Edwin Chadwick and the Engineers, 1842–1854: Systems and Antisystems in the Pipe-and-Brick Sewers War

CHRISTOPHER HAMLIN

To the English sanitary reformer Edwin Chadwick, author of the famous *Report of an Inquiry into the Sanitary Condition of the Labouring Population of Great Britain* (1842), goes credit for recognizing the central importance of public works—waterworks, sewers, better-ventilated streets and houses—to public health. Chadwick's career as a public health official lasted only from 1848 to 1854, yet his influence was great. In a broad sense, the administrative structures, the sanitary sensibilities, and the technologies (e.g., indoor running water and water closets) he developed or endorsed were adopted, and on great scale: by 1905, local authority debt in England and Wales for waterworks and sewers was nearly one hundred million pounds.[1]

One might think engineers would have aligned themselves with Chadwick's programs—he brought them business. In fact, however, Chadwick's relations with engineers were wretched. For Chadwick, mid-century British civil engineers were part of the problems, not the solutions. He saw them as both loyal to a primitive laissez-faire and in cahoots with the most corrupt and irrational institutions of local government: the ancient municipal corporations, sewers commissions, and navigation trusts. He represented their works as hyperexpensive, uninformed by science, even dangerous. Worse, they clung to obsolete doctrines and rejected truths from outsiders. Historians, even those critical of Chadwick, have shared this view. They have seen

DR. HAMLIN is associate professor of history and the history and philosophy of science at the University of Notre Dame. His research was supported by National Science Foundation grant DIR-8804685. An earlier version of the article was presented at University College, London, in May 1990, and he thanks seminar participants and Gerald Berk, Thomas P. Hughes, Joel Tarr, and David E. Wright for criticisms and suggestions.

[1]See the "35th Annual Report of the Local Government Board," *Parliamentary Papers* (hereafter *PP*), 1905–6, vol. 35 [cd. 3105], p. cciii.

0040-165X/92/3304-0004$01.00

engineers as key actors in Chadwick's downfall, collaborating with tightfisted politicians to block needed improvement.[2]

At the center of Chadwick's troubles with engineers is an obscure technical controversy over sewer design, the "pipe-and-brick" sewers war of 1852–54. On one side were Chadwick and a handful of marginal engineers who advocated a novel system of small-bore pipe sewers; on the other, prominent members of the Institution of Civil Engineers, notably Thomas Hawksley, a leading water engineer, and Joseph Bazalgette, later builder of London's main drainage, who opposed this novelty.[3] Like many technical controversies, this one took place on many levels. Facts were in dispute: was there really mud in certain sewers? How fast did a sewer of given design discharge a given amount of water? There were also conflicts about the nature of expertise, the proper institutional and social framework for sewerage projects, and what constituted success or failure. The two sides even disagreed about what they were disagreeing about; only one side (the

[2]For example, M. W. Flinn writes of Chadwick as "sickened by the squandering of public money in purchasing the services of ill-qualified quacks . . . the main weight of his criticism fell upon the engineers." Likewise, Chadwick's pipe sewer is seen as "so sensible that its subsequent universal adoption has obscured its radical nature at the time." See M. W. Flinn's "Introduction" to Edwin Chadwick, *Report of an Inquiry into the Sanitary Condition of the Labouring Population of Great Britain*, ed. M. W. Flinn (Edinburgh, 1965), pp. 60–61. See also S. E. Finer, *The Life and Times of Sir Edwin Chadwick* (London, 1952), pp. 439–52; R. A. Lewis, *Edwin Chadwick and the Public Health Movement* (London, 1952), pp. 222–23, 295–300. Anthony Brundage's *England's "Prussian Minister": Edwin Chadwick and the Politics of Government Growth, 1832–1854* (University Park, Pa., 1988), is critical of Chadwick but does not significantly depart from earlier views of engineers (see p. 151). A recent engineering historian has also seen the dispute as about "prestige"; see G. N. Binnie, *Early Victorian Water Engineers* (London, 1981), pp. 31–42, esp. p. 36.

[3]It has not been recognized just how marginal Chadwick's partisans were. Of eighteen engineers and surveyors who advocated Chadwick's sewerage concepts, only seven appear to have held any class of membership in the Institution of Civil Engineers, while only nine appear in S. P. Bell's *A Biographical Index of British Engineers in the Nineteenth Century* (New York, 1975). The partisans can be divided into three groups: those who were only advisers (Morgan Cowie, Butler Williams, Edward Cresy, Sr., William Dyce Guthrie, James Vetch), those who were also surveyors on the Metropolitan Sewers Commission (John Roe, John Phillips, John Grant, Thomas Lovick, Joseph Medworth, J. L. Hale, Edward Gotto, George Donaldson), and those who were superintending inspectors for the General Board of Health (Henry Austin, Robert Rawlinson, William Ranger, William Lee, Thomas Rammell). Some achieved fame only later, while others achieved it in areas other than sewerage. Several rejected aspects of Chadwick's doctrine during his years in power. On concepts of marginality, see Ian Inkster, "Aspects of the History of Science and Science Culture in Britain, 1780–1850 and Beyond," in *Metropolis and Province: Science in British Culture, 1780–1850*, ed. Ian Inkster and Jack Morrell (Philadelphia, 1983), pp. 39–43.

Chadwickians) saw itself in a doctrinal "war." To Chadwick's biographers the quarrel was between progress and stagnation (literally and figuratively), right and wrong, even good and evil. Yet it ended not, as they presumed, with the triumph of Chadwick's system, but with an affirmation of the flexible, client-driven practice that characterized British engineering.

Using the pipe-and-brick sewers war as a focus, this article reassesses Chadwick's relations with orthodox engineers. I hope to make clear that the engineers' opposition was far more than a matter of professional jealousy or personal pique, for when one focuses on what S. E. Finer called the "insufferably tedious" technical literature of the controversy, many of their criticisms appear well founded.[4] But at the heart of the disagreement were conflicting views of good engineering: Chadwick's allies thought in terms of "systems" while the orthodox engineers took an explicitly decentralized and anti-systems approach.[5]

* * *

While historians of technology have given little attention to sanitary technologies, urban historians and historians of public health have had much to say about the conditions that led to the need for new water supplies and sewers. Growing industrial cities found traditional sources of water and means of removing wastes inadequate. Unplanned growth meant there was often no coordinated drainage (or even no drains at all). The new water closets and macadam pavements strained what sewers there were, increasing the input of both foul water and sediment. Contemporary medical theory gave prominence to environmental causes of disease, while fear of revolution height-

[4]Finer, pp. 448, 451.

[5]I use "system" much as the concept has been developed by Hughes and several commentators. See Thomas P. Hughes, *Networks of Power: Electrification in Western Society, 1880–1930* (Baltimore, 1983), pp. 2–17, and "The Evolution of Large Technological Systems," in *The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology,* ed. Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch (Cambridge, Mass., 1987), pp. 51–82; Bernward Joerges, "Large Technical Systems: Concepts and Issues," in *The Development of Large Technical Systems,* ed. Renate Mayntz and Thomas P. Hughes (Frankfurt, 1988), pp. 9–36; B. Barnes, "Review of Hughes, *Networks of Power,*" *Social Studies in Science* 14 (1984): 309–14. The engineers' opposition to technological systems is especially interesting as it is in an area of technology that might be expected to exemplify such systems. The term "network," explicitly applied to the technologies considered here, carries many of the same connotations as "system"; see Joel Tarr and Gabriel Dupuy, eds., *Technology and the Rise of the Networked City in Europe and America* (Philadelphia, 1988).

ened the need to do something for (or to) the industrial working classes, and cholera epidemics lent immediacy to all these matters.[6]

Such was the situation confronting Edwin Chadwick in the late 1830s. A disciple of the utilitarian Jeremy Bentham, Chadwick was already well known as a poor-law reformer and as secretary to the Poor Law Commission. The poor law provided the initial context for his concern with sanitary engineering, which was predicated on the argument that preventing pauperism by preventing disease was cheaper than supporting paupers.[7] After making his *Sanitary Report* of 1842, Chadwick went on to become in 1848 chief member of the General Board of Health (GBH), established to administer the Public Health Act his work had inspired. He was deposed in 1854, a victim of old vested interests and opponents of centralized government.

Although Chadwick is often seen as a dogmatist, his views on sanitary engineering changed significantly over the years. The *Sanitary Report* focused on the old association of disease with dampness and was more concerned with the provision of drains than with their size or construction (there was some concern with flushing them of obstructions).[8] In the 1843–45 investigations of the Royal Commission on the Health of Large Towns and Populous Places (Chadwick was not a member but helped organize the inquiry and write the reports), that focus had shifted from class to urban conditions. Many English towns had public sewers and cesspools, which removed surface water but did not carry it to an outfall. As a result, sewage stagnated underground, generating unpleasant and presumably pestilential gases.[9] This led Chadwick to think in terms of sewage flow rather than sewer capacity and to the evolution of his "arterial-venous" conception of a city in which water constantly moved in, through, and out, removing all wastes to the country for recycling.[10]

[6]A good summary is Flinn's "Introduction" to Chadwick's *Sanitary Report,* 1965 ed. (n. 2 above), pp. 3–21; or see Anthony Wohl, *Endangered Lives: Public Health in Victorian Britain* (Cambridge, Mass., 1983).

[7]Flinn, ed., "Introduction" (n. 2 above), pp. 42–44. Compare F. Barker and J. Cheyne, *An Account of the Rise, Progress, and Decline of the Fever Lately Epidemical in Ireland,* 2 vols. (London, 1821), 1:24.

[8]Chadwick, *Sanitary Report,* 1965 ed., pp. 80–81, 88–89, 99–104, 109–10, 380, 424. He had already commissioned John Roe, surveyor to the Holborn and Finsbury Sewers Commission, to investigate use of cheap ceramic pipes for sewers.

[9]Royal Commission on the Health of Towns, *First Report on the State of Large Towns and Populous Districts* (hereafter HOT, *First Report*), *PP,* 1844, vol. 17 [572.], p. x. Chadwick's contribution has been reevaluated by Brundage, pp. 93–96.

