The Tauranga Joint Generation Committee

Mangapapa hydro - electric power project

L. MANDENO, O.B.E., B.E., C.Eng., F.I.E.E., M.I.E.E.E., F.N.Z.I.E.*
L. S. PATTERSON, C.Eng., M.I.E.E., F.I.Nuc.E., S.M.I.E.E.E., F.N.Z.I.E.†

*Principal, Mandeno, Chitty & Bell.
†Manager, Tauranga Joint Generation Committee.

Source: N.Z. Electric Supply Authorities Engineers' Institute Transactions Vol. 42, pp. 61-67, 1972, National Library of New Zealand .
(Searchable PDF version prepared by David Hyde - pseudonym 'David de la Hyde' - with the assistance of Willie Mandeno - a grandson of Lloyd Mandeno)

Locally-owned hydro-electric stations have materially contributed to the development of electric supply in New Zealand, especially in its earlier stages. With the approaching completion of development of the major economic waterpower sites of the nation and the consequent rise in generation costs, local authorities should examine the waterpower potential within their own areas. The results of such an examination, a development which is approaching completion in the Tauranga district, is briefly described.

1. INTRODUCTION

EXPERIENCE over the past 50 years of local development of hydro power at Tauranga has demonstrated its economic advantages and, since comparative statistics have been published by the N.Z. Electricity Department, the overall cost of selling a kilowatt-hour by the Tauranga municipality has been among the lowest listed.

The economy of such local hydro developments is especially noticeable after the borrowed capital has been repaid. This normally occurs before much less than half the life of the asset has been reached. In the meantime, while capital charges are being paid, the owner of the project has the comfort of knowing that the costs of production are substantially stabilised, a point of some importance in these days of continuing inflation.

The present programme of power development in Tauranga is a joint effort between the two local supply authorities. By an Act of Parliament in 1965, the Tauranga Joint Generation Committee, an equal partnership of the Tauranga City Council and the Tauranga Electric Power Board, was established to develop the hydro-electric potential of the Wairoa River.

The Committee has been granted three waterpower licences and these substantially cover the total power potential of the Wairoa River system from 900 ft above sea level down to tide water.

Of these, the lower is “Ruahihi" of 15 MW at 275 ft head, then the “Lower Mangapapa” of 5 MW at 110 ft. The upper one, “Mangapapa", now to be described, is of 15 MW at 500 ft head.

The present McLaren Falls station of 2.8 MW at 83 ft head will remain for service during periods of high discharge and as standby.

Local Authorities Loans Board approvals were received for the preparation of plans and specifications for the Mangapapa and Ruahihi projects and this work completed in 1969. The Board has, however, so far authorised the raising of monies for the construction of Mangapapa only.

It is believed that construction authority for the balance of the scheme will be received at a later date.

This paper more particularly concerns itself with the Mangapapa project.

2. TOPOGRAPHY AND HYDROLOGY OF CATCHMENT AREA

The streams feeding this project drain the northern side of the Mamaku Plateau which, for the most part, is comprised of an immense sheet or series of sheets of various grades of ignimbrite. The streams are entrenched in gorges which for the most part are 200 to 500 ft deep below the adjoining country which slopes at an average gradient of about l00ft/mile to the northward.

Except for the canal, penstocks, and power-station site, the whole area is covered with native bush having an unusually high content of various types of vines. In these conditions precise contouring by aerial methods was not possible and the early surveys called for considerable physical effort.

The area is subject to rainfalls of high intensity, 300 mm/day being not altogether uncommon. Discharges of between 40,000 and 50,000 cusecs have on occasions passed the McLaren Falls station.

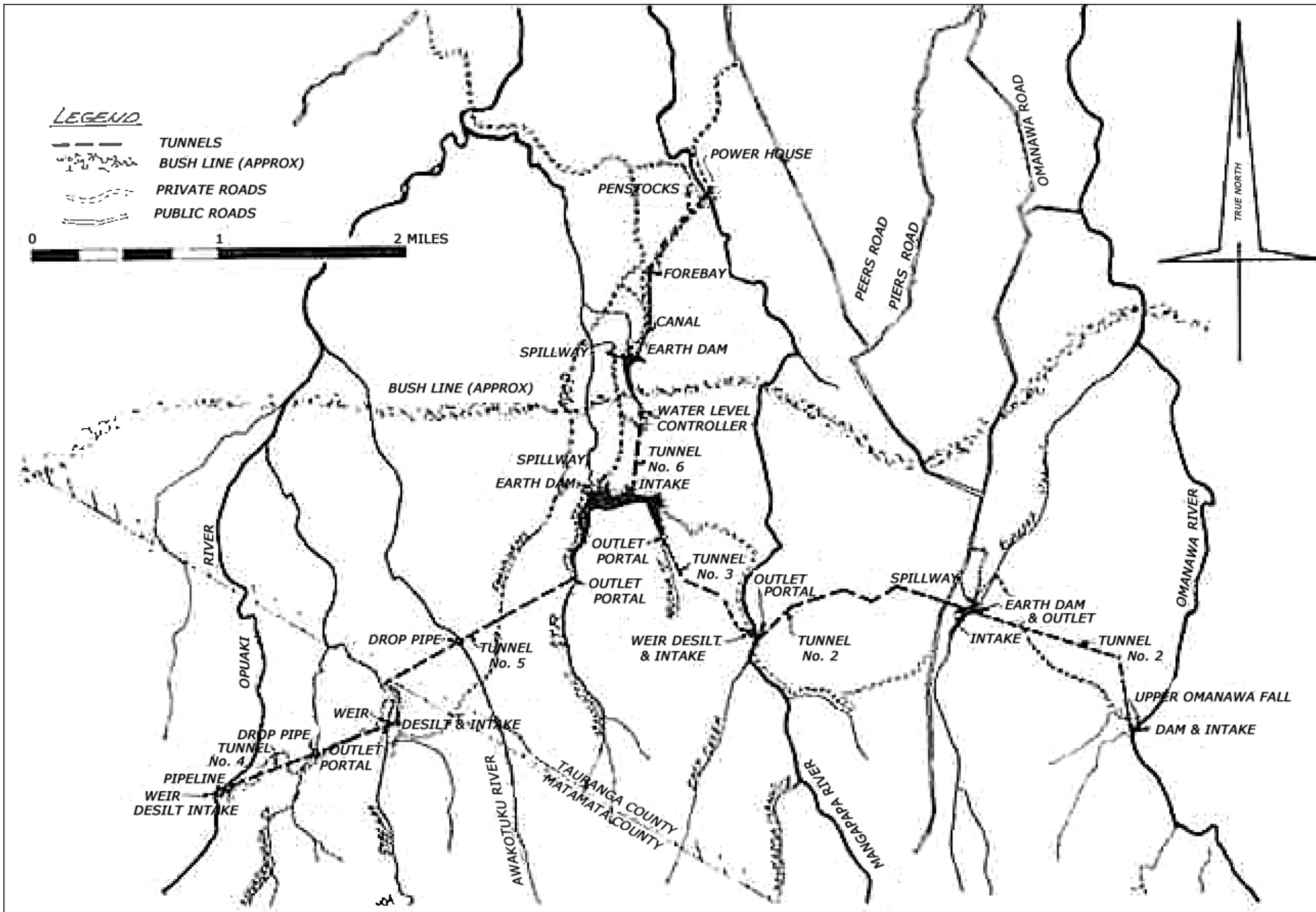

Fig. 1—General layout of scheme.

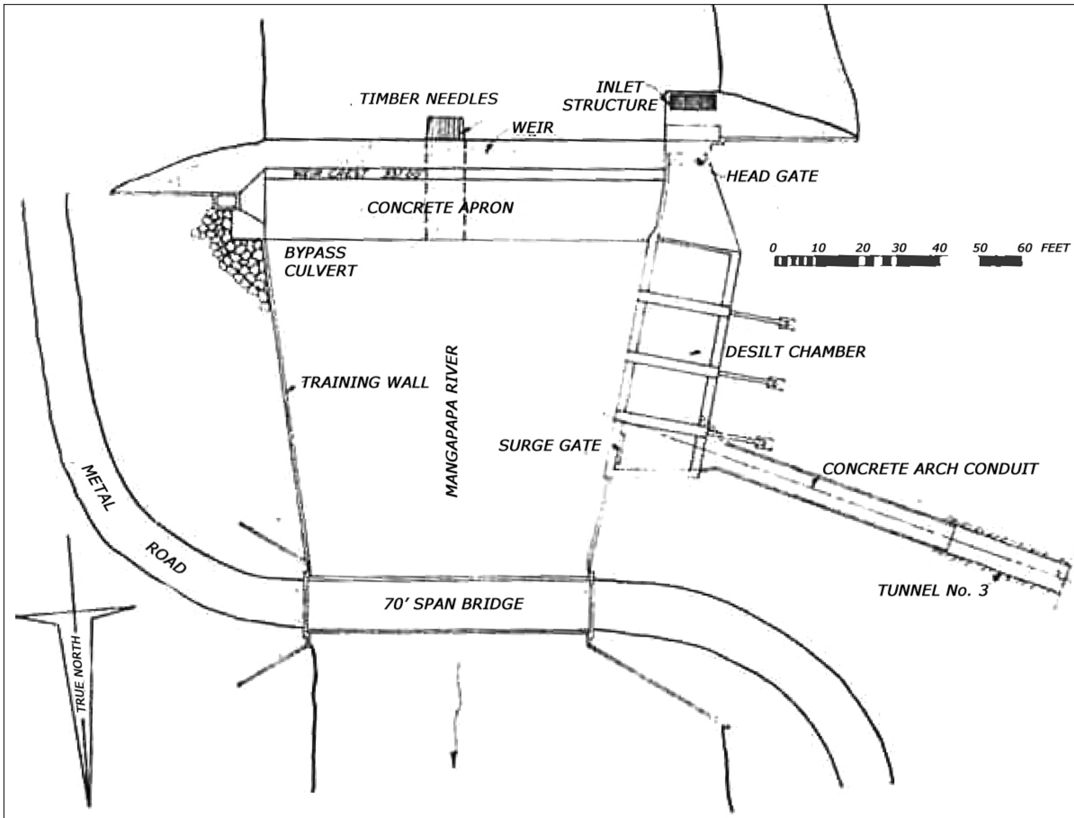

Fig. 2—Mangapapa weir and intake structure.

