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ST. GEORGE STATION REHABILITATION

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ABSTRACT

This paper describes the redevelopment of the St. George Pulp and Paper (SGPP) Hydroelectric Station, which operates as a subsidiary of the J.D. Irving Corporation of St. John, New Brunswick. The facility is located in the middle of Saint George New Brunswick, which has a population of 1,400 and is situated at the confluence of the Magaguadavic River and a tidal estuary of the Bay of Fundy in southwestern New Brunswick. This paper focuses on the technical aspects implemented to economically enhance the project's generating capacity, mitigate environmental impact, and reduce construction costs.

RESUME

Cet article décrit la reconstruction de la Station Hydroélectrique de St. George Pulp and Paper(SGPP) ce qui fonctionne comme filiale de J.D. Irving Corporation de St.John, Nouveau Brunswick. La facilité est située au milieu de Saint George, Nouveau Brunswick, qui a une population de 1.400 et est situé au confluent du fleuve de Magaguadavic et d'un estuaire de marée de la Baie de Fundy au Nouveau Brunswick au sud-ouest. Cet article se concentre sur les aspects techniques exécutés pour économiquement améliorer la capacité produisante du projet, atténuer l'impact enviromental, réduire des coûts de construction pendant la conception et les phases de construction et la performance du projet jusqu'au présent.

1. SITE DESCRIPTION

Figure 1 shows the historical site configuration including the Main Dam, Magaguadavic River gorge, forebay, forebay dam, intake, and 120 m (400 ft) long riveted steel penstock feeding the four units situated inside the lower end of the abandoned pulp and paper mill. The original 13.4 m (44 ft) high water fall is located on the Magaguadavic River about 400 m (1300 ft) upstream of the river's tidal estuary with the Bay of Fundy. The existing 7.5 m (25 ft) high 1902 vintage concrete gravity Main Dam was constructed on top of the original water falls to divert water to power the local paper mill's pulp grinders and other hydromechanical equipment. Although SGPP's operation as a pulp and paper mill was abandoned in 1967, the original turbines were retrofit in 1978 with electrical generators and continued to be used as a manually controlled hydroelectric station.

Much of the original station exhibited continued and significant deterioration such as extensive concrete freeze thaw damage, severe steel penstock corrosion and distortion, and antiquated inefficient generating equipment. The station's four original units consisted of two 1,000 kW and two smaller 500 kW horizontal Francis turbines that were manually controlled by 1955 vintage controls and switchgear. Although the original 1902 turbine runners had been replaced, the water passageway and other mechanical components had serious cavitation and deterioration, resulting in large clearances and lower mechanical efficiency (estimated to be approximately 60%). Operation required 24 hour monitoring by the rotation of seven station operators and maintenance personal. All four units were set approximately 5.5 m (18 ft) above low tide meaning that they could not capture the full gross head during the lower portions of the tide cycle. These original turbines had a hydraulic capacity of 40 cms (1,413 cfs) which was exceeded 32% the time. These constraints had limited the station's production to an average annual generation of 20,000 Mwh.

The St. George site includes several physical constraints and multiple significant aesthetic and natural resources. Because the site is located in the middle of town, the hydroelectric station is surrounded by the abutting properties of local residents, some of which are situated within 100 m (328 ft) of the new facility. The upstream view of the gorge from the lower South Street Bridge is a prominent regional scenic attraction that is featured on Saint George's town logo. The Magaguadavic River is an important anadromous fishery with gaspereau and some Atlantic salmon annually migrating upstream to spawn from May to August, and smolt and spent adults migrating downstream from the late spring to early fall. Upstream fish passage over the natural waterfalls is through the existing New Brunswick Provincial vertical slot fish ladder located at the Main Dam. The fish ladder and associated upstream fish trucking facility also acts as a tourist information site with public viewing windows and a picnicking area. Downstream fish passage at the original station was provided through a surface sluice installed on the right hand side of the original intake that lead to a plunge pool feeding a downstream channel along the abandoned mill building to the gorge.

