

Trinity Church

in the City of Boston

The Church Endangered by the Low Level of the Ground Water How the Danger has been Temporarily Averted

TRINITY CHURCH is supported by some forty-five hundred wood piles. Piles remain sound while covered with water. Formerly the tides of the sea filled twice a day the basin of the Charles River and thoroughly saturated the ground in the Back Bay. When the Charles River Dam was built in 1902, it barred out the sea tides but kept the level of the water above the dam at grade 8, that is eight feet above the City Base.

According to the printed contract and specifications, the piles were to be cut off at grade 5½, but while those under the rest of the Church were cut off at this level, the Architect, Mr. Henry H. Richardson, in his Description of the Church, states that the piles under the four main piers of the tower were cut off at grade 5.

When alterations were being carried out in the Parish House in 1924, excavation was made to ascertain the condition of the piles and the few examined were found to be as sound as when driven fifty years before, and the water level in the ground was at about grade 7.

The first inkling that trouble was ahead came when the Public Library found that the stone platform across the front was settling and that its walls were beginning to crack. Examination disclosed that the tops of the piles had seriously decayed and the Library was forced to incur an expense approximating a quarter of a million dollars.

On June 11, 1929, J. R. Worcester & Co., the engineering firm for the Public Library, recommended an examination of the piles under Trinity Church. The Vestry having adjourned for the summer, the Senior Warden, after consultation with Mr. C. A. Coolidge, assumed the responsibility of authorizing the work to be done. Mr. Coolidge engaged Willcutt & Co. to open *two large pits in the basement* of the Church, one by the northwest pier and the other at the junction of the southeast pier and the east wall of the south Transept. The latter one, called the Manhole, and marked *B* on the map, was bricked around, with a hand rail at one end going down to the bottom, so that the condition of the pile heads could always be re-examined. The other one, called the Test Hole, and marked *A*, was filled up after installing a large pipe to enable the water level to be easily ascertained. The cost was about twelve hundred dollars.

These pits showed that the fill under the Church, as far as it was thus disclosed, was of heavy gravel which packed down very hard, and, when saturated with water, effectively retained moisture. This evidence was corroborated later by the outside pit, by the conductor deep trenches, and by the digging in neighboring streets done for the Edison Steam mains.

As to the *nature of the ground* underlying the Church, Mr. Coolidge and Mr. Bulfinch, from records of the Boston Society of Civil Engineers and of the J. R. Worcester Co., and of other engineers who have made borings in this vicinity, believe that below the gravel fill there is, beginning somewhere around 24 feet below the surface, a bed of peat varying in thickness from 9 to 18 feet, of such consistency that water will not find its way through it readily, and below this peat the material in general is clay for an indefinite distance, probably down to bedrock.

The piles under the piers were found to be wet and in sound condition, so hard indeed that even the thrust of a crowbar could make little impression. Fortunately, these piles are imbedded in a concrete mat, eight inches in depth. Capillary attraction keeps the tops of piles, when surrounded by hard-packed gravel, wet for several inches above the level of the ground water, and the concrete mat helps to retain the moisture. The five piles exposed under the Transept wall, cut off half a foot higher and not protected by a concrete mat, showed some slight deterioration for the upper six or eight inches, but not enough, as yet, to impair the sustaining strength of the piles.

At the next meeting of the Vestry, October 3, 1929, the Senior Warden reported what had been done and suggested that there should be a *Committee on Foundations*, and, on the approval of the Vestry, there were appointed as such Committee Mr. Paine, the Senior Warden, as chairman, Mr. Whiteside, the Junior Warden, and Messrs. Coolidge, Cummings, and Parker, who as architects would have special experience in building problems. Mr. Parker died in April, 1930. After the election of Mr. Barbour to the Vestry in December, 1930, he was, at the request of the Senior Warden, added to the Committee.

At a Committee meeting in the office of Mr. Coolidge on November 21, 1929, a representative was present from the engineering firm of Spencer, White & Prentis of New York, who had done considerable underground hydraulic work. It was felt, however, that more data must be secured before any decision could wisely be arrived at concerning structural changes involving thousands of dollars.

The Committee also considered the possibility of installing a *coffer-dam around the Church*, within which the ground water could perhaps be retained at a level high enough to protect the pile heads.

Mr. Coolidge believed that either splined wood sheeting three or four inches thick, or steel sheet piling, could be driven five or six feet into the peat, forming a continuous coffer-dam around the Church and extending up to grade 6, and constituting an effective barrier to retain water within it at the proper level to protect the piling, providing that sufficient water is introduced behind this dam to maintain the level. With normal rainfall the drainage from the roofs might supply the needed water. The logical place for the coffer-dam would be as near to the Church wall as practical and mostly within the grass portion next

the Church, though in some parts it would have to be under the sidewalks. The cost was estimated to be about eighteen thousand dollars.

Test wells, to determine the level of the ground water, have been in use by the City for many years. When City officials were consulted and inquiry made as to the test well tabulations, it was said that the more one learned of them the less one knew. They were too scattered to afford definite conclusions as to any specific problem. Moreover, most of them were north of Boylston Street, and only a few were south of the subway in the vicinity of Copley Square.

When the trouble developed in the walls of the Public Library, several test wells were sunk in the basement of the Library. They showed varying levels, as did our own basement wells. They indicated that the water was somewhere around grade 4.

It was decided to locate *test wells around the Church*. On December 10, 1929, B. F. Smith & Co., under the direction of Mr. F. V. Bulfinch, at a cost of \$240, placed six on the north, east and south sides, two-inch pipes, open at the lower end, with sides perforated for several feet, and driven into the ground some twenty feet. The engineers then ascertained the grade of the top of each separate pipe. When the distance down to the surface of the water in the pipe has been measured and subtracted from this top level, the level of the water in the ground is thereby determined.

Readings of these wells were taken regularly, first to keep posted as to the danger of pile decay due to dryness, and secondly to see if these levels gave any indication as to source of the trouble. The prevailing slope of the water table was found to be from the north to the south side of the Church. Where was the water running to? What was draining it away?

Pending solution as to the cause or some cure for the trouble, experiments were made as to the effect of *filling with water* the manhole, the test hole and other parts of the ground. The water could not be kept at a high level, but tended to fall towards its usual low levels, though some benefit seemed to be gained.

Mr. Harold E. Miller, the sexton of the Church, showed keen interest in making and checking up on these experiments, as he did on all the work connected with the study of the water levels, and he was faithful and indefatigable in taking and deciphering the measurements of the test wells.