3. PRINCIPAL FEATURES

(see Fig. 1)

3.1. Weirs and intakes

(see Fig. 2)

Each intake is comprised of a weir, a steel grid to prevent entry of logs and other trash, a headgate, and a desilting chamber to prevent the heavier sediments from entering the tunnels.

As anticipated, during the construction of the relatively low concrete weirs, temporary diversion structures proved unnecessary. Low coffer dams were used to push the stream to one side of the bed while the foundations and lower structure at the other end of the weir were being trenched and built up.

Openings were formed in the first section as a bypass for the construction of the second section.

3.2. Embankment dams

By mid July 1972 the construction of embankment dams at the following locations had been completed:

(a) The Mangaonui Stream known as the Mangaonui Dam

(b) Downstream of Tunnel No. 6. known as the Dry Gully Dam.

3.2.1. Mangaonui Dam (see Figs. 3 and 4)

The Mangaonui Dam forms the Mangapapa project central reservoir and impounds some 240 acre-fee, of water in the available 13 ft of drawdown.

The normal flow of the Mangaonui Stream is about four cusecs and has on occasion risen to approximately 900 cusecs.

The flow was bypassed during construction of the dam through a culvert comprising 48 in. socketed rubber-jointed pipes encased in concrete.

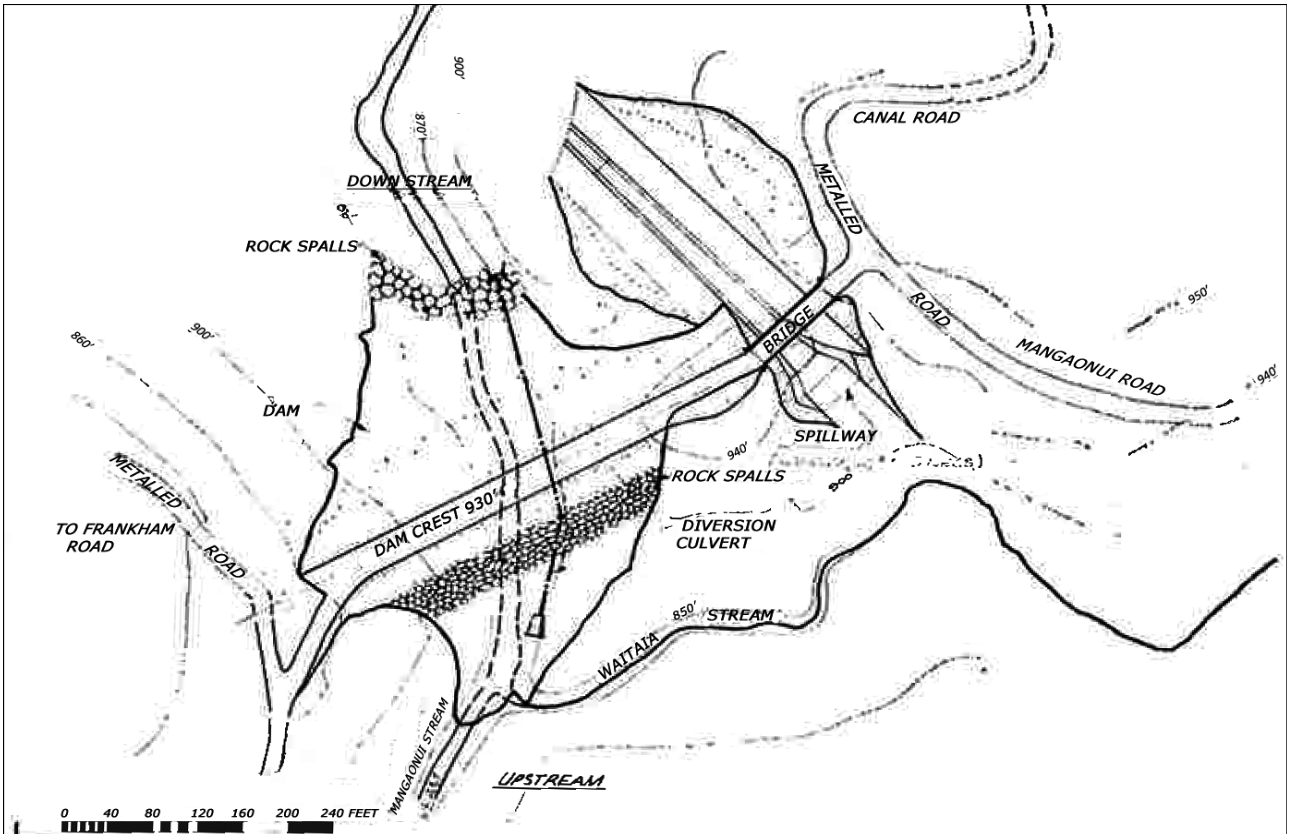

Fig. 3—Mangaonui dam.

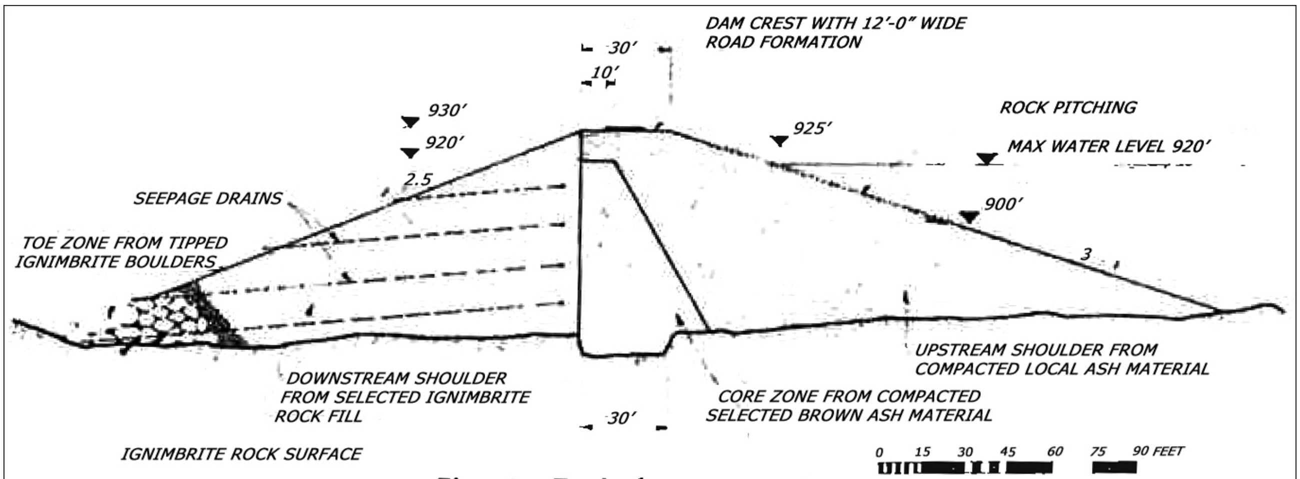

Fig. 4—Typical cross section.

The downstream toe of the dam consists of a graded boulder zone immediately upstream of which is a 5 ft filter zone of evenly-graded spalls and quarry fines. The bulk of the downstream shoulder has been built up from ignimbrite excavated from approved borrow areas. The core-wall zone is of selected brown ash. The upstream shoulder is of pulverised ignimbrite and brown ash, all compacted under careful control of moisture content, density, and porosity.

In order to prevent the possible build-up of pore pressures in the downstream shoulder, drains to intercept percolation passing the core wall were formed by placing 2 in. perforated p.v.c. pipe on 3 in. of screened metal. Three-quarter inch p.v.c. pipes perforated at the junction boxes only, terminate 18 in. outside the downstream batter. The upstream face of the dam from elevation 900 to 925 is protected against erosion by the deposition of spalls.

3.2.2. Spillways

As well as the weirs, which are spillways in themselves, and the overflow from desilting chambers, a spillway is constructed with each dam to handle seasonal or operational overflow.

3.3. Tunnels

The tunnelling programme comprised the major portion of the first of the three projects previously mentioned on .the Wairoa River system. There are six tunnels having a total length of about 5.5 miles.

