The engineers responsible for invention and mechanization in agriculture, manufacturing, and transportation are prominent historical figures, but few people are aware of the men who pioneered the sanitation systems so crucial to urbanization. As cities grew, their initial approaches to waste disposal and water supply proved unacceptable. As early as 1798 Benjamin Latrobe noted in his journal that the fresh groundwater which located the site of Philadelphia was befouled by the city's increasing population concentration. In Latrobe's opinion, Philadelphia's existing water-supply strategy was a major source of disease. Even before he assumed the responsibility for the city's new waterworks, Latrobe was convinced of the project's utility: "The great scheme of bringing the water of the Schuylkill to Philadelphia to supply the city is now become an object of immense importance, . . . though it is at present neglected from a failure of funds. The evil, however, which it is intended collaterally to correct is so serious and of such magnitude as to call loudly upon all who are inhabitants of Philadelphia for their utmost exertions to complete it."1

The emerging concentrations of population and manufacturing in the 19th century necessitated a reexamination of sanitation strategies. With urbanization, the haphazard approaches of the past could not guarantee pure water supplies and adequate waste disposal. Urban growth inevitably required the implementation of sanitation systems, and these systems, in turn, permitted further growth.

Students of Chicago's formative decades inevitably encounter the name of Ellis Sylvester Chesbrough; by studying Chesbrough, a student can focus on the truly unique character and contribution of Chicago's sanitation system. Chesbrough's works were the innovations most responsible for Chicago's unrestricted urban growth; they freed the city from the limitations imposed by an unfavorable

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natural topography. A flat, nonporous terrain, slightly elevated from Lake Michigan and the Chicago River, made drainage and absorption nearly impossible. In rainy weather, the topsoil became swamp-like. Urban growth required a drainage system which could remove both surface water and household wastes. The natural depository for such a drainage system was Lake Michigan; however, the lake was simultaneously the city's natural water-supply source. Lake water had to be conserved if it was to be potable, and this meant it had to be protected from urban wastes. Fortunately, beginning in the 1850s, Chicago's city fathers recognized pollution as a serious threat to the city's health and took immediate action. This paper investigates how Chesbrough responded to Chicago's anomalous water-supply and waste-disposal needs in the 1850s and 1860s, and inquires into his engineering education to discover the antecedents of his innovative ideas.

I

Ellis Sylvester Chesbrough was born of Puritan ancestry in Baltimore County, Maryland, in July 1813. An unsuccessful business venture exhausted the family's means and suspended young Sylvester's education, and so, at nine years of age, he went to work. Between his ninth and fifteenth birthdays Chesbrough spent only a year in a classroom, but he did find time outside his countinghouse duties to pursue his studies. Chesbrough acquired most of his basic education without the benefit of formal training or a regular teacher, and the same was true of his engineering education.

In 1828 Chesbrough's father took a job with a railroad engineering company employed by the Baltimore and Ohio Railroad Company. Through the father's influence, the son gained employment as a chainman with a similar company engaged in preliminary surveying work in and about Baltimore.² Chesbrough's company was under Lt. Joshua Barney, U.S. Army, and most of the engineers were army officers, many of them graduates of the U.S. Military Academy's practical, as opposed to theoretical, engineering course.³ Chesbrough was fortunate in being affiliated with several of the

²The engineering education of E. S. Chesbrough began in this company, and he quickly proved an apt student. See Biographical Sketches of the Leading Men of Chicago, written by the Best Talent of the Northwest (Chicago, 1868), p. 192; see also Journal of the American Society of Civil Engineers 15 (November 1889): 161.

army's most prominent engineers. In 1830-31 he worked as an assistant engineer to Col. Stephen H. Long. Near the end of 1831, Chesbrough joined the engineering corps of Capt. William Gibbs McNeill, where he served immediately under Lt. George W. Whistler.

The Panic of 1837 and the resulting depression dealt a hard blow to the country's internal improvement's bubble, and Chesbrough, like many other engineers, found himself out of work as the flow of funds dried up in the early 1840s. He went to his father's residence in Providence, Rhode Island, where, during the winter of 1842, he spent his leisure time in the workshop of a nearby railroad learning the practical use of tools. The following year he purchased a farm adjacent to one owned by his father in Niagara County, New York. His venture into farming was mercifully brief; after an unsuccessful year, Chesbrough gladly returned to engineering.

In 1846 Chesbrough was offered the position of chief engineer on the Boston Water Works' West Division. This position completed his engineering education. Up to this time, all his experience was related to railroad engineering, and he had mastered many civil engineering essentials, such as grading, tunneling, and surveying. Chesbrough was reluctant to accept the Boston position because he considered himself unacquainted with hydraulic engineering. His friends and Boston's water commissioners implored him to accept

4Of particular interest to Chesbrough's later career is the fact that Long had carried out extensive exploratory surveys in the West. In 1816 Long was asked to report to the federal government on the physiographic features in the region of a proposed canal between Lake Michigan and the Illinois River. Although it is only speculation, one wonders how much knowledge of Chicago's topographical peculiarities Long passed on to Chesbrough. It is known that Long prepared detailed reports of his visit to Chicago. See Richard George Wood, *Stephen Harriman Long* (Glendale, Calif., 1966).

