Chapter 1

The life and times of the Chadwickian solution

Tony Dingle

This chapter provides a thumbnail sketch of the historical evolution of the water-supply and sewage-disposal systems currently in use in Australia's cities. We can begin with the inescapable physiological fact that, as humans, we need to drink a certain volume of water each day to sustain life and we produce a modest quantity of faeces and urine as wastes of our body metabolism. Were we Robinson Crusoe, or any other member of the animal kingdom, we could drink from the pure limpid stream and vacate wherever the fancy took us, confident that natural processes would recycle the nutrients. That option, however, has not been available to us for a very long time, for living in groups has required different strategies and the larger the group the more challenging the problem.

This became painfully obvious as cities began to grow with unprecedented rapidity from the beginning of the nineteenth century. As they did so, they also began killing off their residents at an alarming rate so that the death rates in these places rapidly climbed far above those of smaller towns and the countryside as a consequence of the prevalence of infectious diseases, both endemic and epidemic. The former killed more people, but the latter were more feared by city-dwellers for the suddenness of their appearance and the savagery of their impact. In the cities, death rates climbed way above birth rates, so that growth was sustained only because of the waves of migrants who continued to flood in seeking to improve their economic circumstances (Lampard 1973; Rosen 1973).

In the UK and elsewhere, physicians and others struggled to understand cause and effect. The miasma theory — that bad smells transmitted disease — proved, eventually, to be an incorrect diagnosis, but whenever it led to the cleaning up of rubbish it probably had beneficial outcomes. Under the influence of this theory, sanitary reformer Edwin Chadwick produced his masterly *Report on the Sanitary Condition of the Labouring Population of Great Britain* in 1842. He argued that it was the accumulation of filth in the cities that caused sanitary problems and his solution was the provision of a pure, piped, water supply to the towns and a water-flushed network of sewers to remove body wastes. In the calculus of his times he explained:

> That the chief obstacles to the immediate removal of decomposing refuse of towns and habitations have been the expense of the hand labour and cartage requisite for the purpose.
>
> That this expense may be reduced to one-twentieth or to one-thirtieth, or rendered inconsiderable, by the use of water and self-acting means of removal by improved and cheaper sewers and drains.
>
> That refuse when thus held in suspension in water may be most cheaply and innoxiously conveyed to any distance out of the towns, and also in the best form for productive use, and that the loss and injury by the pollution of natural streams may be avoided.
>
> That for all these purposes, as well as for domestic use, better supplies of water are absolutely necessary. (Chadwick 1965: 423–4)

Chadwick's solution has been almost universally adopted by cities ever since and is still being installed. Hamburg was perhaps the first large town to construct such a complete sewer system in 1843, after a big fire damaged much of the city (Derry and Williams: 426–7). The sewers were flushed weekly with river water. Paris and London, with Bazalgette's great scheme of interceptor sewers, moved in the same direction in the 1850s and 1860s. In Australia, Sydney began building sewers in the 1860s but constructed a much larger network in the 1880s. Melbourne, then a larger city, did not start building until 1892. Adelaide began in 1879, while Brisbane, which was roughly the same size as Adelaide, did not make its first connections until 1923. These differences in timing are intriguing and require investigation in a comparative framework.

There were two components to Chadwick's solution, pure piped water and water-borne sewerage collection. As more cities adopted this approach, there was an increasing focus on improving the component parts of the system so that major improvements were made to the technologies required to implement Chadwick's concept, especially during the second half of the nineteenth century. Attention was drawn to those points where improved technologies and greater knowledge would have a beneficial impact. So, for example, as larger cities sought to guarantee larger supplies of water, bigger, stronger dams were built to impound larger storages. To this time, dam building had been entirely empirical, but applied science began to make a significant contribution to the design of dams from the mid nineteenth century onwards. W. M. J. Rankine, professor of Civil Engineering at Glasgow University, worked on the properties of loose earth, thereby improving the construction of earthen dams, while the French engineer de Sazilly improved the understanding of internal stresses in masonry dams. Much larger dams of both kinds were built as the century progressed, mainly for urban water supplies (Bruce 1 1968: 556–8; Bruce 2 1968: 1368). There were some serious miscalculations — in 1864, the Dale Dyke dam near Sheffield burst, killing more than 200 people — but by the end of the nineteenth century it was common for large towns to draw their water supplies from dams a great distance away, the water travelling along masonry-lined aqueducts or, increasingly, through cast-iron pipes to its destination.