Economic considerations dictated maximum utilisation of unlined tunnels although the country generally consisted of three unconformable ignimbrite sheets:

(a) an upper Mamaku ignimbrite
(b) a lower Mamaku ignimbrite and
(c) Waiteariki ignimbrite.

At some localities, fluviatile sands and gravels with thin interbedded lacustrine sediments were evident.

Because of the variable compaction of the ignimbrites, the task of finding suitable tunnel routes was not easy. Typically the ignimbrite sheets have soft upper parts, a highly compacted interior, and an unconsolidated pumiceous base.

From the surface geology it was found almost impossible to predict the distribution, thickness and depth to the basal parts of the ignimbrites and the unconsolidated material generally unsuitable for containing unlined tunnels.

When tenders for the civil works were called three years ago, tenderers were supplied with the results obtained from about 40 test bores and with professional geologists reports based on field surveys and on these test bores. After the main loan funds had become available, some further 200 bores were drilled to determine more precisely the most suitable alignment and level of the respective tunnels.

The specification was drawn with an indication that machine tunnelling would be preferred. This was mainly for two reasons. Tunnelling by machine gives a much smoother surface than blasting so that in unlined tunnels a much reduced hydraulic friction is obtained, and. secondly, the country is not so disturbed and weakened as it is where blasting is adopted. Consequently machine-bored tunnels may often be unlined in country which, if blasted, would require timbering and lining.

The tunnelling machine first adopted by the Civil contractor was the spider type equipped with borium-faced spade cutters. For muck disposal, hydraulic transport is mostly used, the water supply being pumped into the tunnel from the most convenient source. Then, after mingling with the muck, the water is pumped to a conveniently located paddock into which the muck settles.

Excellent progress was made in the first tunnel to be completed (No. 6) which is 9 ft in diameter and 2,400 ft long. Working 10 shifts per week, it was driven in an overall time of four weeks. Similarly good progress was made in the No. 3 tunnel for the first 1,350 ft, but then a lens of ignimbrite was encountered in the floor and was too hard for the spider machine to penetrate. It was taken out and put to work in No. 5 while the hard lens was penetrated by blasting. At the same time, two boring rigs which had been working on the lines of other tunnels, were put on to No. 3 in order to locate a route through rock within the range of hardness suitable for the machine and which at the same time would be strong enough to be self-supporting. This boring programme is illustrated in Fig. 5, which shows the revised route of No. 3 tunnel and also a section illustrating the varying grades of rock encountered.

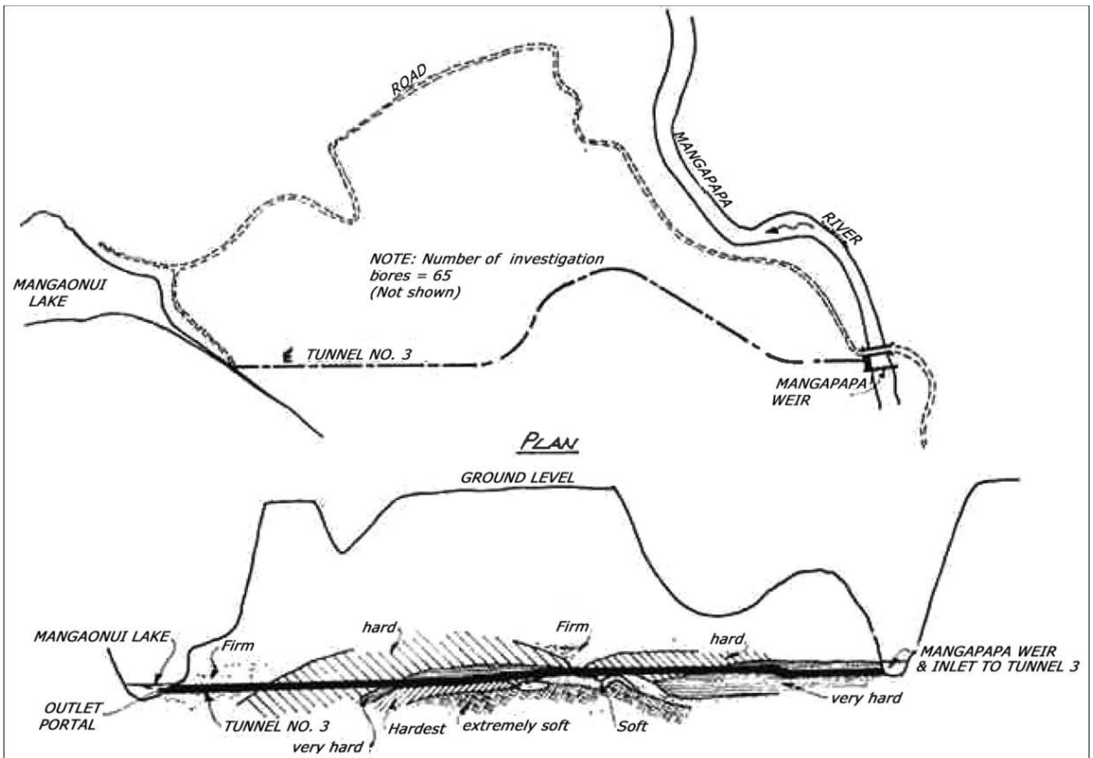

Fig. 5—Long section—tunnel No. 3.

The machine was then put back into No. 3 tunnel which was successfully completed. About 750 ft of the 4,000 ft total length has been lined with 72 in. flush-jointed pipes as a precaution against erosion. Thus, although the original tunnelling machine is making good progress in No. 2 tunnel, experience with it in Nos. 3 and 5 shows that it will not be suitable for some of the footages yet to be bored.

Consequently, a second tunnelling machine has been ordered which will be capable of dealing with the hardest rock samples so far encountered in the boring programme of the past several years. In addition, it will be of the shielded type and thus suited for traversing the zones of weak ground which will require lining.

Although, as stated, for most of the length of the tunnels it was expected that no lining of any kind would be required, provision was made in the specification to cover some form of lining over certain sections.

No. 3 tunnel showing blocky rock encountered.

3.4. Flow controller

A concrete structure and supporting steelwork for an automatic gate to control the flow of water into the canal is located at the outlet portal of Tunnel No. 6.

The design of this controller is somewhat novel. Its function is to maintain a constant level of the water in the canal despite variations in the drawdown of the Mangaonui reservoir and variations in load on the plant. The controller consists of an orifice 20 ft by 1 ft 6 in. high which is covered by a Tainter-type gate. The movement of this gate is controlled by a float 20 ft long by 6 ft diameter, so arranged as to maintain water level within close limits in the canal which leads to the forebay.

3.5. Canals

The principal excavated channel from 4,580 ft in length, is a cut involving the flow controller to the forebay, some the excavation of some 240,000 yd^3.

The excavated material was used to build up low-lying ground at the northern end immediately upstream of the forebay, as well as to form the Dry Gully dam.

3.6. Forebay

This concrete structure is situated at the penstock end of the canal, and is comprised of a screen chamber, a connecting culvert and two headgates which control the admission of water to the two penstock lines.

3.7. Penstock lines

3.7.1. The concrete pipe section

Each is comprised of 600 ft of 6 ft internal diameter, centrifugally-spun rubber-ring-jointed concrete pipes. They were supplied in three grades of reinforcement.

3.7.2. The steel pipe sections

These take the water from the concrete pipe transition to the butterfly valves located in the power house and are approximately 2,100 ft long and vary front 72 to 51 in. internal diameter, and in thickness from 0.1875in. to 0.625in. Whereas the difference in elevation between the forebay and transition structure for the concrete pipe is 47 ft, the difference in elevation between the transition and butterfly valves of the steel section is 452 ft.

Steel penstocks with power station in the distance.

3.8. Power house

(see Figs. 6 and 7)

A 100-year flood would cause the Mangapapa lo rise 19 ft at the station site so that with the prospect of a dam being constructed some two miles downstream, the station is designed to be proof against a flood rise of 30 ft.

These conditions called for the adoption of vertical generating units. There are four floor levels: turbine, generator, mezzanine and ground floor. Access to the lower floors is by steel companion ways which latter can be lifted out in order to permit heavy loads to be handled on the turbine floor by the 22 ton crane. This arrangement was adopted in order to secure utmost economy of space.

The building is basically a cast-in-situ reinforced-concrete structure set on a 2 ft 6 in. reinforced-concrete raft foundation. Above the ground-floor level, precast-concrete wall-slab cladding is fitted to a concrete and steel framework. The precast slabs have exposed aggregate of selected colour on the exterior surfaces.

