CHILDS-IRVING HYDROELECTRIC PROJECT,
IRVING SYSTEM: IRVING POWERHOUSE
Forest Service Road 708/502
Camp Verde vicinity
Yavapai County
Arizona

HAER NO. AZ-65-G

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
Intermountain Support Office - Denver
National Park Service
P.O. Box 25287
Denver, Colorado 80225-0287

HISTORIC AMERICAN ENGINEERING RECORD

CHILDS-IRVING HYDROELECTRIC PROJECT, IRVING SYSTEM: IRVING POWERHOUSE

HAER No. AZ-65-G

Location:	Irving Station No. 203+49. Forest Service Road 708/502, Camp Verde vicinity, Yavapai County, Arizona. USGS Payson Quadrangle, UTM Coordinates: NAD 27 Zone 12 443275.5568E - 3806814.696N.
Date of Construction:	1915-1916.
Engineer:	Iva Tutt; Francis S. Vielé; Raymond S. Masson.
Present Owner:	Arizona Public Service (improvements), P.O. Box 53933, M.S. 3190, Phoenix, AZ 85072-3933; U.S. Government, U.S.D.A. Forest Service (land).
Present Use:	Hydroelectric power generation (August 2004).
Significance:	The Irving Powerhouse of 1915-1916 fulfilled the engineers' original plan to develop two power plants along Fossil Creek, and responded to increased demands from mines, farms and communities in the Bradshaw Mountains and in the Jerome/Clarkdale area.
Historian:	James W. Steely, August 2004.

Project Information:

Between February and August 2004, Arizona Public Service (APS) and SWCA Environmental Consultants documented the hydroelectric complex, under guidance of the Historic American Engineering Record (HAER). Project managers Phil Smithers (APS) and Linda Martin (SWCA) coordinated historian Steely, photographer Jessica Maggio, and draftsman Hanson Todachine to complete the HAER documentation. Archives for the Childs-Irving Hydroelectric Project are at APS in Phoenix, Arizona.

Historic and Engineering Context:

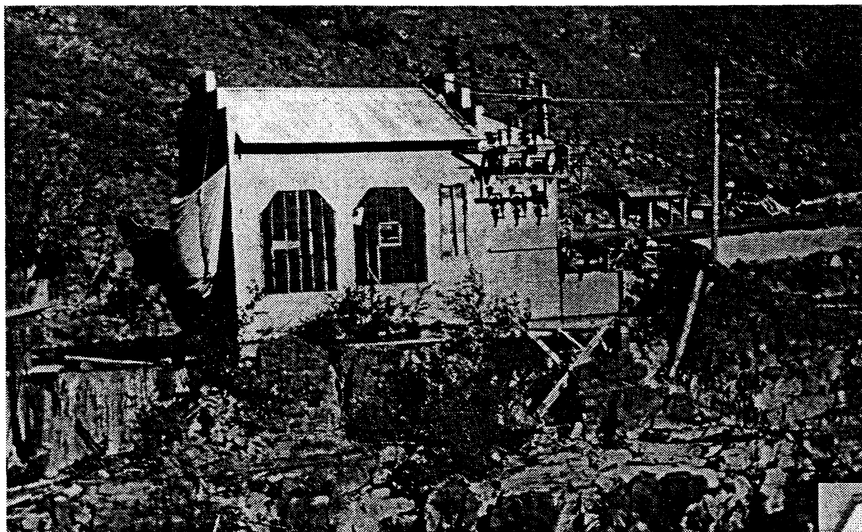
The Childs-Irving Hydroelectric Project encompassed a unique water-pressure/electric-turbine system—according to engineering historians evaluating the historic complex since 1976—that 1) was constructed with great effort in an extremely remote landscape, 2) captured a natural water source and followed dramatic topography, 3) generated electric power in a remarkably simple and efficient manner, and 4) operated continuously for 95 years.