Pure water supplies could only be achieved gradually as the foundations of the new science of bacteriology were laid and understandings of disease transmission improved. London doctor John Snow made a crucial breakthrough in 1849 in understanding the most horrifying curse of British cities, cholera, when he found that it was transmitted through water supplies contaminated with the faeces of cholera victims (Wohl: 124–5). The germ theory of disease, pioneered by Louis Pasteur and others, took over from the miasma theory as micro-organisms of particular diseases were identified under the microscope. By 1880 Carl Eberth had identified the typhoid bacillus and it was realised that typhoid was transmitted by means of contact with the faeces or vomit of an infected person.

Methods of water treatment were improved significantly during the nineteenth century. Sand filters trapped suspended solids and the slow sand filter also proved to be an effective barrier to the germs of cholera and typhoid, although this was only gradually realised once advances in bacteriology had been achieved. By the end of the century it also became practicable to disinfect water by using chlorine and it began to be used on city water supplies, first at Middlekerke in Belgium in 1902; but there was significant public opposition to this practice in some cities (Bruce 2 1968: 1373–81).

With waste disposal there was a similar cluster of major technological advances which greatly improved the performance of the system, but these came somewhat later than advances in water supply, partly because they were often stimulated by the problems generated by an increased water supply and partly because they could usually only be operated on a city-wide scale and were consequently expensive and disruptive to construct and install. Sewers had existed for many centuries, both as surface gutters and as underground pipes or tunnels of some size, but their main function had been to transmit rainwater to the nearest river in order to prevent flooding of the increasingly impervious surfaces of expanding cities. These sewers, and the rivers into which they flowed, were placed under greater pressure as improved systems of water supply delivered far greater amounts for use in the home. Much of this found its way into gutters and drains once it had been used and dirtied.

The water closet became the major problem for existing methods of waste disposal. The concept of a water closet had first been developed by Sir John Harrington in 1596. In 1778, Joseph Bramah patented one with two valves that slowly came into use. A trap containing a water seal to keep smells out of the toilet was developed in 1782, and in the nineteenth century improved models were marketed by Thomas Crapper of Chelsea and many others who also added their own piecemeal improvements (Derry and Williams 1960: 425–6). In towns with improved water supplies, the wealthy increasingly installed water closets. These still emptied into cess pits or into sewers, sometimes legally and sometimes illegally. As a consequence, far more contaminated water was being trapped in the city: old sewers were not designed to flush out suspended solids and much accumulated below city streets and residences, increasing health risks through the increased likelihood of the spread of infectious diseases. The technologies of piped water and the water closet were leading, in combination, to the breakdown of existing methods of waste disposal (Tarr 1988: 162–3). They were also massively increasing river pollution.

Such outcomes hastened the construction of water-borne sewerage systems to cope with these difficulties. Once cities did this, the water closet was transformed from a major polluter to the centrepiece of the new method of waste disposal for it effortlessly flushed body wastes out beyond city boundaries as Chadwick's solution required. As a consequence, an eminent historian of sanitary reform, M. W. Flinn, has even suggested that the water closet 'may well have been in the long term the most life-saving invention of all time' (Chadwick 1965: 9).

