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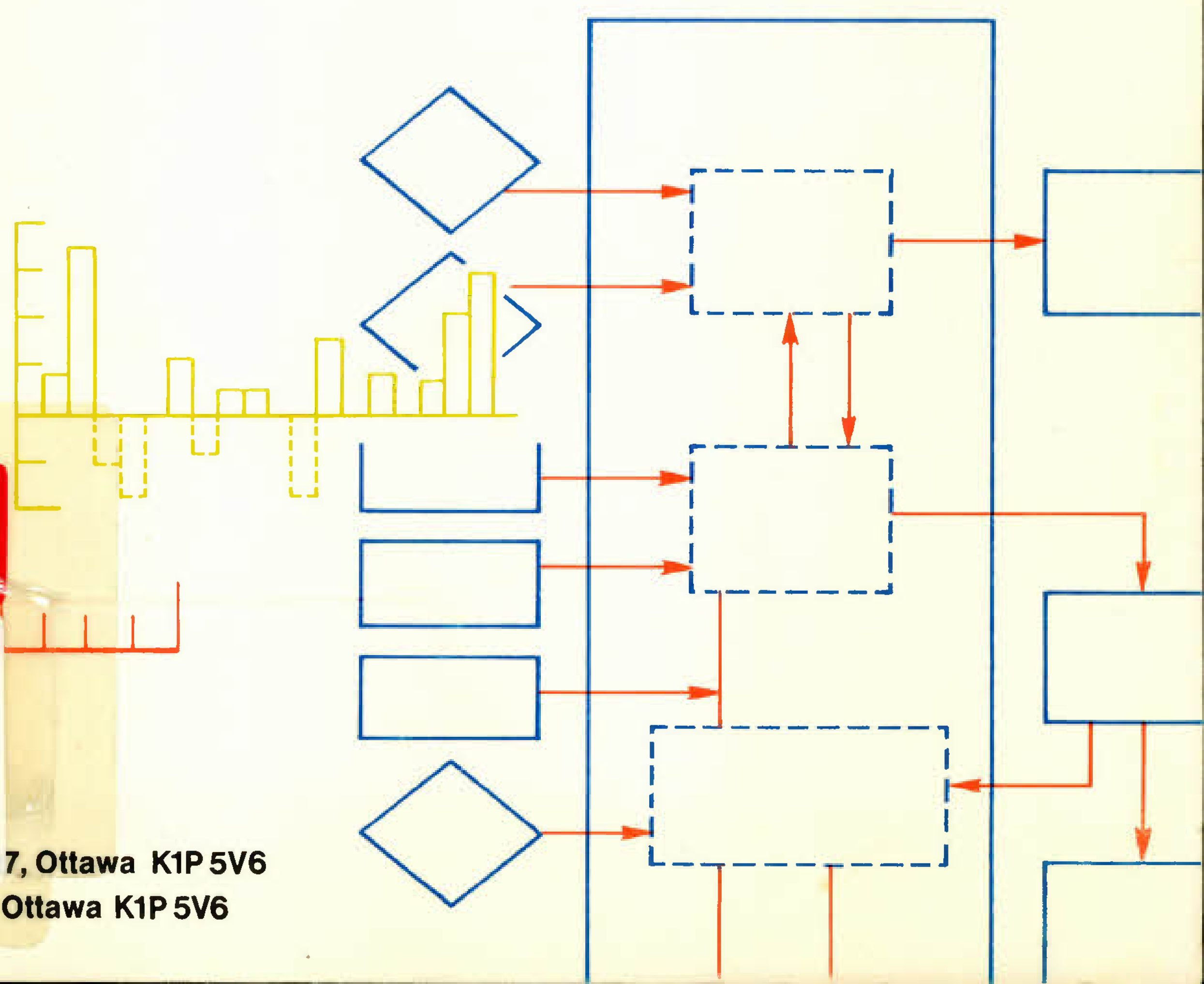

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DISCUSSION PAPER NO. 20

One More River: An Essay on the History of Hydro-Electric Construction

by John T. Saywell

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SUMMARY

One More River attempts to trace the historical growth of the hydro-electric generating industry in Canada. The importance of the industry can hardly be denied. It produces about 26 per cent of the energy consumed in Canada, and has fixed assets of roughly $25 billion. The availability of hydro has helped determine the extent and the location of both resource and secondary industries throughout the country.

The modern industry began with the exploitation of the Niagara and the St. Maurice rivers in the first decade of the century, and has grown regardless of war or depression. However, investment only reached $1 billion in 1929 and $2 billion in 1945. Since then expansion has been staggering: production has increased from 10 million kilowatts in 1950 to 18.7 mkw in 1960 and 35 mkw in 1974, while the value of fixed assets rose from $2 billion in 1945 to $25 billion in the public and private sector to-day.

The construction of this hydro capacity has continually challenged the Canadian construction industry. Each river has posed its unique engineering construction problems, and increasingly the scale of the projects defies the imagination. Scientific and technological advances have been critical to the industry, whether the necessary breakthrough was higher capacity transmission lines, heavier equipment, new systems for transporting materials nad machinery, or the jumbo rock-drillers at Churchill Falls.

With few exceptions, however, the new science and technology have been imported from either the United States or Europe, not only in the past butto-day. Canadian engineering firms have gradually assumed the dominant role in hydro design, increasing their responsibility for major hydro dams from approximately 48 per cent before 1945 to 86 per cent since the end of the war. The same nationalization of the industry holds true for actual construction. Before 1945 Canadian firms built about 60 per cent of the major dams, and since 1945 they have built 94 per cent. The process of nationalization has taken a different form, however, for 28 per cent of post-war construction has been by the subsidiaries of American construction giants. Indeed, one of the most striking features of post-war heavy construction has been the critical role played by American subsidiaries in the largest Canadian projects.

The contemporary view of an industry both Canadian-owned and publicly developed is an historical myth. Initially, Ontario Hydro was the only major public producer, and not until the takeovers in Quebec and British Columbia in the early 1960s did the balance swing decisively to the public side. Moreover, production was largely American initiated and financed. In Quebec, for example, 76 per cent of the power generated in 1929 was by American-owned firms and, despite the expansion of Hydro-Quebec after 1944, over 60 per cent remained so in 1962. Much of the private power developed in Ontario was by Americans,and in 1968 over 66 per cent remained so. And in British Columbia while COMINCO exploited the Kootenay, it was the British-owned B.C. Electric that provided the power needs of Vancouver and the southern mainland until its takeover by Canadians in 1928. The Sagenuay and St. Maurice, the Churchill and the Nechako were developed by foreign enterprise and capital. The beginnings on the Niagara, the Manicouagan, and may other smaller rivers were initiated by Americans.

In short, the construction of Canada's hydro-electric capacity is, like the construction of so much else in the country, a history of a very gradual coming of age not only of the construction industry but also of the Canadian industry that it served.

ONE MORE RIVER

The economist sees hydro-electricity as a factor of production or an item in the balance of payments, the political scientist as confirmation of the benefits of public ownership, and the historian as a stimulant to economic growth or the emergence of new frontiers. The engineer ponders forebays and tailraces, penstocks and surge chambers, the dangers of frazil ice on the intake structure or the optimum height of 735 kv transmission lines. At annual association meetings the big project contractors talk of rivers - the Saguenay and St. Lawrence, the Niagara and the Nechako, the Churchill and the Columbia, the Manicouagan and the St. Maurice. Some day an historian will write - 30 - to the Canadian hydro-electric story, as Turner did to the American free land frontier eighty years ago, for the exploitable rivers are limited. Today, however, scientific and technological advances still bring distant rivers closer and make possible, impossible construction ventures.

PREFACE

One More River is the first of a series of essays on the history of construction in Canada, written as background studies for the Economic Council's report Toward More Stable Growth in Construction. Ultimately the essays may be worked into a monograph, but they are presented as discussion papers to benefit from informed criticism while research and writing continue on the rest of the study. I have taken a topical, rather than a thematic or chronological, approach to the history of construction, and other discussion papers will deal with the history of housing, transportation, pulp and paper, resource towns, the construction labour force, and the organization of the industry. Each essay is more or less self-contained, an organizational reflection of my conclusion that there is really no such animal as the construction industry. There is hydro construction, railway construction, and housing construction; but there is no comparability between the decisions leading to house building and the expansion of pulp and paper capacity, between iron ore developments that create new towns in Quebec-Labrador and the paving of roads on Vancouver Island. Nor do self-supporting saw-and-hammer builders and big project contractors or major urban developers possess even a common working vocabulary. Some conclusions will emerge from the series of essays and some aspects of each are left for an overall analysis, but for the moment each is published for comment as a self-contained study.

INTRODUCTION

The availability of hydro-electricity has undoubtedly altered the structure and the spatial configuration of economic life in Canada. Hydro contributed 26 per cent of the total energy consumed in 1971.[1/] Fixed assets of hydro-electric utilities were estimated to be $19.7 billion in 1972.[2/] Adding a proportionate amount for industrial plants, which generate 18 per cent of the total power, fixed assets by 1974 were roughly $25 billion. With a 1974 capacity of more than 35,000,000 kilowatts Canada ranks third behind the United States and the U.S.S.R. in total generation, and is second only to Norway in per capita production.

The growth of the industry has been continuous. Installed electric power capacity in 1900 was only 133,000 kilowatts. Capacity reached one million before 1914 and two million in 1922. A high level of new construction continued throughout the 1920s and even into the early '30s as projects underway were completed. Construction levelled off in the late years of the depression, but picked up

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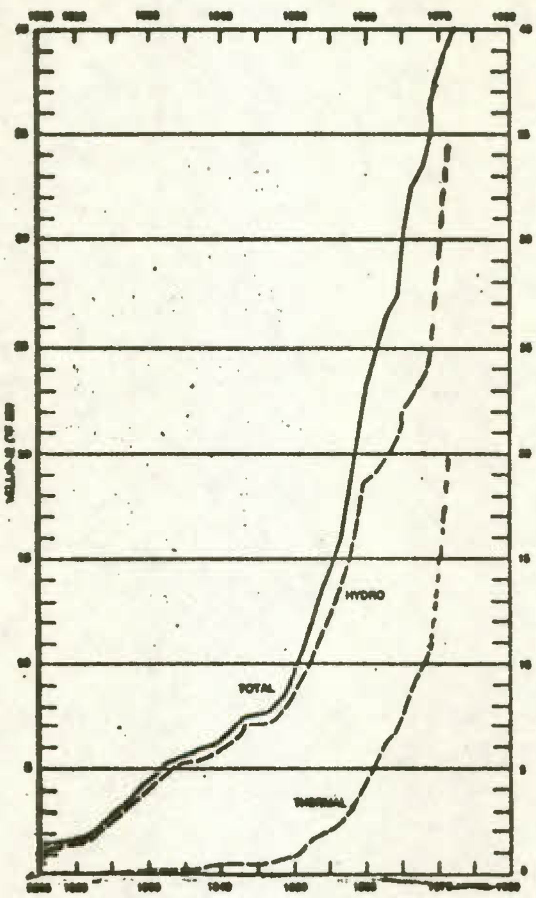
[1/] Canada consumed 310 million barrels of crude oil, excluding transportation. The amount of hydro-electricity consumed was the equivalent of 304 million barrels of crude. Canada Year Book 1973, Table 13.1 (Ottawa 1973), 591.

[2/] The breakdown in 1972 excluding depreciation was $8.1 billion in generating plants, $3.9 billion in transmission lines, $3.7 in distribution systems, and $2.7 billion in construction underway. Cumulative investment in Canadian railways by 1972 was $8.5 billion. Ibid., Table 15.5, 645.



Growth of Electrical
power generating capacity
1915-1973

remarkably as the country mobilized its industrial resources in the early years of the war. The post-war boom did not get underway until the late 1940s, and installed capacity of central electric stations increased from 10 million kilowatts in 1950 to 15.5 million kilowatts in 1955. But the enormous period of expansion began in the late 1950s. Between 1960 and 1974 installed generator capacity leaped from 18.7 to 35 million kilowatts. Capital investment inevitably reflected the same trends. A modest investment of $12 million in 1900 had reached $248.6 million by 1915 and over a billion by 1929.[3] After 1945 capital invested soared from roughly two billion to the estimated $25 billion in fixed assets for utilities and industry in 1974. Despite the enormous growth of the hydro-electric industry in the past fifteen years, however, its relative importance has diminished. At the end of the second world war hydro provided about 98 per cent of

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[3] The capital figures include all electrical power stations.

Canadian electric power, yet it fell to 92 per cent in 1960 and 63 per cent in 1973.

Hydraulic power had been used in Canada since 1607 when settlers built a small mill at the mouth of the Lequille River near Annapolis Royal. By the mid-nineteenth century there were thousands of mills powered by water-power using both overshot and undershot wheels, Water-power was apparently first used in electric form when the Chaudière was tapped to light Young's mill in Ottawa in 1882, and four years later a Quebec cotton mill was illuminated by power drawn from Montmorency Falls. The decade of the 1880s was critical for the scientific breakthroughs and technological improvements that created the modern electrical industry: Gramme's improved generator, Edison's central electric station, the Gaulard-Gibbs-Westinghouse transformer, and the Tesla alternating current motor. Particularly important to the Canadian hydro-electric industry were the advances in transmission capacity. The Americans built the first long-distance line - 26 miles from Niagara Falls to Buffalo - in 1894. Two years later the first long distance line in Canada ran 18 miles from Grand Chute on the Batiscan to Three Rivers, and in 1898 Canada claimed the long distance record with the 35-mile line from De Cew Falls to Hamilton. By 1903 power was delivered more than 80 miles to Toronto from Niagara Falls and almost 90 miles to Montreal from Shawinigan.

Improved transmission techniques continued to be critical. The long distance 50 kv line to Montreal ushered in the modern hydro-electric age, as surely as the first major installations on the St.

Maurice and the Niagara. By 1918 lines of 110,000 kv ran from the St. Maurice, the Niagara, and les cèdres plant on the St. Lawrence.[4/] By 1930 transmission lines from 150 to 300 miles were regularly carrying 220 kv, and engineers foresaw no problems using 300 kv for up to 500 miles.[5/] The breakthrough to 400 was made in Sweden in 1952, however, and its example was followed in Canada. By the early 1960s some of the large new installations were using 500 kv, and Hydro-Québec set a new pace in 1962 when it announced that the power to be generated at the Manicouagan-Outardes complex would be transmitted from collector stations around Baie Comeau to Montreal and Quebec at 735 kv.[6/]

Advances in geological knowledge, the principles and practices of engineering construction, and vastly improved and enlarged construction machinery and equipment were equally essential to the hydroelectric explosion. Not surprisingly, given its geography, Canada has become one of the major big dam builders in the world. Although crest and size of reservoir are equally relevant, height provides one

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[4/] Les cèdres was owned by Montreal Light Heat and Power which sold much of its power to the ALCOA plant at Massena, New York.

[5/] J. C. Smith and C. V. Christie, "Electricity Transmission and Distribution," Canadian Engineer, Volume 59 (August 1930), 206-07.

[6/] Jack Attack, "Brilliant Teamwork by Hydro-Québec Earns Electrical Man of Year Award," Electrical News and Engineering, Volume 75 (June 1966), 66. See also Acres Hydro-Electric Experience, n.d.n.p. [published by the company] for the role of Acres-Canadian Bechtel and Quebec Hydro in research on the use of 735 kv for the Churchill Falls project.

measure of large dam construction. The first dams to pass 100 feet were on the Spanish River near Sudbury in 1909 and Jordan River near Victoria in 1914. One hundred foot dams became increasingly common during the inter-war years but only Abitibi Canyon (290) and Lois (210) at Powell River passed 200. After the war British Columbia led the way with the Kenney dam at Kitimat (340) and the W.A.C. Bennett (600) on the Peace, until 1968 when Hydro-Québec's Daniel Johnson at Manic 5 topped 703. Not to be outdone, however, British Columbia took the lead again in 1973 with the 794-foot Mica Dam on the Columbia, the highest Fill dam outside the Soviet Union.[7/]

[7/] By 1973 there were twenty-nine over 200 feet. On Canadian dams see Registrar of Dams in Canada, World Power Conference International Commission on Large Dams, Canadian National Committee (1970).

ARRIVAL

However, Manicouagan and Mica were far in the future when T, C. Keefer, prominent but aged Canadian engineer, used his 1899 presidential address to the Royal Society to look 'into the future as far as human eye could see.' Keefer foresaw a nation transformed by hydroelectricity: expanded manufacturing and mining, cheaper transportation, extensive use of electrolytic processes, and new manufacturing industries where materials came to power.[8/] When he spoke there were only 57 hydro plants producing 173,000 hp, and five years later only 5 per cent of the 1.5 million horsepower in power-driven equipment was provided by electricity. By the end of the war, however, 270 plants produced 2,378,000 hp. and powered about half of the nation's industrial machinery. Capital investment was estimated at $401.9 million. Most of the plants were small, only 36 generated more than 10,000 hp. and only five more than 100,000 hp. Most of the heads were small, although Ontario Hydro's Eugenia Falls reached 540 feet and the industrial plant at Brittania Beach towered 1820 feet above the powerhouse.[9/]

[8/] T. C. Keefer, "Presidential Address," Royal Society of Canada, Proceedings and Transactions, Second Series, V, 1899.

[9/] The figures on power-driven equipment are from John Davis, Canadian Energy Prospects, a study for the Royal Commission on Economic Prospects (Ottawa 1957), 200. Other statistics from M. C. Urquart and K. A. H. Buckley, Historical Statistics of Canada, (Toronto 1965). Although a review of hydro-electric capacity in 1918 is provided by Leo G. Denis, "Electric Generation and Distribution in Canada," Canada Commission on Conservation, (Ottawa 1918).