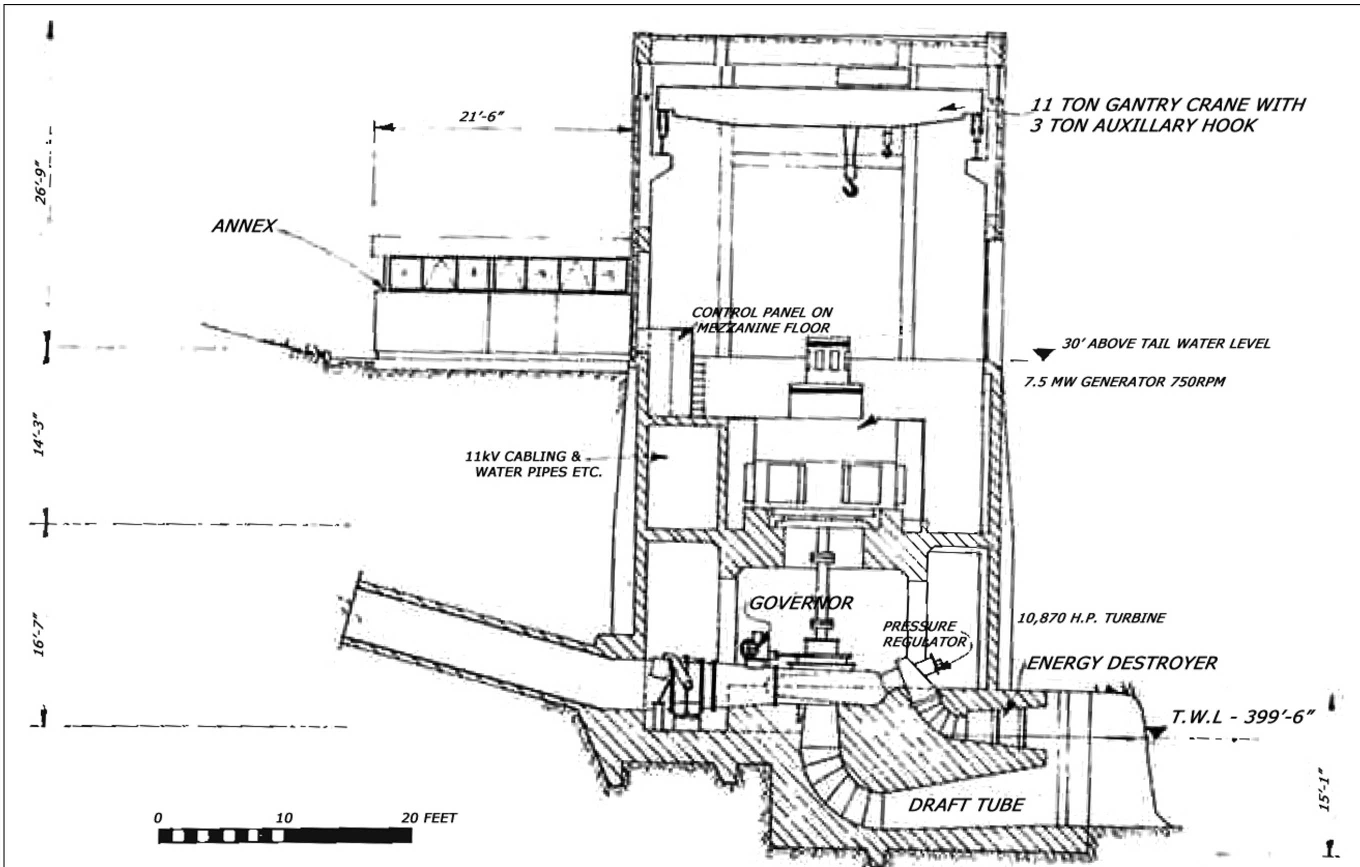

Fig. 6—Section through power house.

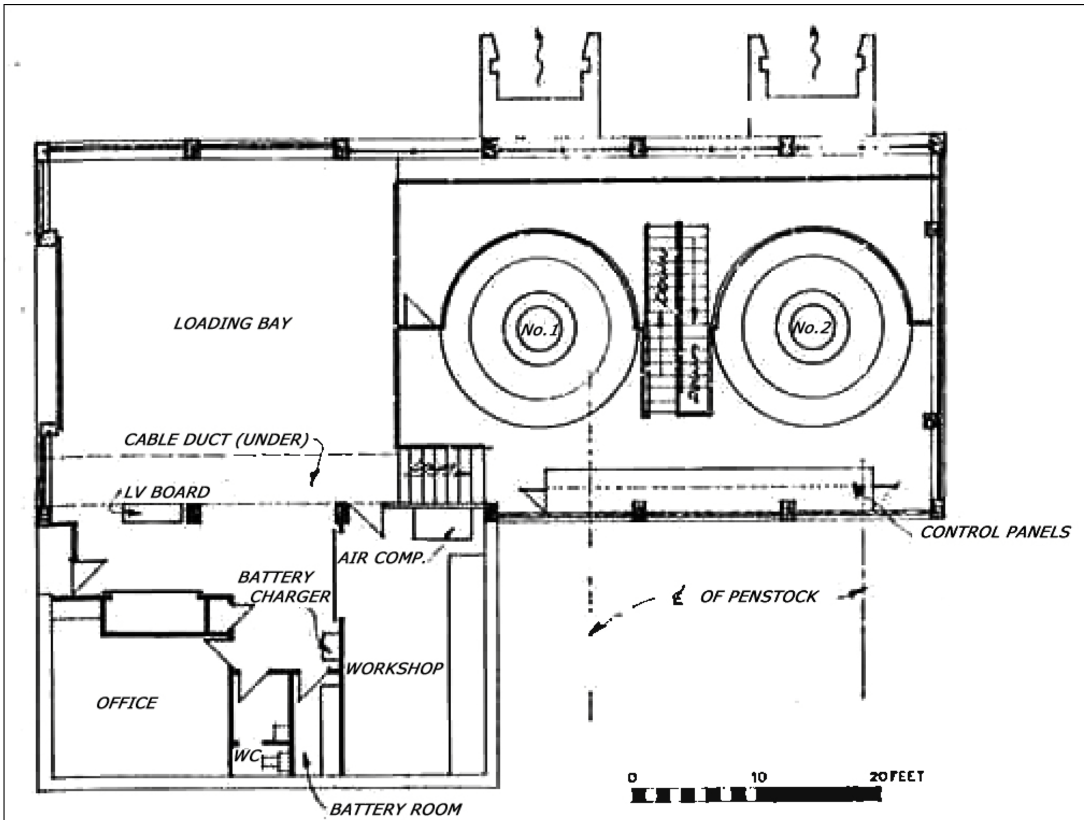

Fig. 7—Power-house plan.

3.9. Turbines

The two vertical Francis turbines were supplied by Litostroj, Yugoslavia.

They are rated at 10,870 hp at 490 ft net head and 215 cusecs. The rated speed is 750 rev/min and the runaway speed 1,250 rev/min.

The turbine spiral case is of welded construction, split in two for transport. The runners, wearing rings and various other parts are of highly polished stainless steel.

The centre line of the runner is 3 ft above tail-water level. As a result the runner can be inspected from a manhole in the upper part of the draft tube without dewatering the draft tube, but dewatering is provided for by the installation of ejectors and stop-log gates. To ensure quiet and vibration-free operation at all loads, air is admitted just below the runner both at the periphery and the centre of the draft tube.

As the station is designed for unattended operation, the turbine is provided with a comprehensive automatic greasing system which lubricates at regular intervals all moving parts other than the main bearings.

A carbon seal is incorporated in the top cover to prevent leakage of water from the turbine into the power house during floods. The speed ring, guide bearing and shaft-driven governor oil pump are mounted above the seal assembly. The links between the speed ring and guide vanes are provided with eccentric pins for adjustment, and with breaking links to prevent damage to the guide vanes if a foreign object becomes lodged between them.

3.9.1. Pressure regulators

As can be seen from Fig. 6 a pressure regulator is fitted to the spiral case to prevent dangerous pressure rise when the governor operates to cause rapid closing of the guide vanes—e.g. following a trip off at full load. In contrast to most pressure regulators in which the fast closing of the guide vanes initiates the opening of the regulator, the Litostroj design incorporates a hydraulic cylinder which holds the regulator closed. This cylinder is connected directly to the closing side of the guide-vane servomotor and it is the opening of the regulator that provides the power for the fast closing of guide vanes. Therefore, if the regulator fails, the guide vanes shut at their normal (slow) speed and there is no excessive pressure rise and no danger of a burst penstock.

With the Litostroj design, failure of the regulator will result in the turbine overspeeding; but, as the generator has been tested at 1,250 rev/min, this is not particularly dangerous. Guaranteed efficiency at 90% gate opening is 91.2%.

3.9.2. Main valves

The 48 in. diameter butterfly valves are hydraulically operated from the governor oil system. To open the valves, a solenoid valve is operated which applies pressure oil to the opening cylinders of the bypass valve and the main valve. Because the main valve has its spindle slightly off centre, it does not open until the spiral case is full and the pressures on each side of it are balanced. Opening time of the valves is 60s and closing time 41s.

3.9.3. Governors

The governor is sensitive to both speed and acceleration. (The acceleration sensitive element serves the same purpose as the damping unit in a conventional governor).

Pressure oil is provided by a 10 hp electrically-driven pump during starting and stopping and by the shaft-driven pump during normal operation. Once started, the units are independent of the auxiliary a.c. supply.

3.10. Generators

The two generators were manufactured by Rade Koncar, Yugoslavia. They are each rated at 7.5 MW, 0.83p.f., 11 kV, 472 A. Excitation is by a d.c. exciter controlled by a Brown Boveri type AB voltage regulator.

