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National Register of Historic Places Multiple Property Documentation Form

This form is for use in documenting multiple property groups relating to one or several historic contexts. See instructions in *Guidelines for Completing National Register Forms* (National Register Bulletin 16). Complete each item by marking "x" in the appropriate box or by entering the requested information. For additional space use continuation sheets (Form 10-900-a). Type all entries.

A. Name of Multiple Property Listing

Hydroelectric Power Plants in Washington State, 1890-1938

B. Associated Historic Contexts

Development of Hydroelectric Power in Washington State, 1880-1938

C. Geographical Data

The State of Washington.

☐ See continuation sheet

D. Certification

As the designated authority under the National Historic Preservation Act of 1966, as amended, I hereby certify that this documentation form meets the National Register documentation standards and sets forth requirements for the listing of related properties consistent with the National Register criteria. This submission meets the procedural and professional requirements set forth in 36 CFR Part 60 and the Secretary of the Interior's Standards for Planning and Evaluation.

[signature]
Signature of certifying official

Date: Oct. 12, 1988

Washington State Office of Archaeology & Historic Preservation
State or Federal agency and bureau

I, hereby, certify that this multiple property documentation form has been approved by the National Register as a basis for evaluating related properties for listing in the National Register.

for Patrick Andrus
Signature of the Keeper of the National Register

Date: 12/15/88

E. Statement of Historic Contexts

Discuss each historic context listed in Section B.

Introduction:

Few regions in the United States are better endowed with mountainous terrain, abundant rainfall, and powerful rivers than Washington. Important advances in the science and technology of electric generation and distribution during the late 19th century harnessed these formidable natural resources for the production of hydroelectric power. Indeed, an article in the Journal of Electricity of January 1926 reported that the State of Washington had more potential waterpower than any other state in the Union.[1] As a result, unlike most other areas of the country, the history of electric light and power development in Washington is largely the history of hydroelectric power systems.

Scientific Discoveries and Technical Innovations which Influenced the Development of Hydroelectric Power

Electricity had been the object of scientific investigation since the 16th century, but the major breakthroughs that led to the generation of electrical power did not occur until the early 19th century. during the 1820s and 1830s a series of monumental discoveries about the nature of electromagnetism made it possible to convert mechanical energy into electrical energy, transmit it along a wire, and convert it back into mechanical energy.

However, numerous applications of electricity did not appear until a reliable and efficient self-exciting dynamo or generator was introduced by Zenobe Gramme in Europe in 1870. The scientific foundations for the commercial generation of electrical power had been laid. Only ten years later the electrical industry in the United States was growing at an enormous pace. Thomas Edison's invention and improvement of a commercial incandescent lamp in 1879, followed by his development of a prototype for the central generating station in 1882, and the discovery of a three-wire distribution system demonstrated the commercial possibilities of electricity. By the middle of the decade there were over 400 private power plants in operation, most of them built by Edison's company for the Edison direct current (dc) system.[2]

The growth of the electrical industry in Washington State paralleled national development patterns. Small dc plants emerged in urban areas throughout Washington during the 1880s. Many of them used equipment manufactured by the Edison Company. Despite Washington's vast water power resources, none of the early electric plants were hydroelectric installations with the exception of the Monroe Street Plant in Spokane. The pioneering electric plants in the West emulated those in the East; they were located in towns and cities no more than 10 miles from the consumer where returns on capital investment were greatest; and they were usually steam powered.

The Development of Hydroelectric Power in Washington

The widespread use of hydroelectric power throughout the West depended upon a number of technological innovations that occurred in the mid-1880s and the early 1890s. The design of large-capacity polyphase hydroturbogenerator units, the development of alternating current, and the introduction of the transformer extended the range of water power application, and changed the course of the electrical industry in Washington.[3]

Unlike the East coast, water resources with the greatest power potential in the western states were located in mountainous regions far from urban centers. The design of a high efficiency, large capacity hydroturbogenerator was critical to the development of

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Washington's boundless power potential. The precedent for such a design was set in 1895 when three 5000 horsepower turbogenerators were installed at Niagara Falls. This plant represented the first large capacity system completed in the world, and signalled the advent of a new technology which would lead to the modern utility system. The Niagara Falls project demonstrated that it was economically advantageous to locate generating plants at the power site, miles from industrial and urban load centers.[4]

The construction of large capacity plants at locations far from consumption districts required an economical method to transmit the current. The direct current used in the early electric stations was not cost effective when transmitted over long distances. There was considerable power loss in the distribution lines of the low voltage direct current system which limited the boundaries of the service area.

The problem is conveyed clearly in the following equations and relationships. Electrical power is the product of EI, where I is the voltage and I is the line current. Power transmitted at a constant voltage varies in direct proportion to I, while power lost in the transmission lines varies in direct proportion to I^2R, where R is the line resistance. As a result, the cost of transmission (that is, the size and cost of conductors) is inversely related to the voltage level. Since the customer's lamp load was fixed at 110 volts, there was no opportunity to reduce the line losses by raising the voltage. The only alternative was to reduce the line resistance R which required an enormous and unrealistic investment in copper conductors and large overhead lines.[5]

However, the alternating current (ac) system was introduced, it became possible to raise the transmission voltage, and consequently reduce the line current and size of the conductors, with a minimum of power loss. The design of the transformer was another critical component in the development of economical long distance transmission. The transformer steps up the voltage before it is transmitted from the power site to the load center, and subsequently steps it down to a suitable voltage prior to distribution to the customer.

Throughout the 1890s there were a number of milestone achievements in the use of high-voltage alternating-current power transmission. In 1891, George Westinghouse installed the first large ac transmission line in America, a 2 1/4 mile long, 3000 volt line which connected a 100 hp. generator to the Gold King Ore mill at Telluride, Colorado. In Germany, in 1891, 100 kilowatts of polyphase power were transmitted at 15,000 - 25,000 volts over 100 miles from Lauffen to Frankfurt, Germany; and in 1896, three-phase power was transmitted 26 miles from Niagara Falls to Buffalo at 11,000 volts.[6] By the end of 1900, transmission lines in the United States had reached a maximum length of 86 miles, and line voltages were as high as 40,000 volts.[7]

However, as voltages were continually raised, a condition called "corona loss" was encountered which threatened to limit the future development of high-voltage ac transmission. The phenomenon, which resulted in major power loss when the current was transmitted above 50,000 volts, was due to "ionization of the air at the high field intensities created around small-diameter wires." In the early 1900s high voltage experiments at Stanford University indicated that the field intensity and the corona loss could be reduced by increasing the conductor diameter and spacing. Following this work, conductor diameters were increased, and line voltages were steadily raised. By 1923, line voltages had reached 220,000 volts.[8]

Most of the pioneering applications of high-voltage transmission occurred in the West. The need for long transmission systems was not an critical in the eastern states, because the geography of the East permitted the generation of power only a short distance from the population centers. As a result, high-voltage transmission systems developed more rapidly in the West. A 1902 article in Electrical World and Engineer revealed the contrast in development patterns between the East and West.

> We in the East have but an imperfect idea of California conditions, and many a striking transmission plant in the region has quietly slipped into service almost unknown even to the engineering public...with everybody working for the common good nobody raises an eyebrow at the installation of a 25 or 35 mile transmission of 15,000 or 20,000 volts -- it takes two or three times both figures to really awaken interest. Here in the East even a very moderate transmission stirs up opposition with a sharp stick.[9]

The growth of high voltage transmission systems in Washington were built almost immediately after the pioneering efforts at Niagara Falls and Telluride, Colorado. One of the earliest long distance systems in the state was completed in 1899. It transmitted current 35 miles at a line voltage of 30,000 volts from the Snoqualmie Falls Power Plant to street railway networks and manufacturing concerns in Seattle and Tacoma. In 1902, the line voltage was raised to 50,000 volts. in 1903, the Puget Sound Power Company completed a 48-mile, 55,000 volt system which linked Seattle and Tacoma to the hydroelectric plant at Electron. An in 1904, the Seattle Municipal Electric Light and Power Company transmitted current 40 miles at 45,000 volts from the plant at Cedar Falls to the distribution center in the city.

There are countless examples throughout the state of power plants which expanded the limits of efficient, large capacity hydroelectric turbine design. For example, when installed in 1904, the turbines at Electron were the largest impulse units in the world; the capacity of the generating units was surpassed only by those at Niagara Falls. In 1906, the largest single wheel Francis turbine ever built was installed at Snoqualmie Falls, and in 1911 White River was equipped with the largest high head reaction turbines in existence. Again in 1915, the 22,500 hp. turbines at Long Lake had the largest output capacity in the world, and when the 90,000 hp. turbines were installed in the Diablo power plant, their output capacity was said to be unequalled.

The technological advances that increased the capacity of Washington plants almost always resulted from the development of a special technology to serve the high head conditions of Washington State plants. The typical Washington plant operated at a high head (over 200 feet) and low volume of water, in contrast to the typical Eastern installations which were characterized by a low head, high volume of water. The reaction or pressure turbines of the East were poorly adapted to these high head conditions. As a result, a separate design technology emerged to tap the power potential of the steep gradients of the western sites.

An important result of that was development of the free jet tangential impulse, or Pelton, turbine. The impulse wheel is placed in operation when a stream or jet of water under considerable head and pressure is directed tangentially against the periphery, striking the wheel's brackets in rapid succession. (By contrast, the traditional reaction turbine consists of two sets of curved vanes, one which remains stationary and directs water to the other, rotating vane). Pelton wheel design permitted minimal interference between incoming and outgoing water, a minimum of fittings and joints, and an ability to be easily expanded. As a result, the efficiency of the wheel was doubled. As late as the 1890s, the tangential impulse wheel was not widely accepted. But by 1900, it was the characteristic turbine of high head hydroelectric installations throughout the West. And the wheels at the Electron plant were the largest impulse units in the world when installed in 1904.