In September, 1930, Mr. Eugene M. Jones, taking readings for the Sewer Department, made the suggestion that the rainfall might be turned into the ground rather than be carried off into the city sewers. Engineers state that it is a fact that a pile that is alternately exposed and submerged will last far longer than one from which water has permanently withdrawn. Therefore most of the large *conductors were disconnected* from the sewers, in November, 1930, at a cost of \$737. On the north side they were carried down into long, deep, stone-filled, dry wells along the outside of the Church. On the south side they were carried inside the Church into the basement and were discharged into the manhole, which is near the southeast pier piling, and into a section near the southwest pier. The test wells having indicated a slope of the ground water from north to south, the rain water was carried to the north, that it

might keep moist the vast forest of piles as it percolated towards the south. The rain water was similarly conserved from the Parish House at its west side, and from the Chancel at its north side. From the Western Porch the water had previously been discharged onto the sidewalks—an unhappy disposition from several points of view. Now the conductors were similarly led into dry wells.

When in December, 1930, the piles were examined from the manhole, Mr. Bulfinch, who had superintended the construction of the manhole and the first examination of the piles, gave as his opinion: "I think we may say that there has been practically no further deterioration of the pile heads since the conductor wells were dug. . . I feel that the piles were greatly benefited on this side of the Church by the water from the conductors."

Acknowledgment is gladly made of the helpful services of Mr. Francis V. Bulfinch, an engineering member of Mr. Coolidge's firm, in co-operating with the Committee and giving advice, and in dealing with the Building and Sewer Departments of the City, the Transit Commission, the Boston & Albany R.R., and the architects and owners of neighboring buildings.

July 11, 1930, the Wardens had an interview with Mr. Joseph P. Rourke, the Commissioner of Public Works of the City, and with Mr. Frederick A. Lovejoy of the Sewer Department, to *ask the City to sink more test wells* in the neighborhood of the Church, especially to the east and south and west, as sporadic holes furnish few clues, while two holes, and better still, three in a row, indicate pretty definitely the slope of the water table. The City officials appreciated the situation and agreed to put down more holes.

A map of the territory in the immediate vicinity of Trinity Church will be found on pages 10 and 11. This map shows where the various test wells were driven and the numbers attached to them, and also the location of the nearest sump pumps.

These nine new holes formed important *circumferential outposts* and supplied essential information. No. 43 was located in Dartmouth Street towards Stuart Street; No. 44 in Trinity Place at its juncture with Stanhope Street; No. 45 near Clarendon Street and Stanhope Court; No. 46 on Stuart Street at the corner of Berkeley Street; No. 47 on St. James Avenue at the corner of Berkeley Street; Nos. 50 and 51 in Providence Street at Arlington Street, and still further east at Columbus Avenue; No. 48 in Copley Square in the large triangle at its easterly end, and therefore northwesterly from the Church, and No. 49 in the small triangle west of the Church.

The readings from these wells, which began October 29, 1930, were correlated with the readings from other wells and were a step on the road toward elimination of more distant causes and concentration on the ground more immediately adjacent to the Church. *The problem was complicated*, first, by the pumping under the Public Library in connection with its restoration work, and later, by the pumping for the Professional Arts Building, of which construction was started in the rear of the Copley Square Hotel, and this pumping seemed to lower the hole nearest to it by at least two feet. Later, pumping was necessitated at many different places for the installation of the new Edison Electric Steam Heating System.

Because the City Departments had shown cordial willingness to co-operate in the attempt to find a solution for the low ground-water level, the Wardens and Vestry, on June 24, 1931, sent a *Resolution of Appreciation* to Commissioners Rourke and Roemer and Messrs. Lovejoy and Spillane of the Sewer and Building Departments.

As inquiry was made into the *possible causes of the lowering* of the ground water, emphasis was placed by some authorities on the checking of the flow of the water from the Basin into the Back Bay ground by the *marginal conduit* built in 1905 along the Basin's southern bank. To overcome this obstruction, several connections had been made to carry the Basin water through to the southerly side of the conduit. Possibly these connections had become blocked up. This remedy was still advocated by one engineer as the correct one as late as July, 1933. But this particular difficulty, if it existed, was seen to concern more especially the Back Bay district north of the subway rather than the Copley Square territory; the study of the next cause showed that we could dismiss it from immediate attention.

A second cause studied was the *subway in Boylston Street* which might act as a check to the free flow of ground water into Copley Square. Engineers of the J. R. Worcester Co., employed at the time of its construction, asserted that the soil in which the subway was built was permeable, so that water would percolate under the subway and equalize the level of the water on the two sides. As the water level in Copley Square had been sufficiently high as late as 1924, the subway had not previously interfered with the receipt of enough water to keep up a proper level in the Square, though, possibly, such water had flowed in from other sources. However, now that the water was low in Copley Square, the subway apparently did act as a check to the free flow from the northerly side, for tests showed that the level on the north side was usually from one to two feet higher than on the south side, and this difference marked the change from safety to danger. In 1929, the new Old South Church, on the north side, found that the water stood at grade 6 and that its piles were sound.

The question of *syphons under the subway* was then discussed, but it seemed as if the results might be too localized and be inadequate.

Two other plans were considered for *introducing more water into Copley Square*. Mr. George W. Dakin, City Sewer Department engineer, suggested in August, 1932, a large *conduit from the Basin* to run along Dartmouth or Clarendon Street and discharge into Copley Square. The cost of this might be fifteen to twenty-five thousand dollars. The second plan was to lead back into the Square some of the vast quantity of water pumped out by the subway at its pumping station near Church Street. This will be referred to again when sump pumps are considered.

Meanwhile other studies, such as those based on the introduction of water into the ground under the Church and on the examination of the effect of rainfall, showed that even when admitted *water could not be retained* in any adequate amount. Therefore it seemed wise to postpone attempts to bring in more water until investigations as to the cause of the leakage came to a more satisfactory conclusion.

A third cause for the low water was, possibly, an old *wooden box drain* which had been built many years ago to run from west of Dartmouth Street, by the Public Library, to

Arlington Street, following Providence Street and the passageway in the continuation of that street to the west. It therefore ran under the north Transept of the Church. Engineers pointed an accusing finger at it: though long discontinued, it might nevertheless supply a channel whereby water could be drained away. However, the piles under the Transept walls would have utterly broken it up and closed it. An acquittal was supplied by our test wells. The ground water did not slope towards it. The level at the drain was higher than to the south by St. James Avenue, and the slope of the ground water was also to the west, or from the Church towards Dartmouth Street, whereas the box drain pitched from the west to the east. Therefore the box drain was not the main cause.

Another possible cause was the recent construction of a *deep drain by the Boston & Albany R.R.* to carry off surface water from their tracks near Dartmouth Street. A study of the layout of this drain made its guilt seem improbable. Again the test wells gave a more decisive answer, for the ground water sloped, not towards the railroad, but from the railroad towards St. James Avenue.