The 270 plants in 1918 were scattered throughout the country, and there was no frontier movement from areas of high to low density. Most of the plants were built on local rivers, often by industry, to supply small amounts of power for local commercial and industrial use. Already the development of large scale installations for heavy local and long distance sale had begun, however, and it was these that were to reflect a frontier movement as the country proceeded to harness yet one more river. The first two - both still in the million plus kilowatt club - were the Niagara and the St. Maurice.[10/]

Niagara - the battle of the cliff

Today the fall of water between Lake Erie and Lake Ontario yields over four million kilowatts, almost half of which is generated on the Canadian side. That power has been used since 1757 when Chabert Joncaire, Master of the Portage and Director of the trade with the West, built a small sawmill powered with an overshot waterwheel. Not until 1786 was the Canadian side exploited, however, when John Burch erected a combined saw and grist mill on Dufferin Island. During the 1880s hydro-electric power was generated on the American side, and by 1895-6 two companies were producing power for industrial

[10/] The million kilowatt club includes the Manicouagan, St. Lawrence, Niagara, Ottawa, Churchill and Peace all with a capacity of more than two million kilowatts, and will soon include the Columbia. The Outardes, Betsiamites, Saguenay, Peribonka and St. Maurice have a capacity of more than one million kilowatts.

use. The power sparked an industrial boom in Niagara Falls, New York, and was transmitted the 25 miles to Buffalo.[11/]

The obvious impact of hydro on the economic growth of the American side of the river provoked Canadians to demand that the potential of the Canadian falls be tapped. In 1892 the Canadian Niagara Power Company, a subsidiary of the major developer across the border, had secured a hundred-year monopoly of the Niagara for a rent of $25,000 a year and an agreement to construct a 25,000 horsepower plant and to supply Canada with current "to the extent of any quantity not less than one half the quantity generated."[12/] The Company's inactivity and the public clamour led to the revocation of the monopoly in 1899, and in the following year the Ontario Power

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[11/] The second scheme for utilizing Niagara power on the American side was critical for future developments. In 1886 Thomas Evershed proposed to build a mile long tunnel as a tailrace for 238 mills built around 12 inlet canals. The Niagara Falls Power Company was formed in 1889 and entered into a contract with the Cataract Construction Company to build the tunnel. Debate over the best way to harness the water power led the company to set up and fund the International Niagara Commission composed of five internationally famous experts on electricity and chaired by Lord Kelvin. Their recommendations led to the decision in favour of a central station, rather than plants in individual mills, and the use of alternating electric current. Construction of the tunnel began in October 1890 and the first power was delivered in August 1895, although the two power houses were not finally completed until 1900 and 1904 respectively. The power was transmitted to Buffalo rather than sold to local mills after the initial idea of multiple canals was abandoned.

[12/] Merrill Denison, The People's Power (Toronto 1960), 25. For an excellent account of the Niagara development and the policies of Ontario Hydro see H. V. Nelles, The Politics of Development (Toronto 1974), 223 ff.

Company, also American, secured access to the waterpower. By 1900 both companies were about to begin construction.

The Canadian Niagara Power Company not only shared a general manager and superintendant with the parent company but also used the same plant design. Construction began in 1901 and the shaft giving access to the tunnel excavation was built between May and September. The tunnel itself, 25 feet high and 2,200 feet long, was excavated by the end of 1902 and in 1904 the first 10,250 horsepower turbine was installed under the supervision of H. G. Acres, a Canadian engineer. The plant was connected electrically to the two plants of the parent company and transmission lines ran to Buffalo and Fort Erie. The principal contractors on the project, many of whom remained involved in hydro construction over a long period of time in Canada, were J. Barry on the cofferdam, Dawson and Riley on the wheelpit and canal, W. Grace on the powerhouse, and A. C. Douglass on the tunnel and portal. C. B. Smith was the resident engineer in charge of construction.[13/]

The Ontario Power Company built on the river below the cliff. The water was diverted from the river by a gathering weir near the Dufferin Islands and carried underground through three 6,500-foot pipelines to the top of the cliff and then through penstocks to the powerhouse, which had a head of 180 feet. Work began on July 15, 1902 and the first conduit was in operation on July 1, 1905. The

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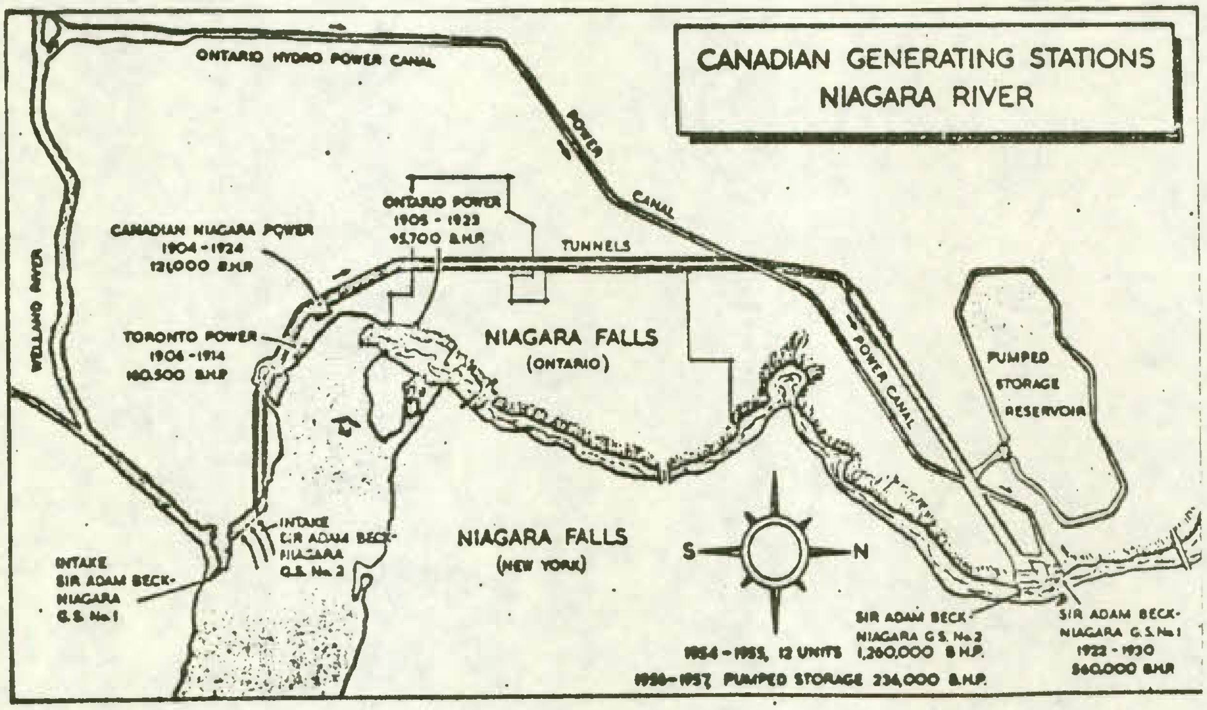
13/ Gordon Kribs "Power Development at Niagara Falls," Historical Notes on Power Development at Niagara Falls. Ontario Hydro Library. These notes provide a good survey of early power development at Niagara.

three pipelines were interesting in terms of the development of construction methods and design. The first was 18 feet in diameter, one of the largest diameter steel conduits of its day; the second, completed in 1910, was one of the largest oblate reinforced concrete pipes in Canada; and the third, built as an emergency measure for World War I, was one of the largest wood stave lines in the country, and was coated in concrete to prevent leakage.[14/]



Source: Ontario Hydro

Before either American company had generated power a group of Canadian financiers also had secured access to the river. Led by William Mackenzie, Henry Pellatt and Frederick Nicholls, the company

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[14/] Richard L. Hearn, "Canadian Hydro Electric Developments on the Niagara River," The Engineering Journal, XXXVII, (August 1954), 933.

was known as the Electrical Development Company, the Toronto and Niagara Power Company, and finally as the Toronto Power Company. The same interests owned the Toronto Electric Light Company and the Toronto Street Railway.

The Toronto plant had much in common with the first, with the turbines located in a wheel pit slot and the tailrace tunnel discharging under the Canadian Falls. As it represented the most frequently used design at Niagara in the early period and was soon to be somewhat obsolete, the construction is interesting. Following the agreement with the Queen Victoria Parks Commission on January 29, 1903 the company immediately let contracts. The first went in March 1903 for the construction of the cofferdam to Barry and McMordie of Niagara Falls, Ontario, a company apparently related to the firm that built the cofferdams for Canadian Niagara two years earlier. Despite their experience the contractors encountered many difficulties, the major one a river that turned out to be twenty-six rather than the expected eight feet deep. (The practice of writing the geological specifications of the site into the contract was not yet necessary.) Not only was the river much deeper and faster than expected, but the bottom was studded with large boulders making the job of sounding in order to get the exact depth of the river at every point and mirror this on the bottom of the cribs very difficult.[15/]

[15/] A complete description of the first, and probably the most difficult year of construction can be found in the Interim Report of the Electrical Development Company of Ontario, Ltd., and Toronto and Niagara Power Company 1903.

On December 12, 1903 F. S. Pearson, the New York consulting engineer, reported that the dam was completed and not leaking badly; "this cofferdam," he added, "represents as great an undertaking in this line of work as has probably ever been designed or constructed." Certainly it was an immense project, and Pearson could be excused for his immodesty. The first timbers were put in place on April 2, 1903, less than a month after the contract was let, and by the end of the year 2,258,568 feet of timber were in place. The timber cribs had been filled with 15,416 cubic yards of rock, and the space between the two rows of cribs was being filled with clay dumped from a tramway along the top of the cribs. The dam backed water far enough to almost flood out the works of the Ontario Power Company still under construction further up the river, and a spur dam had to be built to protect their competitors.

The contract for the tailrace tunnel was let on May 14, 1903 to A. C. Douglass of Niagara Falls, New York, who had also built the tunnel for the Canadian Niagara Company. Douglass was required to build not only 1,935 feet of tunnel, but also a 150.2-foot shaft on the shore and, to give access to the tunnel site, a drift 670.9 feet long, 7 feet high and 14 feet wide, or wide enough for two construction tramway tracks. The excavation of the tunnel had to proceed upstream to avoid drainage problems at the excavation face and with the drift so near the cliff an experimental side drift was planned to test the problems of opening out onto the cliff face behind the falls. It proved to be a difficult task.

By August the crew had completed 101.5 feet of the shaft and excavated 15 feet of the drift, a remarkable rate of speed which, according to the Resident Engineer, Beverly R. Value, had never been equalled. But on October 9 the crews encountered serious water problems in the cross drift about 14 feet from the face of the cliff. A regular shot of powder only opened a fissure in the roof and water from the heavy spray of the falls, which had been forced into the rock through cracks higher up, began to fill the tunnel. Pumps had almost controlled the flow when another rockfall increased the amount of water flowing into the work space. Larger pumps reduced the amount of water enough to prepare one large shot to clear a drain to the cliff face. This explosion merely opened a small hole about a foot from the roof of the tunnel and the water drained to this level.

The Toronto Evening News (November 3) described the next phase in the battle of the cliff:

> Finally a daring scheme was hit upon, and three foremen, John Davis, Michael Abbot and "Shorty" Minor, volunteered for a most dangerous service.
>
> A flat-bottomed boat was procured from the Maid of the Mist Steamboat Company, and taken down the shaft to the end of the flooded tunnel. It rode so high in the water that it would not clear the roof and ballast was put in to make it ride lower. Then into the crazy craft got Davis, Abbott and Minor, with three boxes of dynamite and a lot of copper wire, and, lying on their backs and propelling the boat by pushing with hands and feet against the rugged roof, they started on a hair-raising voyage.
>
> The tunnel was, of course, in total darkness,

save for their feeble torches. Below them was a rickety punt, floating in many feet of black, cold water. A few inches from their upturned faces was the solid rock lying a hundred and fifty feet thick above them, and over that reared the resistless flood of the rapids....at last the venturesome voyageurs arrived at the heading of the tunnel and the hole through the rock which admitted a blast of strangling spray from the thunder of water on the rock outside.

One by one they crawled through the hole and stood, half stunned and borne down by the roar and pressure of imprisoned air, in the most wonderful chamber in the world.

They had no time to look around or analyse their sensations. With careful haste they placed the boxes of dynamite so as to form the most effective blast in the dam of rock which was causing all the trouble. They had to struggle constantly against the blasts of sprayladen air which rushed to and fro behind the falls, and at times were even forced off their feet.

At last the shot was placed, the wires connected, and the men crawled back through the hole and started for the shaft in the boat.

The end of the trip was safely reached, and the electric battery discharged the blast they had set. Again the men entered the boat to go to see the effect, but the boat went down under them, and they were forced to swim for their lives back to the shaft. A raft was built and tried, but it was a failure, and a second voyage through the tunnel was given up.

Later in the day Foreman Davis went behind the falls by way of the new scenic tunnel and made a perilous trip along the chamber to the mouth of the construction tunnel. He found that the blast had dug a big hole in the rock, but done little towards removing the mass that dams the tunnel's mouth. Worst of all, it had enlarged the opening into the tunnel, so that the spray went in faster than ever, but not enough to let one drop of water run out. 16/

16/ As quoted in Interim Report of the Electrical Development Company, 52.

A few days later two of the foremen worked their way around the front of the cliff behind the falls and finally the remaining wall was blown out from the outside.

The contract for the wheelpit was let to M. P. Davis, an Ottawa contractor, and work began on August 10, 1903. Construction proceeded slowly for a railway siding had to be built and, since the main cofferdam had not sufficiently dewatered the site, a special cofferdam had to be added. With all these delays Davis decided to work through the winter and the area was covered with a shed. The wheelpit involved an important design innovation for the turbines were to rest on solid rock rather than artificial structures, thus allowing more pressure with less vibration. Someone obviously violated one of the principles earlier established, for H. L. Cooper, the chief hydraulic engineer, had promised the investors that "one of your principal assurances should be found in the fact the design employed does not invade the field of experiment, but rather follows precedent, with such improvements as are dictated by past failures and partial successes."

By 1907 the three companies had spent almost $15 million.[17/] When completed in 1915 the three plants generated 70 per cent of all the hydro-electricity produced in Ontario. Meanwhile the Ontario

[17/] Canadian Niagara had spent $4.7 million and planned to spend an additional $1.2 million before its 100,000 hp plant was operating at capacity. Ontario had invested $5.1 million and planned to spend $4.7 million to complete its 180,000 hp plant. Toronto Electric had spent $4.5 million of an anticipated $6.1 million on its 125,000 hp station. See Carl A. St. Clair Hall, "Electrical Utilities in Ontario under private ownership," (PhD thesis; University of Toronto), 38.

Hydro Electric Commission had been created. By 1914 the Commission could anticipate a power shortage, a shortage which became more acute with the rapid industrialization sparked by the war. As early as 1914 Sir Adam Beck, Hydro Chairman, had sought government approval for a major construction project on the Niagara Penninsula, and on New Years Day 1917 a plebiscite in the cooperating municipalities authorized Ontario Hydro to become a producer, as well as a distributor, of power.

The way had been paved for Hydro's Queenstown-Chippawa Development by the Canadian American Boundary Waters Treaty of 1909 which allowed the United States and Canada to divert 20,000 and 36,000 cubic feet respectively above the Falls. Without the treaty Beck's plans would have been pointless for the new development involved moving away from the Falls itself to tap the maximum head in the drop between Lake Erie and Lake Ontario. With an intake near the mouth of the Welland Canal and the powerhouse at Queenstown on the Niagara River, well below the Falls, 294 of the total of 326 feet was available.

Apparently the only engineering construction problem of any great importance was the thirteen mile carriage canal. Finally Hydro decided to build an intake structure at the mouth of the Welland River, reverse the flow of the Welland, and use the enlarged river channel for four miles - all for less than $2 million in direct construction costs. The major construction problem remained however - the excavation of an open canal almost nine miles long, 48 feet wide and from 35 to 40 feet, and at one point more than 140 feet below the level of the ground. To this enormous excavation task was added excavation from virtually solid rock for the forebay, the screen-house, the penstocks and tailraces. Excavation totalled 13.3 million cubic yards of earth and 4.7 million cubic yards of rock. The cost of excavation alone by the end of March 1922, when all but the last three penstocks were completed, was $29,700,000 out of a total construction expenditure of about $50 million. Concrete for the canal cost $7 million, and for the total project $10.3 million. Structural steel was less than $750,000, and machinery and equipment $3.2 million.[18]

The young Henry G. Acres, chief hydraulic engineer in charge of design and construction, realized that the critical part of the operations was the cost and speed of the canal and other excavation:

> In conclusion, it might be of interest to make some reference to construction methods and to summarize briefly the reasons which lead to the adoption of the type of construction plant which is now operating on the work.
>
> A careful study of construction methods in connection with the excavation of earth and rock in the canal was necessary by reason of certain existing conditions which would have a vital influence upon excavation cost. These conditions were: first, the availability of cheap electric power for operating construction plant; second, the large quantities of earth and rock to be removed, which made it possible to consider the use of excavating machinery of the heaviest type

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[18] Ontario Hydro-Electric Inquiry Commission [Report] W. D. Gregory, Chairman. Volume 1, Ontario Hydro Archives, Engineering Data, K-82.

and largest capacity obtainable; and third, the unusually good facilities available for the disposal of spoil, within short hauling distance, along the crest of the Niagara escarpment.

Having the above conditions in mind, the Commission's engineers spent several months in collecting and studying data in connection with the type of construction plant required. The operation of electric and steam driven excavating machinery was witnessed and studied in various parts of Canada and the United States, and a large amount of information with reference to output, operating cost, working conditions, etc., was obtained and carefully analyzed.

The most important decision arrived at in connection with the purchase of this plant was that with reference to the use of the largest type of shovel that could be obtained. These shovels are removing the full depth of overburden while working from solid rock against a face averaging 45 feet in height, with a maximum of 80 feet. It was furthermore necessary to use these shovels in the rock cut, where they are lifting and loading into cars 65 to 70 feet above shovel grade. The rock cut, being only 48 feet wide, would not permit the carrying of loading tracks down to a sufficiently low elevation to reach the loading range of an ordinary railroad shovel, and it is certain that excavation by clam or drag-line would have very materially increased the cost and seriously delayed the date of completion of the rock work.

In the earth work it was demonstrated beyond any doubt that on the bulk of the work railroad shovels would have been useless on account of the soft bottom and on some sections of the work it is doubtful if the overburden could have been removed by any possible means other than by these large shovels working from rock.