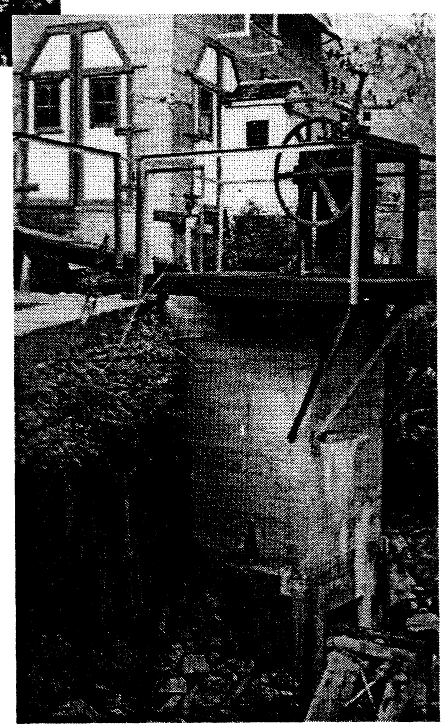
In addition to its individual significance nationwide, the Childs-Irving Hydroelectric Project is a classic part of Arizona history spanning the 20th century: remote low-grade mining operations sought reliable and less-expensive energy; a combination of investors, entrepreneurs and engineers modified a natural resource to supply the energy; cutting-edge technology entered a harsh and remote landscape; an isolated labor force merged those with skills learned far away with local residents, including Native Americans with traditional ties to the land; nearby communities soon offered an additional customer base; farmers and irrigation cooperatives became major consumers for their pumps and agricultural machinery; distant metropolitan areas boomed by tapping the energy source; and finally a conservative operational approach to investment and maintenance retained aging technology within a huge modern power grid for many, many years past a reasonable retirement.

Character Defining Attributes

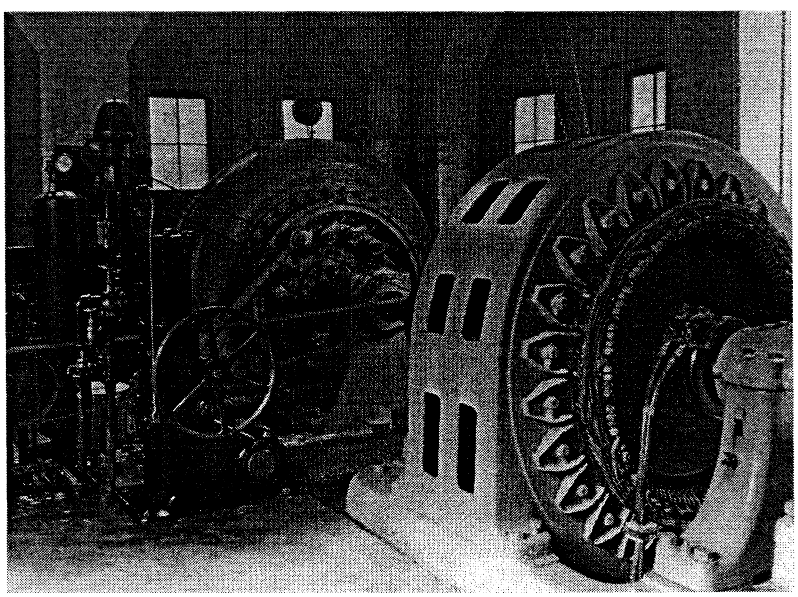
Component/Feature No.15 on National Register form. The Irving plant was built in 1915-1916 and consisted of a one-room concrete building under wood rafters (the concrete walls absorbed lateral thrust and supported the overhead hoist) and a corrugated roof (possibly of asbestos-cement sheets). The plant housed one Allis Chalmers reaction-type Francis-design (wheel partially pressurized to rotate on centrifugal force, a low pressure design as opposed to the Childs high-pressure configuration) turbine (900 revolutions per minute, rpm) of 2100 brake horsepower capacity (at 470-foot head) direct-shaft connected to a General Electric alternating current, 3 phase, 60 cycle, 900 rpm, 1600 kilowatt generator. Except for minor changes to switch panels, window trim, and some doors, the powerhouse functioned through 2004 as originally built. (Effland and Macnider 1991)

See Use and Operation below for in-depth explanation of the Irving Powerhouse.





