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"... for the encouragement of studies and investigations in Science Art Literature and Philosophy ..."

THE ROYAL SOCIETY OF NEW SOUTH WALES

OFFICE BEARERS FOR 2011-2012

The Society originated in the year 1821 as the Philosophical Society of Australasia. Its main function is the promotion of Science by: publishing results of scientific investigations in its *Journal and Proceedings*; conducting monthly meetings; awarding prizes and medals; and by liason with other scientific societies.

Membership is open to any person whose application is acceptable to the Society. Subscriptions for the Journal are also accepted. The Society welcomes, from members and non-members, manuscripts of research and review articles in all branches of science, art, literature and philosophy for publication in the *Journal and Proceedings*.

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Editorial

DONALD HECTOR
HON. SECRETARY (EDITORIAL)

In my last editorial, I referred to the disadvantage suffered by multi-disciplinary publications such as the Journal and Proceedings of the Royal Society of NSW and noted that we are developing a strategy to re-establish the Journal's position in learned publishing in Australia. It is pleasing to note that at the end of May the Australian Research Council announced that it to withdraw the Excellence in Research for Australia (ERA) Ranked Outlets Indicator and to introduce a Refined Journal Indicator that does not use prescriptive ranks. We anticipate that that it will now be less of a disadvantage for authors to choose to publish in a multi-disciplinary journal such as ours. The Society expects that the Journal will be included in the ERA 2012 Journal List.

Since the last edition was published, the Council of the Society held a strategic planning meeting and identified five strategic programmes that will be the focus for the Council for the next two years. Key to success of these programmes are vibrant publications that will continue to raise the Society's profile. The Society's Act of Incorporation states that it is "for the encouragement of studies and investigations in Science Art Literature and Philosophy". The original by-laws placed a heavy emphasis on science and, indeed, many of the Society's activities have been focused on science. We aim to place greater emphasis on the breadth of the Society's activities and at the strategic planning meeting the Council agreed that our role could best be summed up: "we exist to bring science to art, literature and philosophy; and to bring art, literature and philosophy to science". Thus, we will be encouraging submission of papers that recognise the breadth of influence of art, literature and philosophy on the practice of science and, conversely, the way in which science influences art, literature and philosophy.

We are pleased that the Warren Lecture and Prize has now been formally established by the Society and that funding for the Prize has been assured for the next two years. A prize of $1,000 and two prizes of $500 each for the runners-up will be awarded based on a paper submitted for peer review and publication in the Journal. Entries close on 31st October 2010 and the winning papers announced will be presented early in 2012.

The Society is fortunate to have a an enormous breadth and depth of experience among its membership. We would be pleased to receive papers from members covering aspects of their work that they believe would be of interest to our broad and extensive readership. In particular, we believe readers would be interested to read reviews of our major body of work produced by an ongoing research programme. Manuscripts can be submitted electronically to `editor@royalsoc.org.au` (information for authors is available at `http://nsw.royalsoc.org.au/authors.html`).

Donald Hector
Hon. Secretary (Editorial)
August 2011

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Sydney's Water Sewerage and Drainage System

DONALD HECTOR

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.

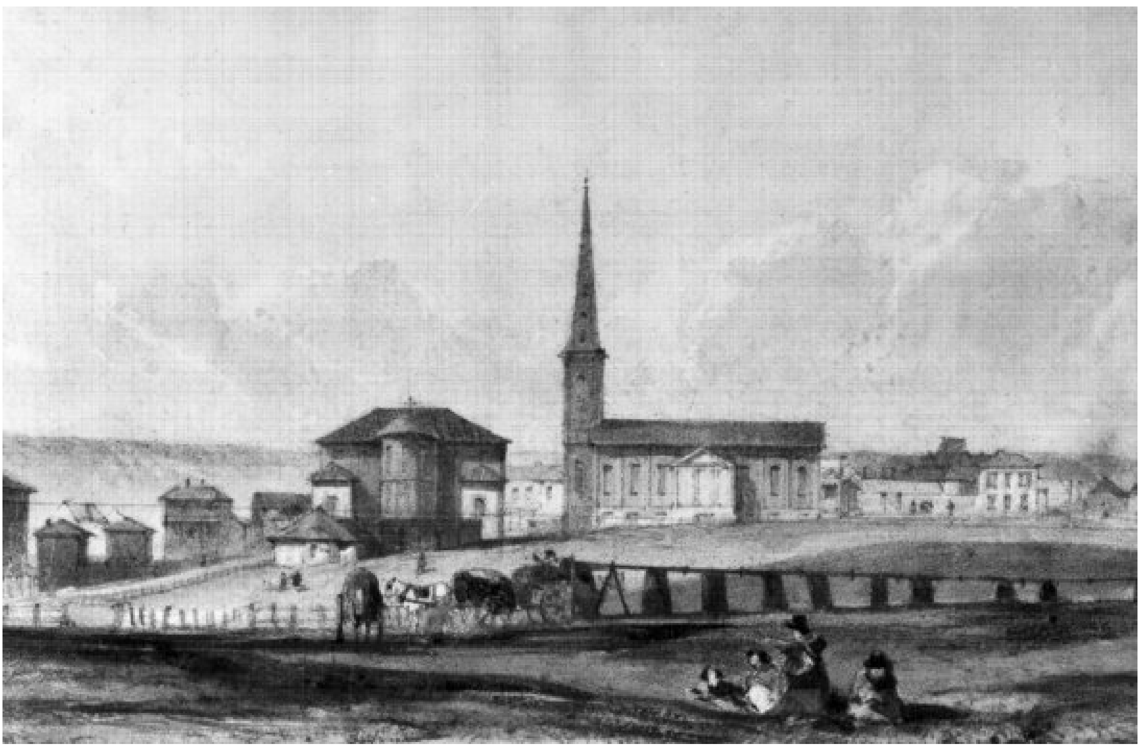

Figure 2: Busby's Bore – Hyde Park, looking towards St James' Church and the Law Courts.

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 stream-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).

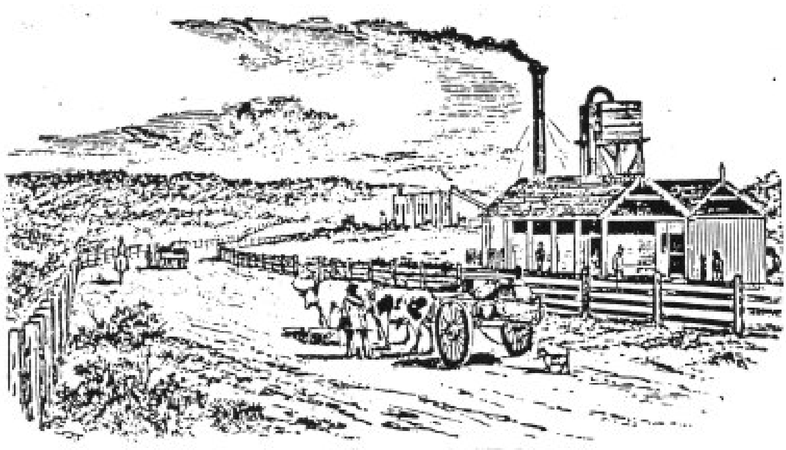

Figure 3: Archival etching of steam pumping station at Lachlan Swamp (c1854). Copy held at Sydney Water archive, drawing by T.S. Gill, Mitchell Library. and Dixson Library and Galleries, State Library of NSW.

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 administer 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).

