, the extension of the separate system in Cambridge and Roxbury will diminish the volume of sewage entering, and the charts at p. 188 of Appendix No. 2 show that the frequency and duration of overflow is much less in summer than for the yearly average. Therefore, plainly and surely the percentage of sewage in the basin will be smaller than this 1 per cent. found by the estimate of the preceding paragraph.

In our chemist's tank experiments with various mixtures of sewage and fresh water it was found, with a deep stagnant tank exposed to sun and air, in very warm weather, that, with from 4½ to 7 per cent. of sewage added, no characteristic sewage odor could be detected; the water was continuously of good appearance, and in the complete chemical analysis of samples each day, free dissolved oxygen was always found.

The chemist sums up certain of these tests on p. 277, saying, in effect: The mixtures have been made to contain vastly greater proportions of sewage than could occur in the proposed basin, and illustrate: —

First, a state of equilibrium in water containing considerable sewage, if oxygen is present.

Second, that water containing as much nitrogenous matter in a state of change as is found with 4½ to 7 per cent. of sewage added to clean river water, retains its oxygen and does not give off odors.

Third, that 4½ to 7 per cent. of sewage can be added to fairly clean river water without exhausting its oxygen, if the addition is gradual.

Fourth, that bacterial action occurs as readily in still as in moving water, if oxygen is present.

The sanitary engineer, in Appendix No. 5, reports the most instructive series of observations for defining the limits of pollution admissible without offence. These form a valuable extension to the observations made by F. P. Stearns for the report of the State Board of Health in 1890, and reported on pp. 785–793 of the special water supply volume of that year. This brief report of Mr. Stearns, rearranged and paraphrased in various forms, appears to have furnished most of the data for certain of the American authorities in their statements as to the permissible limits of stream pollution. It had the great advantage of being founded upon field observations, concerning the offence, or lack of offence, produced on the senses of sight and smell along a few Massachusetts streams by the discharge into the stream of the sewage from a known population. In order to present the data in convenient form for comparison with other streams, Mr. Stearns supplemented these observed facts by a brief study of the chemical composition of ordinary sewage and of the water supply that became sewage by the addition of pollution, and also added an estimate of the flow of each of these streams.

From scantiness of data, Mr. Stearns was compelled to leave the subject in incomplete form in 1890; but he prudently set his limits of the ratio of population to stream flow that was almost sure to give trouble and of the proportion almost sure to be inoffensive, wide apart. Mr. Stearns found that, when the stream flow averaged less than 2.5 cubic feet per second per 1,000 persons whose sewage was received, offensive conditions were highly probable; and also found that with more than 7 cubic feet per second of stream flow per 1,000 persons there was almost certain to be no offensive odor or offensive appearance produced.

Some authorities have attempted to formulate these matters in terms of number of dilutions required. but, because of the daily gallons of sewage per capita varying, somewhat like the per capita water supply of different communities, while the per capita quantity of excreta and waste of all kinds is fairly constant, the Stearns formula of cubic feet of stream flow required per 1,000 of population is a much safer guide than a specified number of dilutions.

If we call the Boston sewage 100 gallons per inhabitant per day, or pretty nearly the same as the water supply, omitting the ground water, this lowest limit of 2.5 cubic feet per second per 1,000 population corresponds to diluting 1 volume of this sewage by 16 volumes of fresh water; and the highest limit of 8 cubic feet per second per 1,000 population corresponds to diluting 1 volume of this sewage by 52 volumes of fresh water.

If, as a standard, we take the more common rate of sewage flow as 75 gallons per capita, the corresponding dilutions are 21 and 70. The Stearns data, thus expressed, say that, with only 16 to 20 dilutions, there is almost sure to be offence; while with 52 to 70 dilutions it is almost certain that no offensive conditions will arise.

Samuel Rideal of London, Eng., in his recent treatise on the "Sewage and the Bacterial Purification of Sewage," 1901 (pp. 14–18), speaks of the well-established fact that "the bacteria, always naturally abundant in river water, are able, by the aid of the oxygen dissolved from the air, to oxidize more or less rapidly any ammonia or organic matter that may be present," and bases his conclusions upon the efficiency of this treatment almost wholly on the sufficiency of the free oxygen present.

He quotes Dupré as stating that, "on the average, a dilution of sewage by 30 volumes of thoroughly aerated river water prevents it from fouling and ultimately purifies it." Since the ordinary European sewage amounts to only about 40 gallons per capita, this would correspond to only about 15 volumes of the less concentrated American sewage, and he quotes his own (Rideal's) experience that "even a less proportion has been effectual." He also cites the River Exe below Exeter, Eng., as having a volume of river flow 40 times the volume of the sewage discharged into it, and states that no chemical evidence of pollution was obtainable a few miles below. This, for American sewage, at 75 gallons, would correspond to about 20 dilutions.

Mr. Goodnough's recent work followed the Stearns method, but covered the examination of a very much larger number of streams and included some ponds. The effect of this broader information was to fully confirm the safety of the rules laid down by Stearns, but it narrowed the doubtful ground by raising the limit below which the dilution will probably cause offence from 2.5 to 3.5 cubic feet per second per 1,000 persons, and lowered the upper limit from 7 or 8 to 6; for Mr. Goodnough found that, "*where the degree of dilution exceeds 6 cubic feet per second per 1,000 persons, objectionable conditions have not been produced.*"

The flow of the Charles in all ordinary seasons is much more than sufficient to give this degree of dilution of 6 cubic feet per second per 1,000 persons, and in extreme drought the large volume of upland water in storage will be far more than sufficient to keep the proportion of sewage far below this limit.

The table on p. 312 of Appendix No. 5 is very instructive, and shows that in Massachusetts 14 streams have been observed in which the entering sewage becomes less diluted than the present average sewage inflow to the proposed basin would be without marginal conduits, with no offensive condition produced save in a single case, where one of the largest woolen mills in New England adds wool-scouring liquor to the ordinary sewage of the population.

In other words, *out of 36 Massachusetts streams reported upon by the sanitary engineer, 13 receive and digest without offence a larger percentage of sewage than it appears that the proposed Charles basin could possibly receive from sewage, street wash and all other sources that can be foreseen.*

XII. *Remedies for the Unavoidable Pollution.*

The best remedy is that provided by nature, and found in almost every natural pond and flowing river, the effects of which natural remedy have long been in part recognized but not understood with any degree of clearness until within the past ten or twenty years. This process is substantially the same as that by which the manure applied to the lawn or garden is made inoffensive, and is the same process on which the most efficient modern methods of purification of sewage and purification of water supply are based.

This process begins with bacterial action. These low forms of life, of which from a thousand to fifty thousand individuals are found in each teaspoonful of the water of the upland Charles (see p. 123, Appendix No. 1, and p. 281, Appendix No. 4), seize on this pollution as their natural nourishment, or, speaking as a chemist, they oxidize it, nitrify it, break it up chemically and transform it into new compounds of different chemical composition, which are directly available for plant food; and on these secondary compounds the algæ, microscopic plants and plants of larger growth find their nourishment; these in turn give food to multitudes of microscopic organisms, crustaceans and others, barely visible to the naked eye, which in turn become food for larger organisms and minute fishes; these plant growths are also browsed upon by the vegetarian fishes, which in turn furnish food for the larger carnivorous fishes.

All of the examinations and tests by the chemist, biologist and sanitary engineer appear to prove beyond any reasonable doubt that the amount of the unavoidable pollution will be no greater than can be readily absorbed and utilized in these processes of nature, and without causing any unsanitary or offensive conditions.

The question of offensive conditions being produced where the marginal conduits discharge below Craigie bridge has given me some concern, and should receive farther study in the final design; but I have come to believe that by the exercise of care and forethought much of the worst of the pollution from the flushing out of sewers in storms could be held in these conduits until the storm was over, and flushed back into sewers. The water flowing ordinarily in the conduits will have its pollution thoroughly diluted and diffused, and at the worst I do not see how any condition can be produced below the dam worse than has been tolerated for some years past in the Fens. The spillways and sluices have purposely been placed close to the outlet of the marginal conduits, so that the full flow of the upland Charles River may aid in the dilution and flushing.

XIII. *Means of circulating Water in the Fens Basin and Cambridge Canals.*

No definite recommendation as to the means by which this circulation could best be accomplished was made in the report of the Joint Board of 1894. The fact that the Fens was not then in such a bad condition as that which developed later, and that the polluted dry-weather flow of Stony Brook was not at that time constantly admitted to the Fens basin, permitted this question of pollution to escape such close attention as now.

One possible method of excluding the foul dry-weather flow of Stony Brook from the Fens would be by a comparatively inexpensive arrangement for controlling its fall into a large branch of the main drainage sewer which passes beneath the new Stony Brook conduit, not far from its outlet. While this might serve as a temporary expedient, there are very evident objections to it as a permanent remedy, both on account of adding a new burden to the main sewer system, which is rapidly becoming overloaded, and also because of the expense of pumping this extra burden of water at the Calf Pasture pumping station, on its way to the reservoirs and outfall at Moon Island.

For producing a circulation of water through the Fens and thus diffusing the pollution brought in, Mr. Percy Blake (evidence, p. 207) proposed a special pumping station, and estimated its cost roughly at $50,000, and that the annual expense for maintenance would be about $6,000. This maintenance charge, capitalized at 4 per cent., would amount to $150,000, which, added to the $50,000 of first cost, would have made the capitalized total cost of circulating the water in the Fens basin by this method $200,000.

The marginal conduit with one or two inflow weirs located near Stony Brook and Muddy River inflow will obviously accomplish this purpose more perfectly and more cheaply, because, instead of merely diluting and diffusing the pollution, it immediately removes it from the Fens and from the Charles. The primary purpose of the marginal conduit is to remove sewage overflow and street wash; but this extra service of providing circulation will add only a very small amount to its cost, and avoids the objectionable power plant and pumps in the park. There will be an abundance of water for supplying this overflow, even in extreme drought; but if, through leakage or lockage or evaporation, during the most extreme drought the inflow from the Charles and Stony Brook should fail to maintain a surplus, a small volume of sea water could be carefully admitted through the deep sluice to the deep lower end of basin without its general diffusion, and without injury to the organic life of the basin, and be siphoned out again readily through the same deep sluices as soon as there was a surplus flow of upland water.

For providing circulation and diffusion of the foul water of the Broad and Lechmere canals, no remedy was proposed at the hearings of 1894 or those of 1902. To do this by means of pumps would require a large expense in plant and maintenance, and without some means of circulation they would surely become intolerably foul. This circulation and removal of the foul water can, I believe, be satisfactorily performed by means of the inflow weirs and their connection to the marginal conduit, as estimated in Appendix No. 19, and described also on p. 59, engineer's report.

XIV. *Lessening Pollution of Basin by extending the Separate System of Sewerage.*

Newton, Watertown, Waltham and some parts of Brookline are sewered on the separate system, so called, under which system, if complete along all parts of the trunk sewer, there would be no overflow of sewage into the Charles basin in time of storm.

A careful investigation was made of the feasibility and cost of extending this method, and it was found that the cost of carrying it out in such completeness as to render the marginal conduits unnecessary was excessive; moreover, many years would be required to complete a work of this magnitude.

The work of separating the storm water from the sewage in Cambridge was begun about two years ago, mainly for the purpose of relieving sewers that had become outgrown and to prevent flooding back into cellars, etc., during heavy storms that occur at high tide; and considerable progress has already been made on the construction, but mainly in the large trunk lines. Comparatively few of the Cambridge house connections have yet been changed.

It is expected that this work will go on in Cambridge, from year to year, at such moderate rate as can be conveniently included in the annual tax levy, regardless of construction of the proposed Charles River dam; but if the dam is built, it will naturally not be pushed ahead so rapidly, and some parts may be indefinitely postponed and much expense to the city thereby saved, for the motive for avoiding sewer overflow in heavy storms at high tide will have then disappeared.