5The major supply of engineers developed from what Calhoun called "the persisting pattern of on-the-job training." The supply provided by the leading scholastic source, the U.S. Military Academy, and the leading civilian source, the New York State canal system, was insufficient. The engineers of that day were active builders; thus, some form of on-the-job training had to be inaugurated to increase the supply and meet the demand. What developed was a hierarchical engineering corps. Lacking any formal education, Chesbrough learned every phase of his job by working his way up the civil engineering hierarchy.

In addition to the books by Hill and Calhoun (see n. 3 above), other recent books which discuss the oral transmission of engineering knowledge are: Stephen Salsbury, *The State, the Investor, and the Railroad: The Boston and Albany, 1825-1867* (Cambridge, Mass., 1967); Harry N. Scheiber, *Ohio Canal Era* (Athens, Ohio, 1969); and Ronald E. Shaw, *Erie Water West* (Lexington, Ky., 1966).
the position, and, after being assured John Jervis's counsel, Chesbrough assented.

There was good reason for Chesbrough to consider an association with Jervis valuable. Jervis had been active in every phase of engineering, particularly those dealing with hydraulics. Jervis was a product of the New York canal system and had learned hydraulic engineering on the job by working on the Erie Canal. In 1846 Jervis was appointed consulting engineer on the Boston Water Works, with Chesbrough the chief engineer. Jervis had the responsibility for designing both the Cochituate Aqueduct and the Brookline Reservoir; Chesbrough, the responsibility for supervising the execution of Jervis's plans.6 In 1850 Chesbrough became sole commissioner of Boston's waterworks, and a year later, he became Boston's first city engineer.

The United States' early experience with internal improvements and the education of engineers coalesced in Chesbrough's career. He learned civil engineering from some of the army's most competent engineers. He learned hydraulic engineering from Jervis, perhaps the most competent engineer trained by the New York canal system. The education and experience which Chesbrough utilized in freeing Chicago from its topographical liabilities and in implementing an effective sanitation system grew out of his first-hand experience with many of the country's internal improvements.

II

In the early 1850s Chicago's random waste disposal methods led to a succession of cholera and dysentery epidemics. The Illinois legislature created the Chicago Board of Sewerage Commissioners on February 14, 1855, to combat what was generally conceded to be an intolerable situation.7 The commissioners sought "the most competent engineer of the time who was available for the position of

6Chesbrough's role in the Cochituate works is mentioned in a study of the waterworks of Boston, New York, Philadelphia, and Baltimore by Nelson M. Blake (Water for the Cities [Syracuse, 1956]).

7The board was empowered to (1) supervise the drainage and sewage disposal of Chicago's three natural divisions; (2) plan a coordinated system for the future; and (3) issue bonds, purchase lots, and erect buildings implementing their plan. The board's actions were made subject to the Chicago City Council's approval. The act is summarized in several works including G. P. Brown, Drainage Channel and Waterway (Chicago, 1894), p. 50.
Their selection, E. Sylvester Chesbrough, resigned his position as Boston's city engineer and came to Chicago. Immediately after accepting the position, Chesbrough submitted a report in which he outlined his plan for a sewerage system designed to solve Chicago's drainage and waste-disposal problem. His plan represents the first comprehensive sewerage system undertaken by any major city in the United States. He had learned about sewer construction, grading, and "building-raising" from different sources. Now he merged them and "pulled Chicago out of the mud."

Prior to Chesbrough's arrival, Chicago's sewerage commissioners solicited the public for plans and suggestions. Thirty-nine proposals were received, and, although the board claimed Chesbrough utilized many of these suggestions, he did not use any of the proposals in its entirety. Chesbrough's task was to construct a sewerage system whose main objective was to "improve and preserve" the city's health. In his opinion, the existing privy vaults and drainage sluices were "abominations that should be swept away as speedily as possible," and that "to construct the vaults as they should be, and maintain them even in a comparatively inoffensive condition, would be more expensive than to construct an entire system of sewerage for no other purpose, if the past experience of London and other large cities was any guide for the future of Chicago."

Chesbrough's 1855 report to the Board of Sewerage Commissioners made several references to the sewers of New York, Boston, and Philadelphia. Additionally, the report showed that Chesbrough was

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9 It is quite possible that Jervis played a significant role in Chicago's choice, for during the early 1850s Jervis was professionally engaged in the Chicago area. Chicago's city fathers would have been aware of Jervis's engineering reputation, and it is probable that he was consulted regarding chief engineer candidates. Because he had worked with Chesbrough just prior to this, it is likely that Jervis gave Chesbrough an excellent recommendation.

