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The Spirit of the Snowy – Fifty Years On

The Snowy Vision and the Young Team - The First Decade of Engineering for the Snowy Mountains Scheme

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SYNOPSIS

The concept of the Snowy Mountains Scheme captured the imagination of all those involved.

From the beginning, the challenges of the project attracted young and capable people. They were supported by wise leadership, and encouraged to accept tasks to the full limit of their capacity. They had access to the best world experience.

As the work proceeded, new challenges arose. Problems were being solved as they arose in practice, and innovations were being adopted without any delays to the overall progress. There was excellent co-operation within the Snowy team of engineers involved in investigation, design, and contract administration, geologists and laboratory scientists, and with the contractors. There was a united focus on achievement.

The scheme evolved in overall concept and was improved in detail. The project was finally completed not only on time and within the original estimate, but with much greater installed capacity and electricity output, and with much greater water storage. That ensured secure water releases for irrigation in long term drought.

The paper will try to describe some of the many engineering and scientific advances, especially in the first decade, and to give credit for some outstanding contributions.

A PLAN FOR THE NATION

It is now 50 years since the Snowy Mountains Hydro-electric Power Act of 1949 was passed by the Commonwealth Government. The time was right.

The nation had almost been invaded during the war. Darwin had been bombed. Ships had been sunk along the east coast. Enemy submarines had entered Sydney Harbour. During the war, almost all civil works had been deferred. The nation now had to rebuild. There was a need for greater electricity supplies for new industries, and there were blackouts as supplies failed to meet the demand. The international situation had become tense again. There was an Iron Curtain across Europe. It was the time of the Berlin Air Lift.

The Snowy Scheme was a plan for the nation, for national development. The prospect of diverting the Snowy waters inland had been considered for over 60 years, very seriously in times of drought, but always leading to argument between the colonies, and later the states, about the rights to the waters.

In 1941, Mr L R East, Chairman of the State Rivers and Water Supply Commission of Victoria proposed that the Commonwealth and the two states of NSW and Victoria create a separate authority to undertake the work, on the lines of the River Murray Commission. However, the allocation of the diverted waters to the states of NSW, Victoria, and now also to SA, remained contentious.

In 1943 the conflicting proposals for the development of the Snowy waters led Mr Arthur Calwell, MP, to ask in Parliament that "plans be formulated for the best use of the waters in the interests of the people of Australia as a whole."

In 1946, the Commonwealth and State Ministers from NSW and Victoria finally discussed the national aspect of the project. The engineering investigations for the project became the overall responsibility of the Commonwealth Department of Works and Housing, The Director General was Mr L F Loder (later Sir Louis). The Director of Engineering was Ronald B Lewis. The detailed work of investigations and evaluation of alternative proposals was the task of E F Rowntree, Engineer for Major Investigations.

Rowntree had been a courageous aerial observer in WWI, and had won the DFC for several missions at low altitude in the face of heavy machine gun fire. He was a member of a Quaker family in Hobart, but the pacifist Quakers disapproved of his war effort. After WW1 he worked with the Hydro-Electric Department in Tasmania, where he designed entire hydro-electric projects virtually single-handedly. His professional background was ideal for the task of developing a plan for the Snowy Scheme.

He assessed many possible alternative layouts. Every variation involved site inspections, estimation of river flows, and calculation of reservoir capacity and regulation of storages, outline designs and costs of dams, tunnels and power stations. This task was the sole occupation of Ted Rowntree over about four years. He alone carried out the development of ideas, and studies of economic feasibility. It was a remarkable achievement by one man. Rowntree developed the concept of the diversion of Snowy water to the Tumut River for power and irrigation in the Murrumbidgee Irrigation Area, thereby gaining NSW support for the project.

Figure 1: A picture of E F Rowntree DFC, taken towards the end of World War 1. Rowntree carried out the bulk of the engineering studies that led to the proposals to develop the Snowy Scheme, and to the Snowy Act of 1949.

Another remarkable contribution was by O T Olsen, an officer of the State Electricity Commission of Victoria, who had carried out the investigations for the Kiewa hydro-electric project in Victoria, and had studied the potential of the Snowy River from the mountains in NSW to the sea in Victoria. It was Olsen who proposed the diversion of the Upper Snowy River to the Murray River for power production and irrigation along the Murray River. (The development of the significant hydro-electric potential of the Lower Snowy River still awaits its place in time.)

These two concepts came together in the detailed studies by Rowntree, leading to an overall concept that met the objectives of a plan for the nation as a whole. The final reports were presented to the Commonwealth and State Committee, and then to the Premiers' Conference. The next task was to build the project, in circumstances that would be alive with prospects for continued rivalry and procrastination by state governments.

Much of the credit for establishing the Snowy Authority should go to Nelson Lemmon. He was the Minister for Works and Housing in the Australian Government of Prime Minister Ben Chifley. A Western Australian, he was determined that the national interest would prevail, but understood that the Australian Constitution of 1900 did not assign any powers to the Commonwealth to build a project like the Snowy Scheme. The key objectives of the Snowy were to develop electricity and water resources, and these activities remained as residual powers of state governments.

Here is Lemmon's account of what, I believe, is one of the most decisive moments in Australian history:

I went to Chifley...and I said, "There's only one way to handle this...Put the whole thing under the Defence Act ... and we'll be the boss." He said, "WHAT? Your name's Nelson Lemmon, not Ned Kelly - you can't do that?" So I said, "Why can't I?" "Well, he said, you tell me how you can!" So I said, "Listen! You had subs in the Harbour. The way we're building everything now, all they want is a decent cruiser and they could sneak through the guard and they could blow all your power stations out without an effort! You've got Bunnerong built on the water, you've got the big one at Wollongong built on the water ... they could blow all your damned electricity out in one night's shooting! Where'll you produce the arms, where'll your production be with all the power of New South Wales buggered?" Chif says, "You might get away with it ... If you can get Evatt to agree with it - and if there's a case he'll have to fight it in the High Court - if you can get Evatt to agree, I'll go all the way with you!"

Lemmon went to see Evatt. He knew that Evatt did not like Dedman, who was the Minister for Defence and Minister for Post-War Reconstruction. They were rivals. Lemmon told Evatt that Dedman had said they could not use the Defence Act. Evatt's support of Lemmon was immediate. Lemmon had his constitutional defender.

At the Premier's conference, Prime Minister Chifley advised the Premiers that the Commonwealth would proceed with the Scheme under the Defence powers. The Premiers were taken by surprise by this decision and simply noted the matter. They then proceeded to the next business.

It was an immense gamble, but there was no other way. Lemmon was aware that the Commonwealth did not even have the power to compulsorily acquire land for the project, as that was a state function. The Commonwealth did not have powers over diversion and use of water resources.

Chifley and Lemmon decided to move quickly towards construction to offset any possible legal challenges from the state governments, especially NSW. For this reason the Snowy Act of 1949 concentrated on the hydro-electric aspect of the Scheme, but not the diversion of water inland for irrigation. The costs of the project were to be recovered from power charges, with the additional water for irrigation being provided at no cost to the benefiting states of NSW, Victoria and SA.

