BURRINJUCK DAM AND No1 POWER STATION

NOMINATION FOR

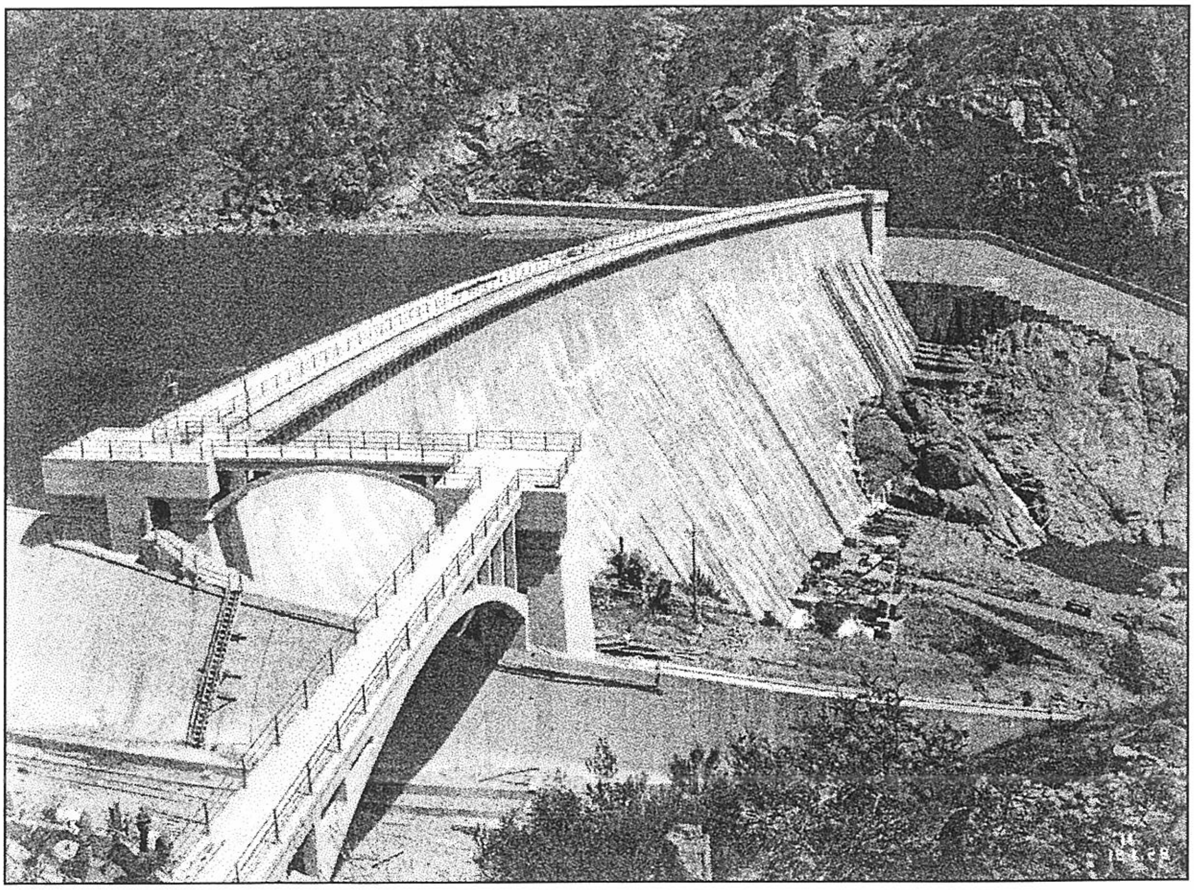
NATIONAL ENGINEERING LANDMARK

INSTITUTION OF ENGINEERS AUSTRALIA

Submitted by Heritage Committee of Sydney Division

in consultation with

NEW SOUTH WALES DEPARTMENT OF LAND AND WATER CONSERVATION
and
PACIFIC POWER



BURRINJUCK DAM AS COMPLETED 1928

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STATEMENT OF SIGNIFICANCE

- At the time of its construction and for some years thereafter, Burrinjuck ranked as the largest water storage in Australia and among the largest dams built anywhere in the world.
- Design was carried out entirely by Australian engineers, drawing on the experience of the Chief Engineer L A B Wade in building water supply dams throughout NSW
- Burrinjuck was the critical component of the Murrumbidgee Irrigation Area Scheme, a vast and courageous concept that required the builders of the Scheme to be engineer, land developer, agricultural engineer, municipal authority, landlord, and migration agent.
- The ninety two year history of Burrinjuck encapsulates the progressive refinement of the techniques of design and hydrology for large dams in Australia, and its survival is a tribute to the courage and intuitive skill of early designers.
- The hydro-electric power station and power scheme based on Burrinjuck was the first in NSW directed at integrated planning of a power generation and transmission scheme over a wide area, and pre-dated by twenty five years later developments of that character in NSW.

INTRODUCTION

Burrinjuck Dam, initially constructed over two decades starting in 1907, was, at the time of its construction, Australia's largest water storage dam. An English writer of the time, Archibald Marshall described it thus "The biggest work of this kind in Australia, and, next to the Assouan Dam, the biggest in the world, is now being undertaken by the State of New South Wales." [1] (As originally constructed Burrinjuck had a storage volume of 766,234 ac ft compared to the Assouan's 863,000 ac ft.) - [Note however that contrary to Marshall's statement,the records of the Department of Land and Water Conservation show Burrinjuck as the *fourth*-largest in the world at the time of its construction] Figures quoted in the text use the original Imperial system of units. Metric equivalents are shown in a Glossary of Units at the end of the document.

The conception and execution of Burrinjuck since 1907 provide a living history of the evolution of Australian engineering competence in many fields - hydrology, dam design and construction, and the interpretation of meteorological data. By today's standards, the tools and data available to the original designers were seriously short of the mark. Inadequacies in the hydrology and the design of the structure emerged at several points along the way but the problems were faced and solved, and Burrinjuck stands today, on so many counts, as a National Engineering Landmark. Indeed the list of engineers whose names are associated with Burrinjuck is a roll-call of the some of the "greats" of engineering practice in this country.

In one sense, Burrinjuck deserves to be recognised as a National Engineering Landmark because it is still there! This is not said frivolously but rather as a tribute to the courage of early engineering designers, who, notwithstanding the severe limitations of the state of knowledge in their profession, were prepared to undertake this major work. It represents the triumph of empiricism and the use of the "safety factor" in engineering design to make provision for the unknown and unknowable. We are invited therefore to recognise the kind of genius that allowed early engineers to produce designs that would endure, relying on intuitive perception and judgement, rather than cut-and-dried formulae that reduce design to mere arithmetic.

Burrrinjuck was the key to the development of the Murrumbidgee Irrigation Area, a courageous experiment in social engineering on a scale unprecedented in Australia. The scheme itself has had its critics over the years, - not least many of those who tried unsuccessfully to "make a go of it" in the MIA - but in the fullness of time it has matched the ambitious hopes of its original proponents.

From the outset it was recognised that Burrinjuck offered the potential for joint hydroelectric development[2]. From the vantage point of the end of the century the generating capacity seems trivial, but by the standards of that era it was significant. Of far greater significance from an engineering standpoint was the quite sophisticated plan to integrate the hydroelectric capacity at Burrinjuck with coal-fired generation - on the Southern Coalfields of NSW and in the Federal Capital - by way of electrical interconnection in order to provide an optimal use of both resources[3]. The implementation of this plan had to await the growth of electrical demand and the construction of the high voltage interconnection between Burrinjuck and Port Kembla, but the soundness of the original concept was vindicated in the 'twenties and 'thirties and provided a model for the later development of the NSW interconnected system.

FIRST MOVES TOWARD IRRIGATION IN NEW SOUTH WALES

In order to appreciate the significance of Burrinjuck and the MIA it is necessary to consider the primitive background from which they sprang. There were private irrigation efforts as early as the 1880's, the most notable being that of Samuel McCaughey whose Coonong Station in the southern Riverina was recognised as the State's most successful demonstration of irrigation.[4] (much of the material in this section is drawn from C J Lloyd's book prepared on behalf of the Department of Water Resources and cited at ref [4]). All of these early developments proceeded without benefit of any systematic study of the hydrology of the NSW rivers or the construction of on-river storages. The first serious study was the Lyne Royal Commission of 1884 chaired by its initiator, Sir William Lyne, with terms of reference as follows:

> *To make a full and diligent enquiry into the best methods of conserving the rainfall, and of searching for and developing the underground reservoirs supposed to exist in the interior of this colony, and also into the practicability, by a general system of water conservation and distribution, of averting the disastrous consequences of the periodical droughts to which the colony is from time to time subject.*

Hugh McKinney, a British civil engineer working with the Indian Irrigation Department came to Australia to work on Sydney's water supply in 1879 until he joined the Lyne Royal Commission in 1884. He organised a program of river gauging to obtain stream discharge measurements and began a comprehensive program of obtaining land levels and making basic surveys.

The Royal Commission led to a number of important policy changes, - the subordination of navigation to irrigation, the substitution of State control of waters as against the dominance of riparian rights, and the beginnings of consultation with Victoria on the management of the Murray. The Commission initiated debate on the creation of headwater storages on principal rivers and their tributaries, but made no specific recommendations. However, the efforts of the Lyne Commission appeared to run off into to the sand, particularly by comparison with the vigorous development of irrigation in Victoria along the Murray and its Victorian tributaries. This was an outcome of the Victorian Royal Commission chaired by Alfred Deakin, later to be Prime Minister.

In the 1890's McKinney continued his pioneering hydrographic work, most notably in the Public Works Department and began to develop specific proposals for irrigation schemes on the Murray and Murrumbidgee. A retired Indian Army colonel, Frederick J Home, was commissioned to report in 1897 on the prospects for irrigation and water conservation in NSW. His overall assessment was sombre but he did identify potential irrigation projects on the Murray and the Murrumbidgee, and of the various storage sites considered, apparently favoured that finally chosen for the Burrrinjuck Dam.

