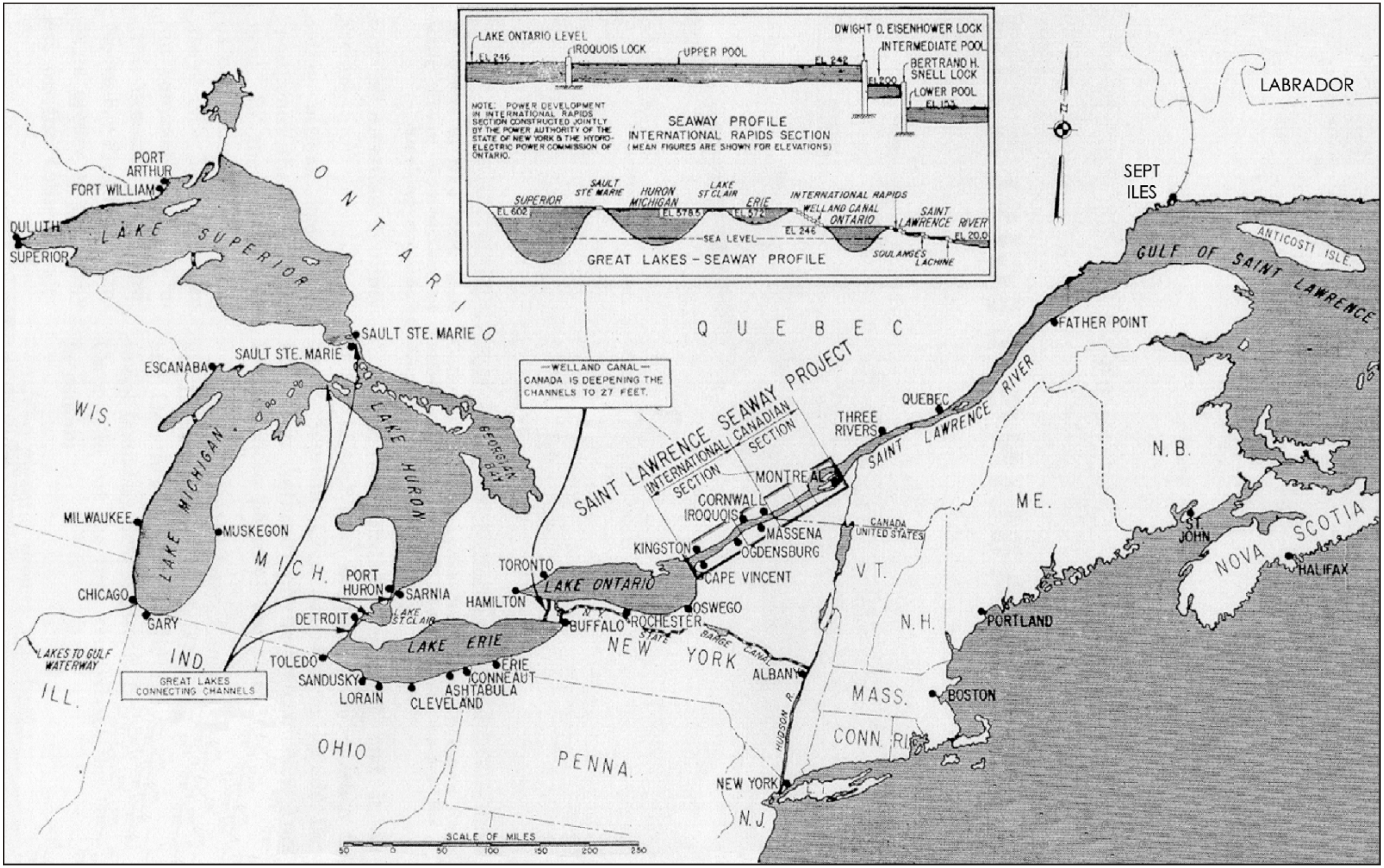


Great Lakes–St. Lawrence River waterways system. (St. Lawrence Seaway and Power Projects)

CONSTRUCTION OF THE ST. LAWRENCE SEAWAY

Robert W. Passfield

Introduction

The St. Lawrence Seaway was constructed in 1954–1959 to enable lake boats from the upper Great Lakes to reach Montréal and the lower St. Lawrence River ports, and ocean-going ships to enter the Great Lakes in the continental interior. It superseded a smaller-scale Canadian ship-canals system that had become a transportation bottleneck on the upper St. Lawrence River. Extending from Montréal to Lake Ontario, a distance of 181.5 statute miles, the Seaway overcame a 226' drop in the river by means of three major dams and seven large locks. The construction project had three distinct components: the construction of a deep waterway for navigation purposes; the building of an international hydroelectric plant for power generation; and the establishment of a water-control system. The navigation component of the project was an international undertaking by the Canadian and U.S. governments; the power-project component was undertaken jointly by the Ontario Hydro-Electric Power Commission and the Power Authority of the State of New York; and all four authorities coordinated the development of the water-control system.

The present paper will provide an overview history of the construction of the St. Lawrence Seaway focusing on the complex organizational nature of the construction project, the magnitude of its several component projects, and the challenges overcome by the engineering staffs to keep the project on a tight fast-track construction schedule. It will conclude with an assessment of the engineering achievement realized in the construction of the St. Lawrence Seaway.

Background

From the beginning of settlement in North America, the use and improvement of natural waterways have played a critical role in the expansion of settlement, trade, and commerce into the continental interior; and for Canadians, the St. Lawrence River and its Great Lakes headwaters have constituted the main transportation artery into the interior. However, the improving of this waterway has posed several long-standing engineering challenges involving the overcoming of a series of extensive rapids on the upper St. Lawrence River above Montréal, and the bypassing of Niagara Falls, a 326' vertical fall of the Niagara River between Lake Erie and Lake Ontario. A further obstacle to navigation, an 18' drop in the St. Mary's River rapids between Lake Superior and Lake Huron, posed a lesser challenge.

From the late eighteenth century onwards, Canadians constructed a series of canals of ever-increasing dimensions on the St. Lawrence River and at Niagara, and by 1896, with the opening of a Canadian canal at the St. Mary's Rapids, there was a Canadian ship-canals system in place that enabled steam-powered lake freighters, so-called "Welland Canallers," to travel between the ocean port of Montréal and the head of Lake Superior. The ship-navigation system consisted of six canals on the St. Lawrence River and a canal bypassing Niagara Falls (the Third Welland Canal), which were built to a uniform scale with 270' x 45' locks on canals of 14' depth; and an even larger-scale canal on the St. Mary's River at Sault Ste. Marie, with a single 900' x 60' flotilla lock on a 20'-deep navigation capable of passing three Welland Canallers in a single lockage.[1]

On the St. Mary's River, the State of Michigan had opened a canal on the American side of the river as early as 1855, and it was subsequently enlarged and deepened by the U.S. Army Corps of Engineers. By 1897, the American St. Mary's Falls Canal had two parallel flotilla locks on a 20'-deep navigation built in response to the stupendous growth of American iron ore and grain shipments on the upper Great Lakes in the late nineteenth century; and the Canadian canal at the Sault Ste. Marie Canal was likewise constructed with a flotilla lock to handle the heavy traffic of the burgeoning upper-lakes shipping trade. However, with the availability of large flotilla locks on both the American and Canadian canals at Sault Ste. Marie, shipbuilders dramatically increased the size of the lake boats launched on the upper lakes. Within a decade of the completion of the Canadian ship-canals system, a new class of lake boat was being built to a colossal 600' x 58' standard. These huge "upper lake boats" came to be employed in large numbers in transporting iron ore and grain eastward to Lake Erie ports for transshipment into rail cars and the New York Barge Canal, and coal westward to the American Midwest, but were confined to the upper lakes, unable to pass through the Welland and St. Lawrence ship canals.[2]

In Canada, a parallel boom in the grain export trade strained the existing rail and water transport system beyond its capacity, and Canadian shipping and business interests began demanding that the Welland and St. Lawrence ship canals be deepened and enlarged. It was calculated that an upper lake boat could deliver grain to Montreal at half the cost of a Welland Canaller, and in immensely greater quantities. In response, the Canadian government in 1913 undertook to construct a large deepwater canal to bypass Niagara Falls (the Fourth Welland Canal), and subsequently sought to secure American participation in the construction of a St. Lawrence deepwater navigation.[3]

Origins of the St. Lawrence Seaway Project

In September 1918 the Canadian government approached the United States with a proposal that the two countries enter into an agreement to jointly construct either a St. Lawrence deep waterway navigation, or a combined St. Lawrence deep waterway and hydroelectric power project. Several studies were undertaken subsequently by a Joint Board of Engineers, which recommended that the two countries undertake a combined navigation and power project on the St. Lawrence River; and that the navigation be 25' deep with locks 800' x 80' to match the scale adopted for the Fourth Welland Canal.[4] The cost of the proposed joint St. Lawrence deep waterway project was to be borne equally by Canada and the United States, with the revenue from electric power sales used to pay the capital costs of the project, as well as subsequent operating and maintenance costs, so as to maintain the entire St. Lawrence-Great Lakes deep waterway free of tolls.[5]

Although the U.S. government and U.S. Army Corps of Engineers favored the construction of a St. Lawrence deep waterway and power project, it aroused strong opposition in that country. In the U.S., in contrast to Canada, the St. Lawrence River was a comparatively minor trade route. Most of the export trade of the American continental interior was carried on railroads to east-coast ports, on the upper Great Lakes to Lake Erie ports for transshipment by rail carriage or the New York State Barge Canal to New York, or on the Mississippi barge system to New Orleans and the Gulf ports. Fearful that a St. Lawrence deep waterway would divert trade away from existing channels, American railroads, the Atlantic and Gulf ports, and shipping interests attacked the proposal as an unwarranted subsidy to a competing, foreign (Canadian) navigation system; and they were joined by coal and oil interests, who supplied thermal-power generating plants, and private electric-power generating companies, who objected to the American government sponsoring a competing public power project.[6] Despite the signing of a Great Lakes Waterway Treaty in 1932, and a Great Lakes-St. Lawrence Basin Agreement in 1941, which committed both countries to joint construction of a St. Lawrence deep waterway-power project, and the attainment of a 27'-deep navigation throughout the Great Lakes-St. Lawrence system, American participation was blocked in each case by the U.S. Senate refusing ratification.

Several subsequent efforts to ratify the 1941 agreement failed; and finally, in 1951, Canada announced that it would "go ahead alone" to construct a St. Lawrence deep waterway totally within Canadian territory. Several new factors combined to make a Canadian deep waterway feasible. Canada was enjoying a postwar economic boom, with its population and industrial base rapidly expanding; and power shortages were being experienced in Ontario. Morever, neighboring states in the U.S. had power shortages as well, and the Power Authority of the State of New York and the Hydro-Electric Power Commission of Ontario wanted to undertake joint development of the 2.2 million h.p. capacity of the Long Sault Rapids in the International Rapids Section of the St. Lawrence River. This raised the possibility of constructing the combined St. Lawrence deep waterway/power development project, with the hydro authorities paying for the power component of the project. Moreover, with planning proceeding for the development of the iron-ore resources of Quebec-Labrador to feed the steel mills in the Great Lakes basin, the potential economic viability of a deep waterway was greatly enhanced.

The completion of the Fourth Welland Canal (1913–1932) was an equally crucial factor. The new 25'-deep canal had 800' x 80' locks, with 30' of water on the sills to allow for future deepening, and enabled upper lake boats to descend past Niagara Falls to Lake Ontario and beyond to Prescott at the head of the upper St. Lawrence River rapids. There the upper lake boats transshipped their cargo into rail cars and the smaller Welland Canallers capable of passing downriver to Montréal through the 270' x 45' locks on the 14'-deep St. Lawrence ship-canals system. A Canadian St. Lawrence deep waterway, however, would remove this bottleneck in the navigation system. It would enable the huge upper lake boats to carry grain directly to the ocean port of Montréal, and then proceed further downriver to Sept-Îles to pick up iron ore, another high-value bulk cargo, for the return voyage inland to the Great Lakes. Moreover, a St. Lawrence deepwater navigation would also enable large ocean freighters to enter directly into the Great Lakes, greatly reducing overseas shipping costs.

For the first time a solely Canadian deepwater navigation was deemed economically feasible. If the two hydro authorities would finance and construct the power component of a combined navigation and power project, Canada was in a position to construct a St. Lawrence deep waterway on its own, totally within Canadian territory. Moreover, the power-project dams would reduce the cost of constructing the deep waterway.[7]

In 1951, Canada established a Crown corporation, the St. Lawrence Seaway Authority, to construct, operate and maintain an all-Canadian seaway; and authorized Ontario Hydro to construct power works in the St. Lawrence River. Thereafter, approval was gained from the International Joint Commission for the construction of the navigation and power works in the International Section of the St. Lawrence River; and the U.S. Federal Power Commission approved the New York component of the power project in May 1953. The final obstacle was overcome in June 1954, when the U.S. Supreme Court refused to hear a legal challenge to the power project.[8] Thereupon, the way was cleared for the construction of an all-Canadian Seaway by the Canadian government, in conjunction with an international power project undertaken by the Ontario and New York power authorities. For strategic defense reasons, the U.S. federal government and military favored the building of the Seaway, and yet also wanted to participate in the navigation component of the project.

With the depletion of high-grade ore in the Mesabi Iron Ore Range on Lake Superior, American steel mills in the Great Lakes basin needed a secure source of iron ore, which the Quebec-Labrador mines could provide economically with a deep waterway in place; and there was a concern to increase American electric power capacity, which had been highly strained during the Second World War. The American navy was also anxious for the construction of a St. Lawrence deep waterway to gain access to the shipbuilding capacity of the Great Lakes ports for the construction of warships in any future war; and the St. Lawrence deep waterway, in conjunction with a two-foot deepening of the Fourth Welland Canal and the Great Lakes river channels, would make that possible. However, the American government did not want such a strategic deep waterway to be totally under foreign control.

Faced with the imminent threat of an all-Canadian St. Lawrence Seaway, Congress passed the Wiley-Dondero Act (May 1954), which authorized the construction of deepwater navigation facilities on the American side of the International Rapids Section of the St. Lawrence River, and created a St. Lawrence Seaway Development Corporation to carry out the construction project. To obtain passage of the act, Congress was assured that the cost of the seaway would be self-liquidating within 50 years through the imposition of tolls on the Seaway.[9] Thereafter, American representatives went to Ottawa, and during July and August negotiated American participation in the St. Lawrence Seaway project.[10]

Once agreement was reached on the division of responsibilities in the international sections of the Seaway project, both countries proceeded quickly with getting the long-delayed St. Lawrence deep waterway construction project underway. On August 10, 1954, a sod-turning ceremony was held at Cornwall, Ontario, to launch the construction project. American participation, however, was far less favorable to Canada than previously planned. Since almost 75% of the required construction work for the Seaway would be within Canadian territory, Canada would now pay a much greater proportion of the cost than the 50%-50% sharing of costs specified in the earlier, abortive, joint construction agreements; and the imposition of tolls was contrary to Canada's desire to minimize shipping costs on the Great Lakes-St. Lawrence waterways system. However, there was a major gain over Canada going it alone. The U.S. would construct and pay for over one-quarter of the navigation component of the St. Lawrence Seaway project.[11]

Construction of the St. Lawrence Seaway

In the United States the Army Corps of Engineers was appointed the construction agent for the St. Lawrence Seaway Development Corporation; and in Canada, the Special Projects Branch, Department of Transport (DOT) was incorporated into the St. Lawrence Seaway Authority to supervise all work on the Canadian component of the seaway navigation. This arrangement greatly facilitated a surprisingly fast start of construction as both the DOT engineers and the Corps of Engineers had extensive data, surveys and plans already in place. Hence, Canada was able to begin awarding contracts as early as October 1954, and the U.S. in January 1955.

Almost from the start, there was an accelerated construction schedule in force. The initial plan called for the power and navigation components of the Seaway to open with the commencement of the 1959 navigation season, but this was moved up to July 1, 1958, at the insistence of the Power Authority of the State of New York (PASNY). The power authority was anxious to get power on line as early as 1958 to secure revenues to offset heavy interest charges on monies raised to construct the power project, and to meet the terms of a bond issue. Hence, a planned five-year project was fast tracked for completion in less than four years.[12]

The construction project was organized in three major geographical sections: the Thousand Island Section; the International Rapids Section; and the Canadian Section, which was sub-divided into three work zones: Lake St. Francis; the Soulanges; and the Lachine. Construction proceeded simultaneously on all three sections of the Seaway. Seven locks, 800' x 80' with 30' of water on the sills, would be required to provide 226' of lockage to overcome the fall of the St. Lawrence River rapids, and the river and lake channels were to be dredged to a 27' depth from Lake Ontario to Montréal. The power components of the project were to be constructed in the International Rapids Section.