Other advances came along with better water closets. Ovoid or egg-shaped pipes were developed to increase the scouring capabilities of sewer networks during times of low sewage flow. Flow rates and the gradients at which pipes were laid were calculated with increasing accuracy. Bazalgette's system in London was built to maintain an average speed of one-and-a-half miles per hour when the sewers were half full (Derry and Williams 1960: 427). Bricks were used to construct the larger sewers but by the end of the nineteenth century concrete was increasingly used. Large, slow-acting steam pumps were developed to pump water and sewage wherever it was not possible to use gravity. A major issue for any city was whether to build a combined or a separate system; that is, would the sewers be built large enough to cope with both sewage and stormwater, as they were in London and Paris, or would the two be channelled into separate systems? The advantage of the latter was that the sewers could be made far smaller for a largely predictable load of sewage and if there was to be any treatment it would only be sewage that was treated, not the stormwater also. The disadvantage was the extra costs involved in constructing two separate systems.

It had long been assumed that if sewage could be emptied into rivers it would soon be rendered harmless by the moving water, but such assumptions were challenged as ever-larger quantities were emptied into the same river at various points along its length by growing towns. Cities without a convenient ocean or river looked at ways of treating sewage. Chadwick himself was a great enthusiast for putting sewage to productive use in fertilising the land, thereby recouping some of the expenses incurred in the construction of sewers as well as the re-fertilisation of the soil which had been depleted by growing the food eaten by city dwellers. Of course, largely solid town wastes had long been used as manure in market gardens on the peripheries of towns: what was new and imperfectly understood was how to employ huge volumes of water-diluted sewage and the value it possessed as a manure (Goddard 1981: 32–6). Some towns in Britain did establish sewage farms and run them for a time but it was in Berlin and Paris and in Australian cities, notably Melbourne and Adelaide, that such farms were used extensively, in the way Chadwick had envisaged.

New knowledge of bacteria and, especially, of their role in breaking down and oxidising organic materials opened up new possibilities for sewage treatment. This led to the development of various methods of biological filtration in which sewage was sprayed over beds of stones, encouraging the growth of bacteria on the surfaces of the stones and the oxidisation of organic matter in the sewage. The activated-sludge process was an alternative and ultimately more-effective approach. It was developed from the observation that if some of the sludge that had settled out of a batch of sewage that had been aerated — that sludge consisting of active, living bacteria, hence the term 'activated sludge' — was introduced to a new batch of raw sewage, the process of aeration and stabilisation would proceed far more rapidly. This process was widely adopted from the 1920s in Britain and elsewhere. Leftover sludge was difficult to dispose of but it was discovered that if it was digested or fermented by anaerobic bacteria in a septic tank it was rendered inoffensive and could be used as a fertilizer. Karl Imhoff pioneered this process of sludge digestion on a commercial scale (Bruce 2 1968: 1387–94).

By the early years of the twentieth century, the inhabitants of cities in modern economies had largely overcome the challenges of living in close proximity to each other without succumbing to infectious diseases. There existed a set of interlocking technologies that could provide an ample supply of pure water for household use, for commerce and manufacturing and to fight fires. There were also effective ways of removing wastes along water-flushed sewers and of disposing of those wastes in ways that would not impact adversely on others. Cities knew about these advances, which were publicised in engineering journals and through the diaspora of increasingly well-trained engineers from England, Scotland and parts of Western Europe to countries of recent European settlement elsewhere in the world. This meant that it was possible to build water supply and sewerage infrastructure just about anywhere where materials, men, finance and an engineer could be brought together.

The distinctive pattern of technological development that led to this outcome constitutes an example of path dependence; that is, a situation where existing technologies shape and direct future developments, or, to put it in another way, technological change depends largely on its own past (Mokyr 1990:162–5). Once the Chadwickian system had demonstrated its superiority over earlier methods of water supply and waste removal, experimentation with alternatives to it virtually ceased. In the Netherlands in the late 1860s, Charles Liernur developed a pneumatic or suction system that was used on a significant scale in Amsterdam and in parts of Prague and St Petersburg but no other cities were persuaded to adopt it in preference to water-borne waste removal (Bruce 2 1968: 1384). Instead, innovators focused on the bottlenecks, the weak spots in the Chadwickian system in order to improve them; hence the developments sketched above. In this way the whole system became more tightly integrated and efficient.