The great drought from 1895 to 1902 stimulated fresh interest in irrigation and especially in the question of storage works. In 1902 an Interstate Royal Commission was created to deal with the allocation of the Murray waters and to make recommendations for reservoirs, weirs and headworks. This was an important step but the practical results were slow to emerge. By about 1905 the NSW government began to show greater interest in the potential of the Murrumbidgee, probably in recognition of the lesser difficulty of promoting a scheme totally within its own borders, without the need for Victoria's agreement.

Hugh McKinney re-emerged as a key figure in about 1903 as consultant to a private group headed by Robert Gibson, a grazier and stock and station agent in the Hay district. This group proposed the construction by government of a storage reservoir at Barren Jack, the site favoured by Home and endorsed by McKinney, and the creation by private enterprise of irrigation in the region between the Murrumbidgee and the Lachlan.

This proposal was taken up and amended by the government as a totally state owned project under the advocacy of Joseph Davis, head of the Public Works Department, with technical input from L A B Wade who had succeeded McKinney as the PWD's predominant hydraulic engineer. The revised scheme was the subject of a report to Parliament by Wade on 7th September 1905[5] and on 23rd December 1906 Parliament passed the *Barren Jack Dam and Murrumbidgee Canals Construction Act 1906.*

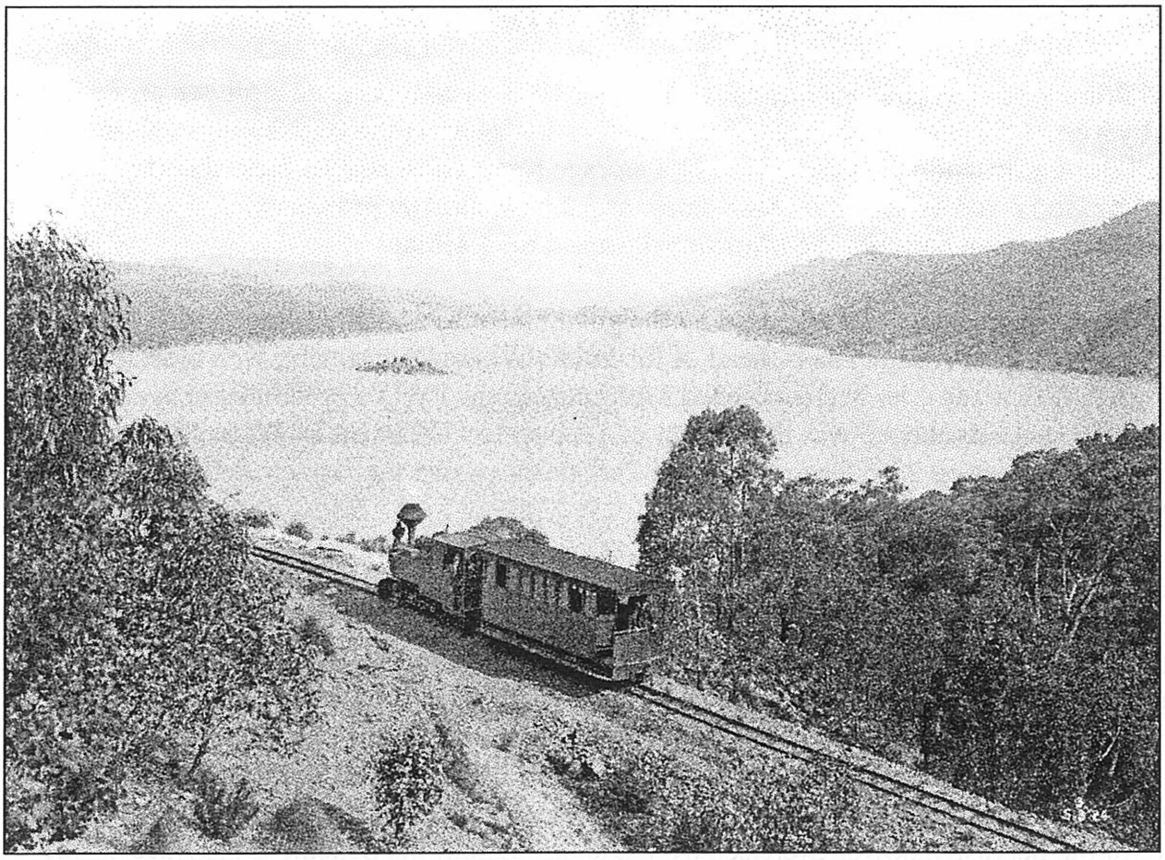
The Public Works Department was named as the initial constructing authority. Water policy was in the hands of the Murrumbidgee Irrigation Trust comprised of three ministers, with L A B Wade as Secretary and Executive Officer. This appointment for Wade was in addition to his responsibilities as Chief Engineer for Irrigation in NSW. In 1912 the Water Conservation and Irrigation Commission was created to take over the constructing functions of the project from PWD, and the policy functions from the Irrigation Trust. L A B Wade became the Commissioner and as such the "supremo", of the MIA until his death three years later. A measure of the pervasive power exercised by Wade throughout the Scheme is provided by the Government's decision, upon Wade's death, to appoint the Minister for Agriculture as Chairman of the Commission in succession to him.

Who should be regarded as the father of the Burrinjuck and MIA projects ? There is no doubt that Public Works Minister Lee, his Department Head Joseph Davis and L A B Wade were the prime movers in finally bringing the project to reality, but Hugh McKinney must also be accorded his due share, as the person who first brought order and professionalism to hydraulic practice in NSW and was then the person regarded as the inspiration behind Robert Gibson's proposal for the private development of irrigation in the region.

Finally, credit must go to the Minister for Lands, Arthur Griffith for actually giving the dam its name of Burrinjuck. The original name was Barren Jack, taken from one of the two peaks that enclosed it - Barren Jack and Black Andrew. The name "Barren Jack" was itself a European corruption of the aboriginal name for the mountain - rendered as Borrin-yiak - meaning a bold rugged feature of the landscape. As Clem Lloyd notes in ref [4] "Concluding that the original name of Barren Jack had dismal connotations for a great scheme of fecundity, partly based on attracting new settlers from the other side of the world, the Minister ...changed it to Burrinjuck which he considered a closer approximation to the original Aboriginal name".

ACCESS TO SITE

One of the first tasks was to provide access to the site. It was determined that in such difficult terrain, the most effective scheme would be the construction of a 2 foot gauge railway from a new siding on the Main southern Line at Goondah, south of Yass. The route for this line had been selected within three months of Parliamentary approval to proceed with the project and the line itself was completed in less than eighteen months.



The two foot gauge rail line and word-burning locomotive - 1923

The engineering problems to be overcome in the provision of rail access, the establishment of a site camp, the excavation of foundations and the construction of a diversion channel, were recounted in an address to the Sydney University Engineering Society in 1908 - one of the learned societies later incorporated within the Institution in 1918[6]. The author was E M de Burgh, Acting Chief Engineer of Rivers, Water Supply and Drainage in the NSW PWD.
Mr de Burgh filled this post with distinction during the extended absence through illness of his chief, L A B Wade. He was appointed Chief Engineer of the Harbours and Water Supply Branch in 1909 and in 1914 took over the role of Chief Engineer Water Supply and Sewerage.

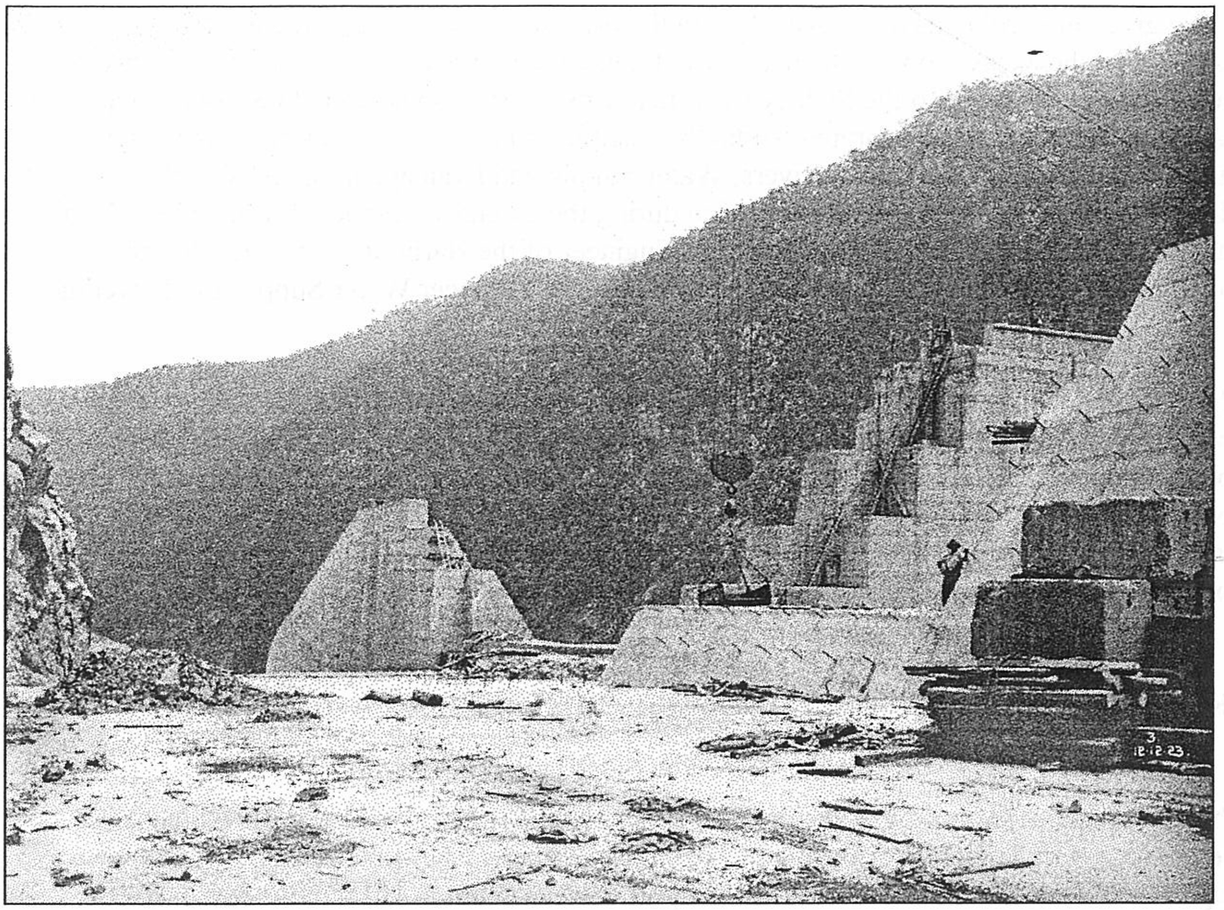
The access rail line was, for many years, the longest narrow gauge line in Australia, and in itself was a project of some significance. The line was 26 miles in length and involved the construction of three concrete dams. These served the dual functions of bridging water-courses and of storing water needed for the locomotives and at the construction site. The largest of these dams, 99 feet on crest and 16 feet high, impounds Lake de Burgh, named in honour of the Acting Chief Engineer. The dam and lake are still standing.