It was found that a *sump pump in the Copley Square Hotel* was used to keep out the water that leaked into its lower basement. As this pump was near grade o, it might well draw out much water and reduce the ground level.

Were there *other sump pumps* in our neighborhood? Application was made to the City Building Department. Commissioner Edward W. Roemer arranged to have his inspectors make a survey. In June, 1931, a plan of the territory was furnished by Mr. Michael A. Spillane, the chief inspector, giving the location of some twenty-six pumps, with much data as to the level of installation and capacity for pumping water. What effect did these pumps have? Again resort was had to the test wells, though these were not in every case adequate in number or location to supply definite answers.

The largest pump, of abnormal capacity, was installed in the *subway at Church Street*. Records showed that it pumped out a tremendous quantity of water, possibly 117,000 gallons a day. At the office of the Transit Commission it was held that the pump, being inside the subway, could not have a direct effect in lowering the level of the ground water. Where did this water come from? Could there be leaks through the subway walls? No direct connection between this pump and our Copley Square trouble could be traced, and some intervening test wells were higher. Even though no proof could be adduced that the water came in part from Copley Square, might not an arrangement be made so that some of the water pumped out could be carried by a five-inch pipe inside the subway for the half-mile to Copley Square and there be discharged into the ground? This would help the Public Library, in which the City is financially heavily concerned, as well as Trinity Church. Pending discovery of the cause for the disappearance of the water, and of how it could be stopped, this inquiry was not further pursued.

Some of the other sump pumps seemed to be exonerated by the test wells. For others there were as yet no means of judging. The *Young Women's Christian Association Building*, on the corner of Stuart and Clarendon Streets, had a sump pump that handled ten thousand gallons a day, or three hundred thousand a month. The rainfall may average, perhaps, three

and a half inches a month, and therefore on an acre of ground would give some ninety-five thousand gallons. The ordinary Back Bay block, or, say, between Berkeley and Clarendon Streets, with half the adjoining streets, may contain a bit more than seven acres, but from roofs and paved streets and sidewalks rain water is carried away by surface water drains, so that on only about one-third of the area can rain water sink into the ground. Thus on this ordinary city block there would be in a month less than three hundred thousand gallons of rainfall to sink into the ground, and each month the Young Women's Christian Association Building takes out of the ground more than that amount of water.

For a time it seemed as though these many sump pumps in the vicinity of Copley Square might, in considerable degree, be responsible for lowering the ground water level. What *legal right* had these neighbors to take out this water? What remedies might be resorted to, either in law or equity or under the obligations of civic good-neighborliness? A study of the legal situation was made by Mr. Whiteside and his office. In disposing of its Back Bay lands, the Commonwealth of Massachusetts had inserted in its deeds a restriction stipulating that there should be no cellars below grade 8. Yet many cellars and subbasements had been built at lower levels, and sump pumps were then installed to keep them free from water that seeped or leaked in. The construction of deep cellars, if watertight, would be harmless. It would be the pumping out of the water that they almost necessarily involve that would be objectionable. The Courts, however, have held that there is no common law right to have ground water maintained that does not run in defined streams.

Attempt was then made to ascertain when this low level of the ground water was first observed. In 1924, at the time of the alterations in the Parish House, the water had been found at grade 7. On inquiry it was learned that in 1926, when the University Club was being built, the level of the water was at grade 4, as it was also in 1928, when the Young Women's Christian Association Building was being built.

This radical *dropping of water level*, from 1924 to 1926, would suggest that something had happened in the interval to allow the water to drain away. At a Committee meeting, Dr. Barbour, the Director of the Agassiz Museum at Harvard University, suggested that in 1925 there had been an *earthquake* which had shaken buildings and injured chimneys, and therefore, possibly, had jarred open the joints of sewer pipes.

In January, 1932, the Committee felt that an expert engineer should be engaged to pursue the investigation, follow up the clues disclosed, co-ordinate the accumulated data, and give the benefit of his engineering experience. Several firms were considered. Fortunately the happy choice was made of Mr. X. Henry Goodnough, with whom Mr. Whiteside had had very satisfactory dealings on engineering questions. For many years he had been in the service of the State. He was familiar with the sewer problems of the City and acquainted with the officials. His courteous manner and the authority attaching to his name helped towards the necessary co-operation of the City. His assistant, Mr. Bayard F. Snow, exhibited skill, ingenuity, and perseverance in the analysis of the problem, and to him also the Church is indebted. The total compensation paid Mr. Goodnough for the period from January 13, 1932, to December 21, 1933, was \$2,612.50.

Mr. Goodnough entered with zest on the study of our water problem. He prepared maps showing historically the old marsh conditions, the location of Muddy River and of former creeks. He checked up thoroughly on what had been done by the Committee in trying to eliminate one cause after another, tested the accuracy of the engineers' measurements of the test wells, took readings more frequently, plotted charts and diagrams based on their readings, and advised as to where more wells should be placed. In a report of March 14, 1932, he states that "the indications are that the lowering of the ground water is probably due for the most part to drains in St. James Avenue."

As well No. 6, nearest to St. James Avenue of our eight wells, was generally lowest, it was decided to drive *four more wells* along the Church frontage on St. James Avenue so that we might ascertain whether there was a slope of the water along the Avenue in either direction, and whether there were low pockets at different places. These wells, numbered 7, 8, 9 and 10, were driven in May, 1932, by B. F. Smith & Co., for \$180.

All these new holes gave very low readings, averaging over ten inches lower than the three holes on the north of the Church, with a maximum difference of over a foot. The center hole No. 8 was usually lowest, though hole No. 10, towards the John Hancock Building, was occasionally lower than the others.

In June, 1932, the first contour maps made by Mr. Goodnough covered a rather wide range of territory and showed other very low spots. He conferred with Commissioner Rourke to ask for more test wells, so as to secure much more definite information. However, this was a more general city problem, for between those other low spots and the Church there were intervening wells showing a higher level of water. The Church wanted for its own immediate territory certain additional wells, and the Senior Warden agreed that the Church would pay for them if the City would arrange for their being driven.

In July, 1932, *five more holes* were sunk at strategic points: Number 12 on the other side of St. James Avenue, in the center of the block, or about opposite our low well No. 8, but also on the other side of the sewer; No. 11 to the west in the small triangle west of the Church; No. 15 to the east in St. James Avenue, in the center of the Berkeley-Clarendon Street block; and two to help test the effect of a sump pump—No. 14 on the corner of Stuart and Clarendon Streets, just opposite the Young Women's Christian Association Building, and No. 13 in the passageway back of the Westminster Hotel, and therefore between No. 14 and the holes along St. James Avenue. As these holes were not on our own land, permission had to be obtained from the City, and B. F. Smith & Co. drove them for \$225, which expense the Church paid. The first reading was obtained July 20.