The Magaguadavic River downstream of the St. George waterfalls, is the hydrostation's tailwater and experiences significant 8.45 m (27.8 ft) Bay of Fundy tides. This lower section of the river is subject to salt water intrusion, particularly in the lower stratums of the 16 m (53 ft) deep gorge during in-coming tides.

The Magaguadavic River is hydraulically connected to Lake Utopia approximately 5.2 km (3.2 miles) upstream of the St. George falls. Both the Magaguadavic River upstream of the Main Dam, and the Lake Utopia shoreline, are ringed with cabins and homes, and experience considerable recreational usage use such as kayaking, swimming, and fishing. Residents along these upstream sections were very concerned about either excessively high water levels due to flooding or ice jams, and recreational restrictions due to large drawdowns. Also limiting the headpond water level fluctuation was the need to maintain high enough water levels for the annual spawning migration of endangered dwarf smelt each spring from Lake Utopia into tributary streams. The hydraulic significance of Lake Utopia to the St. George hydrostation is that it buffers the Magaguadavic River flows and, within the acceptable 0.6 m (2 ft) water level fluctuation, provides an 843 hectare meter (6,834 acre feet) of storage reservoir.

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2. FEASIBILITY STUDY AND CONCEPTUAL DESIGN PHASE

Due to the station's aging SGPP looked at numerous rehabilitation and redevelopment alternatives throughout the 1980's and 1990's. These included the repair and selective replacement of existing facility components, addition of a supplemental powerhouse to the existing structure, and complete station replacement. SGPP investigated multiple station replacement options including a new above ground powerhouse within the existing mill and a buried powerhouse at the tidal estuary where it would be feed by an underground water tunnel. Vertical-shaft, underground powerhouse options, located at the upstream end of Ivy Island and downstream of the existing intake, were also investigated.

As these studies evolved it became apparent that the unusually large tail water tidal variations presented several opportunities to maximize the site's full generation potential. The first obvious factor was that the turbines should be placed below low tide -4.26 m (Elev -14 ft), thereby recovering the 5.5 m (18 ft) of head that was lost by the existing station during the hours of lower tide. Also it became evident that the relatively large Lake Utopia reservoir presented the opportunity to utilize a larger hydraulic capacity within the acceptable 0.6 m (2 ft) headpond fluctuation to concentrate more of the flow into the period of higher station head during lower tides. A feasibility study in January 2001 determined that a hydraulic capacity of 90 cms (3,178 cfs) provided the optimum balance of generation capacity with construction costs. This resulted in an optimum station hydraulic capacity at 15% of the annual flow duration exceedance, compared with a typical annual 20 to 25% exceedance for newer run-of-the river hydroelectric developments.

The total effect of: maximizing the site's head by hydraulically connecting to the Magaguadavic River tidal bay estuary, increasing the hydraulic capacity to reduce spring spillage, replacing the 60% efficient existing turbines with new equipment able to achieve 92% efficiencies, and increasing the station's hydraulic capacity to more efficiently manage the upstream storage and concentrate the available flow during periods of maximum head (*i.e.* low tide), resulted in energy projections that effectively doubled the existing station's average annual energy generation of 20,000 Mwh/year to 44,000 Mwh/year.

The January 2001 study also investigated and confirmed the feasibility of the new configuration shown in Figure 2 and Figure 3, which included a new dam, gated spillway, an intake located slightly downstream of the existing intake, two new steel penstocks connecting the intake to the reinforced concrete powerhouse excavated into an adjacent hillside, and a 128 m (420 ft) long tailrace tunnel connecting the turbine draft tubes to the tidal gorge. The top of the tunnel exit was located below low tide to prevent any visual degradation to the gorge's scenic vista.

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Two 7.5 MW turbines were selected as the optimal configuration based on costs, generation revenues, and the reliability benefits of turbine redundancy compared to a single unit station.

In May 2001, SGPP selected Kleinschmidt to proceed with services to obtain the project's governmental permits and to prepare the facility's preliminary design for the new two-turbine 15 Mw station configurations shown in Figure 2. The Kleinschmidt team also included the firms of Jacques Whitford's Fredericton, New Brunswick office to prepare the project registration/permits, and Haley and Aldrich's Cambridge, Massachusetts office for tunnel and geotechnical engineering.

