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Sydney's Water Sewerage and Drainage System

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Abstract: This paper traces the development of Sydney's metropolitan water, sewerage, and drainage system and considers the underlying arrangements of the institutions responsible for the construction, operation, and maintenance of the system as the city grew over the last two centuries or so into a substantial metropolis.

Keywords: water supply, metropolitan water systems, sewerage and drainage, policy development, institutional arrangements

INTRODUCTION

Broadly speaking, since European settlement in 1788, there have been four eras of differing institutional arrangements governing Sydney's water system. The first of these was the progressive development of relatively minor infrastructure to provide water for the newly established township and, as its population grew over the subsequent fifty years, to address issues of security of water supply and sanitation. This work was done under the direction of the Governor and, later, with advice from the Governor-appointed Legislative Council. The second phase began in the 1840s and continued for about forty years. This was a transitional period as responsibility for water administration was progressively transferred from the Governor to the municipal Council of the newly-declared City of Sydney and subsequently to the Legislative Assembly of NSW, established in 1856. The third phase commenced in 1888 with the appointment of a statutory board to oversee and manage the water supply and sewerage systems – this arrangement continued for about a century. The final era commenced in the 1970s with major reforms to the statutory authority and continues to the present day. The general thrust of the argument presented here is that these institutional arrangements are both reflective of and, in part, responsible for the issues that exist with Sydney's water system.

THE EARLY ERA – COLONIAL GOVERNMENT

At the Royal Commission into Sydney's water supply in 1869, Prof. John Smith, the chairman of the Commission, summarised the history of the city's water supply up to that time (Smith 1869, 94–98). The original choice by Governor Phillip of the location for the settlement was made on the basis of having a clean water supply, so the Sydney Cove site, with its clear stream, was selected. Unfortunately, plentiful water was not to be found: Smith quotes an article in the Sydney Gazette (19 October 1811), which refers to a drought in 1789, the second year of settlement, during which the colony nearly ran out of water. The Governor ordered that three tanks be cut into the sandstone banks of the stream, near where Hunter and Pitt Streets now intersect, to hold additional water for dry times. Although the exact time of construction is not clear, Smith dated the tanks (which gave the Tank Stream its name, Fig. 1) at about 1802. It was not long before these were becoming polluted and in 1810 orders were given by the Governor to protect the water supply. Smith reports a further drought in 1811, in which the tanks dried up for several weeks. After a period of relatively wet years, there was another drought in 1820, and a severe drought in 1823/24. The reported rainfall in 1823/4 (about 19 inches, 480 mm), was less than half the average.

By the early 1820s, it was becoming apparent that Sydney was subject to a wide variation in rainfall and that prolonged dry periods might be common. By then, the population of Sydney had reached 10,000 and the supply of water was becoming critically important. By 1826, pollution of the Tank Stream had become so severe that it was abandoned as a water supply and water was carted from Lachlan Swamp (now the ponds in Centennial Park) to a watering point in Hyde Park (Smith 1869, 94–98, Aird 1961, 3–11).

Figure 1: The Tank Stream, Sydney (c 1842) John Skinner Prout; pencil, watercolour, opaque white highlights, 25.5 x 37.5 cm; Purchased 1913; Art Gallery of New South Wales.

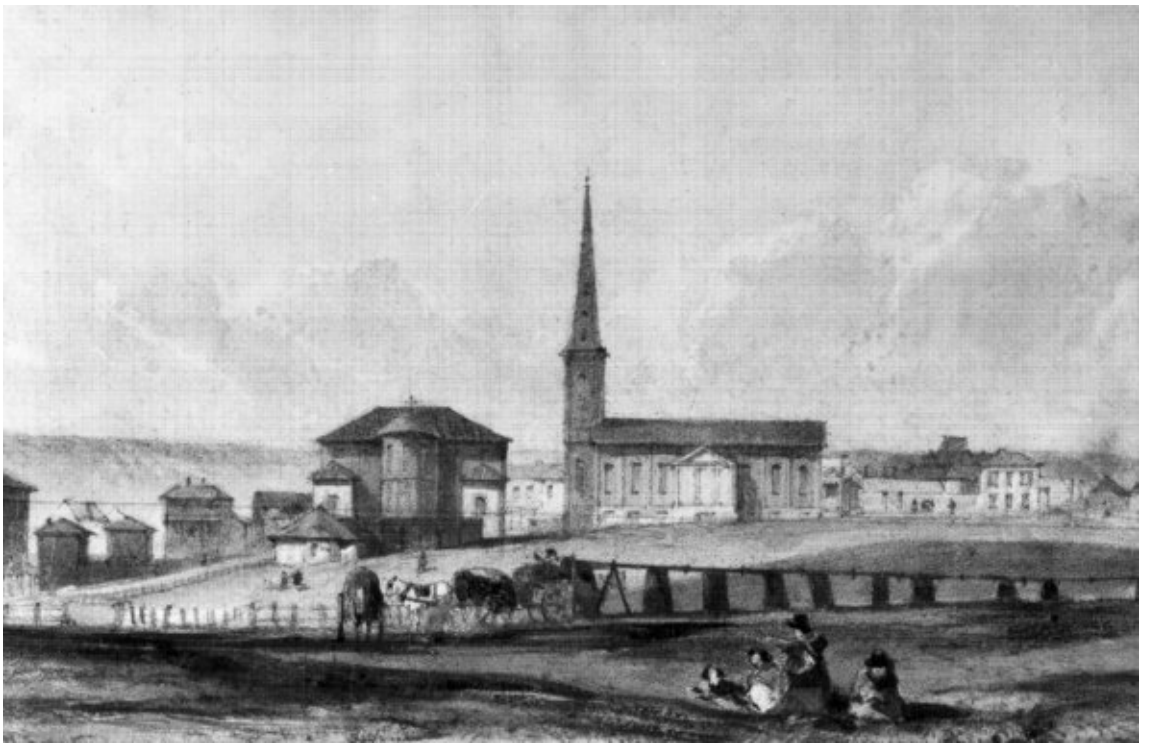

Figure 2: Busby's Bore – Hyde Park, looking towards St James' Church and the Law Courts.

John Busby, appointed as Mineral Surveyor to the Government, arrived in Sydney in 1824 and proposed cutting a tunnel from Lachlan Swamp to Hyde Park (Figure 2). Hence, the first piece of legislation relating to water supply in Sydney was enacted: The Sydney Water Supply Act (1833), which approved the construction and maintenance of Busby's Bore, to bring water from Lachlan Swamp to Hyde Park, with the Tank Stream becoming the de facto sewer and rainwater drain for the town. The tunnel was started in 1827 but was not completed until 1837, however seepage into the tunnel was able to provide enough drinkable water for the city from 1830. By the time Busby's Bore was completed, the population of Sydney was over 20,000 and the tunnel was capable of delivering a barely-adequate 350,000 gallons (1.5 million litres) of water per day. However, in 1838/39 there was another drought (referred to in Darwin's Voyage of the Beagle) and Busby's Bore was not able to supply enough water (Aird 1961, pp. 3–11).

