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NEW ZEALAND.

HYDRO-ELECTRIC DEVELOPMENT.

NORTH ISLAND SCHEME.

Laid on the Table of the House of Representatives by Leave.

REPORT BY THE CHIEF ELECTRICAL ENGINEER TO THE HON. SIR W. FRASER, MINISTER OF PUBLIC WORKS.

OUTLINE OF THE SCHEME OF DEVELOPMENT.

THE scheme of development herein advocated as regards the sources of power is practically identical with the scheme advanced in my interim report* on this subject. Briefly, it comprises the development of three principal power sources—viz., Mangahao, Waikaremoana, and Arapuni—with the reservation that the construction of the dam required for the latter may be found impracticable, or at least inadvisable, when the character of the foundations has been more definitely determined by tests, in which event Arapuni would be replaced by Aratiatia, which is the next in order of merit as regards size and location.

Of the three sources, Mangahao is the best situated in respect to the load, and it is to be regretted that this source is not capable of yielding a larger amount of power. The general scheme falls short of the ideal in two other respects—viz., the lack of a moderately large source of power in the Taranaki district, and a similar lack in the Whangarei district. If it were possible to obtain 50,000 horse-power or more from Mangahao, and if a source of about 20,000 h.p. in the Taranaki district and one of about 10,000 h.p. in the Whangarei district were available, the scheme herein outlined would be materially improved; but the ideal is never attained, and the scheme here advocated is the best under the circumstances, and, while being adequate, economical, and eminently practicable at the stage described, can be still further developed and enlarged as required.

It is recommended that in the interest of national economy and production the scheme should be planned in such a manner and on such a scale that a supply of power shall be available, with the co-operation of the local authorities, for every householder in the North Island, and for any industry requiring the supply of power, temporarily or otherwise; for main-line electrification, light railways, coal and other mines, for winding, pumping, ventilating, and smelting, and for any other purpose.

In order to provide for the requirements outlined above a total substation load of 130,000 h.p. is necessary, requiring a plant capacity in the main power-stations of 160,000 h.p., allocated as follows—viz.: 96,000 h.p. at Arapuni, 40,000 h.p. at Waikaremoana, and 24,000 h.p. at Mangahao. The power to be provided is equivalent to one-fifth of a horse-power per head of the present population of the North Island, which provision is ample for ordinary requirements, but not sufficient for such extraordinary developments as have taken place in Tasmania. The sources mentioned have, however, greater potentialities than it is proposed to develop under the present scheme, which can be developed later to satisfy extraordinary demands for power over and above those now provided for. The route length of transmission-lines is 1,421 miles, and the number of primary substations is twenty-nine. The location of the power-stations and the primary main-line substations, together with the routes of the primary transmission-lines, is shown on a map attached to the report. The system of transmission as designed, together with a system of distribution radiating from the main substations, is sufficient to ensure a supply of power to the whole of the Island. The distribution system allowed for cannot be shown on the present map.

* "Hydro-electric Development: North Island Scheme." Public Works Statement, 1917, Appendix E, p. 49.

The total capital expenditure is estimated at £7,303,042, including interest during construction, working capital, and a sum to enable financial assistance to be afforded to power-users and local authorities. It is pointed out that the whole expenditure is recoverable in from six to seven years in coal saved alone, productive power is increased and economy secured, country districts settled, and closer settlements generally accelerated, whilst at the same time the undertaking is self-supporting after a reasonable interval for development and growth.

On the basis of 7½ per cent. per annum the capital charges will amount to £547,728, and working-expenses are estimated at £220,000 per annum, making a total of £767,728, requiring an average return of £5·9 per horse-power of substation load, which return should be easily secured.

A similar scheme for the South Island is under consideration, but the details have not been worked out. The outlines of the scheme are simple. Briefly, it would consist of a system of power-stations, all linked together; starting from Lake Coleridge, this power-house would be linked up on the north to a power-station in the Marlborough district and to Westland, and in the south to a power-house intermediate between the present Waipori power-house and Lake Coleridge; this would in turn be linked up to the Dunedin Corporation's plant at Waipori, and Waipori to a power-house in Southland. The inclusive cost would be less, if anything, than the North Island scheme.

The report is divided into headings in the following order:—

The Function of Hydro-electric Power in the State.

The development, distribution, and marketing of electric power on a comprehensive scale has since the war come to be generally recognized as one of the most essential agencies in national reconstruction. Previous to the outbreak of war its importance in national life was but dimly sensed except by a comparatively few persons possessed of an unusual amount of imagination and foresight, and it is evident from reading *Hansard* of a few years ago that even the far-seeing one regarded electric power more as a means of industrial development in the narrower sense in which the term is commonly used than as the nerve-system of the community and as touching every phase of national life.

Neither was it recognized at that time that national organization for production and the promotion of national efficiency was a function of a Government. The war has made it imperative that the nations shall be reorganized on a national scale, and that in future the marshalling of the forces of production must be a definite and conscious function of the Government of a country.

The change in the attitude of public men towards electric-power development is well illustrated by the recent action of the Government in Great Britain. Before the war the generation and distribution of power was left to private enterprise; it is now proposed to set up a body of Commissioners to co-ordinate the activities of the various power-supply authorities and to bring them into line for the advancement of the national interests, and by so doing it is recognized that the organization of power production and distribution will result in a national saving of not less than £100,000,000 per annum; or, putting it in another way which is very striking, the coal saved would be sufficient to generate continuously not less than fifteen million horse-power.

The largest hydro-electric system owned by the State is probably that of the Swedish Government, which has three large hydro-electric stations aggregating over 200,000 h.p., supplying power to a large system for electric smelting, railway electrification, and general industrial supply.

Another of the most notable instances of the development of hydro-electric power by the State is to be found in the Province of Ontario, where the system is managed by a body consisting of three Commissioners. They commenced operations in 1908, and the load has now attained a magnitude of 160,000 h.p. The total length of primary transmission circuits is about 1,500 miles, and of secondary transmission circuits about 1,600 miles. Altogether some 143 municipalities are supplied. The supply reaches to a distance of 245 miles from the main source.

Another notable instance is to be found in Tasmania. Originally a concession was granted to a company authorizing them to undertake the generation and distribution of power in Tasmania; but the company failed, and after some negotiations the State took over the works and completed them. They started with 10,000 h.p. of plant, which was augmented by 8,000 h.p. soon after, and a further 16,000 h.p. of generating plant is on order. Arrangements are being made for developing other sources, as the present source is quite unequal to the demand. The magnitude of the contracts entered into is a feature of this undertaking. One contract alone amounts to 25,000 h.p. for electro-metallurgical purposes, and it is significant that when the State took over the plant from the company such big demands were not anticipated. Nor was there any indication that the business of electric smelting would attain such proportions. The total contracts already entered into amount to 42,000 h.p., and further contracts amounting to 50,000 h.p. are being negotiated.