In 1881 Chesbrough, serving as consulting engineer of the New Croton Aqueduct, employed Jervis, who discussed the work with Chesbrough daily. This indicates the esteem in which Chesbrough held Jervis, for Jervis was then eighty-six years old. Chesbrough, at sixty-eight years of age, belonged to another generation.

10 Although the commissioners' report mentions the public's proposals, it does not indicate what they were, or even which parts of Chesbrough's plan were adapted from these suggestions.

11 Brown, p. 53.
familiar, through his reading, with the sewers of London, Paris, and other European cities. It is important to remember, however, that not one U.S. city at that time had a comprehensive sewerage system, even though most had sewers. Consequently, Chesbrough had to rely on his training and intuition in assessing sewerage system alternatives.

Chesbrough's 1855 report considered four possibilities: (1) drainage directly into the Chicago River and then into Lake Michigan; (2) drainage directly into Lake Michigan; (3) drainage into artificial reservoirs to be pumped and used as fertilizer (sewage farming); and (4) drainage directly into the Chicago River, and then by a proposed steamboat canal into the Des Plaines River. Although this fourth possibility was the method which Chicago eventually adopted (the Chicago Sanitary District's Sanitary and Ship Canal), the city's 80,000 inhabitants in 1855 did not warrant the expense which this alternative involved.

Chesbrough recommended the first plan. This is not to say he failed to realize that his preferred method was a potential health hazard, particularly during the warmer months, and might obstruct river navigation by making the waterways shallower. Chesbrough discussed the objections to his recommended alternative:

> It is proposed to remove the first [health hazard] by pouring into the river from the lake a sufficient body of pure water into the North and South Branches to prevent offensive or injurious exhalations . . . The latter objection [obstruct navigation] is believed to be groundless, because the substances to be conveyed through the sewers to the river could in no case be heavier than the soil of this vicinity, but would generally be much lighter. While these substances might, to some extent, be deposited there when there is little or no current, they would, during the

12 Report and Plan of Sewerage for the City of Chicago, Illinois, adopted by the Board of Sewerage Commissioners, December 31, 1855, hereafter referred to as the 1855 Report. Also quoted in CREB Report, p. 71. Chesbrough had a systematic approach to costs, but a very general approach to benefits. This evidently was consistent with the approach adopted on other U.S. internal improvement projects. Lawrence G. Hines, "The Early Nineteenth Century Internal Improvement Reports and the Philosophy of Public Investment," Journal of Economic Issues 2 (December 1968): 384–92.

13 Chesbrough planned to pump sufficient lake water into the north and south branches of the Chicago River to flush offensive solid pollutants. He also proposed flushing the sewers as well. See reprinted article, Langdon Pearse, "Chicago's Quest for Potable Water," Water and Sewage Works (May 1955): 3.
seasons of rain and flood, be swept on by the same force that has hitherto preserved the depth of the river.14

Apparently, Chesbrough did not realize that spring freshets and floods might force the sewers' accumulations into the lake in such a way as to pollute the city's water supply. This is somewhat surprising, as the basic sanitation principle of the day was to locate the eventual sewage outlet as far from the water-supply source as possible.

Chesbrough had three objections to the second possibility, drainage directly into Lake Michigan. First, it would require a greater sewer length and, consequently, would incur greater cost. Second, he supposed that this plan would seriously effect the water supply, if any sewer outlets were located near the pumping station. At this time, Chicago's water-supply intake was located a short distance offshore at the Chicago Avenue lakefront, approximately 1/2 mile north of the Chicago River's mouth. Chesbrough did not elaborate on this objection. Third, he felt drainage into the lake would create difficulties in preventing sewer outlet injury during stormy weather, or snow and ice obstruction during winter.15

Sewage farming was rejected in part because of the uncertainty whether future fertilizer demand would be sufficient to cover distribution costs. Further, Chesbrough was uncertain as to both the needed reservoir capacity and the expense of building the necessary reservoirs. Finally, Chesbrough thought there would be a great health hazard created by foul odors emanating from sewage spread over a wide surface.

Chesbrough termed the use of a steamboat canal not yet constructed to flush the sewage into the Des Plaines River, the fourth possibility, "too remote." Although he was aware of the "evils" which would result when raw sewage passed into Lake Michigan, Chesbrough felt it impossible to create an outlet to the southwest. Brown claims, however, that "he appears to have believed that this would be the ultimate solution of the sewerage problem," as, in fact, it was.16

With regard to the fourth plan . . . which would divert a large

14 1855 Report. Also quoted in Andreas, 1:191.
15CREB Report, p. 72; Pearse, p. 3.
16Brown, p. 53. To be precise, the Sanitary District's Sanitary and Ship Canal was the last step in Chicago's adoption of the dilution method. Ultimately, Chicago's growth was sufficient to require sewage treatment in addition to dilution.
and constantly flowing stream from Lake Michigan into the Illinois River, it is too remote a contingency to be relied upon for present purposes; besides the cost of it, or any other similar channel in that direction, sufficient to drain off the sewage of the city, would be not only far more than the present sewerage law provides for, but more than would be necessary to construct the sewers for five times the present population. Should the proposed steam-boat canal ever be made for commercial purposes the plan now recommended would be about as well adapted to such a state of things, as it is to the present.\textsuperscript{17}

Certainly his plan was readily adaptable to such a scheme. The Sanitary District of Chicago was created in 1889 for the express purpose of implementing this fourth possibility. The Sanitary District then constructed the “proposed steamboat canal,” which unquestionably was beyond the means of Chicagoans in 1855.