In compliance with our request, through the mayor of Cambridge, Mr. Hastings kindly made designs and estimates for completing this separation throughout all that portion of Cambridge tributary to the Charles River, and found that it would require about 76 miles of drains and sewers, for which the cost was estimated as follows: —

For work on the sewers and drains,	$787,763
New house connections so arranged as to separate the storm water from the sewage water, roughly estimated at $100 per house,	1,123,200
Total,	$1,890,983

A supplementary estimate showed that the cost of this separation for all of the Cambridge territory tributary to the Charles, after excluding that tributary to the Binney Street main sewer, whose overflow it is proposed to divert into a marginal conduit, was as follows: —

This was found to require about 48 miles of sewers and drains, the cost of which was estimated at	$507,925
The number of houses in this district is 6,033, for which, at the price of $100 each, assumed above (probably excessive for this class of house), the cost of separating roof water from sewage in the house connections would be	603,300
Total cost of making the change throughout the Cambridge district, excepting that tributary to Binney Street,	$1,111,225

It is of interest to note that, *at the cost assumed* for changing house connections, this secondary branch of the work costs more than the sewers and drains themselves, and, coming directly on the house owner, will naturally impede this branch of the work.

The city engineer of Boston, at our request, detailed one of his assistant engineers to make careful studies of the cost of separating the sewage from the storm water on the Boston side of the river in the territory tributary to the Charles. These estimates are reported with considerable detail in Appendix No. 15.

The cost for that portion of the territory lying mainly westward of Stony Brook and the Fens was estimated at	$2,701,000
For the territory lying mainly to the east of the Fens and Stony Brook, the overflow of which can be nearly all diverted into the proposed marginal conduit, the cost would be	2,004,000
It was found that, for an entire district tributary to the Charles, the total cost, including both the work in the street and the changing of the house connections, would amount to	$4,705,000
Adding to this the cost of the complete separation for Cambridge, it appears that the cost of separation for both sides of the basin would amount to about	$6,596,000

This amount is so enormously in excess of that required to lessen the pollution of the basin by means of the marginal conduits, which conduits also remove much of the street wash, that further consideration of this separation of sewage from storm water as a condition precedent to the construction of the dam may be dismissed. Yet without doubt this work of separation will gradually progress, from entirely independent reasons; and, as it will naturally be spread over a long period of time, it will obviously be best to first carry out those portions of the work which lie in the territory up stream from where sewage overflow will be discharged into the proposed marginal conduits, particularly in that part of Cambridge which lies up stream from the Captain's Island playground and bathing beach.

XV. *Effect of Stagnation upon Odor, Appearance and Character of Water.*

The words a basin of "stagnant water" have been used by some of the opponents in a way that appeals to popular prejudice and not to modern science. "*Modern science has reversed the tenet of thirty years ago, and now unhesitatingly affirms that it is quiet water rather than running water that purifies itself.*" *

Stagnation of itself does no particular harm, and still water is not of necessity unsanitary. The ponds on Boston Common and Public Gardens are but stagnant pools. Every reservoir from which Boston, Cambridge, Lynn and Winchester draw their water supplies for drinking and other domestic purposes is a "stagnant" pond, and the great

* From p. 17 of Pittsburg report by Sedgwick; same report cited by Dr. H. J. Barnes, evidence, p. 300, but a little farther along, not supporting his view and not quoted.

artificial lake of the metropolitan water supply will be much more nearly stagnant than the proposed Charles River basin.

The balanced aquarium is maintained with stagnant water.

The main advantage possessed by running water is that the constant delivery insures a constant mixture and completeness of diffusion not attained when pollution is discharged into a pond (and the one difficulty to have been feared, if it had been proposed to get along without the marginal conduits, would have been lack of quick diffusion).

The popular idea as to the superiority of running water as a means of disposing of pollution comes mainly from the fact that by its motion it takes the pollution away and out of sight of the persons or the community that produced it, and they seldom follow down to see what really becomes of it; but, in addition to this, there is even in a slow-moving stream a circulation of the deeper water to the surface which aids in oxygenation to a degree not found in a deep pond, where difference of temperature impedes vertical circulation. The wind-swept surface of the Charles gives ample opportunity for oxygenation.

The popular idea of stagnation attaches more particularly to a pool that is so shallow as to give favorable rooting to vegetation on its bottom, and is at the same time, because of being so shallow, made more warm by the heat of the sun than this deep basin can ever become; a pool filled with algæ, or with shallow, sedgy banks, in which mosquito larvæ may find shelter, like those described on p. 113 of Appendix No. 1. This is something utterly different from the proposed basin, with its deep water, wind-swept surface and clean-walled shores.

The pathologist found no reason for expecting malaria around a large, quiet pond, with clean banks such as are proposed for this basin.

One of the best available items of proof on this question of stagnation is to be found in a study of the Mystic lakes, particularly the upper lake, until recently used for a part of Boston's public water supply.

During nearly ten years' residence at Winchester I was familiar with this, and familiar with the pollution of the stream that entered it and with the marvellous way in which the forces of nature appeared to dispose of this pollution, and this experience has strengthened my confidence in the answer to this question. The chemist refers to this experience with Mystic Lake on pp. 287, 289, 290 of Appendix No. 4.

The chemist (Appendix No. 4, p. 275) made a few laboratory experiments having a bearing on this question of the effect of a gentle motion in the water upon its capacity to dispose of pollution, from which he concluded that "purification by bacterial action occurs as readily in still as in moving water, if oxygen is present," and on p. 291, in summing up his conclusions, he reiterates this statement in opposition to the popular idea that running water purifies itself more quickly than still water.

The most reliable information on this subject for our present purposes is that derived from natural ponds in comparison with rivers, into both of which known proportions of sewage are discharged; and therefore Mr. Goodnough's collection of new data is particularly valuable at this time.

His conclusion (p. 311, Appendix No. 5), from the experience with the ponds at Easthampton, Attleborough and elsewhere, is that *sewage discharged into a pond or slow-moving stream, such as the proposed Charles River basin, has a less noticeable effect than an equal volume of sewage has* upon a rapidly moving stream of equal volume.

Observation of natural ponds and artificial storage reservoirs has shown that sedimentation and the bleaching effect of the sun have a noteworthy influence in the purification of quiet or stagnant water, in addition to the effects of bacterial decomposition.

XVI. *Effect of this nearly Stagnant Fresh Water on Public Health. — Malaria.*

This question has been largely answered in the preceding pages. Appendix No. 1 is mainly devoted to its discussion in much detail, and, as already stated at p. 47, it appears to be demonstrated that there is no danger whatever of introducing conditions favorable to malaria because of the stagnation of water in the proposed basin.

On the contrary, it appears that by the shore line improvements which become more easily practicable and within economic reach, when the basin is held at a constant level and with the margins of the river sloping and drained so that the present small shallow portions in which mosquitoes now breed will no longer exist, with the pollution of the basin lessened and with no foul mud flats exposed at low tide as now, *there will be a distinct gain to comfort and health in the neighborhood of the river*, that will come directly from the building of the dam and stopping the present tidal ebb and flow.

Although it is yet unproved that the foul smells of the Fens basin or those from the mud flats of the Charles at low tide are producers of disease, they are distinctly unsanitary, by reason of tending to lower the vital resistance, and make life less cheerful and comfortable.

XVII. *Effect of cutting off Tidal Prism upon Shoaling of Harbor.*

This matter is fully discussed in Appendices 8, 9, 10 and 11. *The estimate of shoaling given by the maps presented at the end of the volume of evidence before the Harbor Commissioners in 1894, and also discussed in Massachusetts Senate Document No. 303, 1895, appears to be of very doubtful accuracy, because of lack of completeness and precision in the surveys compared, particularly for the main portion of the harbor*, after excluding the portions immediately adjacent to the outlets of the Charles and the Mystic rivers. Comparing the survey of 1835 (the best survey of all) with the survey of 1861, the survey of 1861 shows a deepening in the same areas where a comparison of the surveys of 1861 and 1892 shows a shoaling.

Since it has often been said that the records show that a shoaling has occurred in the harbor, it is perhaps necessary to briefly refer to those records at this time.

Under chapter 74 of the Resolves of the Legislature of 1895, the Massachusetts Harbor and Land Commission was directed to report "What shoalings have taken place in Boston harbor since 1860," the extent and nature of the deposits, the extent of dredging by federal, State or municipal government, whether to deepen the natural channel or to remove deposits.

They reported in Senate Document No. 303, 1895. Their engineer, F. W. Hodgdon, found by a comparison of the surveys of 1861 and 1892 that there had apparently been a very large and noteworthy shoaling immediately down stream from the Charlestown bridges, and also a large shoaling down stream from the mouth of the Mystic River and Chelsea Creek.

In the main portion of the upper harbor he found but little shoaling, and found a large deepening in the broad areas lying down stream from Anchorage Shoal, which is not far from a line joining the Simpson dry dock with the most southerly of the walls on the Commonwealth's South Boston flats.

The two sources relied upon in the Harbor Commissioners' report of 1895 for exhibiting this shoaling were the Boschke survey of 1861 and the United States Coast Survey Soundings of 1892, under Lieut. W. F. Low. Translating Mr. Hodgdon's estimates given in cubic yards on p. 4 of that report, into *change of depth in feet*, I find that from the mouth of Chelsea Creek and Mystic River to the line joining the point of the Navy Yard and the Atlantic Works, on an area of about 130 acres, the apparent shoaling averages 1.4 feet, while on the area of about 26 acres, between the lowest Charlestown bridge and a line joining the Boston slip of the Chelsea Ferry and the point of the Navy Yard, the apparent shoaling averages 2.7 feet; but on the larger area of the main upper harbor, comprising the 156 acres between the Navy Yard and Anchorage Shoal, the average shoaling shown during this period was only 0.8 foot.

On the other hand, on the much larger area of 1,130 acres lying between the Anchorage Shoal and Castle Island, a comparison of these maps of 1861 and 1892 indicates an average deepening of 0.3 foot during this period; and the net result in difference of depths shown by these two maps when averaged for the entire area of 1,500 acres, gives an average deepening of only about ¼ inch.

On comparing the soundings of 1835 with those of 1861, still other differences are found, but very curiously many of the areas that apparently shoaled between 1861 and 1892 appear to have deepened between the years 1835 and 1861. Curiously, the map of 1835 appears to present the most complete and precise survey of the upper harbor that has ever yet been made. I have taken pains also to inspect copies of the complete sheets of the surveys of 1861 and 1902, and on each the soundings average scarcely 100 feet apart, and the depths on cross ranges agree so well that the discrepancies between one map and another are hard to explain.

As is stated later, there is some small uncertainty about the real elevation of the datum plane to which these soundings are referred, and a strong probability that the whole bed of the harbor is slowly lowering, from geological causes, at the rate of about an inch in 8 or 10 years, or about one foot in 100 years; but the main reason for the discrepancy between the ancient and modern soundings within the main harbor appears to be the lack of precision in the measurements. On the Boschke map many depths are figured to fractions of a foot from the tide reduction where I find original notes show the record taken in fathoms and whole feet.

The reasons why shoaling of the harbor may not be expected to follow a lessening of the tidal flow, that were advanced by Mr. F. P. Stearns, on pp. 20, 21 of the report of the Joint Board of 1894, and in his evidence before the Harbor Commissioners, appear to be fully sustained by our additional information: —

(*a*) That the currents are already too feeble to produce scour or to prevent shoaling.

(*b*) That there is no adequate source of material to produce shoals in the inner harbor.

The results of our recent investigations may be summarized as follows: —

(1) Notwithstanding that the area of tidal water about Boston inner harbor has been reduced during the past century by an amount very much greater than the present area of the Charles estuary, and that a volume has been cut off from the tidal prism of the Charles, by the filling in of the Back Bay lands and the Cambridge embankments, about as large as that which it is now proposed to cut off, no noteworthy shoaling of the harbor has followed.