Other developments in the early 20th century improved the efficiency of the Francis reaction turbine, so that by 1918 the Francis and impulse turbines were the two standard type. The Francis turbine was well suited for low and medium heads and for moderately high heads when large capacities were involved. But improvements in the early 20th century made the Francis easier to adapt to a wide head range. Although before 1906, it was rare to find a Francis turbine for operating heads exceeding 400 feet, improvements after that date changed the situation, and in five years the largest inward flow reaction type Francis turbines in the world were installed at White River, Washington where there was a 480 foot head. The installation was an important landmark; after that, all large capacity high head installations built in Washington State consisted of Francis turbines.

Another critical design dilemma facing hydraulic engineers at the turn of the century was the compatibility between the turbine and generator. Engineers long had attempted to adjust the rotating speeds and positions of the wheel and generator to insure a direct connection between them. The traditional horizontal position of the turbine was used until the 1920s, when the so-called "Niagara solution", with the generator up-ended, was widely accepted. The vertical design eliminated the need of the solid disc bearing, or roller bearing, both of which operated with oil under heavy pressure and required expensive pumping systems. The vertical turbines were also more efficient and accessible to engineers. All turbines installed in Washington plants after 1921 were of the vertical configuration.

Water conveyance systems, as well, were characteristic features of the high head installations. A variety of flumes, tunnels, canals and storage units were constructed in Washington State to divert water from miles away to the power site. Many of these systems were among the most advanced in the nation at the time of their construction.

Power installations equipped with large capacity, high efficiency hydroturbogenerator units and long distance high-voltage transmission systems characterize hydroelectric development in Washington. These installations were built throughout the state almost immediately after the technical innovations and developments emerged from the design laboratory. (A more complete description of these technological features is in the description of the Hydroelectric Power Plant property type.)

Economic and Organizational Development of Hydroelectric Systems

I. National Context: Stages of Development

The design technology of electrical systems and the institutions formed to administer them evolved together. in his book, Networks of Power, Thomas Hughes delineates three stages in the evolution of power and light in the United States between 1890 and 1930.[11] In general, the development of the electrical supply system in Washington conformed to these nationwide patterns.

During the first stage numerous small, low voltage dc lighting companies emerged. It was the era of the central generating station, the forerunner of today's electric utility industry. These centrally located generating plants supplied light to contiguous customers. The number of central generating plants grew rapidly because the low-voltage dc systems could serve only a small geographic area. By 1900, there were more than 2800 small dc stations throughout the United States. It was a period characterized by homogeneity of supply and load. The system loads consisted almost entirely of incandescent lamps. The generating components used to supply a given area were located at a single site, while the distribution system transmitted a standard voltage from the central station and delivered a standard voltage to the consumers.[12]

The second phase of development was launched in 1893 when the "universal supply system" was introduced at the Chicago exposition. The systems of this era were characterized by increased heterogeneity. They consisted of a wide range of generating and transmission equipment and served a rapidly expanding diversified market. Generators in different plants with polar characteristics were interconnected. Varying outputs from dissimilar generators were incorporated into a single transmission system by means of couplers, transformers, and synchronous generators. The invention of the rotary converter -- a machine with a dc commutator on one end, and ac slip rings on the other -- made it possible to serve a diversified load by combining alternating and direct current in a single system. These inventions expanded the scope of the electrical industry and transformed the central lighting stations into light and power companies.[13]

Two underlying management principles which shaped the structure of electric companies emerged during this era of "universal supply systems." For the first time, different kinds of loads were systematically linked according to the concept of load factor and load diversity. The load factor, which measured the efficiency with which the system equipment was being used, was the ratio of the average load to the maximum over a specified period of time. The diversity factor, which was the ratio of the sum of the peaks of the separate loads to the actual peak load, indicated the amount of equipment and capital needed to operate a station. The application of load growth and load diversity concepts to utility management proved to be critical to the growth of planned electrical systems.

In his insightful study, Hughes categorizes the vast regional systems of the 1920s and early 1930s as the third stage in the evolution of electric supply systems in the United States. The systems of this period were more heterogenous and complex than those of the previous phase. The proliferation of these vast "far-flung" systems followed the introduction of turbines and high voltage transmission. During this period voltages of 100,000 and higher became state-of-the-art which allowed for the economical transmission of current over hundreds of miles, and precipitated the expansion of point-to-point transmissions into networks.

During this third period of growth, diverse energy sources were systematically combined into a single system in an effort to insure reliable service and continuity of supply. Power plants with diverse and complementary energy sources were interconnected, and incorporated into one vast system. An ideal economic mix included an urban power plant fuelled by wood waste or hard or bituminous coal, a high head hydroelectric plant supplied from a natural storage reservoir at high elevation, and a low head plant powered by the running water of a river. The operation of the plants was carefully scheduled to take advantage of their complementary characteristics. For example, during periods of drought and water shortages, the load was carried by the high head hydroelectric plants and steam plants. In the move to create more efficient and economical power, the systems became larger, more diverse, far-reaching and complex.[15]

II. Influence of Electric Transportation on Hydroelectric Development

Although technical innovations and advancements provided the means to change the physical form of the electrical supply systems, many factors contributed to the growth of the electrical industry. One major development which influenced the configuration of the early electrical installations was the introduction of commercial electric-powered transportation in 1886-1887.

By the late 1880s, managers found that the lighting business had grown slower and profits had been lower than anticipated. Although the plants had the capacity to provide full time service, customers demanded light for only a few hours every evening. Following the installation of street car systems and interurban lines, the energy sold by the central stations could be substantially increased with only a small capital investment. The economic benefits associated with entering the traction business were indeed enticing. By the end of 1889, 154 electric street railway systems operated in the United States, and by 1905, the traction movement had reached boom proportions. Throughout this period the traction companies dominated the light and power industry.[16]

A number of early hydroelectric stations remaining in Washington were built to generate power for expanding interurban railway systems. These installations include the Nooksack Falls, the Nine Mile, the Snoqualmie Falls, the Electron, and the White River plants. In 1903, the Whatcom County Railway and Light Company began work on the construction of a 1500 kw power plant at Nooksack Falls. In addition to supplying power for the railway, this pioneering facility provided enough current to light the city of Bellingham and surrounding communities. In 1908, a year after the Spokane and Inland Empire Railroad Company was incorporated, it began work on the construction of a hydroelectric plant in a granite rock canyon 13 miles northwest of Spokane. This 12,000 kw plant powered a vast regional railroad system. The company's president, Jay P. Graves, dreamed that these "highways of steel" would not only serve the city of Spokane, but they would stretch for 212 miles to link the city to Coeur d'Alene, Moscow, and Colfax.[17] In addition, the company would benefit from selling electricity to several small towns throughout the region.

Although surplus power generated at the Nooksack Falls and Nine Mile plants were used for lighting purposes, the installations were built primarily to provide current for expanding electric street railway systems. The Snoqualmie Falls, the Electron, and the White River plants, on the other hand, were built in 1899, 1904, and 1911 respectively to meet the escalating commercial and domestic light and power load demands of Seattle and Tacoma. A major part of this load consisted of supplying power for the operation of sprawling, interurban electric railway systems in the two cities. By 1904, the systems included 168 miles of trolley road, two cable roads, and a third line linking the two industrial centers. In the case of these three plants, the traction load served as the foundation upon which the electric companies built their light and power businesses.

The traction boom proved to be short-lived. It began about 1897, reached a peak in 1907, and was over by 1917.[18] Electrical development in Washington reflected these national patterns. The Nine Mile plant was operated by the Spokane Inland Empire Railroad until it went into receivership in 1919. In 1924 the Washington Water Power Company purchased the generating facility and tied it to its expanding transmission network. Before the Nooksack plant was completed, the Stone and Webster Association, a large engineering and management organization, assumed operation of the plant. The installation continued to serve the Whatcom County Railway and Light Company until 1912. At that time, the Stone and Webster Association purchased and consolidated five power companies including the Whatcom County Railway and Light Company and the three companies which owned and operated the Snoqualmie Falls, Electron, and White River plants. The early power installations in Washington State associated with the traction industry survived the decline of the interurban railroad because they were acquired by large diversified companies which incorporated them into vast transmission networks.

Though the era of the interurban railroad was brief, the traction market stimulated the development of power generating facilities. As the traction loads diminished in Washington, domestic, commercial and industrial light and power loads increased. New markets emerged with the proliferation of electrical appliances. Installations built during this period of street railway development provided an infrastructure which served as a foundation for the expansion of electrical supply systems, and played an instrumental role in the transformation of lighting businesses into light and power companies.

III. History of Light and Power Companies in Washington State

The history of light and power companies in Washington reflects the national patterns of electrical development. A cursory examination of the evolution of Washington's major power companies graphically conveys the change that occurred in the configuration of electrical power systems within the state between 1890 and 1938.