This also meant that alternatives were less likely to be developed. Where a technology is expensive and disruptive to install, it is less costly to expand an existing system as the number of consumers grows rather than replace it with something different. Heavy investment in the internal combustion engine over many decades, for example, has discouraged large-scale investment in alternative forms of propulsion for cars such as electric or steam power. As an interlocking set of technologies develop around a particular way of, say, harnessing energy or removing domestic wastes, it tends to become self-reinforcing for other reasons also. New usage habits grow up around new technologies; for example, in this volume Graeme Davison discusses how people have consumed increasing amounts of water to satisfy a range of needs beyond what is required for drinking, cleanliness and waste disposal. Usage cultures then determine what is perceived to be an adequate supply. The creation of institutions that depend on the technology for their existence further reinforced commitment to the existing system; water supply and sewerage authorities, for example, were and are committed to sustaining the large centralised systems which they construct and manage.

Despite the dominance of the Chadwickian system, each city faced its own unique set of circumstances pertaining to climate, geology and location in relation to the availability of rivers and of rainfall. There were also varied governmental and financial constraints that shaped what was likely to happen. No cities adopted best practice along the whole range of technologies mentioned here, and some adopted very few. Our focus is on Australia and while I will use Melbourne as an Australian example and as the city I know most about, but it is only in the timing and detail of its development that it differs from other cities in Australia and elsewhere.

Initially, water was supplied to the rapidly growing settlement by water carts and from tanks filled from rainfall on roofs. As the city grew and polluted the Yarra River, from which water carriers drew their supplies, the system became increasingly inadequate. British migrants worried about the possibility of a cholera outbreak in Melbourne and by the later 1840s there was support for the construction of a city-wide system of supply to replace these private and decentralised approaches. Cost was a central issue and the debate was between a system that would pull water from the Yarra not far upstream from the city, but would require constant pumping, and one that would draw it from much further afield and would consequently cost far more to construct but would have much lower operating cost because it could rely on gravity, as the Romans had done in their pioneering water-supply systems. The latter was chosen and construction of the Yan Yean began against the backdrop of the Victorian gold rushes.

This activity benefited from the accumulation of medical and engineering skills taking place in England but also extended it in some ways. The English-trained chief engineer, 27-year-old Matthew Bullock Jackson, built an earthen dam at Yan Yean that was one of the longest then attempted, to create what was perhaps the world's largest reservoir at that time. He was elected as a member of the prestigious Institution of Civil Engineers in London for his work and for his paper describing the construction of Yan Yean. Jackson's brief stay in Melbourne was tumultuous, but it was for his achievement in building Yan Yean that he was included among water engineer and historian G. M. Binnie's handful of outstanding water engineers of the early Victorian era (Binnie 1981). Some locals worried that the dam wall was unsound but their concerns were unfounded and the embankment still impounds some of Melbourne's water. Local conditions were not well understood and some sceptics feared that during hot Australian summers the much higher rate of evaporation would result in a dry reservoir, but these fears too were unfounded.

Yan Yean massively increased the supply of water to Melbourne but it was not pure water. Lead from the reticulation pipes poisoned some Melburnians. More became ill over the next few decades because the water contained organic impurities. Only gradually, as knowledge of disease transmission became available and local investigations identified polluted catchments, could suspect supplies be eliminated and new clear water sources from catchments closed to all other uses be redirected into the Yan Yean reservoir. This became Melbourne's approach for the next century. It would harvest its water from closed catchments and so save the cost of water treatment. This involved intermittent fights with logging interests and irrigators, but the city succeeded in cornering enough pure water for itself until the 1970s (Dingle and Doyle 2003).