Closed-circuit air cooling with air to water heat-exchangers is employed.

Above the rotor is a combined thrust and guide bearing and below a guide bearing only. All bearings are of the self-pumping type and have oil to water heat-exchangers.

Combination brake and jack units are provided to bring the machine to rest quickly when it is being shut down and to lift the rotor for maintenance and to flood the thrust bearing pads before starting after a long shutdown. These units are operated by compressed air for braking and by oil for jacking.

Guaranteed efficiency of the generators at full load and 100% power factor is 96.5%.

3.11. Cooling water arrangements

The cooling of the bearings and generators requires a cooling water flow of about one cusec. Because of its lower turbidity during times of fresh, it was preferred to take water from the penstocks rather than from the river outside the station.

In the arrangement adopted, the water is taken from the penstocks, and its surplus energy is absorbed by a Pelton wheel driving a 30 kW induction generator by direct coupling at 1500 rev/min.

3.12. Automatic control of sets

The units are designed for fully- automatic starting and stopping (both locally and over the remote control system) and for emergency manual operation.

When set for automatic starting a “start” command starts the electric oil pump. When the oil pressure is normal the bypass valve opens, followed by the butterfly valve. When the butterfly valve is fully open, the load limiter is operated to a preset position of about 20% of full gate. The guide vanes follow and the machine runs up to speed. Once speed and voltage are normal a “synchronise” command puts the auto-synchronising equipment into operation. This equipment adjusts speed and voltage and closes the synchronising switch at the correct moment. The load limiter then moves to the 100% position and the operator adjusts load and excitation as required.

When the “stop” command has been given for the unit to be shut down, the voltage regulator setting is immediately screwed down to approximately 9,000 V and the brakes applied intermittently between 50% and 15% speed and continuously thereafter. Finally, the butterfly valve is closed and the oil pump stopped.

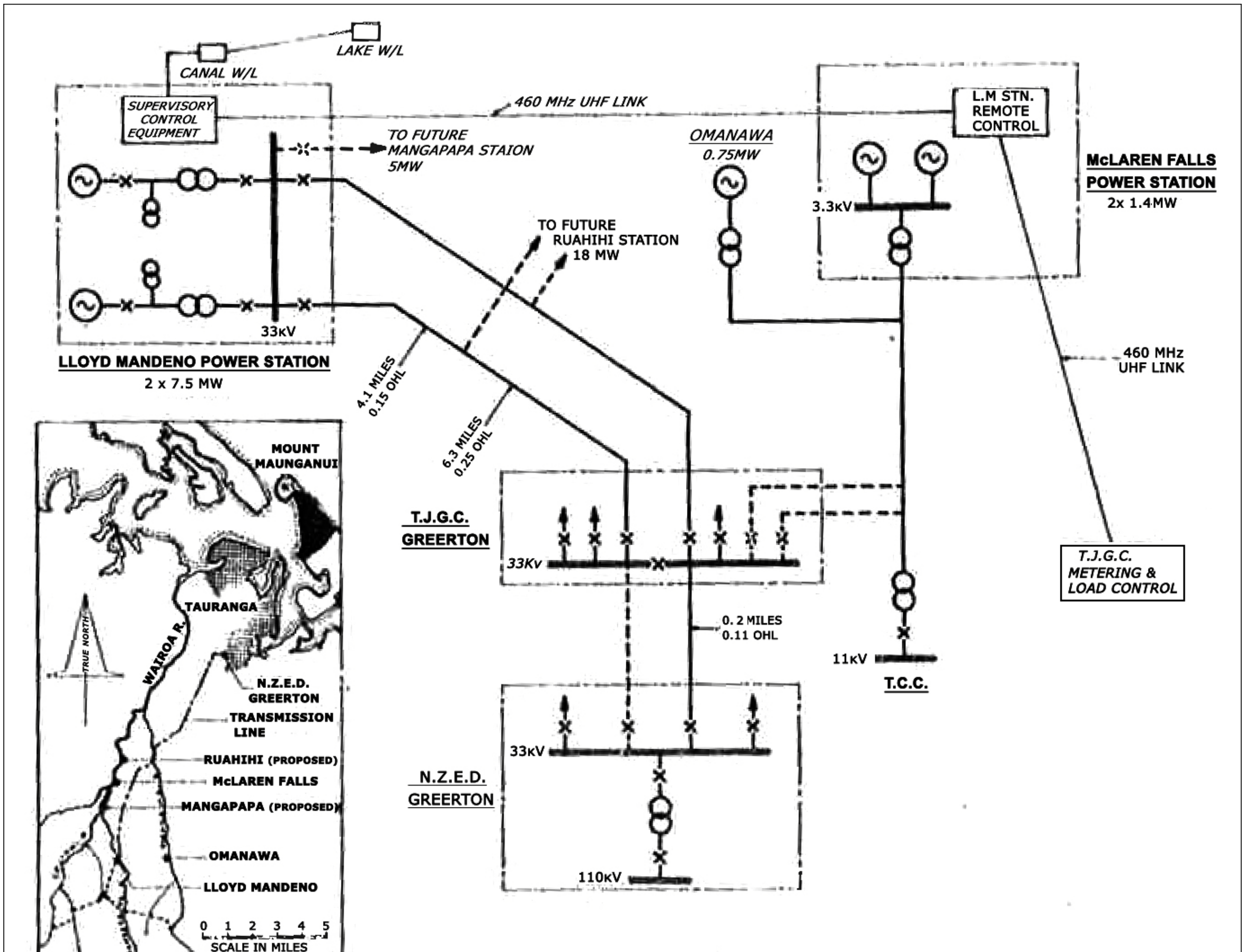

Fig. 8—Single-line diagram and location plan.

3.13. Switching and control (see Fig. 8)

The control board is located on the mezzanine floor immediately above the cable tunnel while the step-up substation is just north of the station cartdock. Each generator has its own step-up transformer rated at 9 MVA 11/34.7, 52.5 kV. Each of the two outgoing feeders is controlled through an oil circuit-breaker and gang-operated air breaks so that the generators can energise the feeders individually or in parallel.

3.14. Transmission lines

Two single-circuit “Dingo" (0.15 in) lines run from the Lloyd Mandeno Station to the future junction with the lines from Ruahihi. From this point a single “Cockroach” (0.25 in) circuit runs to the N.Z. Electricity Department substation at Greerton.

3.15. Supervisory system

The supervisory system is fully solid-state. Initially the remote control station will be at McLaren Falls about four miles distant, but it will later be moved to Greerton. Transmission is by means of a 460 MHz radio link working between Yagi antennae mounted in line-of-sight in suitable locations above the respective stations.

A mimic panel at the remote station provides all the necessary controls together with comprehensive alarm and indication facilities. Provision is also made for the transmission of water levels at the Mangaonui reservoir and at the forebay.

As all alarms are initiated by hand-reset flag relays on the main control panel, a full record of the cause of any shutdown is available at the power station.

The supervisory system transmits the following:

48 commands
74 indications and alarms
17 analogues 2 kWh meter impulses.

These are all carried on four voice-frequency channels with frequency-shift signaling.

3.16. Metering

For tariff and accounting purposes the Tauranga Joint Generation Committee will become the N.Z. Electricity Department's sole customer for the purchase of power. It will re-sell to the Tauranga E.P.B. and the Tauranga C.C. It therefore must know the cumulative kilowatt-hour and half-hour maximum demand of:

(a) The input from its system power stations.
(b) The demand on the N.Z. Electricity Department.
(c) The load taken by the Tauranga E.P.B.
(d) The load taken by the Tauranga C.C.
(e) The combined load of the Tauranga E.P.B. and Tauranga C.C.

In addition, for load-control purposes, a knowledge of the instantaneous load of all five of the above, together with an indication during any half-hour period of whether or not the target load on the N.Z. Electricity Department is likely to be exceeded by the end of the half- hour period is provided for.

The above requirements have resulted in an unusually complex summation and load-indication scheme.

To avoid the expense of having one set of impulsing kWh meters for kWh metering and another set of transducer driven meters for MW indication, high speed impulsing (2 to 6 impulses per second) meters have been used, a simple pulse-rate-to-analogue converter then provides the MW indication.

A conventional metering scheme employing five summators was investigated, but it was found that a scheme employing five electronic accumulating- registers which, in sequence, transfer their contents to a strip printer every half-hour was more economical.

In the final arrangement the strip printer prints out each half-hour the date, time. N.Z. Electricity Department load, Tauranga J.G.C. load, generation. Tauranga E.P.B. load, Tauranga C.C. load and the MWh deviation from the target load.

To aid the load-control operator, the "Deviation from the target load" is displayed on a chart recorder and on a digital meter.

This deviation is derived by differencing, at half-hour intervals, pulses obtained from a target-load generator and from the N.Z. Electricity Department load. The "deviation" displayed therefore represents the cumulative difference in MWh between the target load and the N.Z. Electricity Department load and is chart-recorded to illustrate trends (in addition to a digital-meter printout), because of its much greater accuracy. A second trace on the chart recorder can be switched to the output of any of the pulse-rate-to-analogue converters to provide a record of the instantaneous loading.