PRINCIPAL FEATURES OF THE WORKS

The design and construction of the dam were described comprehensively in a 1928 paper to the Institution of Engineers Australia by H H Dare, the man who succeeded L A B Wade as Engineering Commissioner of the WC&IC upon Wade's death in 1915[7]. The dam spans the gorge between Barren Jack and Black Andrew, parts of a range of granite that rises to 2,000 feet above sea level and 1,000 feet above the level of the storage.

The catchment area is some 5,000 sq miles and the total storage volume was intended to be 772,000 ac ft with a full-supply level of RL1180 above datum. For reasons later discussed these storage levels were not achieved for a considerable time.

As originally constructed, the dam had a maximum height above foundations of 247 feet, a crest length of 765 feet, a depth at the base of 160 feet and a radius of curvature on the upstream face of 1200 feet. It was designed as a mass concrete gravity dam built in blocks with a maximum length of 30 feet and a maximum width of 36 feet. The blocks or units were each three feet high and vertical joints were staggered so that no vertical joint came immediately over the vertical joint in the tier of units below. The Assistant Engineer responsible for the design calculations for Burrinjuck was the young J J C Bradfield, later to achieve eminence in his own right on the Sydney Harbour Bridge and City Railway projects, as well as numerous others.



The wall under construction

Construction of the lower tiers was in cyclopean concrete for economy and to achieve higher density than normal concrete, - ("cyclopean" - pertaining to the Cyclopes, a mythical race of giants whose king was Cyclops the one-eyed giant, and referring to the very large irregular shaped stones used in the concrete). This form of construction was used up to 94 feet above the invert of the discharge pipes and involved the use of granite "plums" in a concrete using 5 parts broken granite quarried on site, 3 parts sand barged from higher up the reservoir and 1 of Commonwealth Portland cement. Individual plums were as large as 10 tons but the average size was in the range four to five tons. Due to the difficulty of winning the plums the upper part of the structure was completed in a concrete of 6.75 stone : 3 sand : 1 cement. The outer faces were built of a richer mix placed concurrently with the concrete in the main body of the dam.

The foundations of Burrinjuck are solid granite from one embankment to the other. The exposure of the granite foundation and the construction of the coffer dam and diversion channel on the floor of the river were carried out by the PWD on a day-labour basis. The Department also erected the construction power station and installed the three Lidgerwood cableways each of 1200 feet span and 15 ton capacity, together with electric and steam cranes of 6 ton and 15 ton capacity. This stage was completed in 1908.

Having determined the character of the foundations it was decided that the balance of the work should proceed by contract. On 23rd January 1909 a contract was awarded to the firm of Lane and Peters on a schedule of rates basis for the construction of the rest of the structure. The contract provided that all cement, outlet pipes, sluices and other ironwork would be elivered to the contractor free of charge, and that the cableways, cranes, power house, concrete mixers and other plant would be handed over to the contractor for his use. The railway was maintained and operated by the government railways, and stores were hauled at 2½ pence per ton-mile. All employees on site were to reside in "Burrinjuck City" where barracks had been provided for single men; a deduction of one shilling and threepence per week was made from wages to cover the cost of accommodation, water supply, sanitation and medical expenses.

The contractors, Lane and Peters, had previously held the contract for the construction of the Cataract water supply dam in the Sydney Water Board system, and much of the plant and equipment for that project was moved to Burrinjuck..

This contractual arrangement proceeded satisfactorily for a number of years but had finally to be terminated in about 1919 when it emerged that the scope of the work would substantially exceed contractual expectations as a result of the need for much deeper foundations on the northern side of the dam and the need to construct bigger spillways. The rest of the project was then completed by the WC&IC by day-labour.

THE CONSTRUCTION TIMETABLE

Some comment is necessary on a construction programme which might at first appear more like that of a mediaeval cathedral than a modern-day construction project. The first point to make is that an extended construction program for the dam and the later hydroelectric works was clearly in the contemplation of those responsible at the very outset of the project. As to the dam itself, L A B Wade made it clear in his 1905 report to Parliament that the pace of dam construction would have to be matched to the rate of development of the irrigation scheme some 200 miles downstream. This in turn would be determined not so much by the physical progress on the construction of canals and channels as by the success of the scheme in attracting settlers to take up allotments.

In the event, the dam did match the earliest planned start date for irrigation storage and release, and storage began in 1913 behind a partially completed wall in time to meet the needs of the first group of settlers. At no time thereafter was there a gap between the capacity to store water and the growing need for it downstream. However, completion of the work was delayed beyond the original expectation partly owing to causes arising from the 1914-18 war, but principally due to the extension of the spillways and the deep foundations on the northern side. The major flood of 1925 added to the need for remedial works, of which more later, and the construction of the hydroelectric works further delayed the completion of the project. A final completion date is difficult to identify but the publication of two major papers on the project at the Institution's 1928 Conference seems to suggest a 1928 completion, twenty one years after the commencement of work.

THE SPILLWAYS

The story of Burrinjuck is very largely the story of its spillway capacity and the way in which this has been evaluated and re-evaluated over the decades. Four episodes of major significance define its history.

- The years of first construction 1907 - 28
- The years of remedial and enlargement work 1937 - 56
- Low level outlet works failure and rebuilding, and closure of No 1 Power Station 1974 -79
- The years of raising the wall and post-tensioning 1986 - 94

Because of the steepness of the sides of the gorge it was determined at the outset that it was not feasible to arrange for the discharge of the flood waters over an extension of the dam wall in line with the flow of the river. Side spillways were therefore used, in the form of concrete weir walls parallel with the river, with crests 17 feet below the top of the main wall. Flood waters were discharged over these weirs into deep excavated channels, one on each side of the dam. The weir walls upstream of the dam were ogee in section so that the overfalling water followed the face of the concrete. Downstream, where the walls act as training walls only, a trapezoidal section was used.

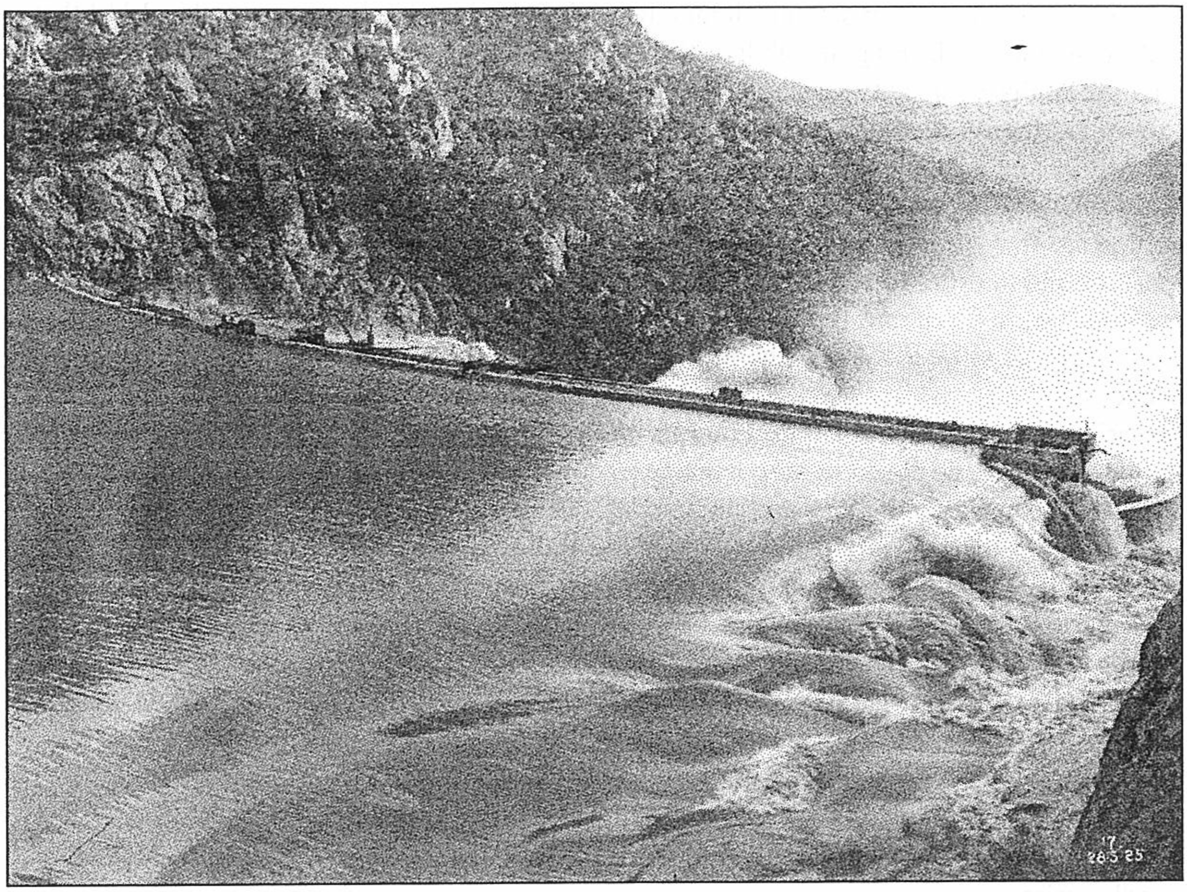
The correct selection of spillway capacity was in reality an impossible task given the lack of reliable hydrological data and the short term over which data had been collected. River heights had been read daily at Gundagai, downstream of the site, since 1887, giving only twenty years of record prior to the actual start of construction. Based on these records and allowing for inflows from tributaries between the site and Gundagai it was estimated that a maximum flood flow of 58,000 cusecs should be provided for. Recognizing the limitations of this data

> *"it was decided to make an assumption as to the maximum intensity of the flood based upon a comparison with the known maximum discharge of a river of somewhat similar character in Victoria. The Chief Engineer then in charge of the scheme, after consulting the Victorian Authority, decided to make provision for spillways to discharge 80,000 cubic feet per second, irrespective of the impounding effect of the reservoir in reducing the rate of which the flood would pass the dam"*[4]

(It is of interest to note that today the Dam is designed to handle a peak spillway discharge of 1,130,000 cusecs, some fourteen times the originally selected figure!)