3. PERMITTING AND PRELIMINARY DESIGN STAGE

The permitting and preliminary design stage more accurately defined five major uncertainties and risks facing the proposed development. These were governmental project approval, the proposed tailrace tunnel, the site's hydrologic characteristics, the water to wire and other equipment's characteristics/costs, and the total project costs.

GOVERNMENTAL APPROVAL AND PERMITS

Although Canada does not require licensing of hydroelectric stations, the project did need to be registered under the New Brunswick Clean Environment Act. During this process a committee of provincial regulators determine if a project can proceed, with or without required conditions, or if a full Environmental Impact Assessment (EIA) is required. The costs and one to two year duration to prepare a full EIA were significant project uncertainties.

On June 15, 2001, SGPP initiated the approval process by hosting a workshop to introduce the proposed project to the primary provincial regulators and Non-Governmental Organizations (NGO). These parties included the New Brunswick Department of the Environment and Local Government (NBDELG), the Canadian Federal Government Department of Fisheries and Oceans (DFO), and the Atlantic Salmon Federation. During this workshop governmental agency and NGO concerns were solicited, and recorded so the concerns could be actively addressed during the preparation of the registration application. Their primary concerns centered on downstream fish passage, Magaguadavic River and Lake Utopia water levels, and construction related environmental effects. During the summer and early fall of 2001 more than 23 public outreach and individual stakeholder consultations were held by SGPP to explain the proposed project, solicit concerns, and shape the proposed project to economically address these concerns. On September 27, 2001 SGPP presented the formal Environmental Overview, which comprehensively summarized the issues and proposed mitigation measures to the NBDELG. In late December 2001, after SGPP addressed some additional questions, the Saint George Project received governmental approval to proceed with defined mitigation conditions, but not requiring a full EIA.

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PROPOSED TAILRACE TUNNEL AND FOUNDATION CONDITIONS

The proposed rock tunnel shown in Figure 2 and Figure 3 connecting the proposed powerhouse to the lower tidal gorge of the Magaguadavic River also presented a significant project risk. Therefore, in July 2001, Haley and Aldrich started a detailed geotechnical site investigation that included lithiologic and geologic mapping, five rock borings, multiple water tests, and laboratory testing of the rock cores. The borings and subsequent analysis indicated that the site consisted of alternating siltstone beds and diabase sills. However, most importantly the rock where the tunnel was proposed was found to be unfractured diabase which had a low permeability. These conditions allowed the project to avoid installing a costly tunnel liner for either structural support or seepage control. Based on the tunnel's relatively short length, it was judged that a tunnel boring machine would be uneconomical, and therefore tunnel construction costs were based on excavation by drilling, blasting, and excavation in about 3 m to 4 m (10 ft to 13 ft) segments.

Geotechnical testing at the locations underneath the proposed new water retaining dam and intake revealed similar rock foundation conditions to the tunnel, although seams of low grade metasedimentary layers of siltstone and shale were found. This necessitated installing a dam seepage cut off wall with cementations grouting of 10 m (33 ft) deep holes in a 6 m (20 ft) center to center split hole pattern, and a 3 m (10 ft) deep on 3 m (10 ft) center blanket grouting of surface cracks and fissures.

HYDROLOGIC CHARACTERISTICS

Although the feasibility study determined the development's overall water flow and resulting generation, it had only qualitatively determined the detailed flood water levels and flow distributions. During August and September 2001 Kleinschmidt performed detailed hydrologic/hydraulic analyses to closely define the site's flood flows and water elevations, since they could significantly affect the final design. The upstream hydraulic connection of the Magaguadavic River to Lake Utopia and the distribution of flood flows at the site between the existing Main Dam and the new proposed spillway necessitated the use of a detailed stage storage HEC-RAS hydraulic analysis. This analysis showed that while the hydraulic constriction at the forebay entrance across from the Main Dam significantly throttled flow into the forebay, it still allowed enough flow so that the combined existing Main Dam overflow and new Tainter gate controlled discharge would equal the 500 year flood. This hydraulic analysis also confirmed the forebay's 500 year flood water level of 18.9 m (62.0 ft) that the new dam and intake would have to contain to prevent powerhouse flooding.