[10]Lewis, pp. 52–54. Chadwick's associate James Kay-Shuttleworth claimed credit for the concept. See Frank Smith, *The Life and Work of Sir James Kay-Shuttleworth* (London,

The claims made here for "system" were new to Chadwick. What systematicity there had been in the *Sanitary Report* had been mainly administrative—how much easier it would be if all streets and all understreet infrastructure were under one authority: pipe-and-main laying and repairing and street breaking and building could be done in a coordinated manner; a scientific municipal administration by well-trained practitioners would become possible.[11] By contrast, the approach that took shape between 1843 and 1845 was driven by economic, technical, and physical considerations. Underlying it was the hope that the agricultural use of urban sewage could finance much urban improvement. If one took this view, end-use considerations dictated upstream components of the system. For example, Chadwick, believing that the best sewage was fresh and dilute, would increasingly insist on rapid removal of wastes. Other design features followed: the kinds of sewers to be used (velocity-augmenting pipes), the layout of the network and locations of outfalls (arranged for easy access by farmers), the material to be used as road pavement (that which would minimize grit), the control of what was allowed to enter sewers (useless road grit and storm water had to be kept out), and the rate at which it entered (effective flushing had to be ensured).[12]

This was very much then a technological system as Thomas Hughes has conceived such systems; it was centrally controlled, and its development impelled by a momentum, both social and physical, that was subject to impediments—in Chadwick's case, failure to secure control of water supplies would be the principal one—that resulted in "reverse salients."[13] So mutually necessitating were the system's com-

1923), p. 33. The analogy to the city as a body was sometimes explicit. See C. Fowler in discussion of J. Thornehill Harrison, "On the Drainage of the District, South of the Thames," *Minutes of Proceedings, Institution of Civil Engineers* 13 (1853–54): 107; "Review of General Board of Health, Minutes on Sewer Manure," *Builder* 10 (1852): 77–78. See also Graeme Davison, "The City as a Natural System: Theories of Urban Society in Early Nineteenth-Century Britain," in *The Pursuit of Urban History*, ed. D. Fraser and A. Sutcliffe (London, 1983), pp. 349–70.

[11]Chadwick, *Sanitary Report*, 1965 ed., pp. 380–96.

[12]For early expressions of the system, see James Smith of Deanston in discussion of James Green, "The Sewerage of Bristol," *Minutes of Proceedings, Institution of Civil Engineers* 7 (1848): 87–88.

[13]Like the inventor-entrepreneurs of electrification, Chadwick had to consider minute details of the system: gratings that removed road grit, household fixtures suited to high-pressure water service, even kilns and molding machines to supply cheap and uniform pipes. See General Board of Health, "Minutes of Information Collected with Reference to Works for the Removal of Soil Water or Drainage of Dwelling Houses and for the Sewerage and Cleansing of the Sites of Towns" (hereafter "Minutes on House Drainage"), *PP*, 1852, vol. 19 [1535.], pp. 98–124, 185–90.

ponents that one could start with any one and deduce the others: one could start with the imperative of cleansing cities with water and deduce the details of drainage and outfall works, or one could start with the imperative of removing decaying matter and deduce the requisite stream of water and the system of drains needed to remove that water. The sewage farms would still be necessitated as the only adequate means of purification. Equating technological with economic rationalization, the Chadwickians also claimed that their system was economically optimal.[14] Appeals were made to all these arguments—as they all led to the same conclusion, there was no tension among them.

The prospect of developing a coordinated hydraulic system led Chadwick to seek engineering expertise. Unlike the *Sanitary Report,* the Health of Towns reports were full of engineers' opinions, from Robert Thom, William Hosking, Henry Austin, William Dyce Guthrie, Edward Cresy, Thomas Wicksteed, Thomas Hawksley, and J. Butler Williams. Chadwick's star engineer was John Roe, who had gone from canal building to become surveyor to the Holborn and Finsbury Sewers Commission. Roe was full of ideas. Egg-shaped sewers (pointed end downward) would increase hydraulic mean depth for a given flow, thereby increasing velocity and consequently carrying capacity. Tangential junctions of branch sewers into a main sewer would diminish turbulence and prevent deposition. Most important, a system of flushing dams could be installed in existing sewers that would allow one to accumulate the head of pressure needed to flush out sediment in the sewers below.[15]

In contrast with Roe's enlightened practice stood the corrupt and inefficient technical and administrative practices of other sewers administrations, particularly the seven Greater London sewers commissions. As Chadwick would blame engineers for much of what he found wrong there, it is well to consider what the problems were. Each of the commissions (for the City, Westminster, Holborn and Finsbury, Tower Hamlets, Surrey and Kent, Ravensbourne, and Poplar) consisted of a large number of appointed members (e.g., 220 in Westminster in the early 1840s). Some took no part in the business (some were dead, it was noted), while others—architects, builders, and surveyors—were all too active, using their membership to advance their own careers. Lavish dinners and cumbersome procedures made

[14]Chadwick, *Sanitary Report,* 1965 ed. (n. 2 above), p. 130.

[15]For engineering testimony, see HOT, *First Report* (n. 9 above), question nos. 108–72, 369–95, 807, 1075–1113, 2094–2130, 4480–4528, 5345, 5423–46, 5827–46. On Roe, see his obituary in *Minutes of Proceedings, Institution of Civil Engineers* 39 (1874–75): 297–98.

the commissions targets for criticism, and, beginning early in the century, calls for reform had led to amendments to their charters and to construction of a significant number of new sewers.[16] Yet Chadwick's surveyors still found sewers that appeared

> not to have been conducted on any system, nor are the capacities of these lines proportioned to the requirements of the drainage. The sections are of all shapes and sizes, from squares nearly to circles, and to various modifications and combinations of these forms, differing greatly in very short distances, that of the outfall being frequently one of the smallest parts,—they are generally without artificial bottoms,—the sides, in parts, are built upon or supported by piles, which project to a great extent. Their falls are frequently from, instead of to, the outfall; pits or cesspools are thus formed, in which there must always be accumulations of deposit.[17]

"Sewers of vicious construction" was Chadwick's label for such works. Aside from generating deadly gases of decomposition (and sometimes undermining nearby buildings), such sewers required cleaning out by hand, a task Chadwick regarded as inhumane, unhealthy, and unduly expensive.[18]

Corrupt and incompetent the commissions may have been, but Chadwick was also judging them on new criteria of his own. Founded as quasi-judicial bodies to apportion costs among householders and settle drainage disputes, the commissions were ill suited to construct or administer sewers. Their borrowing powers were minimal; when funds were gone, building stopped until a new rate was in. They did not build, nor did they control all sewers in their districts; many sewers were private. Conceiving of sewers as *systems* was foreign to them; sewers were built bit by bit, here and there. And they were

[16]Select Committee on Sewers in the Metropolis, *Report, PP,* 1823, vol. 5 (542.), pp. 6–17, 33–35; Select Committee on Metropolis Sewers, *Report, PP,* 1834, vol. 15 (584.); Select Committee on the Health of Towns, *Report, PP,* 1840, vol. 11 (384.), evidence of J. W. Unwin, B. Drew, J. Peeke, W. Baker; HOT, *First Report,* evidence question nos. 2303, 2318; Royal Commission on the Health of Towns, *Second Report of the Commissioners of Inquiry into the State of Large Towns and Populous Districts* (hereafter HOT, *Second Report*), *PP,* 1845, vol. 18 [602.], pp. 7–10; Metropolitan Sanitary Commission, *First Report of the Metropolitan Sanitary Commission, PP,* 1847–48, vol. 32 [888.], evidence pp. 24, 33–39, 74–75.

[17]T. Lovick and J. L. Hale, "Report on the State of Sewers in the Surrey and Kent District, near Borough," in *Times* (London) (August 7, 1848), p. 8f.

[18]"Minutes on House Drainage" (n. 13 above), pp. 27, 29–30.

built, not to move waste to the countryside, but to drain the surface.[19] Nor was there a close link between engineers and the commissions. The surveyors, their chief technical officers, tended to come to their work from building or architecture. Professional engineers, like John Rennie, who had advised the Westminster Commission in 1807, shared Chadwick's concern for finding a good gradient to avoid deposition.[20] Because most engineers recommended larger sewers than he did, however, Chadwick equated their views with the uninformed practice of surveyors and architects.

* * *

When the Health of Towns inquiries ended in early 1845 Chadwick was still on good terms with the engineering profession. Roe's innovations were well received by engineers if not always by sewers commission surveyors.[21] In Hamburg, the English engineer William Lindley was working along similar lines; he sought Chadwick's patronage while remaining independent. Indeed, in the coming controversies, engineers would claim both Roe and Lindley as their own, as proof that they were masters of sewer building.[22] Chadwick was satisfied with the profession's competence. Requiring government inspectors to sanction engineers' plans of sanitary works would only "clog procedure," he wrote; the guarantor of quality was to remain "the ordeal of local scrutiny."[23]

The first threat to this harmony was Chadwick's break with the water engineer Thomas Hawksley, who, with J. F. Bateman, would

[19]Sidney Webb and Beatrice Webb, *English Local Government*, vol. 7: *Statutory Authorities for Special Purposes* (London, 1922). Borrowing powers were increasing; see Metropolitan Sanitary Commission, *First Report*, evidence pp. 91–92.

[20]John Rennie, reports 1807–8, WCS 873 (WCS is a designation for reports to the Westminster Sewers Commission), Greater London Record Office (hereafter GLRO).

[21]See Braithwaite, Wicksteed, and Walker in discussion of Green (n. 12 above), pp. 102–7. The chief anti-Chadwick polemic, *Engineers and Officials: An Historical Sketch of the "Health of Towns Works" (between 1838 and 1856) in London and the Provinces* (London, 1856), pp. 44–47, also saw a consensus until 1847.

[22]See the obituary for Lindley, "William Lindley," *Minutes of Proceedings, Institution of Civil Engineers* 142 (1899–1900): 363–70; Lindley to Chadwick, October 1842–February 1844, Chadwick MSS, no. 1235, University College, London (hereafter Chadwick MSS). On the reception of Lindley's work, see J. Walker in discussion of Green, p. 104; Fowler, Bidder, Manby, and Simpson in discussion of Harrison (n. 10 above), pp. 78–81; "Health of Towns: The Government and the Profession," *Civil Engineer and Architect's Journal* 11 (1848): 17–18.