Figure 2: Hon. Nelson Lemmon, Minister for Works in the Commonwealth Government, speaking at the official opening to mark the start of work on the Snowy Scheme, 17 October,1949. Lemmon had the courage, or audacity, to start the Scheme using the Defence Act. However, Lemmon had only five months as Minister in charge of building the Snowy, losing his seat at the next election. His contribution had been vital.

These considerations of residual state rights for public works, under the Constitution, have meant that the Snowy Scheme remains the only national public infrastructure project in the history of our nation.

The project only became possible through the leadership of two groups of outstanding people. It was the engineering experts under Dr L F Loder who developed the vision of a national project. It was the political leaders, Prime Minister Chifley and Minister Lemmon, who believed that the merits of the grand design outweighed all objections on legal and constitutional grounds, and courageously began the Scheme.

The Leader of the Opposition in the Commonwealth Parliament was Robert Menzies. He formally opposed the proposals of the Government. But he privately congratulated Lemmon after the passage of the Snowy Act. Shortly thereafter there was a change of government, and Robert Menzies became Prime Minister. He accepted the decision of Parliament to proceed with the enterprise, supported the Snowy Authority, and ably dealt with the constitutional issues that continued to arise as the work proceeded. Menzies ensured the continued flow of funds to meet the needs of the project.

AN ORGANISATION FOR THE TASK: A CORPORATION SOLE

The administrative form of the Snowy Authority was deliberately chosen to ensure that the construction of the project would proceed unimpeded by changes in the political environment.

The construction of the Scheme was seen as an engineering task, and Cabinet preferred the appointment of a single outstanding engineer to manage the Project, unimpeded by any Board or group of experts, or any representatives from state governments. They deliberately chose rule by one man.

The Authority was formally constituted as a single commissioner. Thus the Snowy Mountains Hydro-Electric Authority was, in law, one person. That was a fundamental departure from a normal ministerial department, although the concept of corporation sole had been quite effective in other public enterprises.

In the case of the Snowy Scheme, it was outstandingly successful. There was no indication that the ultimate control of the project by a single commissioner was anything other than beneficial.

It was Nelson Lemmon who selected William Hudson as the Commissioner, and made a single recommendation to Cabinet. The record of the project shows that Hudson was an extraordinarily fine choice, and that the combination of capable leadership and unimpeded authority enabled the huge project to be built on time and within the estimate.

Hudson selected his two Associate Commissioners. Mr T A Lang, a young and distinguished civil engineer, and Commissioner of Irrigation and Water Supply in Queensland, and Mr E L Merigan, Electrical Engineer, State Electricity Commission of Victoria. It was the beginning of a great adventure. Australia had a population of only 8 million in 1949, and there were wide-ranging and critical post-war shortages of men and equipment.

Figure 3: The top team. Commissioner William Hudson (centre) with Associate Commissioners Thomas A. Lang (left) and E. L. (Tony) Merigan.

SITE INVESTIGATIONS

Before any detailed design or construction could proceed, it was necessary to gain a great deal more information about the prospective sites. This included survey data, geology, hydrology. Hudson moved quickly. Even before he was formally appointed, he had contacted the only manufacturer of diamond drilling equipment in Australia and placed an order for his immediate needs. The firm was paid a year or so after their first deliveries.

High priority was given to acquiring field information to form the basis for design and construction. The early surveyors, hydrologists, geologists, drillers and the investigating engineers had to work in remote areas, often living in tent camps. It was rugged work, and attracted capable people of adventurous spirit. It also led to these people having an understanding and affection for the mountains and the bush, and helped to establish the reputation of the Snowy for care and protection of the mountain environment.

SURVEYING IN THE MOUNTAINS

The first Snowy surveyor into the mountains was Lieutenant-Colonel Clews, popularly known as Major Clews. He had served in the Survey Corps in France in WWI, and then again in Queensland in WW2. When the Snowy began, Clews, at age 60, started a new career leading survey teams into some of the remotest parts of the mountains.

At that time, there were relatively few experienced surveyors in Australia, and virtually none with experience equal to the new needs of the Snowy for geodetic control surveys, and topographic surveying using photogrammetry.

The Snowy Authority recruited surveyors in Europe. Many were highly qualified. Within about two years the Snowy had assembled a skilled team and the latest equipment. They were the most expert group in Australia in their field.

There was excellent collaboration between the surveyors, the geologists, and the engineers. The use of photogrammetry enabled the surveyors to produce detailed contour maps of damsites and tunnel portals from terrestrial photographs. This was of great benefit to the field geologists. They were able to identify geological features on the photographs and on the very detailed contour plans.

HYDROLOGY

The plan of the Scheme prepared by Ted Rowntree was based to a large extent on estimated flows in the rivers. These were intelligent estimates, obtained by correlation with the relatively few longer term records of river flows and weather in the area.

It was now necessary to fill in the picture. More accurate assessments were required of potential power output and reliability. There was a need to obtain an understanding of extreme events of rainfall, snowfall and river flows.

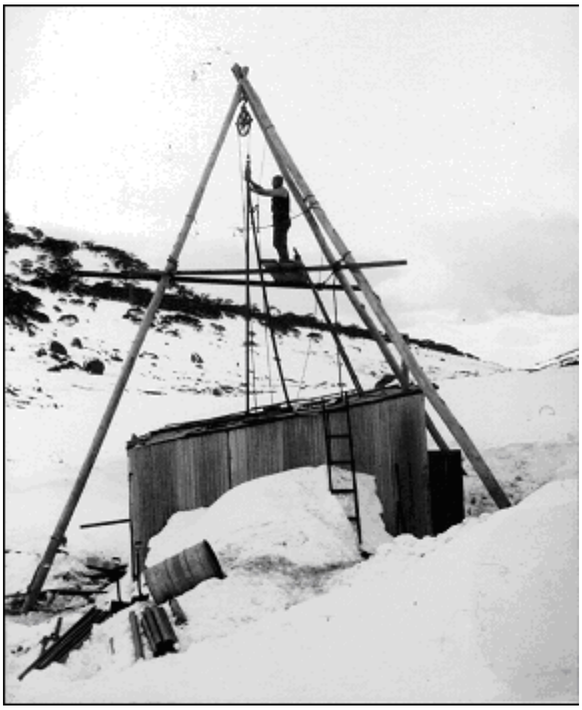
New stream gauging stations and weather stations were established throughout the Snowy region. Hydrographic staff were recruited and trained in short courses. It was their task to ensure that all the automatic recording devices were visited each month and working correctly, and to remove and replace charts. Stream flow measurements had to be made, sometimes with hydrographers standing waste deep in icy waters.

By the end of 1951, the additional information was already revealing that the Scheme had much more potential for power and irrigation diversion than had been previously thought. Techniques of "snow hydrology" were introduced, whereby measurements of winter snow cover enabled early predictions of spring and summer stream flows.