Puget Sound Power and Light Company

The origin of the Puget Sound Power and Light Company, which remains one of the state's largest private power companies, is linked to the early commercial electrical developments of Seattle. Its parent company, the Seattle Electric Company, was the first business to market electricity in the city. When this pioneering company constructed a steam plant in 1886 to power two 660-light dynamos, it was one of the first central stations in the West to provide incandescent lighting. During the next ten years almost 30 privately owned electrical companies emerged in the "hasty anticipation of a new golden era" of electricity. However, many of these early ventures were extinguished in the depression of the 1890s because they proved to be "unwisely conceived, poorly managed, and badly financed."[19]

By 1899, it had become apparent that power generation in Seattle could progress only if the myriad of independent, isolated electrical companies were merged. A banking syndicate of eastern investors was formed to acquire, manage, and consolidate these electrical properties. The syndicate hired the young firm of Stone and Webster to provide management advice on methods of breathing new life into the young, chaotic, and mismanaged utility industry. The Stone and Webster managerial association, responsible for organizing the company that eventually became the Puget Sound Power and Light Company, was a broad-based firm which installed "accounting methods as well as dynamos"; it acquired and managed electric properties and provided expertise in engineering, management, and finance.[20]

Under a plan devised by Stone and Webster, the Seattle Electric Company was organized in January 1900 to operate in conjunction with the syndicate and acquire electrical companies throughout the city. Stone and Webster served as general managers of this new utility company. By 1903, 16 electric railway, light and power companies were consolidated under Stone and Webster management.[21]

This consolidation of power and light companies coincided with the second phase of electrical development outlined by Hughes, and represented an important step in the evolution of commercial power generation in western Washington. For the first time there was an attempt to link and unify the individual systems. The Seattle Electric Company also sought to extend and improve the existing lines. In their effort to expand services, it was necessary to recondition and upgrade the generating equipment which proved to be a monumental task. Many of the small companies had been financially strapped or insolvent, and their equipment was left to deteriorate. The Seattle Electric Company pressed into service almost every made of engine and generator available to them. In addition, they purchased other second-hand engines and generators in an effort to keep pace with the load demands of the rapidly expanding market.[22] It was a period of increased heterogenerity in which a wide range of generating and transmission equipment was interconnected to serve a rapidly expanding and diversified market.

It was out of this effort to meet an enormous power load demand that the Electron system was built. In 1902, Stone and Webster interests formed the Puget Sound Power Company to construct a plant on the Puyallup River which would provide current to Stone and Webster properties in Seattle and Tacoma. At the time of its construction, the Electron plant generated more power than any other facility within the state. Its completion in 1904 marked a turning point in the technological, economic, and commercial development of hydroelectric power in Washington. It represented the beginning of a proliferation of large-scale commercial hydroelectric installations constructed throughout the West during the first two decades of the 20th century. For the first time the utility industry in Seattle and Tacoma had an adequate water supply. Rates were substantially reduced; and for a few short years it was necessary to develop new loads to meet the supply.

In 1911 the system was expanded again when Stone and Webster interests formed the Pacific Coast Power Company to construct the White River installation. Hailed as the largest power facility in the Northwest, the White River plant was the second major hydroelectric system in the state constructed by Stone and Webster. unlike earlier projects, the design of the White River system included an immense storage reservoir which provided a means to keep pace with escalating load demands. The reservoir was formed at Lake Tapps from a series of natural lakes. By 1911 Stone and Webster had created an enormous transmission network in western Washington which included the Electron and White River power plants and a sprawling interurban electric railway system.[23]

This rapid and continuous growth led to a second major organizational consolidation which profoundly influenced the course of hydroelectric development in western Washington. in 1912, Stone and Webster incorporated the Puget Sound Traction, Light, and Power Company to purchase and consolidate the Seattle Electric Company, the Seattle-Tacoma Power Company, the Pacific Coast Power Company, the Puget Sound Power Company, and the Whatcom County Railway and Light Company -- five large power companies in the region which together served customers from Bellingham to Tacoma. Prior to the consolidation, Stone and Webster had interests in all of the companies except the Seattle-Tacoma Power Company. The purchase of the Seattle-Tacoma Company represented an important organizational development; this company owned and operated the earliest large scale power facility in the state and was a major competitor. The consolidation placed for the first time the Snoqualmie FAlls, the Electron, and the White River plants -- the three large scale commercial hydroelectric installations in the region -- under a single ownership; and marked the beginning of the distribution of electrical service in western Washington on a vast regional scale.[24]

The national precedent for the unification of isolated small utilities was set in 1911 when Samuel Insull spearheaded the consolidation of 55 municipal or privately owned plants in Lake County, near Chicago. The plants were replaced by four large and efficient central stations which distributed current over 875 miles of high voltage lines. The consolidation of companies in western Washington occurred almost simultaneously with this seminal effort to unify the electrical utility industry in Illinois.[25]

The formation of the Puget Sound Traction, Light, and Power Company represented a critical turning point in the evolution of electrical systems in western Washington. The enormous scale of the installations, and the centralized organization of the company pointed to the regional systems of the 1920s. Following its incorporation, millions of dollars were invested in the Puget Sound Traction, Light, and Power Company to acquire and reconstruct small independent hydroelectric facilities, to extend rural lines into the surrounding farm areas, and to interconnect the disparate systems into a vast transmission network. In a company history the author writes: "without centralized management, and without the credit advantages of the [Stone and Webster] management company, it is doubtful that the job could have been done."[26]

It is no coincidence that this pioneering system was formed by one of the first electrical engineering consulting firms in the county. The growth of regional installations was directly linked to the rise of the consulting engineer in the financial and technical management of electrical supply systems. The technical, organizational and financial problems inherent in the systematization of electrical supply demanded the entrepreneurial spirit and comprehensive management strategy of the engineering consulting firm.[27]

Stone and Webster had been in the business of designing and supervising the construction of electric light and power plants ever since the 1890s. The firm developed a set of interrelated services and financial interests which were institutionalized into a coherent concept and structure that anticipated holding company functions usually associated with the 1920s.[28] By 1906 Stone and Webster provided centralized management, engineering, and financial services to 28 independent power, light and traction utilities throughout the United States.

Stone and Webster's financial relationship to the Puget Sound Traction Light and Power Company was typical of its association with other utilities. It shared financial interest in the Puget Sound Traction Light and Power Company stocks, but the company had its own officers, board of directors, and bank accounts. Although Stone and Webster performed most of the functions of a holding company, it did not become one until 1925 when it was forced to compete with a proliferation of holding companies. At this time it formed and financed the Engineers Public Service Corporation. The transformation of Stone and Webster into a holding company was part of a trend which dominated the privately owned electric utility industry throughout the 1920s.[29] The Puget Sound Power Company became a subsidiary of the Engineers Public Service Company in 1928.

Typical of most large electrical companies, the Puget Sound Traction Light and Power Company grew rapidly throughout the 1920s. The decade began with a name change which reflected the decline of the interurban railway and the disappearance of the traction loads. In 1920, the company was re-incorporated as the Puget Sound Power and Light Company. Characteristic of electric supply systems during this period, the Puget Sound Power and Light Company launched a far-reaching program of reconstruction and standardization of service. The Puget Sound Power and Light Company was a pioneer in the development of regional electrical systems. As regional systems proliferated throughout the 1920s, the Puget Sound Power and Light Company accelerated its process of interconnection.

In his study of the early electrical industry, Thomas Hughes compares the developments that occurred in electrical supply systems in the 1920s to those that occurred in railway systems in the second half of the 19th century. Like the electrical supply systems of the 1920s, the major railroad systems of the late 1800s were interconnected and the tracks and equipment were standardized which led to the identification of the major traffic centers and the routes of the regional and national railroad systems. The principal routes were upgraded, traffic nexus and switching yards were laid out, and trunk lines were extended.

Similar developments occurred in the electrical supply industry. Throughout the 1920s the Puget Sound Power and Light Company continued to purchase countless independent power companies, recondition and standardize them, and connect the distribution systems to a sprawling transmission network.[30] By the mid 1920s the Puget Sound Power and Light Company had tied its transmission system to the Washington Water Power Company System. This resulted in the interconnection of the two major private power systems in the state; for the first time it was possible to transmit electricity across Washington. Because one system could assist another in emergency situations, economy of operation and continuity of service was insured on a scale never known before.

Washington Water Power Company

The history of the Washington Water Power Company is remarkably similar to the organizational evolution of the Puget Sound Power and Light Company, though an engineering and management consulting firm never played a part in its development. Like the large private utility company in western Washington, the original of the Washington Water Power Company is linked to the early commercial electrical development of a major urban center.

The company was formed to develop the lower falls of the Spokane River in the heart of Spokane, one of the largest cities in eastern Washington. Typical of national development patterns, a multitude of small dc lighting plants were built throughout the city in the 1880s. In 1887, the Edison Electric Illuminating Company was formed to build a new 1100 kw station on the lower falls. The Washington Water Power Company was incorporated two years later to continue the lower falls development. Unlike the Puget Sound Power and Light Company, which was financed by eastern interests, the Lower Falls Project was opposed by the company's eastern stockholders who declared that water power had little or no value. As a result, local stockholders formed the company.

When the Monroe Street Plant was finally completed on the lower falls in 1889, it represented the first large generating station in the state; its capacity was more than double the capacity of all of the station's operating within the city. In 1892, it became one of the first plants in the state to transmit alternating current.[31] Though portions of the original plant remain, it has been substantially reconstructed, and all of the original equipment has been removed. The completion of the Monroe Street power station "sounded the death knell" for the numerous small lighting companies that had operated throughout the city since the beginning of the decade.[32]

Developments in the electrical utility industry in eastern Washington paralleled national patterns. By the turn-of-the-century there was a move to merge the small independent companies into a large unified system which could meet all emergencies. The author of the company history wrote that consolidation was an economical necessity in the electric light and power business. In 1899, the Washington Water Power Company "emerged from its chrysalis as a purely water power developing concern and became a full fledged electric service company." At this time, it purchased and consolidated the Edison Electric Illuminating Company and several small electric railway companies.[33]

Like the Puget Sound Power and Light Company, the Washington Water Power Company expanded its services following the consolidation. In 1901 the company transmitted electricity for the first time beyond the downtown limits of Spokane. By 1903, the company had become a pioneer in long distance, high voltage transmission; it had completed a one hundred mile long, 45,000 volt transmission line from the Monroe Street generating station to the mines in Coeur d'Alene, Idaho -- a line that was unusually long and of an unusually high voltage for its day.