There were now *nine holes along St. James Avenue*. The readings for several weeks adhered to the following formula—low at No. 11, at the western end of these holes, then high; low at No. 12, then high; low at No. 15, and then again higher to the east (though considerably lower than the other highs). At holes Nos. 11 and 12, there were five readings between 2.90 and 3.26, and four readings from 3.47 to 3.67. Evidently there were outlets for the ground water at or near these lowest points. Low No. 15 might be due to the sewer or to a neighboring sump pump. Could further evidence be obtained by more holes to the west and east and to fill in rather wide gaps between existing holes?

The former *sewer in St. James Avenue* had been replaced in 1912 by a new one, of thirty-inch interior diameter. The crown of the sewer, at Trinity Place, is at grade 2.13 and the invert, or bottom, at —0.37.

It was possible that owing to settlement of buildings, or earthquakes, *house sewers* had been broken. While the Edison Electric Company were laying their new steam mains, Mr. Nawn, the contractor for the work, was generous enough to dig more deeply to find out what the level of these connections might be. In front of the Church it was about grade 10, with a slight slope from the building to the center of the street. Obviously broken connections near a house, or the Church, could not, at that level, be guilty of carrying off the ground water.

But these house sewer pipes, when they approach the main sewer trench, drop sharply into the connections with the sewer, through what were called *chimneys*, which enter into the main sewer at the upper sides, or a little below the top. These are the connections which it is suspected may have been jarred or broken open enough to admit water from the surrounding ground. Inside the sewer was found a substantial deposit of sand and sludge—a rather incriminating bit of evidence, as sand is not a natural part of the sewage.

Opposite the Church, there are a number of these house sewer connections. There were five houses where the Westminster Hotel now stands and these old house sewers were in 1912 reconnected with the new sewer. Our suggestion was that the Sewer Department should dig down at some of these connections and ascertain their condition. The Sewer Department has preferred other methods. In September, 1932, Mr. Goodnough reports that the Public Works Department is considering means by which it may discover the points at which the most serious leaks are taking place in the St. James Avenue sewer. On October 10, *uranine* was placed in adjoining ground to see if signs of it could be detected later inside the sewer. Then early in November, the Department constructed, so that it could be pulled through the sewer, a *float with mirrors* reflecting upwards and towards the manhole, so that any stream of water falling from broken connections could be observed. This experiment involved a great deal of intricate detail. No success attended these experiments.

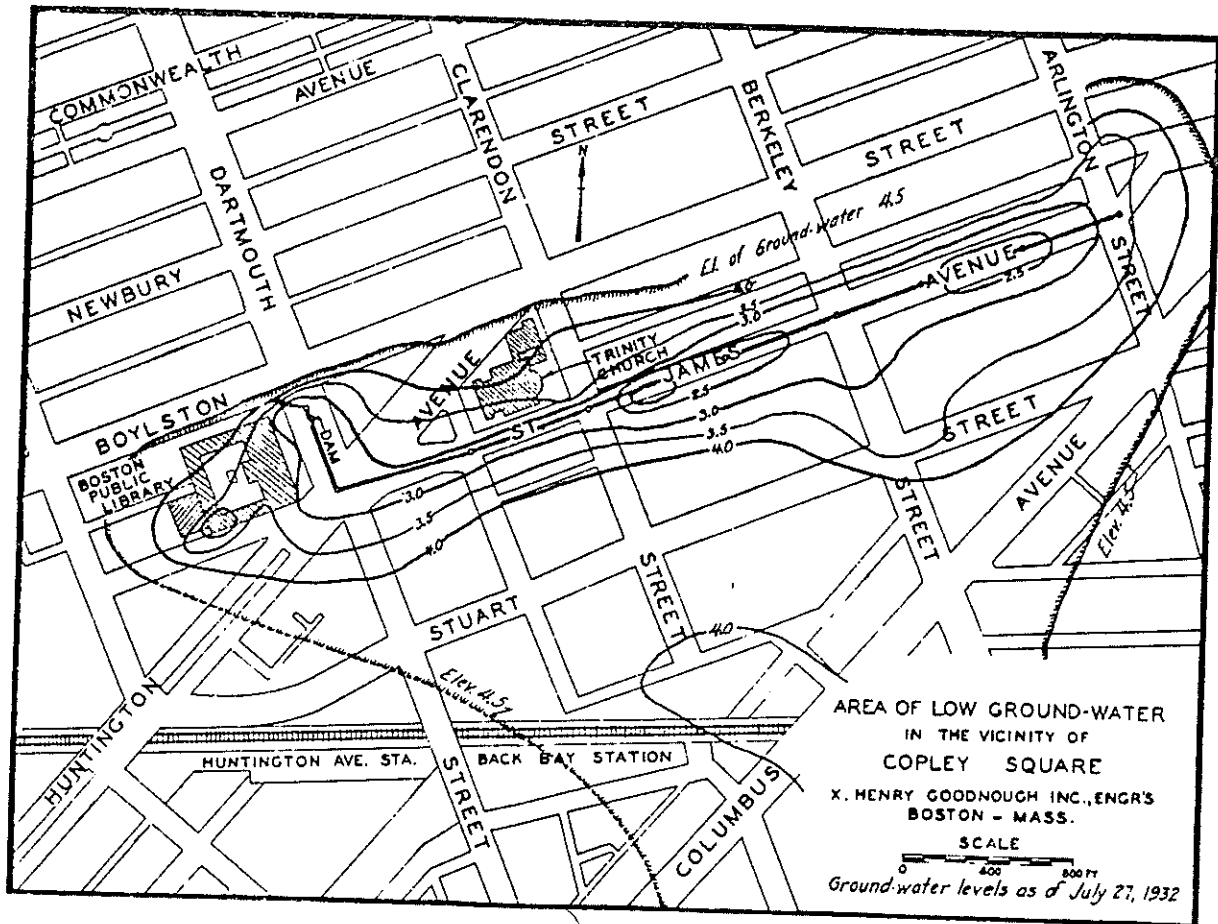
In the same sewer trench is a *surface water drain*, but as the bottom of this drain is at grade 6.47 it can hardly be responsible for carrying off the water below that level.

Our engineers at conferences in August with the City officials arranged for the *driving of seven more wells*: two, Nos. 54 and 55, on the north side of the subway at Berkeley and Dartmouth Streets, and five on St. James Avenue; two—Nos. 56 and 57, further to the west, and two—Nos. 59 and 60, further to the east, and one—No. 58, in a gap between Nos. 10 and 15. These last holes conformed more or less to the existing high-low pattern and extended it along St. James Avenue; but all holes registered dangerously low levels.