The economy of this construction plant is rather plainly indicated by the fact that in 1917, when work commenced with railroad type shovels, direct labor cost comprised 29 per cent of the total unit cost of excavation. Today, with labor costing 250 per cent more than in 1917, the labor

> cost per yard of excavation has only increased 4 per cent over the 1917 figure of 29 per cent, This would appear to indicate that the saving of man-power resulting from the use of the large excavating units has practically off-set the 250 per cent increase in labor expenditure. In the month just past (July) 500,000 cubic yards of earth and rock were removed and finally disposed of in 26 working days, with a total working force of 2,000 men, not more than half of whom were engaged in the direct excavating operations. These two facts alone would indicate that the type of construction plant on the Queenston-Chippawa work has fully justified the decision which led to its adoption and that the results being achieved would not otherwise have been possible. 19/

Given the war-time and post-war shortage of labour, as well as the soaring labour costs for a work force that averaged more than 4,000 and reached a peak of 10,000 men, the extensive use of heavy equipment and of labour-saving transportation system was essential. In the end, Hydro, which constructed the canal itself, built a road-rail-water transportation system. Perhaps for the first time in Canadian construction history automobiles and trucks totally replaced horses, and were used for carrying small work gangs, delivering goods, fighting fires, and as ambulances.[20/] A water system of boats and barges was used for construction work in the intake and the Niagara and Welland River. On land a main double-track railway connected to about 90 miles of single and double track

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[19/] H. G. Acres, "The General and Economic Features of the Queenston-Chippawa Development," The Bulletin, VII, No. 8 (October 1920), 310-312.

[20/] Ontario Hydro Research Note 0717 from Gregory Commission, 1.

lines serviced the excavation and concrete gangs, and carried the debris to disposal areas a few miles away on the escarpment. Twenty-six 55-ton electric locomotives were used for the excavation work, while a similar number of smaller steam locomotives handled yard and service duties. Excavation itself was carried out by 14 shovels, both steam and electric, five of which were larger than any used before. The bulk of the work on the canal was excavated by five high-lift electric shovels with a 90-foot boom and 58-foot dipper stick capable of handling an 8-cubic yard dipper which could load the 20 cubic foot cars, 60 feet above, in 90 seconds.[21/]

In January 1922 the first unit was put into operation, and the complete installation, known as Sir Adam Beck No. I, was completed in 1925 at a cost of $76 million. With the Completion of Beck No. I development in the Niagara ended until a new diversion treaty in 1950 permitted both countries to increase their power dramatically. The principle followed for the construction of the Beck No. 2, with a capacity of 1.2 million kilowatts, was much the same as the first. Water was carried from above the falls through a tunnel 5.1/2 miles long and 45 feet in diameter and an open canal to penstocks situated beside those of Beck No. I. Once again excavation was a major cost of construction as the new tunnel and canal needed more than 17 million cubic yards of excavation, 11.4 million of rock and 5.8 million of

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21/ F. A. Gaby, "Queenston-Chippawa Development of the Hydro-Electric Power Commission of Ontario," Ontario Hydro Archives, HB 1924 - 1, (June 1924) earth, the reverse of the earlier ratio. Four times as much concrete, almost 2 million cubic yards, was poured. Beck No. 2 took three and a half years to build; cost almost $350 million, of which an estimated $215 million was for construction; had a maximum number of 3,138 construction workers employed; and paid $57,260,000 in gross wages.[22/]

Today Beck No. I (403,900 KW) No. 2 (1,223,600), a pumping-generating station built in 1957-58 (176,700 KW) and the old plants of the Niagara Power and Toronto Power (186,000 KW) generate almost two million kilowatts or 2.7 million horsepower - as much as was generated hydraulically everywhere in Canada in 1920.

A necessary monopoly - the St. Maurice

The birth of the modern hydro-electric industry in Quebec occurred on a river totally unlike the Niagara. Rising in what is now the Gouin Reservoir, the St. Maurice races 250 miles to the St. Lawrence, strengthened by the flow of the Manouan, the Mattawin, and a dozen smaller rivers. The descent is seldom gradual, and there are seven steep, almost perpendicular, drops of from 100 to 300 feet between the Reservoir and Three Rivers. The large catchment area of 16,500 square miles and the numerous natural heads made the St. Maurice an incredibly

[22/] See R. L. Hearn, "Romance of the Niagara," Ontario Hydro News, XLI, (July-August 1954) 6-14. Figures on construction workers from Documentation Centre, Ontario Hydro.

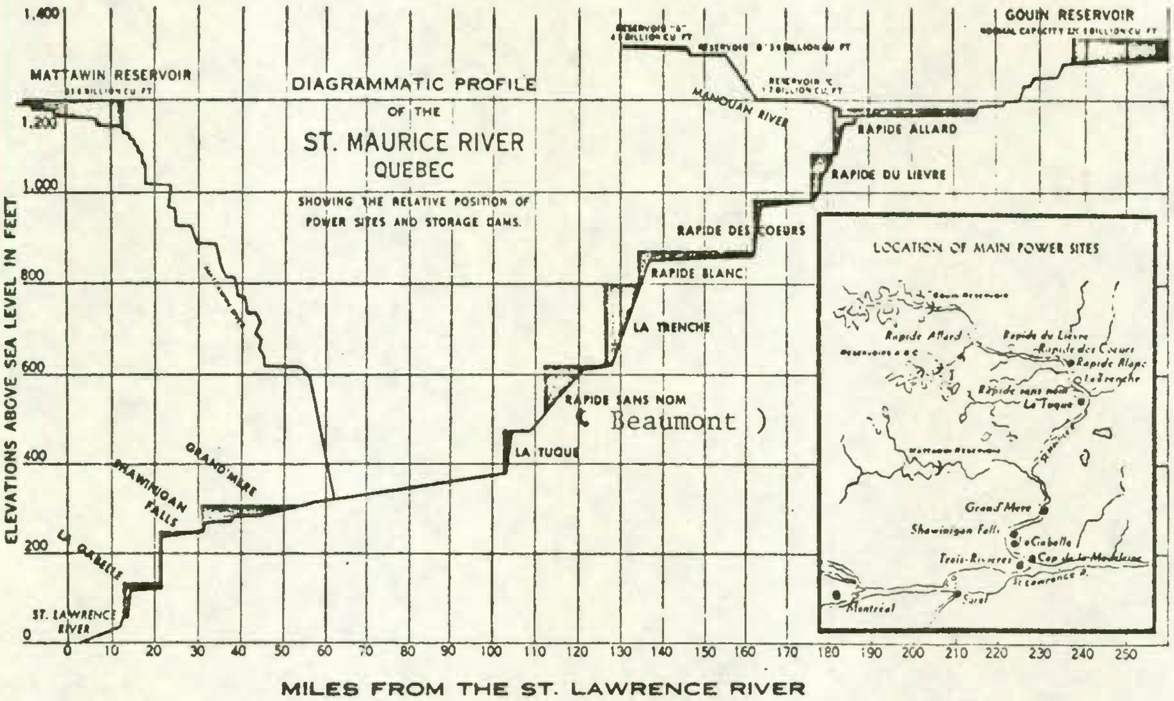

Figure 2. Profile and Plan Views of the Development of the St. Maurice River, Showing both Actual and Proposed Hydroelectric Stations (drawing prepared from materials supplied by The Shawinigan Water & Power Company).

rich hydro-electric site, but geography also demanded that from the drainage basis to the St. Lawrence the river be treated as one.[23/]

The power of the river was first tapped hydraulically at Grand Mère by John Forman of Laurentide, who apparently also believed that he had secured the rights to the falls at Shawinigan. By the mid-nineties local entrepreneurs at Three Rivers were beginning to harness the Batiscan, eighteen miles away, and another group headed by Uldéric Carignan and Navigius Malhiot, with some Montreal backing, attempted to secure concessions on the St. Maurice. The small sum of $10,000

[23/] The profile is from John H. Dales, Hydroelectricity and Industrial Development in Quebec, (Cambridge, Massachusetts 1957) demanded by the provincial government was less a barrier than the legal process necessary to test Forman's claims.

Meanwhile, the provincial election of 1897 returned a new Liberal government which set new conditions. The price for developing the St. Maurice was $50,000 cash, the expenditure of $2 million within 18 months and an equal amount in the following year, the completion of a plant within twenty months, and an annual expenditure thereafter of $200,000 in wages. François-Albert Angers argued that the failure of the Quebec government to support the local capitalists was "le point tournant de notre histoire économique, et qui condamnait d'avance un Forget à la dépossession ultime."[24/] Given the large capital investment and engineering expertise involved, however, John Dales was probably more accurate when he wrote: "The terms were beyond the means of the local entrepreneurs, but the government was not deliberately pricing itself out of the market, for it had already heard that American capitalists were interested in the property. Would Shawinigan Falls have been developed by local enterprise if litigation and an election had not delayed proceedings and allowed time for foreign capital to become interested in the project. Probably not. Successful development of the immense power potential of Shawinigan Falls required monetary and engineering resources on a scale that was almost certainly beyond what the local group could have

[24/] François-Albert Angers, "Naissance de la pensée économique au Canada francaise," Revue d'histoire de l'amérique française, XV, No. 2 (September 1961), 211.

commanded."[25]

The American interest appears to have come from John Joyce, a wealthy Boston brewer who was not only promoting a new fangled razor but had acquired a patent on an electric furnace for the manufacture of calcium carbide. By September 1897 Joyce had acquired the site and in 1898 received a charter from the provincial government. Meanwhile, Joyce had interested J. E. Aldred, vice-president of Puritan Trust in Boston, in the project, and after a visit to the Falls Aldred had become so involved that he left Puritan to devote his full attention to Shawinigan. Aldred and Joyce also associated a number of prominent Canadians with the enterprise: J. N. Greenshields, a Montreal lawyer with close connections with the Laurier government through Israel Tarte; J. L. Forget, prominent Conservative financier and industrialist; Herbert Holt, "engineer and capitalist," as he liked to list himself; and other local political, financial, railway, and industrial figures. While these were men of considerable means and every effort was made to raise money in Montreal, Dales remains

[25] Dales, Hydroelectricity and Industrial Development, 51. Angers on the other hand attacked the provincial government for selecting entrepreneurs who offered better guarantees of success. "Cette réaction, qui est dans la plus pure tradition de l'économie libérale du temps, un économiste pur de l'époque l'aurait sans doute appuyée de toute la force de ses convictions scientifiques. Ce qui a fait défaut à ce moment, en somme crucial de notre histoire économique, ce n'est pas la domination d'un sentiment agriculturiste, ni même l'absence de pensée économique scientifique, c'est l'absence d'une pensée nationale, qui aurait suggéré au gouvernement une politique d'appui et de soutien à des hommes d'affaires canadiens-français." Angers, "Naissance de la pensée économique," 211-12.

skeptical that Shawinigan was Canadian financed.[26]

Construction of the plant began in 1899 with Wallace Johnson of Holyoke, Massachusetts, who had some experience at Niagara, as chief engineer. The contractor was Warren-Burnham Company of New York, which agreed to take payment in stock. A fairly conventional plan of canal, forebay and tailrace was used. To facilitate construction a four mile spur was built to the Great Northern Quebec City-Hawkesbury line. Apparently much of the work was done by local labour, many of them under-employed farmers who, according to Dales "flocked to the new construction projects during the first few months of operation in the spring of 1899."[27] Shawinigan alone employed 1,500 construction workers, many of whom spent the winter of 1899-1900 in tents, while the more fortunate found shelter in the shacks that mushroomed around the site. In addition there were the construction gangs for the Northern Aluminum Company, which signed an agreement to take hydraulic power in 1899, and Belgo-Canadian Pulp which did so in 1900.

Shawinigan laid out an industrial park around the Falls and

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[26] Dales, Hydroelectricity and Industrial Development, 235. Dales repeats a story, which he suggests may be apocryphal, by John E. Aldred: "We raised as much capital as we could in Montreal but we were left with many unsold bonds. I went to London to sound out the English money market. On my arrival I went around to see Lord Strathcona. I told him the reason for my trip and had barely started to explain the possibilities of our scheme for the St. Maurice Valley when he interrupted to say: 'Show me the map. There's the portage at Shawinigan Falls. I made it dozens of times for the Hudson's Bay Company. Here's what I'll do Aldred: I'll take a $1,000 bond for every portage I made at the Falls.' He took $50,000 of the bonds."

[27] Ibid, 55.

created a 500-acre townsite for an industrial city, as Aldred clearly intended to sell hydro-electricity locally. The contracts with the aluminum and pulp and paper companies, however, were for the sale of hydraulic power, and Northern Aluminum built its own electric plant. Apparently more important for hydro-electric development was the anticipated long-distance sale of power. In 1902 a contract was negotiated with the Holt-Forget Montreal Light, Heat and Power, and a year later power was transmitted the 90 miles to Montreal on wooden poles at 50 kv. The success of the venture enabled Shawinigan to round the financial corner with a $1.5 million bond issue sold mainly in New York and Boston in 1903 and a $5 million issue in 1904, handled by Royal Trust but sold to a large extent in the United States and England.[28/] Local markets increased as Shawinigan Carbide emerged in 1904 after involved patent and legal battles and Wabasso Cotton built a factory in 1907. Already Shawinigan was beginning to question the wisdom of selling hydraulic power, although Dales could write in 1957 that the last hydraulic contract was likely to be repurchased "before long."[29/] Shawinigan itself was an industrial city of 7,000 by 1914 and 600 miles of long distance lines carried power to more than forty communities from Quebec to Montreal, and across the river from Three Rivers to the south shore.

But Shawinigan was not alone in attempting to tap the potential of the St. Maurice. In 1913 Laurentide, which had previously used

[28/] Ibid., 54

[29/] Ibid., 57

hydraulic power, began a major expansion of the pulp mill and the construction of a large hydro-electric unit.[30/] George Hardy was hired as the consulting engineer and the Talbott Company of Dayton, Ohio, received the contract for the multi-million dollar project. The power project did not involve a high head (77 feet), but the seasonal variation necessitated the construction of a high capacity spillway to pass the spring floods. An island in the middle of the stream had to be levelled--but not before the contractor was compelled to break up a craggy rock bluff piece by piece and reassemble it near the company office--and the concrete spillway constructed across it.

Over 400,000 cubic yards of rock and earth were excavated, and 175,000 cubic yards of concrete, 1,000 tons of reinforcing steel and 2,000 tons of structural steel were installed. Before the damsite was finished 2,000 carloads of materials were imported. Railway cars and clamshell buckets were used to haul the sand to the site, where a system of cableways carried the concrete from the mixing plants to the dam and powerhouse. Talbott established an efficient system: in a ten-hour shift a 2.4-yard bucket could carry 187 loads over the 1,100 feet from the mixing yard to the site. Talbott also used an extensive monitoring system which the Engineering News found interesting and apparently novel:

> In order that the rate of progress of the work might be carefully watched, a large diagram was

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[30/] Financial Post, February 22, 1913.

> plotted at the outset with lines showing the expected rate of progress on excavation, concrete laying, steel erection, and other principal items of work. This diagram is posted on the wall of the main office and upon it is plotted daily the amount of work accomplished. By comparison of the lines of expected and of actual progress, it is seen at a glance whether the work is proceeding faster or slower than is necessary to reach completion at the time originally planned. Daily reports are also filed, showing the output of each principal piece of plant, bucket of concrete handled, skips of rock transported, cars of sand delivered etc; also the hours of time during each of the machines was shut down, with the reason why the shutdown was necessary.

The same article also provided useful information about the construction crew at Grand Mère:

> The contractors have had, at times, a force of some 1,100 men on the work, and the care of this force was as important a feature in securing rapid and efficient work as the provision of efficient machinery. Nearly all the foremen and even some of the workmen have been employed more or less continuously by the contracting company on various construction jobs since 1898.
>
> As is usual on large construction operations, the working force is made up of a mixture of many nationalities, mostly brought in from outside. The local French Canadians were little used to construction work of this sort, and comparatively few were employed. A resident physician was constantly on the work and gave a careful physical examination to every applicant for employment....
>
> There being no suitable housing accommodations in the village of Grand Mère for the working force, a workmen's camp was built, on the east side of the river.... About 40 of these bunk houses were built and a system of discipline was put in force to keep the camps in sanitary condition, occupants of the camps who did not keep their houses clean or who did not use the sanitary closets provided for them, being fined.

> For the foremen and English-speaking workmen, a boarding house was built for those without families and a row of neat cottages was erected which were rented to married men. Adjoining the boarding house was erected a bath house with showers and tubs for the free use of all employees. A club house was also built and equipped with pool tables, cigar stand, reading room and a barber shop. A nominal charge of 50¢ per month was made for all club privileges.
>
> These various provisions were effective in attracting to and retaining on the work an efficient force of contented employees. 31/

The expansion programme cost an estimated $4.2 million, but even this was too much for Laurentide which, with the outbreak of the war, was forced to delay completion until early 1916.

Meanwhile, the river had been tapped further upstream at La Tuque.32/ In 1904 the Brown Corporation of Berlin, New Hampshire (under an affiliate, the Quebec and St. Maurice Industrial Company, capitalized at $2 million) purchased the falls for $75,000. In return Brown promised to build a pulp mill and to ship 4,000 cars a year on the Lake St. John Railway, which in turn sold Brown the enormous timber limits it had acquired as Crown grants. To generate 3,000 hp Brown adopted the simple expedient of running penstocks directly from the river above the falls (without the benefit of a dam) to a power-house. The penstocks were 6 feet in diameter and 2,300 feet in length, and the cost of the installation was only $150,000.33/

31/"Methods of Construction of the Grand Mère Hydro-Electric Plant, Quebec," Engineering News, LXXII, No. 14 (October 1914), 687-89

32/Dales, Hydroelectricity and Industrial Development, 89, 91-92. William F. Ryan, The Clergy and Economic Growth in Quebec (1896-1914) (Quebec 1966), 81

33/Denis, Commission on Conservation, 50.

As Shawinigan expanded its power generation, it also took the initial steps to control the flow of the lower St. Maurice. Not only did the enormous seasonal variations wreck havoc with the hydraulic systems, but they also led to the generation of considerable secondary power which could only be sold at a lower rate than steady power generated under normal conditions. Control of the flow would increase the regular flow, and thus maximize the profitable sales. Between 1908 and 1915 Shawinigan built three dams at the head of the Manouan to trap the spring run-off and create a storage capacity of 20.5 billion cubic feet. The company also joined other power and lumber companies on the St. Maurice to encourage the Quebec government to create the Quebec Streams Commission for the management of running waters in Quebec. Created in 1910 the Streams Commission immediately turned its attention to the St. Maurice, and within a few years it had drawn up plans for the further development of storage reservoirs on the St. Maurice. Meanwhile Shawinigan had created a subsidiary, St. Maurice Construction Company, which successfully secured the Stream Commission contract for the dam above La Loutre rapids at the headwaters of the river.