Over the course of the next 15 years, the Washington Water Power Company sought to provide efficient and reliable service for a population that was becoming increasingly dependent upon electricity to light their homes and to operate their industries. Typical of electrical utilities throughout the West, the Washington Water Power Company cultivated a highly diversified power load from the beginning. The power did not only provide residential and commercial light for the City of Spokane, but it also supplied electricity to the farmers, farming communities, irrigation pumps, mines, current mills, and the interurban railways. The population of the region continued to escalate as the uses for electricity expanded. A company publication stated that by 1906 it had become apparent that the Washington Water Power Company would have "to maintain a more or less continuous power plant construction and development program in order to keep up with its load growth."[34]

Like the Puget Sound Power and Light Company, the Washington Water Power Company began construction of large scale commercial hydroelectric installations during the first decade of the 20th century. In 1906, the Washington Water Power Company completed the Post Falls Plant to serve the mining districts in Idaho. It was one of the first hydroelectric plants constructed outside of Spokane, and it was hoped that this 6750 kw facility could meet the expanding power demands of the surrounding communities. However, the mining loads proved to be enormous. An engineering journal claimed that the Post Falls plant carried "a continuous load with nearly a 100 percent load factor." As a result, the company could not guarantee continuous service during low water periods. As soon as the Post Falls Station was completed, plans were prepared for the Little Falls Power Plant on the Spokane River, 39 miles west of Spokane. When the 20,500 kw installations was completed at Little Falls in 1910, it served to regulate the entire system.

However, prior to the completion of the Little Falls Plant, it became evident that the new facility would not be able to adequately meet the escalating power load demands of the Inland Empire. In 1910, the Washington Water Power Company began work on its largest and most ambitious undertaking. During that year, it acquired the Long Lake Power Station site, and plans were developed for the construction of a generating facility whose capacity would eventually be four times that of the Little Falls Plant.[35]

The rugged topography of the Long Lake Station was ideal for hydroelectric power generation. It is situated 4 1/2 miles upstream from the Little Falls installation at a point where vertical rock walls rise 400 feet above the river. The construction of a dam at this location impounded 2,695,000,000 cubic feet of water. Although Lake Coeur d'Alene, a few miles east of the Post Falls Plant, supplied the Company with some storage capacity, it proved to be inadequate. The immense storage reservoir formed by the Long Lake dam provides an endless source of water for power generation to both the Little Falls and Long Lake stations. As a result, both of these facilities were able to regulate the load fluctuations for the entire system, and to insure dependable, uninterrupted service.

The Washington Water Power Company and the Puget Sound Power and Light Company were pioneers in the development of regional electrical systems. Throughout the teens they constructed large scale hydroelectric installations which characterized national electrical developments of the 1920s, and demonstrated the extended range of water power application made possible by the technological innovations of alternating current and the transformer. Like the Puget Sound Power and Light Company, the Washington Water Power Company purchased, reconstructed, and interconnected small utilities throughout the region during the teens. This process of interconnection was accelerated throughout the 1920s. In 1924 the company purchased the Nine Mile Plant, and in 1926 it acquired the Chelan Power site from the Great Northern Railway. Typical of systems of this period, the Washington Water Power Company built its first 110,000 volt line in 1924 from the Long Lake Station in Spokane. It was the development of the high voltage line of 100,000 volts or more that made these vast interconnected networks possible on a scale never before realized.

Other Private Companies

The Washington Water Power Company and the Puget Sound Power and Light Company are the two largest and oldest private power companies that continue to operate in the state; their history and the power plants that they constructed reflect the evolution of the private electrical utility industry in Washington. However, several small companies also built and operated plants throughout the region, and their development plays an important role in the history of the electrical industry in the state. The installation that they built shed light on the evolution and changing shape of electrical systems in Washington.

Several pioneering electric facilities were constructed to furnish power to individual industries. Many of them provided a foundation for the expansion of large electric supply systems. The Condit Plant in Skamania County is the only major early hydroelectric installation remaining in Washington built to supply power to a specific industry. On July 14, 1911, the owners of the Crown Columbia Paper Mill at Camas incorporated the Northwestern Electric Company for the purpose of constructing a 20,000 hp plant to supply additional power to their expanding mill. A few years later the company completed a substation in Portland which enabled it to sell and distribute its surplus power and electricity throughout the region. In 1923, the transmission line to Camas was extended to serve the industrial section of Vancouver. Two years later, the Northwestern Electric Plant became an integral part of an expanding transmission network which continues to supply current throughout northern Oregon and southern Washington.

The Elwha River Project was constructed on the Olympic Peninsula in 1914 to power several industries throughout the region. However, unlike the Condit Plant, the Elwha River system was not built to supply a single industry exclusively. Unlike many other early power installations in Washington, which were built to serve the needs of a developed urban industrial center, the Elwha River Plant was constructed to spur development; and it was evident that the growth of the peninsula was inextricably linked to industrial expansion within the region. In order to convince companies to invest capital in the area, it would be necessary to insure an abundant and reliable source of electrical power.

In 1910, Thomas T. Aldwell, an early settler in the northern peninsula was instrumental in forming the Olympic Power and Development Company which completed a 9000 hp power plant in a rugged canyon on the Elwha River. For ten years the pioneering Olympic Power Company was the major source of residential, commercial, and industrial power on the Olympic Peninsula.

The development of the electrical industry on the peninsula was distinct from concurrent hydroelectric developments in other parts of the state. The comparatively small Olympic Power Company system began operation at a time when small power companies throughout the state were consolidated under large parent companies. These conglomerates were building power installations that operated at more than three times the capacity of the Elwha facility.

However, these comparisons do not diminish the significance of the Elwha River Power system to the economic and industrial development of the peninsula. The physical separateness and contained nature of the peninsula set it apart from other regions within the state. When the Elwha River system began operation, the power load demands of the area were limited; the peninsula did not have the concentrated population centers nor the industrial base that had already been developed in other parts of Washington.

It is interesting to note that the Elwha River system reflects national hydroelectric development patterns more closely than statewide trends. Like most installations throughout the country, it did not become part of a vast interconnected regional system until the 1920s. In time, the Olympic Power and Light Company, which later became the Northwest Power and Light Company, could not meet the load demands of the peninsula's inhabitants and industries. The construction of an additional 15 MW powerplant at Glines Canyon did not suffice for long. Finally in 1926, ten to 20 years after the phenomenon occurred in other parts of the state, a large power company bought up and consolidated the small local entities on the peninsula. Portions of the Northwest Power and Light Company's distribution system were purchased at this time. In 1937, the Elwha River and Glines Canyon Plants were acquired by the Crown Zellerbach Corporation.

Municipal Systems

Seattle Municipal System

Prior to 1930 the United States electrical industry was compromised of two organizational systems: the private electrical company and the municipality owned utility. Throughout the earliest years of power development in Washington, the industry was dominated by the private utility companies. However, by 1910 in the urban regions of western Washington, the municipal electrical systems were expanding rapidly and competing with the private power companies for the utility business.

The first large scale municipal hydroelectric facility within the state was completed in 1904 at Cedar Falls by the City of Seattle. The construction of this pioneering public power utility was part of a national municipal ownership movement which flourished at the turn-of-the-century; the growth of municipal ownership gave rise to the unprecedented expansion of public services, and was inextricably linked to the rapid urbanization that occurred throughout this period. As people crowded together, the problems of public health, sanitation, fire and police protection, transportation, water supply, and lighting were magnified; the municipal effort to solve these problems -- to build an infrastructure to meet the public needs -- became paramount.[36]

Many factors fuelled the municipal ownership movement. The historian Samuel Hays argues that this movement did not emerge from a socialistic ideology, but from a pragmatic attempt to implement the objective of urban reform. Over the years the support for a municipal power system in Seattle grew because the electrical services provided to the city by private companies proved inadequate. In addition to the poor and limited service, the private companies in Seattle were tainted in the public eye as a result of their exorbitant rates and their lack of public mindedness.[37] A editorial in 1895 articulated the prevailing public protests:

> Away from the principal streets Seattle is a miserably lighted town. The incandescent light serve to mark where the corners are when the night is not foggy, but as for serving any other imaginable purpose they might as well not be there at all.[38]

Another element in the movement for municipal ownership was the awakening of America's "civic conscience" -- an awakening which focused on the abuse of franchise rights by various monopolies. In an attempt to obtain lucrative public franchises, the private utilities often became a part of the corruption and venality that prevailed throughout city politics during this "gilded age." While opponents of public ownership claimed that the emergence of public utilities would increase political intervention in business affairs, advocates of municipal reform hailed publicly owned utilities as the most expedient means of dismantling the corrupt ties between city officials and utility corporation spokesman.[39]

In 1900, the Seattle Electric Company, a corporation organized by Stone and Webster, supplied electricity to the City of Seattle. From the outset, the public was suspicious of the goals of this newly formed company which had quickly gained control of the electrical industry in the region. In 1900 in a speech before the City Council, Judge McGilvra, a prominent Republican who opposed vested corporate interest, claimed that the owners of the Seattle Electric Company, J.D. Lowman and Jacob Furth, were respected citizens, but "they are not principally engaged in distributing charities, while their associates from Boston are clearly after the almighty dollar."[40] Formed during an age renowned for the dissolution of monopolies, the Seattle Electric Company became a symbol of the "evils" of monopoly control. The company was viewed as a "plunderer of the public welfare." Moreover, because it was owned by a Boston "syndicate," it was distrusted as "foreign."[41]

In 1899, the Seattle Times declared:

> The people have grasped the club of city ownership in defense against the attack upon their resources and future made by the Boston syndicate...The opportunity is now in the hands to pioneer in America the path to a thorough business municipality.[42]

Countless newspaper articles of the period support the contention that antipathy towards the private utility companies contributed to the promotion of municipal ownership in Seattle at the turn-of-the-century.