(2) Good reasons appear for believing that the apparent shoaling indicated by a comparison of the old surveys with the latest surveys was mainly due to lack of precision of one or another of the soundings compared, and perhaps in small

part due to discrepancies in the elevation of the bench marks to which these soundings were referred.

(3) The small depth of the deposit of silt now found on top of the hard blue clay which formed the original bed of the harbor, so far as yet investigated, proves, irrespective of all soundings and surveys, that there has been no important shoaling of the harbor.

(4) The Board of Commissioners on Boston Harbor, of forty years ago, made surveys and current measurements, which, although good according to the standards of those days, are incomplete and imperfect when judged by the standards of to-day, and their theories were necessarily formulated in ignorance of the geological principles that have been learned in more recent years; and, while at that time it was natural to attribute the formation of the harbor channels to tidal scour, the recent researches of geologists have shown other far more probable causes for a case like this, and it now appears certain that Boston harbor is mainly a submerged valley, eroded many thousands of years ago, soon after the glacial times, when the rivers were larger than now and the land higher than now relatively to the sea, and that this valley was afterwards partially submerged by a slow subsidence of this whole Massachusetts coastal region, which subsidence is probably still in progress.

These matters of the geological history of the harbor are thoroughly discussed in Appendix No. 7.

(5) The velocities of the harbor currents at and near the bottom are found by our recent measurements to be too slow to produce scour and too slow to prevent the deposition of any sand or silt that might be suspended in the water; therefore, a further lessening of these currents can work no harm.

These bottom velocities found now in Boston harbor are smaller than those under which certain deposits of fine sand take place in the Lawrence canal, and much smaller than those found necessary for producing scour. In other words, silt would now be continually deposited in Boston harbor, and the deposit would have been going on steadily for many years past, if there had been any considerable quantity of silt in the water.

(6) The assumptions of the Board of Harbor Commissioners, forty years ago, concerning the velocities necessary to produce scour, were very erroneous, and were based largely on some imperfect experiments made by the French engineer, Dubuat, more than a hundred years ago, which data has unfortunately long posed as authority in sundry

text books, without having been traced back to its original source, as is now briefly done by Mr. Hiram F. Mills, in Appendix No. 9.

(7) The enlarged channels of the Boston harbor of to-day, and of the future, are, and must be, essentially artificial channels, created and maintained by the dredging machine; and by this very enlargement they would be taken beyond the power of the natural tidal scour to preserve them, supposing this tidal scour to have been their cause. This matter is made plain in Appendix No. 8.

XVIII. *Effect of Dam on Navigation and Commerce in Charles River Basin, Cambridge Canals and Upper Harbor.*

This has already been briefly discussed on pp. 64, 65, and the opinion expressed that the gain from a constant level at grade 8, with freedom to move vessels in and out at all times, would more than offset any loss caused by the future height being less than that which is now obtained at the peak of the tide.

The folding diagram showing the present tidal fluctuations, inserted at p. 68, presents the main features of the change in level which affect navigation so plainly that little discussion of this is needed, and an inspection of the photographs opposite p. 67 indicates how great the improvement arising from constant level will be.

It is proposed that the level of the future basin should be at least grade 8, Boston base, and it is proposed to raise this permanently as nearly to grade 9 as future observations upon ground water and the improvement of the margins shall show to be feasible.

There are now periods of neap tide when for nearly a week at a time the basin level rises but little if any higher than it will constantly be after the proposed dam is built; and with the dredging and deepening of canal provided for in the estimate of cost, and with the recent change in design of lock by which a depth of 18 feet below mean low water is to be secured, boats larger than have ever yet been occupied in the commerce along the present wharves around this basin can enter at any hour and proceed directly to their berths, and have far greater facilities and safety than they have ever yet enjoyed.

For filling the lock, passages of such ample size have been designed that it need not take more than eight or ten minutes to fill or empty it under extreme conditions of low water, and it will take much less time than this when the harbor is at above half tide. Winch heads worked by electric motors could aid in the quick entrance or exit of the boat. The main lock gates can be moved very rapidly, and the conditions are particularly favorable for making this one of the most rapid-working locks that can anywhere be found. Its location permits the combination of its power plant and operating crew with that which will be necessary for the operation of a drawbridge.

The one interference with navigation that may be strongly urged is the long period which ice will endure on this body of quiet, fresh water, in comparison with the endurance of ice on the present fluctuating, salt-water basin.

It must not be forgotten that the navigation of the basin is now sometimes closed for more than a week at a time because of ice. The statement presented in the evidence that vessels now enter the basin every month in the year may give a wrong impression to one who has not been familiar with this basin for years.

It appears feasible to keep channels broken through the ice in the future basin by means of a tug boat of special design, maintained as a part of the necessary outfit of the basin, through which channel the wharves can be made nearly as free to navigation as heretofore; and in the design now presented, provision has been made for running out a greater or less amount of the broken ice into the tidal water, by means similar to those used on some of the large water power canals in New England which are maintained open and free from ice throughout the year.

The estimate in evidence of 1902, p. 409, that the change from salt to fresh water would cause a vessel to sink 5 inches deeper, is based upon slightly erroneous data, for it assumes the basin is now filled with sea water at a specific gravity of 1.028, whereas the present basin contains, in the region frequented by navigation, about 10 per cent. of fresh water, thus making the loss of depth of flotation 10 per cent. less, or in all about 0.38 foot for a vessel of 15 feet draught. This objection can be easily met by the amount of dredging provided for and by the deeper lock.

XIX. *Storm Flood Levels in Proposed Basin.*

This matter was carefully investigated by the engineers of the Joint Board of 1894. On p. 16 of their engineers' report it is stated that: "Taking 6,000 cubic feet per second as the amount of water which would flow into the basin in a freshet as great as any of which there are records, and assuming at the same time successive tides considerably higher than the average, careful estimates show that the water in the basin can be prevented from rising more than 2 feet above the normal level." Two feet above their proposed level of 8 is grade 10, Boston base.

The above estimate assumed a flood of larger volume than the great "Stony Brook flood" of 1886, the most severe on record; the basin considered was somewhat smaller than now proposed, because of the dam being about 600 feet farther up stream; it was then proposed to use the lock in emergencies as a sluiceway; and the flood sluices then proposed in the dam were of 300 square feet area, whereas they are now proposed to be of 500 square feet area, with about 400 square feet additional area available for storm flow through the marginal conduits, spillways, ice runs and lock-filling gates, exclusive of the lockway itself. Additional sluiceway would not be expensive.

The present proposition to raise the basin level to grade 8.5 or 9, or as high as ground-water observations made after dam is built shall show to be feasible, will not necessarily raise the flood level at all, for the two features which mainly control the flood level are: —

(*a*) The volume of upland water arriving during the time while the sea tide is above the basin level; and

(*b*) The ability to draw the basin down 1, 2 or 3 feet on the preceding low tide.

There will remain the same opportunity to do this that was contemplated in the plan for constant level at grade 8.

Professor Porter, in preparing his estimates (evidence, p. 405), assumed the flood volume of upland water at 7,000 cubic feet per second, and also assumed that the larger openings and sluices proposed by Mr. Blake would be available and the lock also open; and he assumed the extreme high tide of Dec. 5, 1898, in which, under influence of strong easterly winds, the flood tide reached grade 12.2 and the ebb was held up to grade 3.8, to illustrate extreme conditions, which might some time retard the outflow from the sluices. Under these adverse tidal conditions, with a great freshet, but with a vast amount of sluiceway, he found the basin might become filled to grade 9, and, assuming the still more severe tidal conditions of Nov. 28, 1898, the storm in which the steamer "Portland" was lost, perhaps the most severe wind storm in the past half-century in its effect on tides, with the easterly wind holding the ebb tide up so it did not fall below grade 5.4, he computed that the basin level might rise to about grade 10.4.

The storage area in the basin was assumed by Professor Porter at 33.4 million cubic feet per foot in height; whereas it now, with dam at Craigie bridge, averages 34.4, or 3 per cent. larger, between the contours of 5 and 9.

This computation of Professor Porter's is not applicable to the dam as now proposed, because no tidal sluiceways are now proposed, but is interesting, as showing that, under those extreme assumptions of a freshet greater in volume than any ever yet known coincident with tides of an extreme height at low water that has never yet been observed as coincident with a great freshet, he found the extreme limit 10.4 feet, or slightly lower than the mean level of the marshes and slightly lower than the level now reached by the average daily tide in the upper Charles.

It is now proposed to omit the large tidal sluices, and to make a deeper lock; and it is not certain that it will be thought best to provide gearing sufficiently strong to pull the up-stream lock gate open or close it under pressure, therefore it will be proper to omit the lockway from the areas available for drawing the pond down in preparation for freshet storage during the succeeding high-water interval. Therefore, we will for the moment accept the extremely improbable coincident condition of extreme freshet and extreme tide, and apply it to the sluiceway areas shown in the drawings on which the present estimates are based.

The four large sluices and the two small sluices beside them present a net area of 500 square feet, for which, from experiments on canal headgates at Lawrence, Mass., and Manchester, N. H., we will call the coefficient of discharge at least 80 per cent. The full discharge of the spillways and ice runs on Boston and Cambridge end is allowed for, because, during the time that the basin is above the level of their crests and the harbor tide below it, these spillways and the marginal conduits are assumed to be discharging at their full capacity. The emergency gates for filling the locks could be included, but their discharge is relatively small. The main lock gates are assumed closed.

Although the greatest flood ever known on the Charles, of which record or tradition remains, was that of February, 1886, when (see Appendix No. 16) the flow at Waltham was probably not over 4,000 cubic feet per second, and the main flood from Stony Brook and the lower tributaries had spent itself and passed before the greatest height over the Waltham dam had been attained, we will follow the prudent suggestion of the late James B. Francis, and assume a flood of much greater volume, such as might come if a rain like that of October, 1869, should fall on frozen impervious ground, and assume a flow of 7,000 cubic feet per second. It is absolutely certain that the main freshet from the Charles would not arrive until a day or two after the main flood from Stony Brook has passed, and that there would thus be ample warning and opportunity to draw the basin down 1 or 2 feet to receive it.

There are two quite different tidal conditions which may be conceived of as lessening the discharge of flood water through the sluices: —

(*a*) Extremely high flood tide caused at a period of spring tides by strong and prolonged easterly winds, thus increasing the length of time during which the freshet water must be stored because of harbor being above basin level, and with the low-water level of the spring ebb held up in about equal measure by the wind, thus impeding the outflow from the sluices, but less than under some other conditions, because the effect of the easterly wind in piling up the water is counteracted by the spring tide tendency to fall low.

(*b*) An extremely high ebb tide at the neap tide period, induced by a strong and prolonged easterly wind, which would pile up on top of an ebb already high from neap tide conditions.

Our computations show that, with all these unfavorable conditions of extreme tide and extreme freshet coming together,* *which probably would not happen once in a hundred years, and with the basin not drawn below grade 8* during the preceding ebb because of the opposing height of 5.4 feet on the harbor side while it rose in the harbor to 14.6 on the flood,† *the extreme height reached would be 11.8 feet above Boston base, which is 2.8 feet less than the height in the harbor at the same time*, and a less height than the tide in the Charles now reaches in almost every month; and, even if it did reach this height, and some of the park lands became flooded with fresh water for three or four hours, no particular harm would be done.

I consider that fears of trouble from failure of ability to control the flood level of the basin in great storms are groundless.

XX. *Cost of Dam and Lock.*

These questions of cost are answered in detail in Appendix No. 19.

The complete dam and lock, combined with a roadway and drawbridge, with all needful accessory structures, all of the best material and workmanship, can be built for anywhere from $1,000,000 to $1,600,000, according to the elaborateness of detail and the width and height of roadway, and the dam in combination with a bridge will cost just about the same as the bridge alone, of the same width and height, which must inevitably soon be built to replace the present old, worn and decayed Craigie bridge.