New Zealand, now at the outset of its career as a nation, has a unique opportunity of securing the utmost possible efficiency for all time by developing its water-powers on such a scale and by providing for such a wide-reaching system of distribution that electric power shall become available to every householder throughout the Dominion, and available at any point where circumstances require the application of power.

The functions of that Department of State which deals with the generation and distribution of power is one involving great responsibility and wide range of knowledge, as it touches every phase of national life in its industrial aspect. It has to generate and transmit electric power; it has to make contracts with local authorities and other State Departments and individuals; it has to negotiate terms with industrial organizations outside New Zealand which may be desirous of taking advantage of the supply of hydro-electric power; it has to finance local authorities to enable them to reticulate their districts; it has to finance power-users to enable them to convert from steam or other power to electric power; it has to assist industry by carrying out experiments in industrial processes on a commercial scale, for the lack of which a great deal of talk concerning industry and science is lacking in cohesion. It may further be required to undertake the manufacture of a special class of product in the national interest.

Electricity in Agriculture.

The extension of the Lake Coleridge supply to the country districts in Waimairi, Eyre, Halswell, Paparua, and Springs has served to demonstrate its convenience, utility, and its effect in lessening the drudgery of farm life and in increasing production, especially so in dairying districts.

Electricity as a power agent is so flexible and adaptable, and its uses therefore so manifold, that there is scarcely an aspect of human activity to which it cannot be applied, the number of processes to which it is capable of being applied on farms being about 125.* The supply of electricity to farms and homesteads has already attained considerable dimensions in some parts of the United States of America, the extent of which is not generally known. A census made by the Western Power Association† of California in 1915 gives the total horse-power of electric motors on farms at 190,141, and the estimated figure for 1918 is 200,000.

Electric pumps are largely used in the districts mentioned for pumping water for irrigation purposes, which accounts for a large proportion of the power used, but after allowing for this there remains a substantial balance for other purposes.

One of the most remarkable and deplorable movements of the present day is the drift of the country population into the towns. Various reasons have been advanced to account for this tendency, but it will be admitted that the drudgery associated with farming is one of the main if not the primary cause. This drudgery will certainly be lessened when a general supply of electricity is available and the farming community has had time to become habituated to its various uses. In fact, the movement will then be in the opposite direction, as the stimulation given to production and the improvements made possible in the conditions of living will result in closer settlement of the country areas. At the same time these districts will be brought more closely into touch with the towns by the construction of light railways, made possible by a general supply of electric power.

Electricity and Industry in General.

Using the word "industry" in a more restricted sense of manufacture, the importance of a supply of cheap electricity for manufacturing purposes is one of paramount importance. It places at the disposal of the manufacturer a subtle and flexible form of energy which is adaptable to every kind of power, to heating, or to electro-chemical and electro-metallurgical uses. He is able to extend and adjust his business to the growth of demand without being hampered with the many considerations which a manufacturer has to face if he has to provide a generating plant or increase its capacity.

These advantages are of course well known and appreciated, but what is not appreciated enough is the importance of a general supply of electricity available for use anywhere in the Dominion. At present if a manufacturer wishes to avail himself of a supply of electric power he has to locate his works in the vicinity of a town where he can get a supply, or he has to consider the question of the coal-supply and the cost of coal, with the result that the factory is not always placed where it is best suited for the exigencies of the business. Moreover, it is quite certain that a number of industries which might be carried on are neglected altogether owing to the element of power being difficult to procure.

*C. I. Rohrer: G. E. Review, V, 16, p. 714. †I. H. Davidson: G. E. Review, V, 21, No. 2, p. 130.

We have abundant evidence of the effect of a supply of cheap electrical power in Christchurch and district: within a comparatively short time—less than a year in fact—the preliminaries were settled and contracts made for supplying power to every factory within an economical radius of supply from Christchurch. But what is more noticeable is the way in which a cheap supply of power has stimulated the industrial mind into activity in many directions, such as the manufacture of caustic soda, hydrochloric acid, calcium carbide, and steel smelting. Another fact worth noting is that for the lack of sufficient machinery in the Government power-house one large electric-smelting industry which contemplated starting at Christchurch or wherever power was available was lost to the Dominion—which is regrettable, as it promised to be the beginning of a large development.

The general distribution of electric power makes possible a much larger use of the electrically propelled battery vehicle which has proved so successful in the Christchurch district, and has already been adopted by some of the dairy companies in this Island for the collection of their cream, with pronounced success.

Wood-pulp Industry.

The wood-pulp industry is one which has assumed large dimensions in Sweden and Canada, and, whilst forest reserves have been set apart in New Zealand for this purpose and preliminary steps taken to establish the industry, no actual work has been done up to the present. The provision of electric power at suitable points would greatly assist promoters in overcoming the initial difficulties, and would no doubt lead to the establishment of a wood-pulp industry and of allied industries using wood-pulp in its various forms.

Electro-chemical and Electro-metallurgical Industries.

Such industries as employ electricity as a heat agent or chemical agent are distinguished from the general industrial uses of power by the fact that the cost of power forms the largest item of expenditure, whereas in general the power expenses are small in proportion to the total expenditure upon production. Such special industries cannot, for the reason stated, afford to pay the same price as the average obtained for general industrial purposes. Nevertheless provision has to be made for such industries, as they have a very important place in national production and development. Such industries range from comparatively small magnitudes, from the power standpoint, to very large dimensions. As a rule they are local in character, depending upon the occurrence or deposit of a mineral, and it is essential that a supply of power should be available wherever the circumstances are such as to favour the establishment of an industry of this kind. It will even be found that in some cases it will be profitable to bring raw material to a convenient locality where an abundance of cheap power is available, and to have it treated there.

Electrification of Main-line Railways.

The provision of an adequate and dependable supply of electric power which shall be available when and as required at such points as may be desired by the Railway Department is indispensable to them if they are to be enabled to keep pace with the development of the country.

It should be clearly understood that railway electrification does not mean the displacement of steam locomotives altogether and at once, but the gradual substitution of electric haulage for steam haulage on grades and in tunnels when and as the limits of steam haulage are reached, after making every possible improvement short of entire duplication and extensive regrading.

The steam locomotive is easily the most economical tractor under ordinary railway conditions, but its speed becomes severely limited on grades because there is a limit to the power which can be accommodated on a steam locomotive. The electric locomotive, on the other hand, does not generate the power, but merely converts electric power to mechanical power, which it draws from a power-station situated elsewhere. The electric locomotive, being able to draw on a large central generating station for its power, can when required supply large amounts of power and so maintain higher average speed and increase the capacity of the line for traffic.