In American territory, all the navigation works were designed and constructed by the U.S. Army Corps of Engineers, acting under the authority of the St. Lawrence Seaway Development Corporation; and the power works were designed, and their construction supervised by a Boston engineering firm, Uhl, Hall & Rich, acting for the Power Authority of the State of New York. On the Canadian side of the boundary, the navigation works were designed and constructed by the St. Lawrence Seaway Authority engineers, and the power works by Ontario Hydro engineers. The acquisition of the lands to be flooded and relocation of the affected communities were the sole responsibility of the hydro authorities. All construction work was let on competitive bid to private contractors and supervised by the respective authorities, with the exception of dredging in American channels, which was carried out directly by the U.S. Army Corps of Engineers. Canadian contractors performed the work within Canada; American contractors did likewise on the American side of the international boundary line.

In the Canadian Section, the St. Lawrence Seaway Authority was solely responsible for the project, and all the dredging and construction work was carried out by Canadian contractors. Here, planning and construction work had to be coordinated with Quebec Hydro, which had a major power installation already in place at Beauharnois, and with the municipalities of the greater Montréal area to establish the impact of changing water levels, and to ensure that hydro, telephone, sewage and water facilities, as well as highway, railway and bridge arteries would not be cut or blocked until they could be moved, realigned, or replaced with new facilities.

All construction work in the Thousand Islands and International Rapids sections was coordinated by a Joint Board of Engineers, with equal Canadian and American representation. The board reviewed and approved all plans, specifications, and work schedules, oversaw their coordination at all work sites, and was responsible for inspecting the completed work. Initially, the board was responsible as well for securing agreement on the establishment of water levels and the navigation criteria governing construction of the deep waterway. These criteria encompassed the required depth of channel in earth and rock (27'and 29') and the minimum width of channels (450'); criteria governing acceptable alignments and allowable curvatures in the navigation channel; and the maximum river-current velocity allowable during the navigation season (4' per second/2.75 mph). It also had to achieve agreement on the establishment of a uniform system of measurement and calculation methods between the two countries for recording and interpreting data relating to "negative deviations" (short-term fluctuations in water levels) and "negative surges" (sharp natural variations in water level), as well as agreement on how the water levels were to be controlled by the Seaway works; and how water was to be diverted during the construction period while maintaining the water levels needed in the river for an uninterrupted operation of the existing 14'-deep ship navigation until superseded by the new Seaway.

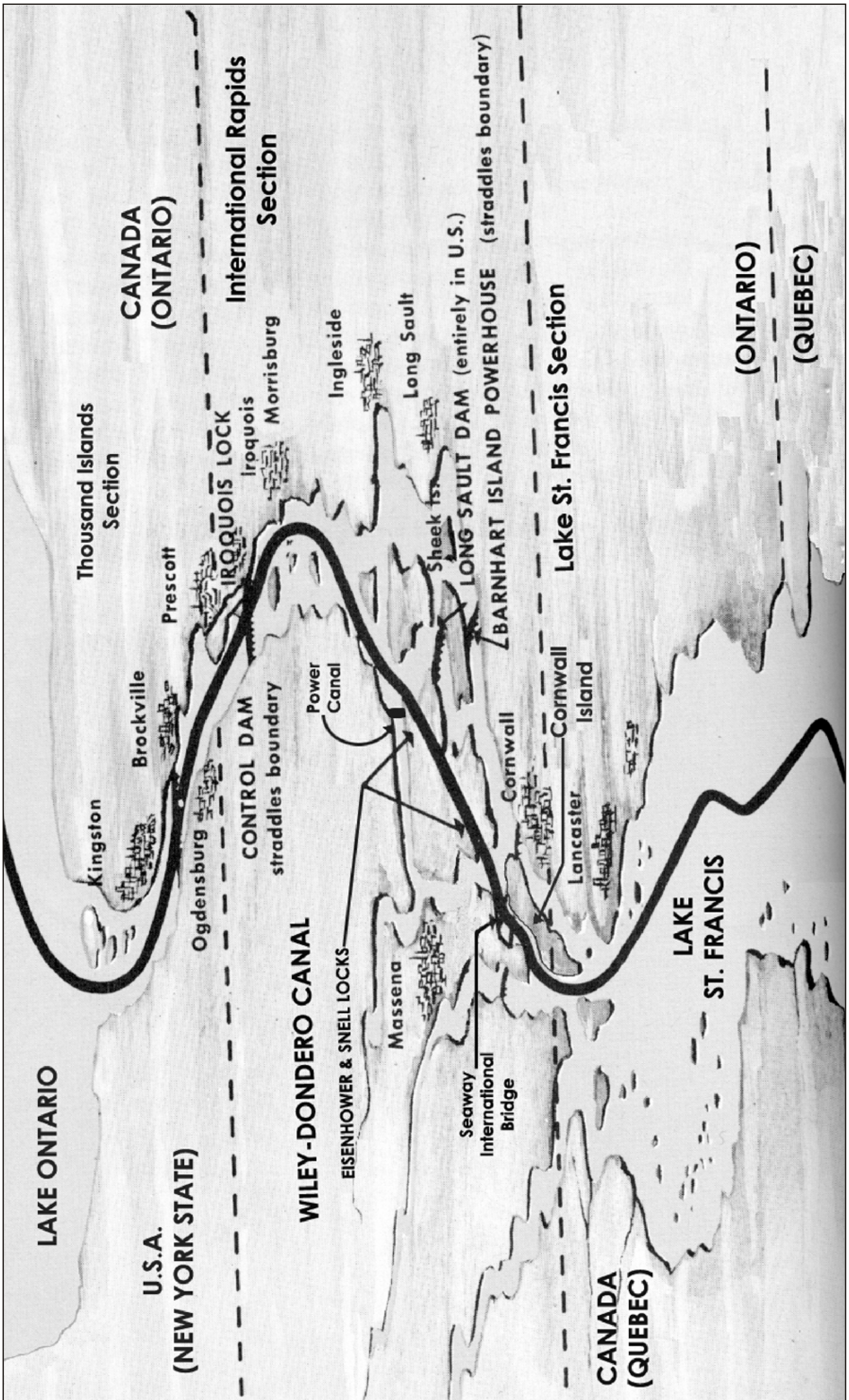
Early in the project, the Joint Board of Engineers managed to achieve agreement on the navigation criteria and water-control measures, after extended negotiations with the four authorities and some major compromises between navigation concerns and power-project needs. Once approved by the International Joint Commission (IJC), detailed design work proceeded quickly on the navigation and power works while dredging, excavation, and embanking work were pushed forward at a rapid pace on all sections of the St. Lawrence Seaway project.[13]

The nature, complexity, and volume of the work differed greatly within each section, as did the construction challenges encountered; and although the construction technologies employed on the Seaway were typical of contemporary large-scale North American engineering projects, there were significant differences in the construction approaches adopted by the contractors, and advanced construction technologies were introduced at some work sites.

Thousand Islands Section

The main river channel through the Thousand Islands was navigable to a 25' depth for its entire 68 miles from Wolf Island on Lake Ontario to Chimney Point, just below Prescott at the head of the upper St. Lawrence River Rapids. Here the work consisted mainly of straightening and dredging the main river channel to a 27' depth and a minimum 450' width, and the removal of upwards of sixty rocky shoals to a 29' depth. In the Thousand Islands, the upper 45 miles of the navigation channel was in American waters and was dredged by the U.S. Army Corps of Engineers, while the channel from mile 45 to mile 68 was in Canadian waters and dredged by Canadian contractors. The Thousand Islands section was almost an arm of Lake Ontario, with only a one-foot drop over its entire length and a very slow current.

To enable Canadian and American work vessels and sub-contractors to engage in cross-border work where the navigation channel straddled the international boundary, an agreement was concluded between the U.S. Secretary of State and the Canadian Secretary of State for External Affairs. Hence, in the Thousand Islands section there was close cooperation between the U.S. and Canadian seaway authorities in pursuing the dredging required. The work was quite heavy, but not technically demanding, and the only problem experienced, by both parties, was in securing enough dredging equipment to perform all the work required to meet the accelerated work schedule in force.[14]



Great Lakes–St. Lawrence River waterways system. (St. Lawrence Seaway and Power Projects)

International Section

The International Section extends from Chimney Point to Cornwall, a distance of 44 miles, in which the upper St. Lawrence River dropped 82' through a series of rapids: the Iroquois, Galop, Rapide Plat, Farran's Point, and Long Sault rapids. In this section, major power and navigation works were constructed, and the river channels improved for both navigation and power purposes, with all four authorities involved in coordinating and carrying out heavy construction work. The power project required the river to be dammed completely at two locations: the head of the rapids, at Iroquois Point, where a control dam was constructed to control water levels in the upper river and Lake Ontario, and at the foot of the rapids, at Barnhart Island, where a spillway dam and the international powerhouse dam were constructed on either side of the island to raise a power pool, or head of water, to drive the turbines of the new powerhouse as well as flood out the upstream rapids for navigation purposes. The Seaway navigation required the construction of a lock at Iroquois Point to bypass the control dam, and a ten-mile-long canal with two locks, the Wiley-Dondero Canal, on the American side of the river to bypass the power dams at Barnhart Island as well as extensive dredging and excavation work to deepen and straighten the river channels.

In addition to the power and navigation works constructed in the International Section, the planned raising of the water level by the power dams required the relocation of a number of communities, the laying out of several new towns, the moving of a major highway and railway mainline, and construction of a new high-level bridge over the Seaway channel. All of these works had to be closely coordinated and completed on a fast-track schedule governed by the deadline for raising the power pool. Moreover, the complexity of the work was complicated further by a related project to save a number of historic structures for relocation, and preservation, in an historic village park setting.

All of the engineering works in the International Section required an unusually high degree of coordination in their design and in the scheduling of the construction work. They were part of a common, integrated system of water control, navigation and power, with contractors from Canada and the United States working on adjacent work sites and, at several sites, employed in constructing different components of a single structure. Difficult construction challenges were faced, as well, on the International Section in completing some of the engineering works.

The *Iroquois Control Dam*, which crosses the St. Lawrence River between Iroquois Point, Ontario, and Point Rockway, New York, was constructed to regulate the level of Lake Ontario and to form a reservoir to ensure a dependable flow of water to the power pool downstream. A 74'-high concrete structure, 2,000' long, it maintains Lake Ontario a foot above its natural minimum level; the gates are opened, as required, to maintain a minimum river flow of 180,000 cubic feet per second (cfs), 12% greater than the natural minimum river flow. In times of high water, the control dam can pass a maximum flow of 310,000 cfs, almost the maximum natural flow of the river. In the spring, flood waters are held back for storage in Lake Ontario, and released into the power pool in the summer during periods of low water.

Iroquois Lock and Control Dam, looking downstream, 1958. (St. Lawrence Seaway and Power Projects)

The *Iroquois Lock*, which enables ships to bypass the control dam, is located at the Canadian end of the dam in a 1¾- mile-long canal channel. It functions as a guard lock, with a low lift that varies from 6" to 6', depending on the relative level of the power pool to the fluctuating river levels above the control dam. The control dam was constructed by the power authorities, and the Iroquois Lock by the St. Lawrence Seaway Authority. Both were built behind cofferdams, and the excavations were difficult and time-consuming. The concrete construction work was quite conventional.[15] The lock, however, was constructed with two sets of steel sector gates at each end, rather than the conventional mitre gates, to enable the lock gates to serve as an emergency dam in the event that any one pair of gates were destroyed by a vessel striking them; a Scherzer rolling-lift bascule bridge was erected across the lower end of the lock to provide access to the control dam.[16]

The *Robert Moses-Robert H. Saunders Powerhouse Dam* was constructed at the foot of the rapids in the International Section across the north channel (the international boundary) of the St. Lawrence River at the foot of Barnhart Island. The powerhouse dam, in conjunction with a spillway dam, the Long Sault Spillway Dam built across the south (American) channel at the head of Barnhart Island, raises an 81' head of water, and floods the river back for 35 miles upstream to a maximum width of four miles. The flooded section of the

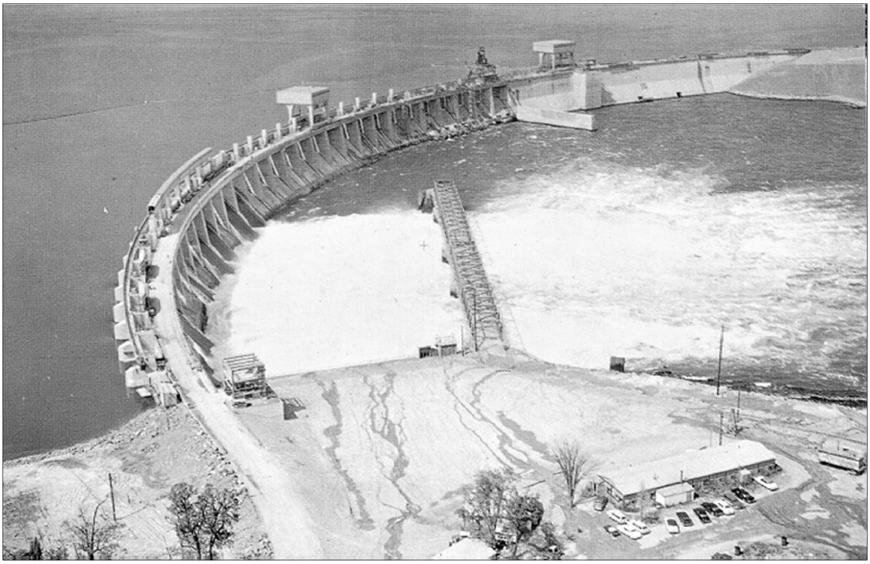
Moses-Saunders Powerhouse Dam. (K. Elder Postcard Collection)

river created a new 100-square-mile lake, Lake St. Lawrence, which serves as a power pool for the international hydroelectric power generating plant.

The Moses-Saunders powerhouse dam was built jointly by Ontario Hydro and PASNY, with the powerhouse forming an integral part of a 167'-high concrete gravity dam, 3,000' long. It contains 32 turbine/generator units, with 16 units in each country, and a combined installed capacity of 1,824,000 kilowatts, shared equally between the two power authorities. Each hydro authority designed its own electric power generating plant and power distribution system, independently, to its own national design standards. The powerhouse dam was constructed on bedrock behind cofferdams, and construction proceeded rapidly with the Canadian contractor working year-round, and the American contractor pushing forward construction with a large workforce during the summer months.

The *Long Sault Spillway Dam* controls the water level in the power pool. It is a concrete gravity dam on a curved axis, 2,250' long and 145' high at its maximum height, and is equipped with thirty vertical-lift gates, each 50' wide. The dam has a discharge capacity that far exceeds the maximum recorded flow of the river, to enable flood waters to be passed downstream. It is of a standard spillway dam design, and was constructed behind cofferdams in a conventional manner.[17]

To impound the water of the power pool, a total of twenty-one miles of dykes had to be constructed on both sides of the river, which required the placing of almost seventeen million cubic yards of compacted material, and 200,000 cu. yds. of riprap on the water face of the dykes. The largest dyke, the 3.5-mile-long Cornwall Dyke, ran from the powerhouse dam along the Canadian side of the river at a maximum 85' height and 485' base width. It contained a concrete head frame opening into an embanked diversion canal which enabled ships to pass between the river upstream of the dewatered power-dam site and the existing Cornwall Ship Canal below the dyke. Ultimately, stop logs were inserted in the head frame to close off the diversion canal for the raising



Long Sault Spillway Dam. (K. Elder Postcard Collection)

of the power pool.[18]

A major construction problem at the Iroquois Lock was the difficulty of excavating a sticky marine clay and a cemented glacial till, found in most of the excavations on the International Section of the river. Both materials proved very difficult to remove with scrapers and tractors, and to overcome this problem the Canadian contractors resorted to winter excavation work, with which they were thoroughly familiar. Once the frozen clay was broken up by blasting, it was readily removed with shovels, trucks, and earthmovers, as was similarly done with the glacial till.[19]

To meet the tight construction schedule in force, work on the Cornwall Dyke continued throughout the winter, in all but the most extreme temperatures, and potentially dangerous problems associated with the compaction of hard frozen materials were successfully overcome. This was done by working quickly in small areas to expose only a minimum surface area to the air and by spreading the fill material in shallow 6" layers, removing frozen clods, and compacting the material immediately with heavy loaded trucks. Field control testing at three on-site laboratories was used to ensure that the compacted frozen earth was watertight and had adequate strength; it was found that the compacted frozen earth had lesser densities, but ranged from 90% to 95% of the standard Procter density for both glacial till and clay when compacted in an unfrozen state.