The dam to form what became the Gouin Reservoir was to be one of the largest of its day--1,646 feet across, 90 feet from the river bed at its highest point, 72 feet wide at the base, and 20 feet wide at the top. Building a dam with these dimensions was a respectable task for the period, but building it fifty miles upstream from the nearest railway was a mammoth undertaking. The first engineering parties went in on dog sleds, and the first construction season was spent assembling a fleet of boats and barges to navigate the first thirty miles where the river was more or less navigable, or could be made so. The "alligator" was built with long cables to tow barges over a sandbar and through a long and nasty series of rapids. A base camp was built at the Hudson Bay Post of Weymontachinque, (called Sanmaur to make it easier all around) where 45 men were stationed to handle all the equipment and supplies brought in by rail for the thirty-mile barge trip to Chaudière. Only ten men were needed there as the supplies were crudely containerized for easy transhipment from the barges to the standard gauge railroad that was built to cover the last twenty miles.

Although the contract was let early in the fall of 1915, by October 900 men were at work trying to get the railroad finished by freeze-up. But freeze-up arrived on November 5 and the equipment had to be moved in by dog sled so that construction could start in the spring. During the winter the crews continued to work on the railroad, the construction camp, the sawmill, and the temporary hydro plant built at the rapids to provide necessary immediate power. The construction camp ultimately included 28 log dormitories for 20 men each, 14 houses, dining halls, a hospital and a separate camp for the loggers, in addition to offices and workshops. Work on the dam began in May 1916, although the railroad was not finished until August. Poor communications slowed the work, but so also - as with so many construction projects during the Laurier boom and the war - did a severe shortage of labour. It was difficult to keep a labour force at the northern site, and almost impossible to hold skilled labour. The Engineering News-Record of October 25, 1917, reported that the contractors had "procured labour from the internment camps to replace the Italians who had been called home to fight," but the men naturally were inefficient. Work continued through the 1916-17 winter in temperatures as low as 49 below, and by spring both channels were ready for excavation. By December 73,000 cubic yards of concrete had been poured and the dam was finished.

By the end of 1918 the St. Maurice was used to generate 175,000 kw; today it provides over 1.5 million kw, and further developments are possible. Since tapping the full potential of the river demanded control over the entire flow, Shawinigan found it relatively easy to persuade Laurentide to merge its power interests in 1916. Even the giant International Paper, which had secured options on La Gabelle, agreed to form a company controlled by Shawinigan to develop the lower St. Maurice. In 1928 Shawinigan secured control over the entire river above La Tuque, and found the Brown Corporation willing to sell 50 per cent of La Tuque Falls for $2.5 million and form a partnership for the development of a new plant at La Tuque in 1931. Meanwhile, the boom of the 1920s and the expansion of local industrial and long distance sales had led to the rapid development of the exisitng sites at Shawinigan and Grand Mère and the construction of a 123,750 kw plant at La Gabelle. By 1930 Shawinigan had a generating capacity of 525,000 kw, making it one of the leading hydro-electric companies in the world.[34/]

Shawinigan engineers had spent several years in the late 1920s examining the entire flow of the river to determine the best strategy for developing the 630 feet gross head on the upper river. Six sites were chosen above La Tuque, and Rapide Blanc was selected as the initial location because it "offered the exceptional advantage of providing the largest pond of all proposed sites and insured the maximum regulation of the river in this region."[35/] Moreover, the geological setting provided a high head and solid rock foundations, while close and steep river banks promised relatively inexpensive construction, as of course did falling wage rates in the early 1930s. By 1938, five years after the first unit was completed at Rapide Blanc, construction started on a large plant at La Tuque. Within 30 months the plant was operational. J. A. McCrory, the chief engineer, provided an interesting commentary on the development of construction techniques during the inter-war years:

> Probably the most important change that has taken place in the Company's construction procedure, during the past few years, has been in connection with the planning of the work. In the old days the head office planning was confined largely to an outline of the general construction methods, leaving to the field organization the task of filling in the details. Frequently, especially during the busy Twenties, the superintendent was hustled onto the work from another

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[34/] Dales, Hydroelectricity and Industrial Development, 91.

[35/] L. A. Duchastel, "The Rapide Blanc Development," The Engineering Journal, XVI, (October 1933), 434.

job, with little time for preparation and only the specification drawings and a few sketches to give him an idea of what he was supposed to build, and was expected to form an organization and make a good guess as to what his requirements would be for the next two or three years. It was a good bit to expect of a superintendent, no matter how experienced, and the result was that he usually grabbed all the construction equipment he could lay his hands on, in the hope that he would find it useful, and sometimes found, later on that he had placed some of his temporary structures in positions that interfered with the permanent works. The method was not conducive to economical construction.

Beginning with the Toro storage dam on the Mattawin, in 1929, a change in procedure was initiated by laying out part of the construction plant in the office. This process was further extended in 1931 when beginning the construction of Rapide Blanc development, with such good results that, when the final design and detailing of the La Tuque development was begun in the fall of 1937, the layout of the construction plant and the scheduling of the various operations was begun at the same time and carried out in complete detail.... The results of this careful planning are well illustrated by a brief comparison of an earlier job with the La Tuque job. La Gabelle development was built in 1924. It was considered to be a well built job and the unit costs, for the period, were low. However, if the unit costs for concrete and excavation at La Tuque had been the same as those for La Gabelle, these two items alone would have increased the cost of La Tuque project by almost $1,500,000.00. This is not entirely due to the advantages of more careful planning, however, but reflects also the improvement that has been made in construction plant and the difference in construction methods.

The construction plant used at La Gabelle was typical of the period. Transportation on the job was by dump car and steam donkey, with tracks, more than 11 miles of them, radiating from the construction yard to all parts of the job. Most of the mucking was done by hand. The concrete was carried from the central mixer plant, in

> hoppers on flat cars, to wooden concreting towers located at various points on the job and distributed from these to the forms by chutes. At La Tuque, on the other hand, transportation was mostly by motor truck, with a small amount of rock hauled by gasoline locomotive. Most of the mucking was by means of power shovels. The concrete was carried from the mixer plant by belt conveyors to hoppers located at various points along the dam and handled by derricks to the point of deposit in the forms in two-yard, bottom-dump buckets. The location of derricks and of the various temporary structures was very carefully studied so that they would be of use in as many operations as possible without unnecessary shifting. 36/

For all that, the job was delayed because of rock falls caused by blasting with too large a charge and 15,000 cubic yards of rock had to be removed from one cliff face that had not been budgeted for.

During the second war the demands of the St. Maurice industrial complex were insatiable, and all plants worked to capacity. After the war a new unit was built at Shawinigan, Premier Duplessis opened the 286,000 kw plant at La Trenche in 1950, and in 1958, with the assistance of a $500,000 fourteen cubic yard walking dragline that dug a two mile tailrace, Shawinigan opened Beaumont. By 1962 when Shawinigan was acquired by Hydro-Québec the company directly owned and operated nine hydro plants with a capacity of 1.8 million hp and owned St. Maurice Power at La Tuque, Southern Canada Power, and Quebec Power, Shawinigan Engineering, and Shawinigan Chemicals. The estimated value of plant and equipment of a company that had played

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36/ J. A. McCrory, "Construction of the Hydro-Electric Development at La Tuque," The Engineering Journal, XXIV, (February 1941) 59-60.

an enormous role in the economic development of twentieth century Quebec was $493 million.[37/]

37/ Paul Sauriol, The Nationalization of Electric Power, (Montreal 1962), 79, from The Financial Post Survey of Industrials, 1962. See also Financial Post, October 20, 1962.

COMING OF AGE

The 1920s witnessed a tremendous increase in the development hydro-electric capacity of the country. As the amount of power tripled and the value of fixed assets leaped from $400 million to over a billion between 1918 and 1930 Grattan O'Leary was not alone in hailing the dawn of yet another new era for the country. The development of the available hydro-electric power, he wrote jubilantly in 1928, "would support an additional 30,800,000 souls, and provide in wages the stupendous sum of $9,279,600,000 a year."[38] Despite the depression, investment in hydro-electricity continued during the 1930s, not only to complete projects started during the 1920s but also to satisfy growing domestic and industrial demand. Fixed assets increased by $500 million during the decade, and the generating capacity grew from 5.1 million to 7.6 million kw between 1930 and 1939. Not only were there the major developments on the Niagara and St. Maurice, but the inter-war years saw massive developments on the Ottawa, the Gatineau, the St. Lawrence and the Abitibi, and important new installations from British Columbia to the Atlantic provinces.[39] But the history of construction in the kingdom of the Saguenay overshadowed

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[38] M. Grattan O'Leary, "Power," Maclean's, XLI, No. 16 (August 1928), 3.

[39] Canadian projects did not match the massive Hoover and Grand Coulee developments in the United States which generated 1.3 and 2 million kw respectively.

all the others.

The Spectacular Saguenay.

Fed by rivers such as the Peribonka, the Mistassini, the Mistassibi, the Ashuapmuchuan and the Ouiatchouan, Lake St. Jean drains an area of 30,000 square miles in northeastern Quebec between the power-laden drainage basins of the St. Maurice to the west and the Betsiamites and the Manicouagan-Outardes to the east. The Saguenay River leaves the lake in two channels, the Grand Décharge and the Petite Décharge which, after their separation by Alma Island, join seven miles downstream. In its first 35 miles the Saguenay drops more than 300 feet before it enters a broad and deep tidewater channel between mountain shores for its last 65 miles to the St. Lawrence.

Since that day in 1535 when the Indians told Jacques Cartier of the glorious kingdom of the Saguenay, its romance has not disappeared: Tadoussac, at its mouth, was for many years the major ocean-going port for the early French colony; at Tadoussac the first house was erected in Canada in 1600 by Pierre Chauvin; there in 1615 began the first mission work with the Indians and in 1646 the first stone church was built. The Lake itself was discovered in 1647 by Father Jean De Quen, after whom it was named. Meeting place of Indians and traders, the territory remained a fur trading preserve and closed to settlement until the 1830s when a group of venturesome French Canadians from La Malbaie formed la Société des Vingt-et-Un, defied the Hudson's Bay monopoly, and established eight small sawmills and settlements along the Saguenay. Agricultural settlements followed the end of the monopoly in 1842 and by the turn of the century there were over 3,000 settlers in the Lake St. John area.[40/]

The first loggers were assisted by William Price, the Quebec timber king, and during the 1840s he purchased most of the small mills. By 1852 Price controlled the timber industry in the entire region, and maintained his monopoly until almost the turn of the century. The first pulp mill was constructed in 1896 by J. E. Alfred Dubuc and his Compagnie de Pulpe de Chicoutimi, and by 1915 Dubuc's mills produced 325 tons of pulp a day. The Price family was not far behind, however, and by 1914 was producing not only pulp but also 50,000 tons of newsprint annually at a large mill at Kenogami. By 1914 there were three hydro electric plants in the region: a 550 hp municipal plant at Jonquiére on the Au Sable River, which cost $27,000; a 7,500 hp plant on the Chicoutimi River serving the needs of Chicoutimi's 5,000 people; and Price's 10,500 hp plant on the Shipshaw, which fed the mills at Kenogami and Jonquiére and cost $900,000.[41/]

Meanwhile, rights to develop power on the Saguenay River had been

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[40/] Ryan, Clergy and Economic Growth, 119-120.

[41/] See Denis, Commission on Conservation for details on various generating stations.

acquired by three parties, the first T. L. "Carbide" Willson who had developed the electric process for the manufacture of calcium carbide.[42/] In 1913 Willson persuaded James Duke, who had been looking for a power site for the production of nitrogen, to look at the Saguenay. "We went in a duck boat up to the end of tidewater and then walked up the trails on the bank of the river for possibly two miles," recalled W. S. Lee, an engineer with the party. "The river breaks through regular gorges at that point and was a very impressive sight. Mr. Duke got down on his knees in the wet bushes, with total disregard of his clothing, and looked into the gorges, fascinated. Then, within thirty minutes, he turned to me and said: 'Lee, I am going to buy this.'"[43/]

Buy the three properties Duke did, and in 1914 his engineers ran geological tests and hydraulic surveys on the Saguenay. Studies by the Quebec Streams Commission, the first war, delays due to the fear of uncontrolled flooding of farm land, and the waning enthusiasm for nitrogen fixation led to delays of almost a decade. Finally, in December 1922, in partnership with Sir William Price, who provided one guaranteed market, the Duke-Price Quebec Development Company, capitalized at $25 million, announced that it would begin construction on the first stage of a Saguenay development. By this time Duke was

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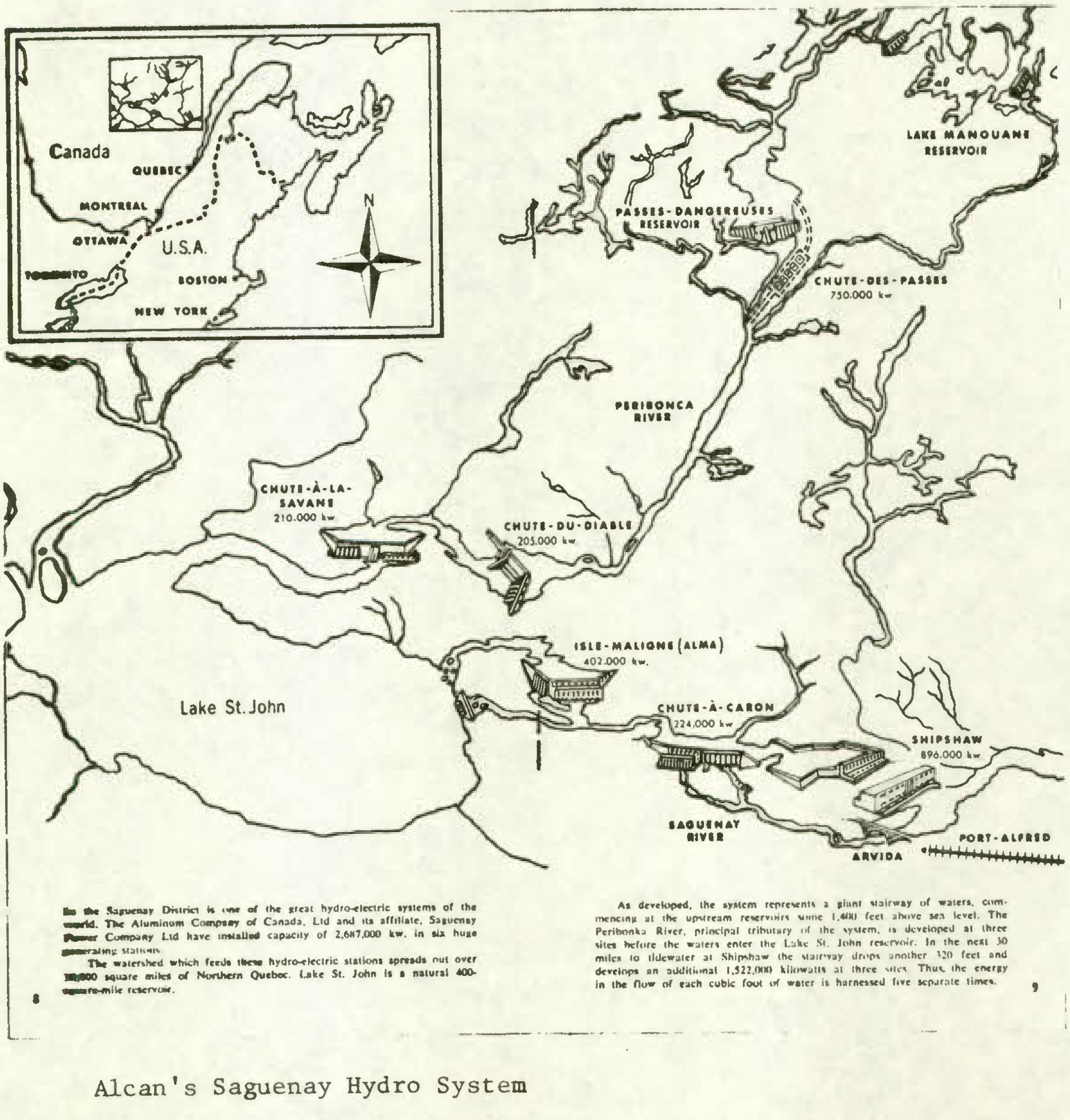
[42/] Willson, a Canadian working in the United States, had investigated Shawinigan in the mid-90s and then the Saguenay in search for power. He actually established a plant at Merriton, Ontario on the Welland Canal.

[43/] John K. Winkler, Tobacco Tycoon; the story of James Buchanan Duke, (New York 1942), 267.

pinning his expectations on aluminum. Whether he fully intended to move into the aluminum business himself seems unclear, but by 1923 at least he was negotiating with ALCOA, the American giant already on the American side at Niagara Falls, buying power from Les Cèdres plant of Montreal Light, Heat, and Power for its Massena plant, generating electricity from hydraulic power purchased from Shawinigan, and still in search of more power. In June 1925 Duke received ALCOA shares worth $17 million in return for the lower properties. And in



Alcan's Saguenay Hydro System

1926 ALCOA purchased from the Duke estate 53,1/3 per cent of the stock in the Duke-Price, now the Saguenay Power Company. In 1928 the Canadian operations of ALCOA were established separately as the Aluminum Company of Canada, or ALCAN.[44/]

The first phase of the Saguenay development was the construction of a dam and powerhouse where the Grand Discharge is separated into two channels by the Isle Maligne. The Isle Maligne project, described as the first stage in the world's largest hydro-electric development which would generate 1.2 million hp, involved the construction of a 710 foot long and 146 foot high powerhouse dam, a large earth dam, and seven spillways (two of them over 100 feet high to control the water flow through both the Grand and Petit Décharge.) During the first winter construction materials were hauled in by sledges on a snow road. Before construction could begin the company built a standard gauge railway to the Canadian National at Chicoutimi, as well as three steel bridges, the foundations and piers for which were finished by

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[44/] The Electrical World of August 1, 1925 reported "The proposal of Aluminum Company of America to merge with the Canada Power and Manufacturing Company was approved by stockholders today. It is proposed to build a huge power and manufacturing plant on the Saguenay River in Canada.

James B. Duke (President of the Canada Power and Manufacturing Company) and Mr. A. V. Davis, President of Aluminum Company, recently acquired an 800,000 hp site at Chute-à-Caron, in addition to the 360,000 hp Isle Maligne site now under construction.

The decision of the Aluminum Company to build at the Saguenay River site will mean a ready market for all power to be developed. The combined industrial and power project will involve the expenditure of approximately 100 million dollars.

It was soon public news that the Aluminum Company had acquired the controlling interest in the upper Saguenay development at Isle Maligne." See N. S. Crerar, History of the Development of the Saguenay Power System, speech given before Electrical Club of Montreal April 2, 1958.