By 1956, some 105 stream gauging stations were in operation, 100 rain gauges and 14 meteorological stations. The data was providing a firm basis for design of the project and later operations.

Figure 4: Diamond drilling at Spencer's Creek. It was chilly work, and the glacial moraine at the site was

extraordinarily difficult to drill, and recover core.



DIAMOND DRILLING

In the examination of the geological conditions at damsites, tunnels and power stations, the critical information is the defects in the rock mass, rather than the rock itself. This requires especially careful drilling techniques.

These exacting requirements for core recovery had to be met under the most arduous conditions. The drill sites were almost always remote and on steep slopes. Each drill weighed over a ton, and had to be winched into position, or dismantled and re-assembled on site. Fuel and drillrods had to be carried to the site. Drill core was carefully packed into core boxes, and the heavy core boxes had to be carried to the nearest access track.

The diamond drilling crews were a very mixed group of nationalities. They lived in remote localities, sometimes for months on end, but there was very little racial animosity. A critical factor was the continued focus on the quality of their work.

ENGINEERING GEOLOGY

Figure 5: Dan Moye, Chief Engineering Geologist from 1949 to 1967. A most capable engineering geologist and highly respected leader of his team. A plaque on Tumut Pond Dam is dedicated to his memory, and records that by their work they established the profession of engineering geology in Australia.

In a few years the Snowy geologists had refined the knowledge of the geological structure of the Snowy region, and were rapidly advancing in the knowledge of the engineering properties of the rock types, including stages of weathering and depths of weathering of the various rock types. This was particularly useful in predicting rock conditions in tunnels and in dam foundations.

Seismic refraction surveying was used to assess approximate depth of weathering over large areas, and the thickness of gravel and soil deposits.

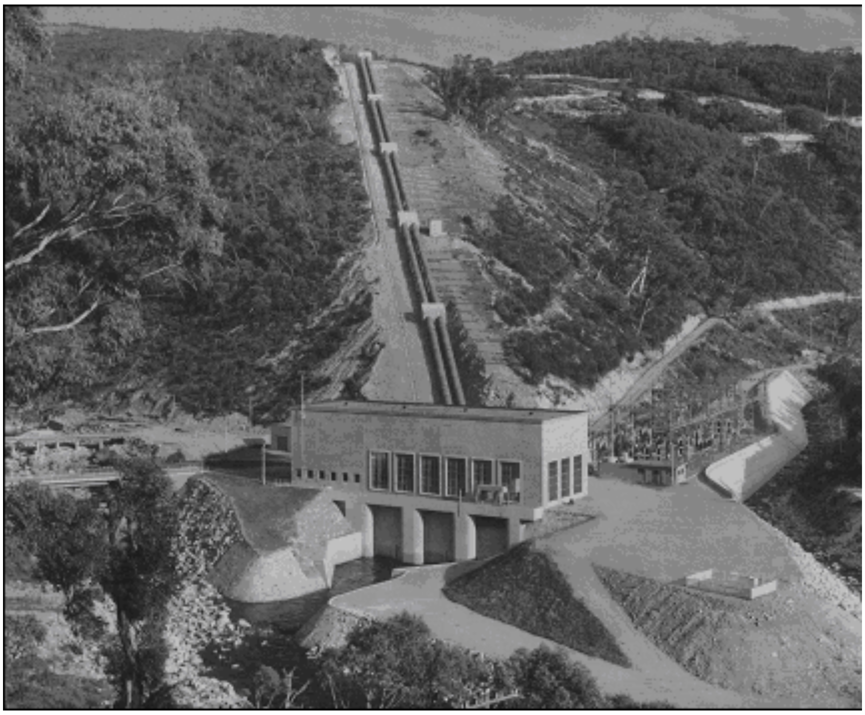
They had introduced advanced techniques in diamond drilling, and in downhole testing of boreholes, including water pressure testing and electric logging. There was excellent collaboration between the engineering geologists and the drillers, and constant pressure on drillers and equipment manufacturers to improve core recovery. This resulted in the development and introduction of triple tube core-barrels, made by an Australian manufacturer for the Snowy needs, well in advance of the rest of the world. The quality of core recovery on the Snowy became the highest in the world.

Special mention should be made of the leadership of Dan Moye, the Chief Engineering Geologist from 1949 to 1967. He then took up a senior position in BHP, and was killed in a tragic car accident in 1976. On Tumut Pond Dam there is a Plaque dedicated to his memory, which records the contribution of Dan Moye and his team of geologists to the successful completion of the Snowy Scheme, and notes that they "thereby established the profession of engineering geology in Australia".

AN IMMEDIATE START: THE GUTHEGA PROJECT

At the time the Authority was formed in 1949, and continuing into 1950, there was a critical shortage of electricity in New South Wales. There were blackouts and drastic power restrictions. Encouraged by the New South Wales electricity authorities, the Snowy Authority looked for a project that could quickly produce a block of power to meet NSW needs. This presented a possible conflict of requirements at a time when the Authority was establishing its headquarters in Cooma and was pushing on with site investigations and preparations for the major works. It was important that the selected project should not compromise the ultimate development of the Scheme as planned.

Figure 6: Guthega power station and penstocks. The Guthega Project included a concrete gravity dam, a pressure tunnel 4.6 km long, and the power station and penstocks. It was all completed in just over 3 years, seemingly without hassle. It was a remarkable achievement having regard to Australian conditions at the time.



The Guthega Project was one part of the Scheme that could be constructed quickly as a separate run-of-river plant to provide peak energy. In a very short time, site investigations were undertaken, general arrangement drawings prepared, and specifications written. In January 1951, just over one year after the start, tenders were called for the first project.

Tenders were called for civil design and construction by a contract based on Target Estimate and Fixed Fee. Because of the difficult labour conditions in Australia at the time, arising from the competing demands for post-war reconstruction, it was specified that a maximum amount of labour was to be imported from overseas. The successful tenderer was the Norwegian firm, F. Selmer A/S, who retained A. B. Berdal of Oslo as their Consulting Engineers.

The requirement to supply most of the workforce was welcomed by the Norwegian Government, who required Selmer to draw workers from the northern parts of Norway, where unemployment was highest. Some 330 Norwegians came out for the start of work on the project.

The Snowy Authority tried to ensure that the construction of the Project should not be impeded by factors in Australia that could be outside the control of the Contractor. At that time, the steel situation the world over was most critical. The Snowy Authority decided to order steel plates for the penstocks from wherever obtainable, to avoid any delay in the completion of the contract. Orders were placed with one Belgian and three German rolling mills.

One consignment, although meeting British specifications, was unsuitable for penstocks and was replaced with an order for Australian steel plate from BHP. But BHP also had difficulties in providing steel of the quality required to resist brittle fracture at low temperatures, but eventually met the requirements.

The rapid completion of the project was also made possible by the opportunity to obtain turbo-generators for the Guthega Project which were similar in design to those at Loch Sloy in Scotland, and which had just been supplied by English Electric. The ready-made design enabled much time to be saved. Commercial operation of the turbo-generators began in February 1955.