Above – Irving powerhouse, 1916. APS Photo Library #74. Right – side gate at Irving. APS Photo Library #64. Below – interior of powerhouse. APS Photo Library #70



Use and Operation *(see also Photos, Maps and Drawings)*

Engineering Context

The use of wheels turning shafts for generating mechanical power is a human-work multiplying innovation dating at least from Roman antiquity. The guidance of natural watercourses to turn wheels and shafts for mechanical power grew to widespread use in Europe during the middle ages. In the early 19th century in the United States, tests of the mechanical efficiency of such water wheels led to vastly improved designs. One British-born engineer—James B. Francis working with water-powered industrial mills on the Merrimack River through Lowell, Massachusetts—combined efficiency studies with French development of the water "turbine." Nineteenth century turbine innovators such as Francis sought to extract the maximum power from the water's "head," or pressure from its drop in elevation, whether from a flowing stream or from a natural or artificial "fall." The turbine they envisioned is "a rotary engine that extracts energy from a fluid flow...usually [with] a casing around the blades that focuses and controls the fluid" (Farlex 2004).

> The main difference between early water turbines and water wheels is a swirl component of the water which passes energy to a spinning rotor. This additional component of motion allowed the turbine to be smaller than a water wheel of the same power. They could process more water by spinning faster and could harness much greater heads. (Schoenau 2004)

The "Francis turbine" developed in Massachusetts in the 1850s utilized 90 percent of the force of water directed to its rotor blades, as opposed to a contemporaneous industry standard of 65 percent or less (Hawke 1988). The Francis design, "the first modern water turbine," is an "inward flow reaction turbine," meaning that penstock-pressured water fills the turbine housing, the wheel turns in reaction (rather than from highly focused "impulse" pressure as with the Childs Powerhouse Pelton wheels), and a low-pressure head of water moves the turbine relatively fast (Farlex 2004).

> The water is directed into the side of the turbine and exits out the bottom [at Irving, water exists from the turbine's center]. On installations that have low-head and large flow the turbine is mounted in an open c[h]amber where water is directed onto the runners by adjustable guide vanes. By placing the turbine higher than the tailwater a suction head can be created. (Schoenau 2004)

"By the 1870s variants on the Francis turbine became the most widely used hydraulic prime movers in America, at a time when water power was still more important than steam for industrial purposes" (Hawke 1988).

The first large-scale production of electricity for consumer and industrial use resulted from a burst of innovations and spirited competition in the 1880s in the United States. In 1879 Thomas

Edison adapted the direct-current (DC) generator—producing a flow of electricity from the rotary motion of magnets, an 1830s British discovery of Michael Faraday—to the successful power of a vacuum-tube light bulb. The most credited first "hydroelectric" application linking Edison's DC-powered lights to a water-powered system opened in 1882 at two paper mills in Appleton, Wisconsin. The same year a small California system, with a generator and paddle wheel turned by irrigation water in Etiwanda Colony below the San Gabriel Mountains, lit the colony developer's home and an elevated outdoor carbon-arc light (Clucas 2002). Soon Edison offered a number of other inventions powered by DC, including powerful motors that approached the output of steam engines. But Edison's motors, like steam engines, needed to be close to the application of power, since DC voltage drops considerably when wired too far—less than two miles—from the generator (*EPRI Journal* 1979:36). Edison's obsession with DC devices obscured consumer and industrial opportunities possible through centralized generation of electricity distributed over long distances. (*EPRI Journal* 1979; Farlex 2004)