In December 1855 Chesbrough submitted his plan for Chicago’s sewage disposal and drainage. Under this plan, all of the sewage of Chicago’s west division, all the sewage of the north division except for the lakefront area, and about one-half the sewage of the south division was deposited in the Chicago River. This sewage passed from the river into Lake Michigan. The dividing line in the south division was State Street; the area east of State Street drained directly into the lake. As the area east of State Street was primarily residential, Chicago’s business district was sewerized into the river. This district, west of State Street, included the majority of Chicago’s packinghouses, distilleries, and hotels. Thus, the river received large quantities of pollutants daily.\textsuperscript{18}

The sewers themselves were outstanding phenomena. Brick sewers, 3–6 feet in diameter, were laid above the ground down the center of the street. Chicago’s topography, being unusually flat, was unfavorable to sewer construction. The Chicago River banks were only 2 feet above the water level. Near the river’s north and south branches, the ground level reached a maximum of 10–12 feet above the lake. In reality, the task of constructing underground sewers required raising the city.\textsuperscript{19} From the beginning, Chesbrough insisted

\textsuperscript{17}1855 Report. Also quoted in Brown, p. 55.


\textsuperscript{19}CREB Report, p. 69.
that a high grade was necessary for proper drainage and dry streets. Chicago lacked this high grade, and, thus, the decision to raise the city’s level, concomitant with sewer installation, was one which solved the waste disposal and drainage problem in the context of Chicago’s existing topography and future necessities.20

The Chesbrough plan called for an intercepting sewer system which emptied into the Chicago River. The sewers were to be constructed on the combined system; that is, they would collect sewage from both buildings and streets. This was consistent with the best contemporary thinking and practice. As sewer construction progressed away from the river, the streets had to be raised beneath the sewers. After the sewers were laid, earth was filled in around them, entirely covering them. The packed-down fill provided roadbeds for new, higher streets. These streets were rounded in the center, with gutter apertures leading to the sewer. Such streets would stay dry and could be paved, as contrasted to the mud which had plagued the city previously.

A second facet of Chesbrough’s sewerage plan involved dredging the Chicago River. The river had been dredged previously, but it was still too small to handle the anticipated sewage load. Chesbrough planned to widen and deepen the river, as well as to straighten its meandering course. Contracts for this work had been let to the partnership of John P. Chapin and Harry Fox. It was Fox who suggested using the dredgings from the river as fill around the sewers.21

It is interesting to digress on the consequences of Chesbrough’s plan to raise the city. Where vacant lots existed, they were filled to the new level. A few old frame buildings were torn down, and the lots filled. It proved relatively easy to raise frame buildings to the new level, if the owners could afford it. The city’s newer buildings were brick and stone, however, and they were constructed on the old level. These newer buildings would not be torn down, and many of

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20 The grade which the city council adopted was lower than Chesbrough advocated, but it was sufficiently high to permit the construction of 7-8-foot cellars. The council’s decision was to raise the grade to 10 feet on streets adjacent to the river; Chesbrough’s higher grade was rejected because the city fathers felt there would be difficulties in locating sufficient fill. See CREB Report, p. 70.

21 Biographical Sketches, p. 482. Fox’s company was responsible for almost every topographical improvement in the Chicago area. The company deepened the Chicago River, developed the Chicago Harbor, installed road and railroad bridges, dredged the Illinois and Michigan Canal, and then performed similar services throughout the Midwest.
Chicago's homes and offices were to be left "in the hole." When new buildings and sidewalks were constructed on the higher level, Chicago increasingly became a city built on two levels. Legal attempts to maintain the lower level were uniformly settled in favor of the city and its new level.

The raising of brick buildings proved to be a difficult proposition. George Pullman, who later became famous for his "Palace cars," devised and instituted a method to raise brick buildings. Pullman first used his method in connection with the Erie Canal enlargement of the 1850s, so Chesbrough would have known that the problems concomitant with raising the city's grade were surmountable. One of Pullman's biographers described his activities during those years:

He made contracts with the State of New York for raising buildings on the line of the enlargement of the Erie Canal, which occupied about four years in their completion. At the end of that time, in 1859, he removed to Chicago, and almost immediately entered upon the work, then just begun, of bringing our city up to grade by the raising of many of our most prominent brick and marble structures, including the Matteson and Tremont Houses, together with many of our heaviest South Water street blocks. He was one of the contractors for raising by one operation, the massive buildings of the entire Lake street front of the block between Clark and LaSalle streets, including the Marine Bank and several of our largest stores, the business of all these continuing almost unimpeded during the process—a feat, in its class, probably without a parallel in the world.