Busby's Bore was in use for many years and at its peak was capable of delivering 400,000 gallons (1.8 megalitres) per day. There was to have been a reservoir excavated in Hyde Park to hold 15 million gallons (68 megalitres) but it was never built. In the 1838/39 drought, although Busby's Bore did not run dry, there were very serious water shortages, with people paying 6 pence (5 cents) per bucket for water during this period.

At this time, the population of Sydney was growing quickly. Throughout this period, the institutional arrangements consisted entirely of direction by the Governor, together with legislation enacted by the Legislative Council. There were two pressures which led to a change in these arrangements. First, was the Colonial Office in London seeking ways to reduce cost and to move the administrative responsibility to the local residents and second, was a growing discontent from within the colony demanding a greater urgency in responding to problems of water supply and sanitation (Clark 1978, p. 55). This led to the declaration of Sydney as a city in 1843 (Richards 1883) and a municipal council was established as the corporate body for its administration (Clark 1978, 55). The primary responsibility of this council was to provide water to the rapidly growing city.

THE ERA OF TRANSITION – FROM COLONIAL ADMINISTRATION TO SELF-ADMINISTRATION

Following the 1838/39 dry spell, there was a wet period of about nine years, during which there was frequent flooding, again followed by a dry year in 1849 (the rainfall at South Head was only 21.5 inches (550 mm), compared to an average of about 50 inches (1,270 mm)). By the early 1840s, it had become clear that Lachlan Swamps and Busby's Bore were not capable of delivering adequate water to the city and in 1849, there was a proposal to build two small dams holding about 10 million gallons (45 megalitres) in the area of the Lachlan Swamp but this work was not commenced. In 1850, a Special Committee was appointed by the Municipal Council of Sydney 'to inquire into and report on the best means of procuring a permanent supply of water to the city of Sydney'. The committee considered areas around Bunnerong, Cook's River, George's River, and the Nepean River, however before the committee could report, a new Governor, Charles Fitzroy, was commissioned and he appointed a board to re-examine the question. The board made recommendations relating to the development of Botany Swamps and these were implemented. The first step was the installation of a steam pump in 1854 (Smith 1869, 94–98, Aird 1961, 3–11) (Figure 3).

The board recommended confining activities to the Lachlan Swamp area, pumping water to a new reservoir to be built at Paddington, with a capacity of 12 million gallons (55 megalitres) which was about 40 gallons (180 litres) per head of population. In 1854, a small pump was installed to transfer water through Busby's Bore. In 1858, three 100-horsepower steam-driven pumps were installed, two of which generally ran 24 hours a day. A 30-inch (750 mm) main delivered water from the pumping station at Lord's dam to a reservoir at Crown Street

holding 3.5 million gallons (15.9 million litres) and another at Paddington holding 1.5 million gallons (6.8 megalitres). These reservoirs contained only two days' supply. The major problem with the system was that capacity was insufficient to accommodate a prolonged dry period, even with the subsequent construction in 1866–67 of six small dams down the course of the stream to Botany Bay. Reticulated water supply was introduced in 1844, with about 70 houses being connected. The cost of this was 5 shillings per room per year (Aird 1961, 6). The reticulation network increased significantly in the 1850s and 1860s, requiring night-time water restrictions to be applied in 1862. In 1868, 956 million gallons (4.34 gigalitres) of water were pumped or 2.62 million gallons (11.9 million litres) per day and by 1874 this had increased to 4 million gallons (18.2 megalitres) per day. To accommodate this growth, a further dam was built at Bunnerong 1876–77. At the time of completion of the first stage of this scheme in 1858, the population of Sydney was estimated to be about 87,000 people. When the Smith Royal Commission (referred to above) reported in 1869, the population had grown to about 118,000 (Smith 1869, 98).

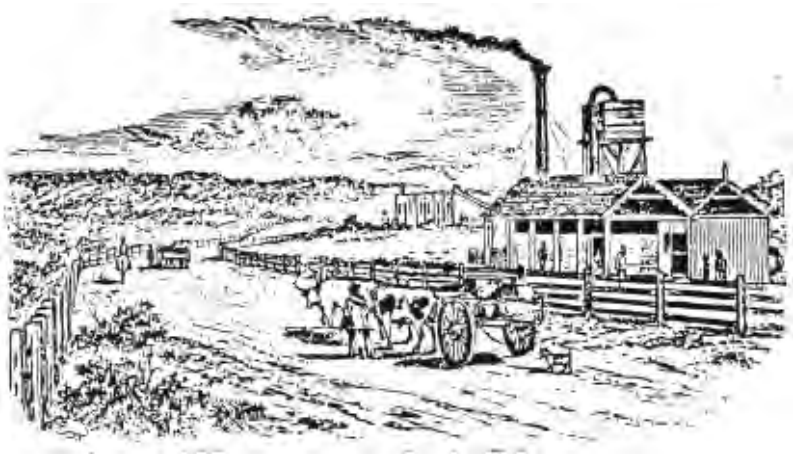

Figure 3: Archival etching of steam pumping station at Lachlan Swamp (c1854). Copy held at Sydney Water archive, drawing by T.S. Gill, Mitchell Library. and Dixson Library and Galleries, State Library of NSW.

Figure 4: Botany pumping station (c1870?).

At the Royal Commission hearing on 31 March 1868, Thomas Woore read a paper proposing the construction of a dam on the Warragamba River. The dam wall would be 600 feet (182 m) along the top and about 170 feet (52 m) above the floor of the gorge. The wall would have been masonry, supported downstream with rubble and with puddling materials in front of the dam wall. Gravity feed of water to Sydney would allow three years' supply. The president of the Royal Commission, Professor Smith, reluctantly rejected the proposal on the basis that the Warragamba dam would have been the largest dam in the world and he was concerned by experience with smaller dams in England which had failed and had 'spread devastation in their course'. The risk of economic loss was considered too great, despite that 'if successful, the results would be magnificent, and the work would be a monument of engineering skills and boldness that could not fail to command a world-wide fame'. Professor Smith added that although he later became aware of a dam in the Upper Loire in France nearly as great, the risk of flood at the Warragamba site during construction would also be substantial (Woore 1869). This Royal Commission and the subsequent report of an expert engineer from Britain, William Clark, appointed to confirm the recommendations of the Royal Commission in 1877, set the direction for the next eighty years for development of the Upper Nepean as Sydney's water supply.