In addition to the upstream flood flow study, the unusual site condition of this station's tailwater tidal fluctuations necessitated an independent detailed tide study, projecting available tide information from other sites to the Magaguadavic estuary. The results projected a maximum high tide of 4.68 m (15.4 ft) and a minimum low tide of -3.77 m (-12 ft) resulting in a tidal variation of 8.45 m (27.8 ft).

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WATER TO WIRE EQUIPMENT AND COSTS

Since the conceptual design phase indicated that the water to wire package possibly constituted around 40% of the total project costs, SGPP solicited firm bid prices for the Water to Wire Equipment in October and November 2001. Tender documents were prepared for two 7.5 MW Kaplan turbines with design criteria meeting the detailed hydraulic data previously discussed. Although the horizontal configuration in Figure 3 was shown in the tender documents, the bid documents also specifically solicited vendor ideas for cost effective alternatives. The project team was particularly interested in a vertical shaft orientation since it could potentially offer long term maintenance advantages. Discussions with turbine vendors during bidding confirmed the earlier feasibility studies indicating that the horizontal configuration was optimal for this site. Additionally several vendors who felt that they would not be able to economically provide horizontal units of this size dropped out of the turbine bidding. Four lump-sum, fixed-price water to wire proposals were received in late November, with less than a 2% spread between the high and low prices. These equipment prices were subsequently incorporated into the final project budget assembled by SGPP.

4. FINAL DESIGN AND CONSTRUCTION PHASE

In January 2002 SGPP decided to proceed with the project, and authorized Kleinschmidt to begin with final design. Gulf Operators, an Irving subsidiary, was selected to build the project. The first final design priority was the award of the turbine supply contract because turbine delivery was this project's longest delivery lead time and the turbine's dimensions dictated the powerhouse's final dimensions. The tunnel construction was also designated as a high priority because the tunnel had to be completed and the large excavation equipment removed from the tunnel before powerhouse construction could begin.

GENERATION EQUIPMENT SELECTION

Presentations by turbine equipment vendors began in February 2002, followed by SGPP's internal evaluations and comparisons. Evaluations were based on the effect of turbine efficiencies and capacities on the project's annual generation estimates, depth and footprint of powerhouse excavation, maintenance requirements and access, operating history and performance of similar units, vendor references, and corporate preferences. In June 2002, SGPP selected two identical 7.5 MW horizontal double-regulated units from GE Hydro. GE Hydro provided several unit configurations and alternatives, of which SGPP selected the slightly more expensive option for a physically larger generator, thus eliminating an intermediate speed increaser. This alleviated the associated speed increaser maintenance/reliability concerns, and avoided the loss of approximately 2% efficiency in energy generation. To obtain the proper submergence for the two 2.3 meter diameter units, they were set 9 m (29.5 ft) below minimum low tide. To reduce the water to wire capital costs and facilitate maintenance, SGPP removed the switchgear equipment from GE's water to wire supply, and purchased it from a local Cutler Hammer supplier, who provides similar equipment to nearby Irving paper mills.

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TAILRACE TUNNEL

The tailrace tunnel was designed concurrently with the final generation equipment selection. For the rated plant discharge of 89 cms (3143 cfs) the optimum tailrace configuration was found to be a 6.7 m (22 ft) "D" shaped tunnel. The tunnel's flat floor facilitated access for the large drill rig, mechanized scaffolding, and front end loaders used to excavate the tunnel. This tunnel size, with rock projections limited to 6", provided a maximum 0.25 m (0.81 ft) headloss. The tunnel final design included the installation of 25.4 mm (1 in.) diameter 304 stainless steel untensioned rock dowels spaced at 1.98 m (6.5 ft) centers. Although the tunnel was unlined, a wet process shotcrete liner option was designed in the event that any tunnel sections of poor quality rock were unexpectedly encountered during excavation.