I consider that the design called No. 5 (see Appendix No. 19), the high dam 130 feet wide, of solid filling between massive granite walls, with the deep lock having its entrance sill at 18 feet below mean low water, shown in section and in elevation, but without the catch-basins, is well adapted to meet the conditions, and for this I estimate the cost at $1,425,000.

Since this will serve for a bridge, and cost no more than

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* We have in Appendix No. 18 compiled such records as can be obtained relative to extreme tides, and to the conditions of rainfall and flood at the same time. The continuous tidal records at the Navy Yard were kept only from 1847 to 1876, and again in 1902 and 1903. These can be supplemented by the year's observations at India wharf by Baldwin in 1867 and by the records of the Deer Island sewer station in recent years.

It is interesting to note that there is no record of any remarkably high tide at the time of the Stony Brook flood.

† These are the heights reached in the great storm of November, 1898, in which the steamer "Portland" was lost.

the necessary new bridge, it would appear fair to divide its cost between the adjacent cities, just as the cost of the new bridge would be divided.

XXI. *Cost of Marginal Conduits.*

The marginal conduit required on the Boston side to intercept the sewage overflow, street wash and polluted Stony Brook discharge, and for providing circulation in the Fens basin (see Appendix No. 19), is estimated to cost $500,000.

The marginal conduit on the Cambridge side for intercepting sewage overflow and street wash from the large Binney Street district, and for providing circulation in the Cambridge canal, is estimated to cost $88,000.

XXII. *Cost of making Good any Injury to Navigation.*

The cost of making good the injury to navigation interests along the Cambridge canals is fully discussed in Appendix No. 12, also briefly in Appendix No. 19, also in argument of Albert E. Pillsbury, Esq., on p. 459 of evidence.

It does not appear reasonable that the State should dredge these private canals to give a depth several feet greater than ever before enjoyed, and rebuild all of the present old and shaky walls, or that contract obligations should be incurred to give greater freedom from ice in the future than has ever been secured in the past, all of which might be called for under the stipulation proposed by the petitioners, and which might cost, as estimated by the chief engineer of the Massachusetts Harbor Commission, nearly half a million dollars (see p. 427).

It appears that a fair and liberal allowance for making the owners fully as well off as they are to-day, and in fact much better off, will be $100,000. The cost of additional dredging in the main basin for navigation and for removal of the three sludge banks is discussed in Appendix No. 19, and I have estimated this at $25,000.

The channels can be greatly improved, simply and cheaply, by the use of discretion in dredging the large quantities of filling required for the dam and for the new esplanade on the Boston side in the rear of Beacon Street, the cost of which dredging is covered in the separate estimates for the cost of these structures, and it is this which favors so small an estimate as that just given.

XXIII. *Cost of dredging Foul Sludge Banks.*

The dredging of the sludge bank in the Fens appears to be purely a city of Boston affair, necessary for sanitation without reference to the dam. There is probably somewhere from 50,000 to 70,000 cubic yards of this material. Although it is stated that dredging of somewhere between 15,000 and 30,000 cubic yards from this basin in 1898 cost $25,000, this is not a fair criterion for an estimate of cost per cubic yard, because of a large part of this expenditure having been absorbed in getting the dredge into position and taking it away. By deferring this dredging until the dam and marginal conduit are built, and an open entrance provided into the Fens basin, the cost can probably be reduced, and it now appears that total cost should not exceed, say, roughly, $40,000.

XXIV. *Cost of Shore Line Improvements.*

The cost of shore line improvements is discussed in some detail in Appendix No. 19, and other interesting data are found on p. 31 of the report of the Joint Board of 1894; and it is easy to understand that, with the basin at constant level, a much cheaper type of wall will serve for extending the proposed marginal improvements up river than will be required under the present conditions with a 14-foot tidal range.

Finally,

It appears that the advantages of the dam and the basin at nearly constant level largely overbalance the possible disadvantages; that sanitary conditions will be improved, and danger of malaria not increased; that interests of navigation and manufacturing will be bettered; that the harbor will not be shoaled by loss of tidal currents; that a magnificent opportunity for wholesome recreation and the enjoyment of a more beautiful landscape will be made possible by the construction of this dam.

s a result of careful estimates, the remarkable fact appears that *this great public improvement, with dam, lock, marginal conduit, esplanade and new embankment walls, and all necessary appurtenances attendant on the substitution of a clean, sanitary and beautiful fresh-water lake, into which large ships can enter and proceed to their berths at any hour, for a foul tidal estuary, need cost not a dollar more than to continue the highway improvements, marginal improvements, sewer and sanitary improvements to which* *the cities of Boston and Cambridge and the metropolitan district are already definitely committed under tidal conditions without gaining the advantages above named.* It will, however, call for an earlier expenditure.

In other words, the dam complete, with roadway, bridge, lock and sluices, costs little, if any, more than the bridge that must necessarily soon be built in place of the old Craigie bridge; and the marginal conduits and their accessories, necessary to the purification of the basin, will be fully met by the lessened cost of improving the present dirty margins of the upper basin, and a moderate dredging of the mud flats exposed at low tide, improving the present unsanitary marshes, and deferring the building of certain new sewers and storm drains already begun in Cambridge.

Respectfully submitted,

JOHN R. FREEMAN,

Engineer.

Editor's Note

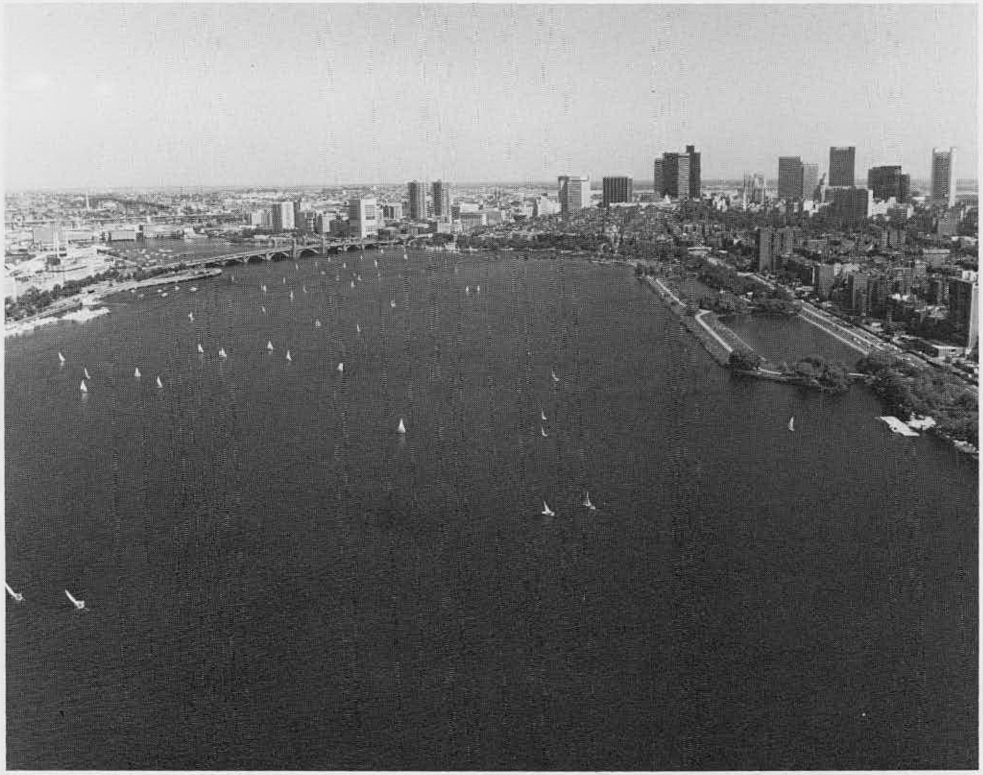
Following submission of the Freeman report in January, 1903, there was little further opposition to the Charles River Dam. The Great and General Court (state legislature) passed enabling legislation, and dam construction was completed in 1910 under the able supervision of Frederic P. Stearns. Thus the clam flats that had shown up every 12 hours from time out of mind (see photo at Report page 10) were no longer in view. In their place is a permanent water surface bordered by appropriate structures, perhaps one of the most charming sights anywhere.

During following decades and especially after the hurricanes of the 1950's, it became apparent that further protection against flooding would be desirable. The U. S. Army Corps of Engineers undertook construction of a second dam (see last photo in following series) plus a pumping station capable of handling the entire storm flow of the river and delivering it over the dam to the harbor at times when gravity flow is prevented by high tide or hurricane conditions. This dam was dedicated on May 24, 1978. Its impact on the environment is evaluated on the following paper.

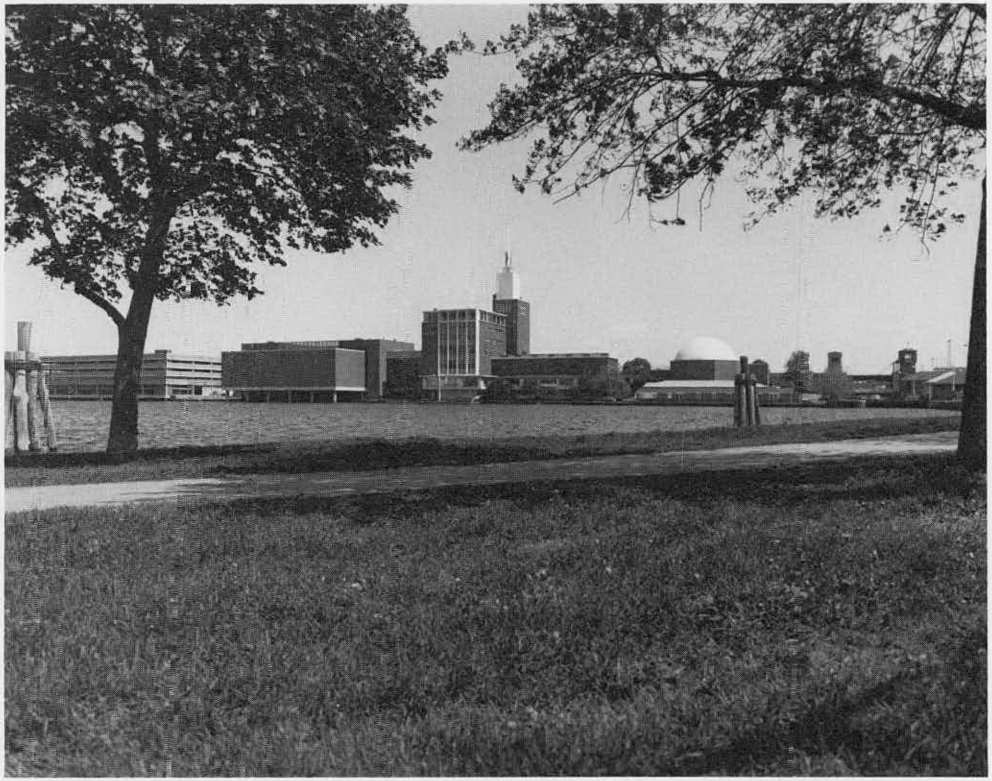
Completed lock, 1909. (From MDC files).

Sluices under construction, upstream face, June 1907. (From MDC files).

Northerly end of basin, from Cambridge side. The original dam is under the highway that crosses the river, flanked by the Museum of Science (white dome at far end) and the trolley car viaduct (arches). Lock entrance is beyond museum. (MDC photo by Jack Maley)



General view, lower basin. First structure across river is Longfellow Bridge (also called West Boston Bridge). Museum of Science (dam location) is at end of basin as established in 1910. (MDC photo by Jack Maley)



Museum of Science (dam location) seen across water from Embankment Road on Boston side. Lock entrance at right, drawbridge across lock beyond. (MDC photo by Jack Maley.)