In retrospect, it must be admitted that the complete design and construction of the Guthega Project by the Contractor in just over 3 years was a remarkable achievement. It would probably take longer today. At the time we thought it was normal.

CREATING COMPETENCE

The critical challenge from the beginning of the Scheme was the enormous magnitude of the task ahead.

There were very few engineers in Australia with experience in projects of that magnitude. The Authority had attracted an initial team of mostly young engineers, many with honors degrees and all with strong potential, but with no experience at all in hydro-electric engineering or major projects. In retrospect, it seems that only the Commissioner had any comprehension of what was involved.

The Authority decided to obtain overseas assistance in the preparation of designs and specifications for certain of the first major projects, and also to train the young engineers to a level whereby the Authority could complete the remainder of the Scheme from its own resources.

At that time many engineers around the world had been inspired by the achievements of the American civil engineers in the imaginative public works they built during the thirties. These projects were undertaken in a deliberate program of national economic recovery from the disastrous effects of the Great Depression. These great US public works included the projects of the Tennessee Valley Authority, and many big projects by the U.S. Bureau of Reclamation such as Hoover Dam, and the Central Valley Project in California.

Politicians around the world had also been impressed by these achievements. When President Roosevelt took office in 1933 there were 13 million unemployed in the United States. Roosevelt was determined to provide direct vigorous leadership and put the nation back to work. His legislation for the New Deal included the Tennessee Valley Authority and many other projects. The Roosevelt program faced constitutional challenges but the inspiration prevailed.

This strong example in America undoubtedly aided the acceptance of the idea of the Snowy Scheme in Australia, and encouraged Lemmon and Chifley to provide similar direct and vigorous leadership.

The Snowy Authority decided to seek assistance in the United States for the initial group of major projects. This prospect was examined in America by Associate Commissioner T. A. Lang. He proposed an agreement between the Commonwealth of Australia and the United States of America whereby the Bureau of Reclamation would undertake the preparation of designs and specifications for certain tunnel projects and dams, and provide training and experience for a number of Snowy engineers.

At the beginning of 1952, twelve Snowy engineers began work with the Bureau, studying their practices in design and construction of dams and tunnels. Eventually, over 100 young engineers benefited from the program.

I was in the first group of 12 engineers. My own assignment from the Snowy was the study of the design of tunnels and underground structures. The Bureau of Reclamation promptly set me to work in the Denver offices on the actual designs for the Eucumbene-Tumut trans-mountain diversion tunnel, the associated regulating structures, and Junction Intake Shaft.

After 12 months I returned to Cooma with a big bundle of contract drawings and specifications for the Eucumbene-Tumut Tunnel and Associated Structures, Tumut Pond Dam and T1 Pressure Tunnel, hoping I would be able to answer any questions on the details of the projects.

The relationship between the experienced Bureau engineers and the young Australians was exceptionally cordial. We appreciated the way they openly shared their experience with us. They liked the way we were eager to learn, and asked questions.

As an illustration of this kindly and avuncular spirit, I include below an extract from a letter I received on the completion of my assignment with the Bureau:

Your efforts contributed immeasurably to progress of the Snowy Mountains design work. The Bureau engineers with whom you have been associated report that you have demonstrated an exceptional degree of resourcefulness and adroitness in the performance of your duties.

At the time I simply noted the letter with pleasure. After all, I had quite enjoyed my work on the design and drawings of such major engineering works. It was only later that I understood the extent to which we had all undergone a unique training experience. It was a deliberate program by the Snowy to get on with the job of building the Scheme and creating a competent team at the same time.

The happy association with the Bureau of Reclamation was undoubtedly of tremendous benefit to the Authority, and to Australia. The concept of such detailed co-operation with an agency of another government, and the consequent inter-governmental agreement, was an act of much foresight and a credit to all concerned.

Within a few short years of the Authority being formed, the young engineers had matured into a capable, confident and united engineering team.

It is now of interest to reflect that it was all deliberately planned that way. The positive approach to training was later extended by the Authority to include training course was given in Cooma for inspectors for duties on the major construction contracts.

NEW APPROACHES IN CIVIL ENGINEERING CONSTRUCTION

Up until the second world war, governments in Australia normally carried out major civil engineering work with their own day labour forces. Continuity of employment was a major consideration. The Snowy Scheme was one great project, and time was of the essence. The magnitude of the works in the Snowy scheme favoured the use of the contract system.

The collaboration with the Bureau of Reclamation was directed to the provision of designs, drawings and technical specifications on which firm tenders could be based. At that time, it was recognised that Australian contractors had limited knowledge and experience in construction works of such magnitude and financial risk, and it was anticipated that overseas contractors would be the major tenderers.

It was the beginning of a new system of contracting in Australia, and one in which Australian contractors later came to be prominent.

The Authority followed certain basic principles in this new pattern of contracting in Australia. The objectives were:

- to give tenderers as complete and comprehensive information as possible on which to base their tenders. The objective was to lessen unforeseen elements in contracting. As much of the work was underground, extensive reports were prepared on all the exploratory drilling and geological mapping. Data was also provided on site conditions, Australian wage structure and facilities available in Australia;
- to consider only competent contractors with financial resources, technical ability and experience equal to the task;
- to provide the contractors with facilities at work sites such as access roads, power supplies and initial accommodation so that an immediate start was possible;
- to offer Contractors advances on their initial outlay for construction plant and equipment.

Large overseas contracting firms formed joint ventures to tender for the first major contracts. Later, some of the overseas contractors in the joint ventures established companies in Australia. In due course, substantial contracts were awarded to Australian firms, finally leading to Australian contractors undertaking more work than overseas firms. There had been a far-reaching change in the nature and magnitude of civil engineering contracting in Australia.

DESIGN OF THE EUCUMBENE-TUMUT TUNNEL

When the Authority started work in 1949, little was known about the likely rock conditions for the long lengths of the several tunnels proposed in the Scheme.

This led to extensive site investigations, but even so these could only provide limited data on the rock conditions at tunnels depths of over 1000ft and more underground. Thus the design of the tunnel, and the contract specifications and estimated quantities, had to provide for a variety of rock conditions that were known with relatively little certainty. The uncertainties about the level of support required for construction purposes also applied to the quality of the rock to support the lining of the tunnel as a pressure tunnel.