The Tremont Hotel was the first brick building which Pullman raised in Chicago. Soon his method was utilized to raise all Chicago's brick buildings from their former muddy level. The work required years. No one knows the cost, but it has been estimated at $10,000,000.

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22 Randolph, p. 229. For many years, some sewers lay wholly above the ground, at the same level or higher than adjoining buildings.

23 "Up from the Mud: An account of how Chicago's Streets and Buildings were Raised," compiled by Workers of the Writer's Program, WPA in Illinois for Board of Education, 1941. The raising of cities was relatively common. It was pointed out to me that all of downtown Atlanta was "raised" by the construction of roadways.

24 Ibid.


26 Lloyd Wendt and Herman Kogan, Give the Lady What She Wants (Chicago, 1952), p. 57. Wendt and Kogan do not say how they arrived at this number, and give no reference. Pullman reportedly received $45,000 for raising the Tremont Hotel. At
In December 1856 the sewerage commissioners sent Chesbrough to visit several European cities in order to discover if their sewage disposal techniques were relevant to Chicago's needs. Chicago was taking an open-minded approach to this question, and, evidently, the city was prepared to adopt an unconventional approach if it proved to be the best solution. The report of this trip, which Chesbrough submitted in 1858, represents one of the first sanitary engineering treatises. Chesbrough visited and reported on the sewerage of Liverpool, Manchester, Rugby, London, Amsterdam, Hamburg, Paris, Worthing, Croydon, Leicester, Edinburgh, Glasgow, and Carlisle. He concluded that none of these cities furnished an exact criterion to judge the effects of disposing sewage directly into the Chicago River, but he felt their collective experience suggested that it probably would be necessary to keep the river free of sewage accumulations.

Chesbrough ended his report by relating the European experience to Chicago's sewerage needs. Two points which Chesbrough made in this concluding section are worthy of special mention. The first is the experience of Worthing, "a small watering
town on the southern coast of England." At one time this town of 5,000 had drained directly into the sea, "but owing to offensive smells caused by this practice, and the consequent injury to the reputation of town as a watering place, upon which its prosperity very much depends," Worthing decided to find an alternative sewerage scheme.\textsuperscript{30} Chesbrough concluded that Worthing's experience "shows that the mere discharge of filth into the sea gives no security against its being cast back in a more offensive state than ever, especially when the prevailing winds are toward shore," and that this suggests "the possibility of creating on the lake shore as great a nuisance as would be taken from the river."\textsuperscript{31}

Second, Chesbrough included a prophetic paragraph which could serve as a summary to Chicago's sanitary history for a half century thereafter:

Under these circumstances it seems advisable to do nothing with regard to relieving the river at present, nor towards carrying out that portion of the plan which provides for forcing water from the lake into it, during the summer months. Should the Canal Company [the Illinois and Michigan Canal] not be obliged to pump enough during warm weather to keep the river from being offensive, it is understood that they would pump as much as they could for a reasonable compensation. This would furnish some criterion by which to judge of the probable effect of a still greater quantity driven in from the lake, according to the plan. The thorough [sic] cut for a steamboat canal, to the Illinois River, which the demands of commerce are calling more and more loudly for, if ever constructed, would give as perfect relief to Chicago as is proposed for London by the latest intercepting scheme.\textsuperscript{32}

The Chicago River's south branch became quite polluted shortly after sewage was admitted into it. The Illinois and Michigan Canal's pumps, however, utilized south branch water to provide the canal's summit level, and, consequently, the pumps relieved a portion of the river's pollution load. The real significance of Chesbrough's statement lies in the fact that, as early as 1858, Chicagans recognized the Illinois and Michigan Canal's sewage disposal potential.\textsuperscript{33} In

\textsuperscript{30} 1858 Report, p. 39.
\textsuperscript{31} Ibid., p. 93.
\textsuperscript{32} Ibid., p. 94.
\textsuperscript{33} Nevertheless, in 1863, the Board of Public Works issued a report on purifying the Chicago River. This is discussed in Brown, chap. 6. The report recommended the construction of flushing canals along the lines of Fullerton Avenue and Sixteenth Street. Therefore, although the Illinois and Michigan Canal's potential was realized, city officials evidently were not ready to pursue it.
following years, the canal's pumps were used regularly to relieve the pollution load. Further, the canal itself was deepened and additional pumps were installed to increase the canal's capacity for handling sewage. Finally, the Chicago Sanitary District was formed in order to construct a new and enlarged canal to service Chicago's waste disposal needs, as Chesbrough had prophesied.