Melbourne's changing methods of waste disposal mirrored the experience of many other cities. Cess pits, located at the bottom of the garden where there was one, were widely used, as they had been in Britain. Poorly constructed and inadequately regulated, they were eventually banned in the city, though not in the suburbs. A system of pan collection replaced it. This worked effectively for some time but, by the 1880s, urban growth led to its breakdown, especially in the inner suburbs, as it became increasingly difficult to find locations where the growing tonnages of wastes could be deposited safely and effectively (Barrett 1971: 75–86, 127–137). Eventually it was agreed that something better was needed. A Royal Commission looked briefly at alternatives to water-borne systems and at criticisms of them, but there was overwhelming support for them (Third Progress Report 1889: xv–xvi). James Mansergh, an eminent British sanitary engineer asked by the Victorian Government to visit and recommend the most appropriate plan, explained that as 'nightsoil does not improve with keeping … the true policy is to get it off the premises as rapidly as possible': Chadwick could not have put it better. Mansergh advocated a water-borne sewerage system. Local engineers had long asked for this too, but the Government listened to Mansergh (Report on the Sewerage and Sewage Disposal of … Melbourne… 1889: 13).

There has been some debate as to why Melbourne was so slow in switching to a water-borne sewerage system. Was it an economically rational decision to change once the costs of the old system became greater than the new, as Gus Sinclair has argued (Sinclair 1975)? One critic has disputed that the evidence supports this conclusion (Merrett 1977). Or was it a fragmented structure of urban governance that delayed a decision until the threat was seen to be too great to be ignored any longer, as David Dunstan has argued (Dunstan 1984: 233–74)? The threat to public health was a factor, as it had been in England, although in Melbourne it was typhoid rather than cholera that was the scourge and there were epidemics in the 1880s which were not experienced by Sydney or Adelaide, which already had sewers. This was enough to persuade residents of the salubrious outer suburbs in Melbourne — who had long argued that they did not have the public health problems of inner areas and thus did not need to help finance a city-wide sewer network — that they were not immune from epidemics, especially as many of them travelled into the city to work.

The Melbourne and Metropolitan Board of Works (MMBW) was created, largely in the image of its London namesake, and began its work in 1891. A locally trained (Melbourne University) engineer, William Thwaites, was appointed chief engineer. While saying he was building Mansergh's plan, he went ahead and built his own, superior, separate system. The first connection was made at the All England Eleven Hotel in Port Melbourne on 17 August 1897 and rapidly thereafter most of the metropolitan area was connected. Perhaps the most interesting feature of Melbourne's scheme was its total reliance initially on a sewage farm to treat all wastes. This was adopted only because it would have been far more costly to have built a pipeline to the coast at a point where a significant tidal scour could have washed Melbourne's wastes out to sea, but it represented a serious attempt to realise Chadwick's vision of putting wastes to productive use, and its size attracted international visitors. Interestingly, Melbourne built its sewerage system just before more-sophisticated methods of treatment had been developed. Had it begun two decades later it could have utilised an activated-sludge treatment plant from the outset (Dingle and Rasmussen 1991).

For the last century Melbourne has relied on expanding the systems it had in place by the beginning of the twentieth century to cope with its growth from a city of around half-a-million to one of three-and-a-half million at the beginning of the new millennium. For water supply it relied on building more dams. The engineers estimated future supply needs and planned and built the dams required to store the requisite amount of water to meet those needs. Yan Yean was augmented by storages at Maroondah and Silvan in the interwar years.

There was a major threat to the effectiveness of this approach after the Second World War. Rapid population and housing growth in the 1950s and 1960s, and a shortage of investment capital that had first been felt in the depression of the 1930s but was not eased until the 1970s, meant that storages and pipelines to bring the water to the city were both inadequate. The Upper Yarra dam was finally built in the 1950s but taps ran dry on hot days and frequently applied water restrictions forced people to use buckets instead of hoses to water their large gardens. Suburbanites were irritated by this but they were encouraged by the prospect of more dams and greater supplies in the future, as promised by the MMBW. The Greenvale and Cardinia dams were built after increasingly difficult political fights but other proposals were knocked back. The mighty Thomson Dam filled in the 1980s. It did indeed 'drought proof' the city until recently, as promised, but despite demand-management programs from the 1990s that have reduced the rate of increase of per-capita water use, Melbourne is once more on restrictions.