March 1923 in temperatures that fell as low as 42 below. Fifteen miles of yard track linked the widely scattered construction sites to a central crushing and mixing plant with facilities for delivering warm concrete in below zero weather.[45/] A large trestle over the powerhouse dam enabled giant derricks to unload 337,000 cubic yards of concrete.

One of the most challenging tasks facing the construction crews was the cofferdam above the powerhouse. The work had to be done during the January-March low water period, but the river was so deep and so cold that it did not freeze over. Ingenious engineers, who had hitherto regarded frazil ice only as an enemy of intake structures, threw a brush boom across the river on which the ice rapidly formed. Cribs were built up on the ice and as each was completed the ice was cut and the crib dropped into position.

A second challenge was described to the Engineering Institute by an ALCAN engineer in 1944:

> One construction feature at Isle Maligne should be recorded for it marked the engineers' first struggle against the power of the Saguenay.

[45/] The methods used for winter concreting were described by Duncan Kennedy: "Two 100 hp boilers are installed at the mixer house for heating the building and the mixing water. Heating of the sand was also attempted by means of another 90 hp boiler but this was not found very practicable, and experience showed that by raising the water temperature to about 170° the heat of the mixed batch was sufficient to ensure its being deposited on the wall in good condition. The large size of the batches helped to conserve the heat, and the buckets in transit were kept covered and supplied with steam heat from the locomotives." Duncan Kennedy, "Two Units at World's Largest Power Centre Will be Ready Next Month," The Electrical News, XXXIV, No. 1, (January 1925), 48-55.

When the time came to build cofferdam No. 6 in Barnabé channel, so that the No. 4 spillway could be thrown across the right channel to complete the final closure, trial after trial determined that although the season of minimum flow had been chosen, ordinary methods could not cope with the tremendous quantity and velocity of water encountered. The result was an engineering novelty. A canal almost completely by-passing the site for the No. 6 cofferdam was excavated in rock. Concrete piers with stop-log grooves were constructed across this canal. Then the piers were completely submerged with thousands of yards of loose sand for protection and the entrance to the canal was opened by a shot of 100 tons of dynamite placed in tunnels below the rock plug which had been left at the entrance of the canal. When this shot was fired, rocks rained down a mile away, the water from Barnabé channel rushed through the canal and cofferdam No. 6 was easily built. Then, stop-logs were put between the concrete piers in the canal and for the first time in history the Saguenay was controlled. The water was diverted into the channel leading to the powerhouse, and the No. 4 spillway, the last step in the construction, was completed in early 1926. 46/

By the time Isle Maligne, which by 1937 generated 336,00 kw, went on steam in the summer of 1926 the town of Arvida and a $75 million aluminum plant had been started and plans had been made for the construction of the Chute à Caron or Shipshaw I dam and powerhouse. Construction started in 1926 but was spasmodic until 1928. With only half the project completed and one powerhouse in operation construction stopped in the early years of the depression, and the latter half of the project, Shipshaw 2, with modifications was not finished until

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46/ McNeely Dubose, "The Engineering History of Shipshaw," The Engineering Journal, XXVII, (April 1944), 197.

the enormous need for aluminum led to striking developments throughout the Lake St. John basin during the second war. According to Engineer DuBose: "Nothing need be recorded, historically speaking, about the initial construction at Shipshaw No. 1, except the unique use of a pre-cast concrete dam 92 feet long, 40 feet deep and 45 feet thick, which was built on end and toppled into the river to divert it from its natural bed into a previously prepared by-pass canal, so that the concrete dam across the Saguenay could be completed. For the second time, the first being the 100 ton blast at Isle Maligne, heroic methods had to be resorted to, and by the use of this obelisk the Saguenay again contributed something new to engineering history."[47/] To the layman the achievement seems slightly more striking: the structure weighed 10,900 tons, the water was 28 feet deep and was expected to cushion the fall, the concrete was reinforced with all the old used steel cables that could be found lying around, mathematical and hydraulic models were designed and tested by engineers at ALCOA in Pittsburg and at Carnegie Tech, and the obelisk fell within one inch of its calculated position with only a few hair-line cracks. "In fact, the impact, as measured by recorders attached to the obelisk, was almost imperceptible - no more than that which would be caused by a free fall of only 4 inches. The falling mass of 11,000 tons settled so gently into place that, apparently, it would have been perfectly safe for a person to ride on the obelisk during the entire period of its fall."[48/]

[47/] Ibid., 198

[48/] C. P. Dunn, "Blasting a Precast Dam into Place," Civil Engineering, I No. 3 (December 1930), 163-164.

The construction of the enormous Shipshaw 2, with a capacity of 717,000 kw, between 1941 and 1943 by the Foundation Company and a number of large subcontractors was remarkable for the scale and speed of the construction operations. The work force averaged 3,960 men, peaked during June 1942 at 9,863, and total labour turnover in two years was 47,747. However, it was the extensive use of heavy equipment that appears to stand out, as every phase of construction seemed to call forth heavier equipment than had been customary in hydro-electric construction in the mid-30s. The following equipment kept 750 men busy in the mechanical department:

> Forty 1½ to 2½-cu. yard shovels, crane or drag-lines; two 4 cu. yard and one 6-cu. yard draglines; two Jordan spreaders; eight 12-cu. yard Letourneau scrapers; fifty D7 and D8 caterpiller tractors; sixty 20-cu. yard standard gauge side dump cars; sixteen standard gauge 40-ton locomotives; twenty 10 and 13-ton Athey wagons; twenty-one 10-cu. yard Euclid trucks; one hundred 2 to 4-cu. yard dump trucks; thirty-eight Canadian Ingersoll Rand, FM2 wagon drills; 124 Canadian Ingersoll Rand, N82 sinkers; one hundred and ninety-eight light jack hammers of various makes; thirty-nine 6 and 7 in. diameter well drills of various makes, and eighty pumps of various makes and capacities. 49/

The only construction novelty that engineers talked about was the final play of the game when a natural rock plug which had been left to block the tailrace was blown out. The plug was 310 x 75 x 35 feet in size. A crew of 80 men spent two days placing 82,000 pounds of dynamite in the carefully drilled holes, and after the blast only 500 of the 18,000

49/ Walter Griesbach, "Construction of Shipshaw No. 2 Power Development," The Engineering Journal, XXVII, (April 1944) 244.

cubic yards had to be dug out.

Far more interesting wartime construction projects were the control dams far to the north at Passe Dangeruese and Lake Manouane. The dams were necessary to maximize the power potential on the Saguenay by controlling the flow from the Manouane and Peribonca watersheds, the major inputs into the Saguenay. The Lake Manouane rock-filled timber crib dam was built in 1940-41, and at Passe Dangeruese a timber crib and two earth dams were built between 1941 and 1943. Construction posed no problems, but distance did.

To reach Lake Manouane men and materials moved 16 miles up the Shipshaw from Chicoutimi, 44 miles by truck road to Beauchesne on Lake Onatchiway, and 110 miles by air to the dam site. In all more than 3,000 tons of material and equipment was freighted in or out, at a cost of 7 cents a pound, in what may have been the first major use of aircraft in Canadian construction.

> Major equipment flown into the job included a 3/4 yard gasoline heavy duty dragline, a 3/4 yard Diesel medium dury shovel, seven tractors up to a D7, two 6 yard Athey wagons, three 315 cu. ft. per min. Diesel air compressors, four 1½ and 2 ton trucks, etc. In addition, eight draught horses and several oxen were flown in.
>
> The largest aircraft on the job was the so called "Box car," a Junkers JU 52 equipped with a 825 hp Rolls-Royce engine developing 925 hp on takeoff. This ship hauled in a 5,400 lb. piece during the winter.
>
> The maximum number of aircraft in service at any time was eight, with 32 flights in one day.
>
> The aerial transportation was most successful.

> There were some minor mishaps but no freight was lost and no injuries were suffered by airborne personnel.
>
> Equipment used on the Manouan[e] job had to be selected of such type and size as could be torn down into components within the capacity of available aircraft. For instance, the 3/4 yard dragline represented the maximum size equipment of this nature adaptable to air freighting. In some cases the chassis of a construction machine was specially sectionalized to permit loading into aircraft. 50/

The larger dams at Passe Dangerouse were not quite as isolated but access to the site again involved a gigantic transportation undertaking. Construction of 57.5 miles of truck road to supplement logging roads, with four wooden bridges designed for a 43,000 lb. tractor drawing two 18 ton sleighs, occupied the period from August to December 1941. During the construction of the access road 24 tractors, mostly equipped as bulldozers, four shovels and three air compressors were used, as well as a large fleet of trucks. The work force averaged 305 with a peak of 497. Because of the urgency the work on the road and preliminary work at the site was serviced by air freight:

> The freight flown into Lake Peribonca was moved to Passe Dangereuse by 22 ft. freight canoes with 22 hp outboard motors. For ordinary package freight and small equipment, single canoes were used but for tractor transmissions and other heavy parts an assembly of three such canoes stoutly lashed together with poles and powered by a 22 hp outboard motor

50/ F. L. Lawton, "The Manouan[e] and Passe Dangereuse Water Storage Developments," The Engineering Journal, XXVII, (April 1944), 201-202.

served. A single piece weighing in excess of 3,800 lb. was transported on such an arrangement, which satisfactorily carried a total load of 3.9 tons. Cost of this freighting was $0.686 per ton mile.

Freight moved in the above manner included two $1\frac{1}{2}$ ton and two 2 ton trucks from Manouan[e,] as well as four D4 tractors from Manouan[e] and Beauchesne. Two horses sent out overland from Manouan were moved 14 miles down the Peribonca on the assembly of 3 canoes. 51/

Truck transport, road maintenance, and all other aspects of the transport operation were contracted to Price Brothers and Company. From December 1941 to November 1943, 10,774 truck loads of material, 1,055 taxis, and 292 buses carrying 10,436 men travelled north on the route to Passe Dangereuse. The trucks travelled in convoys with dispatchers keeping track of movements so that there would be minimal delays in the one-lane sections. Northbound convoys had the right of way.

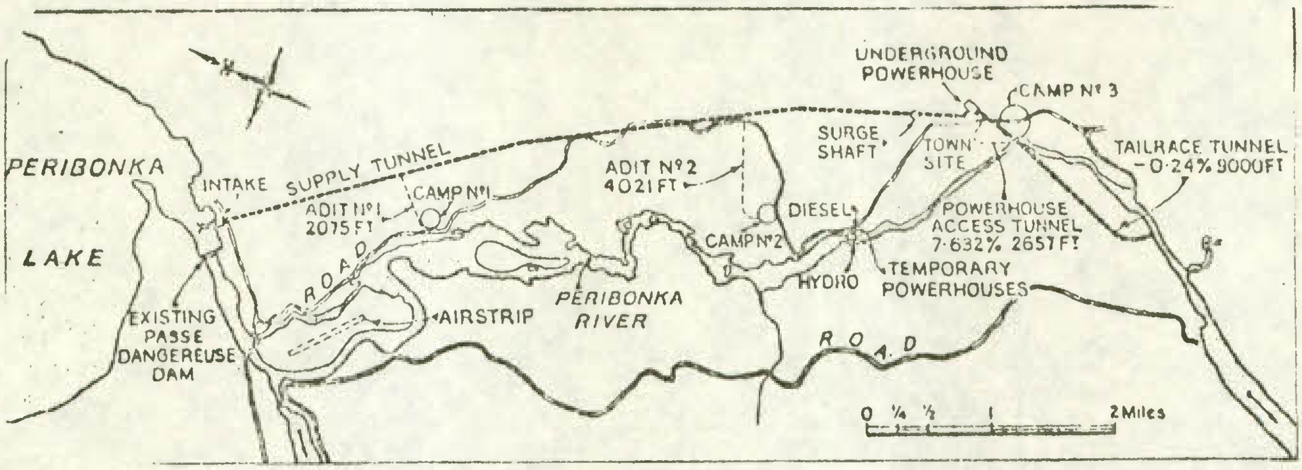
The camp and construction plant was large for so isolated a spot. The workmen were housed in 64 units (similar to the ones used at Manouane) each holding 24 men, with sanitary camps in a separate location. Two log dining halls could accommodate 1,260 at a sitting. A small hospital with two doctors, store, post office, laundry, barber shop and shoemaker completed the workmen's quarters. The staff had a slightly more luxurious layout. Living quarters and construction plant were not separated as was usually the case for the terrain made such a layout impossible. Heating the plant and camp required 29,700 cords of firewood and 5,740 tons of coal.

51/ Ibid., 211

The plant had most of the facilities usually found in construction projects at that time, but was not as conveniently arranged because of the rough ground and the absence of adjacent aggregate deposits for the concrete work. A fleet of forty trucks travelled 730,000 miles moving the aggregate from its source to the screening and stockpiling areas. The most novel part of the construction plant was a taut line cableway for the pouring of concrete in the main dam. The system was by no means unique but had been used relatively infrequently in Canada, the most usual method being the construction of a trestle above the dam site.

A little more than a decade later construction crews were once again at Passe Dangereuse. By 1950 ALCAN found that the demand for power outran the 1.2 million kilowatt generating capacity already installed. In 1952-53 it built two 187,000 kw plants at Chute à la Savanne and Chute au Diable near the mouth of the Peribonca River. The Price company also built two 51,000 kw plants on the Shipshaw. But the demand remained and in 1956 ALCAN began construction of the Chute-des-Passes powerhouse at the foot of Lake Peribonca below Passe Dangereuse. The Chute-des-Passes was to generate a million horse-power, and when in 1960 a channel was completed to divert some of Lake Manouan through the Passe Dangereuse reservoir the firm generation of the entire system was increased by another 700,000 hp.

The enormous project involved a six mile 34-foot intake tunnel, a 500-foot underground powerhouse, and a 48-foot tailrace almost two miles long which ran under the Peribonca River from the east side to



discharge on the west. The engineering and design contract was awarded to H. G. Acres & Company Limited of Niagara Falls, and while the final design was being completed ALCAN rebuilt the 100 mile road and bridges to carry the anticipated heavy traffic. The unusual contracting procedure was described as follows:

> While access facilities were being provided, work was going on leading towards contracts for the main project. A unit price or lump sum contract was desired if such could be obtained on attractive terms. The alternative was a cost-plus fixed-fee-type contract. Because it was certain that it would take some time to develop satisfactory project contracts. Alcan assumed direct responsibility to build access roads to within 1,000 ft. of the various working areas of the project, to build an airstrip, to furnish construction power, and to purchase the permanent equipment. Permanent equipment in this case was construed to mean almost everything that would be specified on a construction drawing.... Review of preliminary proposals from contractors in mod-1956 provided confirmation of early planning and early scheduling and gave better information about probable costs but none were sufficiently firm to be acceptable. In the meantime, much more design information had been developed.

> Discussions with contract bidders and analysis of information given in their preliminary proposals led to changes in the final contract bid invitation terms that clarified the more difficult points of uncertainty and probably led to more favourable bidding. The contract was a unit-price contract with lump-sum bids for camp, plant and equipment. The contractor was responsible for all of the construction areas and for construction materials not furnished by Alcan....
>
> Certain extra work items were anticipated but not included specifically in the contract, anticipating negotiation of unit prices later. Failing negotiation the work could either be awarded to an outside contractor or performed by the general contractor on a cost-plus fixed-fee basis with a predetermined schedule of fees. Certain items, such as tunnel supports, grouting and guniting were intentionally omitted from the contract on the basis that too little was known to establish firm unit prices at the time of the contract award. Subsequently, firm unit prices were negotiated. 52/

The contract also involved an advance payment to the contractor to cover the mobilisation of personnel and prepay costs of camp equipment, construction plant and buildings.[53/] Yet the $75 million contract was too big for most companies, and was finally awarded to Perini-McNamara-Quemont, a joint venture group organized for the purpose, with Perini (Quebec) as the sponsor.

The contractors were in the field in September 1956. Many of the key personnel were drawn from the recently completed Bersimis I built for Quebec Hydro by Angus Robertson. Probably many of the 2,300

[52/] F. T. Matthias, F. J. Travers, J. W. L. Duncan, "Planning and Construction of the Chute-des-Passes Hydro-Electric Power Probject," The Engineering Journal, XLIII, (January 1960), 48-49.

[53/] F. T. Matthias, "Chute-des-Passes Project," Water Power, (May 1959) 169.

workmen on site in 1957 were also drawn from Bersimis.[54/] By 1960 the five units were in full operation and Chute-des-Passe momentarily became the fourth largest hydro-electric plant in the country. The watershed of the Saguenay had been harnessed from source to tidewater.[55/]

[54/] E. B. (Jack) Fontaine, Engineering and Contract Record, (December 1957) 88.

[55/] By 1974 Alcan had installed a generating capacity of 2,687,000 kw at the following powerhouses: Shipshaw - 896,000 kw; Chute-des-Passes - 750,000 kw; Isle Maligne - 402,000 kw; Chute-à-Caron - 224,000 kw; Chute-à-la-Savane - 210,000 kw; Chute-du-Diable - 205,000 kw. In addition the Price company has seven plants in the Shipshaw, Chicoutimi, and Au Sable river with a capacity of 140,000 kw. Four other smaller plants with a capacity of 46,000 kw raise total capacity of the watershed to over 2.8 million kilowatts.

POST-WAR GIANTS

"The world's work seems to be coming along in increasingly large packages," observed William D. Mulholland in 1972. "It is important that there be applied to these tasks the best possible management and engineering techniques to avoid an unacceptable toll in waste and inefficiency. However, the demands of scale are such that even while they require performance to higher standards in all of the traditional areas, they additionally impose their own special requirements."[56/] The observation was appropriate, for it was made at Churchill Falls at the formal opening of what was then Canada's largest single hydro plant. Yet Churchill Falls was only one of several new installations that soared beyond the million kilowatt mark after 1945. In the fifteen years between 1945 and 1960 the amount of hydro-electric power doubled, and in the next fourteen years since it doubled again to pass 3.5 million kilowatts in 1974. The value of fixed assets increased five-fold and was estimated to be $25 billion by 1974.