[23]Chadwick to Duke of Buccleuch, December 17, 1844, Chadwick MSS, no. 2181/6. Compare HOT, *Second Report*, pp. 6, 20–21.

dominate that field for the next forty years. Impressed with Hawksley's development of constant-supply water service in Nottingham, Chadwick had recruited him as engineer to the Towns Improvement Company, a for-profit company Chadwick was organizing to sell cities integrated gas, water, sewerage, and sewage recycling systems. Their split had many causes: incompatible understandings of whether Hawksley was co-promoter, regular consultant, or key employee; contrasting estimates of how feasible were the technologies Chadwick advocated; and incompatible conceptions of the company's mission. For Chadwick, sanitary improvement was a moral obligation backed by the security of utilitarian proof (and, if needed, by natural theology). He would guarantee the validity of the system, was unconcerned with details, and reluctant to have the company sell partial services (e.g., water supplies) to particular cities. Hawksley saw the company (and himself) as selling services in a free market. Far from trusting Chadwick's system (he doubted the profitability of sewage recycling), he saw his reputation as being at stake in every estimate he approved. For Chadwick, the client was an abstract notion of public good (embodied in himself, no less); for Hawksley, the client was a real person, group, or public authority, whose problem had to be solved within unique constraints.[24] These differences would loom large in the pipe-and-brick sewers war a decade later.

By January 1846, the Towns Improvement Company was fast fading and Chadwick and Hawksley were no longer speaking. For Chadwick, the episode would do much to confirm a distrust of engineers; he saw Hawksley as the archetype of the hypocritical professional who would endorse any position for a fee.[25] Still, there was no irreparable break with the engineers. What changed was not the engineers' views but Chadwick's power base. After two difficult years (1845–46) at the Poor Law Board and the Towns Improvement Company, Chadwick went on, within about a year, to hold three significant positions in the engineering world, as key member of the Metropolitan Sanitary Commission, the General Board of Health, and the new Metropolitan Commission of Sewers that replaced the local commissions. It became clear that he meant not just to suggest new technologies but to orchestrate their introduction and dominate the profession that would put them into place.

Established in early 1847 to investigate sanitary conditions and to reform London's sewer administration, the Metropolitan Sanitary

[24]See Brundage (n. 2 above), pp. 101–12; Lewis (n. 2 above), pp. 120–21; Binnie (n. 2 above), pp. 14–30.

[25]Lewis, p. 133.

Commission was dominated by Chadwick. The attack on engineers began in the commission's first report in November 1847.[26] True sewerage principles were now known, it insisted; they were "demonstrated with a degree of clearness which admits of no misapprehension by well-informed minds earnestly directed toward the attainment of the object."[27] Yet engineers of high repute ignored them.[28] Their opposition could be easily explained, Chadwick observed; because their fees were a percentage of project costs, economy and efficiency were not in their interest. Conventionally trained engineers also were incompetent to build sewers, he added: sewer building was a recondite science that "could not be reasonably expected to be dealt with incidentally, or collaterally to ordinary occupation, or even to connected professional pursuits, but require[d] a degree of special study which not only place[d] . . . [it] beyond the sphere of the discussions of popular administrative bodies, but beyond that of ordinary professional engineering and architectural practice."[29]

This stronger tone reflects Chadwick's growing conviction that the gap between what was and what might be was even greater than he had thought. That conviction had been imparted by a new star engineer, John Phillips, who was displacing Roe as his chief sewerage theorist. A bricklayer, Phillips had taught himself hydraulics and worked his way up to become a clerk of works and, in 1846, surveyor to the Westminster Commission.[30] His stay in Chadwick's camp would be brief—he was purged in mid-1849—but he was the main source of the pipe-sewers dogma Chadwick would defend so bitterly.

Phillips's effect on Chadwick was as much personal as technical. He was bright and ambitious but tactless and quick to take offense. He encouraged Chadwick to equate technical error with moral failing, to believe that there could be no legitimate opposition to their views on

[26]Chaired by Lord Robert Grosvenor, the commission's members were Chadwick, Dr. Thomas Southwood Smith, the anatomist Richard Owen, and Richard Lambert Jones, a City of London politician. Owen and Smith were orthodox Chadwickians, Grosvenor sympathetic and pliable; only Jones was independent.

[27]Metropolitan Sanitary Commission, *First Report* (n. 16 above), p. 24; see also pp. 2, 49.

[28]The target here was James Walker, longtime president of the Institution of Civil Engineers, who as surveyor to the Poplar Sewers Commission had endorsed flat-bottomed sewers. Walker protested that it was years ago (1834) when no one was interested in self-flushing sewers. See Metropolitan Sanitary Commission, *First Report,* evidence pp. 36, 41; Walker in discussion of Green (n. 12 above), p. 105. By contrast, Roe credited Walker with having recognized the desirability of curved-sided sewers; see the Clowes edition of E. Chadwick, *Report of an Inquiry into the Sanitary Condition of the Labouring Population of Great Britain* (London, 1842), app. 1, p. 373.

[29]Metropolitan Sanitary Commission, *First Report,* pp. 2, 24, 42–43, 51.

[30]On Phillips, see ibid., evidence p. 42; and his obituary in *Minutes of Proceedings, Institution of Civil Engineers* 64 (1897–98): 203.

sewerage and that ostensibly technical criticisms hid ulterior motives. For example, to Phillips, the Westminster Commission's rejection of his innovations could only be explained in terms of its corruption.[31] In 1842, Chadwick had suggested that poor administration went hand-in-hand with poor technology, but he had been concerned more with inefficiency and incompetence than with corruption and conspiracy. Yet by 1854, he had come to share Phillips's outlook: opposition to pipe sewers could only reflect the persistence of old vested interests, expelled from power but not annihilated.

A key task of the Metropolitan Sanitary Commission was to design a sewerage system in accord with the principles of 1845—that is, to determine how small sewers could be and how much water they could carry. Phillips (and Chadwick) found Roe's approach deficient in two respects. First, they objected to Roe's emphasis on flushing sewers on the grounds that even temporary deposits of sewage would endanger the public. Phillips proposed a self-flushing system in which there would be no deposition, no emanations, hence, no disease.[32] There was also to be a change in sewer construction: the egg-shaped brick sewers of Roe were to be superseded by glazed earthenware pipes, not only cheaper but better overall (by concentrating flow and thereby augmenting velocity, they would keep sediment in suspension even at low gradients). Chadwick called this scheme a "second revolution" in sewerage (the brick, egg-shaped sewers of Roe had been the first).[33]

The key to the effectiveness of self-flushing sewers was ensuring that sewage always flowed at the same rate, Phillips asserted. Constant velocity could be achieved by controlling the input of sewage and by arranging converging (and diverging) lines so that sewage from upper districts would flush lower districts. To control flow in this way would require controlling the input of water, closely matching sewer size to discharge (and minimizing size to maximize velocity), and keeping extraneous water (whether rainfall or soil moisture) out of the sewers—in other words, significantly redefining what a sewer was for.[34] The vision was thus one of a finely tuned system, virtually a

[31]Metropolitan Sanitary Commission, *First Report,* evidence pp. 42–48, 73. Roe, by contrast, was more tactful if no less aware of the inadequacies of the sewers commissions.

[32]Ibid., pp. 23–24, 44, evidence p. 130; "Minutes on House Drainage" (n. 13 above), p. 59.

[33]General Board of Health, *Report on the Supply of Water to the Metropolis,* app. 2, engineering reports and evidence, *PP,* 1850, vol. 22 [1282], pp. 113–15.

[34]Metropolitan Sanitary Commission, *First Report,* pp. 49–51; cf. L. C. Hertslet in discussion of G. Donaldson, "An Account of the Drainage of the Town of Richmond, Surrey, under the Authority of the Metropolitan Commissioners of Sewers," *Minutes of*

perfectly engineered city, and it entranced Chadwick. In practice he was forced to compromise on almost all of its particulars, but he maintained the ideal of theoretical perfection. The engineers who would oppose him would use the opposite approach: one started, not by stating an ideal and backing down from it, but by gradually optimizing actual conditions.[35]

The chief concession the Chadwickians had to make was in control of input. In London they did not secure control of the water supply (though they did in some towns sewered by the General Board of Health), and there were usually pressing reasons to let sewers receive street drainage, soil moisture, storm runoff, and industrial effluents, all of which had to go somewhere. In practice, therefore, the Chadwickians focused on increasing velocity, the hope being that the full carrying capacity of rapidly flowing sewage would never be called upon. As Roe had shown, in most sewers there was great room for significantly increasing velocity by decreasing diameter. As long as sewers were still less than half full this approach was uncontroversial. But Chadwick tried to apply it to sewers flowing full; it is hard to reconstruct his thinking (various rationales were given), but the argument was that in a full sewer a further decrease of diameter would increase velocity almost infinitely, with discharge remaining constant and no significant back pressure.[36]

To observations that there seemed a limit to how fast water flowed and that sewers did back up, the Chadwickians replied that much more water could be put through if there were additional branches entering. Some saw the influx of each successive branch into a descending sewer as delivering an increment of velocity (see fig. 1); others believed sewage would accelerate so that a pipe initially full would become partly empty during flow, leaving room for more sewage or even drawing it in by vacuum.[37] As the Reverend Morgan Cowie,

Proceedings, Institution of Civil Engineers 11 (1851–52): 414; R. Rawlinson, "The Drainage of Towns," *Minutes of Proceedings, Institution of Civil Engineers* 12 (1852–53): 31.

[35][Thomas Wicksteed], "A Copy of a Report by Thomas Wicksteed, CE, on the State of the Works of Drainage and Sewerage in the Town of Croydon," *PP,* 1854, vol. 61 (450.), p. 5.

[36]Metropolitan Sanitary Commission, *First Report,* evidence pp. 133–34. He was already thinking of this in 1842; see Chadwick, *Sanitary Report,* Clowes edition (n. 28 above), app. 1, p. 379n. Compare Gibbs in discussion of Rawlinson (n. 34 above), p. 95, and Hale in "First Report of Mr J. L. Hale on Some Experiments already made to Ascertain the Practicability and Advantages of substituting small Pipes in the Places of existing large Sewers and Drains," December 1848, p. 8, GLRO MCS 476.