In 1904, city forces completed a 3500 KW power installation at Cedar Falls. In January, 1905 following the erection of the 36 mile long transmission line, the plant furnished current to operate Seattle's street lighting system.[43] The control of the lighting system was transformed from the Seattle Electric Company to the newly formed municipal Lighting Department marking the beginning of a new era in electric power generation in Seattle.

The organizational structure and financial resources of the municipal utilities were very different from those of the private electrical companies. This difference is probably most clearly revealed in the physical form of the early municipal installations. The original physical layout of the Cedar Falls Plant and the manner in which it was constructed reflects the piecemeal method in which it was funded by public bond issues. In contrast to the publicly owned installations, the initial capital outlay for most of the private hydroelectric facilities of the period was enormous, and typically these private power plants built a single, monumental structure which housed both generating units and transformers. The Cedar Falls plant, by contrast, was constructed slowly and in parts, beginning with a frame structure that necessitated construction of an unusual complex of fireproof switching and transforming structures. Even when the plant was expanded in the 1920s, it was built in several stages in an attempt to be frugal with taxpayers' money.

In 1911, J.D. Ross, one of the nation's leading proponents of public power supplies, was named superintendent of Seattle municipal power system. A disciple of the principle of public power, Ross approached his work with zeal and eventually served the city for 27 years. The year after Ross was hired, the power load needs of the City of Seattle surpassed the capacity of the city's plant on the Cedar River. A temporary steam plant was constructed; however, its capacity to meet the escalating load demands was limited. It was not until 1918 that the City of Seattle began work on the development of the Skagit River site in the northern Cascades.

An engineer reported that the power generation potential of the Skagit River was greater than any river on the west slope of the mountains. Over 150 miles long, the Skagit River extends from British Columbia to Puget Sound, and drains an area of more than three thousand miles. A contemporary engineering journal described the unusual site conditions: "For fifteen miles the Skagit River flows in a narrow gorge where the river's 700 foot descent provides unexcelled sites for three dams and generating plants, all in solid rock."

Though the power potential of the upper Skagit was undisputed, the cost of building structures in this steep, mountainous, inaccessible wilderness of granite rock was staggering. Construction was further complicated by the fact that there was no road access to the site. The wagon road ended at Marblemount. The only means of transportation beyond this point was by pack-horse on a "tortuous trail" used by hunters and prospectors.[44] In September, 1924, after six long years of construction, the first Skagit facility at Gorge Creek delivered electric power to Seattle. It was transmitted on a 105 mile long line to the north substation where it was distributed throughout the city.

In 1927, work began on the second phase of the Skagit River development. The capacity of the 60,000 KVA Gorge Powerhouse seemed enormous when it was completed in 1924. However, it soon became clear that it would not be able to meet the mounting industrial and domestic power load demands of the City of Seattle. Because the water was diverted by a low timber crib dam at Gorge Creek, the powerhouse depended solely upon the river flow for the generation of power. The flow fluctuation of the Skagit River proved to be great; during the winter months, ice could reduce the flow to a trickle. The construction of a dam at Diablo Canyon, six miles above the Gorge Plant, would not only supply water to operate an additional powerplant; it would also furnish 90,000 acre feet of storage to regulate the flow of water to the Gorge powerhouse and to insure that it operate to its capacity.[45]

The Diablo damsite was located in a deep and narrow canyon where vertical granite walls rise 400 feet above the streambed. Engineers designed for the site a spectacular concrete arch dam, 389 feet high and 1180 feet long at the crest.[46] Although the dam was completed in 1929, the power plant was not completed until 1935 due to funding difficulties caused by the depression. When the power plant finally transmitted current to Seattle in 1936, its 90,000 hp turbines were hailed as the largest in the world. Architecturally, the plant was imposing, as well, and signalled the intentions of its designers to house the plant in a monumental ediface.

The Skagit River Project marked the beginning of the second phase of large scale hydroelectric development in Washington State, and represented the move to develop the more costly and remote sites. By the 1920s most of the inexpensive power facilities located close to urban areas where the loads were concentrated had already been developed. The Gorge and Diablo plants reflected the advancements in high-voltage, long distance transmission technology and high capacity turbogenerator design of the 1920s which made it economically feasible to transmit current over hundreds of miles.

Tacoma Municipal System

The other major municipal utility in the state was owned and operated by the City of Tacoma. Its organizational development paralleled the evolution of Seattle City Light. Tacoma was one of the first cities in the Pacific Northwest to own and operate a municipal electrical system. Like the Seattle system, it was initially organized to provide municipal lighting. The utility was formed in the early 1890s, and for several years its dc dynamos provided the city with sufficient power. However, by the late 1890s Tacoma was forced to purchase electricity from various private companies in the region. Finally in 1909 the public voted to construct the city's first hydroelectric generating facility at La Grande on the Nisqually River. By 1913 the La Grande Plant supplied the city of Tacoma with electricity. The capacity of the four 8000 hp units proved to be sufficient until 1917 when the city's power load demands increased at an unprecedented rate.

Because the Nisqually facility had a limited storage capacity, it was particularly vulnerable to river flow fluctuations. During low water periods the plant could provide only a quarter of its total capacity. In order to insure continuity in service for its customers, the acquisition of adequate storage for the city of Tacoma became paramount. Studies indicated that the quantity of additional storage available at the Nisqually Plant would be small, and the unit cost would be high.[47] It was evident that it would be necessary to develop another site to generate the power required for Tacoma's expanding market.

Following a systematic investigation of potential power sites, city engineers selected a location on the North Fork of the Skokomish River, on the Olympic Peninsula 44 miles northwest of Tacoma. The site, which would initially generate 50,000 hp for the city-- almost double the capacity of the Nisqually Plant -- was located in an area that was notorious for its heavy rainfall.

One of the distinctive features of the Cushman Project was the enormous 440,000 acre foot storage facility; and it proved to be a critical component in the development of the site. The project was remote and costly and would not have been warranted without the unusually large storage reservoir. By May, 1926, the two vertical turbines at Cushman No. 1 were brought on line to carry Tacoma's entire 32,000 KW load.

While Cushman Plant No. 1 was built to meet an unprecedented increase in domestic power and light demands, Cushman No. 2 was constructed primarily to serve the load requirements of an expanding commercial power market. Since its inception, the municipal utility sold power for commercial purposes in order to reduce the cost of residential power and light. The city managers also understood that the adoption of policies -- that is, the institution of low power rates -- to encourage the establishment of large and small industries within the city limits would play an instrumental role in the "building up of Tacoma."[48]

The move to promote industrial expansion within the city directly influenced municipal power development. Following the completion of Cushman No. 1 in 1926, several large industrial enterprises located plants in Tacoma. A city Light Department publication reported that the growing number of industries in Tacoma and the decision of others to move to the city clearly indicated that a "shortage of electrical energy would be reached in 1930 unless the power output was increased." As a result, in December, 1927, the Public Utility Commissioner, Ira S. Davisson, submitted a resolution to the City Council, for the construction of the second unit of the Cushman Power Project which ultimately would provide an additional 90,000 hp for the City of Tacoma.[49] In 1931, the Cushman No. 2 installation was completed. This ambitious project included the construction of a 240 foot high concrete arch dam, located several miles downstream from the Cushman No. 1 dam.

Although public funding and the organizational structure of the municipal utilities influenced the physical layout and form of the early municipal installations, general changes in the configuration of city-owned electrical supply systems in Washington between 1890 and 1930 were similar to the changes that occurred in the privately-owned systems. Like the private power installations, the earliest municipal facilities were dc plants which generated electricity exclusively for lighting. When the private companies were building their vast regional networks, the municipalities were building their first hydroelectric stations. But limited funding and service areas restricted the size of the systems.

Not until the 1920s did the public systems rival the scale of the private systems; both Skagit and Cushman were examples of this second phase of large scale hydroelectric development in Washington. Yet only the largest municipalities could afford such vast systems. Though there were several municipal utilities throughout Washington, only Seattle and Tacoma developed large scale hydroelectric facilities. The construction of these large municipal electrical systems presaged the enormous publicly funded hydroelectric installations that were built throughout the country during the 1930s.

IV. Impacts to the Environment and Native American Culture

Throughout the period, the development of hydroelectric power plants transformed the physical landscape of Washington. Most significantly, power plants altered free-flowing rivers through the construction of dams, reservoirs, artificial lakes, and diversions. As a result, thousands of acres contiguous to each project were flooded, including valuable wildlife habitats, and the natural runs of anadromous fish were curtailed.

These environmental impacts had a dramatic effect of the lifestyles of native Americans. Traditional village sites, and rich hunting and gathering areas were inundated; and treaty-secured rights to anadromous fish were violated through the decimation of natural runs. The cumulative effect of these changes, in some areas, resulted in the disruption of the subsistence economy, the depletion of food sources, and the desecration of once-pristine environments rich in traditional cultural values. (See Ray Verne, Ethnic Impact of the Events Incident to Power Development on the Colville and Spokane Indian Reservations, Port Townsend, 1977, for an overview of these issues.) It was a serious intrusion in traditional lifestyles that was not mitigated at the time by the owners or operators of the plants.