In 1861 the Board of Public Works was formed by incorporating the duties of the Board of Sewerage Commissioners, the Board of Water Commissioners, and other miscellaneous departments. Chesbrough was named chief engineer of this new board and, consequently, inherited the water-supply problem in addition to the waste-disposal problem. His inheritance was the "vicious circle" created by Lake Michigan's dual role as water supplier and eventual waste disposer.

III

Chicago's continued population growth through the decade of the 1850s, the new sewerage works, and the expansion of packinghouses and distilleries had increased the number of pollutants drained into the Chicago River. Lake Michigan soon became fouled by the river's influx, and Chicagoans began to complain of the public water supply's offensiveness and pollution. The existing water intake was a wooden pipe which extended a few hundred feet out into Lake Michigan, \( \frac{1}{2} \) mile north of the Chicago River's mouth. In 1859, one of Chicago's water commissioners "proposed to sink a wrought iron pipe . . . one mile out into the lake, to obtain the supply from a point which could not be affected by the river."\(^{34}\) Chesbrough was asked to study and report on the commissioner's plan, and to do the same on "erecting additional pumping works, in such locality as shall secure a supply of pure water."

Chesbrough's report discussed several methods without making a specific recommendation. Even at this early date, however, he considered a tunnel under the lake to be the most desirable alternative. Chesbrough was not afraid to combine grading, tunneling, and hydraulic principles to create a new water-supply system. When he later offered plans for a lake tunnel, his innovative proposal drew considerable opposition at the start and unmitigated acclaim when it proved successful.

Shortly after its formation in 1861, the Board of Public Works adopted as its goal the acquisition of an unpolluted water supply. Consequently, the board requested Chesbrough to make a canvass of

\(^{34}\) Brown, p. 32.
the various water-supply possibilities and to investigate several filtration methods. Chesbrough dismissed the existing filtration methods as inadequate; his studied opinion was that the tunnel method was the most desirable:

The engineer of the Board [E. S. Chesbrough], after much doubt and careful examination of the whole subject, became more inclined to the tunnel plan than any other, as combining great directness to the nearest inexhaustible supply of pure water, with permanency of structure and ease of maintenance. The possibility, and, in the estimation of many, the probability of meeting insuperable difficulties in the nature of soil, or storms, or ice on the lake, were fully considered. One by one the objections appeared to be overcome, either by providing against them, or discovering that they had no real foundation.35

Chesbrough continued to explore the tunnel plan's potential. When he had worked out the details, a proposal was submitted to several engineers, all of whom considered the tunnel plan to be feasible. Nevertheless, the 1861 board was against adopting the project. After a new board was elected and additional soil examinations had been made, Chesbrough's water-supply tunnel plan was adopted. The new board reported:

What is most to be desired by the city is, that the supply should be drawn from the deep water of the lake, two miles out from the present Water Works... The careful investigation of the subject has satisfied us sufficiently to say, that with our present knowledge, we consider it practicable to extend a tunnel of five feet diameter the required distance under the bed of the lake, the mouth or inlet to such a conduit being the outmost shaft, protected by a pier [crib], which will be used in the construction of the tunnel.36

In their 1863 report, the Board of Public Works noted that three projects had been considered, any one of which would have afforded Chicago a healthier and better protected water supply. These were (1) a 2-mile lake tunnel, (2) a filtering or settling basin, and (3) a 1-mile lake tunnel located 5 miles to the north.37 The board had two principal objections to the second plan. First, they commented:

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35 Reported in Brown, p. 33.
37 Cost estimates for each of the projects were as follows: 2-mile lake tunnel exclusive of light house, $307,552; a filtering or settling basin, $300,575; a 1-mile lake tunnel 5 miles to the north, $380,000 (1863 Report, p. 9).
For settling and filtering the water from sediment, we are of the opinion that the basin would be found effective, and would continue to be so, but that for filtration it is not safe to rely upon it. There have been filtering basins of the character in other places. Some of them appear to have continued to work well during long use, and others have failed and become useless.\(^{38}\)

Second, the board objected to the basin scheme because the water supply intakes would still be in the shallow water close to shore, and would not be located in a deeper point where the water was considered to be better.

Chesbrough's 1863 report acknowledged that the board had considered the three most promising possibilities and had rejected one; he was to assess the remaining two. Almost immediately he dismissed, on the grounds of greater cost, any project which required moving the existing water works, such as the board's third proposal:

Other projects, such as erecting a new pumping works at Winnetka, or going to Crystal Lake and bringing a supply thence by simple gravitation, as is done for cities of New York, Boston, Baltimore, and Albany, have been considered, but their great cost, as compared with that of obtaining an abundant supply of good and wholesome water at points much nearer the city, is deemed a sufficient apology for not discussing their details here.\(^{39}\)

Chesbrough concerned himself only with those plans which would bring water from a point 2 miles east of the existing Chicago Avenue Water Works, and there were two of these:

Of the plans proposed for obtaining water from the lake, where it will be free from not only the wash of the shore, but from the effects of the river, two classes only have been considered; one, an iron pipe with flexible joints; and the other, a tunnel under the bottom of the lake.\(^{40}\)

Although the cost of the iron pipe project was slightly less than the tunnel project, Chesbrough chose between them on other than an initial cost basis.\(^{41}\)

In consequence of the possibility of such a pipe being injured by anchors, by the sinking of a heavily loaded vessel over it, or by

\(^{38}\) Ibid., p. 8.