The first re-evaluation of spillway capacity was made necessary by a flood in 1916 with the wall only partially complete. A model was constructed of concrete in the bed of the river to a scale of 1:24 full size and an extensive series of tests carried out. A Committee of Engineers evaluated these tests and recommended an increase in the length of the southern spillway weir and a corresponding increase in the discharge capacity of the spillway channel. It was then estimated that with the above alterations, the spillways would have a capacity of 130,000 cusecs, (compared with the originally adopted 80,000) and that this should be sufficient to cope with a flood inflow with a peak maximum inflow intensity of 230,000 cusecs, making due allowance for flood detention in the reservoir.

Even this figure proved to be inadequate. A major flood in 1925 put the structure seriously at risk. At that time, in order to keep the river bed dry during construction of the power station and penstock, the discharge sluices had been kept closed for some time and the storage level had risen to within 4 feet 9 inches of the spillway crest. A storm of cyclonic proportions, coming on top of saturating rains a fortnight earlier, caused a flood inflow which is estimated to have peaked at almost 465,000 cusecs. Water overtopped the parapet of the dam wall by 3 feet 4 inches and continued to pour over the wall for 29 hours! The overfalling water eroded an area of concrete at the toe of the wall to a maximum depth of 2 feet 9 inches over an area of 90 feet by 15 feet. This damage was easily repaired and no serious harm was caused to the structure. Clearly, "they had builded better than they knew".



The 1925 flood, showing water still above the level of the wall but by then below the parapet

STABILITY OF THE STRUCTURE

We have already discussed the inadequacy of the data available for spillway design. The project had also to cope with the inadequate state of knowledge of the techniques of dam design as existed in 1905. In particular, there appeared, at that time, to be no appreciation of the need to make allowance for uplift pressure within the concrete or at the foundation of the dam, nor to make any special provision for the cut-off of leakage through and under the concrete.

[Given that the structure survived flood inflows far greater than design assumptions, it has been speculated that the original conservative assumption of designing as a gravity dam, ignoring the substantial contribution of the arch form of the structure, may have provided the extra margin of safety required. Whether this was a conscious decision, or simply a reflection of the designers' intuitive approach in unexplored territory, is not disclosed by the records. Certainly, the techniques of designing thin-walled arch dams were known to Colonial era designers, as witness the slender proportions of the Parramatta water supply dam, and were well appreciated by L A B Wade, the Chief Engineer for Burrinjuck and designer of the slender concrete-arched dam at Medlow Bath . Whatever the reasons, Burrinjuck is still standing today.]

In the mid-thirties a comprehensive review of the works was prompted by evidence of extensive seepage through the walls indicating deterioration of the concrete; and by awareness of significant advances world-wide in the processes of flood estimation and the stability analysis of gravity dams. British consultants, Rendel, Palmer and Tritton reported in 1938 that the wall was seriously lacking in stability, that the concrete was being weakened by seepage, and that the spillway capacity was quite inadequate to pass the floods which contemporary hydro-meteorological methods assessed as probable. Remedial works approved in 1938 were to include:

- cutting ten feet from the crests of the spillways to increase flood discharge. As an interim measure and in order to retain storage capacity other than in flood times, heavy timber "needles" were fitted into the cut-away sections of the spillway walls. If serious flooding was perceived to be imminent, the needles could be lifted to provide greater discharge capacity.
- provision of a grouted cut-off curtain near the upstream face of the dam and an extensive drainage system, designed to stop damage to concrete by percolating water and to reduce uplift pressure within the wall and its foundations.
- buttressing against the downstream face of the wall to improve stability.
- raising the crest of the wall by 13 feet to contain the revised estimate of flood surcharge.
- raising the side-channel spillway crests by 5 feet to restore lost storage capacity and additionally, to increase it to 837,340 acre feet.
- installing three 15 feet high sector gates - 2 x 50 ft and 1 x 80 ft - with crest at the new FSL to further increase spillway discharge capacity for the design flood outflow of 342,000 cusecs. These works necessitated demolition of the access bridge from the northern abutment onto the dam crest, to be replaced by a bridge above the northern spillway crest. These sector gates served as an elegant replacement of the hazardous needle weirs.
- enlargement of the spillway discharge channels.

These works were carried out by day-labour employees under the direction of professional engineers of the Water Conservation and Irrigation Commisssion from early 1939 until 1942 when the demands of WW II lead to a suspension. Re-commenced in 1945 they proceeded without a halt until completed in 1956. The renovated dam was formally opened by Premier J J Cahill on 23rd March 1956.

The first phase involved the drilling and grouting of the wall and underlying foundation, the cutting of the galleries and drains and the buttressing of the back wall. A shaft 85 feet deep was sunk into the foundation at the downstream toe. From this shaft a series of galleries 6.5 feet by 6.5 feet were driven into the dam and the bedrock below. In all, 432 feet of galleries were driven inside the dam wall and 1,003 feet through the bedrock. All of this work is detailed in a 1955 Institution paper by S M Munday[8]

The raising and post-tensioning of the dam occupied the years 1986 - 1994. Once again, it was a re-assessment of the potential for flood which led to very substantial modifications to the dam to give it satisfactory stability and increased spillway capacity. This re-assessment was an outcome of a major national revision of probable maximum rainfalls by the Commonwealth Bureau of Meteorology which indicated that the spillway capacity of many of Australia's large dams was inadequate to handle the Probable Maximum Flood.

Details of the works carried out in those years is set out in a document prepared for a post-meeting tour of the International Commission on Large Dams, following its meeting in Sydney in May 1990. The text of that document is attached as Appendix 1. Engineering design and management of this phase of the work was the responsibility of the NSW Department of Public Works on behalf of the Department of Water Resources. The works were performed under contract by Thiess Contractors Pty Ltd, with post-tensioned cable installed by VSL Prestressing (Aust) Pty Ltd.

A succinct history of the progressive up-grading of Burrinjuck is to be found in the following tabulation of its spillway capacity over the years:

Year	Spillway capacity (cusecs)
1907	80,000
1916	130,000
1925	170,000 (est'd)
1956	342,000
1994	1,129,000

Burrinjuck has probably been under the microscope of professional scrutiny on more occasions and to greater effect than any other structure in Australia. It is a substantially larger and more costly structure than the one envisaged in 1905, although clearly there was, in that initial concept, a willingness to design for the long term and to modify the structure as need and knowledge emerged. Over the years its owners have exploited advances in knowledge and techniques and in this way have contributed significantly to the body of engineering skills in Australia. Both literally and figuratively they have provided an abundant harvest downstream.

THE IRRIGATION AREA

The whole rationale for the building of Burrinjuck was founded in the belief that Australia must develop closer settlement of its hinterland. Other socially worthy causes attached themselves to the scheme - the provision of soldier settlement allotments after World War I, the rehabilitation of silicosis-affected miners from Broken Hill, the encouragement of British migration, the re-settlement of Welsh Patagonians, and indeed the "drying out" of Henry Lawson in a nominal PR role on the alcohol-free scheme. The early years of the scheme encountered economic and social difficulties requiring a change in the policy adopted as to minimum allotment size, a re-think of the best uses for the water, and the granting of financial concessions.

In the view of some, the Scheme did not in fact become viable until the advent of rice growing on the third class soils of the area in the early 1920's, the serendipitous result of a visit to California in 1920 by John Brady, the manager of the Leeton Cannery. Whatever may have been said of the scheme in years past, there is no denying that it has made a notable contribution to the development of what had been a parched and underpopulated area.. Before irrigation, the total population of the Yanco and Mirrool Irrigation Areas was not more than 100 people. There were no towns. Today there are 31,000 people living in or near the towns of Leeton and Griffith, both of which owe their existence and prosperity to the Scheme.

BURRINJUCK AND GEOSCIENCE

One little known aspect of the Burrinjuck project is its association with research to advance the understanding of movements in the strata adjoining large dam structures.[9] The size and topography of Burrinjuck prompted Dr W G Woolnough of the University of Sydney to propose investigation of the behaviour of the earth's crust under a fluctuating load of considerable magnitude as the level of water rose and fell.

An actual test program using three horizontal pendulums was devised by Fr Pigot SJ of the Riverview College Observatory, Sydney, upon his return from study in Europe. In a joint project between the WC &IC and the Australasian Association for the Advancement of Science, the pendulums were installed in tunnels 20 to 40 feet above highest water level and some 60 to 80 feet long. Site supervision was the responsibility of Resident Engineer Mr D F Campbell.