Serbian-born inventor Nicola Tesla, while working briefly for Edison, developed an understanding of alternating current (AC) that could be transmitted long distances by wire or cable without dramatic loss of power. Tesla "realised that...doubling the [AC] voltage would halve the current and reduce losses by three-quarters," that AC could be "transformed" back and forth from DC, and AC voltage could be stepped up and down for efficient transmission over long distances (Farlex 2004). Tesla patented his system, based on constant-speed AC generators, including transmission and transformers in 1887. He then joined forces with inventor George Westinghouse in proving their AC power-distribution system superior to Edison's DC inventions. Tesla's breakthrough system produced relatively low-voltage AC current from generators, stepped it up to high-voltage AC for distribution through long-distance wires, then transformed it back to lower-voltage AC to power lights and machines a considerable distance from the generator. Further, AC could be converted to low-voltage DC at the job site to power small variable-speed tools such as drills, saws, and tram locomotives.

> With Tesla and his patents, Westinghouse built a power system for a gold mine in Telluride, Colorado, in 1891, with a water driven 100 horsepower (75 kW) generator powering a 100 horsepower (75 kW) motor over a 2.5 mile (4 km) power line. Then in a deal with General Electric, which Edison had been forced to sell, Westinghouse's company went on to construct a power station at the Niagara Falls [, New York], with three 5,000 horsepower Tesla generators supplying electricity to an aluminum smelter at Niagara and the town of Buffalo 22 miles (35 km) away. The Niagara power station commenced operation on April 20 1895. Its opening set the scene for the electric power industry for over a hundred years. (Farlex 2004)

The same year as the Niagara power project's opening, 1895, the City of Sacramento, California, first drew 11,000 volts of AC power from Folsom Powerhouse on the American River 22 miles away. This innovation demonstrated the rapid spread of hydroelectric technology across the United States, and forced New York's Niagara project to share with California several of its "firsts" in the transmission of AC voltage a long distance for municipal and industrial consumption. The Folsom operation also wedded the experience of water systems related to mining operations—heretofore moving American River water through ditch and flume systems only to assist in mineral excavation and washing—and the growing trend of assisting mining with water-powered mechanical and electrical devices. The Folsom Powerhouse focused a water head of 50 feet into four "McCormick" (probably the manufacturer of Francis reaction turbines) dual turbines of 1260 horsepower each, direct-connected to four 750-kW General Electric generators, producing 3000 kW. (*EPRI Journal* 1979; Bell 2004)

By the end of the 19th century, mining and associated industrial processes embraced electric-powered machinery for a number of reasons. Mines generally developed around deposits in remote areas; electricity transmitted by wires from single generating plants ("central stations") greatly reduced the costs of constantly shipping exhaustible fuel to the mine site. Equipment for excavating mines and extracting minerals had to be compact and portable; by 1900 air-powered mining tools proved most efficient, charged by pumps in turn powered by electrical generators. Air pumps also supplied oxygen to workers deep in mineshaft labyrinths. Once workers opened mineshafts wide enough and deep enough, elevators and trams could be built into mines for hauling workers in and raw materials out; electric vehicles powered by unobtrusive wires brought no dependent fuel or choking combustion into the mine. Successful and large-scale mines processed their low-grade ore as much as possible on site to reduce shipping fees; conveyor belts, tumbling mills, sifters, smelters, and other giant machinery worked most efficiently when powered by electric motors. (Effland and Macnider 1991)

Fossil Creek Water System

The inventions of James Francis and Nicola Tesla, and the early hydroelectric projects of California, were widely published by the late 19th century in the United States, and their successes grew to industrial-scale enterprises. As Arizona and other Western regions opened to settlement and natural resource extraction through railroad connections, government and industrial agents mapped these landscapes thoroughly and noted mineral and water resources necessary to any sustained development. With knowledge of hydroelectric systems already in service in California and east of the Mississippi River, especially those supplying power to mining and industrial operations, anyone with some knowledge of harnessing water power could recognize the potential at Fossil Creek.

Indeed, hydroelectric power arrived elsewhere in Arizona just as the Fossil Creek project investors formulated their plans. "The development of hydroelectric power from Fossil Creek was not the first such project in Arizona," wrote Effland and Macnider (1991:8/4) in their Childs-Irving National Register nomination. "Hydroelectric generation of power in Phoenix began in 1902 with establishment of plants on both the Arizona and Grand canals."