On the Canadian component of the Seaway project as a whole, soil and foundation engineering was applied on an unprecedented scale for any Canadian construction project to that date. With the extremely tight construction schedule in force, it was essential to avoid any delays caused by unforeseen soil, rock, or groundwater conditions that could cause excavation problems, difficulties in forming the foundations and slopes of dykes, or permeability problems. Hence, extensive soil and foundation studies were carried out, both before and during construction, involving the drilling of numerous test bores, the excavation of test pits, and the constant testing of soil samples, as well as the excavation of observation wells to detect water-bearing layers.[20]

Relocation Projects

Among the complexities of the St. Lawrence Seaway construction project were not only numerous sub-contracts within major contracts, but also totally different projects within the main project that had to be coordinated with it. Such was the case with the relocation projects, which involved the moving of villages, towns, utilities, and transportation arteries that were located on lands that would be drowned by the raising of the power pool in the International Rapids Section. Here, it was the hydro authorities that expropriated and cleared the land and relocated the occupants on their respective sides of the border. On the American side of the river, some 18,000 acres of land were drowned, forcing the displacement of several hundred farm families and 500 cottage owners. However, no villages or towns were subject to flooding, and the American relocation project consisted primarily of moving roads, railroad tracks, and power lines, and clearing the land of fences, trees, and isolated buildings.[21] On the Canadian side of the river, Ontario Hydro faced a much more daunting task.

On the Canadian side, 20,000 acres of rich agricultural land would be drowned in a long-settled, historic area of the country, which necessitated the expropriation of numerous properties and the moving of eight river-bank communities (Iroquois, Aultsville, Farran's Point, Dickenson's Landing, Wales, Moulinette, and Milles Roches, and one-third of the Town of Morrisburg) in addition to 225 farm families. It required, as well, the building of three new towns (Iroquois, Ingleside, and Long Sault) a mile or so inland from the original river front to accommodate the displaced communities. A total of 6,500 residents were relocated by Ontario Hydro, some willingly and some less so. Property values were appraised, and lots surveyed and serviced in the three new towns; contractors were brought in to carry out the relocations. All costs associated with property purchases (appraised value plus 15% to cover dislocation costs), the moving of buildings and businesses, new construction work, the moving of eighteen cemeteries to a new Union Cemetery, and the establishment of the three new towns were covered by Ontario Hydro.

The new towns were serviced with paved streets, sewers, water and hydro facilities, and sewage treatment plants, and a total of 525 homes were moved on specially designed carrying- frame trailers capable of lifting 200 tons. Where moving a property was not feasible, replacement structures were built, including 450 new homes as well as new schools, municipal buildings, churches, and shopping centers. At the largest town, Morrisburg, where the business section and part of the town would be drowned by the power pool, a new subdivision

House on carrying-frame trailer, c. 1957. (Public Works in Canada, August 1959)

was constructed and over 40 stores moved. Some 2,700 men were employed by Ontario Hydro on the relocation project, which also required the relocation of 40 miles of double-track railway on the Canadian National Railway's mainline, and 35 miles of Highway #2, the main highway between Canada's two major cities, Montréal and Toronto. Despite the complexity and magnitude of the task, by November 1957 the relocation work was completed, the former town sites cleared, and work was well advanced on completing the landscaping and construction of new schools and churches in the three new towns.[22]

Another major relocation project was also undertaken in association with the St. Lawrence Seaway project when the Province of Ontario undertook to save historically significant buildings along the St. Lawrence River Front, one of the oldest settled areas of the province. A provincial-government agency, the Ontario-St. Lawrence Development Commission, was established to move the more outstanding historic buildings and to place them in a planned historic town site development, Upper Canada Village, on the St. Lawrence River seven miles east of Morrisburg.

Almost 40 historic buildings, dating from the late eighteenth through mid-nineteenth centuries, were relocated and incorporated into a historic village interpreting life in a pioneer community.[23]

The three relocation projects complicated the construction of the St. Lawrence Seaway, and had likewise to be completed on a tight schedule, with all structures relocated within three summer work seasons, start to finish, while construction was pushed forward on the power and navigation components of the Seaway project in the International Rapids Section.

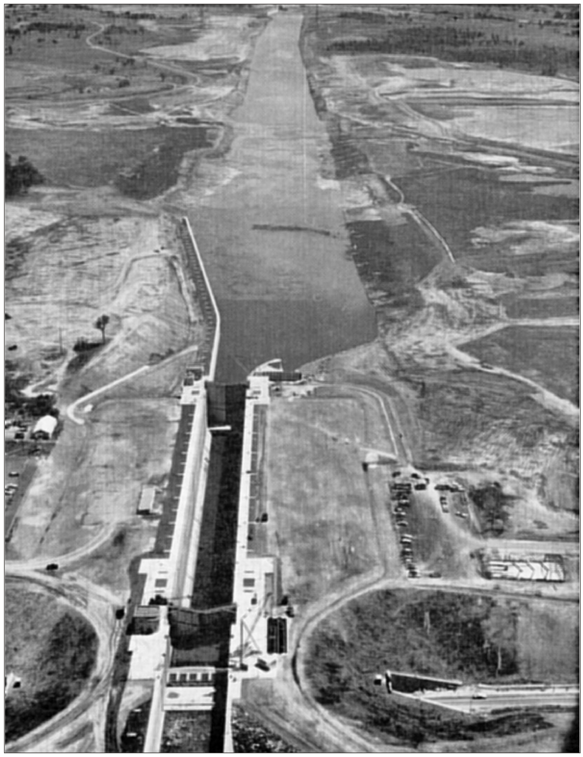
Wiley-Dondero Canal

The ten-mile-long *Wiley-Dondero Canal* crosses a bend in the St. Lawrence River near Massena, New York, on the American side of the river, and was constructed to enable ships to pass the power project dams in the river at Barnhart Island. The canal leaves the power pool and runs overland past Long Sault Island and Barnhart Island, and re-enters the river at the head of the south channel of Cornwall Island, downstream of the international powerhouse dam. American contractors excavated the 442'-wide canal channel to a 27' depth under the supervision of the Corps of Engineers, and constructed two 800' x 80' concrete locks, with 30' of water on the sills, in the canal channel: the Eisenhower Lock, with a 42' lift, at the mid-point of the canal's length; and the Snell Lock, with a 46' lift, at the lower end of the canal. The two high-lift locks pass ships between the level of the raised power pool, Lake St. Lawrence, and the St. Lawrence River downstream of the international powerhouse.

The Corps of Engineers followed standard contracting procedures on the canal project, but ran into a number of construction problems that caused delays and difficulties in keeping to the accelerated construction schedule. On the canal channel excavation, soil conditions were similar to the Canadian side of the river. A sticky marine clay that readily absorbed moisture turned the work site into a quagmire during heavy rains, bogged down machinery, and proved hard to manipulate for removal; and the glacial till in the excavation was cemented, or concretized, by naturally occurring calcium carbonates, making it very difficult to excavate. The original contractor at the upper lock defaulted, and at the lower lock the contractor experienced severe dewatering problems in carrying the excavation to a depth of 80' through a fractured rock. However, when the ground froze, time was made up through removing the marine clay in a frozen state and by employing a huge 650-ton drag line with an 85' boom and 14 cu. yd. bucket, "The Gentleman," on the upper canal where less difficult soils were encountered. Previously used for strip mining in the Kentucky coalfields, it greatly speeded the excavation work and removed 3.9 million cubic yards of material under one excavation contract at a bid price less than half the estimated cost of the work.

Two additional works were constructed at the Eisenhower Lock, a highway tunnel that crossed under the upper end of the lock, and a vertical-lift emergency gate in the upper forebay. In the event of an accident destroying the lock gates, the emergency dam could be activated to close off the canal channel, thereby preventing the power pool from discharging down through the canal.

Concrete work on the American canal was slowed by nation-wide strikes in the American steel industry in 1956 and the cement industry in 1957, which forced the Corps of Engineers to subsequently reschedule steel deliveries on a make-up basis and to obtain exemption from the "Buy American Act" of 1933 to purchase Canadian cement. The concrete work was slowed further by the onset of freezing temperatures each year, which brought a suspension of concrete work on the American canal project during the winter months. None-



Eisenhower Lock, looking downstream along the Wiley-Dondero Canal, c. 1958. (St. Lawrence Seaway and Power Projects)

theless, despite such setbacks, the Wiley-Dondero Canal component of the Seaway project was completed as scheduled by the spring of 1958.[24]

Channel Improvements

In the International Section, river-channel improvements were undertaken for both power and navigation purposes. Major dredging and dry-land excavation work was completed by Ontario Hydro and PASNY just upstream of the Iroquois control dam at three islands (Spencer, Chimney, and Galop) and below the control dam at Ogden Island. It was undertaken to increase the cross-sectional area of the main river channel, so as to reduce the velocity of the river current to less than 2.25 feet per second (fps) and eliminate water turbulence above the power pool. Once slowed, and quieted, an ice cover would form over the river in winter, preventing the formation of frazil ice. At higher velocities, turbulent waters remained open during the winter, and frazil ice crystals would form and float downstream suspended in the supercooled water. On striking a fixed object, the supercooled crystals rapidly combine and build up into a solid mass of ice; when they accumulate on the trash rack of a penstock they could severely restrict the flow of water to the turbines of a powerhouse. Thus, the channel improvements in the International Section were dictated by the needs of the power project, which went far beyond what was required to meet the navigation criteria for the Seaway.[25]

To eliminate frazil ice, the two hydro authorities increased the cross-sectional area of several river channels in the International Section. One of these channel enlargement projects, undertaken by Ontario Hydro, comprised the largest single earthmoving contract awarded in Canada to that date. It was awarded to C.A. Pitts General Contractor Ltd. of Toronto, and involved the excavation of 14,500,000 cu. yds. of earth and 1,000,000 cu. yds. of rock in dredging and excavating work near Galop Island. Moreover, the Canadian contract was only for a component of a broader excavation project. An

American contractor excavated a channel three miles long and 1,300' wide, directly across the island, to obtain a smooth and steady river flow, free of turbulence.[26]

One of the major engineering advances in constructing the St. Lawrence Seaway was the extensive use of hydraulic scale models in the planning of channel improvements and other components of the project. High-precision scale models were built that replicated long stretches of the river in exact detail: the topography, the shoreline, the river channels, the contours and nature of the river bottoms, and the turbulence and velocity of the currents in all areas of the river in its natural state at both high and low water levels. They were used for testing the impact of proposed channel improvements on current velocities and turbulence, for positioning and aligning cofferdams, dykes, power dams, and navigation works, for testing the locks, and for determining the extent of the flooding that would be caused by raising waters levels, as well as for designing the water-control system that controlled, within fixed design limits, the outflow and levels of Lake Ontario and the water levels, flow, fluctuations, and current velocities of the St. Lawrence River.

During the early design phase, Ontario Hydro produced a mammoth hydraulic scale model (1/8" to one foot vertical) of 35 miles of the river in the International Section at its testing laboratory in Islington, Ontario. Subsequently the National Research Council in Ottawa, the U.S. Army Corps of Engineers at its Waterways Experimental Station in Vicksburg, Mississippi, and the St. Lawrence Seaway Authority at Montréal followed suit in building hydraulic scale models of other crucial areas of the river for design and testing purposes.[27]

The use of hydraulic scale models was not unique to the St. Lawrence Seaway project. Ontario Hydro had employed hydraulic models in studying the Niagara River during an earlier mega project, the construction of the Queenston-Chippawa power generating plant (1917–1930) at Niagara Falls, which on its opening was the largest hydroelectric generating plant in the world. However, the extent of their use and the critical role that they played in the planning, design, and construction of the Seaway project were unprecedented.

In the International Section a major channel improvement was also required at Cornwall Island, where the cross-sectional area of the south channel (the international boundary) had to be increased to reduce the current velocity from 12 fps to 4 fps for navigation purposes. Here a serious dispute arose between the United States and Canada when the U.S. Army Corps of Engineers insisted on minimizing the dredging work in the fast-flowing water of the south channel by diverting much of that flow into the north (Canadian) channel. Canada refused outright. A fast, strong current would have made it very difficult to construct a future all-Canadian seaway along the north channel; hence, Canada insisted that the existing division of river flow be maintained. The dispute was referred to the International Joint Commission, which upheld Canada's position, in keeping with the terms of the International Boundary Waters Treaty (January 1909) that stipulated that neither country could alter the natural flow of the river without the consent of the other party.

Thereafter, an agreement was reached on the division of the work required to increase the cross-sectional area of the south channel, and reduce the current velocity. The U.S. Army Corps of Engineers dredged the navigation channel, which was mostly in American waters; Canada undertook a major excavation project to remove part of the shoreline of Cornwall Island, also some dredging in Canadian waters to widen the south channel. A total of 9,500,000 cu. yds. of material had to be removed from the south channel of Cornwall Island by dredging and shoreline excavations, out of a total of 70 million cu. yds. of material removed by the four authorities in the International Section of the St. Lawrence Seaway navigation and power project.

The south channel dredging work was further complicated as U.S. authorities had to negotiate an agreement with the Mohawk of the St. Regis Reservation concerning the dumping of dredging materials along the shoreline of the south channel and the use of 86 acres of reservation land on Raquette Point for Seaway purposes. After two years of negotiations, a compensation agreement was reached in January 1957, just prior to the commencement of the south channel improvement work.[28]

Seaway International Bridge

In addition to the complex of sub-projects undertaken to construct the navigation and power works, to relocate communities, and to improve the river channels, a major high-level bridge was required at Cornwall Island in the International Section. The Seaway authorities had intended to place swing bridges at either end of the Snell Lock to maintain uninterrupted passage across the Seaway for the New York Central Railroad on an existing combined rail and road bridge crossing of the St. Lawrence River. However, when the railroad decided in July 1956 to abandon its branch line, a crash program was undertaken to construct a suspension bridge, the Seaway International Bridge, over the Seaway.

To avoid the complications of a split contract and potential problems over national hiring policies on a bridge spanning the international boundary, it was agreed that the substructure would be built by a Canadian contractor employing American subcontractors and workers on the American side of the border; the superstructure would be built by an American contractor employing Canadian sub-contractors and workers for the erection work on the Canadian side of the border. A two-lane high-level suspension bridge was designed by one of America’s leading bridge engineers, David B. Steinman (1887–1960), and the whole project was completed in a remarkably short period, with the bridge opening in November 1958. The 3,480'-long bridge crossing has a 900' main span providing vertical clearance of 120' over the navigation channel, exceptionally long 450' anchor spans at either end, and a total of 22 viaduct approach spans.[29]

Canadian Section

The Canadian Section extends some 77 miles from St. Regis, opposite the south end of Cornwall Island, to Montréal, and comprised three sub-sections:

Lake St. Francis (30 miles); the Soulanges Section (16 miles); and the Lachine Section (31 miles), which included Lake St. Louis. A navigation channel 27' deep and 450' wide was dredged through the two major lakes; two canals were constructed, each with two lift locks, to overcome the rapids in the Soulanges and Lachine sections; these engineering works involved some of the most difficult, demanding, and costly work, on the whole Seaway project. The Lachine Section, in particular, required a great deal of additional work consisting of four major bridge modification projects and the relocation of public utilities and transportation and communications arteries in a heavily populated metropolitan area.