In general, the environmental damage inflicted by the plants was not addressed at the time of construction and, although several tribes did litigate in state courts, the construction programs made no important variances for environmental or tribal concerns, unlike later federal projects. Later court actions, legislation, and regulatory decisions attempted to mitigate some of the impacts, but even today the issues of tribal treaty rights and fish runs are debated in courts and government agencies.

The 1930s and Afterward

By 1930, a new era of public power was ushered in with the passage of the Washington District Power Bill, sponsored by legislator Homer T. Bone. Bone's bill enabled the formation of county Public Utility Districts and gave them the right to condemn private power systems. Bone was elected to the United State Senate in 1932, where he worked on passage of Franklin Roosevelt's plan to increase federal involvement in hydroelectric production and distribution. During Roosevelt's administration, the Army Corps of Engineers and the Bureau of Reclamation began construction of huge dams on the Columbia River and elsewhere. Water was regulated for irrigation, transportation, and flood control as well as power. The Bonneville Power Administration was created in 1938 to distribute the public power. These grand federal undertakings represented a discrete new era in hydroelectric development. Yet they were a natural outgrowth of the great regional systems of the early 20th century, utilizing the technology and organizational structure pioneered in Washington's early hydroelectric plants. Although built on a larger scale, with more diverse purposes, the federal projects were logical successors to the early efforts to transform Washington's rugged terrain into a limitless source of energy for modern civilization.

[1]O.B. Coldwell, "Hydroelectric Power in the Pacific Northwest." Journal of Electricity, January 1, 1926, p.8.
[2]Thomas P. Hughes, Networks of Power Electrification in Western Society 1880-1930, (Baltimore: John Hopkins University Press), 1983, p. 1; John D. Ryder and Donald G. Fink. Engineers and Electrons A Century of Electrical Progress, (New York: The Institute of Electrical and Electronics Engineers, Inc.), p. 91; Forrest McDonald, Let There Be Light The Electric Utility Industry in Wisconsin, 1881-1955, (Madison, Wisconsin: The American History Research Center), 1957, pp. 4-5.
[3]McDonald, op.cit., p. 24.
[4]McDonald, op.cit., p. 26; Ryder, op.cit., p. 94; Thomas Parke Hughes, "The Science-Technology Interaction: The Case of High-Voltage Power Transmission Systems." p. 647.
[5]Ryder, op.cit., p. 35.
[6]Hughes, "High-Voltage Power Transmission Systems," p. 647.
[7]Ryder, op.cit., pp. 101-102.
[8]Ibid., pp. 101-102.
[9]Electrical World and Engineer, Volume XXXIX, No. 5, February 1, 1902, p. 188.
[10]Hughes, Networks of Power, p. 264.
[11]Ibid., p. 366.
[12]Ibid., p. 366.
[13]Ibid., p. 366.
[14]Ryder, op.cit., pp. 105-106.
[15]Hughes, Networks of Power, op.cit., pp. 366-367.

[16]McDonald, op.cit., pp. 23, 104.
[17]August Wolf, "Spokane and Inland Railway System," Pacific Builder and Engineer, March 23, 1907, p. 4.
[18] Ibid., p. 104.
[19]Arthur Kramer, History of Puget Sound Power and Light Company, 1885-1944, Puget Sound Power and Light Company. Seattle, 1944, pp. 1-3.
[20]Ibid., pp. 1-3.
[21]Henry L. Gray. "Report on the Puget Sound Traction, Light, and Power Company." Seattle, 1915, p. 38.
[22]Kramer, op.cit., pp. 1-3.
[23]Edward J. Crosby. The Story of the Washington Water Power Company, 1889-1930, Washington Water Power Company, 1930, p. 2.
[24]Kramer, op.cit., pp. 6.
[25]Ryder, op.cit., p. 105.
[26]Kramer, op.cit., p. 8.
[27]Hughes, Networks of Power, p. 365.
[28]Ibid., pp. 386-388.
[29]Ibid., pp. 390-391.
[30]Ibid., p. 324.
[31]Crosby, op.cit., p. 15.
[32]Ibid., p. 15.
[33]Crosby, op.cit., p. 17.
[34]Ibid., p. 20.
[35]Washington Water Power Company, History of Washington Water Power Company, 1939, p. 47, Manuscript Division, Washington Water Power Company Library, Spokane.
[36]Clifford W. Patton. The Battle for Municipal. Reform. (Washington, DC: American Council on Public Affairs, 1940), p. 1.
[37]Ibid., p. 10.
[38]Ibid., p. 34.
[39]Ibid., p. 9.
[40]As quoted from Wesley A. Dick, The Genesis of Seattle City Light. Unpublished Master's Thesis, Department of History, University of Washington, Seattle, p. 50; McGilvra to the City Council, January 27, 1900, McGilvra MSS, University of Washington Library.
[41]Ibid., p. 9.
[42]Ibid., p. 50.
[43]J.D. Ross, Seattle Lighting Department, Biennial Report for 1912-1913, p. 14.
[44]"Only Power Pressure Tunnel in the U.S. Opened by the City of Seattle," Pacific Builder and Engineer, August 9, 1924, p. 8.
[45]"The Diablo Dam," Western Construction News, August 25, 1927, p. 52.
[46]Seattle City Light, "Power System Information," 1962, p. 13.
[47]"Purchase of the Lake Cushman Power Site," Journal of Electricity, Volume 43, No. 8, October 15, 1919, p. 361.
[48]Ibid., p. 361.
[49]City of Tacoma, Department of Public Utilities, Light Division, 1926-1927 Information Book, p. 18.

F. Associated Property Types

I. Name of Property Type Hydroelectric Plants

II. Description

See Continuation Sheets

III. Significance

See Continuation Sheets

IV. Registration Requirements

See Continuation Sheets

[x] See continuation sheet

[ ] See continuation sheet for additional property types

G. Summary of Identification and Evaluation Methods

Discuss the methods used in developing the multiple property listing.

The nomination is the result of a systematic inventory of major commercial and municipal hydroelectric plants throughout the state. The survey was conducted from 1981 to 1986, and included a systematic review of the literature as well as site visits to extant facilities. The nomination and inventory focuses on major plants constructed between the years 1890 and 1938 because this half century constitutes the formative years of the history of regional electrical supply systems. Unfortunately no systems built in the 1880s remain intact within the state. Following 1938 hydroelectric installations operated on a scale never known before. The multi-purpose federal projects initiated during this latter period mark the beginning of a new era in hydroelectric power system construction.

☐ See continuation sheet

H. Major Bibliographical References

Aldwell, Thomas T., Conquering The Last Frontier. (Seattle: Superior Publishing Company, 1941).

Beery, E.J., The Electrical Development in the State of Washington. An Unpublished thesis submitted for the decree of electrical engineer. University of Washington, 1915.

Brittain, James E., Turning Points in American Electrical History. (New York: IEEE Press, 1976).

Condit, Carl, American Building Art, the Twentieth Century. (New York: Oxford University Press, 1961).

Condit, Carl, American Building. (Chicago: The University of Chicago Press, 1982).

Dierdorff, John, How Edison's Lamp Helped Light the West. (Portland, Oregon: Pacific Power and Light Company, 1971).

Foster, Abram John, The Coming of the Electrical Age to the United States. (New York: Arno Press, 1979).

Hughes, Thomas P., Networks of Power Electrification in Western Society 1180-1930. (Baltimore: John Hopkins University Press, 1983).

☒ See continuation sheet

Primary location of additional documentation:

☐ State historic preservation office
☐ Other State agency
☐ Federal agency
☐ Local government
☐ University
☐ Other

Specify repository: ______

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II. **Description:**

The physical character of hydroelectric power plants was profoundly influenced by rapid technological developments between 1880 and 1930, and particularly by responses to the natural conditions of Washington. In contrast to the typical Eastern plant which operated under a low head and high volume of water, the typical Washington site consisted of a high head (over 200 feet) and low volume of water. During the early years of the electrical industry, the generating equipment used for low head installations could not be adapted for high head conditions.[50] By the early 20th century, however, a separate design technology emerged in an attempt to develop power from the vast high head resources of the West. With the successful application of that new technology, high head systems came to dominate hydroelectric development in Washington.

Low Head and High Head Systems:

The characteristics of low head and high head systems are slightly different. Turbines in a high head installation are operated by a low volume of water that drops over 200 feet, while turbines in a low head installation are operated by a high volume of water that drops less than 200 feet. Different kinds of turbines and generator units are needed to operate under these different conditions and the varied volumes and velocities of water. Due to Washington's mountainous terrain, high head installations are typical of the state.

Unlike low head systems, high head facilities include a long, elaborate water conveyance system. The water, which operates the turbines, is diverted from a mountain stream miles from the steep power plant site. When water travels a long distance at a high velocity certain design precautions are needed to prevent surge in the pipelines. As a result, high head installations also include surge tanks, stand pipes, and pressure regulators.

In contrast, low head plants include dams that create pondage at the point where the water is used. This arrangement allows for the passage of large volumes of water through a short water conveyance system to the turbine units. In a low head installation, the dam usually extends across the river and impounds a large body of water above it. The large flood discharges typically necessitate the construction of a spillway across the entire length of the dam.