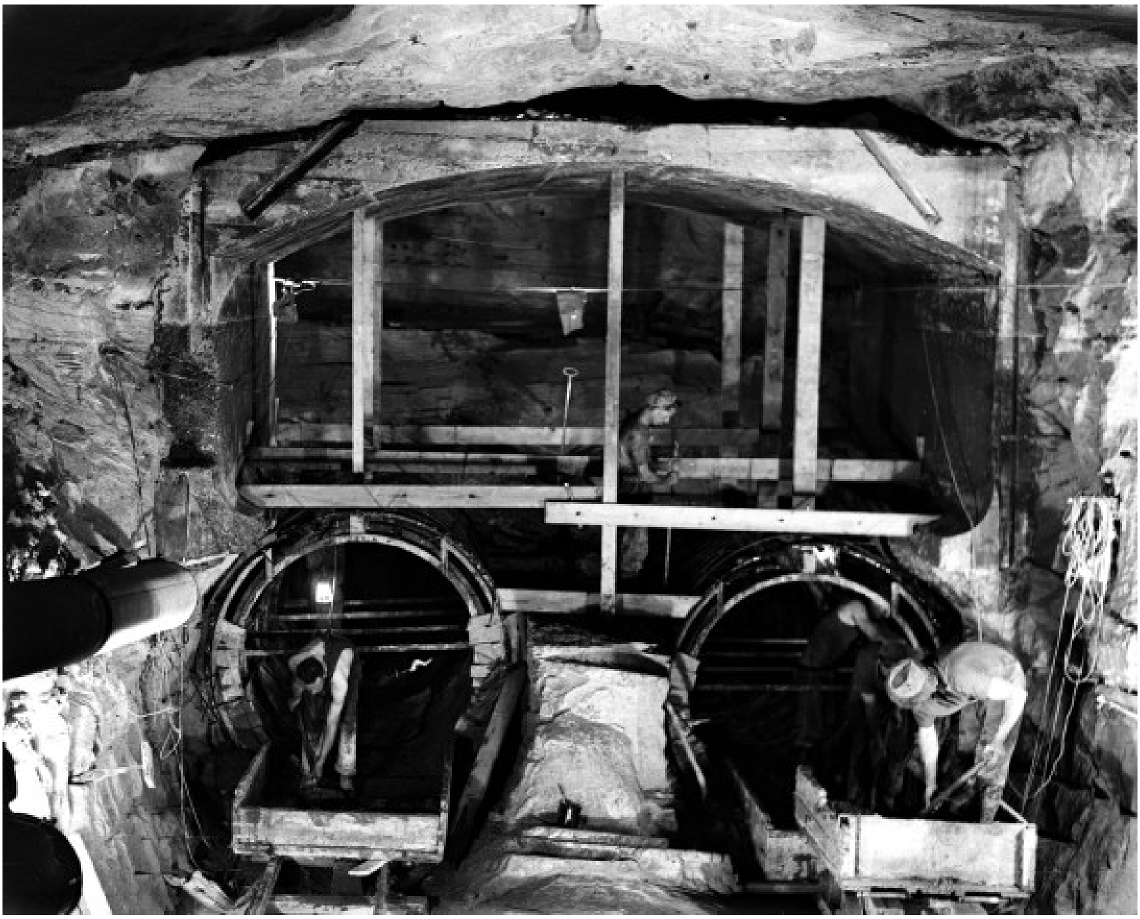

Figure 6: Construction of the Southern and Western Ocean Outfall System (c1915).

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).

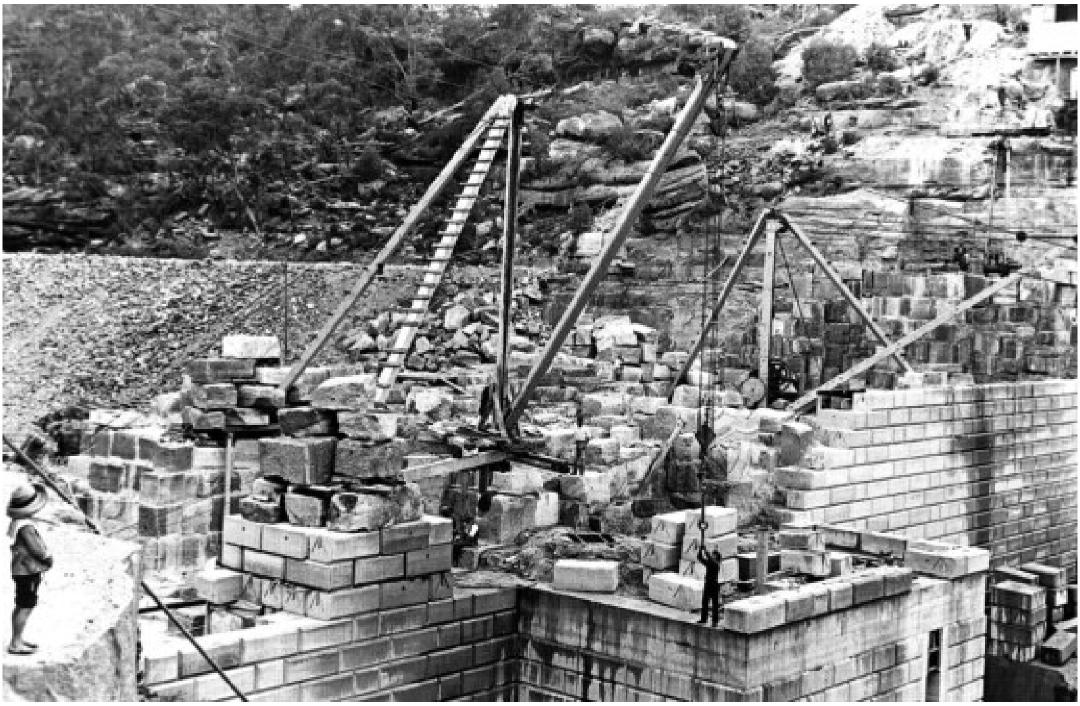

Figure 7: Cataract Dam under construction (c1905).

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 Authority 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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Laser Acceleration up to Black Hole Values and B-Meson Decay

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Paper delivered at the International Conference on Physics in Intense Fields, 24–26 November 2010 at KEK, Tsukuba, Japan.

This paper is dedicated to Professor Chiyoe Yamanaka, Osaka University, for his 88th birthday.

Keywords: ultrahigh laser intensities, pair production from vacuum, efficient antihydrogen production by lasers, alternative laser-fusion

Abstract: Studies of laser produced pair production are followed up from early stages. Pair production by vacuum polarization was discussed with laser produced acceleration up to values similar to those at the surface of black holes leading to the discovery of a difference between Hawking and Unruh radiation. It was found that production of anti-hydrogen by this method is at least a million times more efficient than by present day accelerator technology. Another application of ultrahigh laser fields is to focus them into the collision area of the LHC (Large Hadron Collider) to study the details of the B-meson decay. This also may allow us to detect more details about CP violation of B_s mesons and possible signs of new particles on the horizon. Lasers with picosecond pulses and exawatts of power are now becoming available which will be interesting for studying ultra-intense shock waves in astrophysics and resulting nuclear reactions.

INTRODUCTION AND INITIAL RESULTS

Using very high intensity laser radiation, with the electric and magnetic fields **E** and **H** far above any values applied before, has led to many new physics phenomena and to the realisation that the nonlinear physics involved opens a new dimension of exploration. It has also shown that the linear physics needs to be based on higher accuracy data than previously thought (Hora 2000a).

Examples have appeared where results in linear physics were completely wrong compared to results in nonlinear physics in contrast to earlier instances where there were only gradual differences or approximations. This was discovered not only through using techniques to produce higher and higher laser intensities, mostly realised by chirped pulse amplification CPA (Mourou et al. 2001), but also from considering relativistic effects. The first calculations on how to produce relativistic conditions for pair production of electrons was done by Bunkin (Bunkin et al. 1969) and these calculations were extended to determine the conditions for laser fields to produce quiver motion of electrons with energies above mc^2 (Hora 1973a).

Calculation of the conditions for producing anti-protons (Hora 1973a, Hora 1973b, Shearer et al. 1973) and experiments by Shearer (Shearer et al. 1974) were the very first to show indications of the generation of laser produced positrons. With respect to the quiver motion and drift for proton pair production, the advantages of long wave length laser pulses was found to be of considerable interest (Christopoulos et al. 1988). After interest in antihydrogen for space research became more widely known, the use of lasers for fusion also was found to be of interest because the efficiency was more than one million times higher with lasers due to the available particle density was much higher than with accelerator techniques. It was calculated that a mission to the next star within a reasonable time of 50 years can only be done with laser produced anti-hydrogen fuel (Hora et al. 1986). Thanks to the CPA technique, subpicosecond laser pulses of 2 PW produced for the first time a considerable number of positrons

(Cowan et al. 1999) finally achieving record-level positon beams with intensities above any other method (Chen et al. 2009).