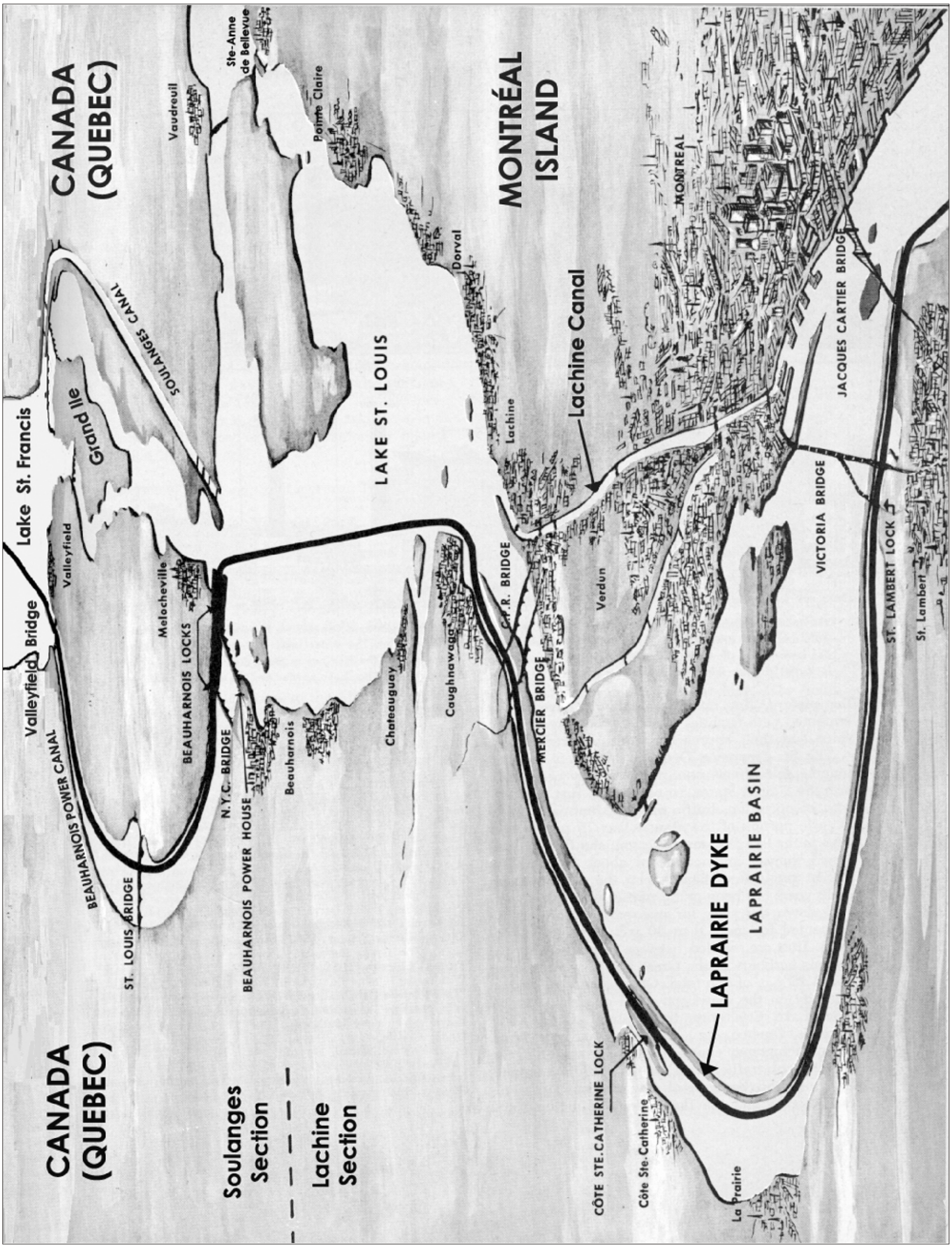
On the Canadian Section, a number of serious construction problems threatened to play havoc with the fast-track construction schedule, but were overcome by the employment of novel construction approaches, the undertaking of winter concrete work, and the introduction of the latest advances in excavating and material-handling technologies, as well as an innovative critical path method of project management.

Soulanges Section

In the Soulanges Section, the St. Lawrence River drops 83' between Lake St. Francis and Lake St. Louis in a distance of 18 miles, and passes through a series of three rapids: the Coteau; the Cedars; and the Cascades. Here, the Seaway was carried overland, south of the river, in an existing power canal that ran from Lake St. Francis to a powerhouse at Beauharnois overlooking Lake St. Louis. The Seaway work consisted of the dredging of Lake St. Francis and the construction of a short two-mile-long canal channel at the north end of the powerhouse with two locks, each of 41' lift, separated by a passing basin, to carry the navigation into the power canal. It required, as well, the construction of a 4-lane tunnel to carry Quebec provincial Highway #3 under the upper end of the lower lock, and the placing of movable spans in three low-level bridges crossing the power canal.

Thanks to the foresight of the Canadian government, much of the work required to construct a deepwater navigation in the Soulanges Section appeared to have been already completed prior to the commencement of the St. Lawrence Seaway project.[30]

In 1929–1933, a private company, the Beauharnois Light, Heat, and Power Company, had constructed a powerhouse at Beauharnois to develop the power potential of the site. In exchange for granting water-diversion rights on a navigable river and $15 million in federal loan guarantees for the prosecution of a work deemed of national interest the federal government had insisted that the power canal be constructed so as to facilitate the future construction of a deep waterway. Hence, at Beauharnois the powerhouse was at the head of a power canal, 15¼ miles long, 3,200' wide and 10' deep, with a channel 27' deep and 600' wide along its north side, running almost parallel to the river. Moreover, the three bridges crossing the power canal were constructed with piers designed to facilitate the future insertion of a movable span where each bridge crossed the projected deepwater navigation channel.



Schematic map detail of Seaway Channel in Soulanges and Lachine sections.
(Canadiana Encyclopedia, Vol. 9. 1967)

When work began on the Seaway project at Beauharnois, the work appeared easily manageable. The only apparent complication was dredging work that Hydro Quebec had underway at that time to widen the power canal as part of a project to expand the powerhouse to a 2.2 million hp. installed capacity.[31] During construction, however, the Seaway contractors encountered unprecedentedly severe drainage and rock-excavation problems and had to introduce novel excavation and construction techniques to complete the Beauharnois component of the Seaway project on schedule.

In excavating the upper lock pit below the level of the power canal, contractors encountered a very wet and soft marine clay, which overlay a hard silica sandstone, Potsdam Sandstone, which was 98% pure silica. The marine clay proved very difficult to scoop up with shovels and drag lines, and the silica sandstone posed a severe excavation challenge. It was badly fractured and water-bearing, both from artesian water and seepage from a 30' head of water in the adjacent power canal, and was so hard that it rapidly wore out drill bits in 4' to 5' of drilling rather than a more customary 50' or 60'. The teeth on shovels and bulldozers had to be replaced every few days; the rate of wear on drill bits was over three times greater than what would be have been expected in granite. Moreover, the blasting caused additional problems. It produced a fine, highly abrasive dust that ground up the working parts of equipment, greatly increasing maintenance work and costs. The blasting also opened fissures in the silica sandstone, which further exacerbated a severe dewatering problem in an excavation where the total seepage approached a startling 3,000 gallons per minute, and necessitated heavy and continuous pumping. The silica sandstone also broke along its own seams, which caused severe overbreaks and underbreaks that required extra concrete to fill up or further blasting to remove. Despite trials and experiments with different drilling equipment, the rock excavation work proceeded very slowly and laboriously, putting the Beauharnois project far behind schedule until a novel thermal borer was introduced: the jet piercer.[32]

The jet piercer rig focused the tip of a rocket flame of 4,000 degrees F, traveling at a velocity of about 5,000 fps against a rock face. A 2"-diameter area would be brought to a white heat by the flame and then dowsed with pressurized water from the blowpipe orifices. The rapid change in temperature caused the rock to spall due to differential heat expansion, and the particles to explode out of the blast hole in a cloud of steam, propelled by the pressure and velocity of the rocket flame. The jet-piercer put down blast holes at the rate of 20' per hour, as compared to churn drills which drove as little as 2' to 3' in an hour in the silica sandstone, and often became stuck in lateral seams. Very heavy shots of dynamite were used to blast the silica sandstone, as well as ammonium nitrate, a newly developed high explosive, which was employed in dry blasting operations. The novel jet piercer greatly increased the speed of the hard-rock excavation work, but the initial rock excavation difficulties, given the large volume of work involved in the removal of over 1,400,000 cu. yds. of rock, largely silica sandstone, in addition to 1,000,000 cu. yds. of common excavation, put the Beauharnois project well behind schedule. Consequently, a high-speed push was needed to complete the concrete work, as was the case elsewhere on the Canadian component of the Seaway where difficult excavation work put the project behind schedule.[33]

On the St. Lawrence Seaway project, Canadian contractors saved time in pouring concrete by following a different system than the Americans. American contractors on the Wiley-Dondero Canal and the power dams projects employed large numbers of cranes, derricks, and buckets to place concrete, suspended all concrete work during the winter months, and poured their concrete in 5' lifts across wide areas; whereas Canadian contractors, unable to match the Americans in manpower and equipment, speeded up the construction work by pouring concrete in high lifts, very large pours, and alternate monoliths of up to 40' wide, and by pushing concrete work throughout the winter months using super-heated concrete, and working within enclosed temporary shelters.

At the Canadian work sites, wooden cribwork forms were placed on rails and slid sideways to pour the alternate monoliths, with lifts up to 40' high on the Iroquois Lock and the Canadian section of the Barnhart Island powerhouse dam. Canadian contractors were not restricted in the height of their lifts, and broke joint at convenient locations. On the upper Beauharnois Lock, to speed construction the contractor introduced a sliding steel form 80' high, reputedly the largest movable form in the world, which enabled the lock walls to be raised in a single operation of four consecutive lifts on each monolith section. The use of the high lifts-alternate monoliths approach was well suited to winter construction work. The high lifts simplified the covering and heating of the winter work site, and the alternate monolith system aided the cooling of the setting concrete, minimized shrinkage, and eliminated any fracturing, all of which were critical potential problems in pouring large concrete works of great extent.[34]

On two of the existing low-level bridge crossings over the Beauharnois power canal, the Valleyfield and the St. Louis de Gonzague combined road-rail bridges, a fixed span was replaced by a 220' long vertical lift span on piers originally constructed to take a movable span. In each case, a submerged barge was floated under the fixed span and pumped out to lift the span off its bearings; the new lift span was floated into place on a specially designed scow. Only nine hours were needed to convert each bridge, with a resultant minimal disruption of road and rail traffic over the busy traffic arteries. The 190'-high, steel-frame lift towers were constructed thereafter, during the fall of 1958, without any further interruption of traffic. On the third bridge, the Melocheville railway bridge, a swing span was inserted in the structure.[35]

Lachine Section

The construction project on the 30-mile-long Lachine Section consisted of dredging Lake St. Louis to attain a 27'-deep navigation channel, and the construction of a canal along the south shore of the river to overcome a 50' drop between Lake St. Louis and Montréal Harbour. The most prominent natural features on the river section were the Lachine Rapids, just below the outlet of Lake St. Louis, where the river narrowed, dropped over 30' in eight miles, and grew extremely turbulent with a strong, fast current; Laprairie Basin, below the rapids, where the river widened into a broad elongated basin, almost four miles wide and eight miles long; and the St. Mary's Current, just below the Montréal Harbour basin where the river narrowed again with an increased current velocity. In the Lachine Section, only navigation works were built. These comprised the South Shore Canal, an 18.5-mile-long navigation channel excavated along the south shore of the river from Lake St. Louis to Montréal; and the Laprairie Dyke, a high dyke running the whole length of the navigation channel to separate it from the river. Two canal locks overcame the difference in elevation between Lake St. Louis and the river at Montréal.

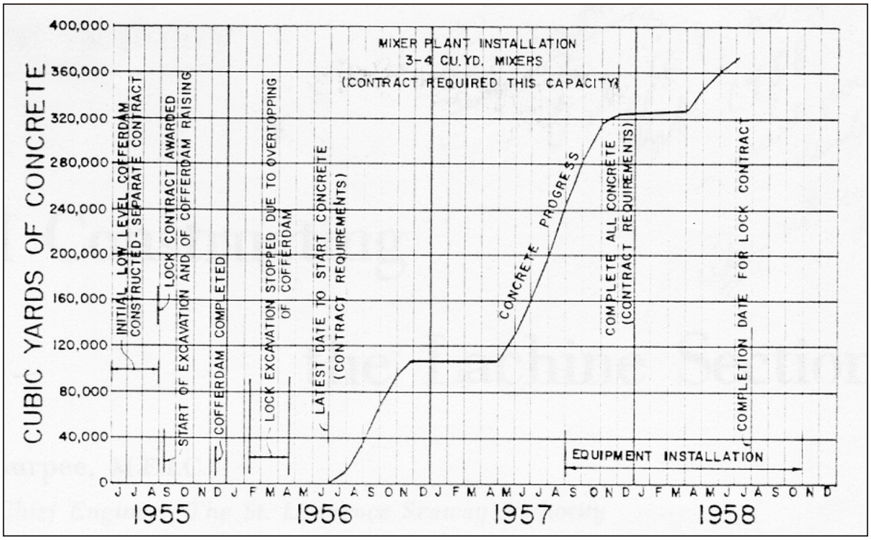
A 4,000'-long wharf, the Côte Ste-Catherine wharf, and two turning basins were also constructed on the South Shore Canal, as well as a regulating weir adjacent to each lock, and a turning basin across the river in Montréal Harbour. In addition, four major bridges that connected Montréal, Canada's then-major metropolis, with the South Shore were modified to obtain a 120' vertical clearance over the Seaway channel; power and communications lines connecting the City of Montréal with the South Shore were relocated; and on the South Shore, two new water inlets, a sewage trunk line, and two sewage pumping stations connected to outlets passing under the Seaway channel were constructed to serve municipalities that were cut off from the river by the construction of the Seaway channel.

The critical problem on the Lachine Section was the great volume and complexity of the work to be completed in a very short time period in confined and congested work areas around the railway and road bridge sites and their approaches. Moreover, the bridges, utilities, and communications systems crossing the seaway right-of-way could not be closed or interrupted for more than brief time periods during the day, and definitely not during the working-day rush hours and periods of peak demand.

Critical Path Planning and Scheduling

The general planning and layout of the Seaway construction project on the Lachine Section were completed in the two years prior to the summer of 1954, but with the commencement of construction that fall project management became a critical concern.[36] A large amount of work had to be accomplished on this section, and within a very tight time period, at some very congested work sites. Given the complexity and interrelatedness of all of the work, and its progressive nature, a highly innovative planning and scheduling system was put in place right at the beginning of construction. It was a project management system that closely resembles the critical path method (CPM) of more recent times.

Initially an overall plan was established for managing the project, through fitting all the work to be done on the Lachine Section within a tight four-year schedule imposed by the need to complete the project by a fixed date, with time built in for the preparation of detailed working plans and land acquisitions. Then, the work was divided up into contracts embodying a reasonable



Schedule and Progress Report graph, Côte Ste-Catherine Lock. (Engineering Journal, September 1958)

amount of work for completion within a specified time period, taking into account the nature, volume, and particular type of the work required, site limitations, whether work could be pursued during the winter months, and the time required for subsequent work that depended on the completion of prior work. Ten main contracts were let by competitive bid; these covered the two locks, all the cofferdam, excavating, and embanking work, inclusive of the related work on the substructures of the bridges, and other infrastructure components at the contract sites along the 18.5-mile-long canal. Some contracts covered only 3/4 of a mile in congested areas where complex construction work was required; whereas other contracts covered almost four miles of construction work along the Seaway channel. In all cases, the critical overriding need was to have all the major construction work and equipment installations completed by August 1958, leaving time for the testing of the locks and the dredging of the lower and upper entrances to the South Shore Canal following the removal of the cofferdams.

Once the amount of work in each contract unit was defined, the preparation of the detailed working plans and awarding of the contracts were placed in a planned sequence, based on the logical order in which work needed to be done as the project advanced, the minimum amount of time required to perform the work, and the need to obtain an early start at sites where an extensive amount of subsequent work was dependent on the completion of the initial contract. Even with similar types of work required within the same construction phase, a priority was given to preparing and letting contracts at an early date for work that would facilitate the undertaking of other components of the project. For example, a contract for limestone rock excavation on one overland section of the channel excavation was let at a very early date to provide material for a coffer dam, and to test the limestone bed for possible service as a quarry for concrete aggregate.

In drafting the contracts, detailed schedules were inserted in the specifications with interval deadlines and production capacity demands to control the contractor's rate of progress, and to establish a fixed completion date for various stages of a contract. The detailed scheduling was introduced to ensure that the project would be kept on the very tight schedule required to meet the fixed completion date, and to coordinate the completion of stages of the work on which other work depended. All contracts specified a starting date for the work, as well as for particular components of the work, with an emphasis on components requiring an early start; and required the contractor to have construction equipment capable of a specified minimum rate of excavation and a concrete mixing plant capable of a specified minimum hourly output. The intermediate deadlines specified when particular components of the project had to be in a certain state of completion, or completed, to maintain the required rate of progress and/or enable dependent work on adjacent contracts to proceed on schedule at their specified start dates. The start and completion dates of each component of a contract, and of the various contracts, were then plotted on a bar graph to enable the work to be readily tracked.

Overall, not every interval deadline was met, but the constant emphasis on the critical time factor in the work schedule, on output demands, on fixed start and completion dates, and on meeting interval deadlines kept contractors striving to achieve the required rate of progress. Despite many complaints from contractors that the work schedule was too tight, the introduction of a critical-path method of project management made possible the completion of the highly complex Lachine Section of the St. Lawrence Seaway project, as planned, and in keeping with the critical time schedule in force.[37]

South Shore Canal

In laying out the South Shore Canal, the overriding concern was to minimize any constriction of the river by keeping the canal as close to the shoreline as possible, while balancing the amount of excavation and embanking work and avoiding settled areas. Hence, at the outlet of Lake St. Louis, a 250'-wide navigation channel was dredged in the river along the south shore and carried along the shoreline past the village of Caughnawaga to minimize any displacement of its residents; where the river narrowed, at the Canadian Pacific Railway (CPR) Caughnawaga Bridge and the Honoré Mercier Bridge crossings of the St. Lawrence River, a canal cut was excavated overland along the bank of the river for a distance of eight miles, past the Lachine Rapids, to avoid any further narrowing or constriction of the river channel. Below the Lachine Rapids, the Seaway channel re-entered the river at Laprairie Basin. There a 300'-wide canal channel was excavated, behind cofferdams, on a sweeping curve along the south shore of the basin and beyond, for a total distance of ten miles, terminating almost two miles below the harbor basin at Montréal. The carrying of the Seaway downstream past Montréal Harbour was deliberate. It would facilitate a future expansion of port facilities eastwards from the existing harbor; would enable vessels to avoid the St. Mary's Current on entering or leaving the Seaway; and would eliminate a perceived problem with potential ship-traffic congestion in the basin of Montréal Harbour.[38]

On the South Shore Canal, the upper lock was built at Côte Ste-Catherine, opposite the foot of the Lachine Rapids, to overcome the differences in water level between Lake St. Louis and the regulated water level in the Laprairie Basin navigation channel. The lower lock was placed at Saint-Lambert, between the south abutment and pier #24 of the Victoria Bridge, to overcome the difference in water level between the South Shore Canal and the river below Montréal. The lower lock was positioned under the bridge to enable a short vertical lift span to be inserted in the bridge crossing at the 80'-wide lock chamber.