For example, let it be supposed that the limit under steam haulage has been reached in some portion of the division of the Main Trunk line between Taumarunui and Taihape—that is to say, no more traffic can be conducted over it. This means that if this constitutes the critical section, the whole Main Trunk system and its tributaries, and to a lesser extent all other lines, are limited by the capacity of the section or division mentioned. If now electric haulage be substituted for steam haulage on this section it would enable possibly twice the amount of traffic to be conducted over it, and by so doing at once double the traffic capacity of the whole Main Trunk system, and substantially enhance the value of the whole of the New Zealand railway system, without any further expenditure than that necessary to electrify the section in question—assuming, of course, that there are no other sections with the same or approximately the same limitations. The only alternative to this would involve regrading and reconstruction, which would inevitably introduce longer tunnels, which in themselves would offer an obstacle to an increased traffic, and at the end it would be found that recourse would have to be had to electrification. The point to be noticed is that a general system of electric-power distribution is necessary in order to enable the Railway Department to deal with any tunnel or section with steep grades as soon as the capacity under steam haulage is reached, and that if a supply of electric power is not available for use when and where required the development of the country will be retarded and progress hindered.

Suburban-railway Electrification.

The question of suburban-railways electrification is already an urgent one in some cases, as for instance between Wellington and the Hutt. There is no doubt in my mind that had the law permitted of it an electric tramway would have been in operation between these two centres long ago, and it is evident that before long the need of a more frequent service will become so great as to necessitate a removal of the present legal obstruction, unless a service of the same general character is provided by the Railway Department. In course of time, in all probability, as a result of the growth of the population, an electric service on both the road and the railway will become a necessity. There is, of course, no question as to the advantages of electricity where frequent service is required—this is a matter of common knowledge; but at the same time, although the necessity may be great, it will be found that the actual conversion is postponed until the matter becomes an acute one, unless facilities in the way of obtaining a supply of power are available. These delays may not have the same direct retarding influence as delays in main-line electrification, but the argument in favour of a provision of electric power is equally valid.

Agricultural Railways

Another branch of electric haulage which may possibly have an important influence upon the destinies of New Zealand is the construction of light railways, by which I mean railways constructed with grades usually adopted for a good class of road—or, in other words, a tramway, which shall serve the country in the same way as a tramway serves a town and its suburbs, except that farm-produce would be conducted over it as a matter of course. These would not take the place of main or branch railways, but would act as feeders thereto. They would relieve the roads of heavy traffic, and would promote exchange between town and country and form an important link between producer and consumer. It is possible, of course, that there is no immediate use for this class of railway in New Zealand, but if there is no system of general electric supply the matter cannot be put to a test, as it would never pay to provide a separate power-station for each line. In any case it is quite certain that there is a future for rural railways where the population is closely settled, as we have the example of Belgium before us, and it is only a question of time before the necessity for them will arise in New Zealand.

Electricity and Coal-mines.

One would be apt at first to conclude that colliery-owners would have no use for electric power transmitted from elsewhere, yet the contrary is the case. In my own experience I have found the collieries amongst the first and most profitable customers of a power-supply undertaking, notwithstanding the fact that coal from outside the district was used to fire the boilers in the power-generating station. Large collieries in South Wales, Lancashire, Yorkshire, and the Midlands derive their electric-power supply from bulk supply services over long transmission distances, and collieries on the north-east coast of England, having an aggregate output of 20,000,000 tons of coal per annum, are entirely dependent on the north-east coast power-supply system for a supply of electricity, and it is calculated that a saving of 1,000,000 tons of coal per annum is effected thereby.*

It is sometimes assumed that the development of hydro-electric power is inimical to the development of coal-mines, and that the saving in coal which is effected by the substitution of electricity for steam-power means that so much less will be mined or imported. The contrary is, however, the case, because any great measure of economy when effected increases prosperity, and increased prosperity invariably increases the demand for coal.

It is suggested that the slack coal now produced will remain unutilized if certain power plants now using the slack cease burning fuel and take a supply of power from a hydro-electric source. My own view is that increased production which will result from a cheap and unrestricted supply of electricity will put up the demand for slack coal for auxiliary purposes; that there will always be a market for mine-slack that is normally produced, especially when improved methods of burning the slack are adopted.

A method is now coming into vogue for steam-raising purposes which has long been in use in cement-mills and in the open-hearth process of steel-making—viz., that of pulverizing the coal and forcing it under the boilers in the form of a jet by means of a fan. It is quite probable that this method will be largely used for marine and railway purposes in future, and experiments have been made with a view to adapting the method to the requirements of both marine engines and steam locomotives. It would seem that the next step in the process of economizing fuel will be in the direction of pulverizing the slack and using it in the way described.

Slack coal of very inferior quality is treated on a large scale in Germany for its chemical contents, and also made into briquettes of a comparatively high calorific value, but it is doubtful if such processes can be operated with advantage in New Zealand.

The erection of a power-house in the Huntly district has been suggested as a suitable source of electric power for the Auckland district, the plant being designed to burn the slack coal produced in mining the more marketable coals. There are several objections to this course. In the first place, if full advantage is to be taken of the cheapness of the slack the output of electricity would be dependent upon the slack produced, and the development of the power-supply business regulated accordingly. On the other hand, if the power business is to be conducted in such a way as to be free to expand and to keep pace with developments unhampered by conditions as to the quantity of slack produced, the power-station must be located in such a position that it can draw upon several coalfields, especially in view of the fact that the quality of the slack produced varies considerably in calorific value and other properties affecting the method of burning. My own experience is that slack even when obtained from the same seams varies even from week to week in such a way as to interfere with the combustion of the coal and the production of steam. I have known of a power-station located in one coalfield drawing its supplies of coal from another coalfield as a matter of economy and to facilitate the operation of the plant.

* "Interim Report on the Electric-power Supply in Great Britain": Ministry of Reconstruction, Cd. 8880, p. 27.

If a power-station were to be designed with a view to utilizing the slack coal produced in the Huntly district it is probable that the best place to locate it would be Auckland, so that it could draw supplies from other sources at the same time. In the second place, the quantity of slack coal now produced in this district over and above that which is sold is in the neighbourhood of 100,000 tons per annum. At a load factor usual in power-supply systems this would only be sufficient for a maximum load of 12,000 h.p., which amount is too restricted for developing the country properly, and is not even sufficient to supply Auckland if all its requirements are to be adequately provided for. In the third place, there would not be any saving in capital expenditure, whilst the working-expenses would be increased.

Electricity in Mining generally.