The physical size of the structures kept pace with the increased generating capacity. Before 1950 there were only two dams in Canada more than 200 feet high. Twenty-nine such dams were built in the 1960s, however, and the 703 foot Daniel Johnson in 1968 was passed by the 794 foot Mica in 1973. Improved engineering and construction

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[56/] "Churchill Falls - Engineering Landmark," The Engineering Journal, LV, (July/August 1972) 22.

techniques, transportation facilities, and transmission technology made larger and more distant developments possible, and as demand continued to press hard upon supply by the mid-1970s very few high potential sources were regarded as unfeasible.[57]

The post-war period, however, was not just one of giant developments in Ontario, British Columbia, and Quebec. There were also the first large scale hydro developments in Saskatchewan, the Northwest Territories, New Brunswick, Nova Scotia, and even Manitoba, where the Grand Rapids on the Saskatchewan (437,000 kw) and Kettle Rapids on the Nelson (612,000 kw) dwarfed earlier enterprises. Beechwood in the 50s and Mactaquac in the 60s brought hydro in a major way to New Brunswick, and by 1974 only Nova Scotia and Prince Edward Island lacked plants with a capacity of 100,000 kw. But it was the giants that so dramatically increased the production of hydro-electricity. The three largest projects, in terms of power to be generated, were Churchill Falls, the Manicougan-Outardes system, and the Peace River in British Columbia. All began in the mid-1950s, and none were completed by 1974.

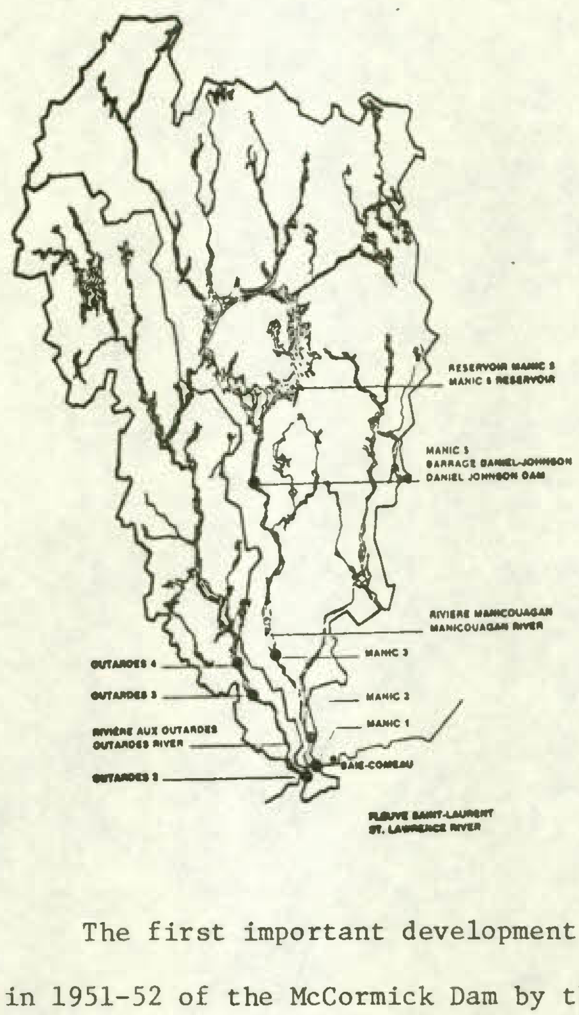
Manic 5

When Hydro-Québec was created in 1944 and expropriated Montreal

[57] The advent of big dam construction in the late 50s and 60s was not only in Canada. In 1962 of the seven dams over 700 feet in height, only Hoover had been completed and the other six were under construction. Manic 5 then ranked fourth. See <u>Registrar of Dams in Canada</u>, 1970.

Light, Heat and Power, Montreal Island Power, and Beauharnois the total capacity was about 700,000 kilowatts. But the post-war years were ones of major expansion in the public as well as the private sector. Hydro-Québec began massive developments on a number of fronts - Beauharnois was doubled, the lower and Upper Ottawa tapped, and Bersimis I and II on the Betsiamites completed by 1960. By 1962 Hydro-Québec had a generating capacity of 3.7 million kilowatts.

The largest development of all, however, was the exploitation of the Manicougan-Outardes watershed in northwestern Quebec. Rivière aux Outardes rises in the Laurentian Plateau and drops 1,800 feet on its 270 mile race to the St. Lawrence. To the west the Manicougan falls 1,900 feet during its 350-mile journey through a rocky, deeply cut valley to the coast. Between them the rivers drain 25,000 miles of virtually uninhabited Quebec, where the snowfall measures 156 feet and men joke that there are only two seasons, winter and July.



The first important development on the Manic was the construction in 1951-52 of the McCormick Dam by the <u>Chicago Tribune</u>'s Quebec North

Shore Paper Company.[58/] By the mid-50s with planning underway on the Ottawa and construction on the Betsiamites, Hydro-Québec turned to Manicougan-Outardes. Hired as consulting engineers at the outset were H. G. Acres and the Montreal engineering firm of Surveyer, Nenniger and Chênevert. By 1959 the overall development had been laid out and construction began. The plan called for seven major installations. Manic I (184,000 kw) and Manic 2 (1,015,200 kw), both finished between 1965 and 1967, were on the first and second falls within fifteen miles of the St. Lawrence. By 1969 Outardes 3 (744,000 kw) and 4 (632,000 kw) were finished. Manic 3 and Outardes 2, with over 1.5 million kw between them, were left for the future. The showpiece, however, was Manic 5, where the Daniel Johnson Dam at the fifth falls was more than 700 feet high and created a reservoir of 750 square miles.

The construction of the $466 million Manic 5 "a nécessité une mobilisation d'hommes, de machines et de matéreaux sans précédent au Canada. Pour réaliser ce projet, l'Hydro-Québec devait non seulement planifier le travail de ses propres ingénieurs, mais aussi coordonner les ressources technologiques mises à sa disposition par les bureaux de génie et par les manufacturiers du Canada entier et de diverses parties du monde."[59/] The completed project had used fifteen engineering consulting firms, including Acres and Surveyer and the

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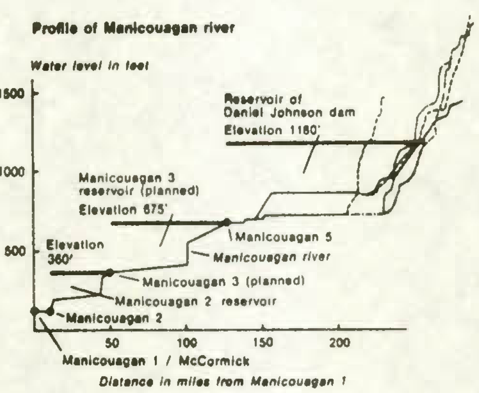
[58/] See Carl Wiegman, Trees to News, (Toronto 1953)

[59/] Yvon De Guise, "Une histoire qui a vingt-cinq ans," Forces, No. 7, (Printemps 1969), 16.

French firm of Andre Coyne and Jean Bellier, seven inspection and testing firms, forty-seven major contractors, and seven transportation firms.[60/]

The first problem to be faced was the 125 miles from Baie Comeau. An advance party began to survey a 135-mile road in 1959, and Komo Construction ultimately built a highway from Manic 2 to Manic 5 to handle a 35-ton bulk cement carrier every fifteen minutes without breaking up. To handle the materials, a 750-foot unloading wharf was built at Baie Comeau and a mile-long airstrip was built at Manic 5.



By December 1960 a base camp was up and soon a small town accommodated the peak 3,500 workers, a "large majority" of whom "came to the project to work because it was a big town compared to the small town and villages where they lived."[61/] A microwave system connected the construction site with Baie Comeau, the field headquarters for the development, and Hydro-Quebec in Montreal.

Of the many problems posed by Manic 5 the most commonly cited was that created by seepage through the alluvium deposits under the upstream cofferdam, sometimes 250 feet deep, which would flood the dam

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60/ Information supplied by Hydro-Quebec.

61/

construction site. Any solution was complicated by the existence of huge boulders throughout the site:

> ....previous experience by an Italian company that had developed the cutoff method had proved that the drilled-in piles could be installed despite large boulders. Whether they could be sunk to such great depths, however, was still a question. The Italians - the parent firm was Impresa Construzioni Opere Specializzate (ICOS) - had built concrete membrane cutoffs as deep as 170 feet, using their patented ICOS-Veder method. Representatives of the Milan company's North American branch, Icanda Limited, of Montreal, huddled with Hydro-Quebec personnel, the panel of experts, and SNC engineers.
>
> Aside from the basic problem - making a cutoff this deep had never been done before - there were the more precise engineering worries. Could the slender holes be drilled and kept well enough aligned to create a positive seal? Drilling an uncased hole through unconsolidated material to depths greater than 200 feet was challenge enough. But where would the drill go when it hit a boulder? Icanda's general manager, the late Ignazio Galbiati, insisted that their big percussion drills would not go off course but would go directly through a boulder.

After a number of tests and experiments, Hydro-Quebéc invited Icanda to demonstrate its capacity:

> ....an Icanda crew came to the north country and showed their stuff. Using makeshift drilling equipment, since time precluded bringing in one of their special rigs, Galbiati's men sank a 100 foot deep pile into the alluvium from the jetty. In the small, 2 foot diameter hole the bentonite slurry held the walls of the hole. Only a moderate amount of the continuously circulated slurry impregnated the alluvium and, best of all, Icanda's drillers kept the pile plumb, within design tolerances of no more than 6 inches from vertical in 200 feet. The technicians were convinced that this slight deviation could be

> easily corrected with the special expansible bit used to sink the in-between piles.

The Icanda crew was impressive:

> It is in this drilling phase of the operation that the artisan comes out in the young drillers. Merely by holding his hand on the hollow drill stem as it impacts, an Icanda man can tell what kind of soil he is in. He knows when he is in sand or gravel; he can tell a boulder from solid rock. And as a final check, the underlying geology can always be determined by the nature of the cuttings being removed from the slurry at any given time. Another novelty apparent in watching Icanda's men work, as compared with the usual scene on a construction project, is the way one of these skilled technicians will stop what he is doing to pick up a shovel or lend a hand to another worker. He does not wait for a laborer to come do the shoveling; if something needs to be done fast, he does it. The unusual spirit of Icanda's men seems to be "We're here to build a cutoff wall, not to squabble over who does what." 62/

The most prominent feature of Manic 5, however, was the world's largest buttressed multiple-arched dam.[63/] Designed by SNC in collaboration with the Paris engineering firm of André Coyne and Jean Bellier, Daniel Johnson followed the same basic design as France's Grandval designed by the same Paris firm. There were, however, structural differences:

> Although all the multiple-arch dams built up to the time of Manic 5 had been made of similar arches for the total length of the dam,

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[62/] Lili Réthi and William W. Jacobus, Manic 5: the Building of the Daniel Johnson Dam, (New York 1971), 31-32, 39-40.

[63/] Basil Caplan, "Pace of Hydro-Quebec's expansion quickens," Electrical News and Engineering, LXXI (August 1962), 31.

> the French and Canadian engineers decided to depart from convention. Because of the difficult topography and the geological formations at Manic 5, the designers elected to use a larger central arch to cross the main river gorge, This led to what is now the most distinctive engineering and architectural aspect of Manic 5 - its two huge oblique buttresses on each river bank, where the main arch and the two small adjacent arches join. More spectacular, possibly, is that the two oblique buttresses are asymmetrical. The right buttress (dam builders assign right and left sides to a river while facing downstream) reached even farther from the arch's centerline than its lift-side counterpart.
>
> These two oblique buttresses consequently distort the symmetry of the two smaller arches next to them, creating two dissimilar, keyhole-shaped configurations. Except for these two arches, all the remaining side arches have spans between the axes of their buttresses of 250 feet. The big central arch measures 530 feet between its buttress axes. The central arch also differs in cross-sectional design from the smaller normal arches. The upstream side of the central arch is defined by a cylinder, while on its downstream side it is defined by an inverted cone. Hence the main arch is much thicker at its base than at its crest. 64/

The massive arch dam was chosen not for its breathtaking grandeur, but for reasons of economy and speed. While the dam used almost three million cubic yards of concrete, a conventional concrete gravity dam would have used five times and a rockfill dam ten times as much. Given the availability of rock a rockfill dam was first contemplated, but given the additional length of time necessary to construct the base in order that impounding the reservoir could begin - perhaps adding a year

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64/ Ibid., 43.

or two to the generation of power - Hydro Québec chose the multiple arch. When completed the dam had 13 arches supported by 14 buttresses, with the central arch 87 feet at the base, 16 feet at the top, and 530 feet between buttresses at the base. The crestline was 4,310 feet, and the dam stood 703 feet above bedrock at the central arch and weighed 6 million tons.

With design and foundation problems resolved the major remaining challenge was to move the 600,000 tons of cement to the site and mix and pour the three million cubic yards of concrete. An oil tanker was converted to carry 6,400 tons of cement from Quebec and Montreal to the special unloading wharf at Baie Comeau, where it was unloaded pneumatically into six 1,500-ton capacity silos. In four minutes, hoppers discharged the cement into 35-ton bulk trucks which transferred the cement into wooden silos at Manic 5. Since the concrete had to withstand pressures of 4,500 pounds per square inch preparation was critical. Low-heating cement was used, and the mixing temperature was maintained between 45 and 60^{o} F. In cold weather the aggregate was heated with steam, and in hot was cooled by ice. The concrete was poured from three overhead cableways, each supporting an 8-cubic yard bucket, running 3,650 feet across the river valley and over the site. The cableway system was brought from Switzerland where it had been used to build the recently completed 940-foot Grande Dixence dam, the world's highest. Since only 140 days in the year were suitable for pouring, mercury vapour floodlights mounted on moveable carriages turned the still northern evening into a raucous carnival.

Behind le barrage Daniel Johnson lay a reservoir that would take eight years to fill. When power began to flow Manic 5 had consumed 3,500,000 man hours and almost half a billion dollars.

Churchill Falls

Yet even the power that flowed from Daniel Johnson over the world's first 735 kv lines into the Hydro-Québec grid could not satisfy the demand for hydro-electricity in the province and from its customers outside, Four years earlier Hydro-Québec had begun discussions with Churchill Falls (Labrador) Corporation (CFLCo) a Brinco subsidiary, about the development and purchase of power.

As early as 1894 A. P. Low of the Geological Survey of Canada had predicted that Churchill Falls would yield several million horsepower. But it was not until the 1950s that serious studies were undertaken, and the British Newfoundland Corporation was formed to undertake the economic development of Newfoundland and Labrador. In 1961 CFLCo was formed and secured a 99-year lease on the Upper Churchill River. By 1963 when negotiations with Hydro-Québec began CFLCo had built a 105-mile road from the Sept Isles railway to the river above Churchill Falls, power had been generated at Twin Falls on the Unknown River for the growing iron ore industry in western Labrador, and the engineering viability of Churchill Falls had been proven. All that remained was a firm contract for power and one billion dollars. Hydro-Québec sent a firm letter of intent in 1966, and then gave the go-ahead to what at the time was the largest civil construction project in North America and the largest single hydro-electric development in Canada.

The contract with Hydro-Québec, part of a larger scheme that involved the sale of power to both New York and Ontario, enabled interim financing to be readily arranged. Two years later, in October 1968, Brinco Chairman Henry Borden reported that the terms of $100 million general mortgage bonds issue had been determined, that an offering of $50 million first mortgage bonds had been arranged in Canada, and that the offering of $500 million first mortgage bonds had been completed in the United States. In addition, Borden told the shareholders, $83 million in required capital had been subscribed and arrangements for $150 million in bank credit had been negotiated with a consortium of Canadian chartered banks.[65/] The president of CFLCo was Donald McParland, a 1952 mechanical engineering graduate of the University of Toronto. On November 11, 1969 McParland and seven other senior and key personnel died when their DH-125 crashed near Wabush airport. To succeed McParland, Brinco and CFLCo selected William Mulholland, graduate of Harvard and a partner in Morgan Stanley and Company of New York, financial adviser to Brinco. Mulholland had been in the forefront in the half billion dollar bond issue.

The billion dollar project was a joint engineering and construction

[65/] Langevin Coté, Heritage of Power, (Montreal 1972), 55.

management venture of H. G. Acres and Canadian Bechtel. The resulting Acres Canadian Bechtel of Churchill Falls, created especially for the project, "brought together the highly reputed engineering and hydro-electric expertise of the Canadian firm of H. G. Acres & Company Limited and the world-wide construction know-how, through Canadian Bechtel Limited, of Bechtel Corporation of San Francisco."[66/] However, a "significant feature of the Churchill Falls development was the retention of the Project Management function by the owner, Churchill Falls (Labrador) Corporation Limited (CFLCo), a separate and autonomous company set up to deal with all aspects of engineering and construction. Being a newly formed company, it was able to structure itself and develop methods, systems and relationships best suited for the project."[67/] Of the four groups CFLCo established, the project group was responsible for the administration of the contract with Acres Canadian Bechtel, which functioned "somewhat like an extension of CFLCo." There was no general contractor and contract "packages were developed in such a way as to encourage the greatest possible response from the maximum number of qualified bidders. Careful consideration was given to financial and physical capabilities of the heavy construction industry. Over 180 construction and service contracts were awarded, ranging widely in value, but

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[66/] _Ibid._, 45

[67/] Churchill Falls (Labrador) Corporation Ltd., _An Energy Giant; the Churchill Falls Power Development_, (1974) 12.