In Laprairie Basin, the Seaway channel and the adjacent Laprairie Dyke were positioned in shallow water anywhere from 1,000' to 2,000' from shore to balance the excavation and embanking work, leaving a wide body of shallower water between the deep Seaway channel and the South Shore. In Laprairie Basin, ice jams in the spring could raise the river level almost 20' above the normal high-water level. Hence, the dyke was raised 25' above the high-water level to protect the Seaway navigation channel during severe floods, and was raised five feet above the high-water level of the river on the upper and lower sections of the canal, above the Côte Ste-Catherine Lock and below the St. Lambert Lock, where the river was not subject to severe flooding. The 18.5-mile-long Laprairie Dyke was also constructed in a very substantial manner, 40' wide at the top with slopes of 1.5 horizontal to 1 vertical, to resist the pressure from ice movements. The Dyke was raised to a height 47' above the floor of the canal channel in Laprairie Basin, and to a height of over 50' above the riverbed at its eastern terminus, opposite Montréal.

Several contracts were awarded quickly in the fall of 1954 to work out the details of the contracting process, excavation and dyke-construction procedures, and to get an early start on cofferdam construction, while detailed planning and the preparation of contract specifications proceeded in parallel for the more complex projects. Ultimately, over 46 contracts were awarded on the Lachine Section, inclusive of the ten main contracts that covered the construction of the two locks and most of the navigation channel excavation and dyking work. The contracted work was scheduled to be completed in phases, and in its entirety, over four work seasons, 1955–1958, and covered a wide diversity of work, including the enlargement and strengthening of the piers of the bridges to be modified; the construction of a South Shore collector sewer, cofferdams, a regulating weir at each lock, a water intake at Longueuil, two sewage pumping stations and sewer outlets, a wharf at Côte Ste-Catherine; the dredging of both ends of the navigation channel, and, in addition, a turning basin in Montréal Harbour; as well as extensive modifications to four major St. Lawrence River bridges.[39]

During the summer of 1955, work proceeded on the overland-canal excavation and cofferdams were built, and pumped out, at the lock and bridge sites where it was critical to get work underway at an early date, while the building up of the Laprairie Dyke continued. Successive sections were dammed off and pumped out as the dyke was extended, with every effort made to keep abreast of the tight construction schedule in force. The largest fleet of construction equipment ever assembled in Canada was put to work by Canadian contractors, employing the most modern machinery available: bulldozers; self-powered graders; power shovels; and fleets of heavy-duty diesel trucks.[40]

On the overland-canal cut, the excavation was carried through Trenton limestone and in Laprairie Basin it passed through Utica shale with some marine clay, embedded with rock, struck at the base level of the navigation channel.[41] Most of the excavated material was deposited in the Laprairie Dyke, which had to be raised 25' above the high-water level of the river.

Despite problems encountered in pursuing excavation work at congested bridge sites, rapid progress was made on the Lachine Section. Three of the eight main excavation and embanking contracts were completed ahead of schedule; one contractor, Miron et Frères Ltée of Montréal, managed to set an excavation record by removing 4.3 million cu. yds. of material some eight months ahead of schedule on a 5,000' section at the eastern end of the canal. Moreover, the excavation rates generally on the Lachine Section set records for the St. Lawrence Seaway project. Overall, the 18.5-mile navigation channel excavation required the removal of 18,000,000 cu. yds. of common material, and 20,000,000 cu. yd of rock (40% limestone, and 60% shale).

Construction of the Laprairie Dyke was expedited by the suitability of the limestone rock and shale materials for compacting in the dyke, with the glacial till used for the core, and the rock as riprap.[42] The compacting was done in a conventional manner using sheepsfoot rollers, but heavily loaded trucks were found particularly effective in compacting the dykes in confined or uneven areas, and even against concrete walls, where they superseded power tampers. The schedules in force required individual contractors, among the eight main excavation and embanking contractors, to place compacted fill in the dyke at rates as high as 225,000 cu. yds. per month.[43]

The most congested work site, and most difficult for access, with cramped working conditions, was at the Saint-Lambert Lock. There 2,000 men were employed at any one time in excavating and constructing a lock chamber under a low-level span of the Victoria Bridge, a combined rail and road bridge. Over 2,000 cars per hour passed over the bridge during commuter hours, and 120 freight trains per day on the Canadian National Railways' mainline to the U.S. eastern seaboard cities. Traffic on the bridge could not be interrupted for other than brief periods during blasting operations, which had to be highly regulated; and traffic flow had to be maintained by constructing temporary approach ramps during the construction period, further limiting the work area.[44]

St. Lambert lock site looking downstream towards the approach spans of the Jacques Cartier Bridge. (St. Lawrence Seaway and Power Projects)

At the Saint-Lambert work site a new method of blasting was introduced: the "air-cushion method." It was developed by Canadian Industries Ltd (C-I-L) to enable contractors to set off underwater blasts in close proximity to the canal walls on the Welland Canal, which was being deepened by the Department of Transport from 25' to 27' as construction proceeded on the St. Lawrence Seaway. In experiments on the Welland Canal, bore holes were drilled in a close line, and a hermetically sealed tube, 6" in diameter and 6' long, was placed in each blast hole to form a compressible air column. When set off, it was found that the air cushion would absorb the blast and the rock would break clean, precisely along the air-cushion line of bore holes, rather than fracturing or overbreaking and/or underbreaking. This innovative system of blasting was so successful, both under water and in dry work, that on the Seaway project a contractor was able to blast 100 tons of rock loose in a single explosion within 30' of the Victoria Bridge, with the millions of tiny bubbles of air in the tubes totally absorbing the shock of the explosion. The innovative "air-cushion" blasting technique was used elsewhere on the Lachine Section excavations at the Côte Ste-Catherine wharf, as well as at Beauharnois in blasting out the forebay of the lower lock, close to the powerhouse.[45]

On the Lachine Section, the close proximity of the Saint-Lambert Lock to pier #24 of the Victoria Bridge posed a critical construction problem. The lock wall for almost 100' of its length passed alongside pier #24, as close as 3' away at one point, and the lock pit excavation had to be carried 40' below the foundation of the stone masonry pier, which rested on shale that was badly fractured and faulted. Moreover, the shale in that area proved unstable when exposed to air, and rapidly deteriorated, posing a problem of how to stabilize the bridge pier and the abutment on the other side of the lock pit to keep them from collapsing into the excavation. This problem was overcome by excavating a 100'-wide cut down the center of the lock pit to the foundation grade, and then excavating a succession of narrow, 12'-wide lateral trenches outward to the bridge pier and abutment foundations. As soon as a lateral trench was excavated, a narrow section of the lock wall monolith at the head of the trench was immediately formed up and the concrete poured, to function as a retaining wall as each section of the lock wall was constructed in turn. In this manner, only a small area was exposed beneath the bridge foundations at any one time, but the piecemeal approach slowed construction to a crawl.[46]

Sliding steel form for pouring concrete monoliths. (St. Lawrence Seaway and Power Projects)

To place concrete in such a confined area where the conventional crane-and-bucket system could not operate, the contractor, McNamara-Piggot-Peacock, introduced a novel system in employing a series of conveyor belts to carry concrete. They were used with a mechanical stacker to deposit concrete into the forms, and proved speedy and economical for placing concrete in confined areas. In open areas concrete was poured directly from dumpsters mounted on trucks, or from buckets suspended from cranes in the conventional system of concrete placement on major construction projects. The placing of concrete in the forms was speeded up by attaching an elephant trunk of rubber or canvas to each crane bucket.[47]

At the Côte Ste-Catherine Lock a different approach was adopted. To speed the placing of concrete by crane and bucket, four giant gantry cranes were imported from France. These tower cranes, counterbalanced on slender high towers, were the first of their type in North America. The Côte Ste-Catherine contractor also designed a unique piece of equipment to speed the concreting work: a fully automated,100-ton steel traveling form, 40' high and 40' wide. It was mounted on rails, electrically powered, and automated, with a traveling apparatus that distributed concrete with speed and precision along the form. The novel form/concrete placer had a placement capacity of 810 cu. yd. a day, and could be readily moved to construct a new monolith in the lock walls.[48]

Concrete work on the Lachine Section locks commenced in July 1956, and was pushed forward, as was work elsewhere on the Seaway project, in two work shifts, 20 hours a day, five days a week. At Côte Ste-Catherine, a total of 350,000 cu. yds. of concrete was poured in the lock chamber and its approaches by the late spring of 1958; and at Saint-Lambert, records were set in pouring concrete at a rate of 4,000 cu. yds. per day, and in achieving a record pour for the Canadian projects of 77,700 cu. yds. in a single month. Completed during the summer of 1958, using three different systems of concrete placement, the Saint-Lambert Lock and approaches required 455,000 cu. yds. of concrete, the most of any Seaway lock. The extra concrete was required to strengthen the foundation of the adjacent pier and abutment of the Victoria Bridge, and to construct a concrete floor over the calcareous shale in the lock pit excavation.

By late August 1958 the lock gates were installed, cofferdams at either end of the South Shore Canal were blasted out, and dredging commenced at both entrances to the South Shore Canal. Overall on the Lachine Section, over 7,000,000 cu. yds. of material was dredged in deepening Lake St. Louis, the South Shore Canal approaches, and Montréal Harbour to form a turning basin.[49]

Bridge Modifications

In addition to the construction of the South Shore Canal, major bridge construction work was required on the Lachine Section and had to be coordinated with the progress of the Seaway excavation and concreting contracts. Four major bridges crossed the St. Lawrence River from the Island of Montréal, and all required extensive modification to their south approach spans to provide a minimum 120' vertical clearance over the Seaway navigation channel. These bridges were: the Caughnawaga Railway Bridge (a double-track Canadian Pacific Railway structure) and the nearby Honoré Mercier Bridge (a highway bridge) at the Lachine Rapids; the Victoria Bridge, crossing over the Saint-Lambert Lock work site (a Canadian National Railways double-track rail and road bridge); and the Jacques Cartier Bridge (a highway cantilever bridge) crossing the river near Montréal Harbour. In addition, a new Scherzer rolling-lift bascule bridge was erected across the Côte Ste-Catherine Lock to provide access over the Seaway to the Laprairie Dyke. At the four major bridges there was a great deal of congestion in confined work areas, and the bridge-modification projects were further complicated because road and rail traffic over these structures could not be interrupted for any but brief periods of time during the construction period.

At Caughnawaga, twin vertical-lift spans of 322' in length, supported on 140'-high towers, were inserted into the south approach embankment of the railway bridge over the new navigation channel; and at the Victoria Bridge, a vertical-lift span was placed in the existing bridge structure over the Saint-Lambert Lock, and another vertical-lift span over the head of the lock with

Construction of new approaches over Seaway Channel at CPR Caughnawaga Bridge and the Mercier Bridge. (Public Works in Canada, August 1959)

several new fixed spans joining it to the existing bridge in a Y-configuration. In this manner, when one lift span was raised for the passage of a ship into or out of the Seaway lock, vehicular and rail traffic could be diverted over the other lift span to maintain an uninterrupted flow over the Victoria Bridge. On the Mercier Bridge (1934), an extensive embankment and a timber trestle were constructed to detour road traffic to the bridge superstructure, while 25 concrete deck spans on the south approach were demolished and replaced with new concrete piers of greater strength and height and new steel approach spans. Erected in 1957, the superstructure of the new south approach incorporated a 300' through-truss span 120' above the navigation channel, and almost 6,000' of new approach spans interconnecting with two major highways.[50]

One of the bridge-modification projects, the raising of the south approach of the Jacques Cartier Bridge, was the largest bridge-raising operation undertaken anywhere in the world to that date, and constituted a complex engineering project in its own right. A 2.5-mile-long, four-lane bridge crossing the St. Lawrence River at Montréal Harbour, the Jacques Cartier Bridge (1929) consisted of a major cantilever structure spanning the river channel at a height of 60', flanked by deck-truss approach spans, which on the south approach crossed the line of the Seaway channel 40' above the planned water level. To obtain a 120' vertical clearance, it was decided to jack up existing spans on either side of the Seaway channel an additional

50', and to replace a deck-truss span over the navigation channel with a through-truss span to gain a further 30' in height.

Special hydraulic lifting jacks of 400- and 500-ton capacity were designed and, in a highly synchronized operation, fourteen spans were lifted 6" at a time, in hundreds of lifts, while maintaining the spans at grade alignments that enabled highway traffic to continue to pass over the bridge during the lifting period. As the spans were jacked, they were blocked, and the piers built up with precast concrete sections until a grade of 4.2% was attained on either side of the span over the navigation channel, which gave an interim 90' clearance. The operation was completed on a Sunday morning, when the existing 30'-deep deck-truss span over the Seaway channel was slid sideways onto scaffolding, and the new through-truss span was slid into place from the other side, achieving the required 120' vertical clearance with only a four-hour interruption in the flow of traffic over the bridge structure.[51]

In a remarkable achievement, all the complex bridge construction and modification projects on the Canadian Section were completed by the fall of 1958 in time to provide a minimum 120' vertical clearance over all water channels at the scheduled April 1959 opening of the St. Lawrence Seaway.[52]

Operation of the Seaway

On the Seaway project, the Iroquois Lock and Control Dam were in service as early as the opening of the 1958 navigation season, bypassing the old Galop Canal; on June 30 shipping was cleared off the St. Lawrence River and the old St. Lawrence Ship Canals system was closed with the placing of stop logs in the head frame of the Diversion Canal adjacent to the Moses-Saunders international powerhouse dam. The next morning, July 1, 1958, a cofferdam at Sheek Island upstream of the international powerhouse dam was blown open to commence the filling of the power pool, as scheduled, on the exact date established four years earlier. Then water was released from the Iroquois Control Dam at a rate of flow calculated to fill the 100-square-mile power pool, Lake St. Lawrence, in 65 hours. On July 4, precisely as planned, the power pool rose to within 4' of its optimum level, and the Wiley-Dondero Canal was opened, rendering the St. Lawrence Seaway fully operational in the International Section after only a four-day interruption in shipping on the St. Lawrence River. One week later, following an amazingly short drying out period, two Canadian generators were placed on line, marking the inauguration of hydroelectric power production on the St. Lawrence Seaway project. Thereafter, dredging continued to deepen several sections of the St. Lawrence River where a shortage of dredges had caused delays, and work continued on the Canadian Section to complete some of the bridge modifications. The entire St. Lawrence Seaway opened as scheduled on April 25, 1959, with a 27' depth throughout.[53]

On June 26, 1959, the Seaway was formally opened at the Saint-Lambert Lock, where 25,000 spectators witnessed Queen Elizabeth II and President Dwight D. Eisenhower arrive on the Royal Yacht *Britannia* and preside over the opening ceremonies. Both speakers praised the St. Lawrence Seaway as a magnificent monument to friendship and cooperation between two nations, and as one of the outstanding engineering achievements of modern times.[54]

The St. Lawrence Seaway, in conjunction with the two-foot deepening of the Fourth Welland Canal and the dredging of the river channels in the upper Great Lakes (Detroit River, Lake St. Clair, St. Clair River, Straits of Mackinac, and St. Mary's River), opened up a fourth sea coast for Canada and the United States. The longest inland deep waterway in the world, the Great Lakes-St. Lawrence navigation stretched 2,355 statute miles from Anticosti Island, in the estuary of the St. Lawrence River, to the head of Lake Superior. For the first time, deep-draught ocean vessels were able to penetrate into the industrial heartland of North America and the huge upper lake boats, soon constructed to an even larger 730' x 74' scale, were able to operate throughout the Great Lakes-St. Lawrence navigation system.[55] However, the cost of the St. Lawrence Seaway navigation, power, and water-control project was stupendous, almost $1 billion. It comprised $600 million for the power and water-control works, shared equally between Ontario Hydro and PASNY and $471 million for the Seaway navigation, with Canada paying $340,000,000 and the U.S. $131,000,000 for the works within their respective borders.[56]

On its opening, it was predicted that the Seaway would carry 25 million cargo tons in its first year, more than double the average annual tonnage on the old St. Lawrence Ship Canals, and that in twenty years it would average 50 million tons per annum, with a slower growth rate thereafter. Moreover, the anticipated traffic, with the tolls in force, was expected to yield revenues sufficient to pay operating and maintenance costs, as well as to amortize the capital debt, at 2.5% interest, over fifty years.[57]

Initially, the Seaway fostered an economic boom in its Great Lakes hinterland. New deepwater harbor facilities were built at Montréal and most Great Lakes ports; heavy industries, such as steel, oil, and chemicals, expanded their plants; and overseas trade increased sevenfold. The Seaway made possible the development of the Quebec-Labrador iron-ore deposits for supplying Canadian and American steel mills and greatly reduced transport costs for grain exports, iron ore, coal imports to Canada, petroleum, newsprint, and other bulk freight. The volume of package freight also grew rapidly, mostly in the overseas trade, and the Seaway brought a major increase in cross-border trade between Canada and the United States.