[37]See Medworth's explanation in "Report of the Trial Works Committee," December 1849, GLRO MCS 193, pp. 20–21; Cowie in Metropolitan Sanitary Commission, *First*

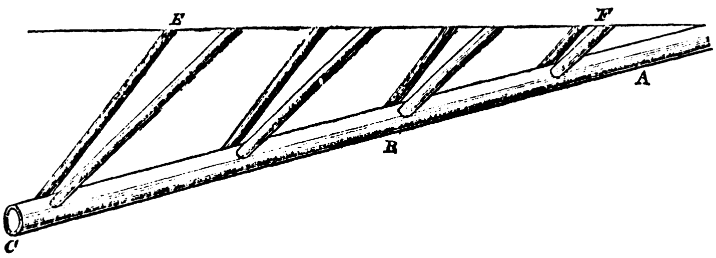

FIG. 1.—Rev. Morgan Cowie's diagram illustrating how additional inputs in a descending sewer would accelerate flow in the main sewer. The greater steepness of the branches would cause their contents to deliver an increment of velocity to the sewage flowing in the main sewer, Cowie argued. (Metropolitan Sanitary Commission, *First Report of the Metropolitan Sanitary Commission, Parliamentary Papers,* 1847–48, vol. 32 [888.], evidence p. 158.)

senior wrangler in 1839 and principal of the Putney College of Civil Engineering, put it, in theory one need not increase the aperture of a main sewer pipe no matter how much sewage from how many branches it received. The only limit was structural: the outlet had to be strong enough to withstand the jet of sewage that would issue forth.[38]

To justify this ambitious proposal, the Chadwickians tried to claim the high ground of hydraulic theory. The first report of the Metropolitan Sanitary Commission carried pages of theorems from treatises of the post-Galilean hydrologists. These were impressive but largely irrelevant. Hydraulic science was in dreadful shape, the Chadwickians argued; equations describing flow through pipes were inconsistent with one another and too conservative. Worse still were the tables derived from them by British engineers: "blindly put forward" and "as blindly followed."[39] Hawksley's equation relating velocity to head of pressure and diameter of pipe was their particular target. It was consistent with Continental authority and widely used by British engineers, but surely incorrect, Chadwick insisted. Were Hawksley right, sewers would be too expensive and "extensive voluntary adoption of works of sanitary improvement" would be impossible. He

Report (n. 16 above), p. 159; Rawlinson in Public Records Office, London (hereafter PRO), MH 13 59, no. 887/54.

[38]Metropolitan Sanitary Commission, *First Report,* pp. 158–59. On Cowie (who became chaplain to Queen Victoria), see J. Venn, *Alumni Cantabrigienses,* pt. 2, *1752–1900* (Cambridge, 1944), 2:157.

[39]H. Austin in Metropolitan Sanitary Commission, *First Report,* evidence pp. 127–28; see also in *First Report,* evidence Phillips, pp. 53–56; Cresy, pp. 141–49; Roe, pp. 81–82; Cowie, pp. 156–59; "Minutes on House Drainage" (n. 13 above), p. 65.

began to decry "hypothetical dogmas founded upon a display of algebraic signs and quantities" as no substitute for "common and empirical observation," and he called for a vast program of experiments to demonstrate what he knew to be true.[40]

Such experiments were undertaken during the summer of 1849 by a second Chadwick-dominated agency, the Metropolitan Sewers Commission, established (on recommendation of the Metropolitan Sanitary Commission) to build and administer a coordinated system of sewers for Greater London. Under the direction of its Trial Works Committee, discharge rates were determined on various sizes of pipe, laid at various inclinations with various heads of pressure and arrangements of branches. It was found, claimed Chadwick, that a single head of pressure produced discharges about a third greater than Hawksley's equation predicted, while with multiple branches discharge could be increased from three to eight times further.[41]

The experiments were put forward as proof that Chadwick's sewerage doctrine had an empirical basis, unlike that of the engineers. Yet neither the raw data nor any explanation of experimental procedure was ever published, and for good reason. Roe was in charge of the research, but most of the time he was ill and absent. Throughout the summer, unsupervised and unskilled technicians neatly plotted the inconsistent, even absurd, results they were getting. In one case, doubling steepness of a sewer from 1:480 to 1:240 led to a 30 percent decrease in velocity. When the commission was forced to resign in October 1849, the experimenters, Joseph Medworth, J. L. Hale, and Thomas Lovick, produced progress reports. Medworth, in charge of the most troublesome experiments, had extracted data that gave the sort of curve one would expect. But the Trial Works Committee, chaired by Cowie, felt itself "unable to . . . place confidence in the comparative results . . . the experiments . . . do not seem to have been

[40]"Minutes on House Drainage," pp. 62, 67. For an assessment of mid-19th-century hydrology, see A. K. Biswas, *The History of Hydrology* (Amsterdam, 1970), pp. 264–69. Among Chadwick's stratagems, his attempt to outflank the engineers on the physics of fluid flow caused the most anger. See the discussion of James Leslie, "Observations on the Flow of Water through Pipes," *Minutes of Proceedings, Institution of Civil Engineers* 14 (1854–55): 273–317. Even Rawlinson ridiculed Chadwick's theorizing: according to theory, house drains "might be reduced . . . to the size of a quill, as more water will pass through such an aperture, in the course of twenty-four hours, than is used in a cottage." See Rawlinson, p. 35.

[41]"Minutes on House Drainage," pp. 38, 67, 69. Compare "Trial Works Committee Papers," report of Medworth, May 5, 1849, GLRO MCS 193, with Medworth's explanation in "Report of the Trial Works Committee," December 1849, p. 22, GLRO MCS 193.

conducted with sufficient care . . . and are thus contradictory when compared with each other."[42]

The appalling quality of the raw data did not become public at the time. Had this happened, Chadwick would have been unable to mount the criticisms he did, but what ensued was a controversy over authority in hydraulic science. The engineers cited Continental authority: Prony, duBuat, Eytelwein, whose approaches were far more consistent than Chadwick's advisors would admit. They argued that something had gone wrong with the sewers commission experiments, even if they could not say what.[43] Chadwick, on the one hand chastising Medworth for incompetence, was, on the other, flaunting the experiments as proof that Hawksley was overthrown.[44] He sent the raw data to Roe, who was to use them to derive tables for sewer design (see fig. 2) and submit these to the General Board of Health, the agency charged with facilitating the building of sanitary works and Chadwick's last stronghold. Eschewing both formulae and the useless data, Roe produced tables based on his twenty years' experience. These indicated how many acres could be drained by a given size of sewer at a given inclination and were, after bitter correspondence between Roe and Chadwick (like Hawksley, Roe expected to be paid), acquired by the board.[45] They indicated the necessity of sewers substantially larger than some of the board's staff advocated and not significantly smaller than those indicated by Hawksley's tables.[46]

[42]See "Report of the Trial Works Committee," December 1849, and raw data, in "Trial Works Committee Papers," undated graphs (probably September 1849).

[43]Even strong opponents like Hawksley, who tried to cast suspicion on the experiments, had little specific information; see discussion of Leslie, pp. 291–93, 315; J. Bazalgette, "The Drainage of London," *Minutes of Proceedings, Institution of Civil Engineers* 24 (1864–65): 355–56. But see *Engineers and Officials* (n. 21 above), pp. 49–52. See also Bateman in discussion of Bazalgette, p. 340; Murray in discussion of Rawlinson (n. 34 above), pp. 54–57; Hawksley and Bidder in discussion of Harrison (n. 10 above), pp. 116–17; discussion of Leslie (n. 40 above), pp. 273–317.

[44]General Board of Health, *Water Supply Report* (n. 33 above), pp. 185–93. See also W. Lee in "Communication from the GBH and Reports from the Superintending Inspectors to the Board, made to the Secretary of State in relation to the Reports of the Metropolitan Sewers Commission in Respect to the Operation of Pipe Sewers" (hereafter "Reports from the Superintending Inspectors"), *PP*, 1854–55, vol. 45 [1891.], pp. 18–21.

[45]"Minutes on House Drainage" (n. 13 above), pp. 67–69; Roe to Cowie, February 19, 1849, GLRO MCS 192; Roe to Austin, February 9, 1852, June 19, 1852, Chadwick MSS (n. 22 above), no. 206; Chadwick to Roe, December 19, 1851, Roe to Chadwick, March 2, 1852, March 9, 1852, Chadwick to Roe, March 30, 1852, Chadwick MSS, no. 1704.

[46]Roe to Chadwick, December 1, 1852, December 8, 1852, Chadwick MSS, no. 1704; Hawksley in discussion of Rawlinson, p. 57. Medworth felt some of his results confirmed Hawksley; see "Report of the Trial Works Committee" (n. 37 above),

TABLE 2.—SHOWING THE QUANTITY OF PAVED OR COVERED SURFACE FROM WHICH CIRCULAR SEWERS (WITH JUNCTIONS PROPERLY CONNECTED) WILL CONVEY AWAY THE WATER COMING FROM A FALL OF RAIN OF ONE INCH IN ONE HOUR, WITH HOUSE DRAINAGE, AS ASCERTAINED IN THE HOLBORN AND FINSBURY DIVISIONS.

	Diameter of Pipes and Sewers in inches.											
	24	30	63	48	60	72	84	96	108	120	132	144
	acres	acres	acres	acres	acres	acres	acres	acres	acres	acres	acres	acres
Level	38¾	67¼	120	277	570	1,020	1,725	2,850	4,125	5,825	7,800	10,100
¼″ in 10′ or 1 in 480	43	75	135	308	630	1,117	1,925	3,025	4,425	6,250	8,300	10,750
½″ in 10′ or 1 in 240	50	83	—	355	735	1,318	2,225	3,500	5,100	7,175	9,550	12,400
¾″ in 10′ or 1 in 160	63	113	203	460	950	1,692	2,875	4,500	6,575	9,250	12,300	15,950
1″ in 10′ or 1 in 120	78	143	257	590	1,200	2,180	3,700	5,825	7,850	11,050	14,700	19,085
1½″ in 10′ or 1 in 80	80	165	295	670	1,385	2,486	4,225	6,625				
2″ in 10′ or 1 in 60	115	182	318	730	1,500	2,675	4,550	7,125				

FIG. 2.—John Roe's table for determining sewer sizes, based on his twenty years' experience, was all that could be salvaged from the Metropolitan Sewers Commission's 1849 experiments. They indicated sewers significantly larger than Chadwick preferred. (Reprinted in E. C. S. Moore, *Sanitary Engineering: A Practical Treatise on the Collection, Removal, and Final Disposal of Sewage* [London, 1898], p. 35.)