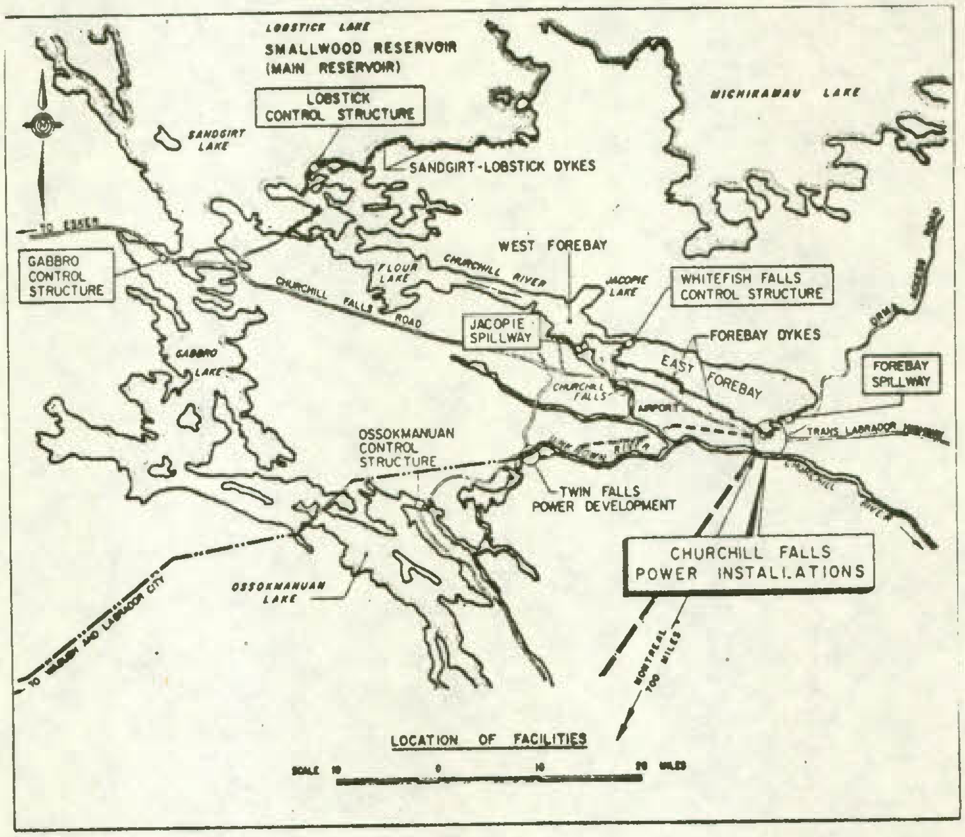
with a maximum of $75 million for a single contract." Both transportation to site and accommodation were handled by CFLCo.[68/]

Direct construction costs were $665 million, of which $650 million was spent in Canada. Fifty-seven per cent went to the Canadian manufacturing industry for equipment, machinery and supplies, the service industry received 17 per cent, and 26 per cent or $170 million were direct labour costs. The labour force peaked at 6,300 in the summer of 1970, and was housed in the camp and townsite of the new town of Churchill, built for a permanent population of more than one thousand. A collective labour agreement between contractors and a council of unions comprised of the Newfoundland-based locals affiliated with international trade and service unions contained a no-strike no-lockout clause and used an agreed formula for periodic wage adjustments. Negotiated in 1967 the agreement was to run until 1975.

When all generators were installed Churchill Falls was to generate 5,225,000 kilowatts, enough to supply the commercial, domestic, industrial and agricultural energy of 3,500,000 Canadians or 11 per cent of Canada's estimated needs in 1976. This enormous capacity was provided by a drainage area of 26,700 square miles, about the size of New Brunswick. Eighty-eight miles of dykes up to 120 feet high, supplemented by numerous large lakes created a 2,200

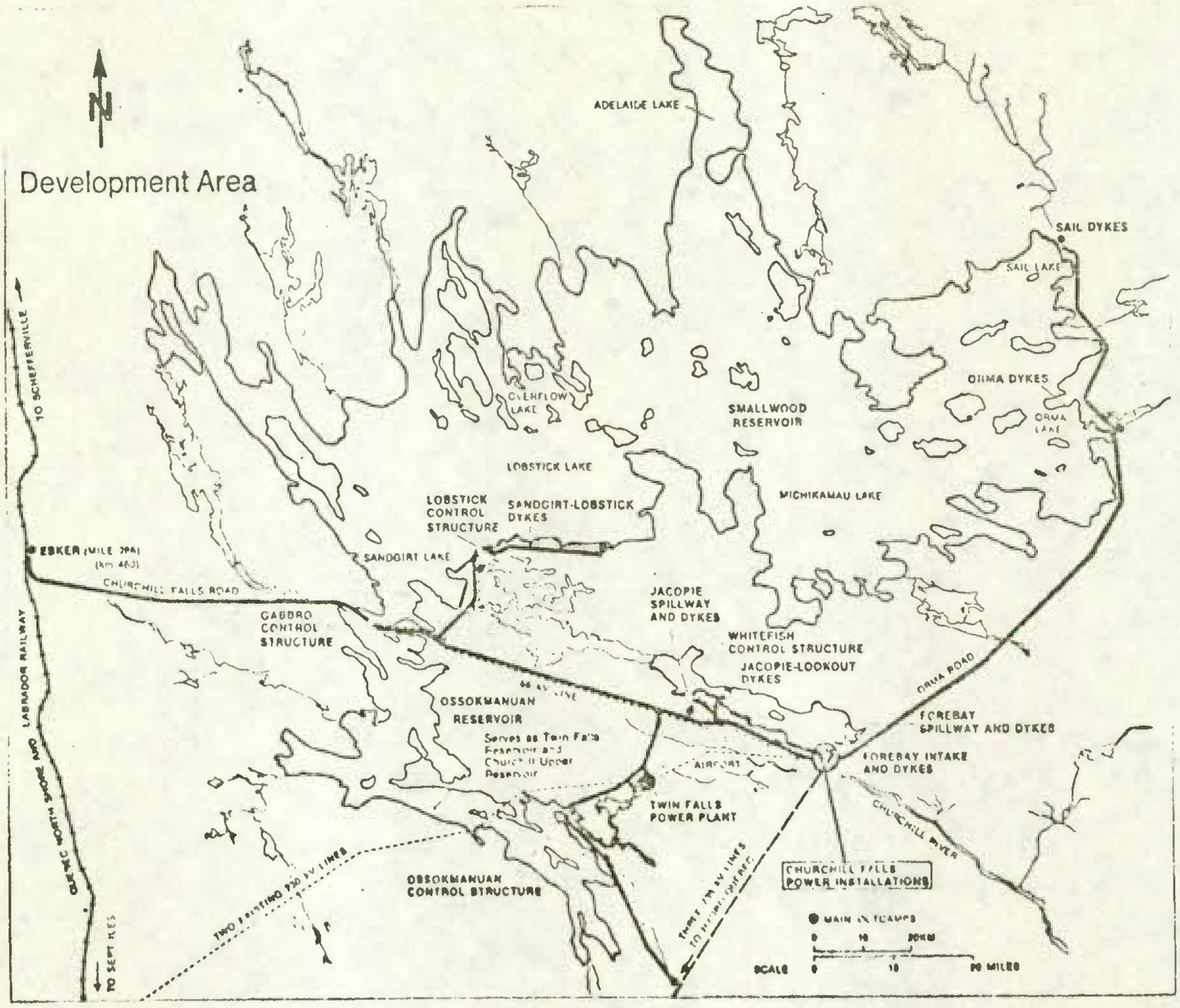
[68/] As the ultimate customer Hydro-Québec also had a close working relationship with the project, and wags said that ACB watched the contractors, CFLCo watched ACB, Hydro-Québec watched CFLO, and God watched Hydro-Québec. Langevin Coté, Heritage, 45.

square mile reservoir. The waters were directed through five control



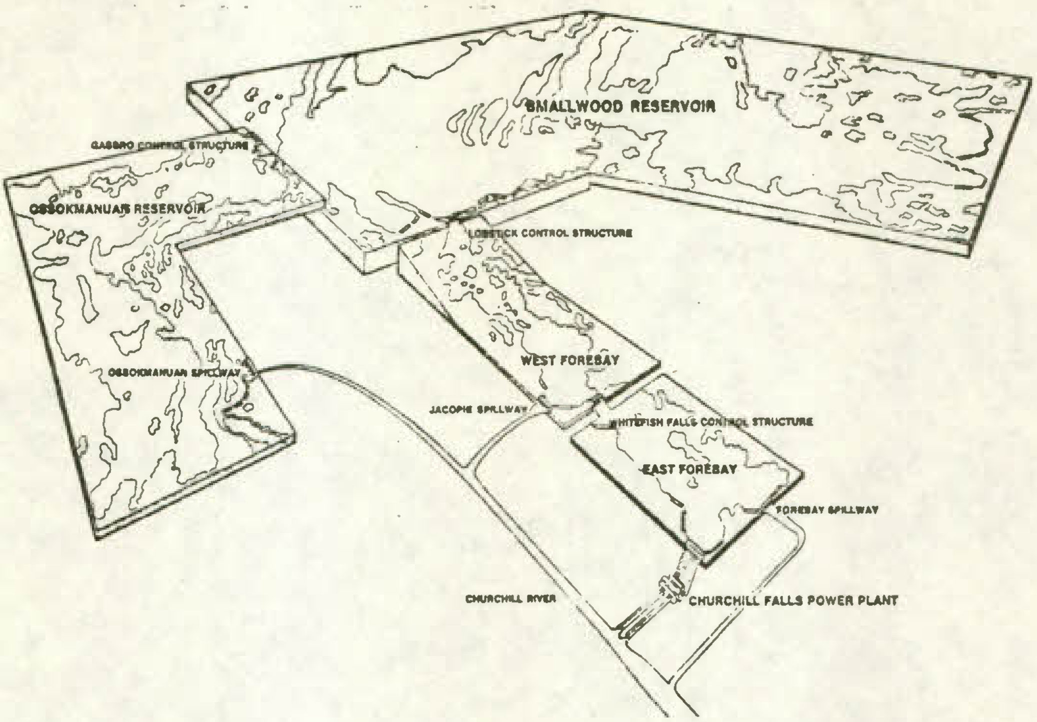
Engineering Journal, October 1971

gates and spillways which had to give trouble free service because of the shallow nature of the reservoir and forebays, the latter holding only enough water for a few days of full plant operation. The huge scale of the project lay in its far flung nature, in its horizontal rather than its vertical dimensions. This factor resulted in the extensive use of helicopters for everything from surveying in the early periods to slinging in buckets of concrete in inaccessable locations and lifting transmission towers into place. The projects used a fleet of six helicopters including a huge Bell 205A-1, the Fat Albert, to do much of its work. One of the tasks of the pilots was



to keep a close watch on wildlife in the slowly flooding reservoir area to ensure that as little damage as possible was done.

The absence of any large vertical structure was one of the most noticeable features of a project of such power dimensions. The key to the development was the re-direction of the flow of the Churchill River above the rapids and falls along a new course through a series of old lakes and new reservoirs. The re-direction started at Jacopie Lake, five miles above the Falls, and was achieved by means of dykes



that filled gaps and depressions in the rim of the plateau and directed the flow to the East Forebay. From the intake, 7,000 feet from the Churchill River but 1,060 feet above it, the water races through the penstocks to the largest underground powerhouse in the world.

"Bigger than the Catacombs and I suspect a lot more useful," mused Prime Minister Trudeau as he surveyed "the hole." The powerhouse (972' x 81' x 154'), the eleven penstocks (1200' x 20'), the surge chamber (763' x 40-64' x 148'), the two tailrace tunnels (5,500' x 60' x 45') demanded the excavation of 7 million cubic yards of solid rock. According to a report in Construction Methods the contractors utilized a diversified range of equipment, bringing in machines new to North American construction and using specially-developed one-of-a-kind rigs.

Leading the way in the most recent phases of the work are two jumbos, the first of their kind to see action on this side of the Atlantic; also, a hydraulic crane specifically built to erect the project's transmission line towers; and a combination hydraulic-percussion drill designed to produce high torque as it penetrates overburden laced with huge boulders.

The custom-rigged Promec T-290C jumbos slant down, almost standing on end as they automatically position their drills to open parallel blast holes for the 1,182-ft-long penstock tunnels angling into the earth at 58 deg.

To maintain drilling positions on the steep grade, the rail-riding jumbos hang suspended at the rear from hoist cables. Up front, they extend jacks against the tunnel face as support and alignment bumpers.

A time-saving sliding plate arrangement enables each jumbo to roll back to the face immediately after a blast and resume work while a fixed rail is laid behind it....

Excavation of the slanting penstock tunnels by Churchill Constructors Joint Venture begins with 8 x 10 pilot holes driven upward from access drifts for each one by Alimak raise climbers - man-carrying platforms traveling on monorails bolted to the rock. The pilots are believed to be the longest ever opened simultaneously at such an angle. And because the pilots are so long, the contractor eliminated power supply installations problems by driving the climbers electrically instead of with conventional air....

Keys to a penstock jumbo's drilling efficiency are the two Atlas Copco Tunmec R 250 Rotabooms precisely located on each of its three working levels. These booms relieve drill operators from spotting decisions and enable them to concentrate on drilling. Using a pantagraph action, the booms

> automatically position feed beams for parallel hole drilling on required centers, leading to a preshear blast effect and saving overbreak costs. The blast holes are drilled parallel to the pilot hole which acts as an oversize burncut. A spectro-Vision laser system keeps the jumbo and tunnel on course....
>
> Before a shot, the jumbo retreats on a sliding steel plate that cantilevers from a fixed track laid as the penstock descends. "This is the only place I've ever known this kind of plate to be used on an incline like this," says veteran tunneler, Lee Lowry, general superintendent, penstocks.
>
> After a shot, the jumbo travels right back to the face to resume drilling. Enroute, any necessary rock bolt drilling takes place from its two upper decks. Also, men working from a hydraulic platform rigged to the jumbo complete scaling where required. As the jumbo drills another round, crews lay a 14-ft section of rail behind it through slots in the sliding plate. 69/

Full-scale construction started with the arrival of spring in 1967. By 1968 most of the details had been settled - including the billion dollars - and the contracts were let for many of the major operations. In May 1969 Hydro-Québec's letter of intent was confirmed by a firm purchase agreement lasting 65 years and worth an estimated $5 billion, one of the largest commercial transactions ever entered into by a private company. By the end of 1970 58 per cent of the work was completed, and the first of the 196 ton transformers arrived in the spring on a special trans-porter 196 feet long with tires seven feet high. Premier Smallwood formally closed the gates at Lobstick on July 1 to begin impounding water in the

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69/ "Churchill Falls Hydroelectric Project is Record-Breaker Above and Below Ground," Construction Methods, LII, No. 5 (May 1970) 65-67.

reservoir named after him. Water moved through penstock I in October, and on December 6, 1971 at 17:17 local time Churchill Falls power was delivered to Hydro-Québec.

The Peace

British Columbia produced one-seventh of Canada's hydro-electricity in 1918 and one-seventh in 1972. Yet despite the towering heights of the Rockies and the Coast Range the construction of large power plants came much later than on the rivers flowing through the ancient granite boulders of the Shield. There were no plants generating 100,000 kw before 1945, and the largest development was on the Kootenay River where COMINCO's three plants generated 150,000 kw. By 1945 COMINCO had started the 108,000 kw Brilliant dam on the Kootenay and by the end of the decade was planning the 292,000 kw Waneta development on the Pend d'Oreille River. A small and scattered population, the absence of a concentrated heavy industrial demand, and the abundance of local private, municipal, and industrial plants clearly explained the late development of major projects. After 1945 the picture changed, however, and by the end of the 1950's the B. C. Electric, now the British Columbia Hydro and Power Authority, had built two plants at Bridge River to add 428,000 kw, Hart at Campbell River (120,000 kw) and Cheakamus (140,000 kw) to feed the rapidly developing lower mainland and Vancouver Island.

Post-war headlines, however, went to the Kitimat-Kemano project on the northern coast where ALCAN blocked the eastward flow of the

Nechako River and drilled a ten mile tunnel through a mountain range to drop the water 2,600 feet to turbines, ultimately capable of generating 1,800,000 kw, a quarter of a mile inside Mt. Dubose.

The largest development in British Columbia was to the north-east, almost in the foothills of the Rockies. Rising to the north in the deep Rocky Mountain Trench is the Finlay and in the south the Parsnip. The Peace is formed by their juncture and flows out of the Rockies through a deep 12 mile canyon to the Mackenzie and on to the Arctic. The territory is virtually deserted, and when the river was backed up to create a 225-mile reservoir only 21 farms, six summer camps, and a few trapping lines were disturbed.

Originating in an agreement between the government of British Columbia and the Wenner-Gren interests for the economic development of northern British Columbia, the Peace River project was controversial from its conception. Wenner-Gren soon became interested in the possible power development, and in the fall of 1957 Premier Bennett issued the first of hundreds of press releases announcing a 4,000,000 hp hydro development on the Peace. For a number of years there was little but press releases and some interim studies, as the controversial Wenner-Gren politics and the Peace-Columbia diplomacy worked their way towards a solution. A giant step was taken in 1961 when the provincial government acquired the B. C. Electric and the Peace River Power Company, and announced that it proposed to develop the Peace and would not "buy back" Columbia power from the United States. A year later Ottawa revoked its ban on hydro exports, and with markets guaranteed enabled the two river policy to proceed,

The Peace River or Portage Mountain Development emerged as one of the country's and world's largest: a reservoir of 57 million acre-feet, the 600 foot W.A.C. Bennett dam, an overall capacity at two sites of over 3 million kilowatts, and an estimated cost of more than $900 million. B.C. Hydro was effectively its own engineer, through a subsidiary which it inherited from the Wenner-Gren interests. There were three or four groupings of contractors, however, that carried most of the construction load: the diversion tunnels were built by Portage Mountain Constructors, a consortium of Drake, Gilpin, Kaiser (Canada), and Mannix; the dam and low level outlets by Kiewit-Dawson-Johnson, the first two through their Canadian branches; the powerhouse access tunnel by Northern Construction and J. W. Stewart; and the powerplant itself by Northern Powerplant Builders, a specially created consortium of Northern, Stewart, Morrison-Knudsen of Canada, Perini Pacific, and J. A. Jones of Canada. When the magnitude of the construction task in building the 230 kv and 500 kv transmission lines 580 miles to Vancouver led to outrageous bids, B.C. Hydro asked for bids on small sections of 100 miles and found that the total of $14 million was $5 million less than the lowest overall bidder.

Again it was the scale that commanded attention. For example, the Kiewit-dominated consortium secured the dam contract with a bid of $6 million lower than its nearest competitor on condition that it could use only the fill from the south moraine, a mile closer than the north moraine but of uncertain volume. Hydro accepted the bid, prepared to gamble the six million against a later demand for extras. The method behind Kiewit's apparent madness was a unique development in construction engineering. The contractors built a three mile long gravity operated conveyor belt from the moraine to the world's largest aggregate plant, where the gravel was sorted and cleaned and sent on another conveyor belt a mile to the site. There the fill spilled into 100-ton bellydump trucks, which never had to leave the dam site, at the rate of 12,000 tons an hour. Dinosaur tracks found in the limestone suggested to observers a prehistoric battle with the roar and crunch of conveyors and gravel, the howling motors of the giant trucks racing over the site at speeds that sometimes threw them feet into the air, or with carelessness axle deep into the mire, and the dwarfed D9 cats hastening to the helpless monster not to devour but to rescue. When the drama ended the dinosaurs had carried 57 million cubic yards from conveyor to dam.