PAIR PRODUCTION BY VACUUM POLARIZATION

Pair production in vacuum was from the beginning considered (Bunkin et al. 1969, Hora 1973a and 1973b) where a laser intensity above 10^{28} W/cm^2 was needed (Heisenberg 1934, Heisenberg et al. 1936). A correction to an about ten times higher value followed later (Hora et al. 2002). At these intensities the acceleration of the electrons by the electric field of the laser is close to the values of Hawking radiation and Unruh radiation at the surface of black holes. This was studied in and compared to black body radiation in which fields are of the same order and where the electrons at thermal equilibrium were not longer following Fermi-Dirac statistics (Hora et al. 1961, Eliezer at al. 2002, Stait-Gardner et al. 2006). Further studies clarified that there was a difference between the Hawking and the Unruh radiation (Hawking 1975) with a relation to the Casimir effect (Unruh 1976, Unruh et al. 1989). These results were based on the theory of electron acceleration in vacuum (Hora 1988, Wang et al. 1998, Hora et al. 2000b) as a basically nonlinear effect (Hora 2000a). The essential aspects of these studies are as follows.

The Unruh effect is a phenomenon whereby an accelerated observer travelling through a true vacuum state – that is the ground state $|0>$ which will be referred to here as the Minkowski vacuum – will experience themselves to be immersed in a thermal blackbody distribution of particles (Hawking 1975). Before comparing the thermal radiation experienced by an accelerated observer to the Hawking radiation of a black hole a brief digression into the physical nature of the vacuum is appropriate.

The Minkowski vacuum is a physical vacuum with pairs of virtual particles manifesting for short durations continuously and, unlike the pre-quantum field theory of vacuum, has observable effects on physical systems (e.g. the fine structure of the atomic hydrogen spectrum and the Casimir effect). Taking the Casimir effect as an example, two parallel mirrors placed in a vacuum will experience an attractive force inversely proportional to the forth power of the distance separating them as a result of the quantum fluctuations of the vacuum. Essentially long wavelength virtual particles cannot manifest between the conducting mirrors resulting in a decreased energy density between the mirrors compared with the vacuum surrounding them where there is no such restriction. The Casimir effect is symbolic of the physical nature of the quantum vacuum.

The quantum field is best decomposed for an accelerated observer using a different basis than the standard momentum basis used in quantum field theory; this basis being related to the standard basis by the Bogoliubov transformations. These transformations play an integral part in analyses of the Unruh effect. The particle number operator differs too and does not give zero when applied to the Minkowski vacuum state (which is not identical to the Rindler vacuum state). The result is, as stated above, that accelerated observers in a pure vacuum will experience themselves in a heat bath with a blackbody distribution.

Thus a state without particles to an inertial observer will be seen to contain particles by an accelerated observer. The dependence of temperature upon acceleration is $T = 2\pi ck_B a/\hbar$, where c is the velocity of light, and a is the acceleration. If a is interpreted as the acceleration at the event horizon of a black hole then the same equation describes the temperature of the thermal radiation emitted from a black hole via the process of Hawking radiation. The similarity of the equations and the equivalence principle of general relativity hint that the mechanisms for the radiation may be the same but this is not the case. Consider the following.

Hawking radiation is sometimes described as resulting from pair production near the horizon of a black hole with one of the virtual particles escaping and becoming real and the other disappearing into the black hole (Hawking 1975). All observers experience Hawking radiation while only accelerated observers experience the Unruh effect. Furthermore, an observer on Earth is effectively in an accelerated coordinate system via the equivalence principle and hence should observe the surrounding vacuum to have a temperature due to the Unruh effect. However, the Earth does not emit Hawking radiation and neither do other gravitational bodies without event horizons. The Unruh effect results from a different mechanism to that of Hawking radiation; it is local, being experienced only by accelerated observers (Stait-Gardner 2006).

PETAWATT LASER PULSES FOR B-MESON DIAGNOSTICS

The present day available PW laser pulses of sub-picosecond duration and the next higher powers can be used for important studies of the details of B-meson diagnostics because their lifetimes are on the same time scale. The use of lasers with as a diagnostic tool for collider beam interactions was studied previously (Hora 1992) for the conditions of the Large Electron Positron (LEP) collider. This can now be extended for the conditions of B-mesons, e.g. at the Large Hadron Collider LHC or similar B-meson factories (Hora et al. 2008).

A prototype of this technique was given by the interaction of 10^{16} W/cm^2 laser intensities in low density helium (Boreham et al. 1979). It was expected from theory that a radial emission of electrons from the focus should convert half of the quiver energy of the electrons into energy of translative motion. The measured energy of radially emitted keV electrons corresponded exactly to the theory predictions. The conservation of the momentum of the photons leads to a slightly forward direction parallel to the laser axis. This was measured (Meyerhofer et al. 1996) and found to be in agreement with the earlier prediction (Hora et al. 1983). Similarly, charged particles generated in the focus of the collider when in the focus of the laser beam, will get an upshift of energy and a change of direction. Petawatt or even the higher exawatt (EW) laser pulses of a few fs duration (Azechi 2011) can then follow up the timing of generating or annihilating processes of the B-meson generation and the decay processes. The importance of this is that further analyzing the different types of B-mesons e.g. with respect to $B_s^0 - \bar{B}_s^0$ oscillations (Abdullenia et al. 2006) where the time resolution can be measured in subsequent steps with the later (Hora et al. 2006). It was mentioned that this open the way to find "possible new particles on the horizon" (Stokstad 2010).

The theory is based on electro-dynamic interaction of the laser radiation with the particles as known from plasma interaction as the nonlinear force given by (Hora 1969, 1985, 1991):

$$f_{NL} = \nabla \cdot [\mathbf{EE} + \mathbf{HH} - 0.5(\mathbf{E}^2 + \mathbf{H}^2)\mathbf{1} + (1 + (\partial/\partial t)/\omega)(n^2 - 1)\mathbf{EE}]/4\pi - (\partial/\partial t)\mathbf{E} \times \mathbf{H}/4\pi c \quad (1)$$

where $\mathbf{1}$ is the unity tensor and c is the vacuum speed of light (see Eq. 8.88 of Hora 1991). The value n is the (complex) refractive index determined by the laser frequency ω and the electron-ion collision frequency ν of a plasma:

$$n = 1 - (n_e/n_{ec})/(1 + i\nu/\omega) \quad (2)$$

where n_e is the electron density, n_{ec} is the critical electron density and where the plasma frequency ω_p is equal to the laser frequency ω. The dielectric properties of the vacuum polarization are to be included appropriately for pair production in a vacuum. The derivation of this force with inclusion of the dielectric plasma properties for the non-transient case (Hora 1969) was based on momentum conservation. The final complete transient case, Eq. (1), was derived later (Hora 1985) and is based on symmetry where it was proved that this, and only this, is the Lorentz and gauge invariant description of the nonlinear force.

For the simplified one-dimensional geometry and perpendicular laser irradiation, the force (1) can be reduced to the time averaged value:

$$\begin{aligned} f_{NL} &= -(\partial/\partial x)(\mathbf{E}^2 + \mathbf{H}^2)/8\pi \\ &= -(\omega_p/\omega)^2(\partial/\partial x)(\mathbf{E}_v^2/n)/16\pi \quad (3) \end{aligned}$$

where E_v is the amplitude of the electric field in vacuum. The last expression is reminiscent of the formulation of the ponderomotive force in electrostatics and is sometimes called "radiation pressure acceleration".

The relativistic limits for the emission of the charged particles from the collider area with a laser focus are given for laser intensities of neodymium glass lasers (Hora et al. 2008):

(1) charged B-mesons;
$I_{rel} = 1.2\times10^{25}$ W/cm^2 $\Delta\varepsilon = 2.41$ keV

(2) protons or antiprotons from the B-decay;
$I_{rel} = 3.9\times10^{26}$ W/cm^2 $\Delta\varepsilon = 424$ eV

(3) charged π-mesons from B-mesons decay;
$I_{rel} = 2.73\times10^{23}$ W/cm^2 $\Delta\varepsilon = 31.5$ keV

The size of the lasers for PW-fs pulses are comparably compact such that the diagnostics with an additional laser focus may not be a too difficult problem. The signals from the detectors for comparable cases with and without the laser will then be done by functional analytical folding of the information about the time dependence of creation, decay and annihilation processes of the numerous types of charged particles.