The discharge of the tunnel into the lower tidal reach of the Magaguadavic River below low tide presented special challenges. During the preliminary design phase the preferred tunnel construction procedure was to cofferdam the tunnel exit so that the exit into the gorge could be carefully excavated in the dry without damaging the gorge cliffs. Large tidal changes and the tunnel size required that the cofferdam would need to be 23.5 m (77 ft) high and 18.29 m (60 ft) wide. The structure would be subject to 21.6 m (71 ft) of hydrostatic pressure requiring an intricate arrangement of struts and braces connected to the rock face. Additional complications were presented by the extremely irregular profile of the jagged rock gorge bottom. In June 2002 preliminary designs for three braced sheetpile cofferdam options along with an underwater videotape of the gorge bottom profile were presented to the bidding tunnel subcontractors. Subcontractors' bid prices for the tunnel exit cofferdam exceeded the budget by approximately $1M CDN. Subsequent discussions between the tunnel subcontractor Talpa, Haley and Aldrich, Gulf Operators, and Kleinschmidt resulted in an alternative where a rock plug would be removed in a single blast with the water pressure pushing the rock into a trap excavated on the powerhouse side of the tunnel floor. Haley and Aldrich designed a pattern of steel dowels supporting the tunnel's cross sectional perimeter by drilling vertically and grouting from the ground surface elevation 30 m (100 ft) above the tunnel's crown. Additionally the rock plug was drilled and cement grouted to form a solid plug, with closely spaced circumferential line drilling to allow the plug to easily separate from the base rock during the final blast.

The tunnel plug blast methodology meant that a rush of water would propel down the tunnel toward the powerhouse. To prevent powerhouse flooding, the draft tube gates were lowered into position prior to the blast and supported with temporary beams designed to absorb the blast waterhammer pressure.

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POWERHOUSE DESIGN

One of the most intriguing design challenges was the design of the walls for the 20 m (66 ft) wide by 25.5 m (83.5 ft) long by 37.6 m (123.5 ft) deep below grade powerhouse. The walls below rock level were designed for a lateral rock load of 47.9 kpa (1,000 psf) as well as hydrostatic pressures. The wall hydrostatic pressures were reduced by installing a french drain around the powerhouse exterior above high tide that drained into the draft tube wet well. The west wall was subjected to backfill and designed for a 171.9 KPa (3.59 ksf) lateral submerged earth pressure. The longitudinal north and south walls were designed with intermediate vertical pilasters stiffened by horizontal 1 m (3.3 ft) diameter tubular struts between the two walls to reduce the concrete pilaster reactions. Value engineering and constructability discussions between Gulf Operators and Kleinschmidt resulted in optimizing the selective use of wall panel concrete shear reinforcement to reduce the wall panels' concrete thicknesses.

CONSTRUCTION

Gulf Operators began site mobilization and demolition in late April 2002, and began excavation for the intake and powerhouse in June 2002. The excavation of approximately 40,000 cm (52,300 cy) of powerhouse rock was completed in November 2002. Talpa subsequently began the tunnel excavation which they completed in February 2003 up to the 6.1 m (20 ft) thick plug at the tunnel exit. The concrete intake construction began in December 2002. After the tunnel was completed in February 2003 Gulf Operators began the powerhouse foundation concrete.

The construction was sequenced so that the two larger 1 MW original station turbines continued operation until late June 2003, capturing the spring freshet generation. After the original station was decommissioned in July 2003, the original penstocks were removed and the construction of the gated portion of the spillway started.

The powerhouse structure was completed in December 2003 and on December 17, 2003 the tunnel exit rock plug was removed. The final blast used progressive charges timed sequentially over a period of fifteen seconds. The gorge hydrostatic pressure at mid-tide assisted the charges in propelling the rock plugs material back into the rock trap. The inrush of water following the sudden rock plug blast imposed a calculated waterhammer force of 22,241 KN (5,000 kips) on each draft tube gate. The blast waterhammer pressure caused the water surface in the wet well to rise approximately 9.8 m (32 ft) above minimum low tide and the initial reflected wave back to the gorge at the tunnel exit created a water column approximately 8 meters (26 ft) tall. The draft tube gates sealed extremely well and withstood the blast pressure without any leakage, distortion, or damage.

GE Hydro's turbine and generator equipment were installed in January 2004, with the remaining associated electrical and mechanical equipment such as the switchgear and cooling water systems installed and commissioned in early March 2004.