The popular Childs-Irving Hydroelectric Project story that about 1900 Verde River rancher Lew Turner spontaneously envisioned a hydroelectric facility in the Fossil Creek wilderness is quaint. But this creation myth conveniently omits the existing context of hydroelectric successes in the last decade in neighboring California and nearby Phoenix. The story also only hints at the presence of growing mining operations in the Bradshaw Mountains to the west, each with management hungry for cheaper power and therefore exploring every water course in the region for hydroelectric potential. Finally, this simplified origin of the The Arizona Power Company (TAPCO), so quickly assembled in 1902 by Turner plus Long Beach, California, electrical engineer Iva Tutt and others, breezes past another inspiration associated with Niagara and Sacramento: their hydroelectric operations represented a pioneering and essential assembly of financing and technological expertise. TAPCO and its Fossil Creek venture assembled a modern consortium of remote investors, equipment manufacturers, engineering designers, industrial consumers, and political opportunists. (*EPRI Journal* 1979; Effland and Macnider 1991)

> TAPCO [and its Fossil Creek venture] is but one of at least five hydroelectric generating projects that were planned at the turn-of-the-century to provide power for expanding mining operations in the region [of central and northern Arizona].... Of these enterprises, it was only the Fossil Creek project that succeeded.... (Effland and Macnider 1991:8/3)

The success of Fossil Creek is based largely on its geology (the consistent springs) and geography (its natural drop—without high natural waterfalls—of 1575 feet from the springs to the Verde River). The Childs-Irving project achieved an unusually strong static head pressure through "the high degree of topographic relief that allows for a drop of 1 foot per 1000 feet over a distance of only 11.26 miles," creating a static head of 480 feet at plant "No. 2," Irving, sufficient for one low-pressure generator ideal for powering a Francis turbine. (Effland and Macnider 1991:8/1)

Thus, designers of the Fossil Creek water diversion and distribution system combined proven techniques (dam and flume construction, basic turbine and generator couplings) with new technology (reinforced concrete, steel pipe) in an extremely remote workplace (portable concrete mixers, machinery and prefabricated structures reduced to wagon-sized loads). (Alston 2004)

Power House No. 2 (Irving) Engineering Design

In 1915-1916 the second powerhouse introduced to the successful 1908-1909 Fossil Creek hydroelectric project fulfilled TAPCO's original concept of multiple generation facilities along the watercourse. A series of broad natural terraces below the Fossil Creek dam, at the junction of the creek and the original Childs flume system, allowed assembly of a construction camp and ultimately the housing and maintenance compound necessary for powerhouse operation. At the southwestern extreme of the terraces all characteristics of the second generating unit—lowest elevation, discharge of the 3201-foot penstock, beginning of the Childs flume, and *raison d'être* of the labor force—came to focus on the relatively small powerhouse.

The 25' by 40' foot powerhouse stood on a concrete foundation that secured the steel-pipe penstock discharge into the turbine intake, then directed dissipated water from the turbine into the adjacent outside tailrace (and thence into the Childs flume). The concrete foundation also anchored the turbine, generator, exciter and other equipment. The cast-concrete powerhouse walls—actually an efficient concrete framework with voids filled by large wooden doors—

supported the overhead crane used for initial positioning of equipment, as well as removing and installing component shrouds during maintenance. The use of a simple wood-beam rafter system for the roof in this later powerhouse revealed confident cost cutting over the more expensive steel-truss roofing system utilized earlier at the Childs Powerhouse. The adjacent electrical equipment room originally housed the powerhouse's switches and transformers before the latter moved to outside positions nearby, probably by the 1920s, for safety and maintenance.