It has already been indicated under the heading of "Electricity and Coal-mines" that collieries are extensive users of electric power derived from bulk supply systems, but the importance of a general supply of power to the mining industry in general is not commonly appreciated. Mining of all kinds is at the best of a temporary character, and the importance of being able to obtain electric power on demand, and discontinue the same when not required, can hardly be overestimated. It would result in the opening and working of mines that would not pay under any other conditions, and numberless works of a prospective and experimental character could be undertaken that would never be entertained under present conditions.

The supply of power for short periods would not cause any difficulty or embarrassment to the power-supply authority, because, firstly, it is presumed that power is available in abundance, and in the second place the power demand over a long period would be fairly even as contracts expire and new contracts are made.

A large extension of electric smelting of ores of various kinds may be anticipated as the result of being able to obtain a supply of electric power in the vicinity of the mines. It is noteworthy that the Tasmanian Government as soon as it established its hydro-electric works was overwhelmed with applications for power for smelting purposes of a kind which had not been previously anticipated; and, although the works were designed on a liberal scale having regard to ordinary requirements of the population and of manufactures, they proved too small to satisfy the demand for power, and immediate steps had to be taken to develop other and supplementary sources of power.

General Principles affecting the Generation and Distribution of Power.

The distribution of the load throughout the Island, and consequently the most economical distribution of generating-stations and location of main transmission-lines, is dependent largely on the location of the population. The attached map (E 116) showing the distribution of population and consequent probable distribution of load over the Island has been divided into districts, and the probable centres of gravity of the loads of the whole and the various districts have been marked. The centre of gravity of the load over the whole Island is on this basis somewhere in the neighbourhood of Okahukura, on the Main Trunk line, and it would be quite feasible to supply the whole Island from one central generating-station such as Aratiatia or Arapuni, situated not far distant from this oint. This, however, is not the best method, and has disadvantages compared with the system adopted.

The question is often asked, How far can electricity be transmitted economically at the present day? The answer depends a good deal on circumstances.

The maximum distance is limited by the highest voltage which may be employed, which to-day stands at 150,000 volts; but this voltage cannot be employed economically unless the power to be transmitted is large enough to justify the use of a certain minimum size of wire, which at this voltage will not cause loss by developing what is known as a "corona."

Under the conditions prevailing in the North Island of New Zealand under the scheme outlined in this report the most appropriate voltage for the primary transmission system is 100,000 volts.

At 100,000 volts the conditions affecting transmission are favourable up to 100 miles, and are not serious up to 150 miles, but above this the difficulties begin to increase. For instance, a transmission-line of certain size of wire and spacing will transmit 17,500 h.p. a distance of 100 miles, 11,000 h.p. 150 miles, and 12,900 h.p. 200 miles, with the same regulation—viz., 6 per cent.—in each case: that is to say, the capital cost of transmission per horse-power transmitted is increased 87½ per cent. for an increase in distance of 50 per cent., and is increased by 170 per cent. for an increase in distance of 100 per cent. Add to this the extra cost of maintenance and it will be evident that the cost of power increases rapidly with increase of transmission distances.

It is true that the above comparison may be modified if we allow a worse regulation on the longer distances, but there are limits to the regulations, and excess must be compensated for by machinery, which adds to the cost.

Long transmission-lines become a necessity when the nearer sources are inadequate for the requirements of a district, or where the power-stations available are of such a size that their cost per unit would be so much greater than the unit-cost from the larger source as to compensate for the extra cost of transmission. As a general rule it may be taken that under New Zealand conditions, provided the market is available, it will pay to develop any source yielding 20,000 h.p. on a 50-per-cent. load factor at a cost of £20 per h.p. or under, as an alternative to obtaining the power by means of a transmission-line over 130 miles in length from another source.

The capital cost of water-power developments is apt to be high for small or partial development, so that existing loads, by helping to pay the heavy interest and fixed charges during the earliest years of operation whilst the load is growing, have an added value over those which are only prospective and dependent on development.

A limited subdivision of generating-capacity with interconnected transmission is also preferable to the single generating-station, because it gives greater security of supply by ensuring that no industry is wholly dependent on one power-station or transmission from one direction for its energy, but may get its supply from a general system which has more than one source of supply. This is particularly desirable in the case of railway electrification and metallurgical and chemical processes involving large amounts of power, where the cost and disorganization caused by a stoppage of supply even for a short time may be so considerable.

The country has also been divided up into districts, and the load centre of each considered separately with relation to possible sources of power, and the scheme of supply shown on the drawing E 116 is submitted as best suiting all the circumstances.

Estimate of Amount of Power to be provided.

In considering the design of a power-supply system it is first of all necessary to determine the total amount of power that will be required. This, of course, bears some relation to the population that will be served when the power-supply is available, and can be estimated in that way. The Lake Coleridge plant, with its present capacity of 8,000 h.p., is supplying an area with a population of 100,000—or, roughly, 0·083 h.p. per unit of population. The demand for power is growing rapidly, and if the plant were available to supply it there is no doubt but the horse-power per unit of population would very considerably increase. Owing to the impossibility of securing extra plant, the supply of power for ordinary cooking and heating has had to be severely curtailed, but there is no doubt that the demand for power for these purposes will increase enormously as soon as we are in a position to supply and its value becomes more generally known. During the last financial year applications for 3,500 h.p. for smelting purposes were refused on account of the insufficiency of the plant at Lake Coleridge. Some of the best-supplied of the smaller towns in the North Island, such as Tauranga, New Plymouth, Hawera, Te Aroha, have from 0·14 to 0·09 h.p. per inhabitant of area served. The three latter are working under severe restriction, due to the limitation as regards the source of supply and high prices, and the figures given are in consequence very much less than would result from an unrestricted supply at cheaper prices. The power supplied by the Dunedin Corporation from Waipori is equivalent to about 0·125 h.p. per head of the population served, but the growth of the load has been checked by the impossibility of getting any more power from the present source. There is evidently a demand for more power in Dunedin, as this Department has received application from a Dunedin firm for 1,000 h.p. at Christchurch.

In other countries the use of electric power *per capita* is considerably greater. In a table appearing in the *Electrical World* of the 11th May, 1918, on the use of water-power for electric-power generation the following figures are given: Norway, 0·468 per unit of population; Canada, 0·216 per unit of population; United States, 0·071 per unit of population. These refer to electricity generated by water-power alone; but, particularly in the United States, there is considerably more generated by steam than by water-power. The proportion has been stated as four to one in favour of steam, so that the consumption per head in the United States would be nearer 0·35. In Canada also the consumption per unit of population would be increased if the steam-generating plants were included.