4. COSTS

It is expected to have the power station plant under test during August 1972. At this stage the 15 MW plant will he operating on water drawn from the Mangapapa and Mangaonui streams and it is anticipated that the total cost, including transmission lines, will then be $4,900,000. To bring in the Omanawa, Ngatuhoa and Opuiaki streams by the driving of Tunnels 1 and 4, and the completion of Tunnels 2 and 5 will, after making generous provision for contingencies, bring the total cost to $6.8 million or $450 per kilowatt. This is 65% more than the provision originally made, the increase being due to the general rise in the level of costs and to the tunnelling difficulties. The energy output is expected to average 90 million kWh per year.

The establishment of this initial scheme makes possible the "Intermediate" development. In addition the influence of the storage in these two upper reservoirs, together with the diversion of the Omanawa river, will improve the performance of the Ruahihi scheme. The per-kilowatt cost of the two lower schemes is expected to be appreciably lower than for the upper one.

5. GENERAL CONSIDERATIONS FOR FUTURE PROJECTS

In the consideration of future similar projects, it is of importance to determine as nearly as possible not only the prospective costs of developing power locally, but also the probable trend in the cost of receiving power from the national grid.

Reference has already been made to me stabilising influence on power costs which a hydro-electric installation normally secures once it is established. This is because while loan indebtedness is being paid off, about 90% of the annual cost is comprised of capital charges, comprising interest, sinking fund and/or depreciation.

Conversely, one has to consider the probable trend in the cost of purchased power.

Of the potential waterpower of New Zealand it is apparent that, of all the major sites, the most economic ones are already harnessed. In consequence, it is not uncommon to find recent projects costing ten times as much per kilowatt as those built 40 years ago. As these recent developments assume an increasing percentage of the total annual production of hydro power, so the average cost of hydro power to the State must increase.

Furthermore, it is obvious that hydro power in New Zealand must shortly be greatly supplemented from other sources of power. The alternatives at present in sight are nuclear power and fossil fuel. So far as New' Zealand is concerned, developments overseas in nuclear power do not appear to encourage the expectation of power at competitive costs for some time to come.

With fossil fuels it is probably not sufficiently realised that New Zealand’s coal reserves are extremely limited. For instance, it can be shown that the coal reserves, known and “inferred” in New Zealand, work out at an average of 16 tons per acre, whereas if one takes the whole land surface of the world, the average is 148 tons for every acre.

Even Japan’s reserves are twenty times as great as those of New Zealand, yet Japan desires to import coal from New Zealand. It would seem prudent that the limited coal supplies should be reserved for industries.

With natural gas and oil, despite the spectacular increase in the world's known reserves, it is apparent that several different factors are combining to force up the cost of these fuels.

There is no space in this paper to attempt a projection of the probable trend of costs of power production in New Zealand, but briefly alluded to are some of the factors which should be taken into account in carrying out a feasibility study on any proposed local power-generation project.

The authors suggest the following guide lines in the consideration and execution of any such future project:

(a) A comprehensive feasibility study, adequately financed, of all relevant parameters (including those just referred to) by a well-qualified consulting firm or organisation.

(b) Coupled with (a), a realistic cost assessment with clearly defined time-oriented escalation and contingency allocations.

(c) An aggressive determination on the part of the participating local bodies to implement fully the scheme and follow it through to finality.

(d) Rapid approval by government bodies and loan agencies concerned.

(e) The employment of independent technical advisory consultation for local bodies which lack technical expertise.

Furthermore, although most of the financially-successful local developments have been installed under fairly flexible arrangements for design, supervision and commissioning, it is suggested it will be in the interest of all parties if the following provisions are made:

(f) A clear agreement with a qualified consulting engineering organisation for the design and procurement activities.

(g) The establishment of sufficient lead time between the design, procurement and constructive phases to permit concise competitive response, suitable for detailed comparative analysis.

(h) Continuing control and reporting by qualified personnel of the procurement, expediting construction and setting to work phases of the project.

(i) The development of operating, safety and maintenance procedures to ensure a smooth take over by the principal on completion of the work.

6. ACKNOWLEDGMENTS

Thanks are due to the Tauranga Joint Generation Committee for permission to publish this paper, to Mandeno, Chitty & Bell for use of their drawings; and to Renwood Studios, Tauranga. for their photographs.

DISCUSSION

N. R. White (Tauranga E.P.B.): 1 have been closely associated with the project, having attended the Tauranga Joint Generation Committee meetings for some seven years, and perhaps I can provide some additional background information.

The speech made by the Prime Minister when he opened the Lloyd Mandeno station a few weeks ago contained some interesting early historical details of development of generation in the Kaimai Ranges.

In 1914, the Tauranga Borough Council was granted a licence to build a station at Omanawa Falls. This was originally a small unit of about 200 kW commissioned in October 1915 and increased to 680 kW in 1919. In 1925 the Council completed its second station at McLaren Falls with two 1400kW generators, and both of these stations are operating today.
The remark made in the paper that "the early surveys called for considerable physical effort" is a masterpiece of understatement considering the terrain, with its bush-covered slopes and very deep gullies. It takes little imagination to consider what the conditions must have been like in the early 1920s when the only access was by logging track.

These were the conditions that faced a pioneer in many fields (including single-wire earth-return and electric water-heaters)—the co-author of this paper, Lloyd Mandeno, when he carried out his early surveys of the area leading to the development of the McLaren Falls station—and now, nearly 50 years later, Mr Mandeno has done it again. In spite of his extra years, he would disappear into the bush with his survey equipment, and many younger men were hard put to keep up with him—as the Committee found when it made its periodic visits to the scheme to view progress in the test-boring programme for tunnel siting.

The paper describes the country as for the most part an immense sheet or a series of sheets of ignimbrites. This material was originally delivered to the site as a result of a series of volcanic eruptions over the ages, and section 3.3 of the paper details some of the problems encountered driving tunnels through these deposits because of the variation in material sandwiched between the various layers of ignimbrite. As the scheme included some five miles of tunnels, I hope Mr Hansen will enlarge on some of the ingenious measures which were adopted at various times to meet unexpected tunnelling problems.

In section 3.5, the canal between the flow-controller and the forebay is described, and members may lately have heard reference to a recent problem of seepage from the canal. It would be of interest if Mr Hansen could describe the measures which are being taken to deal with this.

I conclude my comments by making the following two points:

The first is that the development of the Lloyd Mandeno station was brought to fruition by the Tauranga Joint Generation Committee, a committee comprised of equal representation of members of a municipal electricity authority and a power board, who united to develop a local energy resource for the good of the community.

The second point arises from comments made by the Commissioner of Energy Resources and also the Minister of Electricity, who referred to the rapidly-dwindling sources of relatively-inexpensive hydro-electric potential and said that generation in the future will rely to a great extent upon the consumption of imported fuels. This fact alone surely justifies the fullest possible Government support to any authority in a position to develop a local hydroelectric scheme, which, although relatively small individually, can, with others, make a significant contribution to the production of a national asset.

K. A. Wilson (Marlborough E.P.B.): In section 3.1, reference is made to a desilting chamber. What is the coarse sediment that has to be dealt with and is there a possibility that sand or perhaps shingle will have to be dealt with at a later stage?

In Fig. 2, timber needles are shown. Presumably they are to prevent a blockage in the culvert, but I would be interested in the details of their construction and whether they are vertical or sloping.

Also in Fig. 2, a by-pass culvert is shown. Is that permanently blocked or has provision been made to use it again if need be?

In section 3.9, reference is made to wearing rings and other parts of highly-polished stainless steel. The Marlborough E.P.B. has the Waihope station, built in 1926-27, and about 10 years ago we inserted stainless steel rings. There was some silt in the river at flood times, and the work was not as successful, as we hoped in that the stainless steel has eroded to some extent in 10 years. What is the detailed specification of the stainless steel used here and does it include materials which prevent erosion?

I would appreciate comment on the carbon seals under the top cover of the turbine to prevent leakage during flood time—particularly on where replacements would be obtained in New Zealand?

I can guess the reason for air braking, but I would appreciate some comment on that also.

K. G. Stewart (Taupo B.C.): No mention was made in the paper of any provision for clearing the intake screens, apart from the desilting previously commented on. In my experience, the Achilles heel of the type of project described is water supply blockage by weed or log debris fouling the intake screens.

With the complex hydraulic inflows through various weirs, it might be desirable to monitor the flow into the weirs or at least to have some remote supervision of the spillway water-level. Are either of these measures contemplated?

It seems that 40 test bores were indeed minimal for the very difficult country, and I would very much like Mr Hansen to comment on this. What would he do if he was investigating another scheme in volcanic country?

Could Mr Leyland tell us what the system is for tripping the headgates— or are they slow closing? 1 presume there is some provision for pressure loss in the penstock. If the headgates are tripping, have trip tests been carried out and is there any effect on the water level in the canal?

What interior protection is used in the penstocks, how was it applied, and in particular were the sections sandblasted after being assembled or pre-sandblasted and treated. If the latter, could the authors comment on treating the welded joint areas?

A minimum river flow was not stated in the paper and I rather suspect that this scheme might get short of water in the autumn months.