Water Wheel, or Turbine

For the low-pressure, 470-foot head available through the 3201-foot penstock at Power House No. 2 (Irving), APCO engineers selected a single turbine of reaction-type radial-flow Francis-design. They purchased this 2100 horsepower Francis water wheel, designed to turn at 900 revolutions per minute, from the Allis Chalmers Company based in Milwaukee, Wisconsin (Effland and Macnider 1991). The turbine was mounted on the Powerhouse floor in a position to accept the pressurized water introduced immediately after an abrupt 90 degree turn in the penstock. By mounting the turbine intake above the tailrace water level, a suction effect was introduced into the turbine housing and additional power was achieved through resulting centrifugal force (a characteristic of the Francis design) (Farlex 2004). The Irving turbine housing featured hinged guide vanes, adjusted in unison by the governor to direct water onto the wheel (impeller) fins (or buckets) to achieve constant speed (900 rpm) to maintain the attached generator's "base load" (60 Hz) (Alston 2004).

Pressure Governance

Water pressure in the Powerhouse was regulated through vanes in the turbine housing, to maintain constant turbine speed (900 rpm), which in turn regulated the generator speed within a specific range to maintain the "base load" at the "frequency" of 60 cycles or Hertz (Hz). Generally, a hydropower governor "senses changes in speed and adjusts the water flow to the runner [or turbine wheel] to correct any deviation from the desired speed" (CanREN 2004).

The Irving turbine employed a Woodward oil-pressure governor, consisting of a cluster of spinning flyballs or flyweights (a development of steam inventor James Watt in 1769), housed in a metal dome atop the governor stand. TAPCO replaced the original Lombard governors in the 1940s after that company closed and spare parts were no longer available (Alston 2004). Gears and a jackshaft from the turbine turned a continuous belt to gears spinning the flyballs' small vertical shaft. Thus the turbine-powered governor, through changes in the flyballs' centrifugal spin, sensed any change in turbine speed and mechanically moved two shafts between a bell crank to open a valve in the base of the governor. The valve introduced pressurized oil from the adjacent reservoir (standing vertically on the Powerhouse floor adjacent to the governor stand) into a cylinder (actuator) below the floor. The actuator then moved a series of connecting rods to adjust the hinged guide vanes in the turbine housing.

> A Francis turbine is controlled by opening and closing the guide vanes which vary the flow of water according to the load. The actuator components of a governor are required

> to overcome the hydraulic and frictional forces and to maintain the guide vanes in fixed position under steady load. For this reason, most [reaction, Francis-type turbine] governors have hydraulic actuators. (Gulliver and Arndt 1991:4.58-59)

The governor stand included a safety mechanism in the form of a "dashpot" that served as an anti-racing device that restored the pressurized-oil actuator/cylinder's "distributing valve" to its neutral position once the governor re-established the desired speed.

Generator and Exciter

The Francis turbine in the Irving Powerhouse was direct-shaft connected to a generator built by General Electric as an alternating current (AC), 3-phase, 60-cycle dynamo running at 900 rpm. The resulting 60 Hz cycle standard, credited to Nicola Tesla as one of his innovations with the Westinghouse Company in the 1880s, was the common link between consumer lights and machinery powered by Childs-Irving. This enduring U.S. standard applied at Fossil Creek from initial operations also contributed to this system's long life as part of the 60 Hz power grid of North America.

The generator's shaft continued to a direct-connection with the "exciter," a small DC generator that created the magnetic, alternating field in the main AC generator.

> The output voltage of an AC generator is controlled by...the strength of [its] DC field.... The DC field voltage produced by the [main, AC] generator...is applied to the stationary field of an exciter. An exciter is a small DC generator which is used for the purpose of providing DC field current to an AC generator field.... This concept permits the use of a [AC main] generator...with a lower control current capability as the exciter acts, in essence, as an amplifier. (Kilowatt Classroom 2004)

The Irving Powerhouse's generator-exciter combination supplied 1600 kilowatts at 2400 volts to an insulated copper bar that carried the current to a distribution bus. The bus in turn supplied current to three transformers, each single-phase 1500 kilovolt Ampere (kVA) units that stepped voltage up to 69000 volts (69 kV) to the transmission lines. Historically, TAPCO customers received this current from transformers stepped back down to 2400 volts, then to 120 volts or 240 volts for lighting and machinery. By 2004, from Childs-Irving and other APS transmission through the North American grid, industrial customers typically received their current from transformers as three-phase 480 volts to 13.8 kV, and residential customers received power from transformers stepping current down to 120/240 volts AC. (Alston 2004)