In California, which is one of the States using water-power to a large extent, the Pacific Gas and Electric Company has a plant capacity of 270,643 h.p., equivalent to 0·235 h.p. per inhabitant in the area served by it—about 35,000 square miles. When we consider that there are seven other companies with an additional aggregate plant of 266,500 h.p. operating in almost the same area, and all interconnected, the peak load of the combined systems is about 0·46 h.p. *per capita*.

The Ontario Power Commission supplies power to an area of about 51,000 square miles in Canada, and, although as yet large portions of this area are not reticulated, they have a peak load on their system of 157,048 h.p., equivalent to about 0·136 h.p. per inhabitant. These figures are the more remarkable when we consider that the average price charged in California and Ontario is more than is the case in the Government undertaking at Lake Coleridge.

The statistics kept by the Inspection of Machinery Department show that, excluding the railways, there are 68,716 h.p. in boilers and 78,513 h.p. in machinery other than that driven by steam in use in the North Island for power purposes. Careful records have been taken over a considerable portion of the Wellington district, and from records of the fuel-consumption, &c., a relation between machinery rating and continuous power-output has been ascertained. Applying this relation to the recorded power above indicates that if the existing machinery were connected into a general system it could all be supplied from a common source of 68,100 h.p. capacity, after allowing for losses in transmission, transformation, and distribution.

The scheme outlined below for the supply of the North Island, 44,000 square miles in area, provides for a maximum demand of 0·2 h.p. per inhabitant on the present population. During the period of construction, however, the population will in all probability increase by at least 2½ per cent. per annum, or 25 per cent. in ten years, which would be about the time necessary to completely carry out the proposals suggested. The electrification of the railways as the present lines become taxed to the limit of steam locomotives, and the development of special metallurgical and chemical industries when cheap power is generally available, may increase this load as the scheme develops. The development in Tasmania is very interesting in showing the way the provision of power brings its load. The Great Lake scheme there was started with a plant capacity of 10,000 h.p., and commenced supply in 1916, but by the end of the same year the Tasmanian Government had entered into contracts for the supply of 42,000 h.p., and had under consideration other contracts for a further 50,000 h.p., nearly all for special metallurgical processes which were made possible by the creation of this cheap power-supply. The scheme of generation and transmission herein described does not provide for such large special metallurgical processes as are referred to above, but is confined to providing for the ordinary lighting, heating, and industrial load, together with limited amounts for railway electrification, electro-chemical and electro-metallurgical industries. Each of the two main generating sources, however, has a considerable capacity in excess of what it is proposed to develop, and this can be cheaply drawn upon to meet further special demands as they may arise. The system can also be further extended by developing other sources, such as Aratiatia Rapids and the Kaituna River, if necessity arises. The possibility of having considerably increased loads in certain localities has been carefully considered in laying out the main system of transmission. The scheme submitted herewith has been designed and estimated on the basis of being able to supply 0·2 h.p. per unit to a present-day population of 650,000, or 0·16 h.p. to the prospective population ten years hence. The maximum demand on the system would be 130,000 h.p., requiring a plant capacity of 160,000 h.p. in the generating-stations.

Outline of Scheme of Generation and Distribution.

The three main generating-stations—Mangahao, Lake Waikaremoana, and Arapuni Gorge—are shown by heavy hollow squares, and it will be noted that the Mangahao power-station is almost ideally situated for the supply of the Wellington district, as it is within a few miles of the centre of gravity of the load; so also Waikaremoana is very favourably situated for the supply of the East Coast district. Arapuni, or alternately Aratiatia, is rather far south for the most efficient supply of the Auckland districts, but when we consider that Mangahao is unfortunately rather small for the ultimate requirements of Wellington and Taranaki, which will later have to augment their supply from sources farther north, these Waikato stations are particularly well situated.

To make the arrangement of generating plant ideal we would need to have a source of 50,000 h.p. in place of the present limited one of 24,000 at Mangahao, a cheap source of about 20,000 h.p. capacity in the Taranaki district, and another of 10,000 h.p. in the Whangarei district. A search for a suitable and economical source in the Taranaki district of the desired size has proved fruitless. Smaller developments are possible, and at comparatively great expense for the limited amount of power obtainable, and it is found that the Taranaki district can be more economically and better served by transmission from Arapuni and Mangahao.

The main high-tension lines from these main sources of power are shown on the map, and will be seen to follow the most practicable route to serve the load centres, while at the same time they have been laid out with due consideration to the locations in which development is most likely to extend. From the substations shown other lines at lower pressure will radiate out to other substations, ensuring a supply to the whole of the Island. It is proposed that the Department should sell power wholesale to local bodies, who will erect all distribution-lines and operate the retail business within an area of supply surrounding each of the main Government substations.

Acquisition of Waihi Company's Plant.

The need for having an immediate market available for the power to be generated in these generating-stations is particularly marked in the case of the Waikato schemes, whether Arapuni or Aratiatia is developed. Either of these schemes, which have very large ultimate capacity, and which will later become the main source of supply to the Island, involves heavy expenditure in the earlier stages and will take some time to construct. The acquisition of the Waihi Company's plant at Horahora suggests a possibility of obviating this difficulty to some extent. At present this plant is only working to half its capacity, and, the Waihi Company's main interest being gold-mining, no great efforts are made to develop the power business, and so dispose of this surplus power. It is probable that if this plant were taken over by the Department and lines built into Hamilton the balance of power would soon be absorbed there and in the mining districts on the company's existing line. The license issued to the company gives the Government the right to take over these works at any time at valuation. Up to the present the station has been working to only about half its full rated capacity, and further expenditure on headworks would be necessary in order to secure the full rated output of the 6,000 kilowatts now installed with the freedom of interruption which is essential in an ordinary commercial undertaking. It is possible, as shown in interim report of 1916, to augment the supply at Horahora by a development on the Pokaiwhenua River giving 16,000 h.p. in all, but is not recommended. The amount of power to be so obtained would be so small that after supplying the needs of the balance of the mining districts near the Waihi Company's existing lines, and running lines to Hamilton, Cambridge, and local markets, there would only be a limited amount—about 7,000 h.p.—left to supply Auckland. This amount is not nearly sufficient for the present requirements of Auckland, and would only emphasize the need of the larger development.

Mangahao Development.