Mouth of Charles River, from harbor, Structures are (from bottom): Charlestown Bridge; new dam (see following paper); Central Artery Bridge; railroad drawbridges; trolley car viaduct. (MDC photo by Jack Maley)

AN IMPACT ASSESSMENT OF THE NEW CHARLES RIVER DAM

By Godbey, A.[1,2], McCarley, S.[1,2], Blount, R.[2], Boudreau, M.[2], Demond, A.[2], Freedlund, C.[2], Haggerty, B.[2], Hand, J.[2], Luttmer, E.[2], Tiffany, S.[2], Adams, E.[3], and Harleman, D.[4]

ABSTRACT

During the spring term of 1980 a group of MIT seniors conducted, as a class project, a critique of certain design features of the new Charles River Dam at Warren Avenue, Boston, Massachusetts. The project objective also included an assessment of the impact of the new dam on the Charles River Basin. Topics covered in detail were flood control, recreational navigation, land use, water quality, and aquatic life. The study resulted in:

— development of unit hydrographs for the Charles River watershed
— estimation of navigation times between basin and harbor
— evaluation of adjacent land development plans
— development of a mathematical model for changes in the salt water content of the basin
— discussion of basin water quality as affected by operation of air bubblers and chlorination/detention facilities
— consideration of the new fishway's potential success in establishing an American Shad population in the Charles River.

INTRODUCTION

An assessment of the new Charles River Dam was performed during the spring of 1980 by a group of MIT seniors in the Department of Civil Engineering. The objective of our study was to review the new dam and its possible effects as of 1980, taking into consideration the fact that the design of the new dam was completed in 1968. Our goal was to incorporate available new knowledge and to perform a critique of the project. Our study concentrated on five areas of impact by the new dam. These areas are: flood control, recreational navigation, land use, water quality and aquatic life.

The new Charles River Dam will bring about many changes to the surrounding environment. Most of these changes were expected to be beneficial, although how beneficial is not known. The major reason for

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the new dam was to prevent flooding during hurricane events, but several other factors were also considered in the design. These include the need to improve water quality in the basin, the need to improve the passage of boats between the basin and the harbor and the desire to re-establish an American Shad population in the Charles River.

The new dam has been completed and it will be in operation following completion of the new chlorination/detention plant downstream of the present dam. Fig. 1 shows the Charles River Basin and the two dams. Several features included in the new dam will be discussed later in the paper.

The different sections presented in this paper were investigated by individuals and combined to form a technical report [2]. The following are short summaries.

FLOOD CONTROL

When the decision was made in the early 1900's to build the original dam (at the Science Museum, see Fig. 1) across the Charles River, flood prevention was not the main objective. Replacing unsightly low tide mud flats with a fresh water pond, which could be enjoyed by the city residents, was a more important consideration. However, with the elimination of the tidal variation, people began to depend on a stable basin elevation of about 108 MDC. (The MDC datum is 105.6 feet below mean sea level, National Geodetic Vertical Datum of 1929). The design flood for the original dam was computed using the largest flow on record which occurred in 1886. This flow was measured at the Waltham dam and was increased to account for the drainage basin below the Waltham dam. It was observed [14] that maximum flow over the Waltham dam occurred about three days after the start of the storm. This slow reponse to rainfall was assumed to persist downstream to the location of the proposed dam.

The original dam was designed so that a basin elevation below 111 MDC would be maintained in the event of the design flood of 1886 [14]. The hurricanes of 1954 and 1955 resulted in much larger flows than the design flood. As a result of the flooding caused by these storms, it became obvious that the original dam could not prevent recurring damages due to high basin water levels. It was therefore decided to construct a new Charles River Dam at Warren Avenue approximately one-half mile below the original dam. The original dam discharges water through gravity discharge sluices. The result is that during periods of high tide, when the harbor elevation is higher than basin elevation, no water can be discharged from the basin. The new

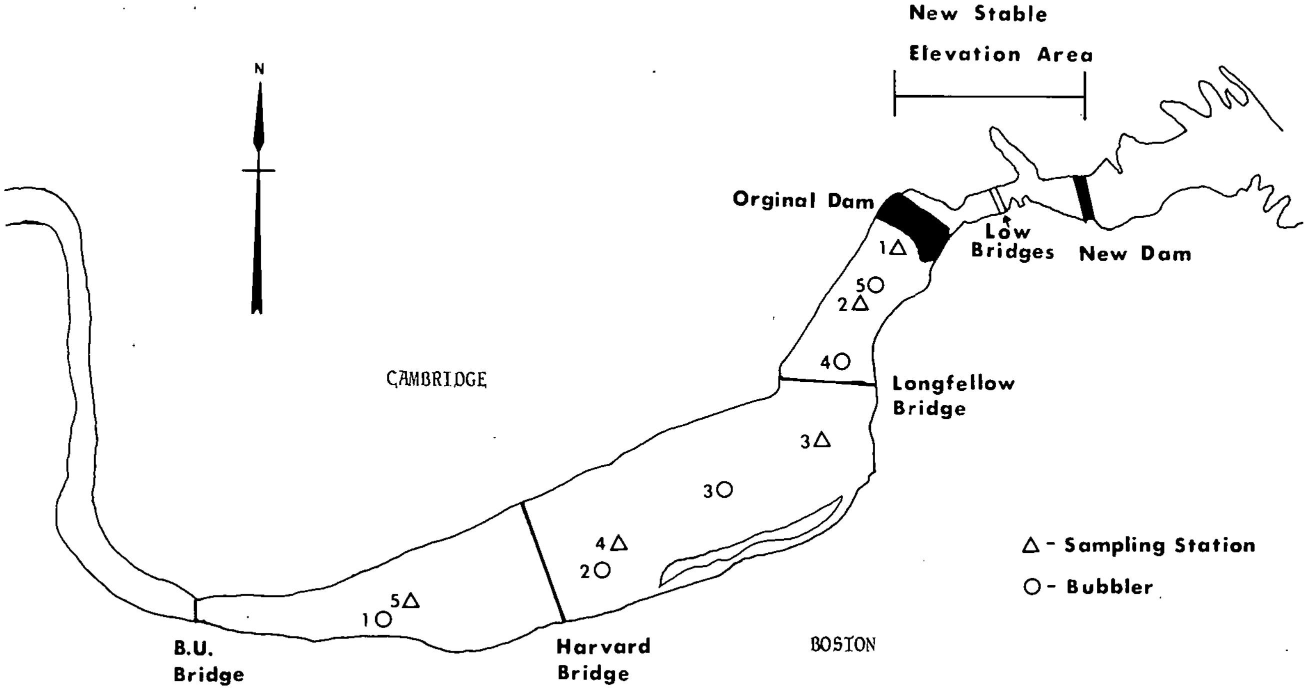

Figure 1: Plan View of Charles River Basin

dam is equipped with a pumping station so that discharge is possible at all harbor elevations.

In this section, the design basis of the new dam is reviewed, an alternate design basis (which uses a unit hydrograph) is presented, a comparison is made between 1910 and 1950 storm response, and a simulation is made of a possible storm event to check the adequacy of the pumping station in the new dam.

New Dam Design

The design flood for the New Charles River Dam had its origin in the August 1955 hurricane. The peak inflow during the storm was estimated to be 12,400 cfs [17]. The shape of the design hydrograph was the same as that of the estimated 1955 hydrograph but design flows were increased by 25%. Thus the design peak inflow was 15,500 cfs. With the design flood and the new dam's pumping and sluicing capabilities, CE Maguire Inc. [6] has estimated a maximum basin elevation of 109.6 MDC, with no resultant flooding.

This design was based on a single past event which could present some problems. To remove individual storm characteristics, we chose to use a unit hydrograph approach. A unit hydrograph was not available for the Charles River so it was necessary to derive one. The unit hydrograph was applied in two ways: (1) as a means to compare basin response in 1910-1920 and 1950-1975, and (2) to simulate response to extreme storms such as the 1955 hurricane. Assumptions made during the derivation include uniform rainfall over the entire Charles River Watershed, a 12-hour rainfall duration, and accurate measurements. To derive the two unit hydrographs, storms with similar total rainfalls, intensities, and durations were selected. Four storms from the 1910-1920 period and their respective hydrographs were transformed into unit hydrographs. This was also done with five storms from the 1950-1975 period. The averages of these unit hydrographs give the unit hydrograph for each period. The computed unit hydrographs are shown in Fig. 2.

From the 1910-1920 unit hydrograph, it is seen that the peak flow, 15,900 cfs, was reached about 11.5 hours after runoff began. This is in disagreement with the assumption of slow response to storms that was made when the original dam was designed. The 1950-1975 unit hydrograph has a peak flow of 12,600 cfs reached 9.5 hours after start of runoff. Comparing the two unit hydrographs provides an indication of how the basin response has changed over time. To determine if this change was significant, we compared it with the variation in the individual storms that were used as our data base. The variation between storms was found to be two to three times larger than the change in unit hydrographs. Therefore, we concluded that no significant change in the hydrologic character of the drainage basin has occurred between the 1910-1920 and 1950-1975 periods.

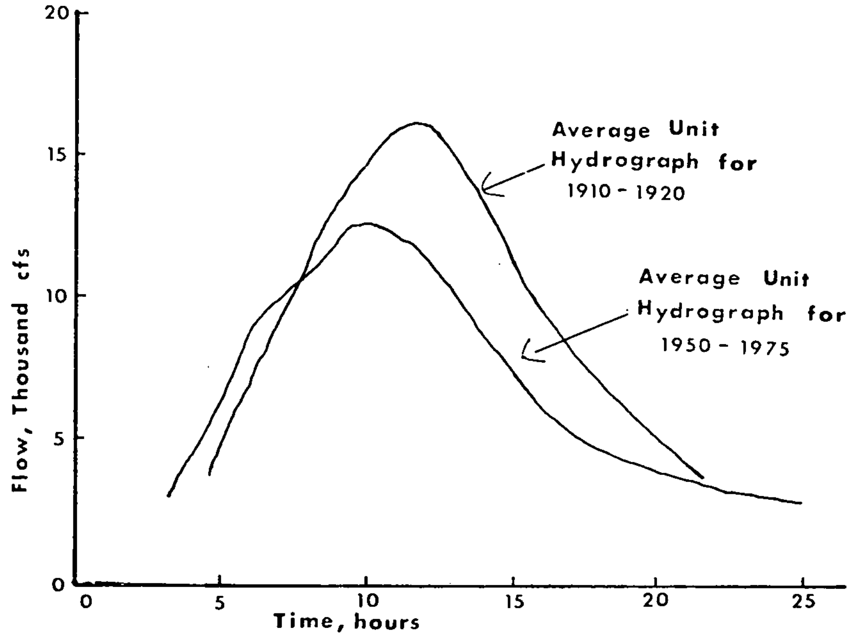

Figure 2: Unit Hydrographs for Charles River

Simulation of an Extreme Storm Event

The isohyetal map of the August 1955 storm is shown in Fig. 3 [1]. The center of the storm was not over the Charles River Watershed but was just west of the Connecticut River. During the three day storm this area received the maximum recorded rainfall of 19.75 inches while the Charles River Watershed received only 12 inches. As a simulation of an equally possible storm, the storm is translated so the maximum daily rainfall, 11.2 inches, occurs over the watershed. The isohyetal line of 16 inches encompasses roughly the same area as the Charles River Watershed. Therefore, the maximum daily rainfall for this region, 9.1 inches, was also used in our simulation. The simulations with 9.1 and