August 24, 1932, our engineers, in a report covering the whole problem, stated that "the more we study these ground-waters the more definitely does the low area in this section of the Back Bay seem to follow the *low sewer in St. James Avenue*. . . . We cannot escape the conclusion that the relation of the water contours to the deep sewers is direct evidence of the part played by these sewers in carrying away the water."

They were now enabled, through these many test wells located at strategic points, to set up the picture in tabular, graphic, and contour form. The *Contour Map of Water Levels* was most convincing, showing the lowest level to be along St. James Avenue and Dartmouth Street, and then as you went further and further away the contour lines rose higher and higher.

CONTOUR MAP OF WATER LEVELS



It will be interesting to follow some of the test well readings of an early October day and observe *the prevailing slope of the water*. Start on the north side of the Church and go south towards St. James Avenue:

Hole	No. 2	1	Test	Man	6	8	12
Water level	4.87	4.64	4.60	4.25	3.84	3.70	3.26

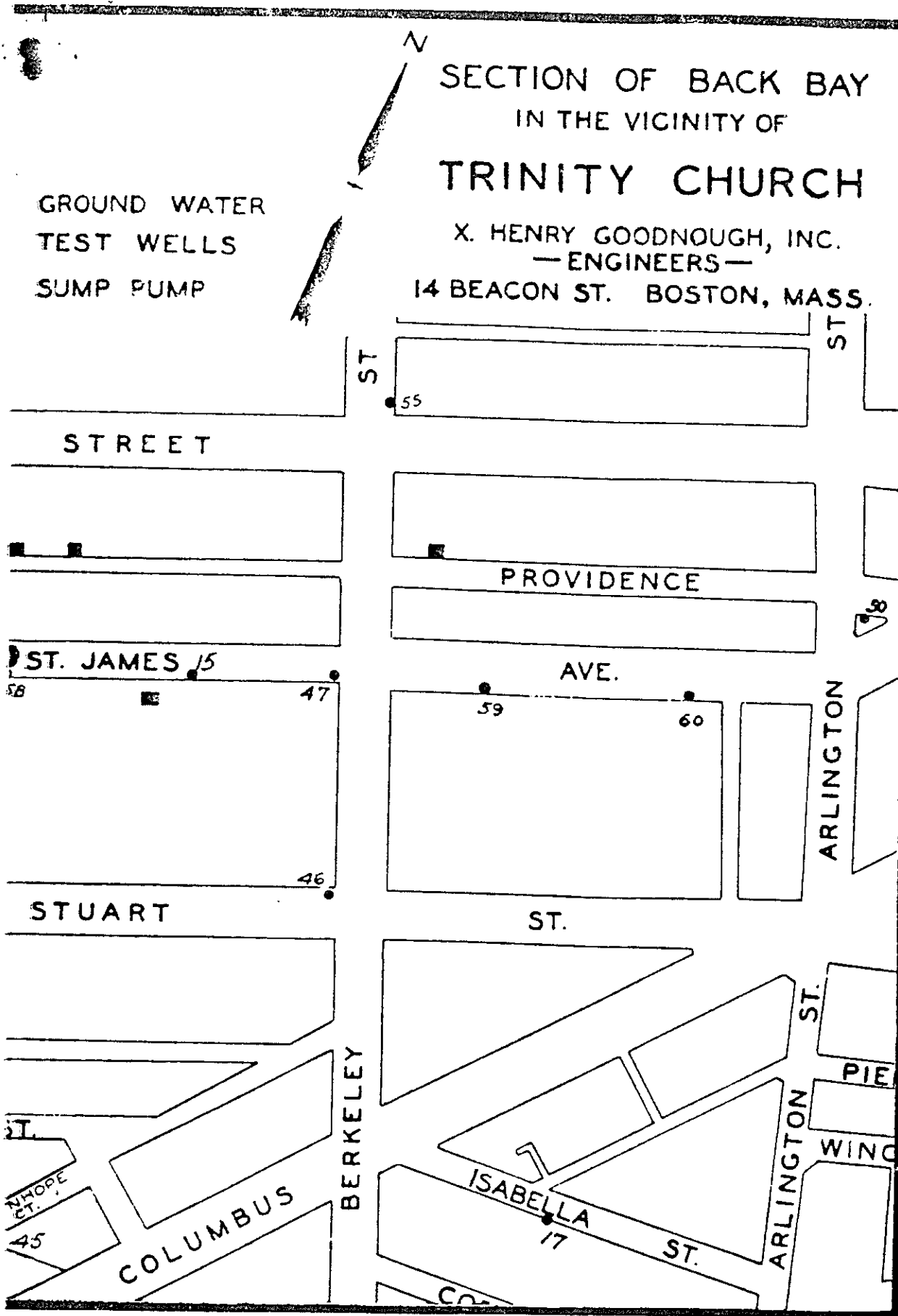
Start on Huntington Avenue near Clarendon Street and go southwest towards the corner of Huntington Avenue and Dartmouth Street:

Hole	No. 3	48	2	1	Test	11	49	41	56
Water level	5.07	5.03	4.87	4.64	4.60	3.51	3.38	3.22	3.03

SECTION OF BACK BAY
IN THE VICINITY OF
TRINITY CHURCH

X. HENRY GOODNOUGH, INC.
— ENGINEERS —
14 BEACON ST. BOSTON, MASS.

GROUND WATER
TEST WELLS
SUMP PUMP



Start on St. James Avenue at Clarendon Street on the Church ground and go to Trinity Place:

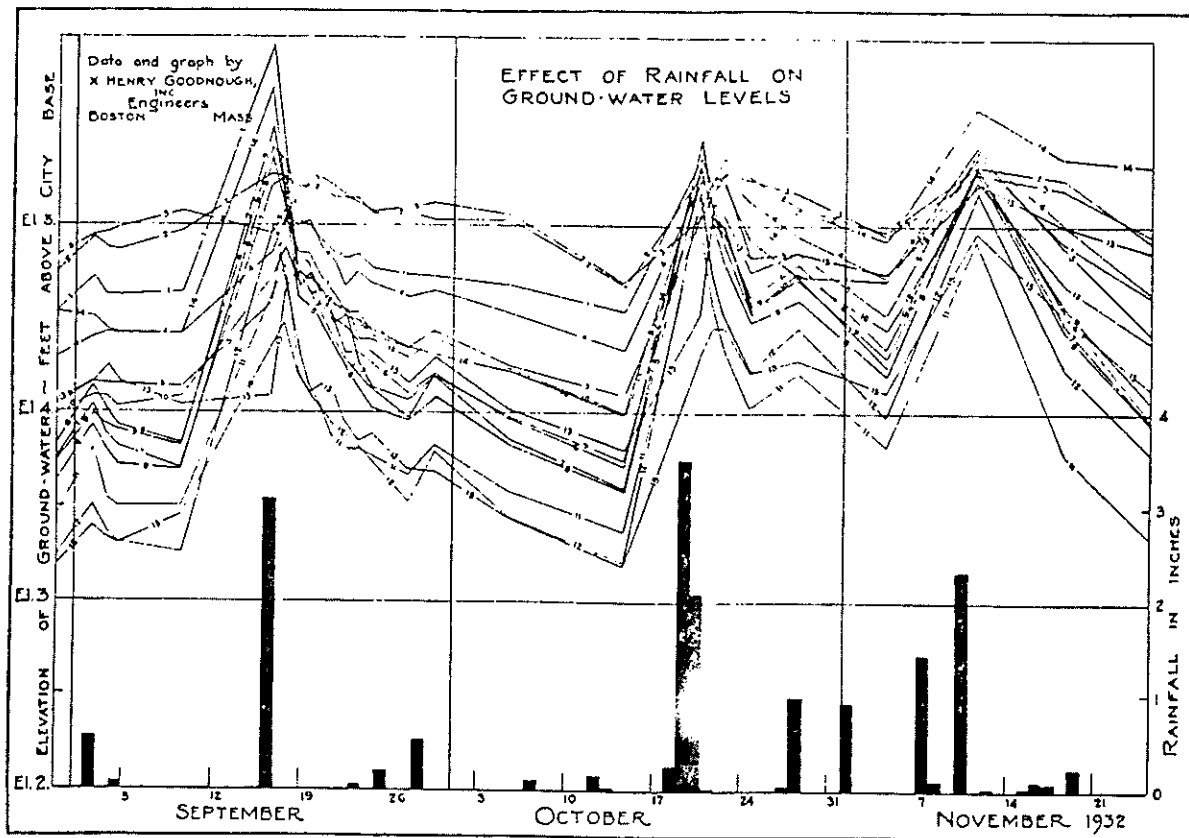
Hole	No. 10	9	8	7	11
Water level	4.09	3.85	3.70	3.70	3.51

Now start again on St. James Avenue, but this time on the south side of the sewer, and begin near Arlington Street and go to Dartmouth Street:

Hole	No. 60	59	47	15	58	12	57	56
Water level	2.98	3.37	3.71	3.46	2.45	3.26	3.26	3.03
	low		high		low	somewhat up		low

It will also be enlightening to glance at a few holes south of St. James Avenue and see that while there is a distinct slope of water, in this case it goes in an opposite direction, or from south to north, but as before towards St. James Avenue. From Stuart Street at the corner of Clarendon Street to St. James Avenue you will find this sequence of holes and water levels: No. 14 at 4.41, No. 13 at 4.04, No. 12 at 3.26.

RAINFALL CHART



The above chart necessarily exhibits only a portion of the whole period studied, and, for the sake of clearness, refers only to the holes nearest to the Church.

One more link in the evidence was set up in a striking diagram showing *the effect of rainfall*. During the summer the drought was broken by heavy downpours which caused the holes to rise in marked degree, but after the rain had ceased the levels began to fall. Those holes which were lowest showed the greatest rise and also were the first to fall. The sewer could not handle or carry away the full rainfall, but naturally, after the rain had ceased, affected first those holes which were nearest to any leaks into it.

There is often a flow of water which finds or makes a *channel alongside a sewer* or water-pipe trench, but in this case the levels to which the different holes dropped seemed to show that the water did not fall as low as the bottom of the trench, but only approached the upper level of the sewer itself. There was also an *under-drain under the sewer* which came in for serious question, but this likewise did not seem to be directly implicated and appeared definitely exonerated by the excavation, referred to later, made by Mr. Baker.

In the summer of 1932, Mr. Snow interviewed or got into communication with many owners of adjoining lands to interest them in the investigation and seek their co-operation in joint assumption of the expense involved. However, now that the sewer was so conclusively pointed to by the evidence, the chief object was to arouse the City Sewer Department to concentrate attention on the sewer until either the sewer was proved guiltless or the trouble was located and cured. Therefore the Committee decided to *call a meeting* of all interested owners and of representatives of the City Sewer and Building Departments. This meeting was held in the Trinity Rectory on October 21, 1932. The Senior Warden presided and explained what the Committee had done, as set forth above, in investigating the various possible sources of trouble, and its method of sinking wells to ascertain the exact slope or drift of the ground water, and called on Mr. Goodnough and Mr. Snow to present their very conclusive charts and diagrams. Mr. Roemer, the Building Commissioner, and Mr. Dakin, the engineer of the Sewer Department, were present and spoke. The Chairman referred to the loss of the beautiful Campanile Tower of the Old South Church on the opposite corner of Copley Square, which had recently been taken down, and asked Commissioner Roemer what he would do as to Trinity if the decay of pile heads caused settlement in the buttress walls supporting the outward thrust of the great tower, which weighed nineteen million pounds, and if, therefore, cracks developed which might jeopardize the safety of the tower, constructed as it is without steel beams to hold it together, and thus imperil the safety of audiences below—would he order the Church closed until the tower were taken down or its cohesive strength in some way restored? A number of the landowners present took part in the discussion.

The meeting was highly successful in its results. The Sewer Department realized the importance of solving the question as to the responsibility of the sewer in lowering the water level. They carried out the investigation by mirrors, mentioned above, and finally, after several conferences between our engineers and theirs, on November 10, 1932, Mr. Lovejoy agreed to try the experiment of raising the level of the sewage in the sewer, and hit upon the ingenious method of installing a *dam in the sewer* whereby the sewage level could be kept at a certain height. This dam was located in Dartmouth Street, some sixty feet south from Boylston Street. The main sewer was broken into and a chamber constructed with a

dam across it, rising to the level of grade 4, with a large opening through the dam to be closed by a gate, controlled from a surface manhole, which would allow of occasional necessary flushing. The sewage, flowing over the dam, would probably rise to a level of 4.25 or 4.50 or more, and, if necessary, the dam could be further increased in height.