The following chart outlines the components of the two prevelent systems:

High (and Medium) Head Systems Include:

Reservoir
Dam/Intake structure
Water conveyance system, including canal, pipeline, penstocks, and forebay
Pressure regulators, including stand pipes and surge tanks
Power house, including the generating equipment
Transformers
Transmission system

Low Head Systems Include:

Reservoir
Dam/Intake structure, with penstocks
Powerhouse and generating equipment
Transformers

Powerhouses: The earliest powerhouses were frame structures, but by the early 20th century most powerhouses were built of brick or reinforced concrete. These structures housed generating equipment and were articulated on the exterior by a series of bays separated by monumental piers. The bays were filled with expansive sash windows which lighted the vast interior. A restrained classicism was often expressed on the exterior by projecting cornices or arched fenestration.

Capital expenditures directly influenced the physical form of the plants. For example, most privately owned power plants consisted of a single monumental fireproof structure which housed both the generating units and the transformers. Although planned for future expansion, the initial capacity of the private plants was usually greater than municipal plants, and as a result fewer additions were required.

Because the funding of the city-owned generating plants was limited and contingent upon the taxpayer's satisfaction with the system, economy of construction was always a priority. The construction of the Cedar Falls plant by the City of Seattle, for example, is typical of the incremental development that characterized publicly owned plants. The original power house was an inexpensive timber structure built in 1904. The small structure necessitated construction of an unusual complex of fireproof switching and transformer structures. When the plant was expanded in 1921 only half of the reinforced concrete structure was built, enough to house a single unit. The remaining segment of the building was completed seven years later. This piecemeal method of construction was not unusual for municipally owned power installations in Washington prior to 1930.

But even public plants expanded dramatically in size after 1920. Unlike the simple utilitarian facilities of the first two decades of the century, power installations of the 1920s and early 1930s were architectural showpieces. For example, striking tile work on the floors and walls of the Diablo plant celebrates the large scale municipal generation of hydroelectric power. Such designs represented a marked change in attitude; the power installations were embraced as monuments, and were elaborately displayed before the public.

Equipment: The powerhouses sheltered massive generating equipment, which reflected important technological developments, particularly those that addressed the needs of high head systems in the mountains of Washington. This technology is most clearly represented in turbine design. The low volume and high heads characteristic of the West Coast were poorly adapted to the old-style water wheels and the reaction, or pressure, turbines employed throughout the East Coast.[51] In an effort to tap the power potential of the steep gradients of the West, the free jet tangential impulse or Pelton wheel emerged.

The impulse wheel operates on a different principle than the more traditional reaction turbine. The reaction turbine consists of two sets of curved vanes; a stationary set which directs water on a second set that us free to rotate. The impulse wheel, on the other hand, is placed in operation when a stream or jet of water under considerable head and pressure is directed tangentially against its periphery, striking the buckets in rapid succession.[52] The Pelton patent consisted of a twin bucket arrangement with curved bottoms, inclined sides, and a raised center ridge which divided the incoming jet of water. This design permitted minimal interference between incoming and outgoing water, and doubled the efficiency of the wheel.[53]

In a paper delivered at a meeting of the associated "mechanicals" at San Francisco in 1892, a California engineer described the salient features of the impulse wheel:

> Figuratively speaking, when a wheel is changed from the pressure to the impulse system it is taken out of its case, mounted in the open air, in plain sight. All the various inlet fittings are dispensed with and are replaced by a plain nozzle and stop valve. Its diameter is made to produce the required rotative speed, whatever that may be. The shaft and its bearings are divested of all strains except those of gravity and the stress of propulsion when the water is applied at one side only. Most important of all three are no running metallic joints to maintain against the escape of water, no friction and no leaks; there are, indeed, no running joints or bearings whatever, except the journals of the wheel shaft...there are no working conditions which involve risk or which call for skill. If a vane [bucket] is broken, another one is applied in a few minutes' time. If a large or small wheel is wanted, the change is inexpensive and does not disturb the foundations or connections. Capacity is at complete control; the wheels can be of 10, 100, or 1,000 horsepower, without involving expensive special patterns.[54]

By 1900, the Pelton wheel had become the characteristic water turbine in high head hydroelectric developments throughout the West.[55] The Pelton wheel at Washington's Electron plant was the largest in the world when it was installed in 1904. Other examples of the Pelton wheel are at Nooksack Falls and Newhalem.

The turbine at Nooksack Falls replaced a Francis, or reaction type, turbine installed in 1906, which proved to be inefficient because it was often clogged with river debris. Because the water passage areas of the Francis turbine runner decreased as the head increased, the turbines were impractical for high head systems. (At 176 feet, the Nooksack Falls plant faced this problem).[56]

During this period, the Francis turbine was adapted for low and medium heads exclusively and for moderately high heads when large capacities are involved, while the impulse wheel was limited to very high head exclusively and moderately high heads when large capacities are involved. Because the individual passage areas of a Francis runner decrease as the head increases, there is a point at which the Francis turbine design becomes impractical due to a generator speed that is too high for a given capacity or a capacity that is too great for commercial speeds. The ratio of wheel diameter to area of an impulse wheel, on the other hand, decreases as the head and capacity increases. As a result, there is a point at which the design of an impulse wheel becomes impractical due to an uncommercially low speed for a given capacity, or a capacity that is too small for a commercial speed.[57]

Given the design features of the two turbines, it was easier to adapt the Francis turbine rather than the impulse wheel to a wider head range. During the first two decades of the 20th century, great strides were made in extending the head range of the Francis turbine to make it suitable for the high head hydroelectric developments of Washington. In 1906, the largest single wheel turbine ever built was installed at Snoqualmie Falls, and in 1911 the largest Francis turbine in the world was installed at the White River plant. Thereafter, all the large capacity, high head installations in the state used Francis turbines.[58]

Another critical design dilemma reflected in the hydroelectric plants in Washington was the attempt to achieve a compatibility between the turbine and the generator. The difficulty centered on the adjustment of rotating speeds and the adaptation of wheel and generator positions to insure a direct connection between them. For many years the problem of matching engine speed and shaft position was resolved by "accepting the long established horizontality of the generator and placing the hitherto upright hydroturbine on its side."[59] As a point in fact all of the Francis turbines in Washington State manufactured prior to 1921 were of the horizontal type.

In his provocative analysis of the History of Industrial Power in the United States, Louis C. Hunter states that by 1920 this awkward and inefficient horizontal arrangement was being reversed in favor of the Niagara solution: "the generator was upended in the so-called umbrella dynamo with its vertical shaft and the hydroturbine resumed its traditional upright stance."[60]

Vertical shaft units were made possible by the Kingberry bearing, or other designs based upon the same principle. The entire rotating element which consists of the turbine runner, the shaft, and the generator roter, is suspended on the bearing which is supported on the top of the generator by a spider. This innovative design eliminated the use of the solid disc bearing, or the roller bearing, both of which operated by means of oil under heavy pressure and required an expensive pumping system.[61] In 1925, a hydraulic engineer reported that the modern hydraulic turbine is almost always a vertical machine.[62]

Water conveyance networks: Because most Washington plants were characterized by high-head systems, long water conveyance networks were an integral part of most early hydroelectric facilities in Washington. These extensive systems, which convey water to the turbines, are an indispensable feature in the effective use of high-head water power. The ten mile long timber flume at Electron is the longest flume associated with power development in the state. The design of the timber structure was typical of railroad and irrigation flume construction of the late 19th and early 20th centuries.

The White River installations also includes a long water conveyance system which consists of a seven mile long network of timber flumes, lined and unlined canals, and a series of settling basins. The designers took full advantage of the land which provided ideal conditions for power development, and did not require the construction of enormous engineering structures in difficult, inaccessible terrain. Instead, the engineers built a succession of small structures--of dams, embankments and dikes, slowly reshaping the landscape for their own ends which was a noteworthy feat of engineering for its time and place.

In the 1920s the development of electrical drill equipment made it economically feasible to build power tunnels through solid rock rather than long, circuitous timber flumes. Large power tunnels convey water to the generator units at Gorge, Diablo, Cushman No. 2, Lake Chelan, and Baker River power plants.

Reservoirs, dams, spillways: Many of the water conveyance systems terminated at or originated in large reservoirs. The construction of reservoirs to regulate the river flow and insure continuity of service during low water periods marked a significant turning point in the movement for large scale planned electrical supply systems. Unusually large reservoirs were a part of the White River, Long Lake, Cushman, and Skagit River projects. The White River facility was one of the first power installations in the state to include a storage reservoir in its design. The immense 2,225,000,000 cubic foot storage reservoir at Lake Tapps impounded sufficient water to operate the White River Plant at full load for an entire month. As a result, the White River facility had the capacity to equalize the load fluctuations of all of the large installations in the region.

The earliest dams of Washington's power plants were often cribbed timber structures. But by the early 20th century, concrete dams of various sizes and designs were universal. The dam above the low head development at Long Lake impounded a 23 mile long reservoir that was 3/8 of a mile wide. The water was contained by a 208 foot high concrete structure. Purported to be the highest spillway in existence when it was completed in 1915, the structure reflected the limits of dam and reservoir design during this period. One of the distinctive features of the Cushman Project was the enormous storage facility which proved to be a critical component in the power development of the site. A basin one mile wide and eight and one half miles long was formed by the construction of a 280 foot high, 1100 foot long concrete dam in a canyon between two vertical walls of basalt at Cushman No. 1. When the 389 foot long concrete arch dam was completed at Diablo Canyon in 1929, it was hailed as the highest concrete arch dam in the world. It furnished the utility with 90,000 acre feet of storage.