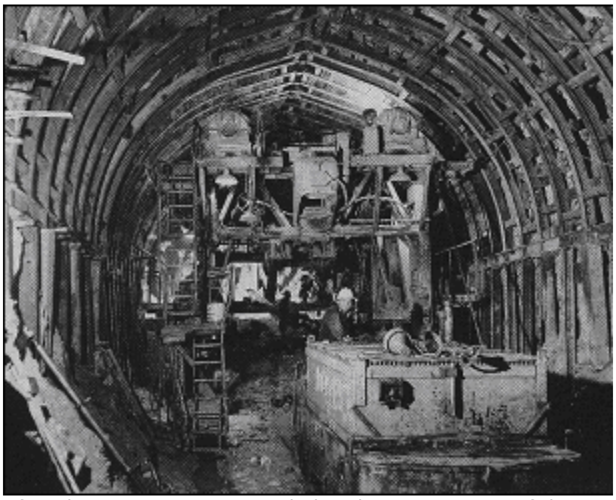
The design provided for heavy steel reinforcing in the concrete lining adjacent to the gate shafts at each end of the tunnel, where the hydraulic pressure differential on either side of the tunnel closure gates reached a maximum of 350ft head (at Tumut Gate Shaft). Thus the design had to meet the limiting requirement of a concrete lined reinforced pressure tunnel of 21ft. diameter, withstanding the full hydraulic pressure of 350ft, which made it a major reinforced concrete pressure tunnel on world standards.

Provision for construction support included:

- Arch steel supports and timber lagging,
- Arch steel supports, timber lagging and invert struts to cope with squeezing ground,
- Support by rock bolts of the slot and wedge type,
- Unsupported rock.

The inclusion of rock bolt support by the Bureau of Reclamation on the contract drawing of the alternative tunnel sections was an innovation for them. I was responsible for that drawing in the Denver offices, and recall reading a Bureau report on the use of rock bolts for temporary rock support in a small tunnel. I wanted to include rock bolts as an option in our much larger tunnel. They agreed. I suspect my youthful enthusiasm helped.

Figure 7: Eucumbene-Tumut Tunnel in ground requiring steel arch supports.



After the contract was awarded and as excavation of the tunnel proceeded, it was possible to review the design of the tunnel in relation to the actual rock conditions.

The quality of the rock near the portals and the two gate shafts was generally better than anticipated. It was evident that we could rely on rock support to carry much of the high hydraulic pressure in the tunnel near the gate shafts. This enabled a major reduction in the amount of reinforcement steel required. The magnitude of the reinforcement originally specified was very large indeed, and the reduction in quantity offered substantial savings in cost, and easier construction.

The contractor was required to excavate the tunnel to provide a minimum thickness of concrete of 10 inches around the circular section of 21ft. diameter. The pay line for the concrete was 8 inches beyond the minimum thickness. Excavation quantities and concrete quantities beyond the total pay thickness of 18 inches were at the contractor's expense.

Thus there was a strong incentive for the contractor to excavate a smooth bore as close as possible to the minimum excavation line. The Contractor saved in excavation, concrete and time by using careful excavation techniques.

The excavation of the tunnel revealed sound massive rock for mile after mile in the deep underground sections of the 14 mile tunnel.

Figure 8: Eucumbene-Tumut Tunnel during excavation. The Contractor was able to excavate the tunnel to a fairly smooth bore even while achieving world record rates of construction. The soundness of the rock and the smooth excavation enabled much of the tunnel to be left unlined.

The sound rock and the smooth bore offered the opportunity to omit the concrete lining over these sections, provided that the hydraulic properties were acceptable. Photographic profiles of the tunnel bore were used to estimate the equivalent hydraulic roughness, and this work indicated that the larger unlined sections would not cause significantly greater head loss than the smaller concrete lined sections. The savings in cost and time from omission of the concrete lining over long lengths of the tunnel were most substantial

The progressive discovery of the actual rock conditions at depth in this first trans-mountain diversion tunnel and the consequent lower costs led to a much more optimistic vision of the potential of the entire scheme, and the expected rate of construction. It became feasible to interconnect Lake Eucumbene with the Snowy-Murray Development via a new two-way Eucumbene-Snowy Tunnel, thereby adding greatly to the overall economics and reliability of the Scheme as a whole.

The trans-mountain diversion tunnels for Eucumbene-Snowy Tunnel and the Snowy-Geehi Tunnel could now be planned as unlined tunnels. The change in the Scheme arrangement involving pumping from Lake Jindabyne enabled more Snowy waters to be stored in Lake Eucumbene, improving overall reliability and income from power sales in an inter-connected system. The dynamic approach to engineering design and construction was being reflected in the value of the entire Snowy Scheme.

TUNNEL CONSTRUCTION

A feature of the work of the contractors was the emphasis on the value of time. Rates of progress were progressively improved, especially in tunnelling.

The figures achieved in the first three major tunnels for maximum advance per face in a 6 day week were:

- Eucumbene Tumut Tunnel: (23ft. dia.) 484ft.
- Tooma Tumut Tunnel: (13ft. dia.) 525ft.
- Murrumbidgee Eucumbene Tunnel: (11ft. dia.) 587ft.

These figures were increases of 20 to 60 percent on world tunnelling records at the start of the Snowy Scheme.

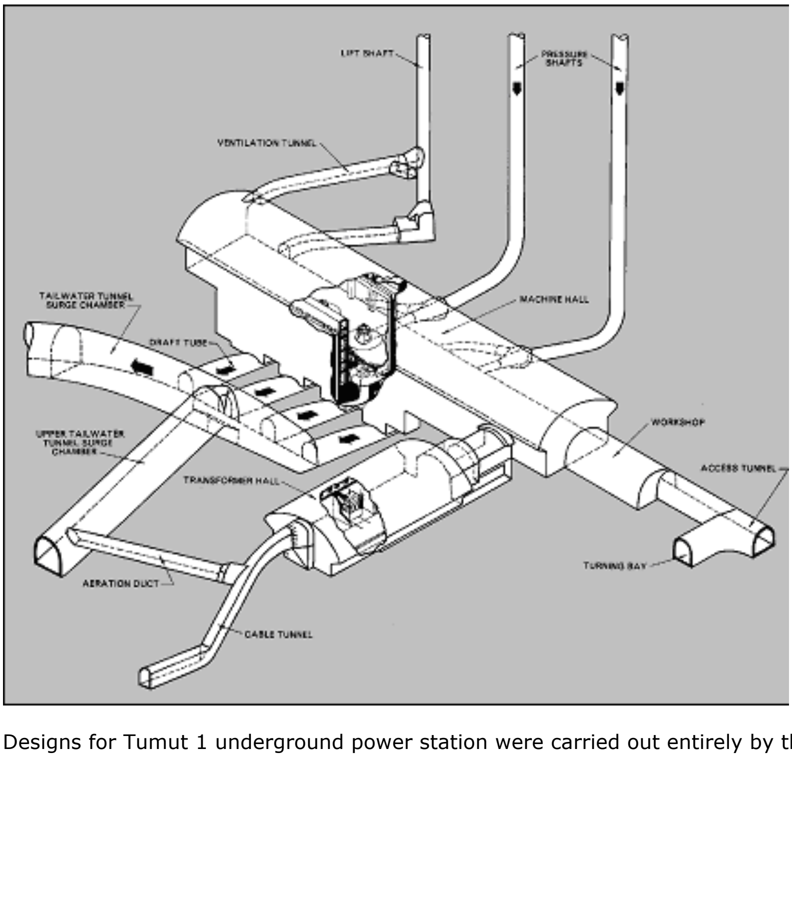
Such achievements were only possible through careful planning of the construction operations and a supportive workforce. The dynamism continued in later works.