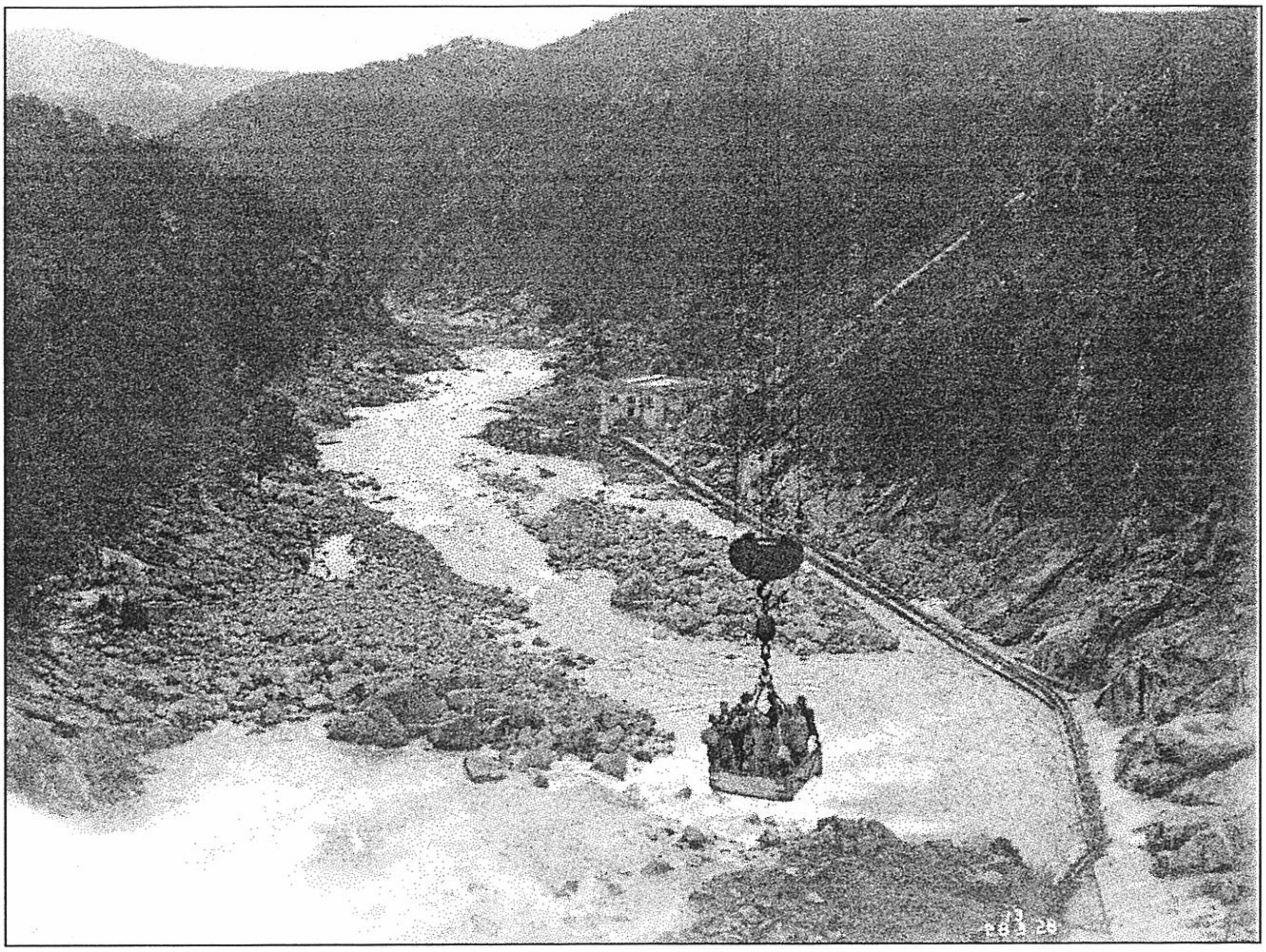
Small slow deflections of the vertical were observed to occur sychronously with changes in water level, but movements of larger magnitude were also noted. Resident Engineer Campbell pointed out that these larger movements were strongly correlated with temperatures measured by a thermometer embedded 80 feet within the dam wall. These results were reported to the Royal Society of NSW by Asst Prof L A Cotton as important in their own right but also as being of considerable practical significance in the analysis of the effect of movements in the level of water in the dam on the surrounding strata.

BURRINJUCK AND ELECTRICAL DEVELOPMENT

The hydroelectric potential of Burrinjuck was explicitly recognised by L A B Wade in his 1905 report to the Parliament. He recognised that a good many years must elapse before this potential could be exploited, noting that until the dam wall reached its full height as determined by irrigation needs, there would be insufficient hydraulic head and insufficient stream regulation to make electricity generation economic. However, prudent provision was made in the design of the structure for the later installation of generating plant.

Early in 1916, E M de Burgh, by then Chief Engineer for Water Supply and Sewerage, put forward a proposal for a power station to supply power for water pumping in the South West Tablelands. Nothing came of this proposal but separately, a complete power survey of the district was carried out by the Electrical Engineering Branch of the Public Works Department. In 1918/19 bids were received for generating plant but prices were deemed to be too high and no further action was taken. Towards the end of 1919 a Hydro-electric Committee comprised of E M de Burgh, H H Dare and W Corin recommended the construction of the Barren Jack Power Station, and in December of that year Parliament authorised the construction of hydro-electric works at Barren Jack plus transmission lines and necessary works for distribution of electricity.

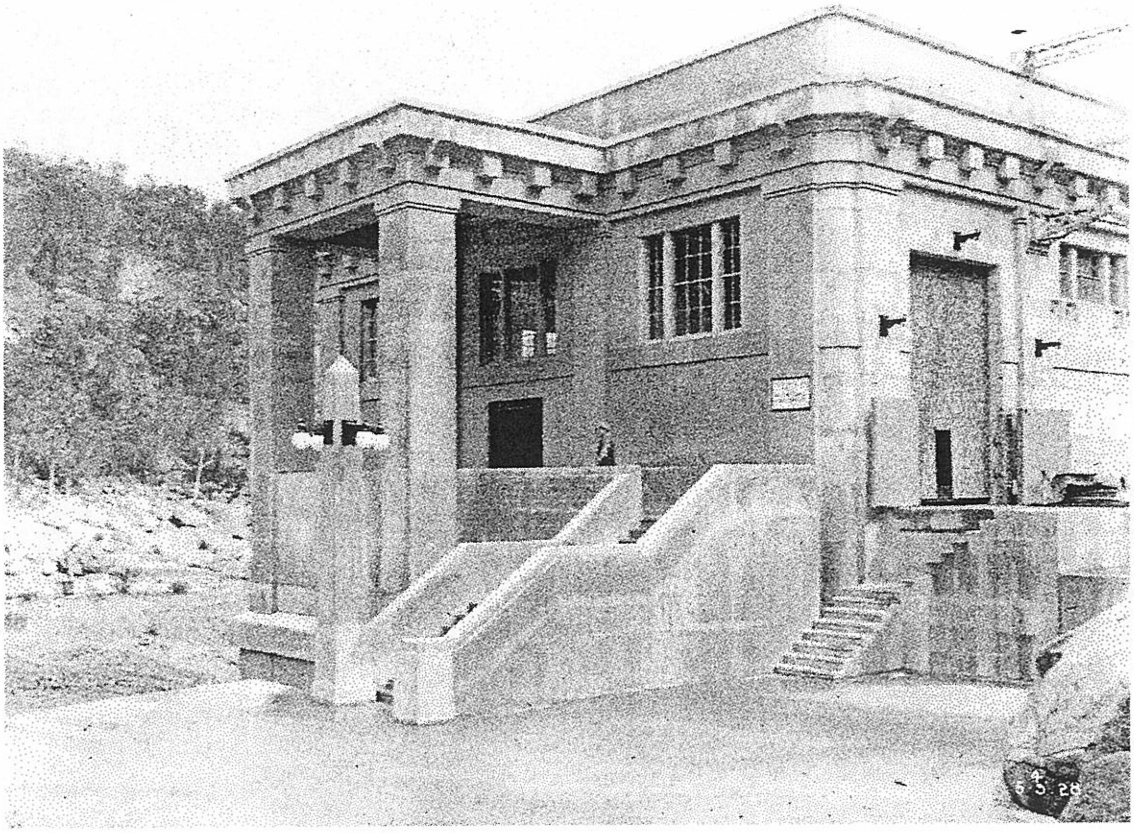
In a 1928 paper to the Institution [3] the then Chief Electrical Engineer of PWD, H G Carter acknowledged the role of his predecessor, William Corin in formulating the Burrinjuck scheme, later to become known as the Southern Electricity Supply.



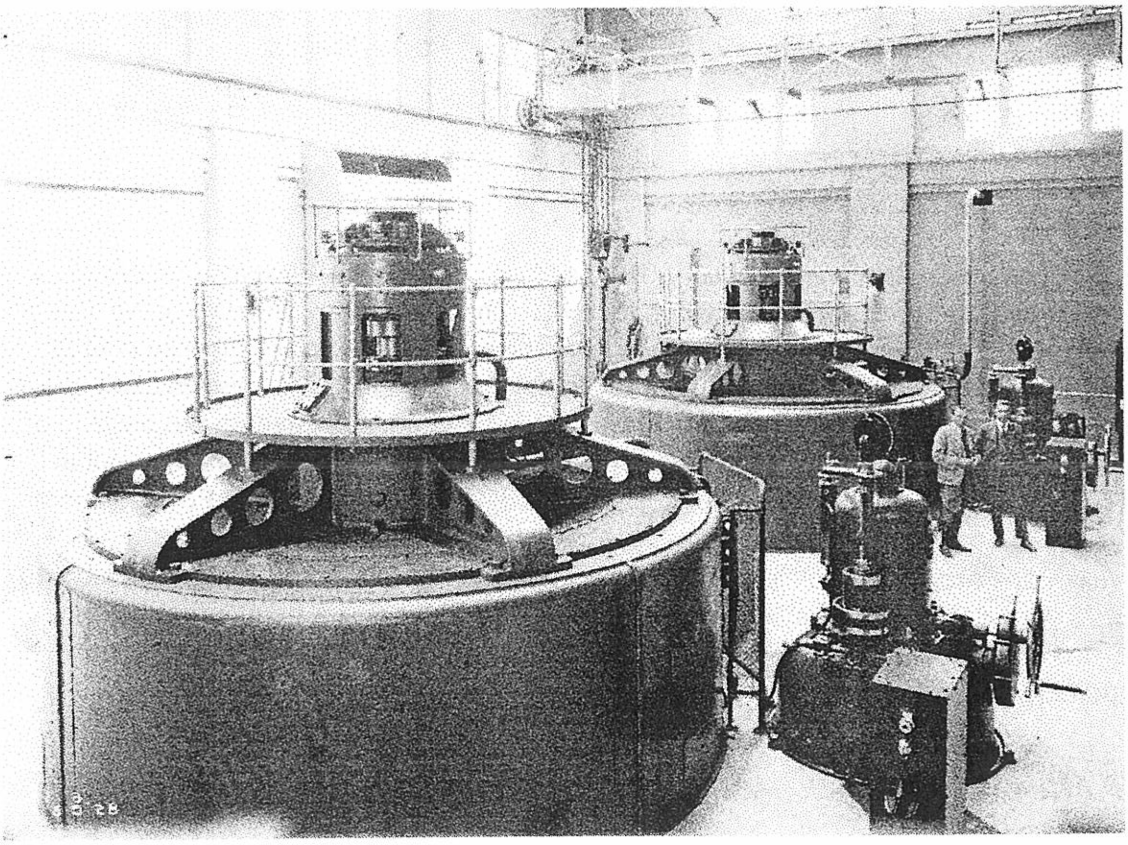
Looking downstream to the site of No 1 Power Station.