The sewer was found to be of splendid construction, solid as a rock. Therefore there are probably no cracks in the sewer itself. The *under drain*, under the sewer, of open-joint construction, was found by Mr. Baker, the contractor, to allow of a free flow of water into the deep opening for the dam chamber, when his three pumps lowered the water well below grade zero so as to permit of proper construction. There appeared to be no indications of any other water channel alongside the sewer. Mr. Baker's excavation went down to a bed of virgin clay, two and a half feet in thickness, lying below the level of the sewer, and water bubbled freely when this bed was pierced. Mr. Baker's pumping, of probably over a million gallons of water, with water running into his deep excavation through the under drain, caused the water level to fall sharply in the test wells, and in some of them near the sewer to drop below the bottom of the well, or below grade 2. As the ground-water level, under normal conditions, may approach grade 3, or slightly lower, which is about the level of the main sewer, but never falls, unless it might be from abnormal pumping, to zero or to minus 2, which may be the level of the under drain, it would seem clear that the under drain is not the chief cause of carrying off the ground water. Sewage is pumped out of the sewer, but there is no pumping out of any water from the under drain, so that the under drain could not carry water away unless there were somewhere a very deep outlet, of which none is known.

Mr. Baker's pumping continued from December 22 to December 31, 1932, while the new dam and gate neared completion. Then a dramatic incident occurred. Sunday morning, January 1, 1933, the *Herald* printed an interesting article on "Back Bay Area Going Dry—Engineers Mystified," and in it said that the Commissioner of the Public Works Department, "Mr. Rourke, with records of five decades at his disposal, absolves the sewer from blame."

The gate in the *dam was closed* on Thursday afternoon, January 5. Immediately the water level in the holes near the sewer began to rise, the effect extending back at least as far as Berkeley Street. Friday morning the gate was opened to permit of machinery adjustment, and the water levels gave an immediate response and started to fall. Then in the afternoon the gate was again closed, to remain so for some time; and, again, the water levels answered as predicted and rose. In view of this crucial experiment, test well readings were being taken frequently, even hourly. The analysis of these readings enabled the drawing of another remarkable contour chart. The holes on either side of the sewer and nearest to it were connected by a line showing a rise of a foot and a half, further away appeared the line indicating where the holes had risen one foot, and still further away was the next line joining the holes where the rise was one-half a foot. Though absolved on Sunday morning, by Friday afternoon *the sewer was proved guilty* beyond dispute. The effect of stopping the draining off of the water was what might have been expected—the very low holes along St. James Avenue rose, so that all the holes began to approximate a common level. The holes

on the south side of the Church started to rise, until, with a heavy rainfall on January 9, the difference between the north and south sides was cut more than in half, or to about three inches by January 31, and then tended to lessen still further into what might almost be called a pond-like level of the water under the whole Church, a condition which had not been observed for many an anxious month.

Great was the relief among the authorities of the Church, but they were not deceived by what must be admitted to be in the nature of a temporary expedient, and still sought to have the sewer itself, or rather its soil pipe or chimney connections, made tight. Readings of the wells continued to be made at regular intervals, that we might keep posted as to just what was happening underground. In general the level continued slowly to rise and to remain at a more satisfactorily high figure. Rainfalls had a more marked effect in raising the level and the higher level did not thereafter fall so rapidly.

After some weeks a *sharp drop* was noticed in the readings. On inquiry of Mr. Lovejoy at City Hall, he made an investigation and found that the gate in the sewer dam had inadvertently not been closed quite tight. A second and similar incident happened later in the spring. Then further trouble developed. One or two business places complained at City Hall that sewage backed up in their soil pipes. Our engineers learned that on May 11 the Commissioner had issued an order that the gate in the dam should be kept open practically all the time. Readings were thereupon made at frequent intervals, and showed the level of the water to be receding towards earlier dangerous low levels. Again a chart showed conclusively the responsibility of the sewer. Our engineers had a conference with Commissioner Rourke and thoroughly explained the situation, and also pointed out that the complainants had their basements and toilet fixtures at improperly low levels, and had had trouble prior to the closing of the gate on January 5. The Commissioner revoked the order.

These experiences emphasize how unsatisfactory and unsafe is reliance on the sewer dam, and that it is *not a permanent solution*. It must not be regarded as, or be admitted to be, a permanent solution. The raising of the level of the sewage is certain to cause continued and possibly increasing annoyance, and may involve more frequent and more difficult flushing out of the main sewer, and will require continual care and supervision. It is now proved that there are openings or leaks into the sewer. If ground water can run into the sewer, then when the sewage is continually backed up, may it not equally seep back through those same openings into the surrounding ground? If ground water runs into the sewer, must not this vast extra volume interfere seriously with the ability of the limited thirty-inch pipe to handle easily and expeditiously the sewage, which may increase in volume in coming years? The cost of permanent repair would not be excessive. The sewer itself is apparently sound. There would be no sewer construction. Digging would be required only to about the top of the sewer, and conceivably only where sewer connections exist. A few thousand dollars would suffice and should not be weighed in the balance compared with the vast damage that may ensue as a result of the sewer's draining off the water in the ground. Indeed, now that it is proved that the City's sewer is responsible, may not the City be liable for damages that may thereby result? It seems inconceivable that the Sewer Department

should be unwilling even to dig a hundred-dollar test pit. The sewer should be made tight from Arlington Street along St. James Avenue and Dartmouth Street to Boylston Street.

At their meeting on March 13, 1933, the Vestry unanimously passed the following vote:

THE WARDENS AND VESTRY OF TRINITY CHURCH

desire to place on record their appreciation of the helpfulness of

X. HENRY GOODNOUGH

in ascertaining the cause of the low level of the ground water.

When he was engaged in January 1932, the water had been dangerously low in parts of the Back Bay and no one knew the cause. Largely through his investigation and analysis, other possible causes were eliminated, he diagnosed the source of the trouble, and by the installation of a dam in the St. James Avenue sewer the level of the water in the ground has been raised and controlled.

We wish to include with Mr. Goodnough his associate

BAYARD F. SNOW

and we hereby instruct the Clerk of the Vestry to extend to them our very grateful thanks.

In the spring of 1932, the Trustees of the Public Library, disturbed by the fact that the low level of the ground water might be endangering still more of their piles and cause further heavy expense, laid the problem before the Mayor. He asked the *Institute of Technology to appoint a committee*, with assisting experts, to study the problem; and put at their disposal the sum of five thousand dollars. When, on September 13, Mr. Snow interviewed Messrs. Henry and Everett Morss, as owners of neighboring property, Mr. Everett Morss, Treasurer of the Institute of Technology, stated that a Technology Committee had been appointed in August—of Professor C. L. Norton, Chairman, and Messrs. C. M. Spofford and R. F. Tucker, but so far as he knew the Committee had not yet met.

Mr. Morss and Professor Norton were invited to the Rectory meeting and were present. Professor Norton had several conferences with our engineers, who, with the consent of the Senior Warden, agreed to put at the disposal of the Technology Committee all the data and studies and memoranda accumulated in the course of our investigation.