EXAWATT LASER PULSES FOR SHOCK WAVES AND NUCLEAR REACTIONS

Studies with advanced PW to EW laser pulses are also important for exotic conditions of shock waves in astrophysics (Hora et al. 2011), ultrahigh acceleration and for related interactions, including nuclear mechanisms. The essential difference from the usual thermal pressure generation processes in plasmas is the direct conversion of laser energy into particle motion. This can be seen from the nonlinear forces including the optical response since 1969 (Hora 1969) expressed in Eq. (1). The then predicted ultrahigh accelerations were first measured by Sauerbrey by the Doppler effect at target interaction with above TW-ps laser pulses. The nonlinear force driven accelerations were 10^{20} cm/s^2 (Sauerbrey 1996) in contrast to comparable accelerations with thermal-pressures of 10^{15} cm/s^2 (Park et al. 2011). The high acceleration was in full agreement with the theory (Hora et al. 2007) and could then be used to ignite solid state density fusion fuel deuterium tritium DT (Hora 2009). This is a rather simplified scheme of igniting hydrogen-^{11}boron that produces less radiation per megawatt of generated energy than burning coal (Hora et al. 2010).

Figure 1 shows the computations of the ion density of the fusion flame in frozen DT at ps laser irradiation of 10^{20} W/cm^2. This demonstrates the expected velocity of the reaction front. In addition this reaction front, propagating through the solid DT, can generate compressions up to four times the solid state value within the moving short-depth shock wave. This numerical result agrees with the factor four of the Rankine-Hugoniot shock wave theory. The shock velocity of 1550 km/s is in the range known for this type of interaction.

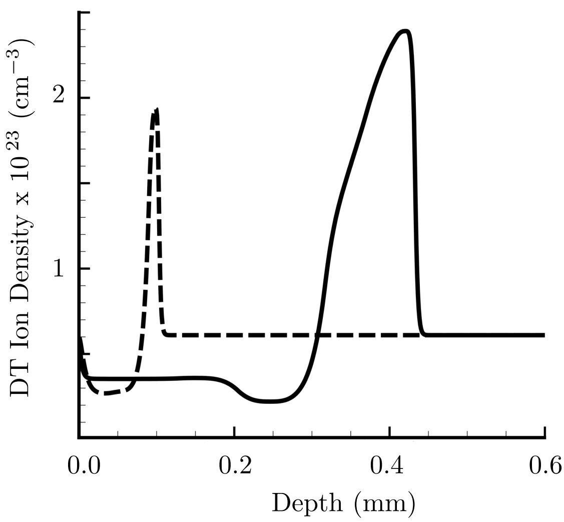

Figure 1. Genuine two fluid hydrodynamic computations (Lalousis et al. 1983, Hora et al. 1984) of the ion density in solid DT after irradiation of a laser pulse of 10^{20} W/cm^2 of ps duration at the times 22 ps (dashed) and 225 ps after the initiation.

For later times the fusion flame shows an increasing deviation of the density profile from the simplified shock wave theory. This is evident from measuring the velocity of the generated alpha particles as the flame moves into the untouched solid DT. The velocities will change as the conditions of densities and temperatures within the DT gradually change. Remarkably, the velocity of the entire flame is unchanged. More properties are given in the references, however, the genuine two-fluid computations arrive at many more details than known from the one-fluid computation (Hora 2009, Hora et al. 2010). It is important to note that these studies model ps laser pulses in the range of 30 PW up to nearly EW.

Generalizing the preceding computations, the genuine two-fluid hydrodynamics (Lalousis et al. 1983, Hora et al. 1984) is used in order to follow up the details of the generated very high electric fields in the shock fronts and to confirm most of the other results calculated before with the usual one fluid hydrodynamics. The results are interesting for astrophysical cases and for shock ignition of fusion (Betti et al. 2007) where in contrast to the thermal pressure process, the new research now is generalized to non-thermal nonlinear force direct conversion of laser energy into plasma motion to reach ultrahigh accelerations.

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Awards 2010

In 2010 the Royal Society of NSW sought nominations for the Clarke Medal (in Geology), the Edgeworth David Medal and the Walter Burfitt Prize. The Society received an outstanding range of submissions from several different States and Territories. The Awards Ceremony was held at the Annual Dinner of the Society at St Paul's College, University of Sydney on 18th February 2011. The Awards were presented by the Society's Patron, the Governor of NSW, Her Excellency Professor Marie Bashir AC CVO.

Prof. Ken Campbell, Prof. Richard Shine and Assoc. Prof. Angela Moles receive their awards from the Governor of NSW, Her Excellency Professor Marie Bashir AC CVO.

The Clarke Medal 2010

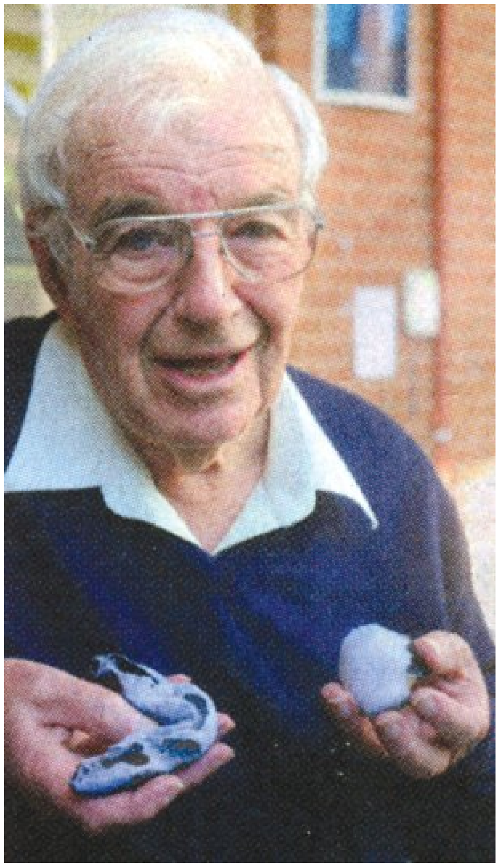
PROFESSOR KENTON CAMPBELL

The Clarke Medal is awarded for outstanding research in the natural sciences in Australia, and rotates between botany, zoology and geology. The medal commemorates the Rev W.B. Clarke who played a key role in the Society in the middle and later part of the 19th Century.

The 2010 Clarke Medal was awarded to Professor Kenton Campbell, Emeritus Professor of Geology at the Australian National University. He began his career under Professor Dorothy Hill at the University of Queensland. Dorothy Hill in her time was a leading palaeontologist and won the Clarke Medal of the Royal Society of NSW in 1966. Professor Campbell then worked at the University of New England, and in 1962 he went to the Australian National University, where he still works. While most of his research has been done in Australia, he worked for short periods in Cambridge, Harvard, Chicago and London. He became a Fellow of the Australian Academy in 1983, and won the Academy's Mawson Medal in 1986. He gave the Clarke Memorial Lecture to the Royal Society of NSW in 1975.

Professor Campbell is Australia's senior palaeontologist. His research began in stratigraphy, at a time when palaeontology was considered merely the handmaiden of stratigraphy. Professor Campbell has pioneered the development of palaeontology in its own right. He became an international authority on fossil marine organisms, particularly the trilobites. In 1965, he started working on the lungfish and became expert on its nervous system and dentition. He developed a method to extract fossils from limestone. This technique uses chemicals to dissolve the limestone, leaving the bones intact, revealing minute anatomical details. In his studies on lungfish, he has been able to compare the earliest fossils with today's living animals. His research has moved into the study of evolutionary biology and genetics.

Professor Campbell began publishing his scientific research in 1952. He has continued to work in the Geology Department of the ANU, where he conducts his research, lectures to undergraduate classes and gives advice to postgraduate students. He is an outstanding Australian scientist and a worthy winner of the Clarke Medal.