OPERATION

AUTHORS

Thomas L. Kahl, PE, is a senior engineer at Kleinschmidt. He was Kleinschmidt's project manager for the St. George Hydroelectric Redevelopment project.

Matthew L. Dunlap, PE, is a mechanical engineer at Kleinschmidt. He was responsible for Kleinschmidt's involvement with the turbine selection and the powerhouse mechanical design.

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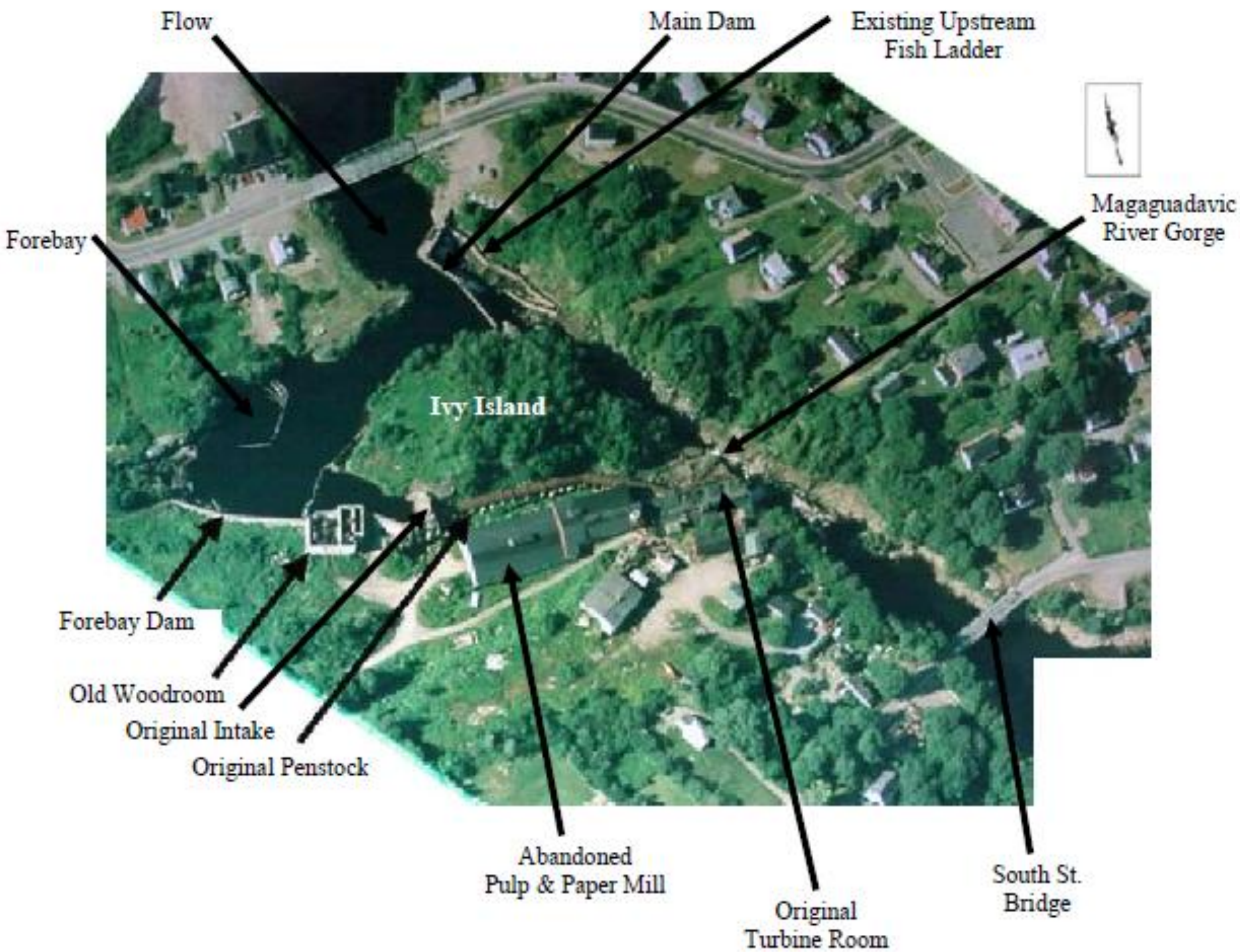