Later it was suggested to Professor Norton that our engineers might well be employed by them to help in what Professor Norton had said was their broad field, an investigation into the conditions of the whole Back Bay.

Considerable correspondence passed between the Senior Warden and Mr. Everett Morss, who, on January 3, 1933, admitted that "your meeting (at the Rectory) certainly stirred the matter up and much has happened since." The Technology representatives at that Rectory meeting, after hearing the full story, leading to the accusation of the sewer, had expressed their doubt as to whether there was yet sufficient evidence to convict the sewer, but stated that they expected to have their own report ready by the middle of January.

After the installation of the dam, Mr. Morss wrote, on January 9, that the delay on our part is with the approval of our direct client, the Boston Public Library. On February 23, he wrote that the report was going that day to the Director of the Public Library, the gist of the report being "that the construction of the gate in the low level sewer near the corner of Boylston and Clarendon (*i.e.* Dartmouth) Streets has apparently stopped the principal trouble, and that the water level is now such that no further rotting of the piles should take place" and added: "I only hope that the problem is permanently solved. If so, you can take personal credit for having rendered a service to the City, because the building of the gate is due to the agitation which you stirred up."

The Senior Warden replied by marshaling the evidence to show that the dam could hardly be regarded as a permanent cure and pointed out that the final conclusion should be that the sewer should be made tight. Mr. Morss answered that "the information in your letter is extremely interesting and was immediately sent to the Technology Committee." Mr. Morss died in December, and we have had no further communication from the Technology Committee.

As the ground water under the Church had sloped from north to south and somewhat to the west, the Committee felt that the most exposed piles were probably at the southwest corner of the south Transept. Accordingly, just outside of the foundations, *an outside test pit* was opened in December, 1932, by the Sawyer Construction Co. under the direction of Mr. Bulfinch, at a cost of two hundred and fifty dollars, and so constructed with two-inch plank sheeting that examination can be made in the future. The piles were found wet and in sound condition, though the water was about six inches below the top of the piles.

The engineers tested the *level of the pile heads* by running a surveyor's level from the Bench Mark on the Copley Plaza Hotel and found the level to be at grade 4.20. Then a retest was made of the piles exposed in the manhole. Those under the east wall of the Transept registered grade 4.59, while those under the pier registered grade 4.17, and the lower edge of the eight-inch concrete mat would therefore be at grade 3.50. The piles under the pier appeared sound, but those under the Transept wall showed some signs of decay to a depth of about three-quarters of an inch, and rather more than that at the top of the pile.

Aspinwall & Lincoln have found that there has been an *indicated settlement of the ground* of some three inches from 1910, when they first ran precise levels from the solid ground of Park Street to Copley Square, down to about 1924. Back Bay streets are supposed to have settled about a foot.

In 1917, the Senior Warden, then being the Treasurer and Clerk of the Church, had discovered more than *a dozen cracks*, chiefly on the north wall of the Nave and the north and west walls of the north Transept. Some of these cracks extended upwards for twenty or thirty feet, and two or three of the large brown Longmeadow stones had been broken. This undoubtedly indicated some settlement and strain. Wentworth & Co. were employed to fill and repoint the joints. None of these cracks have reopened in any serious way, though one or two have disclosed minute fissures. Upon the suggestion of Mr. Coolidge, the firm of Aspinwall & Lincoln was engaged, as Engineers, to take the elevations of all important points in the foundations of the Church; and this survey was repeated in 1924.

In order to ascertain just how the Church stood, the Committee decided, with the approval of the Vestry, March 13, 1933, to employ Mr. William S. Crocker, the successor to Aspinwall & Lincoln, at a cost of seventy-five dollars, to take the necessary *elevations*, and thus be enabled to compare them with those taken in 1924 and in 1918.

A study showed that there had been a *continuing fall for the outside walls*, but with the settlement in the period from 1924 to 1933 less than one-half that in the first period from 1918 to 1924. The first period showed an average drop of .058 foot; and the second period a drop of .022 foot, or .264 inches, that is about a quarter of an inch. It was gratifying to learn that the settlement in the last period had been, apparently, exactly the same on the north and south sides of the Church, for the averages of the seven measurements on each of the sides gave the same result .022 foot.

The four great piers had each settled at about the same rate during the first period. The measurements on the different sides of each pier, with an average settlement of .03025 foot, and a maximum variation of only .00725, showed that the piers had settled almost equally on every side and therefore had not impaired their bearing support, though the northeast pier showed a very slight inclination of .010 towards the north. In the second period, while the two north piers settled only .0215, or less than during the first period, the two south piers settled at a little faster rate than in the earlier period, or by .0325, and a curious divergence in the trend of settlement appeared. The northeast pier showed an increased settlement on the north side over the south side of .024, while the two southerly piers showed an excess on the south side over the north side of .039 for the southeast pier and .012 for the southwest pier, while the northwest pier showed an inappreciable slope towards the west of .003. These measurements deal with such infinitesimal fractions that slight errors may not be unlikely, but if they show any prevailing drift, it may well be that the drift is fairly indicated, even though the exact measurement may be open to doubt. In general it may be said that a very slight centrifugal tendency is shown in the slope of the piers. The danger in such a tendency would seem to be largely negated by the fact that the buttress walls of the Transept, the Nave and the Chancel do not show any dangerous settlement and in general a settlement less than that of their nearest piers.

Measurements were carefully made of the *water table course*. Fifteen places on the north and south sides show that the south side is on the average lower than the north side by one and one-quarter inches.

If the piles under the piers were originally cut off at grade 5 and now register for the southeast pier grade 4.17, there would be a *settlement of .83 of a foot*, or ten inches, to account for. Engineers' measurements indicate a settlement for the four piers as a whole for the last nine years of .027 of a foot, one-third of an inch, and for the previous six years of .03025 of a foot, in all .05725 of a foot, or of .687 of an inch or seven-tenths of an inch. If only the same rate of settlement had obtained for the previous forty-five years as for the last fifteen years, then there would have been an additional settlement of 2.061 inches, or in all the sixty years of 2.748 inches. It is probable that the rate of settlement was higher in the earlier period than in the later, so that a total settlement of ten inches is not beyond the bounds of reasonable

calculation. It may be hoped that a diminishing rate of settlement may now be approaching a comparative stability. This indicated settlement of ten inches may well have been an important factor during these last years of a lowered ground-water level in keeping the pile heads moist and free from decay.

The above story has been set forth to explain what has been found out, and what has been done, in the hope that thus it may be easier to present our plea for a final and complete solution, and win the compliance of the authorities of the City in carrying out this necessary work.

April, 1935.

ROBERT TREAT PAINE.