As with many other large engineering projects there was little time lost by the labour force which peaked at 4,850 in 1967 when the payroll was $46.2 million. The owner created the Peace Power Constructors, in which all contractors were required to become shareholders at a nominal cost, which engaged and paid all workers required by the contractors and obtained them through union offices. In 1962 before construction started the owner negotiated a ten-year agreement with the unions covering all work in the development and providing for periodic wage adjustments and arbitration of all unsettled differences.

Engineering design in what the General Manager called a "design as you go basis" moved quickly ahead in 1961. The river was diverted by Premier Bennett in September 1963. The dam was closed in February 1968 and power reached Vancouver from the first unit in September 1968 when $519 of an estimated $925 million had been spent. By the end of March 1973 the installed generating capacity of the eight units was 1.8 million kw, and the ultimate capacity with all ten installed would be more than 2.3 million kilowatts. Almost 5,000 transmission towers and 13,700 miles of transmission lines fed Peace River power to centres of consumption in northern British Columbia and the lower mainland and the United States. Capital cost, including interest and overhead, was $672 million.[70]

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[70] An excellent survey was written by W. F. Miles, one of the engineering group: "The Peace River Project - From Feasibility Report to First Power Output," The Engineering Journal, LII, (October 1969) 12-24. Recent information supplied by B.C. Hydro, November 7, 1974.

REFLECTIONS

"Within the last ten years high voltage electricity has been firmly established with annually increasing powers of extension, and this has brought Canada into the first rank of economical power producing countries," T. C. Keefer told the Royal Society of Canada in 1899. "Water is thus represented by a power to which it can give birth, but which is superior to its own, in that, where ever transplanted, it can do nearly all the parent power could do, as well as give light, heat and greater speed: moreover it has given rise to industries only possible with abundant cheap electricity. What is more important to us is that such industries are those for which Canada possesses the raw material, but which, without water power she could not engage in." Pulpwood manufactured into newsprint by water power, he estimated, would "yield this country ten times the value it is now exported for." An expanded railway network combined with long distance transmission of hydro-electricity "will promote the local manufacture of such wood products....as can bear transportation; thus giving the largest amount of local employment, as well as tonnage to the railway; and delivering us from the position of 'hewers of wood' for other countries."

Not only would hydro provide the energy base for a rapid expansion of metallurgical and electro-chemical industries for which Canada had the raw materials, it would also bring the work to the power for "when the prime mover is water, we have the cheapest power, and perhaps nearest approach to perpetual motion it is possible to obtain...." While hydro would revolutionize many features of economic life in Canada, he concluded, the greatest benefits would lie in the development of the electro-chemical industries because, "in these it is not merely a question of competition of power producers, but one in which intense electricity has the monopoly, and in the case of some of them, as in the production of aluminum, calcium carbide, carborundum, liquid air, etc., their existence depends upon ample supplies of an intense electric current, for the generation of which abundant and cheap water power is indispensable."[71/]

Keefer was not only accurate but modest in his forecast. A decade later another Canadian engineer predicted that "the territory from Labrador to Fort William must become a great power centre, and, by improved transmission, distribute power to great distances. Indeed, by the end of the twentieth century the Ottawa Valley may be the power heart of the world and the centre of a delightful district unrivaled by coal smoke and beautified by reservoirs of unrivaled natural beauty."[72/]

A full scale study of the impact of hydro-electricity on the history of Canada has yet to be written, but the general conclusions are predictable. With current sales to the United States of more

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[71/] Keefer, Presidential Address, 1899, 11-12.

[72/] Cited in Nelles, Politics of Development, 217.

than 5 per cent of total output and the absorption of roughly half that used by industry in the pulp and paper and base metal industries alone for sale of semi-finished goods abroad hydro certainly conforms to the Innisian staple theory.[73/] "But this is not the whole story," John Dales correctly observed in 1957. "A significant proportion (roughly 30 per cent of firm power sales in Quebec) has been consumed by general manufacturing industries, and in this respect hydro-electricity has definitely not been a staple product. Indeed, it is argued here that arithmetic seriously understates the economic significance of that part of hydro-electric output which is sold to manufacturing industry, and that the new hydro-electric technology, applied to Canada's virgin water-power resources, has played a major role in deflecting Canada from its accustomed narrow path of primary production to the broader road of a more diversified economice life."[74/] After a closer inspection of the pre-1939 economies of central Canada Dales concluded that the different emphasis of the Ontario and Quebec economies could in part be explained by the former's easier access to American coal and the latter's readily available hydro-electricity.

[73/] Dales, Hydroelectricity and Industrial Development, 3. In 1971, 7.3 billion kilowatt hours were exported to the United States and 212.5 billion kwh. were made available in Canada. Ontario exported 4,060 million kwh., New Brunswick 1,335 million kwh., Manitoba 687 million kwh., British Columbia 1,172 million kwh., and Quebec 67 million kwh. Quebec, of course, exported power to Ontario - almost 12 billion kw hours in 1973. Canada Year Book 1973, Table 13.16, 597.

[74/] Dales, Hydroelectricity and Industrial Development, 3. In 1971 industry absorbed 56 per cent of the total electrical energy consumed in Canada, of which one-third was used in the mineral industry, one-quarter in pulp and paper, and one-tenth in chemical manufacturing. Canada Year Book 1973, 571.

Looking at pre-war central Canada as a whole, Dales concluded that without hydro it would have had only 40 per cent "of the materials requirements for an industrial structure, and would have had virtually no chance of industrialization. Water power has been a sine qua non of industrial growth in central Canada, and the same could be said of the region's agricultural resources. Central Canada's large mining and forest resources, on the other hand, would have been unavailing for the region's industrial development if they had not been coupled with good hydro-electric and agricultural resources"[75/]

Equally important hydro-electricity has significantly influenced the spatial configuration of economic life in Canada. Lake St. Jean without Arvida, Shawinigan without chemicals, Kapuskasing without Kimberley-Clark and Kleenex, Kitimat without Kemano and Niagara without the falls are equally difficult to imagine. Hydro has changed primitive sawmills or pulpwood passage points to cities, bushland to urban sites, farmlands to factories. The location of industry near raw materials and hydro was in part a creation of the first half of the century before long distance transmission and large installations made centralization possible, particularly if policies such as Ontario Hydro's province-wide rate equalization in 1960 were followed. Yet even today power still brings materials to the hydro frontier, and helps to transform a mine into a city.

The importance of hydro-electricity to locational decisions in

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[75/] Dales, Hydroelectricity and Industrial Development, 175.

the St. Maurice valley and the Saguenay-Lake St. Jean regions are frequently cited. Hydraulic power would undoubtedly have maintained pulp mills, although it is difficult to say for how long. Only electricity made possible the expansion and diversification of the industrial base. The Niagara Peninsula poses a more difficult problem, for American coal was readily available. In the most thorough study of the region, Jackson and White concluded that while relatively inexpensive power was one factor in the locational decisions of some industries it was critical only for the chemical, abrasives and electrometalurgical industries. Such industries quickly grew up on the American side, and, encouraged by the tariff, Cyanamid came to Niagara Falls in 1907, three large abrasive firms arrived between 1910 and 1916, three cutlery firms located in Niagara Falls between 1895 and 1916, electrometals and specialized steel concentrated in Welland after 1907, and INCO built a refinery in Port Colborne in 1918 in part because of hydro-electricity. On the whole, however, transportation, adjacent markets, nearness to what is often the American head office and other factors have more often played the critical role in the economic development of the peninsula.[76]

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[76] John N. Jackson and Carole White, The Industrial Structure of the Niagara Peninsula, (Brock University 1970) 55-57. Contemporaries certainly believed that cheap power was a crucial factor in industrial location, and watched comparative costs. A Buffalo contractor observed in 1907: "The little town of Welland is now getting all the power it wants for $13.00 per horse power whereas in Buffalo the lowest price is $25.00. The Ontario Power Company and the Cataract Electric Light and Power Company both have their transmission lines running through Welland. They compete for business. I hear the same power companies running through Hamilton are selling power in that city at $20.00 and that even a cheaper rate will be charged when the government enacts a law so that the public will own the transmission lines." Cited in Fern A. Sayles, Welland Workers Make History, (Privately published 1963) 47.

The Kootenay River provides a more direct illustration than the more generalized St. Maurice or the ambiguous Niagara, although far less direct than the Peribonca or the Nechako. The discovery of the Rossland gold and copper mines in 1890 and the Sullivan lead-zinc ore body two years later began the modern mining and smelting operations in the Kootenays. In 1895 F. Augusts Heinze, a mining entrepreneur from Butte, Montana, secured one of the properties, a railway from Trail to Rossland, and a smelter at Trail powered by a small 300 kw plant on Trail Creek. The next few years witnessed an epic Canadian-American transportation and financial struggle for control of the Kootenays. By 1898 the Gooderham-Blackstock interests in Toronto had acquired a number of the properties; the Canadian Pacific had extended its line to Rossland and had acquired the Heinze smelter; and Sir Charles Ross and others had formed the West Kootenay Power and Light Company and built a 1800 kw plant on the Kootenay River. By 1906 the Canadian Pacific secured effective control of the mining properties, and a CPR-controlled subsidiary, Consolidated Mining and Smelting, now COMINCO, was incorporated.

The first lead furnace was blown in 1899 and the metal sent to Montana for refining. But in 1902 with the first application in the world of an electrolytic method for refining lead a ten-ton-per-day refinery went into operation.[77/] In 1916 COMINCO pioneered electrolytic refining of zinc on a commercial scale. The growing scale of

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[77/] J. V. Rogers, "Power, The Pathway to Progress," Eighth British Columbia Natural Resources Conference (Victoria 1955) 262.

operations, the electrolytic process, the solution to the problem of separating the complex ores from the Sullivan orebody, and the construction of a concentrator at Kimberley placed increasingly heavy demands on the hydro-electric system.

The first 1800 kw plant built at Lower Bonnington in 1897 was expanded to provide 3000 kw for the lead refining in 1899. A second plant, at Upper Bonnington, was begun in 1905, its 12,000 kw capacity making it the largest in the province. By 1916 capacity had doubled, and as West Kootenay's best customer COMINCO followed the obvious course and bought control. The increased production of the late 1920s and increased sales to cities in the vicinity compelled COMINCO to expand the old plants and in 1929 construct a 47,250 kw plant at South Slocan. Capacity was expanded again in 1933 and 1940, the Brilliant development began operations in 1944, and the first phase of the large Waneta plant on the Pend d'Oreille River started up in 1954. By 1970 COMINCO's plants on the Kootenay and the Pend d'Oreille generated 550,000 kw, most of which fed directly into the company's operations.

Hydro had not only made possible a vertical industrial extension based on the mines, but as J. V. Rogers observed it also had led to the establishment of a new industry:

> ....one of the effects of low cost power on industry has been the impetus it has provided, in many instances, for the recovery of waste products. An outstanding example of the application of electric power to this purpose is demonstrated in the large chemical fertilizer industry which has grown up at Cominco around the recovery of sulphur

> from the volumes of sulphur dioxide gas which had previously been discharged to the atmosphere. This development, although accelerated by the claims by the U.S. farmers to the south for compensation for crop damages, nevertheless was influenced by the proximity of the Kootenay River water power resources. It was on account of the availability of this power that the decision was made to use the electrolysis of water as the source of hydrogen for ammonia, a necessary ingredient in the manufacture of Cominco's fertilizers.
>
> Cominco has now become one of the largest manufacturers of chemical fertilizers on the continent and today requires 125,000 kw of electric power for this purpose alone.... 78/

Hydro was a passive instrument, however, for it was COMINCO that seized an opportunity to be inventive in Trail and the aggressive salesmanship of Aldred that built up Shawinigan's hydro empire. On the Pacific coast, on the other hand, although B.C. Electric advertised the availability of "cheap and abundant power" in the financial papers it made little attempt to build up a market. As Patricia Roy concluded except "in unusual circumstances, such as the early war years, the B.C.E.R. made no significant attempt to attract new industries to use either its hydro-electric power or its rail lines. Under normal conditions, the company did not encourage new power-using industries such as chemical plants and metal working establishments to come to British Columbia."[79/]

[78/] Ibid., 262

[79/] Patricia Roy, The British Columbia Electric Railway Company, 1897-1928; A British Company in British Columbia (PhD Thesis; University of British Columbia 1970) 357.

The leadership of Ontario Hydro for half a century has helped to create the illusion in Canada that hydro-electricity has been largely developed through public ownership, but an illusion it is. Today almost 80 per cent of the generating capacity is publicly owned. In 1918 more than 80 per cent was privately owned, and more than half of the publicly owned power was generated by Ontario Hydro. Only in 1955 did public pass private by a narrow margin, and the balance did not swing decisively until the takeovers in British Columbia in 1961 and Quebec in 1963.

A related illusion has created the image of hydro-electric development as a uniquely Canadian enterprise, like the rivers. Yet, as with so many other cases, hydro-electric enterprises were in the early stages largely financed, and often initiated, in the United States, with considerable British direct investment. In Quebec, for example, the two major producers before 1914 were Shawinigan and Montreal Light, Heat and Power. The American Shawinigan produced 75 per cent of their combined output. By 1929 American owned or controlled firms produced 76 per cent of the output in Quebec and in 1962 owned or controlled more than 60 per cent and had assets estimated at roughly $750 million. The net cost of nationalisation "exigea une somme de 308.5 millions de dollars, et l'emission sur le marché d'obligations d'un montant supérieur à 53 millions de dollars, à échéance de dix ans. L'Hydro-Québec assuma en outre la responsabilité totale de la dette hypothécaire des compagnies nationalisées, dette qui s'élevait à quelque 250 millions de dollars,"[80/] American and Canadian owners were repayed through the issue of a $300 million bond issue in the United States, spread over fifteen months at the request of the American government. Nationalisation left 10 per cent of Quebec's capacity in private hands, the bulk of which was owned by three American firms.

In Ontario, Niagara Falls was initially developed by two American firms, which by 1913 had almost 50 per cent of the provincial capacity and had more capital invested than Canadians at Niagara. Many industrial plants associated with the pulp and paper industry were American owned, and as late as 1968 American owned or controlled companies generated about one-third of the privately owned hydro-electric power in Ontario. At the same time American companies produced more than 50 per cent of the private power in British Columbia, largely because of Alcan's Kitimat. Earlier, British financiers had built the B.C. Electric, but it was repatriated in 1928 when the A. J. Nesbitt utility grabbers secured control. As late as 1972 two-thirds of Newfoundland's power was privately owned, most of it by Brinco. In the spring of 1974, however, the Newfoundland government bought Brinco's shares in Churchill Falls for $160 million. More than 75 per cent of Alberta's hydro is privately generated by Calgary Power, a corporation established in 1909 by Max Aitken, R. B. Bennett and their friends. Only Manitoba and Saskatchewan followed

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[80/] Yvon De Guise, Forces, "Histoire qui a vingt-cinq ans," 13. See also Paul Sauriol, Nationalization of Electric Power, 79.

Ontario's lead, although all provinces but Alberta have since created provincially owned hydro-electric production and distribution companies.

There is less fiction in the boast that Canadians are among the great dam builders in the world. The stage of Canadian economic development was such by the 1890s, when the scientific and technical breakthroughs had occurred, that Canada could move into hydro development at the same time as the Americans and Europeans. There were, of course, American engineers and contractors on the scene from the beginning, and George Hardy often combined the engineering of pulp mills and hydro plants. But the University of Toronto-trained H. G. Acres, who first cut his teeth working for the Americans at Niagara and then became Ontario Hydro's chief engineer, ultimately established perhaps the country's foremost hydro-electric engineering firm. C. B. Smith acquired experience with Ontario Hydro and later formed Smith, Kerry and Chace, Mr. Chace being the engineer who had succeeded him as chief engineer of Winnipeg's Point du Bois plant in 1906. It is difficult to be precise about engineering and construction, however, for the owner often fulfilled both functions, whatever sub-contracting there may have been. A rough survey of about one hundred of the larger dams yields the following estimates:

	Owner		Engineering		Construction	
	1900-45	1945-70	1900-45	1945-70	1900-45	1945-70
Canadian	13	52	13	52	16	41
American	15	23	14	8	9	3
U. S. Subsidiary	-	-	-	-	-	17

Perhaps the most interesting feature of the Canadianization of engineering and construction is the importance of branches of the giant multi-national American heavy construction companies in post-war Canadian construction.

Labour costs have always been an important aspect of hydro-electric construction. Each river, however, has set its own balance between construction and machinery and equipment, although construction costs seldom seem to have fallen below 40 per cent. Innovation if not invention in the use of machinery and equipment has characterized hydro construction, and large numbers of skilled labour, from draughtsmen and engineers to machine operators, has been essential.[81/] But

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81/ As the contractor for the Eugenia Falls storage dam noted in 1914 the increasing use of machinery posed management problems: "In the old days of contracting when manual labor was largely employed, there was less liability for an error in judgment with regard to the time and cost, as the forces employed were much less complex, and more laborers could be easily added or more work could be produced by better management from a given number of men. In modern contracting, however, when the plant is once installed the time and expense of replacing any units which may fall below their estimated capacity will in all probability eat up the profit and possibly more, so that it is of great importance that first calculations be on the safe side, and a considerable margin be allowed for contingencies." G. R. Heckle, "Storage Dam at Eugenia Falls," The Canadian Engineer, XXVII, (December 1914) 725.

even with the highly mechanized operations at Bennett or Manic the projects consume an enormous number of unskilled man hours. Once again the labour has often been composed of relatively new immigrants. Describing construction at Niagara in 1905 a Canadian reporter wrote: "Strange men from far countries with quaint beliefs helped to dig and build. The rats were safe among them, for the bloodshed might bring evil on the place."[82/] The unskilled labour on the Bassona irrigation dam in southern Alberta in 1910 was "principally Italian, the skilled labour being of all nationalities."[83/] The hearings of the Gregory Commission on bootlegging and drinking during the construction of Beck No. I indicated that a significant proportion of the work force were immigrants. The recitation could continue. But speaking to the Chamber of Commerce in September 1974, however, Manpower Minister Robert Andras warned that "I don't think we can rely on low-paid immigrants to do the dirty work." Canadians were willing to undertake the dirty work, he stated in a stout defence of the Canadian's work ethic, but wanted personal as well as financial rewards.[84/]

82/ Cited in Nelles, Politics of Development, 220.

83/ H. B. Muckleston, "The Design and Construction of the Bassona Dam: Part I," Engineering News, LXXII, No. 9 (August 1914), 485.

84/ Globe and Mail, October 30, 1974.