While the sewer-flow experiments were going on, the "arterial-venous" approach was itself being tested. During the nearly two years his faction dominated the Metropolitan Commission of Sewers (December 1847–October 1849), Chadwick was forced to recognize the great difference between designing an ideal system and implementing it. His biographers attributed his failures to the persistence of the old order that retained enough power to clog the procedure of the new commission.[47] But the Chadwickians held a working majority until their deposition; their failure to achieve anything significant was, as the *Times* recognized, due more to bewilderment about how to begin than to opposition.

So well integrated were the components of Chadwick's "arterial-venous" city that there was no clear place to begin a design. Cowie

pp. 15–16. Roe backed off earlier claims that sewers could be made significantly smaller; see Metropolitan Sanitary Commission, *First Report,* evidence p. 81.

[47]Finer (n. 2 above), pp. 356–78; Lewis (n. 2 above), pp. 216–37.

argued that one had first to think about end use, about sewage recycling. It made no sense to design upstream features of the system until one knew whether sewage was to be recycled in liquid form or as solid precipitate. Chadwick wanted to start with house drains and street sewers, but the *Times,* and Phillips, protested that until the location of the outfall(s) had been decided on it was not clear where the street sewers ought to go. John Leslie, a progressive on the old Westminster Commission but Chadwick's bane on the new commission, invoked Chadwick's own dictum that the success of pipe sewerage depended on control of the water and urged this as a priority. Detailed planning had to await completion of a topographic survey, the Chadwickians insisted, but here the question arose of whether the surveyors should concentrate on the sort of fine-grained survey needed to sewer individual houses and streets or a general survey for determining the line of the main drainage. Temporary drainage works were out of the question: they would represent wasteful, perhaps deadly, expenditure.[48] Thus, a large force was employed for nearly two years on work that brought little immediate benefit to Londoners: a survey, the hydraulic experiments (and experiments on sewage utilization, sewer ventilation, and pipe manufacture), a "subterranean survey" of existing sewers, and a few small, local sewerage projects.

The years from 1850 to 1854 were the main period of application of Chadwick's sewerage program. The Board of Health's superintending engineering inspectors, all loyal Chadwickians, sanctioned towns' plans for sanitary works (and, as they were only inspectors part-time, often undertook to build them as well). But Chadwick's "system" remained a concept rather than a set of rules. The main "how-to" manual, the board's "Minutes on House Drainage" (1852), was aspecific and frequently lapsed into platitudes or into polemics against orthodox engineers.[49] Just how open-ended the doctrine was is clearest with regard to the key issue of sewer size. How much surface runoff should one allow for, for example? Sewers big enough to handle a heavy rain would in drier times be too big to maintain the rate of flow needed to prevent deposition. Unwilling (except in the case of Phillips) to endorse the expense of separate sewerage, the

[48] *Times* (London) (July 21, 1849), p. 6b, (July 24, 1849), p. 8d, (July 27, 1849), p. 6f, (July 30, 1849), p. 3b, (July 31, 1849), p. 7c, (August 4, 1849), p. 4e, (September 24, 1849), p. 3f, (September 28, 1849), p. 5b, (October 4, 1849), p. 6c, (October 20, 1849), p. 4e. Compare Metropolitan Sanitary Commission, *First Report* (n. 16 above), pp. 25, 39–40, 49, evidence p. 61 (Phillips).

[49] "Minutes on House Drainage" (n. 13 above). See also "Report of the Surveyors on House Drainage," GLRO MCS 198.

Chadwickians downplayed the likelihood of heavy rainfalls or suggested alternative outlets for excess rain.[50] Having determined how much discharge to allow for, one faced the problem of calculating sizes. Should one believe the great claims made on authority of the unpublished sewers commission experiments, or Roe's less radical tables, or find a good rule of thumb? When Robert Rawlinson drained 550 acres at Hitchin through a 20-inch sewer, Roe protested. His own tables, based on actual gaugings, indicated a 60-inch sewer. To get the requisite discharge with a 20-inch pipe would require sewage to flow 4 miles per minute, he claimed.[51]

Even when the principles seemed clear, Chadwick's engineers frequently departed from them. Chadwick held that sewers became blocked because they were too large and that, the flatter the sewer, the more important it was to use a small-bore pipe. He also insisted that in properly working pipe systems no ventilation was necessary; rapid flow would create a downstream current of air and remove sewage before it could emit dangerous gases.[52] On all these issues his own engineers broke ranks. Whatever the hydraulic merits of 2-, 3-, and 4-inch pipes, most Chadwickian engineers preferred 6- and 9-inch pipes. Even John Grant, who endangered his career by supporting Chadwick, favored using pipes only for short, steep runs of sewer. And ventilation was admitted as a practical necessity, even by Austin, the most doctrinaire of the Chadwickians.[53]

[50]"Minutes on House Drainage," pp. 14, 62; "Report of the Trial Works Committee," pp. 3–4.

[51]Rawlinson (n. 34 above), p. 41. Roe to Chadwick, December 1, 1852, December 8, 1852, Chadwick MSS, no. 1704; Roe in discussion of Rawlinson, pp. 96–98. Compare the criticisms of Heywood in discussion of Rawlinson, p. 52. Rawlinson and Austin developed their own rules of thumb that did not depend on hydraulic formulae; see Rawlinson in discussion of Bazalgette (n. 43 above), p. 317; Austin in "Trial Works Committee Minutes," pp. 47–52, GLRO MCS 192.

[52]"Metropolitan Sanitary Commission," *First Report,* evidence p. 69 (Phillips).

[53]On sewer sizes, see General Board of Health, *Water Supply Report* (n. 33 above), pp. 108–11 (Lovick), 136 (Grant), 156 (Gotto); Rawlinson and Heywood in discussion of Rawlinson (n. 34 above), pp. 35, 51; Page, in "Reports by Neil Arnott, MD, and Thomas Page CE on an Inquiry ordered by the Secretary of State Relative to the Prevalence of Disease at Croydon and to the Plan of Sewerage," *PP,* 1852–53, vol. 96 [1648.], pp. 39–40. Even Austin admitted that the pipes in Croydon were too small; see "Statement of the Preliminary Inquiry by T. Southwood Smith, Esq., MD and John Sutherland, Esq., MD on the Epidemic at Croydon; together with Reports by R. D. Grainger Esq. and Henry Austin Esq. to the General Board of Health on the Circumstances connected with the Epidemic Fever at Croydon" (hereafter "First Croydon Report"), *PP,* 1852–53, vol. 96 [1683.], pp. 39–40. On Grant, see General Board of Health, *Water Supply Report,* pp. 135–36. On ventilation, see "First Croydon Report," p. 44; and Henry Austin, "Further Report from the Consulting Engineer to the General Board of Health on the Croydon Drainage" (hereafter "Second Croydon

* * *

Prior to 1852 there was little reaction by orthodox civil engineers to Chadwick's campaigning. Land surveyors had fought his proposal to employ military engineers on sanitary surveys, but, despite Chadwick's regular attacks on their competence, the elite at the Institution of Civil Engineers had been remarkably quiet.[54] As the Board of Health's inspectors began roaming the country, however, condemning the plans of leading engineers, undermining their relations with clients, displacing them, and even, it was alleged, stealing their plans, it became impossible to maintain a dignified silence.[55] The inspectors' harassment was no accident. The board's "Instructions . . . to the Superintending Inspectors" (1848) warned inspectors to be on their guard as they visited towns. They would be presented with sewerage schemes not in accord with correct principle, and they were not even to consider these. It was hard to ignore the 10,000 copies of the board's "Minutes on House Drainage," which informed towns that they could have excellent sewers for 40 percent of what orthodox engineers estimated. The board also warned local boards that they might be prosecuted under the Nuisances Removal Act if they built conventional sewerage systems.[56]

Report"), *PP,* 1852–53, vol. 96 [1009.], pp. 9–10; Rawlinson, p. 39; "First Report of Hale" (n. 36 above), p. 6.

[54]But see J. Simpson in discussion of Green (n. 12 above), p. 95. On surveyors' responses, see F. M. L. Thompson, *Chartered Surveyors: The Growth of a Profession* (London, 1968), pp. 115, 119–20; "The Civil Surveyors and the Military Engineers," *Civil Engineer and Architect's Journal* 11 (1848): 198; comments on J. Newlands, "Report to the Health Committee on the Sewerage [of Liverpool]," ibid., pp. 278–79; *Times* (London) (May 26, 1848), p. 8f, (June 10, 1848), p. 8f.

[55]Hawksley and Bidder in discussion of Leslie (n. 40 above), pp. 295, 312; [Wicksteed] (n. 35 above), p. 4. For defense of this practice, see General Board of Health, "Report by the GBH on the Measures Adopted for the Execution of the Nuisances Removal and Diseases Prevention Act, and the Public Health Act up to July 1849" (hereafter "First Report on the Public Health Act"), *PP,* 1849, vol. 24 [1115.], pp. 44–45. See also "Return of all cases in which Superintending inspectors of the GBH have been employed as Engineers in carrying out the works which have been executed under the Authority of the Public Health Act, 1848," *PP,* 1852–53, vol. 96 (512.), p. 1.