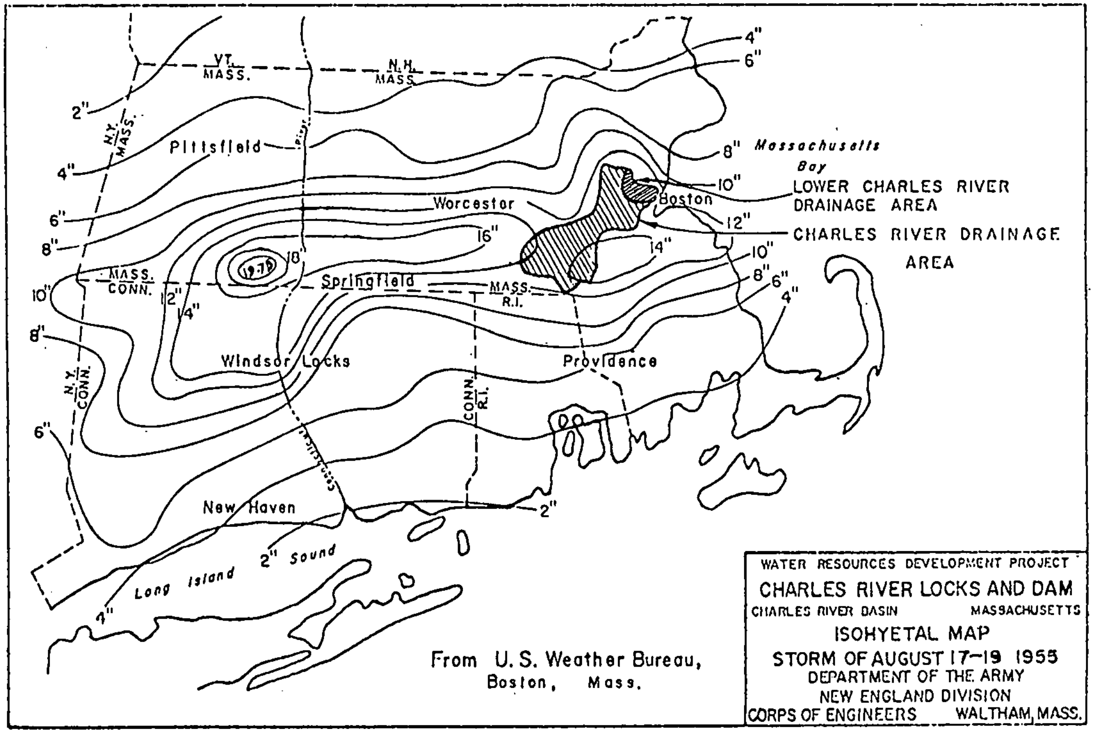

Figure 3: Isohyetal Map of August 1955 Storm [1]

11.2 inches of rainfall resulted in hydrographs with peak inflows of 17,200 and 21,200 cfs respectively. These peak inflows are both greater than the new dam's design peak inflow of 15,500 cfs. To use our unit hydrograph a relationship between rainfall and runoff is needed. This relationship is a runoff coefficient which, when multiplied by total rainfall, gives total runoff. An average runoff coefficient for the 1950-75 period was computed knowing rainfall and resulting from five storms. Using the 1950-1975 unit hydrograph and our average runoff coefficient of .15, the hydrograph corresponding to the translated 1955 storm was computed. Nine sensitivity simulations were then run varying four parameters: rainfall, harbor elevation at peak inflow (high or low tide), beginning basin elevation, and number of pumps. The resulting maximum basin elevations are given in Table 1.

Damage from flooding is estimated to start when basin elevation reaches 110.2 [6]. This elevation was exceeded in 7 of the 9 simulations; the highest elevation was 112.4 MDC, occurring in Run 6. The last simulation (Run 9) used the same worst case condition as Run 6, i.e., 11.2 inches of rain, high tide concurrent with peak flow, and a pre-storm basin elevation of 108 MDC, but with seven pumps instead of the design six. The resulting elevation was only 0.2 ft lower. To determine if the savings from this lower elevation would be greater than the cost of an additional pump requires an economic analysis which was beyond the scope of this paper. In conclusion, we found that the basin's response to storms has not changed significantly since 1910, and, in the event of an extreme storm, the new dam and pumping facilities may not prevent flooding.

TABLE 1. BASIN ELEVATIONS REACHED IN SIMULATIONS (MDC DATUM)

Run	Rainfall	Harbor Elev.	Initial Elev.	#of Pumps	Max. Basin Elev.
1	9.1 in.	113	107	6	110.8
2	9.1	113	108	6	111.3
3	9.1	102.5	107	6	107.7
4	9.1	102.5	108	6	108.1
5	11.2	113	107	6	112.3
6	11.2	113	108	6	112.4
7	11.2	102.5	107	6	110.7
8	11.2	102.5	108	6	111.0
9	11.2	113	108	7	112.2

RECREATIONAL NAVIGATION

Some of the benefits anticipated from the new dam are derived from the enhancement of recreational boating opportunities in the basin and improved navigation between the harbor and the basin. Although the primary purpose of the project is flood prevention, approximately fifteen percent of the estimated monetary benefits of the overall project are expected to accrue to the recreational boating category [1]. In this section we will review the use of the lock at the original dam, consider the expected benefits of the new dam with its three locks, and give recommendations to help alleviate the conflicts between users.

Users and Historical Trends

There are two groups of users of the lock in the original dam: commercial and recreational. The commerical group consists of tugs, barges, scows, and tankers. The recreational vessels are mostly power boats, which either commute from neighboring storage areas or are based in the basin. Other recreational vessels are very common in the basin but seldom use the locking facilities. These are sailboats and rowboats, which will also be affected by the new dam.

Fig. 4 is a plot of the number of recreational and commercial vessels passing through the lock at the old Charles River Dam in the years 1910-1979. Until about 1930, the primary use of the lock was for commercial users. Since then recreational use has dominated and commercial use has dropped to almost zero. These are annual figures but the use is not distributed evenly over the year. It was found that about 64% of the total yearly traffic occurs on about 30 days of the year. These days are the summer weekends and holidays. Along with a yearly variation there is a daily variation in the arrival rate. This variation can be seen in Fig. 5. There are two periods of heavy congestion at the locking facility: 10:00-1:00 and 4:30-7:30. The first period is caused by boats passing out to the harbor and the second is caused by boats returning to the basin. These periods of congestion have resulted in long waiting lines which the new dam was expected to relieve.

Benefits from the New Dam to Boats

The new dam is expected to benefit the boating community in 4 ways: (1) improved water quality, (2) more stable basin elevations, (3) added shoreline within the basin, and (4) time savings.

The poor water quality of the basin has damaged the boating community economically, healthwise, and aesthetically. If water quality can

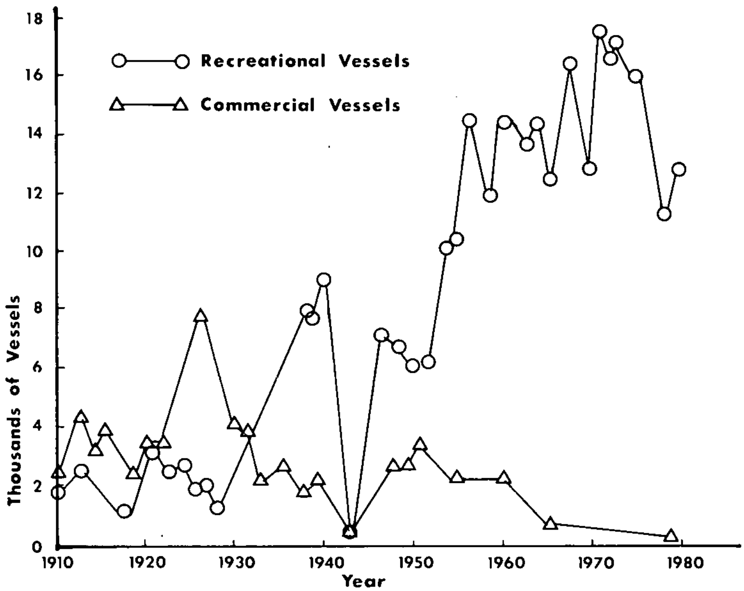

Figure 4: Historical Lock Usage - Annual Average

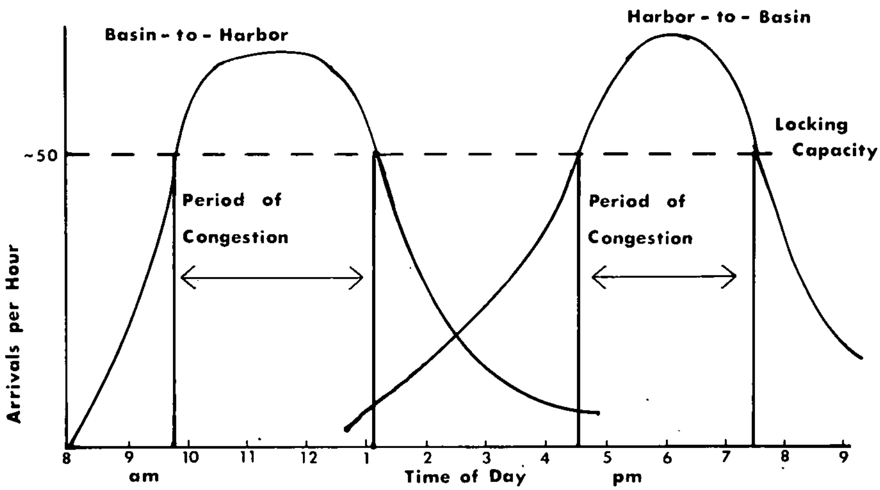

Figure 5: Daily Lock Usage

be improved one can reasonably expect greater recreational use of the basin, everything else being equal. This should benefit all users of the basin.

The new dam should result in a more stable basin elevation. This also will benefit the boating community because problems occur when the elevation varies. Among these problems are: difficulty in boarding and leaving boats at fixed-elevation docks; strained lines in high waters; slack lines in low waters; reduced clearance with high water; and grounding of boats with low water. If recreational boating on the basin is to grow in the future, additional mooring and launching space is needed. Since the new dam is extending the basin, the amount of shoreline is also increased. This is a source for the needed additional space.

The new dam is equipped with locking facilities to handle 140 boats per hour in one direction. There are three locks in the new dam — two 200 x 25 feet and one 300 x 40 feet in plan. The large lock is mainly for commercial use although recreational use may occur during times of heavy traffic. These locks represent an increase of almost three times the old dam's locking facilities. The increase was created to speed up the passage into the Boston Harbor. We considered the expected time savings. Three constrictions were analyzed: the old dam, the drawbridges between the two dams, and the new dam (see Fig. 1). Once the new dam is operational, boats will no longer have to lock through the old dam. A flow constriction will still exist, though, due to the size of the old lock; traffic will be allowed to pass through in only one direction and this could result in a waiting period. A study by Charles A. Maguire and Associates [7] estimated a 15 to 20 minute reduction in the time to pass through the old dam. The new dam and its resultant higher stable basin elevation will hinder passage under the drawbridges between the dams. The stable elevation will average almost 2.5 feet higher than mean sea level. This will cause the drawbridges to be opened more often for boats and thus it will take longer to pass between the dams. Finally, locking through the new dam is necessary. The locking cycle for the small lock is expected to take 20 minutes. An assumption of both small locks operating implies a ten-minute wait. A favorable assumption of a 20-minute reduction at the old dam, no increase due to the drawbridges, and a 10-minute wait at the new dam, gives a net time savings of only ten minutes.

User Conflicts

Conflicts between user groups is not a new problem, but if the groups grow in size, these conflicts become more pressing. To help alleviate conflicts we recommend that powerboat speed limits be reduced and more strictly enforced, and that powerboat facilities be developed in the newly formed part of the basin. Also the Lechmere Canal area could be used for powerboat facilities. New facilities in these lower areas of the basin would reduce the areas of conflict between powerboats and sailboats.

LAND USE

The new dam will extend the Charles River Basin about ½ mile northerly into downtown Boston, Cambridge, and Charlestown. Due to the present lack of flood control and a variety of other factors, these areas are currently underdeveloped. It may be expected that the completion of the new dam will be followed shortly by development of the area. The City of Boston, through the Boston Redevelopment Authority (BRA), has taken the largest role in the development plans. This section will present those plans.

Current Site Conditions

Fig. 6 shows the land adjacent to the newly formed basin area. Most of the large parcels on the Boston side are owned or partially controlled by public agencies. Publicly held land north of the Green Line comprises nearly 70% of the total area. A large area of the affected site is made up of parking lots and railyards; there is a low residential population of approximately 200.