During its first two decades, the Seaway met the expectations of its builders. Traffic grew rapidly from 20.6 million cargo tons in 1959 to 51 million tons in 1970, and reached as high as 63.3 million tons in 1977, with 5,000 vessel transits. However, despite a rapid growth in traffic and an excellent operations record, by the mid-1970s, with higher-than-anticipated operating and maintenance costs and high inflation, the two Seaway operating authorities faced a crippling debt on their capital costs and unpaid interest charges. A financial crisis was averted when Canada in 1977, and the U.S. in 1983, canceled the debt and interest owed by their respective Seaway authorities, and tolls were increased. But difficulties continued, with a dramatic decline in

Lake boat in the St. Lambert lock. (K. Elder Postcard Collection)

cargo tonnage during the 1980s and early 1990s as new technological developments in transportation and shifting trade patterns had a negative impact on the Seaway.

The introduction of unit trains and containerization, as well as super tankers, container ships and ocean freighters too large for the Seaway locks diverted package and bulk freight to deepwater coastal ports served by rail and truck. This diversion brought a severe decline in overseas shipping on the Seaway, and the development of the Pacific Rim economy re-oriented a great deal of trade to west-coast ports, including 30% of the Seaway's grain exports, its principal cargo. Moreover, the construction of pipelines greatly reduced petroleum shipments, and iron ore shipments, which accounted for a quarter or more of Seaway traffic, also declined dramatically with the introduction of a new process for upgrading low-grade Mesabi iron ores, the pelletization of Labrador iron ores before shipping, and the decline of the American steel industry. All these developments combined to have a severe negative impact on the Seaway. Cargo tonnage fell to 41.4 million tons in 1986, and as low as 34.6 million tons in 1992.

Following the recession of the early 1990s, traffic on the St. Lawrence Seaway rebounded somewhat and stabilized around the 40 to 43 million tons per annum level. By the late 1990s, it exceeded 44 million tons (40 million tonnes) per annum for several years in succession, and placed the Seaway on a profitable basis. As of today, over two billion tons of cargo have passed through the St. Lawrence Seaway, making it the world's most valuable inland waterway. Bulk cargoes, such as grain, iron ore, and coal, now account for 90% of the Seaway's annual tonnage. Grain exports, most of which originate in Canada, account for 40% of Seaway traffic, and a further 19% consists of all-Canadian trade between Canadian ports. For Canada, the St. Lawrence Seaway has had, and continues to have, a major impact on the economic development of the country, but less so for the United States economy as a whole. There railroads, trucks, and the coastal ports continue to handle much of the export-import trade; and the Gulf ports, taking advantage of the lack of tolls on the Mississippi barge system, dominate the U.S. grain export trade. Nonetheless, although ocean-shipping trade on the Great Lakes has fallen far short of all projections because of new developments in transportation technologies, the St. Lawrence Seaway has yielded tremendous economic benefits for Canadian and American ports on the Great Lakes, for the American Midwest states, and for the Canadian grain-export trade through the port of Montréal, and it has fostered a booming cross-border trade between the U.S. and Canada in coal, iron ore, and steel products.[58]

Engineering Significance

Since its completion, the St. Lawrence Seaway has been widely hailed, both nationally and internationally, as "one of the greatest construction projects of all time"; as "a monumental engineering and construction feat"; as a "formidable engineering achievement"; as "one of man's greatest engineering feats"; and as "one of the greatest engineering projects ever built." The construction of the St. Lawrence Seaway has been acclaimed as an outstanding engineering feat both for constituting an amazing organizational achievement, and for the stupendous amount of diverse, difficult and demanding work completed within a remarkably short period of time.[59]

From an organizational viewpoint the St. Lawrence Seaway project was extraordinarily complex, and could not have been otherwise. It extended over a wide geographical area, covering upwards of 182 statute miles of an international-boundary river where water levels, and volumes of flow, were governed by an international treaty and an international body, the International Joint Commission. It involved two countries, with separate engineering traditions and separate national employment and purchasing policies, as well as navigation and power authorities with differing design requirements for river-channel improvements, each with its own engineering establishment. Further, all plans, specifications, and work schedules in the International Section had to be reviewed, and all changes in plans approved, by an international Joint Board of Engineers. From an organizational viewpoint, coordinating such a complex project on a fast-track schedule posed an enormous challenge.

On the Seaway project, 475 engineers employed by four separate authorities were responsible for the design, planning, and scheduling of the project, for coordinating and integrating all components of the project, for supervising and inspecting the work of numerous dredging, excavating, and construction contractors, and for ensuring that the required rate of progress was maintained in keeping with a very tight construction schedule. Moreover, this had to be done at widely separate work sites, on a project where the workforce grew to upwards of 15,700 men at the peak periods of employment. The St. Lawrence Seaway Authority alone employed 120 Canadian engineers in designing, planning, and supervising the construction of the Canadian navigation works; on the American side, the St. Lawrence Seaway Development Corporation required the services of 65 American engineers, of whom 30 were members of the U.S. Army Corps of Engineers, on its dredging work, and the construction of the Wiley-Dondero Canal. In addition, on the Seaway power project, Ontario Hydro employed its own design team of 66 engineers, as well as fifty engineers who supervised the construction of the Canadian half of the international powerhouse, the channel improvements in Canadian waters to control current velocities, and the Canadian relocation project, and PASNY engaged almost 100 engineers for construction supervision on the American power works, in addition to the 75 engineers of the engineering consulting firm of Uhl, Hall and Rich of Boston, which handled the American power-project design work.[60]

During construction, differences between navigation needs and power requirements were worked out by the respective authorities in making channel improvements. Agreements were made in allocating responsibilities for overlapping components of the work and in establishing design criteria, as well as in sharing or apportioning costs for common work. To facilitate cross-border work, agreements were concluded, through diplomatic channels, on work-sharing agreements and divisions of work that respected separate national hiring and purchasing agreements. At the commencement of the project, there was a disagreement between the navigation and power authorities over the completion date for the project, but it was resolved when the navigation authorities acquiesced in the needs of the power project for a July 1, 1958, deadline for raising the power pool. Doing so, however, necessitated a planned five-year construction project being completed in almost its entirety in just over three and a half years of actual work and necessitated the introduction of an accelerated or fast-track schedule, which was highly unusual for construction projects of such a magnitude. Thereafter a remarkably close cooperation prevailed in coordinating the work of the four authorities. During construction, only one major dispute erupted between the two countries, and that was over the proposed diversion of river flow from the south to the north channel at Cornwall Island. However, it was settled amicably through arbitration by a third party, and the decision of the IJC was fully respected. Both parties subsequently cooperated fully in sharing the work required, and the cost, for the south channel improvement, with financial contributions as well from the power authorities who benefitted directly from the work.

An equally outstanding engineering achievement, in addition to the remarkable coordination achieved in working within an unprecedentedly complex organizational environment, was the completion of a vast amount of complicated and complex work in a remarkably short period of time, in keeping with a fast-track schedule and the bringing of the project in on time, as scheduled, in the face of almost insuperable construction problems and numerous constraints. Scheduling all the work required on a complex navigation, power and water-control project was a major challenge, and particularly so in populated areas where major transportation arteries had to be extensively modified, eight communities comprising 6,500 persons had to be relocated, and existing infrastructures relocated and rebuilt all along the Seaway. During the construction period, all sections of the river had to be maintained at a navigable level, with a constant flow, and low current velocities to avoid any interruption to the operation of the navigation works and existing power plants; and nine major bridge crossings had to be extensively modified, and a new high level suspension bridge constructed. Moreover, several bridges were on the busiest road and rail crossings in Canada, serving Canada's then-major metropolis, where only minimal interruptions in traffic could be tolerated, and then only during restricted time periods.

On the St. Lawrence Seaway navigation project, it was the Canadian engineers and contractors who were responsible for constructing over 70% of the work required; and it was the Canadian work sites that presented the most severe, and seemingly insurmountable, construction problems. The American construction sites, for the most part, were in unsettled and unobstructed areas where large numbers of men and heavy equipment could be readily employed, and were, to overcome construction problems and speed the progress of the work in keeping with a fast-track schedule. In contrast, much of the Canadian work proceeded in populous areas where a heavily built-up infrastructure greatly increased the magnitude and complexity of the work, and hampered or restricted the use of conventional heavy equipment, which, in conjunction with unusually severe construction problems, necessitated the introduction of novel construction approaches to sustain the fast-track schedule.

On the highly congested Lachine Section, a truly innovative "critical path method" of project management was introduced by Canadian engineers, with highly detailed contract specifications governing starting times, output requirements, and interim deadlines, to aid in the scheduling and coordinating of the work. Moreover, elsewhere on the project where complex channel improvements were required Canadian engineers speeded the work and effected major cost savings by introducing hydraulic scale models, which subsequently were used to an unprecedented extent on the Seaway project as a whole to study the character of sections of the river for positioning dams, embankments, and canal entrances, and for testing proposed channel improvements to ensure that a desired flow characteristic and current velocity would be attained. Canadian engineers were also in the forefront in applying the latest advances in the science of soil mechanics to the design of dykes and embankments on which work proceeded during the winter months to speed the pace of construction.

Although contractors complained of the extremely tight schedule in force, they cooperated fully in striving to meet the construction deadlines. Most of the American and Canadian contractors were major construction engineering firms of national, or international, reputation, who formed joint-venture partnerships to bid on the contracts involving massive amounts of work at construction sites in their respective countries; they were able to bring large fleets of specialized equipment, and construction know-how, to push on the work.[61] Indeed, on the Lachine Section the largest fleet of construction equipment ever seen in Canada was assembled by the contractors; even larger fleets of heavy equipment were employed at the American work sites to drive forward the work each summer.

Where serious delays were experienced in excavating a very sticky marine clay, a concretized glacial till, and a hard silica sandstone, and in working at congested work sites difficult to access, the time lost was invariably made up in the next phase of construction, the forming and pouring of the concrete, and, particularly at the Canadian sites, through the introduction of unconventional approaches and the latest advances in construction-equipment technology.[62] Among the advances introduced at the Canadian sites to overcome construction problems, speed construction, and keep the project abreast of its fast-track schedule were jet piercer borers; air cushion blasting; a new high explosive (ammonium nitrate); large sliding steel concrete forms; French tower cranes; the pouring of concrete in high lifts and huge alternate monoliths; and the pursuing of concrete work throughout the winter months. Despite the constant push to move construction forward, and the fast pace of the work, with thousands of men employed at some work sites in two 10-hour shifts per day, five days a week, the St. Lawrence Seaway was remarkable for its phenomenally low accident record compared to other major construction projects and the almost total absence of management-labor conflicts and strikes. Moreover, the structures on the navigation and power components of the project were exceptionally well built.[63]

On the St. Lawrence Seaway, an immense amount of high-quality work was accomplished in a remarkable short period of time, on a mammoth construction project involving major navigation, power, and water-control works. The entire project required 162 million cu. yds. of dry excavation; 35 million cu. yds. of dredging; 25.5 million cu. yds. of material placed in dykes; and 6.5 million cu. yds. of concrete. These figures were immense by any standard, and what was considered most amazing by contemporaries was that almost all of the actual work, with the exception of the dredging and some bridge work, was completed in just over three years, from the spring of 1955 to the summer of 1958.[64]

In addition to involving the construction of the world's greatest inland deep waterway, the St. Lawrence Seaway project was also an immense water-control project. Complete control had to be attained, and maintained, over one of the world's great rivers, the St. Lawrence River, which drains the interior of half a continent, and five Great Lakes, with a drainage area of 678,000 square miles and a discharge at Montréal of over 310,000 cfs, second only to the Mississippi River in North America.[65] During construction, river levels and moderate current velocities had to be maintained for the benefit of existing power-generating plants and the continued operation of the St. Lawrence Ship Canals system during the navigation season on a swift-flowing river that fell 226' along the 182-mile length of the Seaway; and a permanent control had to be established over the currents and the flow characteristics of the entire river. This challenge was met through the construction of the Iroquois Control Dam, which established an absolute control over the water level and outflow of the lowest Great Lake, Lake Ontario, through the construction of the Long Sault Spillway Dam to control water levels in the power pool, Lake St. Lawrence, and in the successful design and execution of channel improvements that eliminated water turbulence and controlled current velocities according to specified criteria: 4 feet per second for the ship navigation channels and 2.25 feet per second for the combined navigation and power channels, to prevent the formation of frazil ice.

The St. Lawrence Seaway was not only a deepwater navigation and water-control system, it also involved the construction of an international power-generating station which, although a low-head structure, had an enormous output because of the tremendous flow of the St. Lawrence River through 32 massive turbines. When completed in 1959, it had a total installed capacity of 1,824,000 kw. This output was greater than any single-site hydroelectric plant in Canada. It far exceeded the new Sir Adam Beck #2 powerhouse at Niagara Falls, Ontario (1,223,600 kw as of 1958) and its sister plant, Sir Adam Beck #1 (formerly Queenston-Chippawa, 403,000 kw as of 1930), the enlarged Beauharnois powerhouse (1,379,600 kw as of 1961), and the total capacity of the seven Shawinigan power developments on the St. Maurice River, Quebec (1.5 million kilowatts total as of 1959).[66] Moreover, the Moses-Saunders international powerhouse was one of the largest-output hydroelectric power generating plants in the world, exceeded greatly in generating capacity only by the Grand Coulee Dam power plants on the Columbia River in the United States. Although the next two decades saw the construction of a number of colossal hydroelectric power developments world-wide that far surpassed the capacity of the Seaway international power plant, even today the power-generating capacity of the Moses-Saunders international powerhouse is exceeded in North America by only five American hydroelectric power generating plants and four Canadian hydroelectric power sites.[67]

There are deepwater canal construction projects that are comparable to the St. Lawrence Seaway in the scale of the canal work required, such as the Fourth Welland Canal and the Panama Canal, and there were hydroelectric power projects, such as the Sir Adam Beck #2 at Niagara Falls, that are comparable to the Seaway international powerhouse project in power output capacity or, in the case of the Grand Coulee Dam project, that greatly surpassed it in both power output and volume of concrete poured. There are also major international engineering construction projects that required the overcoming of severe water-control problems. However, there is none that embodied the overall complexity and extent of the St. Lawrence Seaway project and the immense amount of complex, diverse, and demanding work that was completed in a comparably short time period on a fast-track schedule. None combined a deepwater navigation, power, and water-control project on such a massive scale or required the integration and coordination of so many major projects within projects. There are none where construction had to be carried through populated areas and involved major relocation and infrastructure modifications projects that had to be phased into a tight schedule of construction, hampered by severe operational constraints at congested work sites. Moreover, there are none that required the coordination of the work of four separate construction authorities at an international level, where diplomatic conventions governed what could be done with the river courses and volumes of flow, and where an absolute control had to be attained and maintained at all times over the water levels and current velocities of one of the world's greatest rivers. However viewed, the construction of the St. Lawrence Seaway was an outstanding international engineering achievement, and a phenomenal feat of construction.

Only the Tennessee Valley Authority (TVA) power, navigation, and water-control project in the United States is comparable to the St. Lawrence Seaway in its multi-purpose comprehensiveness, geographical scale, and its general administrative nature. A federal government authority, the TVA constructed nine power/reservoir dams, and enlarged two existing dams on the 650-mile-long Tennessee River in carrying out its mandate to control flooding on the river, to develop the hydroelectric power capacity (2.65 million hp) of a 500' drop in the river, and to provide a 9-foot-deep barge navigation throughout. Over 1,000 engineers, 400 clerical workers, and up to 7,000 men were employed on the TVA project at peak periods of construction, and a stupendous amount of work was completed. Over 4 million cu. yds. of concrete was poured in constructing the dams, locks, and powerhouses, a total of 2.2 million kw of electric power generation capacity installed, and seven million acre-feet of water storage provided for flood control, power generation, navigation, industrial development, land reclamation, and recreational purposes.