\(^{39}\) Ibid., p. 39.

\(^{40}\) Ibid.

\(^{41}\) Chesbrough roughly estimated the iron pipe scheme to cost $250,000. The choice seems to have been made on the basis of expected cost. Ibid., pp. 40 - 41.
the effect of an unusual current in the lake moving it from its place, it has been thought preferable to attempt the construction of a tunnel under the bottom of the lake.\textsuperscript{42}

His research had convinced him that the tunnel's construction would be less difficult than was generally supposed. Lill and Diversey's brewery, adjacent to the waterworks, was the site of artesian borings which showed that, between 25 and 100 feet deep, the ground at the lake shore was a clay which was also found on the lake bottom where the water was 25 feet deep. A tunnel could easily be constructed in this type of clay, if it were continuous. Chesbrough was confident that the clay was continuous, but he admitted he was uncertain whether beds of sand might not be interspersed with the clay.\textsuperscript{43}

The lake shaft was to be formed by sinking iron cylinders to the desired depth. Chesbrough noted that this was not a difficult problem in that the pneumatic process had been successfully employed on "the Theiss bridge in Hungary, and the railroad bridge across the Savannah River, \ldots and recently the Harlem bridge in New York."\textsuperscript{44}

In giving cost estimates for the tunnel project's component parts, Chesbrough clearly showed the sources of his research. The principal source was the Thames tunnel, and Chesbrough noted that the first thoughts of most people were the great construction difficulties and "enormous" costs which had been encountered on the Thames project. He was quick to refute these thoughts and countered that "as we have every reason to believe, the clay formation here would shield us from such inroads of water as were met within the Thames tunnel operation."\textsuperscript{45} In estimating excavation costs, Chesbrough made the same point: "There is good reason to believe that nothing in the soil here would be more difficult than that through which the sewers of London are sometimes tunneled."\textsuperscript{46}

Chesbrough also used the Thames experience, plus that of the Boston Water Works tunnel, to estimate masonry costs. Cribs had been used principally in pier and breakwater construction, and Chesbrough based his crib cost estimates on figures which had been made for a proposed breakwater in Michigan City, Indiana, at the bottom of Lake Michigan.

After reaching his cost estimate for masonry and excavation,

\textsuperscript{42} Ibid., p. 41.
\textsuperscript{43} Ibid.
\textsuperscript{44} Ibid. Originally, Chesbrough planned on four shafts.
\textsuperscript{45} Ibid., p. 43.
\textsuperscript{46} Ibid., p. 45.
Chesbrough compared it with figures which had been reached for other major tunnel projects. In particular, Chesbrough referred to reports from (1) the commissioner of the Troy and Greenfield Railroad, and (2) the Hoosac Tunnel. Included in the commissioner's report was the report of Charles Storrow, who had been sent to investigate European tunnels. Because the tunnels which Storrow had studied were for railroads, they were all much larger than the one which Chesbrough was planning. Therefore, Chesbrough estimated the cost of each tunnel had it been constructed with a 5-foot width. From these estimates, he concluded that his cost estimate for the proposed water tunnel was reasonable.

The engineering achievement involved in constructing the water-supply system was no less significant than that represented by Chesbrough's sewer system. As conceived, the task was to dig a shaft near the lake shore to a depth significantly below the lake bottom and then burrow 2 miles beneath the lake. A similar shaft was to be dug at the lake end and was to be protected by a crib. The engineering problem was to connect the shore and lake points by a straight line 69 feet below the surface of Lake Michigan. Contemporary compasses could not be used since, below ground level, local attraction rendered them inaccurate. To a worker in the tunnel, the only place where the direction of the line drawn between the two shafts could be observed was at the top of either shaft. Consequently, when the engineers attempted to run the tunnel's axis parallel to this imaginary line on the lake's surface, they ran into difficulties affecting the turn from shaft to tunnel.

When the lake shaft was completed, workers were lowered to begin burrowing westward to meet with the other workers burrowing eastward. The tunnel was sloped 2 feet per mile from the lake end to the shore so that it could be emptied should repairs prove necessary; the water would be shut off at the lake end. Although the methods were primitive—the tunnel was dug entirely by manual labor—it was claimed that the workers caused the two tunnel sections to meet within 1 inch of achieving a perfectly smooth wall.