Clark evaluated the Royal Commission report and other submissions received in the meantime. These were schemes for the Upper Nepean, Loddon and Wingecarribee, Port Hacking, the Lower Nepean, the Warragamba, the Grose, George's River, Port Hacking and Woronora, Erskine Valley, Tube Wells, and 'Mr Sadler's Proposal'. He eliminated all except four, these being the Upper Nepean gravitation scheme, the Loddon and Wingecarribee gravitation scheme, the Lower Nepean pumping scheme and the George's River pumping scheme. In his conclusion, Clark discussed costs, the risk of flooding during construction, operating cost, complexity of construction (including tunnels, pipework etc), long-term storage capacity, and the opportunity for future development for irrigation, pastoral activities and manufacturing. Clark's recommendation was to develop the Upper Nepean scheme (Clark 1877, 1–42). The Upper Nepean scheme consisted of building a small dam, 10 feet (3 m) high, on the Nepean River near Pheasants Nest. A tunnel 4 1/2 miles (7.2 km) long carried water to the confluence of the Cataract, Nepean and Cordeaux rivers. Another small dam would be built on the Cataract River at Broughton's pass and a tunnel 1 1/4 miles (2 km) long, which would take the water to the western slope of the George's River basin. A system of channels and short tunnels would then deliver the water to a reservoir to be built at Prospect. Prospect reservoir would have a wall height of 80 feet (24 m), and would hold 10,635 million gallons (48.3 gigalitres), of which 7,110 million gallons (32.3 gigalitres) would be available for supply by gravitation. From Prospect, the water would be distributed to the existing reservoirs, and a new distribution reservoir at Petersham (Clark 1877, 1–42).

Clark confirmed the Royal Commission's recommendation of the construction of Prospect Reservoir, and in addition, recommended construction of further reservoirs (complementing the Crown Street and Paddington reservoirs) at Petersham, Newtown, Woollahra and Waverley. He also recommended design principles for reticulation of water through the suburbs, the use of ball-cocks to connect the mains, the fitting of stop-cocks and meters, a system of rating which differentiated between properties with gravity feed and those requiring pumping and further recommendations from his experience regarding the setting of water rates.

The first water from the Upper Nepean scheme was delivered in 1886 and the Botany Swamps pumping system was decommissioned and, in 1896, was dismantled. The Botany Swamps dams remained largely intact until they were badly damaged by heavy rainfall in 1931. At its peak in 1886, its annual delivery was 1,864 million gallons (8.4 gigalitres) (Aird 1961, pp. 11–14).

In the early 1850s, there was considerable disquiet on the state of the sanitation of Sydney. In 1851, the Sydney Morning Herald published a series of ten articles describing the inadequacy of the water supply and the unsanitary drainage and sewerage conditions of the city (Clark 1978, 51). The catchment around Sydney, consisting of a number of small creeks had become open sewers and little had been done by the municipal Council to solve the problem. In January 1854, the Legislative Council passed an act which dissolved the municipal Council, appointed three commissioners to administer the Council and, in particular to authorise the raising of a £ 200,000 loan to commence construction of the sewerage scheme. By the end of 1854, the Legislative Council, impatient with the lack of progress, appointed a select committee to investigate the matter. The result was the commencement of five sewers along the creek-lines draining into Sydney Harbour. In addition, minor sewers from a number of city streets were also planned, feeding either into the five main sewers or discharging directly into the harbour (Henry 1939, 56–157). By 1877, 33 miles (53 km) of sewers had been constructed servicing the Woolloomooloo and Fort Macquarie areas, and the area drained by the Tank Stream.

Nonetheless, by the 1870s, there was a substantial pollution problem in the bays of Sydney Harbour into which all the sewers discharged. The Sewerage and Health Board was appointed by the government in 1873 and included two engineers, E.O. Moriarty and W.C. Bennett, both of whom had worked on the Nepean scheme. In 1887, the board proposed construction of two much larger sewerage schemes, the 'northern system' which would service what is now central Sydney and the eastern suburbs, discharging into the ocean at Bondi; and the 'southern system', servicing the area from Redfern, Waterloo and Mascot, discharging at the mouth of the Cook's River in Botany Bay. These designs were approved by William Clark, the English civil engineer appointed to review the 1869 Royal Commission findings. Construction commenced in 1880 and was completed in 1889, with responsibility for its operation being transferred to the newly-established Board of Water Supply and Sewerage (referred to simply as the Water Board) in 1890.

There was a critical water shortage in the early 1880s, with only ten days' water supply being stored. The construction of the Upper Nepean scheme had been started and the Hudson Brothers (the founders of Clyde Engineering) were appointed to build a system of timber-and-iron pipes and viaducts to supplement the Botany Swamps water supply (Figure 5). It was this system (referred to as the Hudson's Temporary Scheme) which, in 1886, delivered the first water from the Upper Nepean scheme to the reticulation system (Aird 1961, 3–11). Two years later, in 1888, the Water Board held its first meeting (Clark 1978).

Institutional Arrangements

There are a number of important aspects of this transition in institutional arrangements during this period. The declaration of Sydney as a city and the appointment of the Sydney City Council, together with the later establishment of the Legislative Assembly shifted the primary responsibility for administering the affairs of Sydney from the Colonial Office in London and the Governor to the citizens of NSW. Furthermore, professional engineers started to become more conspicuous in management of the issues. These engineers, many of whom had military as well as civil engineering backgrounds (these being the only truly distinct areas of practice within the engineering profession at the time) assumed leadership roles in these activities. This transitional period was by no means smooth. The early councillors were accused of self-aggrandisement, making their first priority the building of a Town Hall, rather than directing their limited resources toward social improvements. There were allegations of ineptitude and financial mismanagement and these were substantiated by a committee of enquiry held in 1849. Further public campaigns, including newspaper articles and petitions from local merchants and manufacturers led to the appointment of a further committee of enquiry by the Legislative Council in 1852, resulting in the dismissal of the Council and the appointment of a three-man Commission to ad-

minister the affairs of the city. The optimism within the community on the appointment of the Commission was short-lived: efforts to raise capital through a debenture issue were largely unsuccessful and the engineer-in-charge of the Botany Swamps project was replaced due to incompetence. It seems that incompetence was not confined to the project engineer, with three separate select committees recommending dismissal of the board of Commissioners, resulting in council administration being restored in 1857. Also, there were concerns regarding public health issues, in particular the use of lead piping for drinking water distribution, the slowness of extending the reticulation network and the rising rate of water-borne disease in areas that had not yet received reticulated supplies. Further enquiries were conducted in the early 1860s, culminating in the Smith Royal Commission of 1868/69.

Figure 5: Hudson's Temporary Scheme.