All major contracts on the Scheme were completed ahead of the scheduled date, except one which was completed on time.

The Snowy Authority played its part in expediting the work. The Schedule of Rates contracts were an advantage in providing flexibility in adapting to changing conditions which were not foreseen at the time of tendering.

TUMUT 1 POWER STATION

Figure 9: Isometric drawing of the arrangement of underground excavations that were required for Tumut 1 underground power station. It is located over 1000ft underground.



Designs for Tumut 1 underground power station were carried out entirely by the Snowy design engineers.

The successful contractor for the power station was a French group headed by Etudes et Enterprises.

The machine hall for the power station is 306ft long by 59ft wide and with a maximum height of 111ft It is located about 1200feet underground in the walls of a steep valley.

It is a very large underground excavation, complicated by large adjacent excavations for the underground transformer hall, pressure shafts and penstocks, draft tubes and tailrace tunnel.

The Snowy designers were entering into a field of engineering where there were few guidelines. Tumut 1 was comparatively large in relation to the few underground power stations in Europe, and there were very few examples in North America. The Bureau of Reclamation had not yet designed an underground power station.

A critical question was the stability of the roof and walls of the underground caverns during construction and thereafter, and the requirements for temporary and permanent support.

The early design for the power station had been developed as a compact layout with the machine halls and transformer hall in parallel, with correspondingly short bus-bar connections to the transformers. Photo-elastic studies were conducted on the probable distribution of stresses in the rock in the proposed arrangement.

The photo-elastic studies of the rock stress distribution showed high stress concentrations in the rock pillars between the various excavations. The layout was accordingly amended to locate the transformer hall at right angles to the machine hall, with a short connecting tunnel to avoid a major intersection of two large openings. During construction, the excavation of a pilot tunnel through the machine hall revealed superior quality granite at one end, and it was decided to relocate the machine hall by moving it into the better rock.

Measurements were made of the stresses in the rock in the walls of an exploratory adit. The shape of the adit was reproduced in a photo-elastic model, from which the residual stresses in the rock mass were assessed. This was all most innovative.

Large flows of groundwater were encountered in the exploratory excavations, but as the excavations progressed it was noted that practically the entire groundwater flow came from relatively few open fissures, with the remainder of the rock mass being practically impervious, with tight joints. Flows reduced in time.

It was decided to preserve the free draining properties of the rock in the design of the station. This eliminated any need for grouting of the rock or the use of impervious linings. The roof of the machine hall and transformer hall was designed to be free-draining, with reinforced concrete arch ribs against the rock and a suspended waterproof ceiling.

Figure 10: Tumut 1 power station during excavation of the roof section of the machine hall cavern. The picture shows in the background the steel support system that was installed by the Contractor in addition to the specified rock bolts. The full width of the excavation standing supported by rock bolts alone is shown in the foreground. When the steel support system was removed to permit construction of the permanent concrete arch ribs, there was no detectable movement of the rock.

It was intended in the design of the underground caverns that the excavated roof of the machine hall and transformer hall would be supported by rock bolts as temporary support, with the permanent being provided by concrete arch ribs. For this purpose, only the roof section of the caverns would be excavated initially. The arch ribs would then be constructed, and then the remainder of the cavern below roof level was to be excavated.

At the commencement of the machine hall excavation, the workmen were apprehensive that rock bolts would not be adequate protection in an excavation of this size.

During excavation of the roof section a large rock fall occurred. The contractor began to erect heavy steel sets and a steel framework to take the rock load.

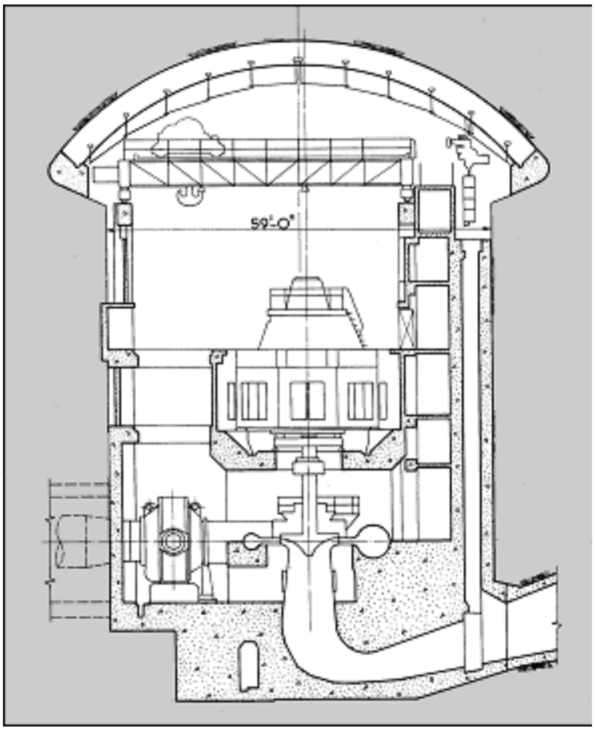
Associate Commissioner Lang was taking a strong interest in this project. He was aware of the potential value of rock bolts as a major means of support in rock excavations, not only in tunnels but in excavations as complex as Tumut 1.

It was considered important that the Contractor be encouraged to persevere with the use of rock bolt support. The Authority accordingly requested the Contractor to install the number of rock bolts specified on the drawings or by our site engineers, irrespective of any decisions that the Contractor himself may take to install supplementary steel support for his own purposes. (Writing about this now after 43 years it seems like exciting times, but it was more a quiet determination to understand the behaviour of the rock and make sure that the excavations were safe and secure.)

Provision was made by the Authority to monitor the rock load on a number of the steel column supports that had been installed by the Contractor. In one area, gauges on one of the columns showed it was carrying a load of about 100 tons. More rock bolts were installed in this particular area, and attention given to any unusual indications of sub-audible rock noise. (This is a technique of listening to the rock as the rock mass adjusts to the changing distribution of stresses with progress of excavation. Minute fractures in the rock emit energy, which is amplified for listening.)

Following the experience in the machine hall, and with improvement in bolting technique, the transformer hall was excavated using rock bolts alone. The overall experience in the excavation and support at Tumut 1 power station was a significant, world ranking achievement in civil engineering (and mining). We were interested to read in a French engineering journal that the Contractor was pleased to report on the innovations in a project he was building in Australia.

Figure 11: Vertical Cross Section of Tumut 1 Machine Hall. The installation of the turbines and generators was carried out by the Authority's workforce.



ELECTRICAL AND MECHANICAL ENGINEERING

The Snowy electrical and mechanical engineers were similarly challenged by the magnitude of the turbo-generating plant to be installed in the Tumut 1 power station, the Upper Tumut Switching Station, and the integration of the Snowy system with the Victorian and NSW electricity systems. At the time of building of Tumut 1 power station, it was unique for these several features:

- The world's largest hydro-electric station capable of complete remote control,
- The most highly centralised remote control installation for a complete hydro-electric project,
- A unique design of heavy current aluminium busbars,
- The first use of a new design of high-voltage isolating switches,
- A unique design for the underground high voltage transformers.