Tenders for generating plant were invited in 1922 and site works for the excavation of the power station and pipeline bench began in April 1923. The first station, Burrinjuck No 1 as it was later termed, was approximately 2000 feet from the downstream toe of the dam wall in order to take advantage of the hydraulic gradient in the river. In hindsight, this selection of a site placed undue value on the additional few feet of head and not sufficient on the security of construction and operation. These would have been afforded by locating the station right at the wall of the dam as was done with the second stage development, the No 2 Power Station.

In the event, construction of the No 1 station was considerably delayed by, and contributed to, the flood damage in the 1925 flood. The dam itself had been put at risk by overtopping as a result of restricting releases to allow construction of the power station and pipeline in the dry, and the partially completed penstock was severely damaged, part being washed away.



Exterior of No 1 Power Station

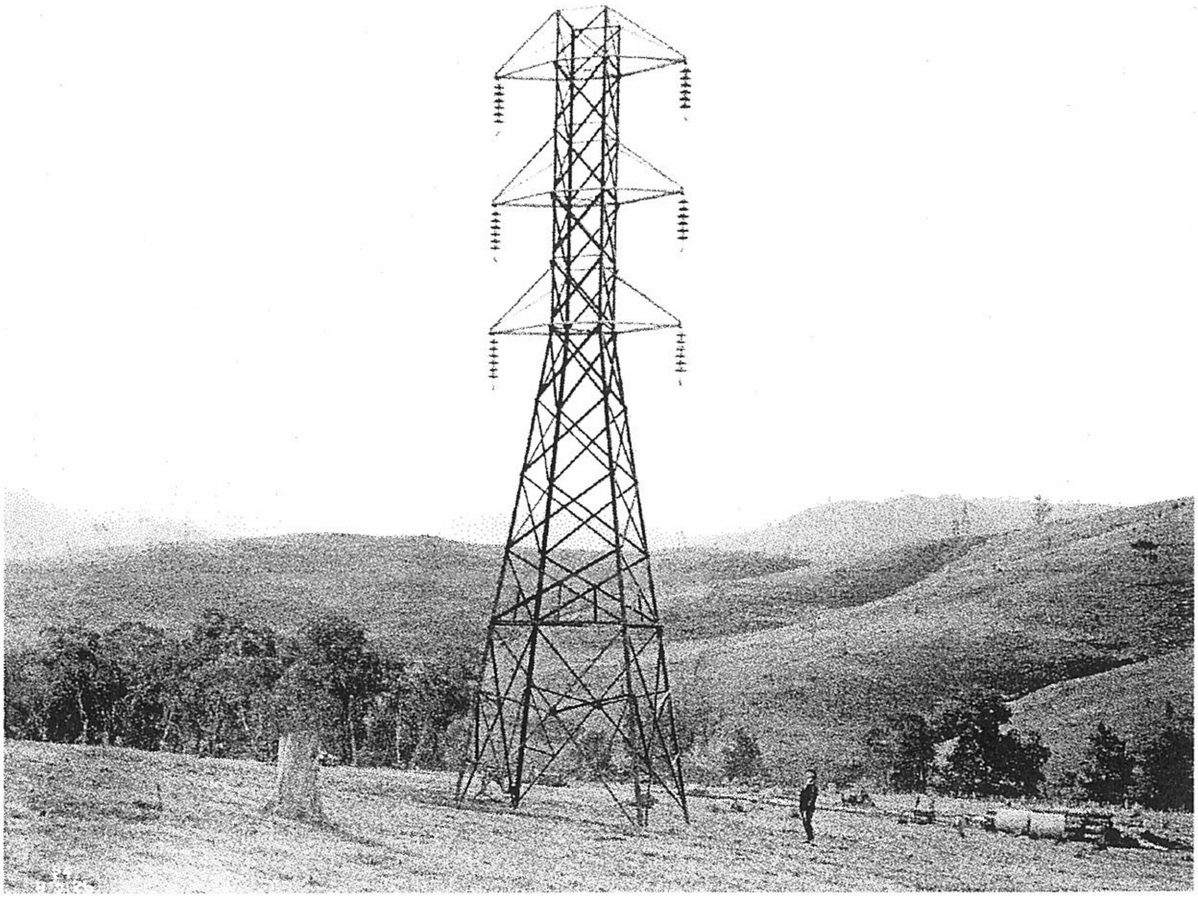


Interior of No 1 Power Station

Notwithstanding the problems which emerged during construction, Burrinjuck and the Southern Electricity Supply made a major contribution to the electrical development of the South West. E M de Burgh's ambition to use the power for water supply was realised with the construction of the Jugiong Pumping Station, and low-cost power from Burrinjuck was but a fraction of the price then being paid for supply from the small fuel-fired power stations that dotted the area, typically with power costs of the order of a shilling a unit.

The most notable engineering feature of the Southern Electricity Supply was its conceptual basis - transmitted supply over a vast area, planned so as to achieve interconnection of the hydroelectric plant with coal-fired generation at Canberra and at Port Kembla on the South Coast. Steel-tower 66kV transmission lines out of the gorge at Burrinjuck were a first for NSW, as was the later use of 132 kV transmission between Burrinjuck, Goulburn and Port Kembla in 1941.

In the initial development of the power system based on Burrinjuck, 204 miles of 66kV transmission lines were built, the highest voltage then in use in NSW and by far the most extensive transmission system built in the State to that time. The towers were manufactured in Sydney to PWD outline designs. Design and construction of the lines and substations were the responsibility of John J Richardson who described the project comprehensively in a 1929 Institution paper.[10]



66kV Steel Tower Transmission Line Under Construction

Each of the two Burrinjuck stations had a capacity of 10,000 kW, small by today's standards but in the blackout era of the 1950's when total state capacity was a mere 490,000 kW, with a potential demand in excess of 700,000 kW, the contribution of Burrinjuck was reliable and invaluable.

A footnote on the siting of the No 1 Power Station. Located as it was on the right bank, downstream of the dam, the power station was vulnerable to flooding. The writer recalls long shifts on duty inside a sandbagged station in the winter of 1952, operating the units manually because of failure of the control cables through flood damage, housed though they were in the concrete protection of the penstocks. The station itself survived on that occasion but was finally damaged beyond economic repair by the flood of 1974.

This 1974 flood was the second highest on record. It was accompanied by a veritable litany of disasters including the stripping of 5,000 tons of rock from the northern spillway, which sliced through the penstocks to the No 1 Power Station. The closing of the sluice valves to isolate the penstocks appeared to precipitate further dramatic events. An emergency baulk, located just above the upstream entrance to one of the tunnels leading to the sluice valves, parted from its moorings and the sudden closure of the entrance precipitated water hammer through the valve system, resulting in damage to nine of the 16 sluice valves. Engineers were confronted with the challenge to devise ways of sealing flows which, at their peak, were running at 7,500 megalitres per day. Five months were required to seal the flow and to allow work to proceed on the installation of a new valve house and sluice valves - one more dramatic episode in the progressive modernisation of Burrinjuck.[11]

DRAMATIS PERSONAE

Hugh McKinney	The State's first hydrologist in PWD, later the consultant active in promoting the building of a dam at Burrinjuck
Robert Gibson	Grazier. The promoter of the concept of the (private) Northern Riverina irrigation area and the building of Burrinjuck
Joseph Davis	Director General PWD. the architect of the proposal that Burrinjuck and the MIA be built by the State
C A Lee	Minister for Public Works who introduced enabling legislation
L A B Wade	Chief Engineer Water Supply PWD author of the definitive proposal to Parliament for construction of Burrinjuck and MIA, first Commissioner of WC&IC 1911-1915
Arthur Griffith	Minister for Lands, the man who coined the name "Burrinjuck"
E M de Burgh	Act'g Chief Engineer Rivers, Water Supply and Drainage PWD 1906-1908,
H H Dare	Engineering Member of WC&IC and responsible for construction of Burrinjuck Dam.
F M Smith	First Resident Engineer at Burrinnjuck, later Principal Assistant Engineer of WC &IC
D F Campbell	Resident Engineer in succession to F M Smith
Wm Corin	Chief Electrical Engineer PWD 1913 - 1924, responsible for the electrical planning of Burrinjuck and the Southern Electricity Supply
H G Carter	Chief Electrical Engineer PWD in succession to Corin and responsible for construction of project
John J Richardson	Designer of Transmission Lines and Substations, PWD
K Fremlin	Resident Engineer PWD, for construction of lines and substations and later Electrical Superintendent, Southern Electricity Supply