Edgeworth David Medal 2010

ASSOCIATE PROFESSOR ANGELA MOLES

The Edgeworth David Medal is awarded for distinguished contributions by a young scientist who must be under the age of thirty-five in the year of the Award. It was established in memory of Professor Sir Tannatt William Edgeworth David, FRS, a past President of the Society.

The winner of the 2010 Edgeworth David Medal, Angela Moles, is an Associate Professor at the University of New South Wales, in the Evolution and Ecology Research Centre. She completed a Bachelor of Science at Victoria University of Wellington in New Zealand, and then did a PhD at Macquarie University, graduating in 2004. After further research in the USA and at Macquarie and Victoria Universities, Angela moved to UNSW in 2007. In 2008, she received a prestigious Queen Elizabeth II Fellowship from the Australian Research Council. In 2009, the Australian Academy of Science gave her the JG Russell award, that goes to the top Queen Elizabeth II Fellow.

Angela's primary research goals are to understand the different ways in which plants grow and reproduce in different environments around the world. Her research aims to better understand the selective processes underlying plant ecological strategies. In her PhD, she achieved international recognition for her work on the evolutionary history of seed size. At present, Angela has three main research projects. Firstly there is the "The World Herbivory Project". This aims to quantify global patterns in interactions between plants and animals. She has travelled to 75 different ecosystems around the world to obtain data for this project. Secondly, she is quantifying the extent to which introduced plants have evolved since they arrived in Australia. Finally she is using clonal plants to get new insights into the evolutionary advantage of sexual reproduction.

Angela has published 37 papers to date, including a first author paper in the prestigious journal "Nature". Her work has been cited over 1200 times. She is an editor of three ecology journals. She has a talent for asking big research questions. Angela is a very worthy winner of the Edgeworth David Medal. She has accomplished a great deal before the age of 35, and the Society looks forward to further achievements in the future.

Walter Burfitt Prize 2010

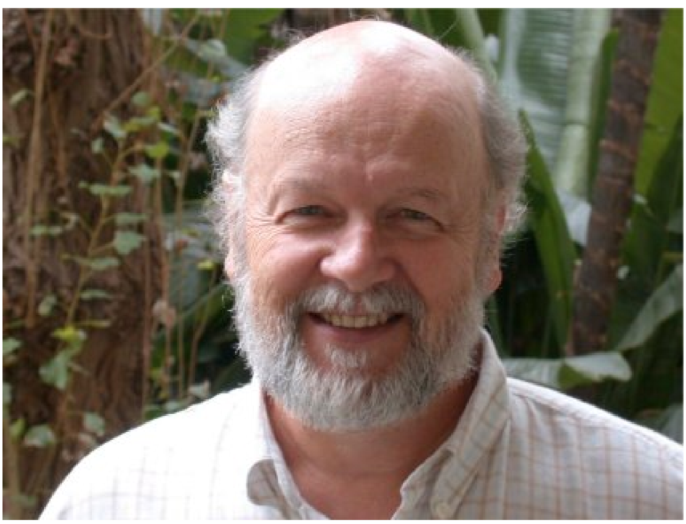
PROFESSOR RICHARD SHINE

The Walter Burfitt Prize is awarded at intervals of three years to a worker in pure or applied science, whose papers and other contributions published during the past six years are deemed of the highest scientific merit. The Prize was established as a result of a generous gift to the Society by Dr W.F. Burfitt, which was augmented by subsequent gifts from his family.

The 2010 Walter Burfitt Prize was awarded to Richard Shine, a Professor in Biology at the University of Sydney. He obtained his BSc honours from the ANU and his PhD from the University of New England. After post-doctoral work in Utah, he returned to Australia in 1978. From that time he has worked at Sydney University, where he was awarded a DSc in 1988. He became a Fellow of the Australian Academy in 2003, and was appointed as a Member of the Order of Australia in 2005. He has won many other honours and awards, including a prestigious Federation Fellowship from the Australian Research Council in 2006, and the Clarke Medal from the Royal Society of NSW for biology in 1999.

Rick Shine's research spans a wide range of species, ecosystems and conceptual areas, but focuses most strongly on the ecology and evolution of reptiles and amphibians. The harsh conditions in Australia favour cold-blooded animals, which need less energy and water than birds and mammals. Rick has conducted extensive and detailed research on Australian snakes and lizards, including the first comprehensive studies of how climate affects the viability of tropical reptile populations. In recent years, his work has transformed our understanding of invasive cane toads, identifying many vulnerabilities reflecting their mismatch to Australian conditions. He has generated a suite of new approaches to reduce toad numbers and mitigate their ecological impact. He contributes regularly to the media. In his dissemination of his research results to the general public, he has emphasized the critical importance of "cold-blooded" Australians in conservation planning.

Rick Shine's productivity during the last six years has been quite astonishing. During this time, he has published 259 papers, out of a career total of more than 700 papers in scientific journals. During the last 6 years, his publications include 4 reports in the prestigious journal Nature. Nor surprisingly, he is among the world's most highly cited authors in his field, with over 16,000 citations. He is a most deserving winner of the Walter Burfitt Medal.



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Applications for Awards 2011

THE EDGEWORTH DAVID MEDAL 2011

The Edgeworth David Medal, established in memory of Professor Sir Tannatt William Edgeworth David, FRS, a past President of the Society, is awarded for distinguished contributions by a young scientist.

The conditions of the Award of the Medal are: (a) The recipient must be under the age of thirty-five years at 1st January, 2011. (b) The Award will be for work done mainly in Australia or its Territories or contributing to the advancement of Australian science.

Nominations are called for the names of suitable persons who have contributed significantly to science, including scientific aspects of agriculture, engineering, dentistry, medicine and veterinary science.

Agreement of the nominee to his/her nomination must be obtained by the nominator before submission of the nomination and included in the submission.

Please submit electronic copies of the nominations and supporting material not later than 30th September 2011. In addition, please mail one hard copy of the nomination and supporting material to the address below.

The winner will be announced and the Medal presented at the Annual Dinner of the Royal Society of NSW to be held in early 2012.

THE CLARKE MEDAL 2011

The Clarke Medal, established in memory of the Reverend William Branwhite Clarke, MA, FRS, FGS, Vice-President of The Royal Society of NSW from 1866 to 1878, is considered for award annually for distinguished work in a natural science done in Australia and its Territories.

This year's award is in the field of Botany in all its aspects, and nominations are called for the names of suitable persons who have contributed significantly to this science.

The Council requests that every nomination should be accompanied by a list of publications, a full curriculum vitae, and also by a statement clearly indicating which part of the nominee's work was done in Australia and which part was done overseas.

Agreement of the nominee to his/her nomination must be obtained by the nominator before submission of the nomination and included in the submission.

Please submit electronic copies of the nominations and supporting material not later than 30th September 2011. In addition, please mail one (1) hard copy of the nomination and supporting material to the address below.

The winner will be announced and the Medal presented at the Annual Dinner of the Royal Society to be held in early 2012. The winner will be notified at least two weeks beforehand.

For further information and inquiries please contact the Society on `info@royalsoc.org.au` or 02 9036 5282. Electronic copies should be sent to: `info@royalsoc.org.au` marked for the attention of the Honorary Secretary. All paper mail should be addressed to:

Honorary Secretary
The Royal Society of NSW
Building H47
University of Sydney, NSW 2006

THE WARREN LECTURE AND PRIZE 2011

Entries for the 2011 award close on Monday 31 October 2011.

The Warren Lecture and Prize has been established by the Royal Society of NSW (with support from the Warren Centre of Advanced Engineering at the University of Sydney and Engineers Australia, Sydney Division) to acknowledge Professor Warren's contribution both to the Society and to the technological disciplines in Australia and internationally. The aim of the award is to recognise research of national or international significance by engineers and technologists in their first two decades or so of professional practice. The research must have originated or have been carried out principally in New South Wales. The prize is $1,000 for the winner and a prize of $500 each for two runners-up.