Water Discharge

After release under pressure from Irving's Francis turbine, water moved through a pipe in the wheel's center 90 degrees down through an expanding-dimension pipe that dispelled the water pressure. Water then flowed into the Powerhouse tailrace in the concrete foundation and into an open concrete-walled tailrace outside the powerhouse, thence a short distance into the Forebay and rock cut leading to the Childs flume. Careful, manual regulation of the open tailrace water level controlled the draft at Irving's Francis turbine and maintained balanced shaft movement through its thrust bearings. A bypass gate in the tailrace wall allowed excess water, beyond capacity of the Childs flume, to be diverted back into Fossil Creek, flowing south just a few feet away, over rocks at the base of the formation terminating the Irving terraces. (Alston 2004)

Irving Powerhouse in Historic Context

Contextual information on other hydroelectric facilities built at the time of Childs-Irving indicates that the Fossil Creek facility's performance stood statistically between many very small projects of the period and a handful of much larger enterprises. One example of smaller operations was the 850 kW generator in Phoenix at Arizona Falls on the Arizona Canal, installed in 1902. The original Arizona Falls operation ceased in 1950, but was revived in 2004 by the Salt River Project with a 750 kW generator reportedly capable of powering 150 modern homes (Phoenix 2004). One example of a much larger operation was the plant of five generators built into the U.S. Bureau of Reclamation's first major dam, Roosevelt Dam on the Salt River 75 miles west of Phoenix, producing 4500 kW by 1909 during its construction. The Bureau of Reclamation completed Roosevelt Dam in 1911 and thereafter increased its generating capacity to 36000 kW, still (in 2004) contributing much energy to the Phoenix Basin power grid (Green Nature 2004).

By comparison, the Childs-Irving Hydroelectric Project first offered 2700 horsepower (1800 kW) when the three generators at the Childs Powerhouse commenced operation in 1909. This output more than met the needs at the time of the United Verde (UV) Mine at Jerome, which initially contracted for 1600 horsepower (1220 kW) to energize its first new electrical mining machinery. Completion of the Irving Powerhouse in 1916 added 2100 horsepower (1600 kW) to the Fossil Creek system, meeting additional mining customer demand during World War I. But this addition also maximized the full potential of the Fossil Creek overall plant, and TAPCO soon added a steam-powered plant at Clarkdale—tied into the existing grid but closer to several mining customers including UV at Jerome—with more than 3500 kW output by itself. (Haffland and Macnider 1991)

The sale of power from TAPCO's combined Fossil Creek and Clarkdale system to customers in the Phoenix Basin throughout the 1920s indicates that about 7000 kW was a substantial output for the region. TAPCO's capacity survived on these urban sales as its large mining customers dramatically scaled back their production after World War I. And Phoenix found a source of electric power to fuel its accelerating population growth even as Roosevelt Dam sputtered for a decade far below its hydroelectric capacity because of an extended drought throughout its surface watershed.

Standardization of the North American electrical power grid by about 1930 (*EPRI Journal* 1979), and commensurate upgrades of the Childs-Irving Hydroelectric Project, ensured that the remote wilderness-spring-fed 60 Hz technology contributed to an ever-expanding national matrix well into the 21st century. Incredibly, the original Childs-Irving water wheels, generators, and much associated equipment, including the water delivery system itself, still functioned in 2004 through excellent maintenance and relatively minor upgrades (Alston 2004). Installation in 2004 of the newest technology at Arizona Falls in Phoenix, achieving 100 kW less output than its 1902 installation, also confirmed that the Fossil Creek system recognized and achieved its greatest capacity from its initial design and equipment, beginning 95 years earlier.