Although an outstanding engineering achievement on an impressive scale, the TVA project was far less of an engineering challenge than the St. Lawrence Seaway. The initial TVA project (1933–1945) was built in successive phases over a period of more than a decade; and it was built by a single federal government authority, dealing with different levels of government within a single country. Moreover, the TVA project employed conventional construction technologies, and neither the administrative and scheduling complexities, the excavation work, the construction site constraints, the water control challenge, nor the relocations projects were anywhere near as difficult or demanding as on the St. Lawrence Seaway project.[68]

In a very real sense, the St. Lawrence Seaway project has no valid contemporary comparisons as an engineering project management challenge with respect to its unusual organizational complexity at an international level, the immense amount and variety of different work that had to be performed in a remarkable short period of time, the constraints in force at several major work sites, and the fast-track construction schedule in force. Although it is difficult to compare engineering projects because the nature of the work and the severity of the construction problems encountered differ widely from one project to another, nonetheless, some comparisons can be made simply in terms of the volume of work achieved and the time frames.

In terms of the total volume of material excavated and dredged (197 million cu. yds.), the St. Lawrence Seaway was comparable to the world's largest and most outstanding canal excavations. It far exceeded the 97 million cu. yds. of excavation and dredging on the 100-mile-long Suez Canal (1854– 1869) and the 61 million cu. yds. of earth and rock removed on the 25-mile-long Fourth Welland Canal (1913–1932), and was exceeded only by the 262 million cu. yds. of material excavated and dredged on the 51-mile-long Panama Canal (total of French project, 1881–1889, and American project, 1904–1914). Moreover, the combined total of American and Canadian excavations on the St. Lawrence Seaway project almost doubled the 100 million cu. yds. of material excavated on the 30-mile-long Red River Floodway (1962–1968) at Winnipeg, Manitoba, on Canada's largest contemporary excavation project.

In terms of the volume of concrete poured (6.5 million cu. yds.), the St. Lawrence Seaway exceeded the 3.6 million cu. yds. of the Fourth Welland Canal and the 4.4 million cu. yds. of the Panama Canal.[69] It also exceeded the volume of concrete in the landmark 726'-high Hoover Dam (1932–1936), which, when constructed, was by far the single largest concrete structure in the world (3.25 million cu. yds.) and inaugurated the era of multi-million-cubic-yard concrete dams. When constructed, there was only one structure that greatly surpassed the St. Lawrence Seaway project in volume of concrete. It was the world's then-largest concrete structure, the colossal Grand Coulee Dam (1933–1942), on the Columbia River in Washington State, with a volume of 10, 585,000 cu. yds.[70]

Conclusion

In its magnitude and the volume of work accomplished, the St. Lawrence Seaway project ranked among the greatest construction projects undertaken to that time; it was distinguished as well by the employment of the latest advances in construction technologies, which made a critical contribution to the successful completion of the project on schedule. However, neither the magnitude of the work accomplished nor the advanced technologies introduced by the contractors, the joint-venture construction companies and their respective engineering staffs, constitute the essence of the engineering achievement. There were other contemporary engineering projects of massive scale, involving a great volume of work, and the introduction of new technologies, developed elsewhere, was simply good construction-engineering practice. Moreover, the nature of the work accomplished on the various component projects within the Seaway project was typical of major large-scale North American construction projects of a variety of different types—ship-canal construction projects, hydroelectric power-dam projects, bridge-construction projects, municipal utilities construction projects, water diversion and water-control projects, and town relocation projects.

The truly outstanding engineering achievement on the St. Lawrence Seaway project was in project management. It was an amazing organizational triumph distinguished by the successful coordination at an international level of the work of four separate authorities, from two different countries, in designing and constructing an extraordinarily complex and highly integrated navigation, power, and water-control project, and the completion of a stupendous amount of diverse and difficult work in a surprisingly short period of time on a novel fast-track schedule. Moreover, it was an outstanding engineering achievement made possible in part through the introduction of an innovative critical-path method of project management.

Notes

1. Robert W. Passfield, "Waterways" in Norman R. Ball, ed., *Building Canada: A History of Public Works* (Toronto: University of Toronto Press, 1988), 113–128. The Canadian ship canals system comprised eight canals totaling 74 miles in length, with a total of 48 locks providing 553 feet of lockage between Montréal and Lake Superior. The ship canals were the Sault Ste. Marie Ship Canal (1889–1896), the Third Welland Canal (1873–1887), and the six St. Lawrence River canals, the Galop (1888–1894), Rapide Plat (1891–1896), Farran's Point (1897–1899), Cornwall (1884–1895); Soulanges (1891–1899), and Lachine (1873–1884)
2. Robert W. Passfield, *Technology in Transition: The 'Soo' Ship Canal, 1889–1985* (Ottawa: Environment Canada, 1989), 16–40, 133. The two parallel flotilla locks on the American canal at Sault Ste. Marie, the St. Mary's Falls Canal, were the 515' x 80' Weitzel Lock (1876–1881) and the 800' x 100' Poe Lock (1887–1897).
3. John N. Jackson, *The Welland Canals and Their Communities* (Toronto: University of Toronto Press, 1997), 270–274; and Passfield, *Technology in Transition*, 132, 141. With the settlement of the western prairies, Canadian wheat exports grew from 422,274 bushels in 1890 to 16,864,650 bushels in 1900, and continued to increase dramatically thereafter. By 1923, Canada would supersede the United States as the world's leading wheat exporter; by 1930–31, Canada would export 258 million bushels of wheat per annum, constituting 40% of the world's wheat trade (*ibid.*).
4. John P. Heisler, *The Canals of Canada* (Ottawa: DIAND, 1973), 156–158; and W.H. Becker, *From Atlantic to Great Lakes, A history of the U.S. Army Corps of Engineers and the St. Lawrence Seaway* (Washington: Office of Chief Engineer, 1984), 10–12.
5. Hon. Lionel Chevrier, *St. Lawrence Seaway* (Toronto: MacMillan, 1959), 31–32; A.W. Currie, "The St. Lawrence Waterway", *Queen's Quarterly*, Vol. LVIII, Winter 1951–52, No. 4, 562–563. There were no tolls on either the Fourth Welland Canal or the American and Canadian canals at Sault Ste. Marie.
6. Becker, *Atlantic to Great Lakes*, 13–17. The state of New York was lobbying for the construction of a Lake Ontario-Hudson River deep waterway totally within American territory, a project that the U.S. Army Corps of Engineers had favored also prior to the completion of the Wooten-Bowden Report in 1921 (*ibid.*, 8–9). The report was prepared under the direction of Colonel William Wooten, U.S. Army Corps of Engineers, and W.A. Bowden, Chief Engineer, Department of Railways and Canals (later Department of Transport), Canada.
7. Chevrier, *The St. Lawrence Seaway*, 28–29, 31–32, 42–47; Currie, "The St. Lawrence Waterway," 558–565; Arnold V. Raison, "The St. Lawrence Seaway, Historical, Legislative, and Administrative Aspects," *Roads & Engineering Construction*, Vol. 96, no. 11, Nov 1958, 27. The driving force behind the decision to build an all-Canadian Seaway was the Honourable Lionel Chevrier, Member of Parliament for Cornwall, Canada's Minister of Transport and, subsequently, the first president of the St. Lawrence Seaway Authority (1954–1957).
8. Chevrier, *The St. Lawrence Seaway*, 46–49; Becker, *Atlantic to Great Lakes*, 20.

9. Becker, *Atlantic to Great Lakes*, 17–18; Currie, "The St. Lawrence Waterway," 558–565; Chevrier, *The St. Lawrence Seaway*, 114–119. In 1947, Canada had agreed "in principle" to the imposition of tolls to enable the Seaway to pay for itself in 50 years (Becker, 17). This concession was part of yet another abortive effort to secure U.S. Senate ratification for the 1941 agreement.
10. Heisler, *The Canals of Canada*, 158–159. Canada insisted on constructing the control dam lock (the Iroquois Lock) on the Canadian side of the river to prevent American participation in the construction of the Seaway serving as a means for the U.S. to acquire complete control over the International Section of the deep waterway.
11. Chevrier, *The St. Lawrence Seaway*, 49, 118–119; Raison, "The St. Lawrence Seaway," 28.
12. Becker, *Atlantic to Great Lakes*, 25, 50–51; Chevrier, *St. Lawrence Seaway*, 51, 62.
13 H.G. Cochrane, "The St. Lawrence Seaway and Power Project," *Water Power*, Vol. 8, April 1956, 136–142; Becker, *Atlantic to Great Lakes*, 23, 92–95; Raison, "The St. Lawrence Seaway," 28. The seven Seaway locks replaced a total of 25 locks in the old St. Lawrence Ship Canals system.
14. Becker, *Atlantic to Great Lakes*, 104.
15. Cochrane, "St. Lawrence Seaway," 134–140; "Progress on St. Lawrence Development," *Roads & Engineering Construction*, Vol. 94, April 1956, 47; "St. Lawrence Seaway," *The Canadian Encyclopedia*, Vol. 3, 1988, 1921. Once the power pool was raised, it submerged the greater part of the downstream face of the Iroquois Control Dam, which consequently has the appearance of a low dam separating two large bodies of water.
16. Robert F. Legget, *Canals of Canada* (Vancouver: Douglas, David and Charles, 1976), 211. Both the Eisenhower Lock and Côte Ste-Catherine Lock, which opened up into large bodies of water, were also equipped with sector gates at their upper end. Moreover, all of the Seaway locks were also equipped in each forebay with a steel truss stop logs/stiff-legged derrick emergency dam for employment should its lock gates be struck and carried away by a freighter. On the function of emergency dams and guard locks on ship canals see Passfield, *Technology in Transition*, 179–246. The Seaway locks were also equipped with a 'fender cable' on a boom at each end of a lock chamber to restrain a freighter, if needed.
17. Cochrane, "St. Lawrence Seaway," 136–138; "Progress on St. Lawrence Development," 50; *St. Lawrence Seaway and Power Projects, 1959* (Montréal: Reid and Boulton Publishing Co., 1958), 247. In the International Section, the Americans employed one of the largest forces of construction equipment ever assembled. It comprised 135 power shovels and draglines, 400 crawler tractors, 730 trucks, and eight dredges (*ibid.*, 133).
18. Cochrane, "St. Lawrence Seaway," 138; and "Progress on St. Lawrence Development," 48–49. The Americans also had to construct a major spillway dam with some extensive dyking at Massena, New York, at the entrance to an existing power canal that supplied water to the town and power for an aluminum plant. The power canal flowed into the Grass River that discharged into the St. Lawrence River below Barnhart Island.
19. "Progress on St. Lawrence Development," 46–47, 49. The glacial till had a high density, ranging from 142 to 156 lbs. per cu. ft. as compared to a 145 lbs. per foot average for concrete. It consisted of a mixture of silt and soil laced with boulders. The blue marine clay consisted of a "wet stinking, slippery 'goup' that clung like glue to buckets and earth-moving equipment" (*St. Lawrence Seaway and Power Projects*, 119).
20. F.L. Peckover & T.G. Tustin, "Soil and Foundation Problems," *Engineering Journal*, Vol. 41, No. 9, 69–72. Extensive soil investigations and aggregate testing were also carried out by the U.S. Corps of Engineers along the route of the Wiley-Dondero Canal (Becker, *Atlantic to Great Lakes*, 62). The Standard Proctor is a test that determines the maximum dry density (in pounds per cubic foot) for specific soil types. It is used as well to measure soil compaction densities based on a percentage of the Standard Proctor for a specific moisture content.
21. Becker, *Atlantic to Great Lakes*, 53; Cochrane, "St. Lawrence Seaway," 138.

22. Cochrane, "St. Lawrence Seaway," 138; Chevrier, *St. Lawrence Seaway*, 107–110; *St. Lawrence Seaway and Power Projects*, 74–83.
23. "Upper Canada Village," *The Canadian Encyclopedia*, Vol IV (Edmonton, 2nd. ed., 1988), 2227; Beryl W. Way, "Upper Canada Village," *Canadian Geographical Journal*, May 1961, 218–233. In 1961, Upper Canada Village opened as part of a newly established 2,000-acre provincial park, Crysler Farm Battlefield Park, commemorating the War of 1812 Battle of Crysler's Farm, fought on November 11, 1813. The old battlefield monument was moved to the new site within the park to escape inundation.
24. Becker, *Atlantic to Great Lakes*, viii, 61–79; Cochrane, "St. Lawrence Seaway," 142; Chevrier, *St. Lawrence Seaway*, 83. During construction the American works had different names: viz. the Long Sault Canal (renamed the Wiley-Dondero Canal), the Robinson Bay Lock (renamed Dwight D. Eisenhower Lock in May 1956), and the Grass River Lock (renamed Bertrand H. Snell Lock in 1958).
25. Cochrane, "St. Lawrence Seaway," 136, 139–140. Supercooled water is water that remains in a liquid form at temperatures below zero degrees Centigrade (32 degrees Fahrenheit). It occurs in a river when water turbulence and a high current velocity prevent the fast-flowing liquid from crystalizing as ice. Another potential danger was that frazil ice crystals would combine with floating pieces of broken shore ice carried downstream by the open river current, and pass under the ice cover of the power pool to form ice packs, or hanging dams, below the ice surface. Such a development would greatly reduce the flow of water under the ice surface to the turbines during the winter months (*ibid.*).
26. "Progress on St. Lawrence Development," 45–46.
27. Cochrane, "St. Lawrence Seaway," 138; John W. Dennis "Models-hard sense and make-believe," *Design Engineering*, Vol. 4, No. 3, March 1958, 46–49; "The construction Period 1954 to 1958," *Engineering Journal*, Vol. 41, Sept 1958, 52; Becker, *Atlantic to Great Lakes*, 16, 64, 100; *St. Lawrence Seaway and Power Projects*, 13, 97, 114. Ontario Hydro alone saved an estimated $5 million on construction costs through the use of the hydraulic models, the largest of which was 146' long and 40' wide.
28. Becker, *Atlantic to Great Lakes*, 95–100, 52–53; Chevrier, *St. Lawrence Seaway*, 62; "Progress on St. Lawrence Development," 48–49; *St. Lawrence Seaway and Power Projects*, 119. The power authorities, after lengthy negotiations, also contributed to the dredging and excavation costs at Cornwall Island because that work reduced the river level by one foot upstream at the International powerhouse, yielding a gain of 20,000 hp for the powerhouse (*ibid.*, 130).
29. Becker, *Atlantic to Great Lakes*, 56–61; L.H. Burpee, Griffin, and Angell, "St. Lawrence Project—planning and construction progress," *Civil Engineering* (New York), Vol. 27, July 1957, 39; Richard Scott, *In the Wake of Tacoma, Suspension Bridges and the Quest for Aerodynamic Stability* (Reston, Va.: ASCE Press, 2001), 119. American Bridge erected the suspension bridge superstructure in just six months. The low-level bridge continued in use over the north channel at Cornwall Island until 1962, when Canada replaced it with a high-level continuous-truss arched bridge to keep open the possibility of future construction of an all-Canadian seaway. Today, the Seaway International Bridge carries 2.2 million vehicles annually, of which 136,000 are commercial vehicles.
30. The existing Soulanges Ship Canal (1892–1899) on the 14'-deep Canadian ship canals system was located along the north bank of the St. Lawrence River. It was 14 miles long, with five locks having a total lift of 82.5' and continued to operate each navigation season during the construction of the Seaway.
31. Cochrane, "St. Lawrence Seaway," 141; Heisler, *The Canals of Canada*, 150; Arnold Roos, "The Beauharnois Power Development" (Historic Sites and Monuments Board of Canada, Agenda Paper 1990, no. 45, unpublished). The Beauharnois powerhouse by the mid-1950s had 21 generating units on line with a capacity of 747,160 kw, driven by an 81' head of water.
32. The jet piercer was developed in 1947 by the Linde Division of Union Carbide, and by the mid-1950s had a major impact in rendering the mining of taconite economical in the Mesabi Range of Minnesota (Lloyd E. Antonides, "Jet Piercing—the

Miners' Rocket," *Engineering & Mining Journal*, Vol. 159, July 1958, 103–107; J.J. Calaman & H.C. Rolseth, "New Look at Jet-Piercing Developments," *ibid.*, vol. 162, May 1961, 100–104).

33. Eric Le Bourdais, "Construction Aspects," *Roads and Engineering Construction*, Vol. 96, no. 11, Nov 1958, 32–35; Chevrier, *St. Lawrence Seaway*, 82. Some hard silica sandstone was encountered in the earlier Beauharnois powerhouse excavation, but it was in well-defined layers, about 18" thick. On the Seaway project, at the upper Beauharnois Lock, there were areas where the churn drills were constantly striking lateral seams and getting stuck; as a result, some holes were bored only 6' in two work shifts.