This Royal Commission, referred to earlier, was one of the most important landmarks in the history of the institutions responsible for the development Sydney's water system. Not only did it initiate the proposals which influenced develop of the water system for the next century or more but also it was the primary stimulus that brought about significant institutional change. The commission was chaired by John Smith, the 'Professor of Physics etc', at the embryonic University of Sydney and its membership included three civil engineers and the Surveyor-General. The Commission sought evidence from a wide range of participants and recommended the commencement of capital works on the Upper Nepean, a reticulation system using a new reservoir at Prospect, with reticulation to small reservoirs in the municipalities, and a rating structure which would cover the interest and maintenance of capital investment (Smith 1869, 33, 43).

However, despite the clarity of the Royal Commission's recommendations, the political process delayed commencement. Political parties had not yet become established and there were frequent changes of ministries. The findings of the Royal Commission and the alternatives it had investigated were extensively debated. There were further public debates and enquiries, including the expert report by Clark in 1877. The influence of the three engineers on the original Royal Commission was still significant and its recommendations regarding water supply were largely confirmed. In addition, the metering and rating of water was also supported and it recommended the construction of a major sewerage system to divert outflows from Sydney Harbour to the Pacific ocean (Clark 1877, 1–42). But the administrative arrangements were still being debated, some favouring private ownership, while others argued for a government-owned or government-guaranteed water company.

Finally, it was agreed to establish a statutory board representing the affected municipalities together with a group of appointed expert members. This resulted in an act of Parliament in 1880, enabling the appointment of the Board of Water Supply and Sewerage (later generally known as the Water Board), but it was not the late 1880s, upon the completion of the upper Nepean scheme, that the board was formally appointed and held its first meeting (Clark 1877, 1–42).

Clark (1978) makes some interesting observations regarding this transitional period in administration. Until about 1860, there was only a limited mechanism for raising public finance and this constrained the development of Sydney's infrastructure. However, the development of water and sanitation infrastructure seems to have lagged other areas (such as railways) that enjoyed significant development at that time. It appeared that an one hand, the colonial government did not want to take responsibility for developing and administering the infrastructure but, on the other, it was reluctant to devolve the authority to local government. It was only when water shortages and the threat of serious disease reached crisis point that action was taken. But there is a different interpretation which may be placed on this set of events. The situation in Sydney was not particularly different from other colonial cities, nor indeed, cities in Britain itself. Sanitation was not well understood (the miasmic theory of disease had not yet been replaced by Pasteur's ground-breaking work, first proposed in the 1870s) and water supplies were not reliable. To understand this more fully, it is illuminating to consider the same period in Britain, not least because at the time Britain still had full authority for the administration of the colony of NSW.

By the early 19th century, the industrial revolution in Britain was well underway. There had been a major migration from the countryside to the growing industrial cities. As the population of these industrial metropolises grew, sanitation became a major problem and there were outbreaks of diseases such as cholera and typhoid with growing frequency and social impact. At the time, the prevailing miasmic theory was that disease was caused by the foul smell emanating from open drains and marshes – that is, the smell was actually the disease itself, rather than its by-product.

Pasteur's work on the origins of disease was published in 1878, yet it was not until the end of the century that his theory was widely accepted in the administration of public health. Nonetheless, notable figures such as Edwin Chadwick drew a correct conclusion from an incorrect theory: that the solution to public health required reform of the water supply and sewerage system. Chadwick's work was focused on London and identified the problem with the sewerage system as being mainly an engineering one but with substantial administrative defects, whereas water supply was largely an administrative problem due to a lack of cooperation between the water supply companies. The solution he identified was to consolidate the sewers commissions and water companies into one organisation and to construct a new design of ovoid, pressurised drains which would be flushed by water, thus removing the miasma from the streets.

One consequence of Chadwick's work was an act of Parliament, the Public Health Act (1848), which established General Boards of Health, to reform the administration of sanitary systems. But within London, Chadwick's reforms were largely unsuccessful, being opposed in Parliament and generally not supported in the community. A major outbreak of cholera in the late 1840s prompted Chadwick to produce another report in 1850 (On the Supply of Water to the Metropolis). This was influential in the eventual disbanding of the London Board of Health in 1854 and the creation of the Metropolitan Board of Works in 1855. The formation of the Metropolitan Board of Works partly consolidated the highly fragmented responsibility for water, sewerage, and drainage and to undertake the major engineering works required for a substantial water, sewerage, and drainage system.

Further consolidation of responsibility took place in 1888, when the Metropolitan Board of Works was replaced by the London County Council. This organisation remained in place until 1965 when it was abolished and the responsibility of its successor, the Greater London Council, was extended considerably to accommodate the growth in London over the previous 80 years. (Boyne and Cole 1998, Schwartz 1966, Parkin 2000, Wheeler 2000).

The point of this comparison is this: Sydney was by no means unique in struggling with the problems associated with its rapid growth in population. There were two fundamental problems identified in this era that were a consequence of rapid urbanisation. One was the technological challenge in dealing with the provision of a clean water supply and the sanitation issues of densely populated urban areas. The other was the challenge of moving from directive to participative public administration, in response not only to social demands for greater representation but also the recognition that the increasingly complex nature of large urban areas required it.

The general solution to this problem was to establish two government instrumentalities: a public works body to develop the capital infrastructure; and an administrative body, to be governed by elected representatives of the municipalities serviced by the infrastructure. In the case of London, the public works body was set up in 1855 and a joint engineering and administrative authority established with the creation of the London County Council in 1888. In the case of Sydney, the administrative authority was established with the appointment of the Water Board in 1888 and the Department of Public Works retained responsibility for major capital projects until 1924. Although the structural arrangements established in London and Sydney were slightly different, the response to the problem was fundamentally the same: creation of a body with a strong technological capability to carrying out the necessary civil engineering work and administrative authority representative of the local government constituencies to provide services to rate-payers.

In both cases, these arrangements remained in place for the better part of a century. Over this period, both cities saw dramatic improvement in standards of public health, with diseases such as typhoid, cholera, dysentery, tuberculosis, diphtheria and even, on rare occasions, bubonic plague being largely eliminated. In the case of Sydney, although there is no doubt that at times progress was frustratingly slow,

the institutional reform which took place over the period from 1840 to 1890 had a profound and long-lasting beneficial impact on the development of the city and the well-being of its citizens. At the heart of these reforms, there emerged a paradigm that recognised the reliance of society on the engineering profession to create and implement technologically sound solutions, with oversight and administration by a body representative of the local government constituencies. But, in the case of Sydney at least, it would be quite misleading to suggest that these institutional arrangements were particularly efficient. As will be discussed below, there were continuing criticisms of the effectiveness of the Water Board and its structure was changed on several occasions, largely as a result of enquiries provoked by public dissatisfaction.