[56]"First Report on the Public Health Act," pp. 64–65, 131–34; "Minutes on House Drainage" (n. 13 above), pp. 143–44; General Board of Health, "Report from the GBH on the Administration of the Public Health Act and the Nuisances Removal and Diseases Prevention Acts" (hereafter "Second Report on the Public Health Act"), *PP,* 1854, vol. 35 [1768.], p. 40. Pipe sewerage cost one-quarter as much as brick according to Austin; see "Second Croydon Report," p. 7. See also Thomas Hawksley, "Letter to the Most Hon Marquis of Chandros M.P. in Relation to the Exercise of Some of the

Not until the end of 1852 were there enough completed works to allow assessment of Chadwick's approach. The following months saw investigations of the new works in Croydon, first town to be sewered under GBH doctrine, as well as in London and elsewhere. The Croydon investigations revealed both technical problems in pipe sewerage and procedural problems in the board's oversight of sanitary engineering. In 1849, William Ranger, GBH superintending inspector, approved a plan for Croydon sewerage submitted by the erstwhile Chadwickian George Donaldson and Thomas Cox, Croydon's surveyor. Ranger soon took over from Donaldson and altered his plans, using even smaller sewers—most 6-inch sewers became 4-inch, most 9-inch became 6-inch.[57] The sewers were finished in mid-1852, and within weeks there were reports of breakages and blockages. Fever broke out. Chadwick ordered an investigation. His medical men found that the sewers had not caused the fever, while Austin, his chief engineer, attributed the defects in sewerage to poor installation: they were Cox's problem.[58]

Chadwick's mistake was to seek the exoneration of an independent Home Office inquiry. This was assigned to Dr. Neil Arnott, his aging Benthamite crony, and Thomas Page, a Board of Trade engineer. Arnott was brief, but Page's engineering report was detailed and damning. The sewers were simply too small and too thin. Page saw no grounds for Ranger's changes nor any rationale for the design as a whole. There were numerous changes of gradient, and no attempt at securing the steady flow Chadwick called for. But what alarmed him most was the GBH's attempt to avoid responsibility. The GBH held that Ranger acted privately in designing the sewers and that its inspection (by Ranger) could not take in "every minute portion of the plans." But Cox and the contractors could not be held responsible, Page maintained; as the GBH insisted on a particular approach, it was responsible for the satisfactory working of the sewers.[59] In fact,

Most Extraordinary Powers Assumed by the General Board of Health and the Superintending Inspectors," in Chadwick MSS (n. 22 above), no. 960.

[57]Page, "Reports" (n. 53 above), pp. 26–27. Ranger denied the systematic downsizing he was accused of, but this denial was not made part of the GBH's official response to the investigation. According to Ranger, he significantly revised the Donaldson-Cox plan, and what had been private drains became small public sewers. See Ranger to GBH, September 19, 1853, PRO MH 13 59. Compare Lewis (n. 2 above), pp. 314–17; Finer (n. 2 above), pp. 447–48.

[58]Austin, "First Croydon Report," pp. 38, 42.

[59]Page, "Reports," pp. 33, 46–47, 51–52. Austin, "First Croydon Report," pp. 38–40, "Second Croydon Report," pp. 8, 10–11.

stipulations in the Public Health Act for rigorous inspection did not appear to have been met.[60]

In late 1852, in the midst of the Croydon controversy, the Metropolitan Sewers Commission, no longer part of Chadwick's empire, sent Bazalgette, its engineer, to investigate pipe sewers in other GBH towns and in London, the latter installed chiefly during the period of Chadwickian dominance in 1848–49. Bazalgette too found blockages and breaks. In February 1853, he made an unannounced inspection of 122 London pipe sewers. Of these, 66 had greater than 2 1/2 inches of deposit, while 47 had deposits less than 2 1/2 inches deep and 23 were cracked or broken. (Or so Bazalgette claimed: it was rumored that the sewers had been opened for inspection by a contractor hostile to pipe sewerage—at best Bazalgette had been tricked.) By 1855, the Chadwickians had regained influence on the commission and the district (assistant) surveyors were asked their views of pipe sewerage. Two of them, John Grant and Thomas Lovick, denied Bazalgette's facts (see fig. 3). Grant, who would later become Bazalgette's chief assistant at the Metropolitan Board of Works, accused his superior of blocking access to records that would show the truth. The episode ended with Bazalgette threatening Grant with legal action.[61]

It is in the Chadwickians' responses to the charges made in these reports that one finds most clearly the image of the righteous few hounded by a conspiracy of reactionaries. Austin accused Page, for example, of biased observation or willful misrepresentation. Chadwick, who was preparing an exposé of corruption among engineers, wanted to take the offensive. Rawlinson and Austin counseled moderation, but the 1854 report of the GBH depicted engineers as part of a cadre of opponents to sanitation.[62]

Yet it is not clear that the critics saw themselves as a united opposition. They approached pipe sewers, not as a doctrine, but as an

[60]"First Report on the Public Health Act," p. 63.

[61]"Copy of the Reports of Mr Bazalgette to the Metropolitan Commission of Sewers, relating to the Application, State, and Examination of Tubular Pipe Drains and Sewers," *PP*, 1852–53, vol. 96 (668.), pp. 12–13; Lee, in "Reports from the Superintending Inspectors" (n. 44 above), p. 17; "Copies of Reports to the Metropolitan Commission of Sewers on the Working of Pipe Sewers, of the District Engineers, Messrs Lovick, Grant, Cooper, Donaldson, and Roe," *PP*, 1854–55, vol. 53 (281.), pp. 3–6, 29–33, 36–40, 42; *Engineers and Officials* (n. 21 above), pp. 76–77.

[62]Austin, "Second Croydon Report" (n. 53 above); "Second Report on the Public Health Act," pp. 45–53; Lee, in "Reports from the Superintending Inspectors," pp. 46–52. For the corruption, see Lee to Chadwick, November 9, 1852, Chadwick MSS, no. 1201; for Rawlinson's caution, see Rawlinson to Chadwick, January 26, 1854, Chadwick MSS, no. 1645.

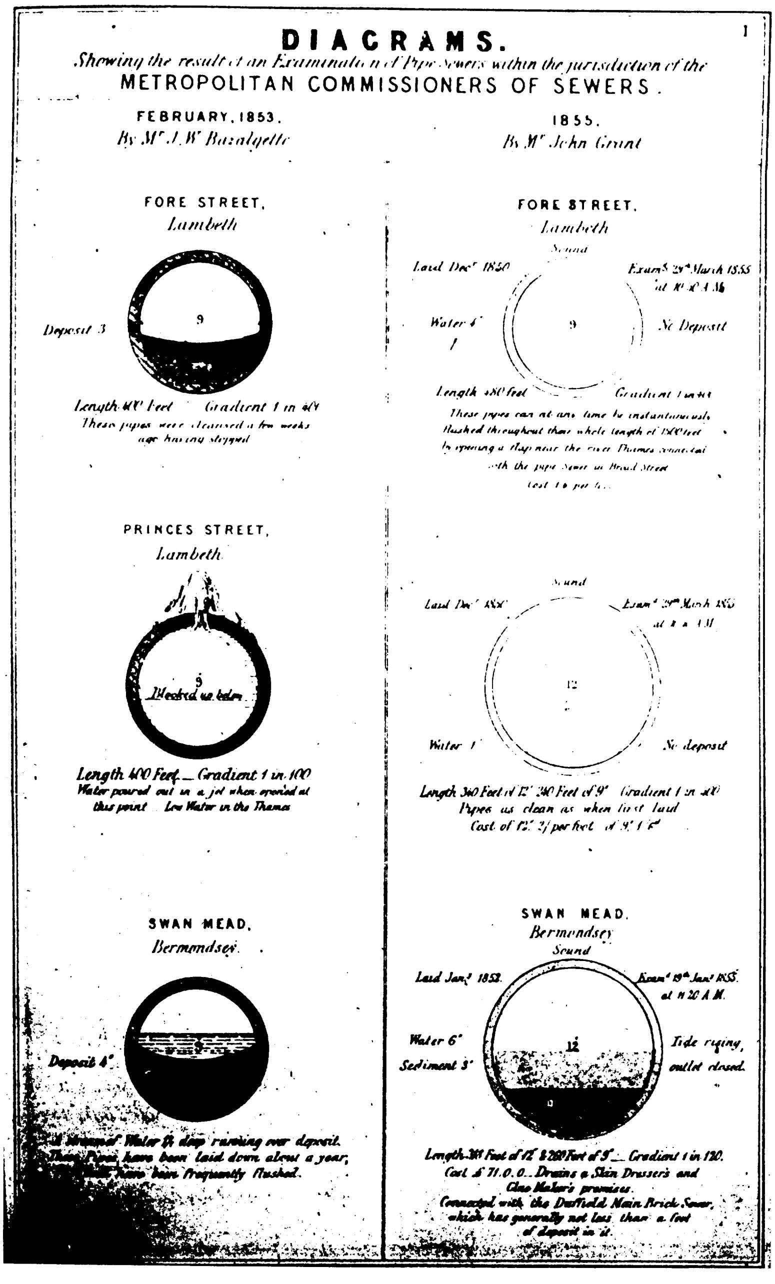

FIG. 3.—Included in John Grant's defense of pipe sewerage were cross-sectional drawings of the sewers in question. The left column reproduced drawings accompanying Bazalgette's 1853 report; the drawings on the right showed the same sewers as Grant found them in 1855. ("Copies of Reports to the Metropolitan Commission of Sewers on the Working of Pipe Sewers, of the District Engineers, Messrs Lovick, Grant, Cooper, Donaldson, and Roe," *Parliamentary Papers,* 1854–55, vol. 53 [281.], p. 45.)

attractive new technique whose applicability had to be worked out.[63] Their perspective is evident in four papers on sewerage read at the Institution of Civil Engineers between March 1852 and February 1855, each generating lengthy discussion of Chadwick's doctrine. The first author, George Donaldson, a Chadwick-appointed assistant surveyor to the Metropolitan Sewers Commission, described the commission's sewerage of the suburb of Richmond. Donaldson had been told to use pipe sewers as far as possible and ended up building about 10 miles of pipe sewers and about 2.5 miles of brick sewers. He opposed pipes except for short, steep runs.[64] Eight months later the general question of "The Drainage of Towns" was taken up by Rawlinson, the most conciliatory and successful of Chadwick's engineers. Yet Rawlinson took much the same line: small pipe and large brick sewers each had advantages, disadvantages, and appropriate uses.[65] In 1855, John Thornehill Harrison's paper considered the main drainage of low areas south of the Thames, and James Leslie discussed flow-through pipes.

The theme of these papers was the engineers' opposition to a single, systemic solution. The GBH had done "great evil . . . endeavouring to suggest general systems which were to prove panaceas, when the very nature of the work . . . required variations in levels, sizes of sewers, and materials, not only varying with different localities, but also in each locality," complained Thomas Wicksteed.[66] Page contrasted two ways of designing sewers, one according to "the maxims of the General Board of Health, which point to the sizes of pipes, to their use as conducts [*sic*] for rubbish, to the ventilation in the direction of the outfall, to the outfall itself, and to the economy in the first cost of the work," and the other (preferable) "depending upon the state and requirements of the population, and so arranged that its operations shall leave nothing to be desired that can practically be effected for their convenience and health, a result which does not depend on the adoption of pipe sewers or brick sewers, but upon the use of such sewers as shall completely, and economically, and enduringly effect the object."[67] Almost all en-

[63]Bazalgette's criticisms were mild; see "Bazalgette to the Metropolitan Commission of Sewers" (n. 61 above), pp. 1–2, 11–12. They led to a Metropolitan Sewers Commission decision to use pipe sewers no smaller than 9 inches in diameter, at a gradient of at least 1:200; see Page, "Reports" (n. 53 above), p. 43.