34. Hal W. Hunt, "Placing six million cu. yd. of concrete on the St. Lawrence," *Civil Engineering* (New York), Vol. 27, July 1957, 464–466; Chevrier, *St. Lawrence Seaway*, 82; Le Bourdais, "Construction Aspects," 36. Concrete generates a tremendous chemical heat in setting, which poses severe problems in pouring large concrete structures, such as the Hoover Dam (1931–1936), the highest concrete dam in the world (726' high, 1,244' long, and 660' thick at its base). There American engineers solved the heat dissipation problem by pouring the dam in separate, interlocked blocks or columns no more than five feet thick, which were honeycombed with 1" diameter pipes through which cool river water and ice-cold refrigerated water were pumped (Joseph E. Stevens, *Hoover Dam: An American Adventure* (Norman: University of Oklahoma Press, 1988), 193–195).

35. Le Bourdais, "Construction Aspects," 37–38; *St. Lawrence Seaway and Power Projects*, 102.

36. For decades all planning for a deepwater canal in the Lachine Section focused on the north side of the river, along the Montréal Island shore, but by 1950 the high degree of development along that shore of the main river channel rendered the existing plan too costly and impractical. Hence, in 1952 planning commenced for the construction of a deep waterway along the south shore.

37. L.H. Burpee, "Planning and Constructing the Lachine Section," *Engineering Journal* (Montréal), Vol. 41, Sept 1958, 55–65. The Critical Path Method is a systematic project-management method for complex, one-time projects that facilitates the organization, planning, and scheduling of interrelated activities, as well as cost estimating and resource allocation, on a critical time path. It was developed in the United States in 1956–58 in two initial versions for managing complex projects by E.I. Du Pont de Nemours, who developed the Project, Planning and Scheduling (PPS) method for constructing major chemical plants, and by the U.S. Navy, who developed the Program Evaluation and Review Technique (PERT) system for managing its Polaris missile program. These early project-management systems evolved into the Critical Path Method, which is widely used on large complex construction projects today (W.F. Chen, Editor-in-Chief, *The Civil Engineering Handbook* (New York: CRC Press, 1995), 35–36 and following). On the Lachine Canal construction project, the Canadian engineers of the St. Lawrence Seaway Authority developed, independently, their own particular critical-path method of project management in response to a complex construction project with many interrelated activities to be planned, organized, scheduled, and coordinated, with sufficient resource allocations, within a critical time frame.

38. At the Caughnawaga Reserve several farms and summer cottage properties and a part of Caughnawaga Village were appraised and expropriated on the overland section of the project. Several property owners resorted to court action, and delayed the excavation work before their property was purchased at the price they demanded (*St. Lawrence Seaway and Power Projects*, 98).

39. Burpee, "Planning and Construction," 56–57, 61–62. The water level in Lake St. Louis ranged from a 65' to 75' elevation above sea level; the Laprairie Basin navigation channel was regulated at a 38' elevation; and Montréal Harbour ranged from a 15' elevation at low water to a 33' elevation at high water. Hence, depending on the lake and river levels, the Côte Sainte-Catherine Lock had a lift anywhere from 27' to 37'; and the Saint-Lambert Lock, a 5' to 23' lift. The Lapraire Dyke was carried at a 80' elevation at the Lake St. Louis end, at a 58' elevation in Laprairie Basin, and at a

40' elevation below the Saint-Lambert Lock. A water intake was also constructed at Saint-Lambert, but was part of the Saint-Lambert Lock construction contract.

40. *St. Lawrence Seaway and Power Projects,* 87.
41. W. Grothus & D.M. Ripley, "St. Lawrence Seaway, 27-Ft Canals and Channels," *Journal of the Waterways and Harbors Division, Proceedings of ASCE*, vol. 84, Jan 1958, 1518:15.
42. Le Bourdais, "Construction Aspects," 40–42; *St. Lawrence Seaway & Power Projects*, 87; Burpee, "Planning and Construction," 60.
43. Peckover & Tustin, "Soil and Foundation Problems," 71.
44. Le Bourdais, "Construction Aspects," 41–42.
45. *St. Lawrence Seaway & Power Projects*, 286–287; Chevrier, *St. Lawrence Seaway*, 100.
46. Burpee, "Planning and Construction," 63; and Le Bourdais, "Construction Aspects," 41–42.
47. Le Bourdais, "Construction Aspects," 41; *St. Lawrence Seaway and Power Projects*, 259. The conveyor belt system at the St. Lambert Lock was able to place 80 cu. yd. of concrete per hour, or 800 cu. yd. in a ten hour shift.
48. *St. Lawrence Seaway and Power Projects*, 264–265. The French gantry cranes had a 100' horizontal boom on an 100'-high tower, were 15' square at their base and weighed only 100 tons. Each had a 7-ton lifting capacity on a 50' radius and a 1.5 ton capacity on a 100' radius.
49. *St. Lawrence Seaway and Power Projects*, 96–98; Le Bourdais, "Construction Aspects," 42. The Côte Ste-Catherine Lock was also constructed with a concrete floor over a shale foundation; whereas the other Canadian locks have bare rock floors.
50. *St. Lawrence Seaway and Power Projects*, 86, 93, 95–96. As work approached a conclusion on the Seaway construction project, construction began on a major new bridge crossing over the Seaway: the Champlain Bridge (1959–1962), which crosses the St. Lawrence River at Nun's Island (L'Île des Soeurs), just upstream of Montréal Harbour. It was built by the National Harbours Board to relieve traffic congestion and crosses the Seaway channel with a six-lane cantilever bridge providing a 120' vertical clearance ("Champlain Bridge in Montreal," *Engineer* (London), vol. 214, 14 Sept 1962, 454–457).
51. *St. Lawrence Seaway and Power Projects*, 90, 227; Chevrier, *St. Lawrence Seaway*, 86; Le Bourdais, "Construction Aspects," 42–43. Dr. P.L. Pratley, Consulting Engineer, Montréal, designed the original Jacques Cartier Bridge, the Seaway jacking operation and south approach modifications, and the new Champlain Bridge, and was the consultant for the foundations of the new Seaway International Bridge at Cornwall Island.
52. "Construction Period, 1954–1958," 53; Burpee, "Planning and Construction," 55–58; Becker, *Atlantic to Great Lakes*, 101. Only the new Champlain Bridge and the construction of the diversion branch of the Victoria Bridge remained incomplete in the fall of 1958, but neither was part of the original Seaway project. The diversion branch, which converted the Victoria Bridge to a "Y" bridge, was a railway project. It enabled freight trains to use the upper vertical-lift bridge as an alternate crossing of the St. Lambert Lock, and provided the railway with the same capacity for uninterrupted passage over the Seaway lock as was enjoyed initially only by vehicular traffic on an alternative south approach with sharp turns.
53. *St. Lawrence Seaway and Power Projects*, 139–140; "The Construction Period 1954–1958," 53–54. A calculated flow of 310,000 cfs was released from the control dam, but 210,000 cfs was passed directly downstream through the power pool at the Long Sault Spillway Dam to maintain a navigable depth of water in Montréal Harbor, and to keep the Beauharnois power station fully operational. At a controlled discharge of 310,000 cfs, the level of Lake Ontario was reduced only 2.5" in filling the power pool, which held 500,000 acre feet of water. The power pool was filled on a "238–242 plan" whereby it was to be initially raised to the 238' level (above sea level), and maintained at that level until the earth dam dykes compacted; then it would be raised to the final 242' elevation for maximum power generation. The first

deep-draught vessel through the Seaway on its opening, April 25, 1959, was the Canadian icebreaker, C.G.S. *D'Iberville*.

54. "Radiant Queen Attends Opening," *Public Works in Canada*, Vol. 7, No. 8, August 1959, 13, 44; Becker, *Atlantic to Great Lakes*, 123. At a second ceremony upstream at the Moses-Saunders powerhouse, the Queen and Vice President Richard M. Nixon unveiled a gold-lettered marble plaque bearing the words:

    THIS STONE BEARS WITNESS TO THE COMMON PURPOSE OF TWO NATIONS WHOSE FRONTIERS ARE THE FRONTIERS OF FRIENDSHIP, WHOSE WAYS ARE THE WAYS OF FREEDOM, AND WHOSE WORKS ARE THE WORKS OF PEACE.

55. Some 60% of Canada's population and 80% of its manufacturing and processing industries were located along the St. Lawrence-Great Lakes waterway; for the U.S., 35% of its population, a great deal of its heavy industry, and 50% of its manufacturing capacity (*St. Lawrence Seaway and Power Projects*, 159). The new "730s" could carry 1,000,000 bushels of grain on a 25'-9" draught. By an agreement of January 1959, the revenue from tolls in the International Section was divided 71% to Canada, 29% to the U.S., based on the ratio of Seaway construction costs; the revenue from tolls imposed thereafter on the Fourth Welland Canal was retained by Canada, which paid for that construction project.

56. "Construction Period, 1954–1958," 53; Becker, *Atlantic to Great Lakes*, v. In addition, the U.S. spent $150 million on the dredging of the navigation channels in the upper lakes; Canada paid $28 million to deepen the Fourth Welland Canal two feet, in addition to the $131 million spent earlier on its construction (1913–1932); and at Sault Ste. Marie, the U.S. Army Corps of Engineers had previously deepened the St. Mary's Falls Canal to accommodate a 27'-deep navigation and constructed an 800' x 80' Seaway-scale lock, the MacArthur Lock (1942–1943), at a cost of $14 million. A further total of $65 million was spent by port authorities in deepening and enlarging the major Great Lakes ports and the port of Montréal. Hence the citing by some sources of cost figures ranging anywhere from $1.1 billion to 1.2 billion for the total cost of the Seaway.

57. "The St. Lawrence Seaway and the Shipping Industry," *Shipbuilding and Shipping Record*, vol. 93, Feb 5, 1959, 181–184; Raison, "The St. Lawrence Seaway," 27–29.

58. Chevrier, *St. Lawrence Seaway*, 132; Becker, *Atlantic to Great Lakes*, 123–143; *Traffic Report of the St. Lawrence Seaway* (Cornwall, Ontario), annual reports, 1959–2000, "St. Lawrence and Lake Ontario Section." Grain transport costs were reduced by 6 to 8 cents a bushel by the Seaway. Commencing in 1978, the annual traffic statistics are listed in metric tonnes instead of short tons. Herein, for comparative purposes, all cargo tonnage figures are cited in short tons. The ocean trade in packaged goods remains a potentially large growth area, if the Seaway were able to handle large container ships. Recently, the U.S. Army Corps of Engineers completed a preliminary study to determine the feasibility and cost of enlarging the Great Lakes-St. Lawrence Seaway system with Panama Canal scale locks, 1,000' x 110', to enable large ocean vessels to enter directly into the Great Lakes ports.

59. See Raison, "The St. Lawrence Seaway," 23–29; Burpee, "Planning and Constructing," 62; "The Construction Period 1954 to 1958," 52–54. The quotes are from, respectively, Chevrier, *The St. Lawrence Seaway*, 54; "St. Lawrence Seaway," *The Canadian Encyclopedia*, Vol. III, 1988, 1921; Becker, *Atlantic to Great Lakes*, v; "Saint Lawrence Seaway," *New Encylopaedia Britannica*, vol. 16, 15th ed., 1980, 174; Robert F. Legget, *The Seaway* (Toronto: Clarke, Irwin, Co., 1979), cover blurb.

60. "Construction Period, 1954 to 1958," 52; and Le Bourdais, "Construction Aspects," 43. Sometimes a figure of 22,000 men is cited for the Seaway project workforce; however, that figure includes the men who were working concurrently on deepening the Welland Canal as well as the St. Lawrence Seaway workforce.

61. See *St. Lawrence Seaway and Power Projects*, promotional entries on the major Canadian and American joint-venture partnerships of the Seaway project.

62. At the American work sites, standard design, contract, and construction approaches were generally followed. Construction was pushed forward with excep-

tionally large fleets of heavy equipment during the summer months. Only some excavation work was carried on during the winter (Becker, *Atlantic to Great Lakes*, 48).

63. Raison, "St. Lawrence Seaway," 29. Over the following decades the only serious maintenance problem experienced on the Seaway was at the Eisenhower Lock where the concrete deteriorated badly (Becker, *Atlantic to Great Lakes*, 143).
64. "Construction Period, 1954 to 1958," 53–53. These figures are exclusively for the construction of the St. Lawrence Seaway from Montréal to Lake Ontario. For operational and administrative purposes the Welland Canal was integrated into the St. Lawrence Seaway from almost the opening of the Seaway. However, the deepening of the Welland Canal during the construction of the Seaway was a separate, although related, construction project. The breakdown for the St. Lawrence Seaway project alone in cubic yards was: dry excavation: Canada 55 million, U.S. 25 million, power project 82 million; dredging: Canada 18 million, U.S. 5 million, power project 12 million; dyking: Canada 7.5 million, power project 18 million; concrete: Canada two million, U.S. one million, and power project 3.5 million.
65. Cochrane, "St. Lawrence Seaway," 134–135. At its mouth, the St. Lawrence River has a discharge in excess of 400,000 cfs. The Mississippi River, measured at Vicksburg, Mississippi, has an average annual mean discharge of 595,000 cfs (John R. Hardin, "Evolution of the Mississippi Valley Flood Control Plan," *Journal of the Waterways and Harbors Divisions*, ASCE Proceedings, Vol. 83, May 1957, 1251:1).
66. Statistics Canada, *Electric Power Statistics*, vol. III, 1983 (Ottawa: Supply & Services Canada, 1984); *St. Lawrence Seaway and Power Projects*, 217. Each of the sixteen massive 660-ton generators in the Canadian plant produced 60,000 kilovolt-amperes (KVA) at 13,800 volts (*ibid.*, 246).
67. In the United States, the Grand Coulee Dam site currently has a total 6,480,000 kw installed capacity; it is the largest American hydroelectric power site and third largest in the world. The next four largest American hydroelectric power generating plants range from the 2,457,000 kw of the Chief Joseph Dam (1949) on the Columbia River down to the 1,950,000 kw capacity of the Robert Moses Niagara Power house (1961); in Canada, the three largest hydroelectric power plants are currently La Grande 2, Quebec (1981), at 5,328,000 kw; Churchill Falls, Labrador (1971), at 5,225,000 kw; Gordon M. Shrum, British Columbia (1980), at 2,416,000kw; and La Grande 3, Quebec (1983), at 1,920,000 kw. In statistical tables, the generating capacity of the Seaway international powerhouse is always broken down and listed separately as a Canadian power plant (Robert H. Saunders, 912,000 kw capacity) and American power plant (Robert Moses, 912,000 kw capacity), which obscures the generating capacity scale of the St. Lawrence Seaway international powerhouse and reduces the Robert H. Saunders power plant to 13th place among the largest Canadian hydroelectric power plants. The planned capacity of the Seaway international powerhouse was 1,640,000 kw, but this was maximized to an actual on-line capacity of 1,824,000 kw by installing 60,000 KVA generators in place of the 57,000 KVA generators originally envisaged.
68. "The Tennessee River Experiment," *Engineering News-Record*, vol. 117, Dec 1936, 771–779, 823–827, 860–865, 897–899; "TVA Harnesses the Tennessee River," *Power*, vol. 80, July 1936, 354–357; "The Construction Program of the TVA," *Civil Engineering*, vol. 9, June 1939, 355–358. The poured concrete figure does not include either the Wilson Dam or the Hales Bar Dam constructed previous to the TVA, but does include the tributary rivers dams constructed up to 1945. The power generation figures include all of the hydroelectric plants as of 1945, inclusive of a steam (coal-fired) plant operated by the TVA. The main river dams ranged from 72' to 160', and the largest of the tributary rivers dams from 175' to 307' in maximum height. During the Second World War, the TVA constructed additional hydroelectric dams on the tributary rivers, and steam plants; in the 1960s the TVA built nuclear power plants to further increase the electric power capacity. The wartime construction project was conducted on an accelerated schedule, but conventional construction and project management techniques were employed ("TVA Rushes Power for National Defense" *Engineering News-Record*, vol. 126, February 1941, 332–335; "Crackless Concrete for Hiwasee Dam," *ibid.*, vol. 123, Sept 1939, 69–72).

69. David McCulloch, *The Path Between the Seas: The Creation of the Panama Canal, 1870–1914* (New York: Simon & Schuster, 1977), 590–592, 539, 611; Robert W. Passfield, "Duff's Ditch, The Origins, Construction, and Impact of the Red River Floodway," *Manitoba History*, no. 42, Autumn/Winter 2001–2002, 7, 12; Department of Railways and Canals, *The Welland Ship Canal between Lake Ontario and Lake Erie* (Ottawa: Engineering Office, 1935), 241.
70. See entries in E.B. Kollgaard & W.L. Chadwick, eds., *Development of Dam Engineering in the United States* (New York: Pergamon Press, 1988).