THE WATER BOARD ERA – 1888 TO 1983

In the latter part of the 19th century there had been considerable debate on the merits of 'wet carriage' versus 'dry conservancy' treatment of sewage (Trevor Jones 1886, Ashburton Thompson 1892). Both technologies were tried. In the period from 1855 to 1875, virtually all of Sydney sewage discharged into Sydney Harbour via the sewers built in the 1850s and 1860s. Water quality in Sydney Harbour worsened and in 1875, following the outbreak of typhoid mentioned above, the petition presented to Parliament and further agitation over the next two years resulted in the Sewerage and Health Board committing to the construction of two outfalls, the Northern System, discharging into the ocean at Bondi, and the Southern System, running to a sewerage farm at Botany Bay (Beder 1989, 369–376).

The Northern System was completed and handed over to the Water Board in 1889 and the Southern System was completed and handed over in 1890. But by 1890, the Secretary for Public Works, the Hon. Bruce Smith was so concerned about deteriorating public health in Sydney due to much of the city's sewage continuing to be discharged into open drains, that he proposed a separate stormwater drainage system to be built as well as the sewerage system. Expansion plans for the Northern (now called the Bondi system) and Southern sewerage systems had been developed and were under construction, but the western suburbs were developing so quickly that construction of the sewers could not keep up with the rate of urban development. Smith believed that stormwater drainage could be built far more quickly than sewerage. At the time, the Nepean scheme (with a draft of 50 million gallons (227 megalitres) per day) had been completed and the distribution infrastructure was capable of delivering 18 million gallons (82 megalitres) per day, nearly double the normal consumption of about 10 million gallons (45 megalitres) per day. Smith proposed that it would be possible to quickly build a network of stormwater drains that could be flushed using the excess water capacity from the Nepean system and which local municipalities could use temporarily as sewers (Beder 1990). Once the sewerage system was complete, sewer inlets would be disconnected and the stormwater drains would revert to their intended purpose.

By 1897, nine major stormwater drains had been constructed in Wentworth Park, Rushcutters' Bay, Balmain, Erskineville, Long Cove, Iron Cove, Homebush, and North Sydney. According to the medical adviser to the Board, there was a dramatic reduction in disease: mortality from diarrhoea dropped from 10.9 to 6.2 per 10,000, diphtheria from 5.2 to 3.1 per 10,000 and phthisis (pulmonary tuberculosis) from 16.8 to 9.5 per 10,000 population. There had been a major problem with typhoid (which had been exacerbated during the construction of the drainage system due to the manual excavation of the existing open drains) in the inner-city area, but after the completion of the stormwater drains, mortality from typhoid in the Erskineville, Redfern and Waterloo districts had dropped by as much as two-thirds (Aird 1961, 201–203). This resulted in Sydney ultimately having separate stormwater and sewerage systems which continues today but, importantly, it established wet carriage as the technology of choice for the transport and disposal of sewage.

By the early 20th century, the area around the sewage farm at Botany Bay was becoming more densely populated and there was growing public concern about its health impact, resulting in legal action by local residents. In 1905, a recommendation was made to cease farming and to treat the sewage. By this time conversion of the western suburbs drainage system to a main sewer was well under way and in 1908, following a Parliamentary committee of enquiry, it was decided to construct a sewer from the sewage farm on the northern side of Botany Bay to divert both the southern and western systems to an ocean outfall at Malabar, near Long Bay (Figure 6). This work was completed in 1916 (Aird 1961, 137–142).

The northern suburbs of Sydney were also serviced by sewers which drained into Sydney Harbour. The original work was done between 1891 and 1898 by the Public Works Department and transferred to the Water Board in 1899. By 1910, the pollution problem in Sydney Harbour from the northern suburbs was extensive and investigations were undertaken to determine whether an ocean outfall could be constructed at North Head. Construction on the North head outfall commenced in 1916 and in the meantime, primary the treatment works at Willoughby Bay were extended. In 1919, legal proceedings were taken against the Water Board for negligence and nuisance, resulting in an activated sludge system being installed together with a system for the chlorination of effluent. The North Head ocean outfall system began operating in 1926 and was fully commissioned in 1928 (Henry 1939, 202, Aird 1961, 154–156).

Figure 6: Construction of the Southern and Western Ocean Outfall System (c1915).

In 1901–2, there was another major drought which brought Sydney to a most perilous position and the government appointed a Royal Commission to determine a solution. The Commission presented three reports in April 1902, July 1902, and October 1903. The first report recommended a major upgrade of the distribution infrastructure, in particular strengthening Prospect Reservoir, upgrading the canal leading from Prospect to Guildford, a major upgrade to the Ryde pumping station to increase capacity to northern suburbs and upgrading mains distributing water to the southern suburbs. The second report identified sites on the Cataract, Cordeaux, Nepean, and Avon rivers and recommended that the catchments for these be proclaimed, that no further mining and forestry leases be granted, and that the grazing of livestock within the catchment be prohibited. In addition, the Commission recommended a greater emphasis on conserving water, an increasing proportion of water which was metered. As a consequence, acts of Parliament were passed to develop new major headworks, the first being a dam on the Cataract River. Construction started in 1903 (Aird 1961, 25–27) (Figure 7).

There was a further sustained dry period from 1907 until early 1911, prompting the Water Board to identify another dam site on the Cordeaux River. This was followed by several years of good rainfall and the intervention of the First World War, so the problem was not addressed seriously until 1918, when a Board of Experts was appointed to advise on development of Sydney's water supply. It recommended the construction of the Cordeaux dam and to commence planning the Avon and Nepean dams. Construction of the Cordeaux dam commenced in 1918 and was completed in 1926. The Avon dam was commenced in 1921 and was completed in 1928 (Figure 8). In 1925, construction began on the Nepean dam near Pheasants Nest and, with some disruption to construction due to the Depression, was completed in 1935.

In 1926, a committee was appointed to continue the work of the Special Board of Experts which had been appointed in 1918. This committee recommended that construction of the Warragamba Dam commence after the Nepean dam was completed, and that the Warragamba should be sufficiently advanced that it could contribute to Sydney's water supply by 1938. In 1928, the chief engineer, G. Haskins, recommended that a small dam at Woronora (originally 60 feet, 18 m high) intended to be a local supply for the Sutherland-Cronulla district be increased in height to 200 feet (61 m), giving it a capacity of 15,000 million gallons (68.1 gigalitres). This would enable deferment of the Warragamba Dam by four years. The Woronora dam was commenced in 1930 (construction was suspended for several years during the Depression) and was completed in 1941 (Henry 1939, 140, Aird 1961, 88–94).

In 1934, a severe drought began. Until 1940, the worst dry period on record had been the drought of 1904–1910 and it was thought that the capacity of Sydney for supply should be adequate to cover such a period. It became clear the upper Nepean system was inadequate and, as an emergency measure, a weir 50 feet (15.2 m) high was commenced near the site of the current Warragamba Dam and was completed in 1940.