All of the power station plant and equipment was installed by the staff and workmen of the Snowy Authority.

ROCK BOLTING

There was an evident need for a better scientific understanding of the mechanics of rock bolting, and a need to explain the principles and practices to workmen whose lives depended on sound rock support in underground excavations.

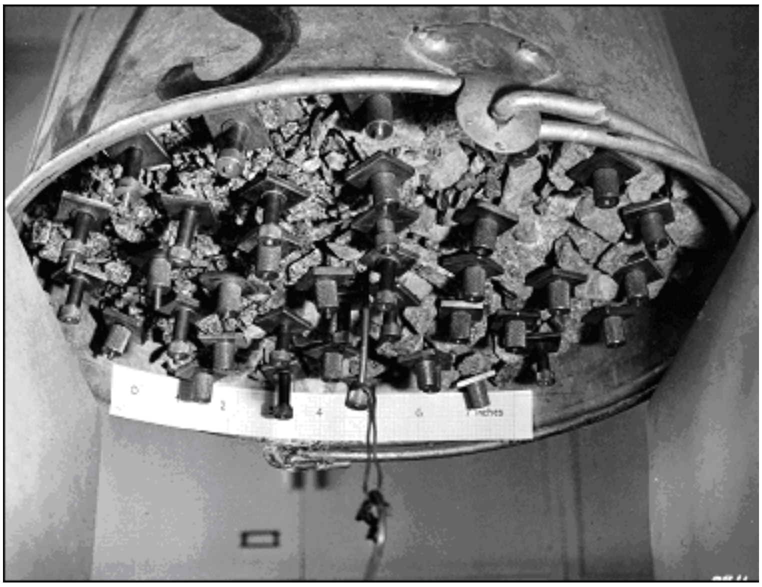
Associate Commissioner Lang initiated a series of studies directed to these purposes. The studies included:

- mathematical models of rock bolts acting in jointed rock, and physical conditions for sliding and stability;
- photo-elastic studies of the distribution of stresses around openings in jointed rock, using gelatin models to simulate self-weight in the rock mass;
- physical block models to simulate the pattern of joints in the rock mass, with model rock bolts providing support;
- photo-elastic studies of the effects of length and spacing of rock bolts on the pattern of stress in the rock created by bolts;
- installation and pull-out tests on actual rock bolts to study setting torque, anchorage behaviour, and bolt strength;
- crushed rock models, with crushed rock being considered as an extreme case of highly jointed rock.

These studies were mostly undertaken in the Scientific Services Laboratories of the Authority. The fact that it was possible to mobilise the expertise required for these studies, and to provide answers for immediate needs in design and construction , reveals the sophistication then available in the Snowy, and the teamwork.

The crushed rock models were the most convincing way of demonstrating the effectiveness of rock bolts in providing support in highly jointed rock.

Figure 12: The upturned bucket demonstration. There was a need to explain to workmen the way rock bolts worked in supporting jointed rock. In this demonstration, model rock bolts were placed in a bucket, crushed rock was then placed around the bolts, and the bolts then tightened on to the crushed rock. The bucket would then be held upside, and the crushed rock would be seen to remain in the bucket. Then, as this picture shows, a weight would be applied, and still the crushed rock would hold. Eventually a heavier load would cause the contents to cascade onto the floor, at which stage some older miner would growl that he knew it wouldn't work!



Studies by Aubrey Hosking showed that open graded crushed rock could be stabilised by rock bolts so that it could span over an opening and carry a substantial load. The rock bolts could create an effective structural member out of otherwise loose rock. Only relatively flimsy support was needed to cope with surface looseness.

One demonstration which was quite convincing to the workmen was to install model rock bolts in a bucket of crushed rock, and then to turn the bucket upside down. The crushed rock remained in place, and did not fall out of the bucket. That was surprising. While still upside down, a heavy weight would then be applied to a middle rock bolt, and still the crushed rock remained in place. That was amazing. The workmen would then be reminded that all this was possible because there was a pattern of rock bolts, and that the bolts worked together.

At Tumut 1 power station, rock bolts were used as construction support. It was now evident that rock bolts could be used as permanent support of the rock if they could be protected from corrosion.

Consideration was given to the use of metals other than steel. Comparative costs indicated that the best solution was to use a tensioned steel bolt grouted in place with cement grout. The grout would fill any open joints, and provide an alkaline environment to protect the bolt shank and anchor from corrosion.

The solution finally adopted on later projects was to use 1 inch nominal diameter steel bolts with a hollow core and deformed shank, with expansion shell anchorages. The hollow core acts as a de-aeration vent, with the grout being injected through a short tube through the bearing plate and drill hole seal.

By the end of the first decade on the Snowy, forward bolting was being used in tunnels, thereby avoiding the use of steel sets in many cases where they would have otherwise been used.

The Snowy had led a major change in world tunneling practice in hard rock.

SAFETY

The safety record of the staff and workmen of the Authority was generally very good, but accidents and fatalities grew alarmingly with the advent of the major contractors.

Major projects like the Snowy are inevitably hazardous, and it is a key responsibility of those in charge to ensure that all involved are fully aware of safe procedures, and have a sense of responsibility for their own actions, and do not endanger the lives of their fellow workers. Sir William Hudson maintained a firm hand on safety within the Authority's workforce, but there was some difficulty in reducing hazards in the works under the control of the Contractors.

Hudson established a Snowy Mountains Joint Safety Council, with the project manager of each major contract, Hudson himself, and two full-time safety advisors. Union and employee representatives conveyed their concerns to the Council, and the Council proposed measures to deal with the problems. The overall accident rate began to decline.

Any accident involving injury or death is a great tragedy. Sadly, very many cases can be regarded as preventable. The accidents would not have occurred if only the worker had known of the hazard or respected it, or if they or their fellow workers had followed safety instructions.

I think it is fair to say that most people who were associated with the project had one or more close encounters. Such a close encounter can have a major influence on the attitude to safety, and the preparedness to discuss safety in an open and realistic way.

In 1960, the Authority made the wearing of seat belts compulsory in all Authority vehicles. It was well ahead of others in Australia, and well ahead of legislation anywhere. Compulsory meant that it was a case of a warning for the first offence. dismissal for the second. The improvement in vehicle accident statistics was remarkable.

SOIL CONSERVATION MEASURES

The contracts for the major works included drawings, specifications, estimated quantities and pay items for soil conservation measures that may be directed by the engineer. The intention was to rehabilitate the works areas after construction was completed. There was some apprehension about the effectiveness of the techniques originally proposed, but the Authority's conservation staff eventually devised procedures that were quite effective.