Melbourne's sewerage system was also expanded to meet growing demand whenever possible. The Werribee Sewerage farm proved capable of expansion for many decades; although the methods of treatment changed also as settlement lakes took over from land irrigation. As with water supply, the sternest test for the system came with the massive post-war expansion of the housing stock. Water supply was given precedence over sewerage so the new suburbs on the outer fringes of Sydney and Melbourne, especially, spread out with water but no sewers. The house blocks were large, though often not the quarter-acre block of legend. But they had room in the back yard for their own decentralised method of sewage disposal, the septic tank, as the planners intended. This represented a failure of the centralised system, not because of technical difficulties but rather because of the scarcity of investment funds. State governments and water-supply authorities threw the capital costs of what they believed to be an inferior system onto individual householders. The situation was not rectified until the Whitlam government pumped federal money into the eradication of the sewerage backlog in the 1970s. Subsequently, connections kept up with suburban expansion; indeed, houses could not be occupied until a connection had been made. A new treatment plant employing modern methods was built at Carrum in the 1970s as the suburbs continued to expand to the southeast.

The process of change in water supply and waste disposal for most cities, including Melbourne, has been from decentralised, often private and small-scale, provision to large-scale, centralised, publicly owned and highly capitalised infrastructure which, for the most part, has performed effectively for a century or more. This was part of a wider networking of nineteenth- and, especially, twentieth-century cities to provide public utilities such as gas and electricity, telephones, trams and trains (Tarr and Dupuy 1988). However, the future of centralised water supply and waste disposal now looks far less assured because it is difficult to see how they can be expanded further without exacerbating current problems. In common with other Australian cities, Melbourne is now chronically short of the quantities of water required to maintain present levels of consumption; hence continuing restrictions. With the prospect of more variable and lower rainfall ahead, the options for increasing supply have contracted. The scope for building new dams has virtually disappeared because viable sites have already been utilised and more harvesting from rivers will further degrade their flows, with adverse impacts on the downstream environment. The pipeline to bring water from north of the Great Dividing Range to augment Melbourne's supplies will make only a modest addition to requirements at the expense of alienating much of Victoria's non-metropolitan population, who see this as another attempt by Melbourne to ensure that it can continue to water its lawns. Even the currently popular desalination plant to be built near Wonthaggi will require massive energy inputs and consequent increases in greenhouse gas emissions. It is likely that any attempt to further increase water supply in the metropolitan-wide system — the traditional solution to shortages — will bring escalating environmental costs.

There have been modest attempts to manage demand and these have been modestly successful from the 1990s in slowing the growth in demand. These approaches appear to work best when people perceive that there is a crisis and they need to do something to lessen it. This is perhaps most dramatically illustrated in Brisbane's case, as discussed by Peter Spearritt in Chapter 2. Otherwise, the experts argue that while this is a worthwhile strategy it is unlikely to yield dramatic improvements (Troy, Randolph and Holloway 2007: 8).

The water closet and all that lies below it now also appears increasingly problematic. It is a major user of potable water in every household and large volumes of potable water need to be used and dirtied simply to keep the sewerage system flushing safely and effectively, as Troy has pointed out (Troy, Randolph and Holloway 2007: 9). In 2007, the ABC urged its listeners to attempt to make do with not more than 40 litres of water per person for two days. Many reported that this was not possible if the water closet was used to flush away faeces. It simply required too much water to operate effectively. At the other end of the line, the disposal of increasingly large volumes of Melbourne's partially treated effluent at the ocean outfall at Boags Rocks is having an adverse impact on the marine environment and there is growing opposition to its continued use.

Why then are we still using this technology that is so wasteful of an increasingly scarce resource? Path dependence does not guarantee the continuation of existing technologies if there are compelling alternatives. For example, steam as a source of power gave way to electricity and the internal combustion engine once the advantages of the latter were seen to be overwhelming. However, it would be difficult to argue that this is yet the situation with water supply and waste disposal. There is not yet the sense of complete breakdown that had persuaded cities in the past that the costs of continuing on in the same way are unacceptable and a new approach must be found, nor are replacement technologies clearly available. Do we then have to experience higher levels of dysfunction before there is sufficient impetus for change?