Who should enter? The Society expects that entries will come from two groups of researchers: early-career researchers who have already established a publication record in top-tier journals around a particular topic and wish to make a broader audience aware of the importance of their work; early mid-career researchers who have completed a larger body of work that they believe has relevance to society generally and wish to publicise this work as part of an ongoing research and teaching programme.

Entries would be expected from academics, researchers in government research organisations (e.g. CSIRO, ANSTO, DSTO) and other public and private enterprises that encourage original research and development. It is the richness and relevance of the research that the Society sees as important, rather than the affiliated institution.

Entries are by submission of an original paper written to academic standards. The paper should review the research done and identify its national or international significance. Preference will be given to entries that demonstrate relevance across the spectrum of knowledge – science, art, literature and philosophy – that the Society promotes.

Only electronic entries will be accepted and must be submitted via e-mail to the Society at this address: `editor@royalsoc.org.au`. Entrants are referred to "Information for Authors" available from the Society's web-site `http://nsw.royalsoc.org.au/authors.html`.

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Royal Society of NSW Scholarships 2010

The Scholarship Awards for 2010 were presented on Wednesday, 1st December 2010 at St. Paul's College, University of Sydney. Congratulations to the winners; Dennis Black, Lidia Matesic & Kerensa McElroy. A short summary of their research appears on the following few pages.

Royal Society of NSW Scholarships 2011

The Royal Society of New South Wales Scholarships are funded by the Society's Council in order to acknowledge outstanding achievements by individuals working in a science-related field.

Applications for Royal Society of New South Wales Scholarships are sought from candidates working in a science-related field in New South Wales or the Australian Capital Territory. Up to three Scholarships will be awarded each year. Applicants must be enrolled as research students at a University in NSW or the ACT, and must be Australian citizens or Permanent Residents of Australia. There is no restriction with respect to field of study, except that candidates working in physics are encouraged to apply instead for the Royal Society of NSW Scholarship to be offered at the NSW branch of the Australian Institute of Physics Postgraduate Awards Event; please refer to `http://www.nsw.aip.org.au` for further information about this Event.

Your application should include a statement of the significance of your work particularly within the broader context of your chosen field, an abstract of your work (ca 500 words), and a brief curriculum vitae, including details of your professional experience. Be sure to enclose a list of your publications. There is no application form. The closing date for applications is 30th September 2011. The applications will be considered by a selection committee appointed by the Council of the Society, and the decision will be made by the end of October 2011. The decision of the committee is final. The Scholarships will be awarded on merit.

The award consists of a certificate acknowledging your achievement, a $500 prize and a free one-year of membership of the Society. The winners will be expected to deliver a short presentation of their work at the Monthly Meeting of the Society on Wednesday 7^{th} December 2011, and prepare a short paper for the Society's Journal.

One (1) hard copy of the application should mailed to:

The Honorary Secretary
Royal Society of New South Wales
Building H47, University of Sydney
NSW 2006

In addition, an electronic copy should be emailed to: `info@nsw.royalsoc.org.au` marked for the attention of the Honorary Secretary.

Closing Date: 30th September 2011

Factors Affecting the Drainage of Gas from Coal and Methods to Improve Drainage Effectiveness

Denis Black
University of Wollongong

A significant amount of gas is produced during the process of coal seam formation, known as coalification. The conditions present during and subsequent to coalification may be highly variable which can result in significant differences in coal seam properties over relatively short distances. The processes and properties that control the generation, storage and emission of gas from coal seams have been investigated.

High coal seam gas content represents a potential risk to the safety and productivity of underground coal mining operations. In areas where gas content is high and the rate of gas emission into the mine environment during mining is likely to exceed the diluting capacity of the mine ventilation systematic gas drainage is typically used to extract gas from the seam prior to mining. However, given the variable nature of coal, zones exist within seam where drainage can be particularly difficult. Where extremely difficult drainage conditions exist conventional gas drainage methods may be ineffective in reducing the seam gas content below safe levels prior to the arrival of advancing mine workings resulting in production delays and even loss of reserves.

This project was initiated to investigate the reasons for poor coal seam gas drainage performance within the Bulli coal seam and to recommend actions to improve drainage performance from such areas thereby supporting improved mine safety, productivity and resource recovery.

The primary aim of this study was to investigate the relationship between gas production from underground to inseam (UIS) drainage boreholes and various coal seam properties and operational factors for which data was able to be collected. Gas production from 279 UIS gas drainage boreholes was collated and assessed relative to a variety of coal properties and operational factors. The highly variable conditions present throughout the study area and extensive data representing gas production, geological properties and operational factors enabled a thorough and comprehensive assessment to be completed.

Degree of gas saturation and permeability within the coal seam were found to have the most significant impact on coal seam gas drainage with extremely poor drainage expected from deeply undersaturated coal with low permeability. In areas were gas drainage was particularly difficult conventional methods were shown to be incapable of reducing coal seam gas content below safe limits ahead of mining. In such areas alternative gas drainage methods must be considered. To improve coal seam gas drainage in advance of underground mine workings, particularly in areas with low permeability and historically poor gas drainage performance, a new method involving the controlled injection of an inert gas, such as nitrogen or compressed air, is presented.

The nature of coal seam gas emission from both fast and slow desorption gas testing methods was also investigated from which a number of significant relationships were identified. From analysis of 4 785 gas tests, collected from eight Australian underground coal mines, new equations have been proposed for estimating average and maximum expected coal seam gas content, based on the use of early stage gas desorption.

The method used to determine outburst threshold limits applicable to Australian underground coal mines has also been investigated. Based on the results of this analysis a new method has been proposed.

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Targeted Delivery of Chemotherapeutic Agents Using Novel Isatin-based Compounds

Lidia Matesic
University of Wollongong

Cancer will affect one in two men and one in two women before the age of 85. Today, cancer is the second leading cause of death in the developed world killing over 39 000 people in Australia in 2005. People of all ages may be affected by cancer, although incidence generally increases with age. Due to Australia's increasingly aging population, it is estimated that the number of deaths caused by cancer will increase by an extra 800 people per year. Financially, cancer costs the Australian health system $3.8 billion per year, a total of 7.2% of the entire health system expenditure. While more than 60% of cancer patients will survive for more than five years after initial diagnosis, current chemotherapeutics need to be improved to further increase survival rates.

Targeted drug delivery increases the availability of a drug at the target site while reducing its availability at other sites, and is currently one of the most challenging problems in pharmaceutical research. A novel strategy which shows promise for the targeted delivery of cytotoxins involves the urokinase plasminogen activation (uPA) system. The uPA system comprises the protease uPA, its cell-membrane anchored receptor uPAR and two endogenous inhibitors, PAI-1 and PAI-2. The uPA system possesses an appealing new target for anti-cancer therapy by exploiting the uPA receptor to deliver cytotoxic agents into tumour cells. This is achievable since PAI-1 and PAI-2 trigger a series of events which internalise the cytotoxin/inhibitor/uPA/uPAR through receptor-mediated endocytosis. The entire complex is then capable of being degraded in the acidic intracellular environment of the cancer cell, effluxing the free drug to cause cell death, while the uPAR is recycled back to the cell surface. To date, the only successful targeting of a toxin conjugated to PAI-2 has involved the use of an α-emitting radiolabelled isotope (^{213}Bi). Investigations into conjugating other toxins, in particular synthetic cytotoxins, are needed since problems arise due to the radioactivity, cost, availability and short half-lives of α-emitting isotopes.

Isatin is a natural substance isolated from the *Isatis* genus of plants and has many biological properties including anti-cancer activity. Our research group has discovered that synthetic 5,7-dibrominated-N-alkylated isatin derivatives exhibit nanomolar activity against lymphoma (U937) and leukaemic (Jurkat) cell lines and are a viable option for targeting the uPA system. To trigger the release of the isatin cytotoxin from PAI-2 inside the cancer cell, an acid-sensitive linker group needs to be incorporated between the isatin derivative and PAI-2. We used imine-based linkers, which have shown excellent potential for further development. To study the acid-triggered release mechanism of the isatin derivatives, they were conjugated to an amino acid through an acid-sensitive imine linker. The release of the cytotoxin was assessed through ultra-violet visible (UV-Vis) spectrophotometry and *in vitro* cytotoxicity assays. The model drug conjugate displayed stability at physiological pH (7.4) and hydrolysed under acidic conditions (pH 4–5). Work is currently underway on the development of an isatin-PAI-2 conjugate linked through an acid-sensitive imine linker. Our previous investigations suggest this conjugate would be a feasible option for the targeted delivery of isatin cytotoxins, which would ultimately lead to increased survival rates for cancer patients.