Chesbrough’s engineering competence was coupled with a sense of economic reality, and these traits combined to insure the reputation he earned in Chicago. His 1863 report contained a section on “plans for improving the Chicago river.” Chesbrough knew that

47 Chesbrough estimated the cost to be $13.54 per linear foot. Ibid., p. 48.
49 Ibid., p. 76.
moving the water-supply intake farther into the lake would not improve the river's offensive condition. In the 1855 sewerage report, he had argued that flushing canals would be necessary in both the north and south branches to purify the river, and he restated this position in several reports thereafter. By raising the issue once again, Chesbrough not only demonstrated the completeness of his approach, but also what one memorialist called "the characteristic firmness of conviction and modest persistence of Mr. Chesbrough."

As before, Chesbrough's methodology was to enumerate and evaluate the possibilities for improving the river: (1) north and south branch flushing canals, (2) Des Plaines River diversion into the south branch, and (3) drainage southwest into the Illinois River Valley. The first was preferred because Chesbrough felt it was "undoubtedly feasible, would be completely under the control of the city, and there is every reason to believe [it] would be effectual." He considered the second plan "defective" in that the Des Plaines River's flow was least when the Chicago River's pollution was greatest. Although Chesbrough correctly assumed that the third project would be the ultimate solution, he rejected it as "requiring much larger means than the Board can at present control." Chesbrough's attention to Chicagoans' ability to pay established him as a practical man and lent credence to his innovative ideas. His consideration of a sanitary canal connecting the Chicago and Illinois Rivers indicates Chesbrough had learned that water-supply and waste-disposal problems are interdependent and must be solved simultaneously.

IV

Chicago is an urban center which had, and still has, serious water pollution problems. Lake Michigan's present pollution problem is primarily the result of industrial discharge in the Calumet and Indiana Harbor areas and the discharge of inadequately treated sewage by the North Shore Sanitary District (Lake County, Illinois) and several Wisconsin cities. Under normal circumstances, the Metropolitan Sanitary District of Chicago diverts the sewage and the

50 *Journal of the American Society of Civil Engineers* 15 (November 1889): 162.
51 *1863 Report*, p. 57. Chesbrough was concerned with a definite planning period which seems to reflect a longer time than the Marshallian short run, and a shorter time than the Marshallian long run.
52 Ibid., p. 57.
treated effluent from Lake Michigan. Presently, Chicago is meeting its responsibility with respect to Lake Michigan pollution. On the other hand, both the Chicago River and the Illinois River valley are polluted because some industries in the Chicago area still discharge their wastes into the water and the Sanitary District falls short of 100 percent treatment. Approximately 10 percent of the sewage goes untreated at this time, but it is the district's stated objective to achieve 100 percent treatment in the 1970s. While these few sentences oversimplify a very complex situation, the outline is apparent. Chicago must seek outside help to reduce Lake Michigan pollution and the consequent threat to the city's water supply. Chicago and its Cook County suburbs, by themselves, could significantly reduce pollution in the Chicago, Des Plaines, and Illinois rivers.

When faced with Lake Michigan and Chicago River pollution in the 1850s and 1860s, Chicagoans had sought the best solutions available. Cost considerations had entered the argument only in deciding among equally effective methods; Chicagoans were not reluctant to pay the price necessary to secure sanitary conditions. They indebted the city through bond issues and themselves through tax assessments in order to finance these public works. Muddy streets and impure water were manifest physical representations of the city's problems, and solutions to these benefitted the city's residents, individually and collectively. The public's acceptance of an increased tax burden to finance these works must be viewed as public recognition of the problems' dimensions. If the city's water supply had not been conserved, and if the city's natural topography had not been improved, Chicago's urban growth would have been severely limited.

When the pollution problem is explored in a historical context, students will find that the objectives which Chesbrough sought—minimize pollution and obtain a pure water supply—are the same as today's objectives. Nineteenth-century engineers, however, were not faced with the imminent "death" of large bodies of water; they were faced only with protecting urban populations from polluted water supplies.

In studying Chesbrough's works in Chicago, one gets the impression that today's pollution problem is not the result of ignorance as to pollution's effects, but ignorance as to how deadly the pollution load has become. In many cases, techniques first utilized in the 1850s and 1860s are still used today. Although these techniques no longer solve the problems for which they were intended, their inadequacies did not become apparent until recently. Perhaps this is because the
demands on these techniques were much less heavy during the earlier period than they now are. Perhaps it is because the engineers of Chesbrough's generation made such dramatic innovations that the declining effectiveness of these techniques and improvements just recently became evident to sanitary engineers and laymen. Or perhaps it is because the 20th-century sanitary engineers who recognize the problem are unable to communicate the necessity for action. While the technology and technicians have been available, an uninformed and apathetic public has not invested sufficient capital in pollution control. Whatever the case, through inaction, the cost of proper treatment has reached a price which may be greater than the public is willing to pay. Unfortunately, the 20th century has been unable to find a sanitary engineer with the same farsightedness in his method, and resoluteness in seeing his proposals adopted, as that characteristic of Ellis Sylvester Chesbrough.