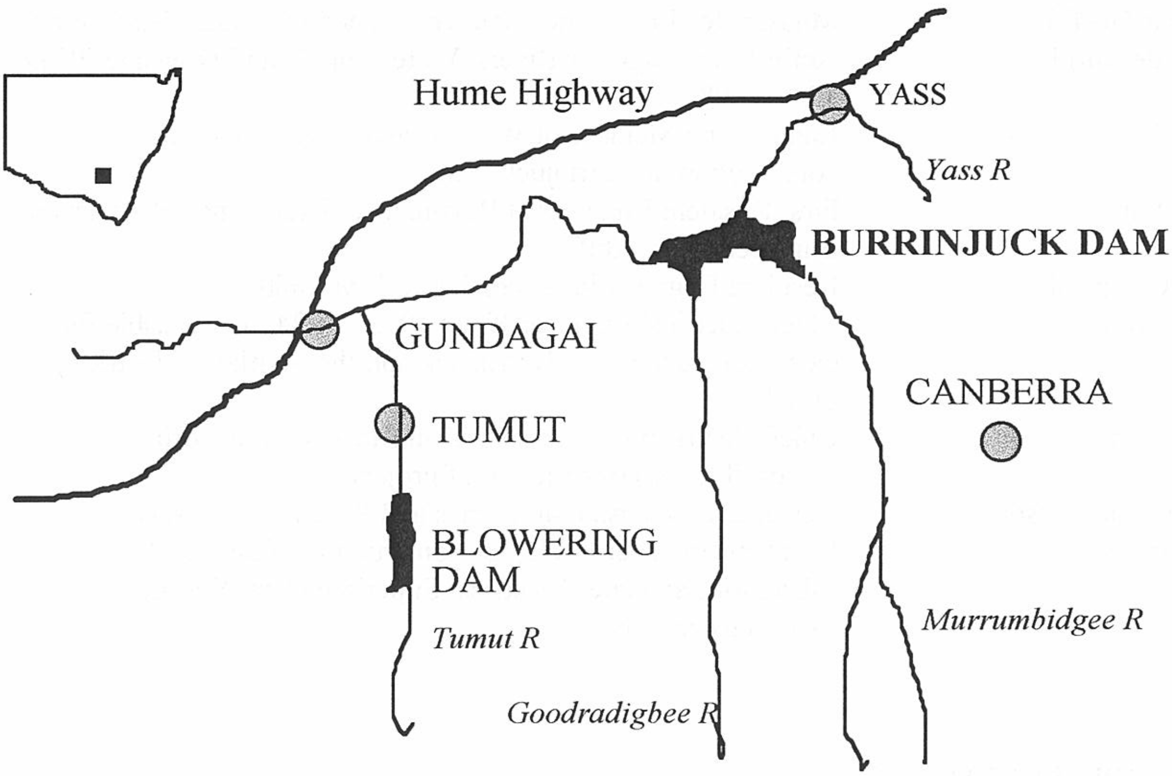
ACKNOWLEDGEMENTS

Thanks are due to the Department of Land and Water Conservation and to Pacific Power for checking the manuscript and for additional material - and most significantly, for their permission to lodge this submission.

Thanks are also due to the State Library of NSW for permission to use, without fee, the images of Burrinjuck included in the submission. These are all from the Government Printing Office Collection held by the Library.

BURRINJUCK DAM

LOCATION MAP



GLOSSARY OF DIMENSIONS

Imperial units have been used almost exclusively, wherever used in the original source material. The following approximate metric equivalents are provided for contemporary reference.

ITEM	Apearing on page no	Imperial units	Metric Equivalent
Original Storage Vol	2	766,234 ac ft	947 Gl
Catchment Area	5	5,000 sq miles	1,297,000 Ha
FSL	5	RL 1180	AHD 362.1
Rail gauge	5	2 feet	600mm
Height of Dam	6	247 feet	75.4m
Crest Length	6	765 feet	233m
Thickness at base	6	160 feet	49m
Radius of curvature	6	1200 feet	366m
Dimensions of blocks	6	30 feet x 36 feet	9m x 11m
Length of rail line	6	26 miles	42 km
Lake de Burgh dam wall	6	99 ft long x 16 ft high	30m x 4.9m
Cableway span	7	1200 feet	366m
Haulage rate on rail line	7	2½ pence per ton mile	1.27c/Te km
Board & lodging per day	7	One shilling & threepence	12.5c
Original est flood flow	8	58,000 cusecs	1,645cumecs
Original spillway cap	8	80,000 cusecs	2,264 cumecs
Spillway cap after 1916	8	130,000 cusecs	3,679 cumecs
Peak flood est in 1916	9	230,000 cusecs	6,509 cumecs
Peak inflow 1925 flood	9	465,000 cusecs	13,159 cumecs
Ht of overtopping 1925	9	3 feet 4 inches	1m
Size of damage in 1925	9	90' x 15' x 2'9"	27.5 x 4.6 x .83 m
Sector Gates North side	10	2 off - 50' x 15' high	15.25 x 4.6
Sector Gates South side	10	80' x 15' high	24.4 x 4.6 m
Size of shaft to found'tns	10	85 feet deep	25.9 m
Size of galleries in wall	10	6.5' x 6.5' x 432'	2 x 2 x 132 m
Size of galleries, bedrock	10	6.5' x 6.5' x 1,003'	2 x 2 x 306 m
Current spillway cap	11	1,129,000 cusecs	32,000 cumecs
Length of penstocks	13	2,000 feet	610 m
Length of 66kV lines	15	204 miles	328 km

ENDNOTES

[1] Archibald Marshall — "Sunny Australia" London, Hodder and Stoughton 1911

[2] L A B Wade — "Proposed Northern Murrumbidgee Irrigation Scheme and Barren Jack Storage Reservoir" - Report to NSW Parliament 7th September1905

[3] H G Carter — "Barrenjack Hydro Electric Development" Inst Engrs Aust Proc No2 Vol 9 1928

[4] C J Llloyd — "Either Drought or Plenty" Dept of Water Resources NSW 1988

[5] LAB Wade — "Proposed Northern Murrumbidgee Irrigation Scheme and Barren JackStorage reservoir" Report to NSW Parliament 7th September 1905

[6] E M de Burgh — Proceedings, Sydney University Engineering Society, 1908 pp29-46

[7] H H Dare — "Burrinjuck Dam" Inst Engrs Aust Trans Vol XI 1928 No 1

[8] S M Munday — "Burrinjuck Dam - Strengthening and Enlargement" Inst Engrs Aust Jour 1955

[9] Asst Prof L A Cotton — Royal Society of NSW Jour v 55 pp143 - 149

[10] J J Richardson — "Transmission Lines and Substations" I E Aust Jour vol 1 1929

[11] W J Youll — "The 1974 Emergency at Burrinjuck Dam" I E Aust Annual Eng'g Conf Cooma 1977

APPENDIX 1

INTERNATIONAL COMMISSION ON LARGE DAMS

SYDNEY, MAY 1990

POST MEETING TOUR

BRIEFING NOTES

FOR THE SITE VISIT TO

BURRINJUCK DAM

FLOOD SECURITY UPGRADING WORKS

FLOOD SECURITY STUDIES

Following adoption by the Commonwealth Bureau of Meteorology of new procedures for assessing probable maximum rainfalls, many dams throughout the State, previously considered to have adequate spillway capacity, are now assessed as being incapable of passing the Probable Maximum Flood (PMF).

Flood security studies were carried out in 1986 for Burrinjuck Dam which is a 79 metre high monolithic concrete gravity structure with adjoining side channel and sector gate spillways each side of the main wall. These studies considered the following options for improving security of the dam:

A. Partial improvement of flood security involving post tensioning stabilisation of the dam with some overtopping allowed.

B. Full improvement of security to PMF standards. All of these options involved substantial post tensioning of the dam wall.

   1. Allowing a major overtopping of the dam (7.0m), and toe slab protection.

   2. Handling the PMF with no overtopping by raising the dam wall by 13.4 metres.

   3. Provision of a new centre spillway 135m wide.

   4. Provision of an side channel spillway 110m wide plus raising of the dam wall.

   5. Enlargement of the existing side channel spillways to a size to be able to pass the peak outflow.

Burrinjuck Dam was considered to be a high hazard dam in terms of high economic loss and numbers of lives at risk, due to a dam failure. The tens of thousand of lives at risk dictated upgrading of the dam to full PMF security.

Consequently the design option adopted involved raising the dam crest to prevent overtopping by a PMF (24 hour duration storm with an inflow of 53 000 cubic metres per second and an outflow of 32 000 cubic metres per second).

THE WORKS

The new works to upgrade flood security of the dam are shown in green on the attached plan consist of the following:

MAIN WALL RAISING

The crest of the concrete wall is raised by a reinforced concrete chamber 13.4 metres in height. The chamber provides for drilling of post tensioning cable holes and installation of cables from the raised crest or roadway level. Cable grouting and stressing operations are carried out from the floor of the chamber where cable anchor heads are located. In the long term, post tensioning cable loads are monitored by load cells which are handled by an overhead crane which also will serve to handle stressing jacks during cable stressing.

The chamber is designed to fill under flood conditions thus increasing the stabilising force on the dam.

MAIN WALL POST TENSIONING

The main wall is stabilised for increased flood loading by a twin row of 63 - 15.2 mm diameter 7 wire strand cables of 1100 tonnes capacity (at 65% minimum breaking load). The 160 cables are located at 1.5 to 2.0 metre centres along the dam crest and average 110 metres in length giving a total length of some 18 000 metres of cables.

Cables are fully corrosion protected by an outer polyethylene sheathing corrugated over the anchorage or bond length (lower 10 metres) with the individual strands bared in the anchorage length and encapsulated in greased polyethylene tubes over the free length. The cables are installed and grouted from bottom to top in one operation. Following stressing the cables are load monitorable by a load cell screwed on to a threaded anchor head.

SPILLWAYS

The existing spillways have a capacity to handle only 0.5 of the Probable Maximum Flood (PMF) before the spillway training walls are overtopped or fail. Hydraulic model studies indicated a 9 metre raising of existing spillway training walls was necessary to contain the design flood discharge. Works to raise the existing walls involving stabilising by post tensioning will be carried out over training wall sections immediately adajacent to the dam. No works will be done on the training wall further downstream where a failure would not prejudice the integrity of the main wall.

PENSTOCK LINING IN HIGH LEVEL OUTLETS

To prevent the adverse spread of uplift in the dam, steel liners have been installed in the previously unlined high level outlets.

Stressing of the cables will involve eccentricity of loads on the dam wall with the possibility of some localised tensile forces on the downstream face where these penstocks are located. Consequently work to install the steel liners to preclude the possibility of hydraulic fracturing was a part of the overall upgrading programme.