The BRA has a plan for development of the site during the next fifteen years. The latest plan is shown in Fig. 7. Due to monetary constraints, it is expected that in the next three years there will be a slow, momentum-gathering phase. During the rest of the planning period several large construction projects should be carried out. These include a Northbound Storrow Tunnel Connector, a new Canal Channel (which would create an island in the basin), bridges to the island, a public building on the island, and other island buildings. The small size of the existing residential population means that the disruption of their lives will not be a major factor. This is a major difference between the current Charles River shoreline development, and, for example, the West End development of 1957.

The City of Cambridge, which borders the opposite shore, has also conducted a development study for its side of the basin. The plans are, however focused more on the improvement of the Lechmere Canal and adjacent area, and on provision of a linear park along the river's edge.

The benefits from these planned new developments were not included in the original cost-benefit analysis of the new dam. These plans require a stable basin elevation which the new dam will provide and perhaps some of the expected benefits should have been included.

WATER QUALITY

The Charles River Basin has been designated by the Massachusetts Department of Water Pollution Control as a Class C water body, which means "for the uses of protection and propagation of fish, other aquatic life and wildlife; and for secondary contact recreation." At present, however, the water is Class U (unsatisfactory), not meeting any of the existing standards. Two major contributors to the poor quality of the basin water are stratification caused by salt water intrusion, and combined sewer overflows. Both of these problems are being addressed by the Metropolitan District Commission (MDC) in conjunction with the new Charles River Dam, and will be discussed in this section.

Role of Salinity Stratification

Vertical diffusion of oxygen through the water column is necessary to maintain good water quality. Oxygen diffusion is aided by natural mixing processes caused by the wind and by fresh water inflows. However, mixing is hampered by density stratification. Density variation can be dependent upon several factors, but in the Charles River Basin it is almost entirely a function of salt concentration. Density and elevation differences cause salt water to leak into the basin through the various gates in the dam. This type of intrusion occurs throughout the year. Additional salt intrusion occurs through the boat locks, mostly during the summer. Once this higher-density water enters the Basin, it fills the deepest pockets of the river bottom. Vertical diffusion to the fresher upper layers helps to flush the salt, especially during spring flows.

To supplement the natural flushing of salt, a program for bubbling the basin was started in spring of 1978. This program was proposed by Camp, Dresser and McKee (CDM) in 1976 [4]. Fig. 1 shows the five air bubblers which have been placed between the Boston University Bridge and the old dam. Bubbling is designed to reduce the salt mass in the basin and thereby reduce the occurrence of anoxia near the bottom. Measurements (discussed below) of salinity and dissolved oxygen taken by MDC before and after bubbler operation show this to be the case. Operation of the new dam will also lead to a reduction, but not an elimination, of the salt intrusion problem.

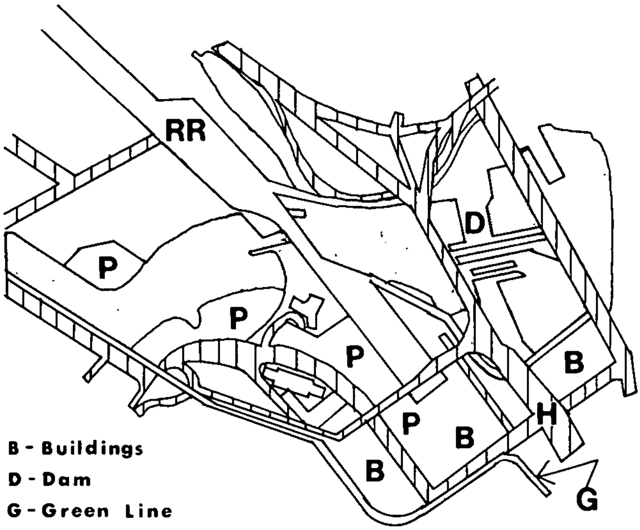

Figure 6: Current Land Use

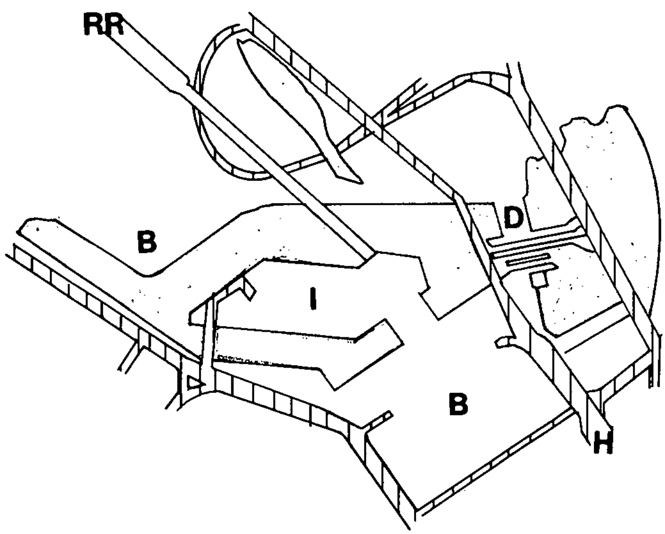

Figure 7: Latest Development Plan

Empirical Results With and Without Bubblers

The MDC has prepared quarterly reports describing measurements of salinity, dissolved oxygen, biochemical oxygen demand (BOD), and phytoplankton production at the stations within the basin, shown in Fig. 1. Fig. 8 compares measured profiles of dissolved oxygen, BOD and salinity taken before bubbler operation (August 18, 1977) and after 1.5 years of bubbler operation (August 9, 1979) as measured at sampling site#2. The profiles in Fig. 8 show that there have been substantial decreases in both the average concentration and the vertical gradients of salinity and BOD since the bubblers have been operational. There has also been an increase in dissolved oxygen concentrations at lower depths while the dissolved oxygen at the surface has decreased slightly. These data clearly indicate improvement in water quality. However, it should be noted that all but one of the sampling sites are located within 100 feet of the bubblers. The one sampling site located 1000 feet away from a bubbler (station#3) shows less improvement than the other stations. The MDC claims that this discrepancy results from the location of bubbler#3 a few feet above a depression, and that the bubbler is unable to mix the deep water in this depression. Since there are no data on water quality at other locations away from the bubblers, it is recommended that such samples be taken to determine whether water quality improvements are occurring throughout the basin, or if improvement is localized around each bubbler.

Measurements (not shown) also indicate that phytoplankton production has remained constant over this period. CDM felt that the mixing caused by the bubblers would circulate phytoplankton out of the euphotic zone, reducing photosynthesis and thus phytoplankton production. Recent studies [16, 19] show that mixing may actually be enhancing phytoplankton growth by reducing photoinhibitory effects of intense light exposure.

Effects of the New Dam on Salinity

The closing of the new dam is expected to have a positive effect on basin water quality through a further decrease in salinity. Several factors can be cited: (1) reduced salinity intrusion through more efficient locking and gate operation (CDM [4] estimates a reduction of about 80% in the annual salt water intrusion with the new dam.), (2) low level pumping and sluicing capability (drawing water from depths of about 20 ft rather than the approximately 5 ft of the existing sluices), (3) a modest increase in basin volume (approximately 3%) and (4) enhanced vertical diffusion due to the decreased salt content. Based on mass bal-

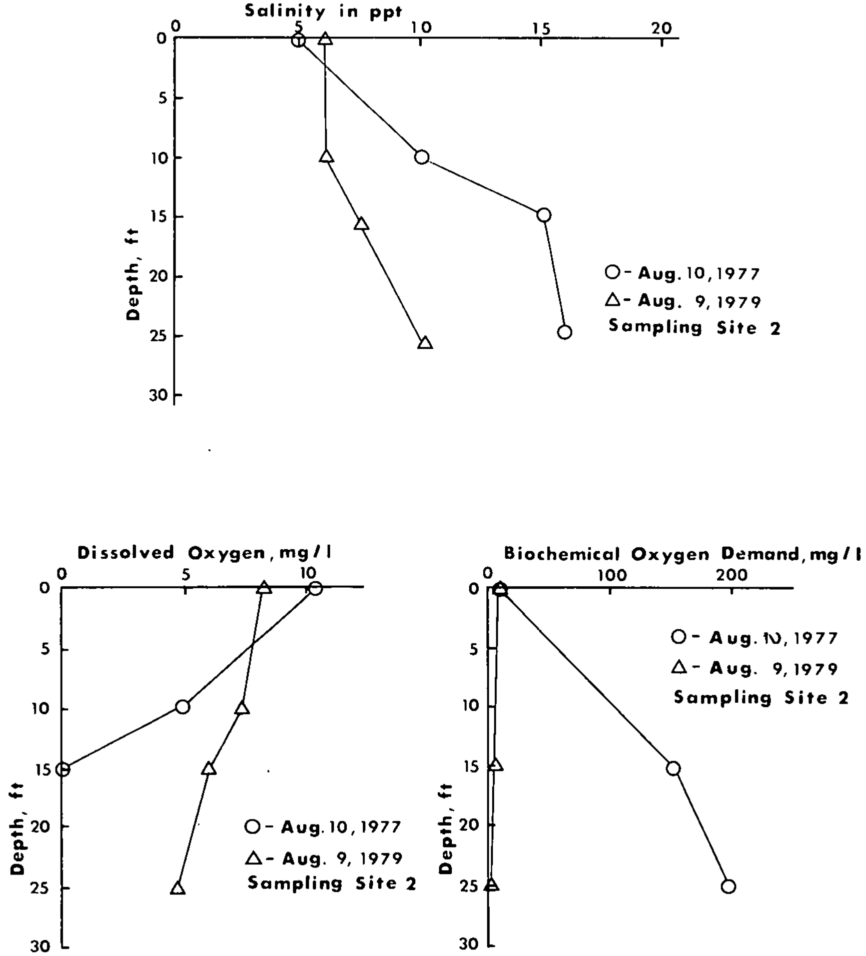

Figure 8: Vertical Profiles of Water Quality Parameters Before and After Bubbler Operation

ance estimates, these combined factors should result in at least a 90% decrease in both the total salt content and the vertical salinity gradient.

To quantify the impact of reduced salinity on water quality parameters such as dissolved oxygen requires a more complete mathematical model including coupled conservation equations representing salinity, dissolved oxygen and BOD. Such an effort is being contemplated as part of another student project. The first step in such an exercise is model verification based on measured profiles for the existing conditions (Fig. 8).

Combined Sewer Overflows

Combined sewer overflows (CSO) occur when rainfall or high tides cause combined sewers to become surcharged and overflow into the Charles River or the inner harbor. The MDC's priorities for treatment of CSO are the removal of floatables and the reduction of coliform bacteria concentrations. One of the efforts involved in combating this problem is the construction of chlorination and detention plants. One of these, Cottage Farm Chlorination and Detention Center, has been in operation since 1971. A similar facility is being constructed in conjunction with the new Charles River Dam. This station, the Charles River Estuary Pollution Control Facility (CREPCF) will collect overflows that are now being discharged into the area between the old and the new dams.

Operation of the CREPCF

The CREPCF will serve as both a pumping station and a chlorination/detention facility. Its total capacity, designed for a 5-year storm, is 323 mgd. The CREPCF has two modes of operation: a dry weather mode and a wet weather mode. In the dry weather mode (inflows of 5 mgd or less) the plant can pump inflows into the Charlestown sewer. When inflows exceed 5 mgd the facility operates in a wet weather mode. Operation during the design peak inflow will cause 44% of the inflow to be pumped into the Charlestown sewer, 50% to be treated at the facility and discharged to the harbor, and 6% of the inflow detained and returned to the sewer system. Treatment of wastewater at the facility consists of screening and chlorination [4]. This treatment has a removal efficiency of 19% for BOD, 23% for suspended solids, and 34% for settleable solids [5]. Coliform removal by the addition of a 15% sodium hypochlorite solution is estimated to be 99.9% [9]. The concentration of chlorine in the effluent will be controlled by a chlorine residual analyzer which will sample total residual chlorine (TRC). The amount of chlorine added to the water during the process will be adjusted so that the residual is 1 mg/l. If the inflow to the plant should exceed 323 mgd, the excess will overflow directly into the Charles.