The system of pressure on the cooling-water is ingenious. Is any allowance made for flushing the system for any vegetable matter in the reduced, pressure portion?

The machine is quoted as 7.5 MW, 0.83 power factor. Was this power factor specified?

Mr Mandeno is known for his preference for all-aluminium conductor but here he has made a concession with one steel core. Is this because of the nature of the line?

What requirement has the N.Z. Electricity Department upon the Tauranga Joint Generating Committee for daily operation of the station? Does generation follow the daily load curve? If so. does this mean that they have to spill water?

Could we hear how the charges are made to each supply authority by the Joint Generation Committee?

Does the Tauranga City Council continue to run the McLaren Falls scheme on its own, and if so, is it also required to conform to the loading conditions which are imposed on the Lloyd Mandeno station?

The observations in section 5 are very true but I would add two of my own. The first is that it is often necessary to spend a considerable sum of money in a feasibility study, even if this might mean that the answer is not to proceed. Secondly, the Government and the N.Z. Electricity Department should encourage this type of scheme by bulk-supply tariff incentives and with high rebates for local generation.

N. Sanders (King Country E.P.B.):

I am disappointed that the authors have not given a detailed analysis of the cost benefits of this station. From my own figuring and the information given in the paper, I would guess that it will show something of the order of $150,000 surplus annually, but 1 would appreciate a detailed analysis including capital charges, operating costs, insurance premium for machinery breakdown, consequential losses and so on. I realise this may not be available yet but perhaps it could be given later.

In times of flood the two supply authorities taking power from the station will not be able to absorb all the energy that will be available, particularly in the early hours of the morning in the summer, and I wonder, therefore, whether water will run waste, whether the Department will get power for nothing, or whether the committee has been able to make arrangements to buy some of the kilowatt-hours generated?

Reference is made to the turbine butterfly valves which have off-centre spindles in order that the valves will remain closed when under water pressure by the penstocks. If this is so, what precaution is taken to prevent these valves slamming closed in the event of a failure of hydraulic pressure in the hydraulic control?

What teething troubles have they had in commissioning the station?

S. R. Anstice (Dunedin C.C.): I note that provision is made for two 7.5 MW generators. There is an obvious advantage in having two machines, but what was the main reason for not putting in one 15 MW machine?

Was a static type of modern excitation system considered?

There is a reference in the paper to the co-ordinated efficiency for the turbines at 90% gate opening and this co-ordinated efficiency is quoted in the paper as 91.2%, but no reference has been made to any model or full tests included in the contract.

If a realistic cost assessment of the scheme means an accurate one, then this is most difficult with a new hydro scheme.

O. C. Stephens (Thames Valley E.P.B.): We are very interested in a very similar scheme but decided that our scheme was not economic.

Assuming that the output of your scheme is 50 million kWh/year and that standing costs are 12.5%, my rough figures show that it would save the Tauranga consumers something like $124,000 a year to buy their power from the Government at the present N.Z.E.D. costs. You can say that in a capital intensive undertaking 12.5% is fairly high, so let us take 10%, at which stage you are about breaking even and admittedly repaying a capital investment.

The paper says total energy output is expected to be 90 million kWh/year. which gives a load factor of less than 30%. When we made application to the N.Z. Electricity Department we were restricted to a load factor of the order of the New Zealand load factor.

R. C. Western (West Coast E.P.B.): I am particularly interested in the early stages of the development of this project, and have several questions. Is the general layout of the scheme in line with that in mind when the authorities began collecting hydrological and other information? And how much information was gathered and for how long?

This scheme involves the collection of water from a number of streams, its diversion to one point, its storage and its ultimate use for generation. Tunnels, races and pipelines are necessary, as well as two dams. The designed capacity of these waterways, the size of the dams, and the size of the plant are all inter-dependent. If optimum return is to be gained on the invested capital, then the relative capacities of these various works must be correctly chosen. I understand that, after a careful study, the waterways under construction in the Tongariro hydroelectric development were designed to take twice the mean annual flow of the streams supplying them. Would Mr Hansen tell us what method was used to determine the size of the waterways and the dams and hence the capacity of the Mangapapa installation? Was the size of the tunnels dictated by the decision to use tunnelling machine?

I note that part way through the job it was decided to purchase a second tunnelling machine. Who purchased it: the contractor or the authorities? The contract itself must have been a very flexible one to enable this and other changes of plan to be made while the work was in progress.

Although no mention is made of it in the paper, I understand that a pipelaying machine was used. Are such machines available off the shelf or was this one specially designed for the job?

Finally, I assume that the station meets the N.Z.E.D. requirement that the output follow the general pattern of the daily load curve in the area. How restrictive were the requirements of the Department and might there be any difficulty in meeting them?

K. D. McLeod (Wairarapa E.P.B.): 1 note that the transformers were designed for both 33 and 50 kV. Why was 50 kV necessary?

C. Hansen (in reply): To cover fully the problems in the tunnelling would take hours. The major problem was the varying degree of hardness of the ignimbrite on the tunnel alignment. This was not evident in the initial 40 test bores. The rock ranges from 5,000 lb/in^2 hardness to material which is not self-supporting. The spider-type tunnelling machine is not capable of handling this range of hardness. Consequently a shielded tunnelling machine has been purchased which will handle the hardest rock to be encountered and also line the weak areas in the tunnel which will require lining.

All projects have their problems, especially where earth embankments are concerned. A crack has appeared in the embankment of the canal adjacent to the forebay, through which water has seeped into a pervious layer some 30 ft below the invert of the canal. The water has flowed through the pervious layer. escaping on the face of an escarpment, causing slight slipping of the cliff face. It was a minor problem and not difficult to overcome. The canal was lined for 100 ft with an impervious rubber lining to prevent water entering the cracked area. A seepage drain was placed under the lining to monitor any future leakage and a grout curtain was placed through the pervious layer to recompact the ground and to prevent the passage of water through it.

The main function of the desilt chamber is to collect material during flood conditions, preventing deposition of the material in the tunnel. The sediments collected will be in the sand/gravel classification. It is not intended that the finer sediments be collected. They will be carried through the tunnels.

The needles across the bypass culvert, which was used during construction, block off the bypass culvert completely. The needles are 6 in. x 4 in. tanalised pine, one against the other. Should silting occur in the lake behind the weir, the needles can be removed by using a block and tackle and the lake desilted.

The bypass culvert at the Mangaonui dam has provision for desilting the lakes by removing a flanged plate from the end of the culvert; the latter has included in it a 9 in. valve.

Screen cleaning is meantime to be carried out by hand. A headworks man. employed full-time on site, will be responsible for cleaning the screens. The designs of the forebay screen and of No. 6 tunnel intake are such that power-driven scrapers can be installed should this be desired in the future.

From the experience gained on the Mangapapa scheme, it is essential that a complete test-boring programme be carried out. You can ascertain the nature of the ground that you are going to mine through only by test boring. Therefore, a comprehensive programme of boring must be carried out before a reliable picture of the strata to be encountered can be obtained. The extent of the investigation is dependent upon the money available for the test programme. It is therefore essential that adequate provision be made for this work.

It must be remembered, however, that no matter how extensive the drilling programme is, you can never get a longitudinal section which is fully reliable. To do this you must drill a horizontal hole through the ground - and this is the tunnel itself.

It is very difficult to estimate the final cost of a tunnel. You base your estimates only on the information that you have available and then allow a realistic contingency sum to cover anything else which may occur. If, however, you go to the extreme end of the scale and allow in your estimates for all the problems that could occur, the project will be uneconomical and will not be constructed. In the case of Mangapapa the costs have certainly escalated, but the job is still economical. This is the important fact.

The interior of the penstocks received a two-coat epoxy tar paint application. The penstocks were delivered to site in 20 ft lengths, sandblasted under controlled conditions and painted with two coats of epoxy paint. The pipes were then assembled in position on the penstock line and welded together. The joints were then carefully ground off and a two-coat mix applied to the exposed steel.

In estimating for a project such as a hydro scheme which may involve tunnelling work and is certainly subject to escalation beyond one's control, it is not possible to assess accurately the final cost of the scheme. One can only base the estimates on the information available at the time of estimating and then allow a reasonable contingency sum for possible cost variation.

In the Mangapapa scheme the diameters of two out of the six tunnels were governed by the hydraulic design. These were tunnels No. 3 and 6. The remaining tunnel sizes were controlled by the diameter of the tunnelling machine available. The minimum size machine available was a 7ft 6in diameter machine which corresponded to the size of tunnel required for tunnel No. 3. To mine tunnel No. 6. the head of the tunnelling machine was expanded to 9ft 0in. A 7ft 6 in. diameter tunnelling machine is the absolute minimum. A more practical size is 8ft 0in.

The second tunnelling machine is being purchased by the Tauranga Joint Generation Committee and is to be sold at the end of the contract to the contractor, at its residual value.

The second stage of this contract has been negotiated with the contractor. Considerable negotiating has taken place to arrive at a price which is both fair and equitable to both the Tauranga Joint Generation Committee and the contractor concerned.