FIGURE 1 PRE-REDEVELOPMENT SITE CONFIGURATION

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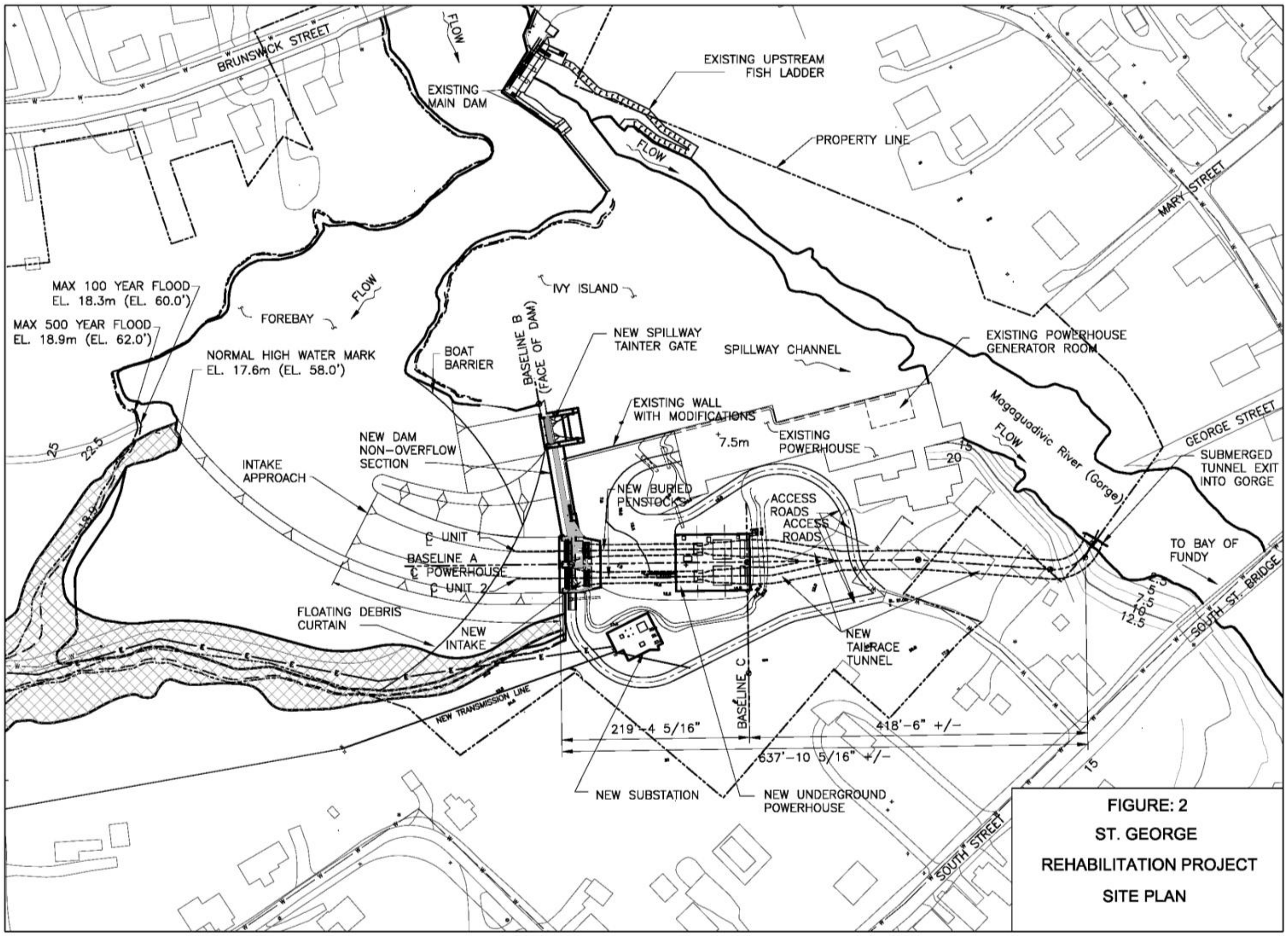