Assessment of the CREPCF and Recommendation for Improved Efficiency

The top priority of the combined sewer overflow control program has been given to the removal of visual pollution (floatables) and the destruction of coliform bacteria in the overflows entering the Charles River. Second priority is to remove organic material and suspended solids in order to help control the oxygen demand and the benthic deposits in the river.

The CREPCF will be successful in controlling these parameters with respect to the combined sewer overflows which now empty between the two dams. It will also be successful in achieving its aim of providing drainage for the combined sewers that would be continuously surcharged when the basin is maintained at a constant level of 108 feet.

Thus the CREPCF will clearly reduce the level of pollutants discharged into the lower Charles River Basin. This should improve the water quality; however, several questions are raised concerning the proposed mode of operation and the assessment of its impact.

First, in analyzing the CREPCF, the level of bacteria kill has been commonly equated with the total residual chlorine in the effluent. The correlation of TRC and bacterial kill is dubious. Many compounds in wastewater react with chlorine and rob it of its disinfecting capacity [8]. Contact time with chlorine in the CREPCF is to average 8-10 min. when operating at capacity, as compared with recommended minimum contact time for primary treated sewage of 15-45 min. [20]. With these variables to consider, disinfection efficiency cannot be measured by a single parameter such as TRC. Some system of accurate and complete water quality sampling should be used to monitor disinfection level.

Second, it might also be mentioned that chlorination as a means of disinfectant for wastewater is under attack. Carcinogenic chlorinated hydrocarbons are formed by the chlorination of sewage. An alternative to chlorination is to simply discharge the screened wastewater into ocean water. Contact with salt water has been shown to kill 90% of the bacteria within 1-3 hours.

Third, removal efficiencies for BOD, suspended and settleable solids in the wastewater treated at CRECPF could be improved. A cleaner effluent could be achieved by changes in operation. Detention tanks could be used to hold the "first flush", treating and discharging the later flow. This would improve effluent because during low flow, solids are deposited in the sewer system and initial water from a rainstorm picks up these additional solids. It would be advantageous to hold this first flush until it could be returned to the sewer system. Treatment and discharge of succeeding cleaner flows will result in a better quality discharge to the harbor. One problem with this method of operation would be that fewer tanks would be available for chlorination and settling. However, flocculating chemicals could be added to speed up sedimentation, and exposure to sea water could provide disinfection. Another plan would be to flush the sewer during low flow by injecting water. This operation would keep solids from building up in the sewers.

Finally, the concept of chlorination and detention plants as a way of coping with combined sewer overflow might, in fact, be questioned. Possible dangers to aquatic and human life resulting from chlorination have already been mentioned, and while such plants are consistent with the current effort to achieve Class C water, the rise in demand for good water quality, may result in a higher ultimate goal. Perhaps the MDC should consider a higher water quality goal when planning programs for water quality improvements.

AQUATIC LIFE

The new Charles River Dam includes a vertical slot fishway designed to allow passage of anadromous fish past the dam. This fishway was specially designed for the use of American shad, which cannot pass fishladders and locks as easily as other anadromous fish. The MDC hopes to restore shad to the Charles along with alewife and blueback herring, which have already been observed to be migrating in the basin. In assessing this fishway, other factors affecting shad habitation and migration should be considered. In particular, water quality in the basin and the inner harbor could affect shad populations.

Life Cycle of the Shad

American shad are anadromous. They spend the majority of their life in the ocean, ascending fresh water streams to spawn. Fry are hatched upstream in fresh water during the spring and remain there until water temperatures drop in the fall. The juveniles migrate to the ocean where they will remain until reaching sexual maturity (3-5 years). Adult shad complete the cycle by returning to their home stream to spawn [23].

Adult shad have been stocked in the Charles at Mother Brook. These operations were begun in 1978 by the Department of Marine Fisheries.

Reasons for Decline of Shad

Impassable dams are cited as the major reason for the decline of shad along the East Coast [23]. In the Charles, fish ladders are provided as far upstream as the Newton Lower Falls Dam. Fig. 9 shows dams on part of the Charles River and areas with suitable spawning grounds. The water quality levels at these grounds are poor, but will not severely hamper shad development [11].

Poor water quality in the lower Charles River Basin and the inner harbor may affect shad habitation. Shad spawning in the Charles must pass through this area during their migrations. Although levels of individual pollutants are not high enough to cause fish kills, the synergistic effects of the pollutants may place stress on migrating fish.

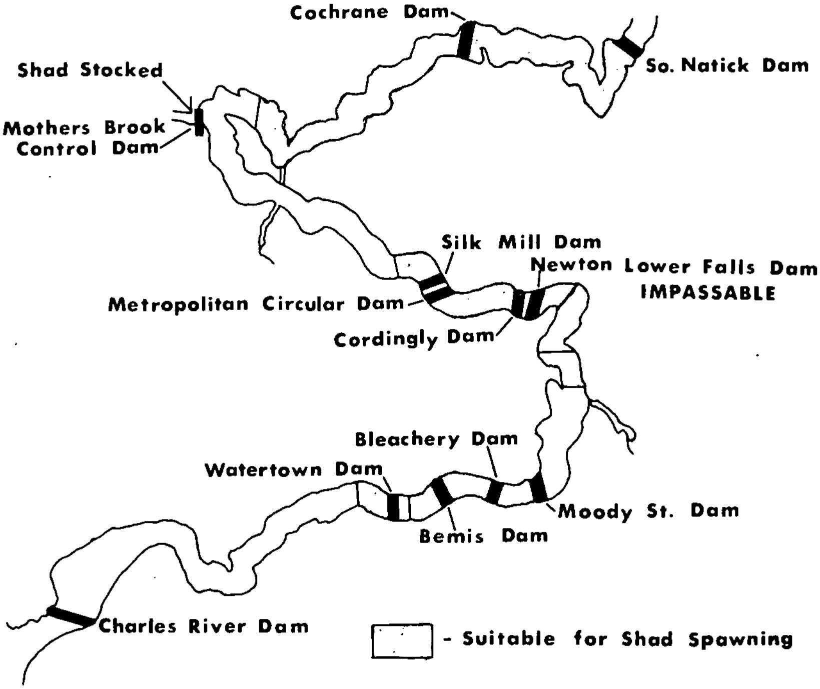

Figure 9: Upstream Dams and Spawning Areas in the Charles River

The largest water quality barrier that shad will encounter is the drastic change in salinity between the inner harbor (20-30 ppt) and the basin (0-5 ppt). In natural (undammed) estuaries, shad spend one or two days in the region of salt water-fresh water interface [12]. The shad meander back and forth with the tide as shown in Fig. 10. This action allows the fish to adjust to the decreased salinity. To pass the new Charles River Dam the shad must undergo a rapid change in salinity. This may cause fish kills or discourage upstream migration. A study by Tagatz [22] showed that a salinity change from 27 ppt to 0 ppt results in 50% mortality of adult shad. In another experiment [18] shad were

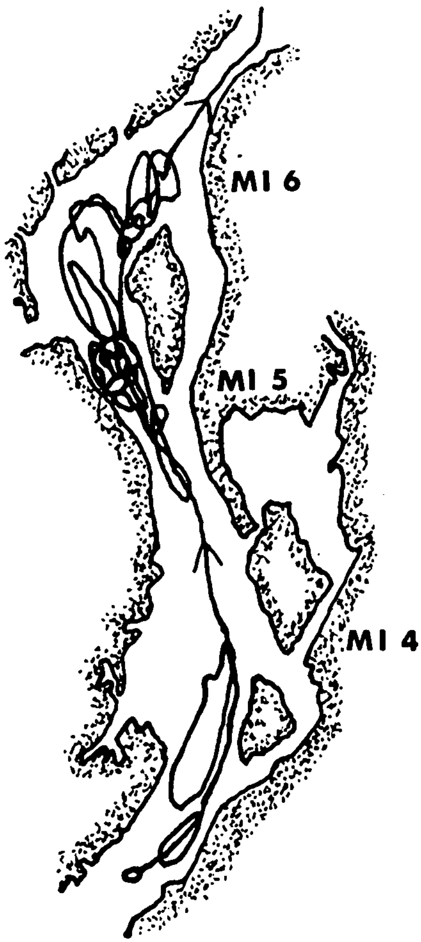

Figure 10: Observed Upstream Migratory Pattern of Shad while Acclimating to Reduced Salinity (after [12])

towed in cages from Long Island Sound up the Connecticut River. This transition took 2.5 hours and the salinity change was 31 ppt to 1 ppt. A control cage was towed in salt water for 5 hours. The result: of the 18 fish experiencing the salinity change 17 died while all fish in the control cage survived. While these experimental methods place significant stress on the fish, they suggest that the abrupt changes in salinity may be a critical inhibition to successful fish migration. We believe that this barrier should be investigated further.

SUMMARY OF CONCLUSIONS

This paper has discussed five impact areas associated with operation of the new Charles River Dam. The conclusions derived for each are summarized below.

Flood control is the major objective of the new dam. Our studies conclude that the basin's response to storms has not changed significantly since 1910 and that the new dam and pumping facilities cannot be expected to prevent all flooding in the event of an extreme storm similar in total rainfall to the 1955 hurricane.

Recreational navigation has been suggested as another major objective. Here, the major benefit is believed to be decreased passage time between basin and inner harbor. However, we found that the time savings will not be significant.

Development of adjacent land was not a stated objective of the new dam, but in fact, new areas can now be developed. Plans have been made for this development.

Water quality is adversely affected at present by salinity intrusion and combined sewer overflow. Data from the MDC indicate that operation of the five air bubblers in the lower Charles River Basin has had a positive effect in reducing salinity and attendant anoxic conditions. Mass balance predictions indicate that further improvement will be possible due to the lower salt intrusion with operation of the new dam. However, it is recommended that sampling be conducted at locations farther from the individual bubblers to verify that the improvement is general rather than local and that additional sampling be conducted in the upper basin. The MDC might also consider operation of one or more bubblers in the upper area. The new chlorination/detention plants should be effective in removing virtually all of the combined sewer overflow between the two dams. However, they could be made more effective by establishing a method to retain the first flush of a storm. This would result in a cleaner effluent into the harbor. Also the use of chlorine as a disinfectant should be carefully reconsidered.

The new fishway in the dam will physically provide for the passage of American shad. However, the shad will have to pass through a very sharp saline gradient which could prove to be detrimental. The poor water quality of the Boston inner harbor and concentrations of pollutants could also prevent a shad population from forming in the Charles River.

ACKNOWLEDGMENTS

This paper resulted from a class project undertaken by ten seniors during their last semester at MIT (Spring 1980). This project resulted in a final report [2] which was then edited into manuscript form by Alice Godbey and Sandy McCarley. Project supervision was provided by Dr. Eric Adams and Professor Donald Harleman.

Appreciation is expressed to a number of individuals who offered assistance in the form of guest lectures, data, critiques, etc. These individuals include: Jekabs Vittands and David Bingham of Metcalf and Eddy, Inc.; Clayton Stokes, superintendent of the Charles River Dam; Frank Notordonato and Richard Doherty of the New England Division, U.S. Army Corps of Engineers; Peter Devenis and Edward Dunn of CE Maguire; and John Bennett of the MIT Writing Program.

Preparation of the final report was facilitated through use of text editing facilities at MIT's Joint Computer Facility, with assistance from Elizabeth Schumacker of the Civil Engineering Department. Financial assistance in the preparation of the paper was provided by the John R. Freeman Fund of the Boston Society of Civil Engineers Section, ASCE. This assistance and the cooperation of Mr. Lee Wolman of the fund committee is gratefully acknowledged. Final typing of the manuscript was performed by Elizabeth Quivey.

We would like to dedicate this paper to the memory of John R. Freeman, Chief Engineer of the 1903 Committee on the Charles River Dam.

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