What we do have is a range of partial technologies that can economise on the use of potable water and the waste-disposal system. These range from harvesting rainwater from the roofs of homes for use on the garden, the toilet and the laundry to recycling greywater for similar uses. These have the capacity to significantly augment and extend the life of the existing centralised supply system. They are small-scale, decentralised and, at present, the costs of utilising them are met by households. Although governments have recently offered incentives for households to adopt these alternatives, they have not for the most part been espoused by the water-supply authorities or integrated into any overall strategy that can utilise both local and central technologies. This is the political challenge to change. With a co-ordinated effort by governments, public utilities and private suppliers it may be possible to avoid a costly major technological discontinuity and modify and add incrementally to what we already have. In this way the Chadwickian solution may yet enjoy an extended lease of life.

References

Binnie, G. M. 1981, *Early Victorian Water Engineers*, Thomas Telford, London.

Bruce, F. E. 1, 1968, 'Water Supply', in C. Singer *et al*. (eds), *A History of Technology*, vol. 5, Clarendon Press, Oxford.

Bruce, F. E. 2, 1968, 'Water Supply and Waste Disposal', in Singer *et al*. op. cit., vol. 4.

Chadwick, Edwin 1965, 'Report on the Sanitary Condition of the Labouring Population of Gt. Britain', Edinburgh University Press, Edinburgh.

Derry, D. K. and Williams, Trevor I. 1960, *A Short History of Technology from earliest times to A.D.1900*, OUP, Oxford.

Dingle, Tony and Doyle, Helen 2003, *Yan Yean: A history of Melbourne's early water supply*, Public Record Office Victoria, Melbourne.

Dingle, Tony and Rasmussen, Carolyn 1991, *Vital Connections: Melbourne and its Board of Works 1891–1991*, McPhee Gribble, Melbourne.

Dunstan, David 1984, *Governing the Metropolis. Politics, Technology and Social Change in a Victorian City: Melbourne 1850–1891*, MUP, Melbourne.

Goddard, Nicholas 1981, 'Nineteenth Century Recycling: The Victorians and the Agricultural Utilisation of Sewage', *History Today*, June.

Lampard, E. 1973, 'The Urbanizing World', in Dyos, H. J., and Wolff M. (eds), *The Victorian City: Images and Realities*, vol. 1, Routledge and Kegan Paul, London.

Merrett, D. T. 1977, 'Economic Growth and Well-Being: Melbourne 1870–1914: a Comment', *Economic Record*, vol. 53.

Rosen, G. 1973, 'Disease, Debility and Death', in Dyos and Wolff *op. cit.* vol. 2.

Tarr, Joel A. 1988, 'Sewerage and the Development of the Networked City in the United States, 1850–1930', in Tarr, Joel A. and Dupuy, Gabriel (eds), *Technology and the Rise of the Networked City in Europe and America*, Temple University Press, Philadelphia.

Mokyr, Joel 1990, *The Lever of Riches: Technological Creativity and Economic Progress*, OUP, New York.

'Report on the Sewerage and Sewage Disposal of the proposed Melbourne Metropolitan District' (1890), Victorian Parliamentary Papers, vol. 2, Melbourne.

Sinclair, W. A. 1975, 'Economic Growth and Well-Being: Melbourne 1870–1914', *Economic Record*, vol. 51.

'Third Progress Report of the Royal Commission to Inquire into and report upon the Sanitary Condition of Melbourne', 1889, Victorian Parliamentary Papers, vol. 4, Melbourne.

Troy, Patrick, Randolph, Bill, and Holloway, Darren 2007, 'A New Approach to Sydney's Domestic Water Supply problems' typescript.

Wohl, Anthony S. 1983, *Endangered lives: Public Health in Victorian Britain*, Dent and Son, Guildford.