FIGURE 2 ST. GEORGE REHABILITATION PROJECT SITE PLAN

Kleinschmidt

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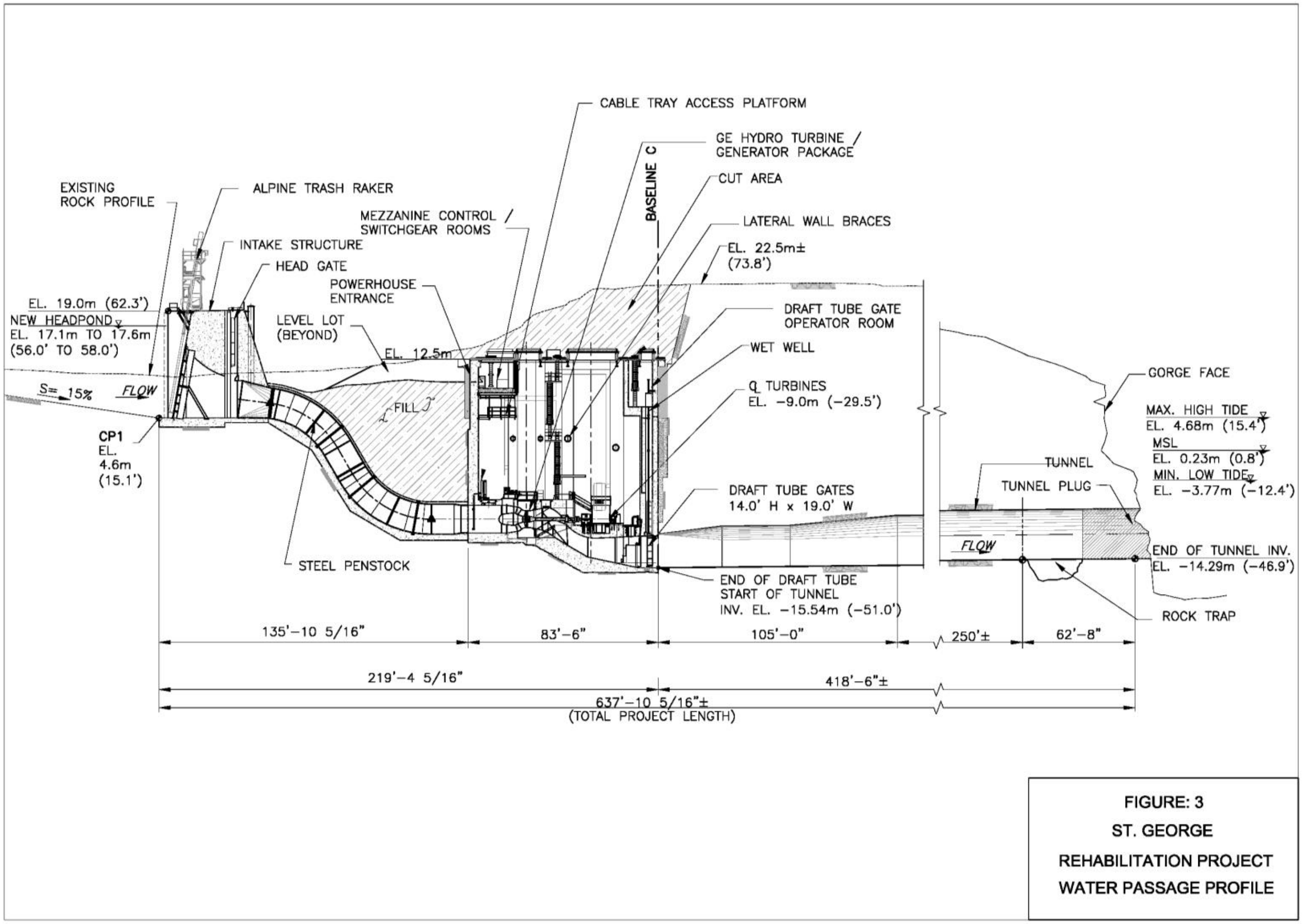

FIGURE 3 ST. GEORGE REHABILITATION PROJECT WATER PASSAGE PROFILE