For the supply to the southern districts the Mangahao River has been selected as the best available source of power. The power is obtained by diverting the waters of the Mangahao by a tunnel, one mile long, from a dam on the river through the hills, first into a large regulating and storage reservoir formed by damming the Tokomaru Creek near the old sawmill, and then from this reservoir through a second tunnel, 1 mile 26 chains long, out on to the hills at the back of Shannon. From the end of this second tunnel steel pipes, 56 chains long, will carry the water to the power-house at the junction of the Mangaore and Mangatangi Creeks, about three miles from Shannon, and give a fall of about 900 ft. The flow in the Mangahao River is very variable, and provision has had to be made for storing water to carry over the periods of low flow which occur periodically The main storage will be in a dam on the Tokomaru near the sawmill, which will be directly connected through the tunnel with the other main dam on the Mangahao. Further up the Mangahao will be a second dam not directly connected to the tunnel, but which will also store a large quantity of water, and which will, in addition, stop any shingle which is being carried down the river. When working on such a high head storage-capacity is of very great value, and the extent to which this value is to be depreciated by moving shingle filling up the reservoirs has been very carefully considered. The greater portion of the drainage-area of the Mangahao above the proposed intake is in standing bush, mainly forest reserve, which protects the slopes from detrition; and, although the river is subject to great fluctuations in flow, our observations show that it carries a comparatively small amount of debris. The difference between the stream and some of the other Wairarapa rivers, particularly the Mangatainoka, which flows in the next valley to the eastward, is very marked It will be noticed at once that where these two rivers emerge from the hills on the Wairarapa side the Mangahao runs in a deep valley, only changing its course occasionally as it erodes away one or other of the banks, while the Mangatainoka runs on a level almost with the surrounding country, and is constantly changing its course in floods. The difference between the two rivers is due in the main to the fact that the Mangatainoka brings down from the hills more shingle than it can transport across the flatter grade into the Manawatu, while the Mangahao brings down scarcely enough to keep pace with the erosion from its lower reaches, and so has no tendency to build up its bed. It is to be expected, however, that there will be some filling-up of the upper reservoir, but this will keep the main basin lower down on the Mangahao clear for a considerable number of years, whilst the reservoir in the Tokomaru, not being in the main river, will be clear at all times. By the time any filling-up of reservoirs will have materially depreciated the storage value the Mangahao scheme will have become linked up with the large schemes to the north, so that a small reduction in output on that account will not be of serious moment. It is also quite possible to build smaller dams as required higher up the river to prevent shingle reaching even the upper dam as now designed.

Very careful observations of the river during the dry summers in 1916 and 1917 suggest 24,000 h.p. as being the maximum plant capacity to install on this scheme, and during very dry summers one of the units, 6,000 h.p., would need to be a spare. The complete installation for delivery on to the main transmission-lines is estimated to cost £438,654. This amount, which is equivalent to £18·3 per horse-power of plant capacity, though not quite so cheap as for some of the larger developments at Waikaremoana and on the Waikato in generating-cost, is quite a reasonable figure for a development of this size; and when, in particular, we consider that it is almost at the centre of gravity of a load which will in a very short time absorb the whole of the power available, the development becomes a particularly good one.

Compared with Coleridge, the capital cost per horse-power to deliver on to the transmission-line, if the complete development is put in, is less than at Coleridge at its present stage, though not quite so cheap as it will be in its ultimate stages. The running-cost per horse-power on account of the larger development will also be cheaper at Mangahao, while the average distance over which the power has to be transmitted is also less, and, though the cost of transmission per mile will be somewhat greater, there is no doubt but that at rates comparable with Coleridge the scheme would be paying all charges in a very short time.

Waikaremoana Development.

For the East Coast district Lake Waikaremoana is undoubtedly the most suitable source to develop, and from the hydraulic point of view is an exceptionally good development. In normal seasons the greater portion of the water of the lake leaks out through numerous underground channels, which unite some distance below the lake to form the Waikaretaheke River. During most of the past year the lake has also been overflowing directly into the river-channel, but this only occurs during very wet seasons. The lowest level of which we have record was in 1915, when the level was down 14 ft. below the overflow mark. With the water at this low level the flow in the river was considerably reduced, and it is calculated that a minimum flow of not more than 420 cubic feet per second can be relied on. The most suitable position for a power-house is on what is known as the Whakamarino Flat, above the junction of the Kahutangaroa and Waikaretaheke. For the first stage of development it is proposed to divert the Waikaretaheke through a short cutting into a small lake called Kaitawa, and from there pipe it to the power-house, 670 ft. below. This small lake has very little storage value, however, so that the amount of power to be obtained from here is limited to about 29,000 h.p. To carry out the scheme outlined herein more than that amount of power is required to be drawn from Waikaremoana, so that provision has been made for controlling the flow from the lake to provide for the varying demand during the day. Still more power can be obtained later by extending the pipes from Kaitawa to connect through the diversion tunnel directly to the lake, and by this means, and by sealing as far as possible the leaks as the water lowers, the power may ultimately be increased to provide a plant capacity of 136,000 h.p. This stage is not, however, required for the scheme outlined herein, where the power required from this source is estimated at a plant capacity of 40,000 h.p. The estimated cost of works necessary to deliver power on to the main transmission-line is £544,369, or £13·61 per horse-power. This unit-cost is somewhat higher than might otherwise be the case, owing to having to make provision for ultimately still larger developments. It is estimated that in the ultimate economical development to the full plant capacity of 136,000 h.p. this unit-cost would be reduced to about £9·4 per horse-power, or a total of £1,272,305.

The worst feature of the Waikaremoana scheme is the distance that has to be traversed through difficult country before getting any load. On the basis of this report—viz., $\frac{1}{5}$ h.p. per inhabitant of present population—there is only a load of 9,191 h.p. that is nearer to Waikaremoana than to either of the other schemes, whilst on the same basis there is a prospective load on Mangahao station of

50,139 h.p. The latter, however, has not a capacity sufficient to supply all this, so that Waikaremoana and Arapuni have to be increased to each carry a portion of the load to the north-east and north-west of Palmerston North. To provide for all contingencies of the scheme it is proposed to make the Waikaremoana development 40,000 h.p., as above.

Waikato Development.

For the Auckland and Main Trunk district supply, and for the bulk of the Taranaki supply, two alternative sources have been selected—namely, the Arapuni Gorge and the Aratiatia Rapids, on the Waikato River. Of these two the Arapuni is the better one, provided our investigations prove the construction of the big dam required to be practicable. It also has the advantage that it is forty-five miles nearer the main market in Auckland, whilst at the same time it is not much farther from the other market in Taranaki. The transmission-line south to Taranaki and the Main Trunk districts does not have to cross the same amount of undeveloped country as from Aratiatia, but will everywhere traverse country that is in process of development along the railway routes. It is to be expected that the loads along the routes of these transmission-lines will develop rapidly as the heavy sections of railway thereon require electrification, and the settlement increases with the improved conditions. The scheme of development proposed is to build a dam in the gorge of the river, raising the water-level about 140 ft., and diverting the river into an old parallel channel at a higher level. Some 60 chains from the dam this old channel approaches within 8 chains of the existing channel, and at an elevation of 165 ft. above it. Here a low weir will be built across the channel, and the water required for power will be taken through pipe tunnels to a power-house on the present river-bank. From observations made during the low-water flows in 1915 it is estimated that we could ultimately install a plant capacity of 162,000 h.p. in this station. To fill its function in the universal scheme outlined in this report a plant capacity of 96,000 h.p. is required. At this stage the development becomes an exceptionally economical one, and the cost to supply on to the main transmission-lines as in the other cases is estimated at £1,078,700, or £10·78 per horse-power. If the scheme were ultimately extended to its limit it is likely that the whole plant capacity of 162,000 h.p. might be installed for £1,426,707, or £8·78 per horse-power. Partial developments of this source would be relatively more expensive owing to the cost of the large dam having to be incurred from the inception, but it is estimated that even a partial development of 37,500 h.p. can be put in for £20 per horse-power.