The 1934–42 drought, (at the time of writing this paper, the longest on record) has been used as the basis for water supply calculations ever since (Aird 1961, 3–11). Prior to the completion of the Warragamba dam the 'safe draft' of the combined Cataract, Cordeaux, Avon, Nepean, and Woronora dams was 92 million gallons (418 megalitres) per day. In 1959–60, Sydney's daily demand was 201.8 million gallons (916 megalitres). The projected shortfall in capacity had necessitated construction of a very large dam, justifying the size of Warragamba.

The original design of Warragamba Dam was for a wall 370 feet (112 m) high, with a capacity of 452,500 million gallons (2,054.4 gigalitres). On completion, based on a nine-year drought, Warragamba had a regulated draft of 274 million gallons (1,244 megalitres) a day. At the time, the daily draft of the entire Sydney system was 310 million gallons (1,407 megalitres) a day. Site survey and selection commenced in 1941 and was completed in 1946. Construction was completed in 1960 (Aird 1961, 105–111).

Figure 7: Cataract Dam under construction (c1905).

Figure 8: A diver entering the water at the Avon coffer dam.

Figure 9: Warragamba Dam under construction. The photo shows No. 2 Cross Connection. Looking south at the cross pipe showing Mk. 26 under the crane. Partly constructed 84 inch valve chamber in foreground.

Figure 10: Warragamba Dam main wall construction.

Figure 11: Warragamba Dam nears completion.

In 1966, the Water Board appointed the Snowy Mountains Hydroelectric Authority (SMEH) to evaluate the Sydney and south coast water supply with water beyond the end of the 20th century. SMEH examined all major catchments feasible for supplying the region with water, rejecting the Wollondilly and Grose catchments because of lack of capacity and rejecting development of the Colo River catchment because of both the relatively high cost of building a dam (due to the thickness of silt on the river bed) and concerns about interrupting freshwater flow into the Hawkesbury River and the consequent effect on salinity. The scheme recommended was the Welcome Reef dam with a dam wall 200 feet (61 m) high, a capacity of 330,000 million gallons (1,498 gigalitres) and associated developments on the Shoalhaven River. An additional dam, with about the same capacity as Welcome Reef, could ultimately be built on the Shoalhaven River, near the junction with Yalwal Creek. Adoption of the scheme was published in the Sydney Water Board Journal in October 1968. A number of environmental and archaeological studies were done in the 1970s, recommending that the project proceed with consultation with local communities, taking steps to ensure protection of local ecology. However, for a variety of reasons discussed in the next section, other than the construction of a small dam in the Shoalhaven Valley at Tallowa completed in 1976, the project did not proceed.

Meanwhile, there had been extensive development of sewerage and drainage infrastructure as both the population and the service area had grown quickly in the first half of the 20th century. In the period from 1924 to 1936, extensive work was done to determine options for dealing with the increasing population in the southern and western suburbs and in 1936 work commenced on duplicating the sewerage main to Malabar and the installation of primary treatment works at all ocean outfalls. This work was completed in 1941 and, in addition, extensive work was done on sub-mains feeding the southern and western systems.

In the period between 1934 and 1960, 878 miles (1,411 km) of sewerage were installed in the southern and western systems (Aird 1961, 148–153) and a further 877 miles (1,413 km) were constructed to service the northern suburbs (Aird 1961, 167). By the 1980s, there was general concern about the level of pollution on Sydney's beaches from the three ocean outfall systems, with beaches regularly being closed to bathers. This resulted in the decision to extend the ocean outfalls at North Head, Bondi, and Malabar so that effluent was discharged several kilometres offshore. Construction on this started in 1984 (Beazley 1988, 219). In addition, a number of smaller systems at Parramatta, Hornsby, Manly, Vaucluse, and Randwick constructed in the first half of the 20th century were integrated into the ocean outfall system.

Figure 12: Bondi Sewerage Treatment Works under construction in 1984.

Institutional Arrangements

The main enabling legislation for the appointment of the Board of Water Supply and Sewerage (the Water Board) was passed in 1880 and a supplementary act was passed in 1888 just prior to the Board's appointment and first meeting. The intention was that the Board would take over the control and management of the capital works built by the government, removing responsibility from the Municipal Council of the City of Sydney. Responsibility for construction of capital works was to remain with the Minister for Works but, practically, the Water Board was granted ministerial approval to carry out smaller projects such as reservoirs, pumping stations and mains, with larger infrastructure being built by the Public Works Department. In 1924, in the wake of growing public dissatisfaction with the reliability of the water supply and frustration at the 'dual control' system for construction, an act was passed which consolidated responsibility for construction and operation for all water, sewerage, and drainage works with the Board. Also at this time it was granted complete control of its own finances. (Aird 1961, 215–219, Henry 1939, 2–3).

The original constitution of the Water Board provided for the Governor to appoint three 'Official Members', one of whom would be the President, for the Municipal Council the City of Sydney to elect two 'City Members', and for councils of a number of municipalities within the county of Cumberland a further two 'Suburban Members'. A rotation arrangement provided for three members to retire every two years. The original intention of the structure was to have official members with technical training and for elected members to represent two constituencies of roughly equal size, the City of Sydney and the other metropolitan municipalities (Aird 1961, 214–219). The 1924 act, mentioned above, increased the size of the Board to 18 members (a President appointed by the Governor for a five-year term and 17 elected members elected from municipal councils within nine constituencies of metropolitan Sydney – two for each of eight constituencies and a ninth constituency with one member). This structure was soon found to be unwieldy, with the need for standing orders to be introduced to control length of meetings, factionalisation, and conflicting advice regarding policy. At this time there were problems with construction works and a Royal Commission was appointed to investigate. It recommended a change to the structure of the board and, after some parliamentary debate, in 1935, a further act was passed reducing the size of the Board to seven members: a President and Vice-President appointed by the Governor and five members elected from five larger constituencies, representing groupings of the metropolitan municipal councils (Aird 1961, 220–222, Henry 1939, 9–14).

In 1972, there were concerns that the structure of the Board had become ineffectual and the act was changed to bring the board under the direct control of the Minister. The new Board consisted of five members appointed by the Minister and a further three selected by the Minister from a panel nominated by the Local Government Association (Beazley 1988, 209–210).

This period, which had lasted for the best part of a century, could reasonably be described as the era of the engineer. Many of the presidents, official members of the Board and a significant number of the elected aldermen were engineers (Aird 1961, 309–321). The Water Board became known as an engineering organisation (Beazley 1988, 172–173) and developed a strong, internal culture. Despite public criticism of the performance of the Water Board and the Department of Public Works (from 1888 to 1925), in the period from 1888 to 1960, notwithstanding the major disruptions of the First World War, the Great Depression, and the Second World War, the development of Sydney's water system was very extensive. Ten major dams were constructed, with a storage capacity of over 400 million gallons (over 1,800 gigalitres) – Warragamba dam being one of the largest metropolitan dams in the world. One hundred and twenty nine service reservoirs were built and over 6,400 miles (10,300 km) of water mains were laid. Over 4,000 miles (6,400 km) of sewers were constructed and nearly 180 miles (290 km) of stormwater canals were built in areas subject to flooding (Aird 1961, 263, 309, 207). But the 1970s, the water board's unique culture (described extensively in Beazley's history of the Water Board (Beazley 1988) was seen to be increasingly out of touch with community expectations. Practices and work habits that had evolved over a century were either no longer relevant or reflected complacency, corruption, and inefficiency that was unacceptable. Public dissatisfaction with Water Board culture, politicisation of the issues, and a change in expectations which took place in Australia across many public institutions during this period had a profound effect on the Water Board. From the late 1970s to the present day, the Water Board as an engineering institution was gradually dismantled and replaced by a quasi-corporate structure. This major institutional change – which is still taking place – will be considered in the next section.