One major concern was the annual burning of the alpine grasslands by the graziers who held snow leases. As they left at the end of summer they would set fire to the grasslands in order to ensure fresh green grass when they returned after the winter. We believed it endangered the catchments, leading to erosion and silting.

On one occasion the Authority's Soil Conservation Officer tried to stop a grazier starting a grass fire, and ended up in Cooma Court charged with assault. Needless to say the publicity helped. Whereas the Authority could not officially condone such actions by a staff member, we all assumed that the gallant officer would be recognised in the next annual review.

THE NEXT MAJOR PROJECTS

The next two major projects were the Murrumbidgee-Eucumbene Diversion and the Tooma-Tumut Diversion. The Authority was prepared to ask the Bureau to assist again with the preparation of design drawings and specifications.

The young design engineers considered they were now equal to the task and met with the Commissioner as a group. The Authority decided that the Bureau would design Tantangara Dam and the Murrumbidgee- Eucumbene Tunnel, while we were given Tooma Dam and the Tooma-Tumut Tunnel. We were delighted. We felt we had come of age.

SYSTEM PLANNING AND SYSTEM OPERATIONS

When the Snowy Mountains Authority was created in 1949, the proposed scheme involved two separate hydro-power developments, the Eucumbene-Tumut and the Snowy- Murray. Continuing and comprehensive studies by the engineers in the Investigations Division led to the integration of these original concepts into a much larger and more effective system. John Kelly spent a year in training with the Bureau of Reclamation working on planning of river and reservoir regulation for two of their major projects. These were innovative studies, and directly applicable to the planning and operation of the entire Snowy system, where the innovations continued.

The Snowy Scheme is now one of the most complex integrated systems of its type in the world, involving peak hydro power supplied to a national grid, water releases for seasonal irrigation demands, and long term provision for drought relief. It is inevitable that the Snowy Scheme will continue to grow in response to national needs, increasing in value as a source of renewable electrical energy, and in value as a source of water for food for expanding world demands. It is a dynamic system. It was planned that way.

CONCLUSION

Possibly the most appropriate summary for this paper was written 30 years ago.

In 1969, at the Jubilee Engineering Conference of the Institution of Engineers, Mr Howard Dann, then the Commissioner of SMHEA, presented a paper entitled: "Two Decades of Engineering - The Snowy Mountains Scheme".

Howard Dann had a long association with the Scheme, dating from the joint governmental studies that led to the Snowy Act and the creation of the Authority. In his paper, he presented a straightforward account of the Scheme. At that time, I had been several years with the Hydro-Electric Commission in Tasmania, and was moved to tell the truth, as I saw it, about my friends and former colleagues in the Snowy team, and their achievements. This is what I wrote in 1969:

In contributing to the discussion I mention that I am a member of the staff of the Hydro-Electric Commission of Tasmania, a friendly rival organisation to the Snowy in the field of hydro-electric development, and that we in the Commission have watched with professional and personal interest the great progress of the Snowy project. Many years ago I was a member of the Snowy team.

In reviewing two decades of engineering development in the Snowy scheme, the author, as present Commissioner, has confined his paper to the evolution of the project layout and the engineering advances over the period.

But there was much more to it than that. We must mention the people involved, as it was by their efforts that the Snowy story is so notable in the history of Australian engineering - the distinguished engineers of the Commonwealth States Committee who developed the concept of the project and advocated its construction, the newly formed Snowy Authority in its real struggle for survival amidst conflicting interests, the enthusiastic young Snowy team, the first Commissioner, Sir William Hudson, a man of outstanding leadership and foresight, and the relatively few experienced engineers who assisted him such as Associate Commissioners Lang and Merigan, and the present Commissioner, Mr Dann.

The circumstances at that time were unique - a great challenge, and an organisation created specifically to meet the challenge.

In building up the organisation, the Authority had little choice other than to recruit young men. I was one of them. There was a shortage of experienced engineers in Australia, and other departments were reluctant to release any for the new project. Fortunately, some few experienced engineers managed to break through. The rest of us were mostly raw graduates, with virtually no knowledge of hydro-electric engineering.

In getting on with the job, the Authority encouraged the young men to accept tasks to the full limit of their capacity, the Authority recognising that some mistakes were inevitable. Mistakes, however, were few. The enthusiasm, dedication and loyalty that flowed through the early organisation reflected this policy.

The Authority also recognised that it was necessary to build up expert knowledge over the wide range of specialist fields in hydro-electric enginnering, and accordingly embarked on a major programme to turn young engineers into experts. Some 120 junior engineers spent periods up to 12 months working with the US Bureau of Reclamation in various areas of specialisation. The Bureau also assisted to a great extent in the design of some of the early projects, and a few top-level Bureau engineers spent periods with the Authority as internal consultants.

The happy association with the Bureau of Reclamation was undoubtedly of tremendous benefit to the Authority, and to Australia. The concept of such detailed co-operation with an agency of another government, and the consequent inter-governmental agreement, was an act of much foresight and a credit to all concerned.

The positive approach to training was later extended to include technician and inspector training for contract administration.

As a result of the stimulation of the job, the association with the Bureau and the new approaches brought by the big contractors, the young Snowy team matured quickly.

It was inevitable that in time some would seek challenges elsewhere, and it is to the credit of the Authority that many are now in distinguished positions in engineering throughout the world, still with the Snowy elan vital. Despite these losses, the enthusiasm has been maintained.

In attempting to summarise in a few words the reasons for the dynamic approach of the Snowy team, I believe four matters stand out, ie, an Authority created for the task; a flexible organisation adapting to changing needs; the continued encouragement and training of the young engineers; and above all, good leadership.

The result is engineering that has become the pride of the nation.

Emeritus Professor Endersbee is a civil engineer and his early professional career included 27 years in engineering practice followed by 13 years at Monash University. His career in engineering practice included service with the Snowy Mountains Hydro-Electric Authority, the Hydro-Electric Commission of Tasmania and the United Nations in South-East Asia as an expert on dam design and hydro power development. He is now active on conceptual plans for several major new national engineering projects directed to Australian national economic and social development. His fields of specialisation include the management of planning and design of major economic development projects, energy engineering and transport engineering. He has been associated with the design and construction of several large dams and underground power station projects and other major works in civil engineering and mining in Australia, Canada, Asia and Africa. He was also a Vice-President of the International Society for Rock Mechanics. His professional awards include the Chapman Medal, the Warren Memorial Prize, and the Peter Nicol Russell Memorial Medal, the highest award of the Institution of Engineers, Australia. He is an Honorary Fellow of the Institution, and an Honorary Member of the Engineering Institute of Canada. In 1976 he was appointed by invitation as Dean of the Faculty of Engineering at Monash University and in 1988-89 he was Pro-Vice Chancellor of the University. He was President of the Institution of Engineers, Australia in 1980-81, and has held several senior positions in the Institution. He has been a Chairman and member on many energy advisory boards, both at national and state levels. He was appointed an Officer of the Order of Australia in 1981, and a Fellow of the Australian Academy of Technological Sciences and Engineering in 1984.