The Aratiatia Rapids also afford a very good source of power, and up to a limit of 66,000 h.p. can be developed in successive stages without unduly loading the earlier stages of development. The limit of 66,000 h.p., however, is not sufficient to fit in with the scheme of distribution herein proposed, and another scheme of development has been adopted. This necessitates building a dam at the head of the rapids which will back the water right into Lake Taupo, drowning out the Huka Falls. With this scheme a fall of 175 ft. becomes available, and with the regulation afforded by the storage in Lake Taupo the plant capacity can be increased to 135,000 h.p. The development will be a fairly economical one at the ultimate stage, though owing to heavy cost of dam it will be somewhat expensive at earlier stages. Unless exploration work proves special difficulties to exist at Arapuni it is unlikely that Aratiatia will prove a better source for generation.

Primary Transmission System.

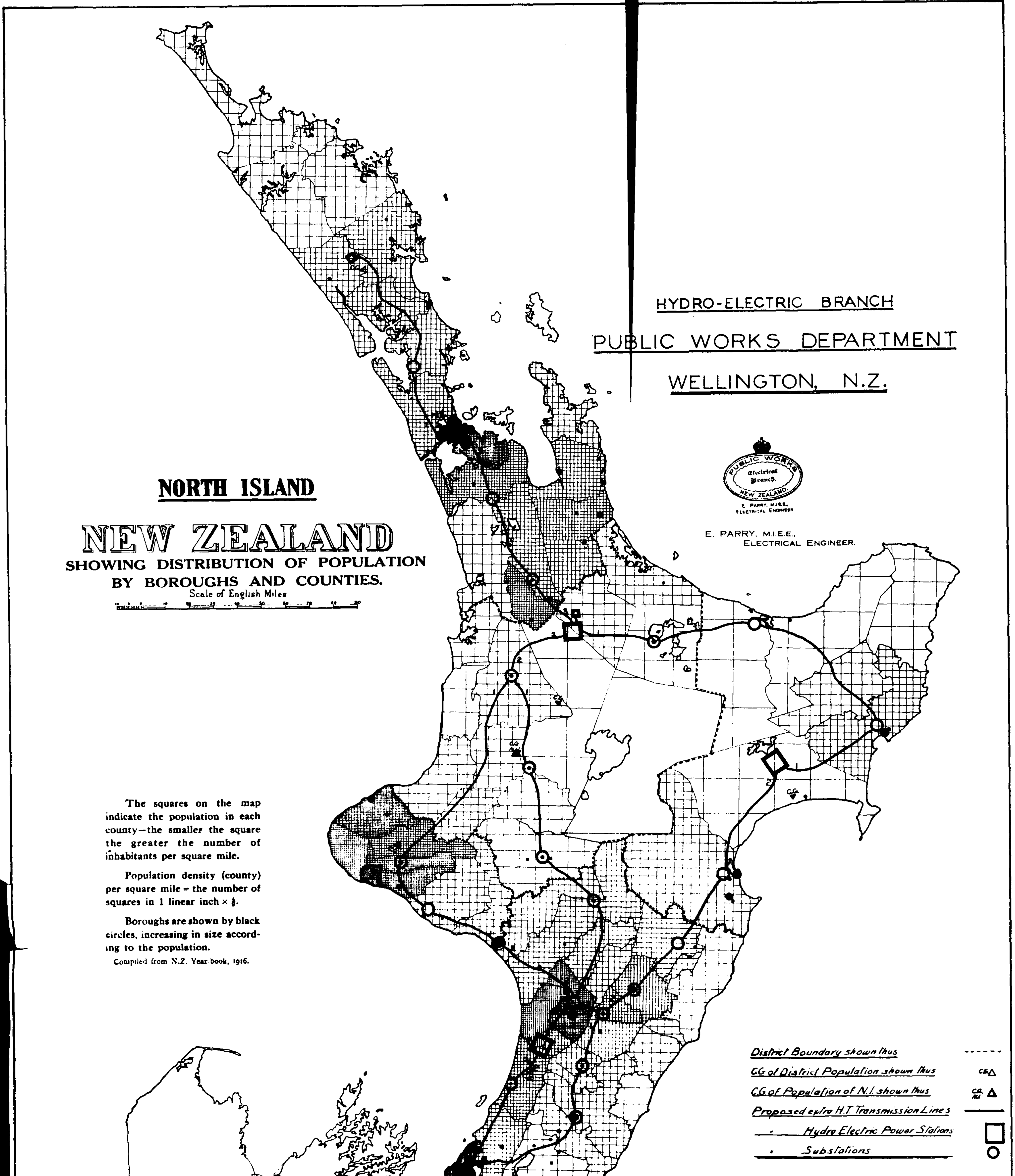
The main transmission-lines are shown on drawing E 116, and will be of the suspension type, carried for the main on ironbark poles, though steel towers will have to be adopted in some cases where special construction is necessary. It will be seen that the various lines have been duplicated and interconnected in such a way that practically every substation is supplied with alternative supply in case of one line breaking down. The lines have been laid out to serve existing markets in the most economical way, whilst as far as possible at the same time the routes best calculated to serve prospective railway and special development loads have been adopted. The scheme provides for a total length of 1,112 miles of main transmission shown on drawing, also for 309 miles of branch mains at lower voltage to supply disconnected main substations.

The configuration of the country is not so suitable for transmission as it is across the Canterbury Plains, where the lines can practically everywhere follow roads. A considerable length of the main lines in the North Island will have to go across country, and provision has had to be made for the extra difficulty of patrol under these conditions. A substantial type of construction has been decided upon, and depots and linemen's quarters at frequent intervals have been allowed for.

The total cost of the main transmission system is estimated at £1,795,240.

Primary Substations.