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Historic photograph collection. Historic drawings collection. Historic documents collection. Available through appointment at: APS, P.O. Box 53933, M.S. 3190, Phoenix, Arizona 85072-3933, 602-371-7689.

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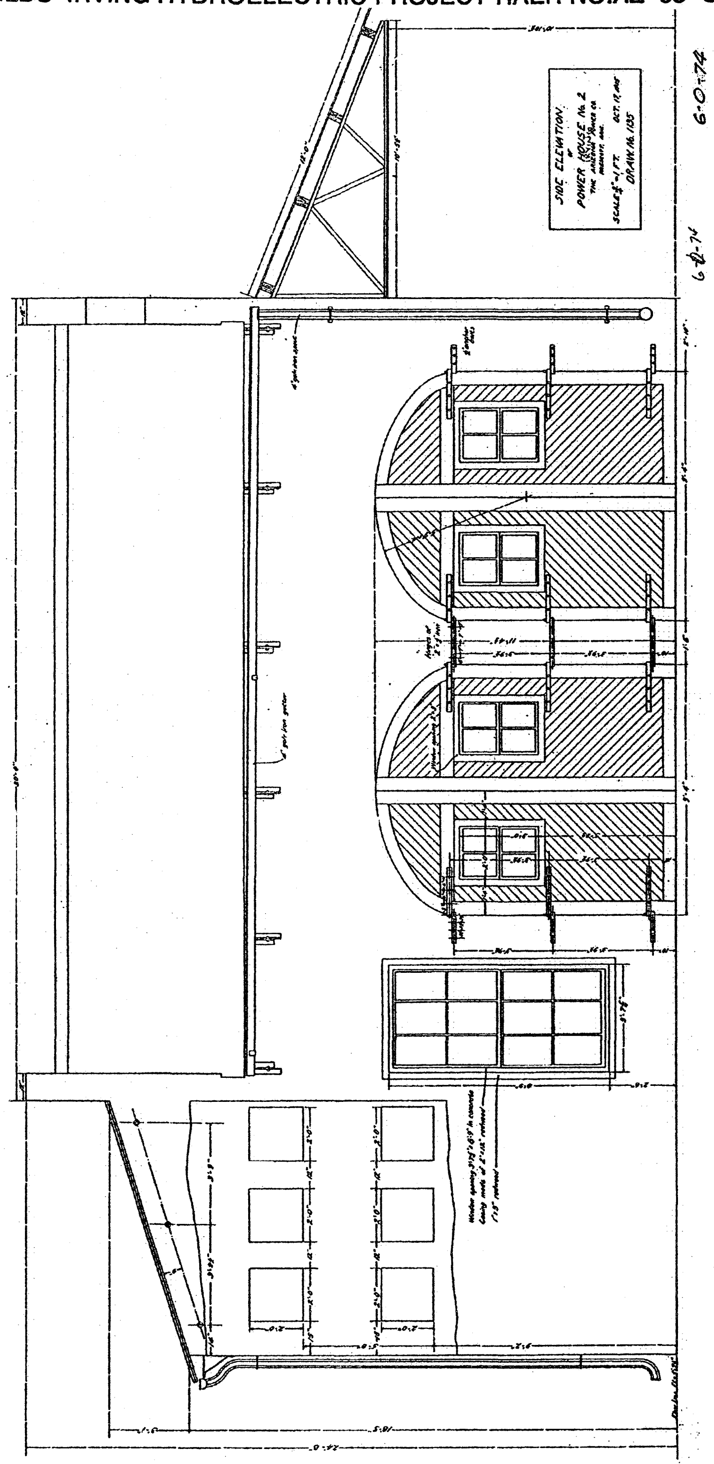
Drawing "Side Elevation of Power House No. 2" 1915:

CHILDS-IRVING HYDROELECTRIC PROJECT HAER NO.AZ-65-G



Drawing "End Elevation Irving Power House No. 2" 1915:

CHILDS–IRVING HYDROELECTRIC PROJECT HAER NO.AZ-65-G