The following terms describe other components of dams mentioned in the individual nominations:

Forebay: the part of a dam's reservoir that is immediately upstream of the powerhouse
Intake: the entrance to a turbine unit at a hydroelectric dam
Spillway: a dam's safety value, where excess water is released to avoid damage or flooding
Storage Dam: a dam with a large reservoir that can hold water over from the annual high-water season to the following low-water season, as opposed to run-of-river dams that have very little storage
Tailrace: the canal or channel that carries water away from the dam

Transmission systems: Another significant component in the development of regional utilities was the construction of extensive transmission systems. These networks were a major feature in early western hydroelectric facilities. One result of the high transmission voltages of the 1920s was the development of remote controlled and automated power plants. The dangerously high voltages made it necessary to locate circuit breakers and switches a safe distance from the control room operators, preferably in an open air switchyard. During this period transformers, circuit breakers, and switches were moved from concrete compartments on the interior of the building to open air switchyards adjacent to the power plants. Remote controlled electric signals were developed to energize electromagnets or small motors which operated the oil-filled circuit breakers and switches from the control room. By telephone instruction, the dispatcher maintained control over circuit breakers and turbogenerators at locations tens or even hundreds of miles away.[63] The Upper Falls Plant built in Spokane in 1922 represents one of the earliest efforts in the state to automate a hydroelectric facility.

Other structures: In addition to the structures directly associated with the production of power, many installations included cottages for plant employees, recreation halls, and even schools at those sites where the remote location and large scale of operation led to the development of small company towns. The structures were almost uniformly plain frame or brick structures that stand in marked contrast to the monumental powerhouses and dams.

[50] T.S. Reynolds, and Charles Scott. Historic Engineering Record. Battle Creek Hydroelectric System CA-2, 1981, pp. 1-20.
[51] Louis C. Hunter. A History of Industrial Power in the United States, 1780-1930, (Charlottesville: University Press of Virginia), 1979, p. 400.
[52] Ibid., p. 401.
[53] Barry Lombard, Electron Project. Historic American Engineering Record Historical Assessment, No. WA-12, Draft, pp. 10-11.
[54] As quoted from Hunter, op.cit., p. 410.
[55] Reynolds, op.cit., pp. 1-5.
[56] Hunter, op.cit., p. 400.
[57] Arnold Pfau, "High-Head Francis Turbines and Their Operating Records," Journal of Electricity, February 1, 1918, p. 157.
[58] Ibid., pp. 157-158.
[59] Hunter, op.cit., pp. 393-394.
[60] Ibid., p. 394.
[61] John D. Galloway, "Hydroelectric Developments on the Pacific Coast," AMSCE Proceedings 48, May-December 1922, pp. 1849-1850.
[62] _____ Taylor, Fifteen Years, p. 10.
[63] Hughes, op.cit., p. 373.

III. **Significance:**

Early hydroelectric plants in Washington State are significant historic resources which reflect the rapidly evolving technology of power generation in the early 20th century, and the emerging business and governmental organizations which developed to harness and distribute that power. The installations are inextricably linked with the development of the electric industry, and are also closely associated with the region's economic and political development.

Engineering and Industrial Significance:

Power plant installations demonstrate the changes that occurred in the configuration of electrical supply systems in Washington between 1890 and 1938. Like California, Washington State was a pioneer in the use of high capacity turbines and long, high voltage transmission systems. These pioneering applications resulted in part from the remote location of the water resources of the state. The enormous power potential could not be developed without the introduction of the turbine and economical long distance transmission.

With the successful development of high efficiency turbines and high-voltage transmission systems in the early 20th century, large scale hydroelectric installations in Washington proliferated. The installations themselves represented significant technological and engineering advances. For example, some of the state's plants were pioneers in the adaptation of the free jet tangential impulse turbine, or Pelton wheel, which made high head hydroelectrical plants feasible. Other plants represented innovations in the adaptation of reaction or Francis turbines to high and medium head facilities. Still other plants were critical in the development of the extensive water conveyance systems typical of high head operations, and in the construction of reservoirs and dams. Washington State plants were also among the first in the nation to incorporate long distance high voltage transmission systems, and to build the automated power plants associated with the technology. Many other examples throughout the state illustrate the effort to expand the limits of hydroelectric technology by creating more efficient equipment with larger capacities.

In most cases, the drive for greater efficiency (especially of water wheels and turbines) was dictated by economic concerns. The capital return on the heavy investment; represented by the construction of water conveyance systems and dam and power plant complexes depended upon the wheel output which accounted for only 10 to 15 percent of the aggregate first cost.[64] But these technical innovations resulted in more than cost savings; they led as well to dramatic improvements in hydroelectric technology which, in turn, led to the development of regional electrical systems. Not surprisingly, the turbine and high voltage transmission innovations reflected in Washington's early plants became standard features of the regional electrical systems throughout the West after 1920.

The regional systems that resulted from these expansions were in marked contrast to systems in the East. While the East supplied primarily lighting load, the regional systems of Washington also carried an industrial and agricultural load, reflecting the widespread distribution of population. As such, the hydroelectric systems were integral to the growth of settlement in the state as well as to the development of industry and agriculture. More than simply satisfying an existing demand, the plants precipitated industrial and commercial growth.

<u>Corporate and Government Significance:</u> The size of the systems naturally led to equally large scale organizations, both public and private, to manage the production and distribution of power. The power conglomerates, or holding companies, that dominated hydroelectrical production in the early 20th century were among the largest and most important corporations in the state, managing regional operations at a scale rarely realized outside the railroad industry. The corporations purchased numerous local concerns, including dozens of private traction and lighting companies, and exercised an influence over public unusual for private concerns.

Organized in response to the private monopolies, the municipal systems in Washington State represented a belief in the efficiency and beneficence of government ownership, a corollary of the Progressive Era belief that public control brought order to modern life, and that private trusts were an encroachment on the public welfare. The hydroelectric plants were among the period's greatest public undertakings, and laid the groundwork for the vast federal hydroelectric projects that followed in the late 1930s.

IV. **Registration Requirements:**

Hydroelectric power plants and installations are eligible for listing in the National Register if they are:

1. significant in the history of hydroelectric generation engineering and electric transmission technology, in the history of hydroelectric design principles, and in the development of construction techniques (Criterion A and C); or,
2. significant in the social, economic and industrial development of the locality, state, region or nation (Criterion A); or.
3. significant examples of hydroelectric power systems designed or built by renowned engineers (Criterion C); or,
4. a rare example, a significant early example, or a significant representative example of a low or high head hydroelectric development (Criterion C).

Because the plants are composed of a variety of elements, and the components are related by a network of interconnections, the state of one component directly influences the state of other components in the system, and the system as a whole. The critical components typically include reservoir; dam; intake structure; water conveyance system, including canal, pipeline, penstocks, forebay; stand pipes and surge tank; powerhouse and generating equipment; transformers and transmission system. In addition, some plants included company housing and related structures.

Eligible hydroelectric installations will retain integrity of most of the components, sufficient so that the significance of the total system is well represented. Loss of some components will not irreversibly compromise the integrity of a plant if the surviving features are well-preserved and (1) convey a discrete significance on their own, or (2) satisfactorily convey the significance of the total system. In addition, because hydroelectric plants were routinely expanded and adapted to meet changing technologies and/or power loads, some replacement in kind or new construction is acceptable if the essential character of the historic plant is preserved.

[64]Louis C. Hunter. <u>A History of Industrial Power in the United States, 1780-1930</u>, (Charlottesville: University Press of Virginia), 1979, p. 392.

Hunter, Louis C., A History of Industrial Power in the United States, 1780-1930. Volume I (Charlottesville: University Press of Virginia, 1979).

Koester, Frank, Hydroelectric Developments and Engineering. (New York: D. VanNorstrand Company, 1909).

Kramer, Arthur, History of Puget Sound Power and Light Company, 1885-1944. Puget Sound Power and Light Company, Seattle, 1944.

Lyndon, Lamar, Hydroelectric Power Volume I and II. (New York: McGraw-Hill Book Company, Inc., 1915).

McDonald, Forrest, Let There Be Light The Electric Utility Industry in Wisconsin, 1881-1955. (Madison: The American History Research Center, 1957).

Paton, Tal, Cmg. and J. Guthrie Brown. Power From Water. (London: Leonard Hill Limited, 1961).

Patton, Clifford W., The Battle For Municipal Reform. (Washington, DC: American Council on Public Affairs, 1940).

Pitzer, Paul C., Building the Skagit: A Century of Upper Skagit Valley History. (Portland, Oregon: The Galley Press, 1978).

Rushmore, David B. and Eric A. Lof, Hydroelectric Power Stations. (New York: John Wiley and Sons, Inc., 1923).

Ryder, John D. and Donald G. Fink, Engineers and Electrons: A Century of Electrical Progress. (New York: IEEE Press, 1984).

Wing, Robert, ed., A Century of Service: The Puget Power Story. (Puget Power: Bellevue, 1987).

Articles and Papers

Pfau, Arnold. "High Head Francis Turbines and Their Operating Records." Journal of Electricity, Volume 40, Number 3, February 1, 1918, p. 158.

Galloway, John D. "The Design of Hydroelectric Power Plants," American Society of Civil Engineers, Transactions, Volume 79, 1915, pp. 1000-1055.

------. "Hydroelectric Developments on the Pacific Coast," American Society of Civil Engineers. Proceedings, Volume 48, 1922, pp. 1846-1858.

Jollyman, J.P. "Practice in High-Head Hydraulic Plants." National Electric Light Association, 38th Convention, 1915, Proceedings, [Volume 3], pp. 460-467.

National Electric Light Association. "Practice of Sub-Committee on Water Power Development on the Pacific Coast." Hydroelectric and Transmission Sessions. Technical Sessions. (San Francisco: National Electric Light Association, 1915), pp. 510-602.

Van Norden, Rudolph W. "Puget Sound Traction, Light and Power Company's System" Journal of Electricity, Power, and Gas, Volume 33, Number 10, September 5, 1914, p. 222.