The main substations connected to the main line will transform down the power to 11,000 volts for distribution to the local substations and surrounding districts. At these stations it will also be possible to cut out sections of line which may develop a fault, and transfer the load to other circuits leading in the same direction, thus adding greatly to the flexibility of the system. Most of the stations will have alternative supplies from either direction to give extra security in case of temporary breakdown of supply on any one circuit. They have been arranged to give supply to the various local authorities and power-users with the least expenditure in the secondary distribution system. The complete main substation equipment is estimated to cost £838,808.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Electrical Branch
NEW ZEALAND
E. PARRY, M.I.E.E.
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E. PARRY, M.I.E.E.,
ELECTRICAL ENGINEER.
NORTH ISLAND
NEW ZEALAND
SHOWING DISTRIBUTION OF POPULATION
BY BOROUGHS AND COUNTIES.
Scale of English Miles
The squares on the map indicate the population in each county—the smaller the square the greater the number of inhabitants per square mile.
Population density (county) per square mile = the number of squares in 1 linear inch × ⅛.
Boroughs are shown by black circles, increasing in size according to the population.
Compiled from N.Z. Year-book, 1916.
District Boundary shown thus
C.G. of District Population shown thus
C.G. of Population of N.I. shown thus
Proposed extra H.T. Transmission Lines
Hydro Electric Power Stations
Substations
C.G.

Secondary Transmission or Distribution System and Substations.

From the main substation lines, mostly at 11,000 volts, will radiate out to smaller low-tension substations and pole transformer substations supplying all the local authorities and large power-users. In a few districts where there are isolated loads of some size at considerable distance from the main substations it will be necessary to run out distribution-lines at 22,000 volts, which can also be tapped along the route in much the same way as the 11,000-volt circuits. These lines will supply low-tension substations from which the local authorities' power reticulation will begin. In other districts where there is a number of fairly large individual power-users close together, lines at lower voltage (3,300 volts) will be run, supplying such larger power-users direct at this voltage. This work will be continually growing, but to make available the load of 130,000 h.p. assumed as the basis of this report it is estimated to cost £13·04 per horse-power of plant capacity, or a total of £2,086,000.

From this point the balance of low-tension reticulation should be carried out by the local bodies, or whatever body obtains the license to supply certain areas, and the expense of such retail business should be controlled directly by the licensees, except in so far as the Department may, as mentioned later, advance sums on short-period loans to assist smaller licensees in putting in the reticulation within their areas, or to assist manufacturers in the installation of their electrical plant. It is proposed to make provision for having a maximum of £100,000 available at any one time for this purpose.

Assistance to Local Bodies.

To assist local bodies in reticulating their supply area, and so help to build up the load on the power-supply system and make it the more quickly come to the profit-earning stage, it is suggested that a fund should be provided for issue on short-dated loans to local authorities, or alternately to bear the cost of the Department carrying out reticulation work which will be taken over by local authorities as soon as it has been put into operation.

Capital Expenditure.

The complete estimate to provide for the general scheme of electricity-supply outlined herein then becomes—

—				Amount.	Per Horse-power.
				£	£
Generating-stations (total plant capacity 160,000 h.p.)—	H.P.	Cost.	Per H.P.		
Mangahao	24,000	£438,654	18·30		
Waikaremoana	40,000	544,369	13·16		
Arapuni	96,000	1,078,700	10·80		
				2,061,723	12·88
Main transmission-lines shown on drawing E 116				1,553,880	
Extra branch transmission-lines at lower voltage to main substations not on main lines				241,360	11·22
Main substations				838,808	5·24
Distribution-lines and secondary substations				2,086,000	13·04
				6,781,771	42·38
Interest during construction				271,271	1·69
Assistance to local authorities and power-users				100,000	0·62
Working capital				150,000	0·94
Total				7,303,042	45·63

In the event of taking over the Waihi Company's Horahora works a further sum dependent on the terms arranged with that company would have to be added.

Throughout this report estimates have been based on a rate not exceeding 12 per cent. above pre-war prices. With the present unsettled condition of markets and supplies it is impossible to estimate exactly on works destined to be completed some time ahead, but even if the present high prices remain after the war the balance will still be in favour of such a scheme of development, for although the cost may be greater the cost of all competing powers will also be greater in much the same proportion, and the revenue obtained will be increased in the same proportion.

It will probably take ten years to carry out all the works included in the estimate. The initial expenditure on headworks would be heavy, but, on the other hand, the plant would only be installed as required to meet the growth of the load. The average rate of expenditure on the above assumption would be about £730,000 per annum.

Financial Result.

It may readily be inferred that, inasmuch as the estimated capital expenditure per horse-power does not exceed the expenditure per horse-power on the Lake Coleridge undertaking, the financial result will be satisfactory. The capital charges for interest, depreciation, and sinking fund at 7½ per cent. will amount to £547,728 per annum. The working-expenses should not exceed £220,000 per annum, making a total annual expenditure of £767,728, requiring an average return of £5·9 per horse-power per annum of maximum load.

The last year's return on the Lake Coleridge expenditure amounted to £5 per horse-power per annum, but this return is influenced adversely by the predominance of the concentrated city load over the more diversified general supply. It is anticipated that in the larger scheme, with a bigger range of distribution and a greater variety in the use of power, and the consequently greater diversity of demand in the system, a return of at least £6 per horse-power can be easily obtained at the same rates as those prevailing in the Christchurch district.

General Remarks upon the Estimates.

Referring to the estimated capital expenditure of £45·63 per horse-power of plant, this rate is somewhat less than the present inclusive expenditure upon the Lake Coleridge undertaking, which is about £50 per horse-power, and as the success of the latter is already assured there is every reason to believe that the larger development will also prove to be a financial success. The significance of the figure may readily be appreciated by comparing it with the cost of a steam plant. The figure mentioned is not at all an uncommon one when all expenditure incidental to the installation of the steam plant is included.

The significance of the proposed expenditure may also be appreciated in another way. It would require at least 1,000,000 tons of coal per annum to do the work of the proposed hydro-electric plant if burnt under existing conditions. Coal would therefore be conserved to that extent, and if its value on the average be assessed at £1 per ton the sum of £1,000,000 per annum if invested at 2¾ per cent. would amount in seven years to £7,600,000, a sum which is slightly in excess of the capital required.

Further, the total capital charges, including interest, sinking fund, and depreciation, of 7½ per cent., amount to seven-eighths of a penny in the pound on the present unimproved value of land in the North Island. We know, however, by experience of the Lake Coleridge undertaking that even at very low rates for power, which compare favourably with rates charged in any part of the world, sufficient revenue is obtained at an early stage of development to meet all capital charges as well as working-expenses, whilst at the same time values are enhanced, production increased, and expenses of production diminished.

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Chief Electrical Engineer.

Wellington, 26th October, 1918.

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