THE RECENT ERA – POST 1972

Following approval of the construction of the first two stages of the Welcome Reef system in 1968, Stage 1, Tallowa dam and a system of pumping stations, reservoirs and canals to transfer water from the Shoalhaven Valley to the Nepean system was completed in 1977. It has relatively small capacity (90 gigalitres) and has been used to transfer water to the Nepean system in times of low rainfall. A further study was commissioned by the Water Board in 1974 to study the environmental effects of the second stage of the system, the construction of the Welcome Reef dam itself. The study was completed by Snowy Mountains Engineering Corporation (SMEC) and Gutteridge, Haskins and Davey (GHD), two large consulting engineering firms. The study, completed in 1978 and explored environmental, social, and ecological impacts of constructing the dam. This report confirmed the findings of the original 1968 study that recommended construction of two large dams on the Shoalhaven River system and proposed that construction should be commenced in 1986 with completion in 2000 (Seebohm 2000).

There were further investigations into the dam proposal in the period from 1982 to 1993. Two studies investigated aboriginal archaeological sites in the inundation area, the second of these recommending that archaeological sites be excavated and aboriginal artefacts collected (Seebohm 2000). In the late 1980s, SMEC and Sinclair Knight & Partners were commissioned to examine the water supply strategy, tabling their report in 1991 (Snowy Mountains Engineering et al. (1991)). This study modelled both demand and headworks and concluded that there were three options to provide Sydney with water. The first of these was either increasing the capacity of the Warragamba dam (by raising the height of the existing dam wall, or constructing a flood mitigation dam downstream of the existing dam), or a two-stage development of the Shoalhaven. Second was development of reverse osmosis and desalination technology for effluent reuse. And third, was a 'risk management' strategy in which further capital investment would be postponed until a crisis point was reached and then additional technology, such as reverse osmosis technology, would be installed expeditiously. The report recommended not pursuing the third option without further evaluation. The report concluded that one or other of these schemes would need to be commissioned by 2011/2012.

In July, 1993 the Welcome Reef development was postponed indefinitely , the NSW Government appearing to be following the third 'risk management' option, together with demand management. Other than the relatively small Tallowa dam (mentioned above), the raising and strengthening the wall of Warragamba dam during the late 1980s, together with a new spillway to protect against the possibility of a major flood in the late 1990s, there have been no significant headworks since 1972 (Warragamba fact sheet). However, there has been significant work done in sewerage and drainage.

In the last 50 years, a number of smaller sewerage systems have been built, particularly in western Sydney (including trials of advanced concepts such as the Rouse Hill re-use system (Law 1996), there now being about 20 sewage treatment systems in the Sydney metropolitan area, although about 75% of sewage still is treated by the three main deep-water outfalls which discharge into the ocean just off the Sydney coast. In the 1980s there was considerable public outcry regarding the pollution of Sydney's ocean beaches and plans were announced to move the sewage discharges from the three ocean outfalls from a few hundred metres off the cliff-face to between 2.5 and 3.8 km offshore (SMH 1989. Further works to upgrade ageing sewage infrastructure and extend the system over a 20-year period was also announced at this time. Although sewerage and drainage work has been the principal infrastructure development during this period, two significant events focused public attention on water supply. First was the apparent water supply contamination by cryptosporidium and giardia in 1998. A Royal Commission was appointed, resulting in Sydney Water Corporation (the government-owned corporation which replaced the Water Board in 1983) being broken into two major parts: Sydney Water which has distribution responsibility and the Sydney Catchment Au-

thority which is responsible for catchment management (SMH 1998, Stein 2000). The second event was a prolonged dry period, lasting from 2000 to 2007. By 2005, concern was growing that were the drought to extend much beyond the longest on record, Sydney's supply of water could become precariously low. There was considerable public discussion and dissatisfaction with both government and Sydney Water's response to the situation (SMH 2006). Various solutions were proposed including tapping previously unutilised aquifers, reverse osmosis treatment of sewage and stormwater, and reverse osmosis desalination of sea water. The solution that was finally implemented was the construction of a desalination plant at Kurnell (Figure 13), privately owned and operated by Veolia Water Operations Pty Ltd, the subsidiary of a French multinational corporation (SMH 2007).

Construction of the plant commenced in 2007 and it was commissioned in early 2010. The capital expenditure was $1.9 billion, with a capacity to provide 15% of Sydney's water needs, expandable to 30%. The current operational capacity is 250 megalitres a day. The intention is to provide the energy required for operating the plant from a wind farm at Bungendore (News release, NSW Govt. 2010b, EPA Licence 2010a).

Figure 13: Desalination plant, Kurnell, 2008.

Institutional Arrangements

Until the 1970s, much of the construction of water reticulation, sewerage, and drainage was done using manual labour. The workforce was unionised but there was a generally harmonious relationship between the unions and management. However, in 1975, during a period of union militancy and high wage inflation in the broader community, the relationship between the unionised workforce and management deteriorated, culminating in a lengthy strike. During the strike, raw sewage fouled Sydney's ocean beaches, broken water mains were not repaired, and public dissatisfaction soared.

Opinions vary as to the underlying causes of this breakdown in industrial relations: one viewpoint was that the harmonious relationship failed to deliver wage increases which were common in other industries during a period of

full employment; another was that it was a generational change as a younger group came through the workforce, a group that had no experience of the hardship of the Depression and post-Second World War period when work was scarce; still another was that it was largely a result of a clash between an intransigent board and a new breed of militant unionist (Beazley 1988, 201–205).

The board had been reconstituted in 1972 in response to perceptions that the prevailing structure was inefficient and bureaucratic. But the continuing disruptions of the 1970s led to an enquiry and a further reconstitution of the board in 1983, reflecting new public expectations regarding statutory authorities. The new board consisted of six part-time board members, and a full-time general manager, all of whom were appointed by the Minister. But the performance of the Water Board had become a major political issue and the problems relating to ocean beach pollution in the 1980s, and continued public perceptions of inefficiency lead to further restructuring in 1993, establishing it as a state-owned corporation, the Sydney Water Corporation (referred to as Sydney Water). The Water Board responded to becoming a target of public dissatisfaction with advertising and public relations campaigns, an approach which was largely unsuccessful (Beder 1989, 369–376).