[64]Donaldson (n. 34 above), pp. 408–9, 421. Donaldson was even more antipipe by the end of the year; see discussion of Rawlinson (n. 34 above), pp. 42–43.

[65]Donaldson, pp. 407–21; Rawlinson, pp. 25–109.

[66][Wicksteed] (n. 35 above), p. 5.

[67]Page, "Reports," pp. 46, 48.

gineers used pipe sewers, leaders of the profession insisted, but not indiscriminately.[68]

One can read such statements as routine assertions of professional autonomy. Yet they reflected the context in which British engineers worked. In the reports they wrote as consultants on sanitary matters, engineers considered problems as they were defined by clients.[69] As a bureaucrat with power, Chadwick could ignore clients; his inspectors could impose a vision of a properly sanitized town on all the towns that came under their consideration.

One implication of the engineers' perspective was that there was no single technical solution. Wicksteed, one of Chadwick's nemeses, observed that larger towns able to afford "a permanent work, [would probably] prefer a large-sized [brick] sewer"; smaller places "might postpone the larger work until they could better afford it" and prefer the cheaper pipes. The choice was "to a great extent, a ratepayers' question, not an engineering one."[70] One was to think not of right or wrong but of advantages and disadvantages of particular designs in particular circumstances. The engineers argued further that many factors other than hydraulics should enter into sewerage design.[71]

[68]Simpson, in discussion of Rawlinson, p. 94. See also Bazalgette and Stephenson, in discussion of Rawlinson, pp. 67, 84–85; Page, "Report," pp. 38–39. Rawlinson placed his own gentle advocacy of pipe sewers in this context; see Rawlinson, pp. 36, 100.

[69]On the structure of the British engineering profession, see Gareth Watson, *The Civils: The Story of the Institution of Civil Engineers* (London, 1988); Charles M. Norrie, *Bridging the Years: A Short History of British Civil Engineering* (London, 1956); F. R. Conder, *The Men Who Built the Railways: A Reprint of F. R. Conder's Personal Recollections of English Engineers*, ed. Jack Simmons (London, 1983); *The Education and Status of Civil Engineers, in the U.K. and in Foreign Countries*, compiled from documents supplied to the Council of the Institution of Civil Engineers (London, 1870); R. A. Buchanan, "Engineers and Government in Nineteenth Century Britain," in *Government and Expertise: Specialists, Administrators, and Professionals, 1860–1919*, ed. Roy M. MacLeod (Cambridge, 1988), pp. 41–58. Compare Edwin T. Layton, *The Revolt of the Engineers: Social Responsibility and the American Engineering Profession* (Baltimore, 1986), esp. chaps. 1, 3, 5.

[70][Wicksteed], pp. 1–5; PRO MH 13 59, nos. 1950/53, 2061/53. This difference in context might account for what to Chadwick seemed hypocrisy on the part of engineers. He could not understand, except in metaphors of heresy, how Hawksley, who favored constant water supply in one case, could advocate intermittent supply in another or how Roe could speak against pipe sewers. But both justified themselves on the grounds of assessing each case independently. See Chadwick to Roe, December 19, 1851, Chadwick MSS (n. 22 above), no. 1704. By contrast, Chadwickian engineers like Rawlinson insisted that there was a single right answer; see Rawlinson, pp. 27–28.

[71]Robert Stephenson suggested the analogy of a steam engine in developing a sewer design: just as one judged an engine not only by its power output per unit fuel but by the "facility for its erection, for its being kept in order, and for its rapid and effective repair," so must one judge a sewer system. See discussion of Rawlinson, p. 86.

Especially important were the questions of sewer capacity, strength of works, and blockages. Chadwick held that any clog in a pipe sewer would generate the pressure needed to remove it and also that a clog indicated too low a velocity due to too large a pipe or too little water. But hydraulic arguments aside, most engineers were unwilling to use pipes smaller than 6 inches. Small pipes clogged too easily, they felt, and it was difficult to unclog them. They continued to insist on flushing provisions despite the GBH claim that these were unnecessary in properly designed sewerage and continued to require steep gradients where pipe sewers were used.[72]

Chadwick's strategy for keeping sewers clear centered on controlling their use by inspecting household connections and instructing the public in the proper use of the new sanitary appliances. But in Croydon and London, failure to address these matters led to blockages. Cloth, paper, hair, and more exotic fare such as a bullock's heart blocked sewers. The Chadwickians believed that, with sufficient effort, the strategy of inspection and instruction could work.[73] But engineers were skeptical. Given the vast number of connections to a public sewer, even if accidents were rare they would cause great damage. To locate a blockage, a long length of pipe might have to be exposed; pipes were difficult to re-lay and often became reblocked at the same spot.[74] And even if it were possible to keep out illegitimate detritus, legitimate materials like hair, grease, and road grit could block sewers. These might resist even high-pressure flushing.[75] Grit-minimizing pavements were not enough; Roe, Rawlinson, and others

[72]"Minutes on House Drainage" (n. 13 above), pp. 33–34; Austin, "Second Croydon Report" (n. 53 above), pp. 14, 22; "Second Report on the Public Health Act" (n. 56 above), p. 23; "Reports from the Superintending Inspectors" (n. 44 above), pp. 25–27, 75, 78, 97. Some early GBH towns (Exeter, Tottenham) did have very flat pipe-sewer systems (1:1,000); "Reports from the Superintending Inspectors," pp. 22–23. Many engineers, including some Chadwickians, insisted that tubular drains required a gradient on the order of 1:60, which significantly restricted their use. See also John Fulton, "Description of the Drainage of the Borough of Dundee," *Minutes of Proceedings, Institution of Civil Engineers* 22 (1862–63): 264; "Reports of the District Engineers" (n. 61 above), pp. 20, 27.

[73]Metropolitan Sanitary Commission, *First Report* (n. 16 above), pp. 41, 122; Page, "Reports" (n. 53 above), p. 49; Austin, "Second Croydon Report," p. 23.

[74]Discussion of Rawlinson (n. 34 above), pp. 46–49; in discussion of Harrison (n. 10 above), p. 91. See also Donaldson (n. 34 above), p. 421; Fulton, p. 268. The GBH experience confirmed these views; see Rammell, in "Reports from the Superintending Inspectors," pp. 57, 66–67.

[75]Donaldson, pp. 410, 413; Hawksley, in discussion of Donaldson, p. 417; Fulton, pp. 262–72, esp. p. 270; Alfred Williams, "Description of the Sewerage and Drainage Works of Newport, Monmouthshire," *Minutes of Proceedings, Institution of Civil Engineers* 22 (1862–63): 273–304, esp. 277.

taxed their ingenuities in designing grit-removing traps as well as traps for house drains. For this reason many engineers continued to favor brick sewers large enough to be cleaned or repaired manually, though not *designed* to require such attention.[76] Since things might go wrong, there was need for access to sewers. The Croydon sewers had only five manholes in 17 miles of sewer, but by 1852 even Rawlinson was calling for a manhole every 100 yards.[77]

Blockages raised the question of system boundaries. Were such problems intrinsic and justly held against the system or extrinsic (somebody else's problem) and therefore irrelevant to its assessment? The two sides might agree on the facts but assess them differently. Were "difficulties, failures, and disappointments . . . to be looked upon . . . as so serious . . . and so necessarily inherent in the system, and that system itself so worthless, as to deter from the attempt to overcome them?" asked Rammell, one of the GBH inspectors. No, insisted Austin: "failures have not arisen from causes inherent in the system, but from causes palpable and preventable. . . . [In] pipe drainage, fairly and properly executed, [these] may be . . . entirely avoided." The fact that pipe sewers in St. Giles had failed in part because the area was inhabited by "the lowest and most filthy of the Irish" was a valid explanation.[78] It had always been made clear that pipe sewerage required a large and constant input of water and control over what went down the drain. That problems arose when this was not provided reflected no error in doctrine and was not the responsibility of its proponents.

Bazalgette, by contrast, held that one had to accept the full weight of circumstance in judging pipe sewers: if they "required more perfect workmanship and greater care than is ordinarily obtainable to make them effective, and that the absence of this degree of perfection subjected them to frequent temporary failures, these facts might become sound reasons for a more limited application of pipe sew-

[76]The Chadwickians misrepresented orthodox views on this issue. They assumed that sewers large enough to permit manual cleansing were intended to be cleansed manually. Rawlinson and Chadwick argued that requiring workmen to clean sewers manually was like forcing little boys to climb chimneys, a practice inhumane as well as uneconomical and (so they claimed) unhealthy. For Chadwick, this was part of the meaning of "sewers of vicious construction." See Rawlinson, p. 28; "Minutes on House Drainage," pp. 26–30.

[77]Page, "Reports," p. 49; Rawlinson, p. 38.