The pipe-carrying machine mentioned by Mr Western is classified as a self-propelled diesel-powered hydraulically driven air-operated shuttle-bottom mine car—known locally as the "Hunchback of Notre Dame". It was designed and built by the contractor and was initially used for transporting from the tunnel the hard material which was excavated in the hand-mined section of tunnel No. 3. It was later modified to carry concrete pipes into tunnel No. 3 for lining a section of weak ground.

The trough under the penstock line is for collecting the rain water which flows off the penstock. Its main function in the case of the Mangapapa scheme is to prevent the erosion of the soft pumice ground under the penstock lines.

B. LEYLAND (in reply): The turbine runner is made of stainless steel with the following composition: chromium 12%, nickel 1%. carbon 0.1%. The constituents of the alloy have been chosen primarily for cavitation resistance. The wearing rings on the runner are also of stainless steel while the stationary rings are of bronze. By drilling out the securing bolts it is possible to remove a worn ring and replace it. We do not expect to have any great problems with wear on the rings— mainly because the water is free of silt.

The manhole in the draft tube is a useful feature. In some cases, however, its value must be balanced against a reduction in speed or increased danger of cavitation resulting from having the turbine above the tail-water level.

The operation of the carbon seals is essentially the same as the carbon seals on a car water-pump except that clean water is fed into an annular groove at the centre of the seal. This clean-water supply is to prevent any sediment from the penstocks entering between the seal faces and damaging the seal We have recently had some experience in modifying a turbine to provide a carbon seal: it should not be too difficult to modify any turbine provided that space is available.

The braking system has three rams which are raised by compressed air. Brake pads on the top of the ram act against a braking ring at the bottom of the rotor. Braking starts at 45% speed and continues intermittently—5 s on and 5 s off-until 15% speed is reached. At this speed braking is continuous. A timing relay monitors the time between 45% speed and 15% speed and brings up an alarm if it is excessive.

To jack the machine the braking rams are connected to a high pressure oil system.

The headgates are raised by hydraulic rams and are held open by oil pressure. A limit switch on each headgate operates when the gates have shut a few inches, as a result of seal leakage, and starts the pump to open them again.

Emergency gate-dropping is initiated by excessive penstock velocity. This excess velocity is detected by a differential pressure-switch connected to pilot tubes. Operation of the differential pressure-switch opens a valve which releases (the pressure oil holding the gate open. The closing speed of the rams is regulated by a leaky check-valve fitted to the rams. (Since the paper was written the gates have been tested against full-load flow: with complete success.)

Regarding the minimum water flow, the records show that there is very little variation in flow during the year—apart from rainy periods and floods.

As the cost of this scheme is very sensitive to machine size—owing to the great length of the tunnels and penstocks—the most economic machine size is bound Io be lower than it would with a scheme with a single dam, a large amount of storage and short penstocks.

The cooling-water system is equipped with an automatic filter which back-washes itself. No other provision is made for flushing. We do not expect to have any significant weed problems because the intake from the lake is well underwater and the lake level varies.

A power factor of 0.83 was chosen because 7.5 MW at 0.83 p.f. equals 9 MVA—the rating of the transformers. (The machines are now cleared for operation at 7.7 MW continuously and 8 MW over peak periods.)

Steel-cored aluminium was used for the first section of the line because it gave the most economic result. For the second section all-aluminium “Cockroach" was used; there was no comparable standard steel-cored cable available. With hindsight, it probably would have been economic to have a special conductor with a small amount of steel manufactured.

As far as I know the N.Z. Electricity Department have not insisted on any restrictions on the operation of the machines. As this is the first of three stations, it would seem reasonable that any restrictions would be placed on the overall operation of the three stations rather than each. In addition, at the moment, our maximum output is well below the Committee’s total load.

The Empowering Act states in effect that the Committee will both generate and purchase power and sell it to the Tauranga E.P.B. and the Tauranga C.C. at a price determined from the total cost of the power generated and purchased and the loads of the T.C.C. and T.E.P.B. The T.C.C. will continue to run the McLaren Falls station for itself until the Ruahihi scheme is commissioned. For this it meantime operates under its own agreement with the N.Z.E.D.

The cost per kilowatt-hour delivered to Greerton Is below 0.75c/kWh (a breakdown is given later).

We feel that we have done more good than harm to the environment. We have opened up a lot of country and the ponding areas formed will provide a refuge and breeding ground for game fish.

Costs

	$
Capital raised	6,900,000
Loan-servicing costs	509,000
Operating costs	46,000
Management	25,000
Insurances	20,000
	600,000

Returns

If power had been purchased from the N.Z.E.D. at the tariff likely to be current when the scheme is completed ($13.95/kW and 0.55c/kWh) the costs would have been:

	$
Peak output—15,600 kW @ $13.95	218,000
kWh output 90 million @ 0.55 c	495,000
Allowance for diversity from combined loads of T.C.C. & T.E.P.B.—1,000 kW @ $13.95	13,950
Gross return	$726,950

Net return=$126,950.

The generated cost of power amounts to 6.67c/kWh. (This elementary analysis makes no allowance for the fact that the water diverted from the Omanawa, Ngatuhoa and Opuiaki rivers will treble the amount of water available for the Lower Mangapapa scheme. In addition the diversion of the Omanawa will give a 20% increase in the flow available for the Ruahihi scheme.)

We do not expect to have any problems with surplus power early on a summer morning because we will be able to store water and use it during the day when the Committee load will be higher.

The closing of the butterfly valves is by means of a weight assisted by the water pressure across the valve. The closing speed is regulated by orifices in the hydraulic circuit of the valve servo motor. When the valves were closed under full-flow conditions, the penstock pressure rise was below 10%.

As far as the turbines and generators are concerned, we have had no major teething troubles. Two minor problems that come to mind were the lack of oil passages in the turbine-bearing oil coolers and the unexplained failure of the automatic synchronising equipment at the official opening.

A single 15 MW machine would have had to run at fairly low loads for some of the time. This would result in a low overall efficiency and, possibly, in cavitation problems. In addition it would be very expensive to shut the whole scheme down for three weeks each year while the unit was under maintenance.

Concerning the excitation system, the original specification anticipated a static system but allowed alternatives to be offered. Rade Koncar preferred to offer a d.c. exciter. This is very reliable and the output is not affected under system fault conditions. (This is a common failing of static systems where the excitation power is taken from the generator terminals.)

The turbine efficiency was derived from model tests in an independent turbine-testing laboratory in Yugoslavia. We will not carry out comprehensive tests as the cost of so doing is very high and it is unlikely that they would serve any useful purpose. If we do have any reason to suspect that there is a large discrepancy between the guaranteed and actual efficiencies, we will carry out proper efficiency tests.*

We agree that it is not possible to make a really accurate estimate of the costs as although the costs of electrical and mechanical equipment can be estimated fairly accurately (say ±15%) the cost of civil works can vary a lot —especially where tunnelling is involved.

The output of the Mangapapa scheme is expected to be between 85 and 95 GWh/year—depending on rainfall.

50 kV is the transmission voltage which has been in use for interconnection with the N.Z. Electricity Department ever since McLaren Falls was commissioned.

Next year a changeover to 33 kV will commence.

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*Since the paper was read a check on the machine efficiency has been made and the results were close to the guarantees.

The President thanked Messrs Hansen and Leyland for their presentation and their answers to the discussion. He asked that they convey to Messrs Mandeno and Patterson the thanks of the Institute for writing a paper on this very interesting scheme.

Written discussion

Lloyd Mandeno (consultant): I have perused a transcript of the discussion and wish to thank Institute members for their interest and constructive contributions. They apparently recognised that, to keep within permissible limits, it was possible to give only an outline of some of the numerous aspects of the scheme. It was, for instance, not possible in the paper and is not possible now, to describe all the various methods of development which were considered. The writer was engaged in varying degrees of intensity on the project for about 17 years, and during that time planning was guided not only by hydrological and topographical surveys, but also by test boring and geological studies and by questions of political negotiations, prospective demand, and of economics.

As to the economics of the undertaking, it is to be emphasised that, provided a hydro-electric project is soundly built, and provided it is shown to be economic at the time of completion, then there is plenty of experience of the performance of such plants to show that they will prove to be increasingly profitable in the future. This is because their operating and maintenance costs are usually nominal while their annual capital costs become definite and fixed once the capital outlay is finally determined.

In this connection I understand that the runners and working parts of the turbines in McLaren Falls power station, now in service for 47 years, show no noticeable wear or erosion although capital charges on the plant have long since ceased. But, on the other hand, because it is a historical fact that the purchasing power of money is continually declining, the value of the output of a station expressed in terms of money is continually increasing. As an example of this it may be mentioned that the average charge for power to local authorities by the N.Z. Electricity Department in 1939 was 0.275c/kWh compared with 0.78c/kWh in 1971.

One could argue interminably about costs. For example, supply authorities have been encouraged to think in terms of some percentage like 20% as representing the total annual cost of rural reticulation extensions. This is convenient and simple as a working rule, but it is obviously not logically sound. And then one can argue about sinking funds and depreciation and renewals funds—that is, how much should this generation bequeath to posterity?

But the outstanding fact is that those New Zealanders who undertook soundly-engineered hydro schemes in the past have benefited themselves, and their successors even more so. Doubtless this experience is general throughout the world. For those who have undeveloped hydro potential in their districts the moral will be obvious.

THE END