Since 1983, the Water Board and its successor, Sydney Water, were transformed from an engineering organisation to a commercial enterprise (Beazley 1988, 173, 213–215). The engineering group was dismantled, most engineering design was let out to private contractors and the large construction group was reduced in size considerably, with much construction work also being subcontracted to the private sector. The NSW government now expects hundreds of millions of dollars each year in dividends from Sydney Water, with the consequence that income which previously had been directed into capital expenditure is now paid to the State Treasury as a dividend.

As noted above, in 1998, the findings of the McClelland Royal Commission resulted in responsibility for catchment management being taken from Sydney Water and given to the Sydney Catchment Authority (SCA), a newly-established statutory body representing the Crown. The board of the SCA consists of a managing director and chief executive, and between four and eight board members appointed by the Minister. The functions of the authority are to supply water to Sydney Water Corporation and other prescribed authorities while taking steps to ensure that catchment areas and infrastructure are managed so as to promote water quality, to protect public health and safety, and to protect the environment. In 2003, the NSW State government, in conjunction with the Federal government, established 13 further catchment management authorities covering all catchments in NSW. These authorities have boards consisting of local residents and landholders and are responsible for advising the government on catchment health. They also have limited funding to undertake environmental projects.

DISCUSSION

Several important matters emerge from this consideration of this narrative. They can be considered from two perspectives. On one hand, Sydney like most major cities in developed countries, saw construction of major water infrastructure over the last 150 years or so which made extraordinary improvements to public health and quality of life. The institutions which were responsible for the construction and management of this infrastructure was strongly influenced by engineers – initially civil engineers but subsequently, engineers of all disciplines. Through protection of catchment areas, treatment of water, distribution systems, effluent management, sanitary drainage, and extensive sewerage, an integrated water management and sanitation system was developed which effectively eliminated many communicable, waterborne diseases. High-quality water was made available at low cost to service both industrial and domestic needs, despite major challenges of climate and rainfall variability. Today, these well-documented technical achievements are largely taken for granted.

But there is another interpretation. From the initial days of the formation of formalised institutional arrangements in the mid-19th-century, engineers were highly influential in decision-making regarding Sydney's water system. From the 1840s onwards, engineers not only took a great interest in development of Sydney's water system but were very influential in the institutional arrangements which evolved. Engineers were strongly represented on the Royal Commission of 1869; it was an engineer from London, William Clark, who reviewed the Royal Commission's findings; and engineers were appointed to 'official positions' when the Water Board was established in 1888. As Beazley (1988) and Beder (1989), 173–174 point out, the Water Board became an engineering institution and that there is a strong influence of engineering culture on the development of Sydney's water system. The reliance on water as a means not only to supply both domestic and industrial requirements for day-to-day life but also as the primary means of sanitation was established early on. For example, in the late 19th century, in the spirited debate regarding dry conservancy versus wet carriage for removing and transporting sewage, wet carriage won the day. Beder argues that this was not simply a technologically-won argument but that the socially-constructed paradigm used by engineers, together with their political influence and expertise resulted in the dismissal of alternative technologies, based on such considerations as cost minimisation (in particular the utilisation of existing assets), institutionalisation of technological education (engineers were taught only one technology – water carriage – without consideration of other technologies). The momentum created by this approach continued to require development of massive infrastructure without adequately evaluating options which may have been more cost-effective and, perhaps, more technologically effective.

Beder touches upon but does not develop fully a further important point – the philosophical paradigm which underlies the practice of engineering. It argued here that the situation arose primarily because of the instrumentalist view which engineers take to their discipline. The engineering profession is focused on technological and economic effectiveness. It utilises science and existing technology to develop solutions with minimal capital expenditure and maximum technological and cost effectiveness. The paradigm is not confined to the utilisation of science in the development of technology or the maximisation of capital utilisation but also extends to utilisation of ecological and human resources. As long as society was willing to sacrifice ecological and individual well-being for some notion of 'greater good', the instrumentalist engineering paradigm and the social paradigm of the day were largely aligned. However, in the 1970s the two paradigms diverged.

In the last forty years, there has been a significant shift in societal values: late modernist thinking, critical theory, and postmodernism have had a notable influence on Western thought. While the technologically-focused disciplines such as engineering continued to be based upon an instrumentalist, positivist philosophical perspective, the change in broad community values led to a collapse in confidence in the technological disciplines, including engineering. Social expectations changed significantly, with expectations that labour should be adequately rewarded, occupational health and safety of workers should be looked after, and that ecological responsibility (recognising either its extrinsic or intrinsic value) was important. Because the Water Board, with its predominantly technologically-oriented engineering paradigm did not recognise this change in social expectations, it slipped out of step with community values. Its inability to respond to this mounting public dissatisfaction and consequent political pressure resulted in the institution being dismantled and the engineering influence which had dominated the Water Board for a century was largely eliminated. Over a period of about 20 years, the Water Board, as an engineering institution, was dismantled and the engineering services moved to the private sector. As a result of public pressure, the Water Board (and its successor organisations, Sydney Water and the Sydney Catchment Authority) became both corporatised and politicised, a state of affairs which still prevails.

In the last thirty years, the complexity of the situation increased greatly: apparently irreconcilable differences among human stakeholders, the environmental impact of proposed solutions – particularly in relation to riparian health, wilderness areas, the significance of archaeologically important indigenous sites, and the interests of non-human species – have further complicated the problem. Social expectations diverged from those of the traditional engineering paradigm: politics, differences in social perspective, shifts in power, coercive behaviour within the problem constituency, differences in stakeholder worldviews, beliefs and values, and a range of issues with differences of opinion regarding importance became increasingly dominant in the discourse.

But it had become clear in the 1970s that Sydney's population growth would require a substantial increase in water system capacity. The Welcome Reef Dam system was shelved but little was done for nearly 20 years either by the State government or Sydney Water to plan other options. The Sydney catchment had relatively high rainfall the last two decades of the 20th century so it was not until the prolonged dry period from 2000 to 2007 that the issue was brought into sharp relief.

In the period from 2004 to 2006 the NSW government scrambled to undertake the necessary infrastructure analysis and, in the face of what was looking to be the longest drought in Sydney's history, committed to the controversial investment in the desalination plant without adequately examining other options. History suggests that there is significant variability in Sydney's long-term rainfall pattern – only time will tell as to whether the decision to build this plant was a good one or not.

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Note: Three references cited extensively here (F.J. Henry 1939, A.W. Aird 1961, and M. Beazley 1988) were official histories of the Sydney Water Board. Henry and Aird both focused on the technical challenges and the accomplishments of the Board, whereas Beazley recorded the social history of the institution.

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