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Bioinformatic Analysis of Genetic Diversity of Two Human Pathogens

Kerensa McElroy
University of NSW

Background

My research focuses on applications of Next-Generation Sequencing (NGS) to two human pathogens, Hepatitis C Virus (HCV) and *P. aeruginosa*. In addition to their medical importance, these organisms were chosen to represent two main pathogen classes – viruses and bacteria – ensuring the techniques developed during my PhD are broadly applicable.

NGS has great potential for understanding pathogen evolution. By generating millions of short 'reads', each revealing the sequence of a tiny bit of DNA from one individual cell, NGS provides a 'snap shot' of the pathogen population's genetic makeup. Combined with mathematical models, this information can give insights into pathogen evolution and population structure, ultimately informing the design of medical interventions.

HCV

HCV is a leading cause of liver disease, with between 123 and 170 million people infected worldwide. Standard sequencing techniques do not generate enough data for in-depth examination of viral evolution. While NGS allows sufficient data to be collected, its high error rate makes distinguishing true genetic variation from technical error difficult.

'Cleaning' NGS data during variant detection is therefore important. Random errors can be removed using standard statistical techniques. Errors can also be systematic, however. After observing that systematic errors are often present only in reads traversing the genome in one of the two possible directions, I developed a program which removes systematic errors by checking the direction of reads covering potential variants, discounting variants if there are significantly more reads in one direction. Using this approach, all 26 true variants in control data were identified, with only one extra 'false' variant detected. By comparison, the standard program VarScan detected over 60 false variants.

Mathematical analysis of 'cleaned' NGS data from HCV patient samples revealed that in most cases, infection started with less than three founding viral variants. This is significant, as characterising founding viruses is vital for the development of effective vaccines. For patients with chronic infection, the viral strain after immune response was genetically distinct from the founding strain, indicating that evolution from the founder virus is driven by strong selective pressure imposed by the immune system.

Pseudomonas aeruginosa

P. aeruginosa infection is the leading cause of death for people with cystic fibrosis. Antibiotic resistance is rife, partly due to high genetic diversity in the colonising population. Mechanisms responsible for generating this diversity are not, however, well understood.

Using a biofilm model of lung infection, our lab has shown that the clinical *P. aeruginosa* isolate 18A develops greater phenotypic diversity than the laboratory strain PAO1. By analysing genetic diversity in 'clean' NGS biofilm data (using the approach described for HCV), we aim to identify drivers of diversification. Unexpectedly, while estimating parameters for a model of diversification, the clinical strain displayed a higher death rate than the laboratory strain. Preliminary simulation results show that in populations with a fixed size limitation, elevated death rates can lead to greater diversification. The clinical strain's high death rate may therefore contribute to its elevated diversity, both in biofilm models and in the constrained environment of the lung.

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Thesis Abstract: Peripheral Benzodiazepine Receptors in Bone Tissue

WINNIE WAI-YING KAM

Abstract of a Thesis submitted for a Doctor of Philosophy
University of Sydney, 2009

Bone is a frequent site of metastasis for many cancers. Positron emission tomography (PET) using [^{18}F]fluoride is commonly applied for non-invasive quantification of bone metabolism. Limitations in detection sensitivity/specificity and quantification methodology of [^{18}F]fluoride-PET hamper precise characterization of bone lesions. The aims of this study were to understand the technical and methodological limitations of bone metabolism investigation by PET and to discover a suitable receptor-ligand system for skeletal imaging – for improving the accuracy of bone lesion evaluation thus giving invaluable information for treatment planning and management.

[^{18}F]fluoride-microPET (PET for small animal imaging) was used to image mice receiving either a 4-day low calcium diet treatment to produce a high bone turnover condition, or 4-day treatment by single 5 mg/kg subcutaneous injection of osteoprotegerin to produce a low bone turnover condition. Based on the microPET dataset, a gelatin phantom was prepared using glass droppers filled with different levels of radioactivity for simulating mouse femur in an *in vivo* situation. This novel design allows partial volume effect (PVE) and spillover to be estimated separately. Simulated *in vivo* bone data demonstrated that PVE and spillover can cause 55% under or 126% over-estimation, respectively, on activity measurement.

Peripheral benzodiazepine receptor (PBR) predominantly expresses in cells with mononuclear phagocytic linkage and is usually upregulated in increased turnover conditions. The continuous cell turnover of bone suggests PBR expression. Together with its specific ligand – PK11195, they may be used as a receptor-ligand imaging system for bone, as has been used in the central nervous system. RT-PCR and DNA sequencing confirmed PBR mRNA expression in normal and abnormal mouse bone tissues; and in osteoclasts and osteoblasts. Cytoplasmic localization of PBR in bone cells was observed using a fluorescent PBR ligand – NBD FGIN-1-27. PBR protein expression obtained from receptor-film autoradiography using [^{3}H]PK11195 showed a significant difference between mice with high and low bone turnover. The potential use of PBR/PK11195 as a receptor-ligand system for PET imaging was investigated by simulating the signal characteristics of PK11195 in microPET bone data based on autoradiographic data and the known spatial resolution of PET. Simulation results demonstrated that PK11195/PET might be sensitive to detect the difference in bone turnover of the currently adopted mouse models, provided the contrast-to-noise ratio is increased to a minimum of 1.23 and/or the spatial resolution of the PET scanner is improved to 0.32 mm FWHM.

This is the first report on the expression of PBR in small rodent bone tissue, and the exploration of PBR/PK11195 as a receptor-ligand system for skeletal imaging. A trend to increase of PBR protein expression was observed from the low to high bone turnover states, suggesting its possible functional significance in bone metabolism. PBR/PK11195 might be a potentially useful receptor-ligand system for non-invasive PET skeletal imaging if either a better ligand can be developed (i.e. better target to background ratio) or a very high spatial resolution PET scanner is used. Exploitation of the findings in this work for the *in vivo* evaluation of animal models of bone disease awaits the development of both improved radiopharmaceuticals and instrumentation. Furthermore, the discovery of PBR in bone cells opens an arena for examining the use this receptor as therapeutic target in various pathologies, including but not limited to bone.

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Biographical Memoir

Gavin Brown AO MA (StAnd) PhD (Newcastle, UK)
HonLLD (StAnd & Dundee) FAA CorrFRSE FRSN

1942 – 2010

Professor Gavin Brown, the former Vice-Chancellor and Principal of the University of Sydney, and a strong supporter of the Royal Society of NSW, was born on 27 February 1942 in Lundin Links, Fife, Scotland. He was Dux of Madras College, St Andrews, where he was awarded a Harkness Scholarship for study at the University of St Andrews. He graduated with a Master of Arts degree (1st Class Honours and the Duncan Medal) in 1963. Professor Brown was then awarded a Carnegie Scholarship which enabled him to undertake postgraduate study at the University of Newcastle-upon-Tyne where he was awarded a PhD in 1966.

Professor Brown began his academic career at the University of Liverpool, where he became Senior Lecturer in Mathematics. After accepting the Chair of Pure Mathematics at the University of New South Wales in 1975, Professor Brown and his family emigrated to Australia. At the University of New South Wales, Professor Brown held a number of academic administrative posts, including Head of the Department of Pure Mathematics, Head of the School of Mathematics and, from 1989–1992, Dean of the Faculty of Science.

During his time at UNSW, Professor Brown's mathematical research and, in particular, his work involving Fourier analysis, led to the award of the Sir Edmund Whittaker Memorial Prize and the Australian Mathematical Society Medal. He was also elected as a Fellow of the Australian Academy of Science and later became a member of its Council (1992–1995) and Vice-President (1993–1994). Professor Brown also held Visiting Professorships at the University of Paris, the University of Cambridge and the University of Washington.