EMERGENCY CLOSURE GATES

Flood procedures require that the upstream gates in the high level outlets be closed during major flooding and the higher head associated with the flood and the effectiveness of the existing Stoney Sluice gates gave rise to a requirement to install new emergency closure gates. These gates will be actuated by submerged hydraulic actuators and will operate under full flow conditions.

BUTTRESS INFILL

Engineering design evaluations dictated the partial infill of buttresses to increase the stability of the concrete gravity wall and reduce the post-tensioning force required.

WORKING PLATFORM AND BRIDGE

The difficulties of access for construction was a major determinant in the design of the works and resulted in an upgrading of the working platform up to the bridge junction by increasing the width to 6.0 metres and providing for a 44 tonne truck load.

The cableway has limited capacity and with the raised wall has a reduced ability to land equipment onto the new raised deck. This was a determinant in the need to provide a heavy vehicle bridge and trafficable roadway on the new raised crest of the dam.

The new bridge will be capable of carrying loads up to 44 tonne trucks including large mobile cranes. It is of balanced cantilever design with two spans of 39 and 45 metres.

Additional rock pinning has been specified underneath the right abutment of the bridge consisting of Y36 rock anchors and 6 post tensioned cables of 27 strands, each strand comprising seven wires of 15mm diameter.

WALKWAY DEMOLITION

Flood studies indicated a risk of possible uncontrolled failure of the present walkway along the northern spillway crest. It was decided that it should be demolished on these and aesthetic / functional grounds.

ELEVATOR

The height difference between the new raised deck and the lower walkway will be some 70 metres or equivalent to a 20 storey building. Unlike other dams Burrinjuck has no vehicular access to the lower downstream and outlet areas.

A simple power operated elevator capable of carrying 2 to 3 people with toolboxes, will be installed on the downstream buttressed face of the dam. Occupational Health and Safety considerations relating to work conditions supported the case for the installation.

ELECTRICAL WORKS

Most of the existing electrical power system cabling is bitumen impregnated paper wrap with poured pitch terminations. It dates to the early 1950's and was considered to be unlikely to be sound after removal and reinstallation. Its present performance under moist conditions is poor. There have also been some instances of difficulty in purchasing spares for the older equipment.

Consequently, a substantial renovation of the electrical system was adopted including some equipment replacement / relocations to facilitate future operation and maintenance of the dam.

ACCESS ROAD

There will be increased construction truck traffic on the Burrinjuck Access Road which will be exacerbated by the need to import concrete aggregate material.

The Department, after submitting estimates to the Yass Shire Council of construction and other traffic along the access road, agreed to a works programme for safety, traffic management and a structural upgrade of the existing road to carry heavy truck traffic.

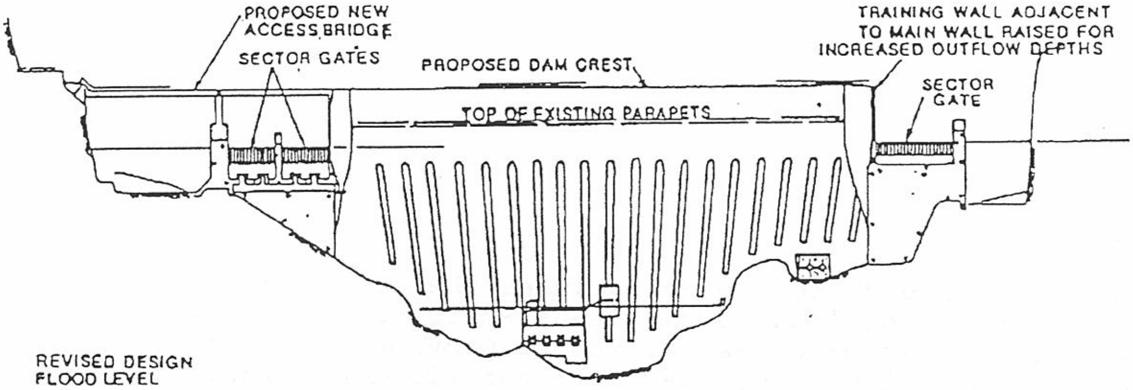
CONSTRUCTION

Initial work already completed includes the provision of a radio communication link to the State Emergency Services regional center at Wagga Wagga, NSW to provide a secure flood warning system. A counter disaster flood warning, evacuation and welfare plan for the downstream valley has been set up in conjunction with the State Emergency Services.

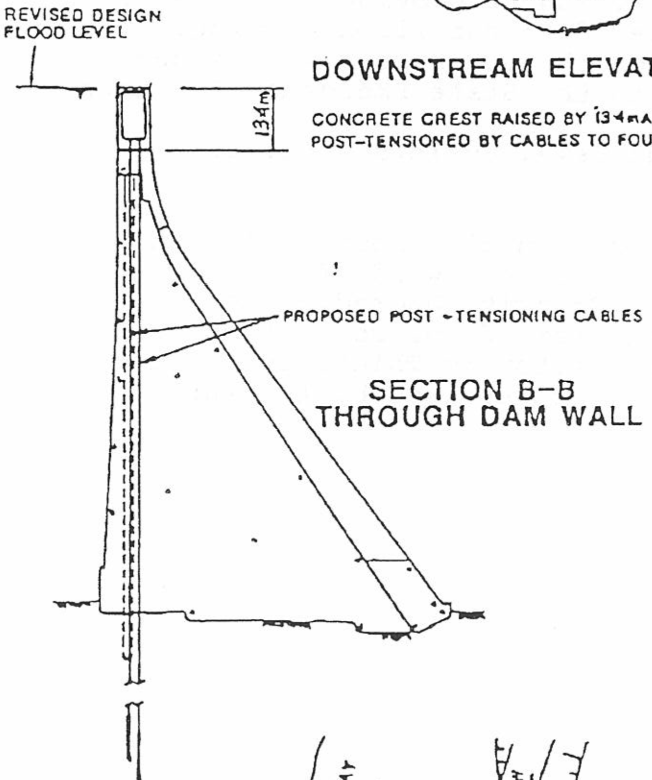
A contract to install the High Level Outlets steel liners was completed in February 1990.

In March 1990, the Minister for Natural Resources in NSW, The Hon. Mr. Ian Causley announced the award of a $33.3 million contract for the Flood Security Upgrading of Burrinjuck Dam. The work is programmed for completion in early 1994. The successful contractor is Thiess Contractors Pty Limited and the work will be supervised by the Public Works Department of NSW.

BURRINJUCK DAM
PROPOSED MODIFICATIONS FOR
ADDITIONAL FLOOD SECURITY

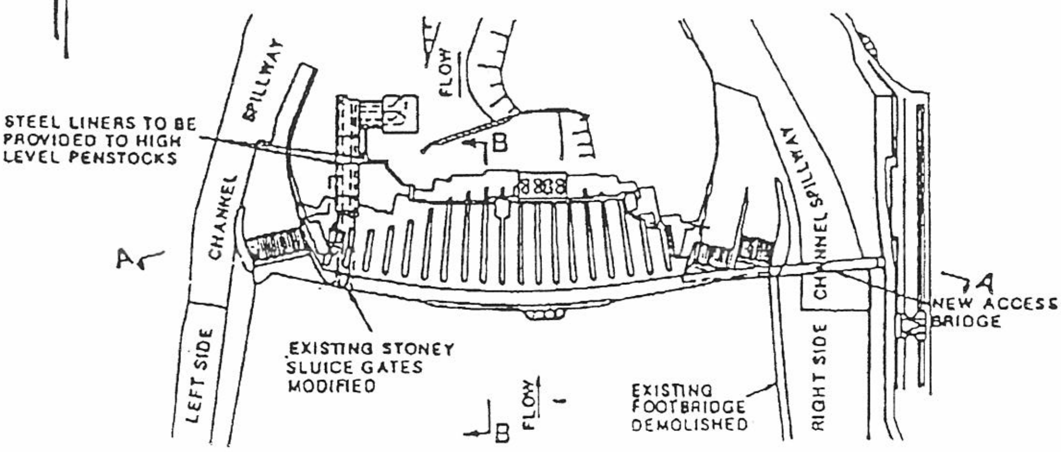


DOWNSTREAM ELEVATION A–A



CONCRETE CREST RAISED BY 134m AND WHOLE STRUCTURE POST-TENSIONED BY CABLES TO FOUNDATION ROCK

SECTION B–B
THROUGH DAM WALL



PLAN VIEW OF DAM

LAND & WATER CONSERVATION

Office of the
Director-General

DGC99/500

Mr Frank Brady
49 Mary Street
LONGEUVILLE NSW 2066

2 9 APR 1999

Dear Mr Brady

Thank you for your correspondence dated the 1st March seeking the Department's concurrence with your proposal to nominate Burrinjuck Dam and Power Station as a National Engineering Landmark.

The Department is pleased to offer our full co-operation in supporting the nomination and will be happy to provide a suitable plaque as well as a contribution towards the unveiling function.

Yours sincerely

for Bob Smith
Director-General

23-33 Bridge Street Sydney NSW 2000 G.P.O. Box 39 Sydney 2001 DX 22 Sydney
Telephone: (02) 228 6111 International: (61 2) 228 6111 Facsimile: (02) 228 6191

PACIFIC POWER

DO

5th May, 1999

Mr F Brady
49 Mary Street
LONGUEVILLE NSW 2066

Dear ~~Mr Brady~~ Frank

NOMINATION OF BURRINJUCK DAM AND POWER STATION AS A NATIONAL ENGINEERING LANDMARK

Further to our previous correspondence in respect of the above matter, I am pleased to advise that Pacific Power is agreeable to the nomination of the Burrinjuck No 1 Power Station as a National Engineering Landmark.

For the purposes of the Institution of Engineers nomination form, Pacific Power recognises the significance of the power station in the development of the New South Wales electricity supply system and welcomes its nomination as a National Engineering Landmark.

Should you require any further assistance in this matter, contact should be made with Paul Flanagan, Assistant General Manager/Environmental Services on (02)9268-7310.

Yours faithfully

R GARLAND
ACTING CHIEF EXECUTIVE