[78]Rammell, in "Reports from the Superintending Inspectors" (n. 44 above), p. 74; Austin, "Second Croydon Report," pp. 5, 11–13; "First Croydon Report" (n. 53 above), p. 40. On St. Giles, see Lee in "Reports from the Superintending Inspectors," pp. 9, 17. Grant protested use of "failure" to refer to a "local or temporary accident"; see "Reports of the District Engineers," pp. 29, 37.

ers."[79] There was no point calling problems "avoidable" if they were not avoided; it might be possible to obtain constant flow, teach people what not to throw down the drains, and supervise every installation, but the designer of sewers had to allow for accident and error. In essence, the question was whether technology was master or servant. For the engineers, a satisfactory system was designed for society as it was; for Chadwick, it was necessary to alter society to suit the system. Page put it simply: "as the population can not be hastily fitted for the sewerage, the sewerage must be fitted for the population."[80]

As to capacity, to determine this one had to decide what sewers were for. Chadwick, as we saw, sought to change their purpose from removing surface and soil moisture to spiriting away wastes. But both jobs needed doing. Reluctant to acknowledge a need for separate sanitary and storm sewers, the Chadwickians held that a single network could accommodate both house waste and modest rainfall, though separate tile drains might be needed to carry off groundwater. In practice, GBH engineers often relied on old sewers to remove storm and groundwater, and critics pointed out that if these supplementary systems really were required their cost should be acknowledged in GBH claims of economy. Brick sewers did all three jobs, they noted. Leaving roof or side bricks unmortared allowed sewers to drain groundwater.[81]

If sewers had to receive some rain, how much should be planned for? Should one plan for averages or extremes? Hawksley accused Chadwick of thinking in terms of a quarter- or a half-inch of rain per day even though there were cases of 2 inches falling in an hour. The Chadwickians saw such observations as excuses for wanton overbuilding, but if sewers really were to have a flood-prevention role, there was a warrant for concern.[82] In essence, Hawksley was criticizing the premium Chadwick put on the fine-tuning of components to a single use; he believed sewer systems should serve as many functions as

[79]"Reports of the District Engineers," p. 34. Finer (n. 2 above), accuses Bazalgette of having "little conception of scientific method" in thinking that a few failures "discredited the system" (p. 449).

[80]Page, "Reports" (n. 53 above), p. 46.

[81]Walker, in discussion of Green (n. 12 above), p. 107; Rawlinson, pp. 40–41; Bazalgette, in discussion of Rawlinson, p. 68; "First Report on the Public Health Act" (n. 55 above), pp. 130–31. Phillips saw need for a triple system, separating sanitary sewage from storm and street drainage. Austin and Lee boasted, however, that pipe sewers could act as subsoil drains, with groundwater entering through cracks in the junctions. Their claim did not sit well with the usual GBH claim that pipe sewers were impermeable. See "Second Croydon Report" (n. 53 above), p. 20; "Reports from the Superintending Inspectors" (n. 44 above), pp. 29, 41.

[82]Hawksley, in discussion of Donaldson (n. 34 above), p. 418; cf. Phillips and Austin, in Metropolitan Sanitary Commission, *First Report* (n. 16 above), pp. 53, 118; Rawlinson

possible. Rawlinson, by contrast, thought sewers should be "adapted, exclusively, for removing all the liquid and soil refuse from houses."[83]

Furthest from Chadwick's experience were problems of structural integrity. He worried about pipe strength but could not decide how strong pipes had to be and had no way to ensure uniform quality, either in manufacture or installation. The early pipes did break often. As rigid structures they were less able to respond to distorting force than were brick sewers; heavy overhead traffic could break an unevenly supported pipe. Prudent engineers, including GBH inspectors, found it expedient to strengthen pipes by jacketing them in concrete, laying them in puddled clay or hard-packed earth, or protecting them with an overlying brick arch. Bazalgette refused to use pipes in deep excavations because he worried both about the damage to structures and the expense incurred by the need to dig down and repair them.[84] The Chadwickians claimed that even if pipes had to be replaced yearly they would still be cheaper than a brick manual-cleansing system. But engineers took a broader notion of public good. Wicksteed opposed use of pipes on busy commercial streets because of the disruption of commerce caused by the need to dig them up.[85] Most engineers, including Rawlinson, would not use pipes greater than 15–20 inches in diameter; manufacturers simply could not produce good big pipes.[86] They also worried about joining pipe segments (either mortar squeezed into the interior, blocking flow, or the joints leaked) and about internal wear: road grit, carried along at the high velocities, would erode the relatively soft earthenware, suggested James Simpson.[87]

(n. 34 above), p. 31; and Heywood, Hawksley, and Roe, in discussion of Rawlinson, pp. 46, 58, 99; Rawlinson, in discussion of Fulton (n. 72 above), p. 298. This was one of the few issues to be quickly resolved, Bazalgette admitting in 1865 that Rawlinson, who held that even with lots of gullies most rain ran off on the surface or was absorbed by the soil, was right. See Bazalgette (n. 43 above), p. 292.

[83]Rawlinson, p. 29. Compare Lavers, in discussion of Donaldson, p. 420; Hawkshaw, in discussion of Bazalgette (n. 43 above), p. 329.

[84]Rawlinson, p. 41; Donaldson, p. 410; discussion of Donaldson, p. 416; Donaldson and Parker, in discussion of Rawlinson, pp. 43, 66; Rammell and Ranger, in "Reports from the Superintending Inspectors" (n. 44 above), pp. 75, 77.

[85]P. H. Holland, in discussion of Rawlinson, p. 76; [Wicksteed] (n. 35 above), p. 5.

[86]Rawlinson, p. 37. In Manchester, pipes up to 30 inches in diameter had been used successfully, but these could be made with very thick walls (almost 4 inches) owing to use of a local clay. See Rawlinson, pp. 42, 45; Cliff, in discussion of Rawlinson, pp. 78–79. Doulton, principal manufacturer of pipes, admitted problems in quality control; see Rawlinson, p. 60.

[87]Donaldson, Doulton, Parker, J. Cliff, and Simpson, in discussion of Rawlinson, pp. 43, 60, 66, 78–79, 92–93; Simpson, in discussion of Harrison (n. 10 above), p. 94; [Wicksteed], p. 5.

* * *

Advocacy of the pipe-sewerage system died out after Chadwick's expulsion from the General Board of Health in 1854. Chadwick expected his engineers to follow him into exile, but most did not.[88] Subsequent sewerage projects generally used both pipe and brick sewers. It was usually felt that for diameters larger than 20 inches (some even said 12 inches) brick was cheaper. Diameters were reduced, though less than Chadwick advocated; manual cleaning died out, though provisions for ventilation, inspection, and repair became commonplace.[89] Chadwick remained unrepentant, but in 1857 Austin apologized: "to confess that some amongst us, over-zealous in the pursuit of new doctrines, should have urged their tenets beyond legitimate limits, and that some partial errors in the earliest practice should have been the consequence, is to admit only that we have not differed from all previous promoters of improved views."[90]

Rather than reflecting the Chadwickian rationalization of engineering, post-Chadwick sanitary administration reflected the engineers' approach. In large part, local authorities decided what projects to undertake, engineers worked out plans with them, and central government inspection focused more on acceptability than optimality.[91] Pipe sewers remained tools to be used in particular client-defined

[88]Rawlinson to Chadwick, August 28, 1854, Chadwick MSS, no. 1645.

[89]Rawlinson, p. 45; Williams (n. 75 above), p. 277; Donaldson, pp. 410–11; Roe, in Metropolitan Sanitary Commission, *First Report,* evidence p. 84. For subsequent sewerage practice, see Baldwin Latham, *Sanitary Engineering: A Guide to the Construction of Works of Sewerage and House Drainage,* 2d ed. (London, 1878). Three decades later the controversy would be repeated in America with respect to Waring's sewerage theories. See Joel A. Tarr, "The Separate vs. Combined Sewer Problem: A Case Study in Urban Technology Design Choice," *Journal of Urban History* 5 (1979): 308–39.

[90]H. Austin, "On a Few Points in Relation to the Drainage of Towns," *Transactions of the National Association for the Promotion of Social Science* 1 (1857): 422–29. Compare Chadwick, in discussion of Bazalgette, pp. 333–40. He admitted pipes had been "often made inexactly, and laid ignorantly, and badly jointed, so as to let out the fluid, and detain the matter which it was the object to discharge; but on the whole they were a success" (p. 334). The principal anti-Chadwick polemic took much the same view as Austin; see *Engineers and Officials* (n. 21 above), pp. 12–16. As the key argument of the work (that inspectors are themselves a vested interest) is uncommon, appearing only once during the public controversy (in similar terms), there is reason to think the pamphlet's author was G. P. Bidder. See discussion of Leslie (n. 40 above), p. 312.

[91]Consider Christine Bellamy's characterization of the Local Government Board, eventual successor to the Board of Health in 1871. It adopted a "political-diplomatic" approach that relied on "general guidelines which are not so much task objectives as parameters for long term exploration of influences and for the conduct of negotiations. . . . Agents seek movement rather than achievement, an acceptable outcome rather than the technically correct solution." The approach is "characterized by

situations, not a system imposed from on high. In the long run, water and sewerage matters were rationalized in Britain, but to a significant degree rationalization remained the achievement of local government and Parliament, not of central administration.

In opposing Chadwick's system and calling for situation-specific technology, these engineers espoused principles of decentralization reminiscent of modern appeals for "appropriate" technology. Yet they did not see themselves as endorsing a philosophy of technology but only as advocating good engineering, which included designing sewers with local needs in mind and making allowances for human error, heavy storms, or town growth. Such an outlook was a professional necessity, for few towns wanted integrated systems; they wanted lengths of sewer here or there or partial waterworks. They expected engineers to respect their concerns and often asked them to change their designs in all sorts of ways and for all sorts of reasons. Chadwick had invited engineers to discard carefully constructed relationships and reputations for the security of a hierarchical bureaucracy, but, with a few exceptions, engineers rejected the risk.

To see the pipe-and-brick sewers war as a legitimate technical controversy is not to deny that it was political as well. The engineers' championship of on-site judgment was incompatible with Chadwick's centralization. Their perspective coincided with that of Chadwick's enemy Joshua Toulmin Smith, champion of local autonomy, but there is no reason to think they were Smith's "creatures" in any sense.[92] Nevertheless, to discover good technical reasons for opposing Chadwick does affect our understanding of his rise and fall: it means we need to look less for sinister motives among his opponents and more for the reasons his adherents followed him. It also raises new questions about urban improvement. If we recognize that technical controversies were not concocted to block progress but reflected legitimate uncertainty, then we uncover a new framework for asking why people advocated the solutions they did and how decisions came to be made.

---

flexibility, discretion, and influence." See Christine Bellamy, *Administering Central-Local Relations, 1871–1919: The LGB in Its Fiscal and Cultural Context* (Manchester, 1988), p. 117. See also C. Hamlin, "Muddling in Bumbledom: On the Enormity of Large Sanitary Improvements in Four British Towns," *Victorian Studies* 32 (1988): 55–83.

[92]In discussion of Rawlinson (n. 34 above), pp. 70–75. Clearly, Toulmin Smith tried to recruit them, arguing that Chadwick's administration was "reducing the engineers . . . to . . . mere clerks of works" (p. 75).