From 1988–1993, Professor Brown was also actively involved in the work of the Australian Research Council. He chaired several of its funding committees and, during 1992–1993, was a member of its Council.

Professor Brown moved to Adelaide in 1992 when he was appointed Deputy Vice-Chancellor (Research) at the University of Adelaide. In January 1994 he assumed the role of Vice-Chancellor at that university and held the position until he resigned on 30 June 1996.

Professor Brown held the position of Vice-Chancellor and Principal at the University of Sydney from 1 July 1996 to 10 July 2008. During his tenure the University of Sydney reasserted its leadership role in Australia dominating each of the major Australian Research Council funding categories and obtaining outstanding National Health and Medical Research Council results. Professor Brown was also active in supporting the overall student experience and encouraging extra-curricular activity such as sport and debating. During this period Sydney University won the Australian Student Games for five consecutive years, provided many Olympian and Paralympian athletes and won the World Student Debating Championships.

The author of more than 100 research papers, Professor Brown remained an active mathematical researcher and was on the board of several international journals. He was a regular commentator on higher education policy and has given invited presentations to international meetings, including in China, Japan, Korea, Thailand, Hong Kong, Germany, the USA and Britain.

He was President of the international group of universities, Academic Consortium 21, Vice-Chair of the Association of Pacific Rim Universities and Foundation Chairman of the Go8 universities. He was on the executive of the Business Higher Education Round Table and the Global Foundation and served on the Australian government's Business, Industry and Higher Education Collaboration Council.

In 1997 Professor Brown was awarded an honorary Doctor of Laws by the University of St Andrews and in 2004 an honorary Doctor of Laws by the University of Dundee. In January 2006 Professor Brown was appointed an Officer of the Order of Australia. In March 2007 Professor Brown was elected a Corresponding Fellow of the Royal Society of Edinburgh and in the same year he was awarded the Royal Society of NSW Medal for services to science and the Society.

In 2008 Professor Brown was appointed the Inaugural Director of The Royal Institution of Australia (RiAus), based in Adelaide. Ill health caused his resignation from this position in mid-2010.

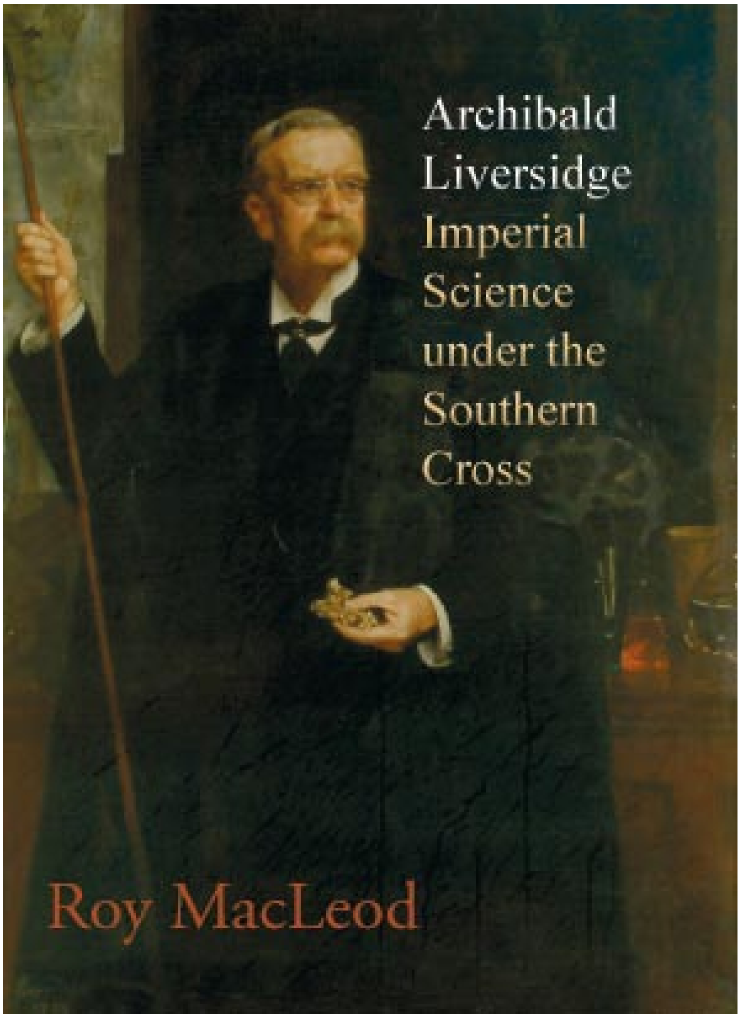
In March 2010 Her Excellency Ms Quentin Bryce AC, Governor-General of the Commonwealth of Australia and Chief Patron of the Royal Society of NSW, presented Professor Brown with a certificate marking his election as one of the Society's Inaugural Fellows, an honour which he particularly cherished. Professor Brown maintained a strong interest in the Society throughout his tenure as Vice-Chancellor at the University of Sydney and was instrumental in ensuring its continuing existence through the provision of accommodation and other support.

Professor Brown passed away on Christmas Day 2010 in Adelaide. He will be sorely missed by the Society.

John Hardie
July 2011

Archibald Liversidge
Imperial Science under the Southern Cross

Roy MacLeod
Royal Society of New South Wales, in association with Sydney University Press
ISBN 9781920898809



When Archibald Liversidge first arrived at Sydney University in 1872 as reader in Geology and Assistant in the Laboratory he had about ten students and two rooms in the main building. In 1874 he became professor of geology and mineralogy and by 1879 he had persuaded the senate to open a faculty of science. He became its first dean in 1882.

In 1880 he visited Europe as a trustee of the Australian Museum and his report helped to establish the Industrial, Technological and Sanitary Museum which formed the basis of the present Powerhouse Museum's collection. Liversidge also played a major role in the setting up of the Australasian Association for the Advancement of Science which held its first congress in 1888.

For anyone interested in Archibald Liversidge, his contribution to crystallography, mineral chemistry, chemical geology, strategic minerals policy and a wider field of colonial science.

To order your copy, please complete the form Liversidge Book Order Form available at: `http://nsw.royalsoc.org.au/books` and return it to:

The Royal Society of NSW, Liversidge Book
Building H47, University of Sydney,
NSW 2006, Australia

or contact the Society:
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If the filesize is too large to email they should be placed on a CDROM or other digital media and posted to:

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Building H47 University of Sydney
NSW 2006.

Manuscripts will be reviewed by the Hon. Editor, in consultation with the Editorial Board, to decide whether the paper will be considered for publication in the Journal. Manuscripts are subjected to peer review by an independant referee. In the event of initial rejection, manuscripts may be sent to two other referees.

Papers, other than those specially invited by the Editorial Board on behalf of Council, will only be considered if the content is substantially new material which has not been published previously, has not been submitted concurrently elsewhere nor is likely to be published substantially in the same form elsewhere. Letters to the Editor and short notes may also be submitted for publication.

Spelling should conform with "The Concise Oxford Dictionary" or "The Macquarie Dictionary". The Systéme International d'Unites (SI) is to be used.

All stratigraphic names must conform with the International Stratigraphic Guide and new names must first be cleared with the Central Register of Australian Stratigraphic Names, Australian Geological Survey Organisation, Canberra, ACT 2601, Australia. The codes of Botanical and Zoological Nomenclature must also be adhered to as neccessary.

Tables and Figures should be in the form and size suitable for insertion in the journal. The pages are B5 format, the text width and height is 150 mm x 200 mm. Tables and figures should be numbered consecutively with Arabic numerals in a single sequence and each must have a caption.

The Journal is generally printed in black and white so photographs will be made into greyscale. If some pages in a paper require color then special arrangements may be made – the author would usually be required to fund the extra cost.

Figures such as maps, diagrams and graphs should generally not be larger than a single page. However, larger figures may be split and printed across two opposite pages. The scale of maps or diagrams must be given in bar form.

References are to be cited in the text by giving the author's name and year of publication. References in the Reference List should be listed alphabetically by author and then chronologically by date. Titles of journals should be cited in full – not abbreviated.

Galley proofs in PDF format will be provided to authors for final checking prior to publication.

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CONTENTS

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