COLUMBIA BASIN PROJECT, GRAND COULEE DAM
AND FRANKLIN D. ROOSEVELT LAKE
(Grand Coulee Dam)
Across Columbia River 1/4 miles southeast
of the town of Grand Coulee
Grand Coulee
Grant County
Washington

BLACK & WHITE PHOTOGRAPHY
WRITTEN HISTORICAL & DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
National Park Service
Cultural Resources
1849 C Street, N.W., Room NC 300
Washington, D.C. 20240
Location: Coulee Dam, Lincoln, Ferry and Douglas counties, Washington
Date of Construction: 1933-1941
Fabricator: Mason-Walsh-Atkinson-Kier, Co. (MWAK); Consolidated Builders, Inc.; Western Pipe & Steel; Pelton Water Wheel Co.; Westinghouse Electric & Mfg. Co.
Present Owner: United States Department of Interior, Bureau of Reclamation
Present Use: Water storage, hydroelectric development
Significance: At the time of construction, Grand Coulee Dam was the most massive structure ever built: construction-plant innovations realized during removal of an unprecedented volume of overburden and placement of an unprecedented volume of concrete established the dam "among the construction classics" and redefined the engineering and construction community's understanding of what was possible, within a given time frame and a given budget.

Construction of the largest thing on earth allowed employment of over 70,000 men and created a stream of manufacture goods, dollars, and jobs that reached 45 states. This immediate employment places Grand Coulee with the major public-works projects of the depression era, representative of a significant new public/private social and economic contract. The unprecedented volume of water stored behind Grand Coulee Dam allows irrigation and cultivation of over half-a-million acres of land, a substantial impact on the economic and social history of the region. By March, 1944, this water volume, run through generators of unprecedented size, established a world's record for electrical production by a single plant in a month's time with a gross output of more than 621,000 kilowatt hours; this output powered Pacific Northwest aluminum plants and other World War II industries.


Project Information: This recording project is part of the Historic American Engineering Record (HAER), a program documenting historically significant engineering and industrial sites in the United States. The HAER program is part of the Historic American Buildings Survey/Historic American Engineering Record (HABS/HAER), a division of the National Park Service. The project was co-sponsored by the Bureau of Reclamation, Lynne MacDonald, Regional Archeologist; the Columbia Cascades SSO of the National Park Service, Stephanie Toothman, Chief, Cultural Resources; and HABS/HAER, Blaine Cliver, Chief. Ann Hubber of Historical Research Associates, Inc. wrote the historical report, and Jet Lowe of the HAER staff completed the large-format photography.
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Section I
Grand Coulee Dam Construction History 1933–1942
INTRODUCTION

On April 26, 1933, Commissioner of the Bureau of Reclamation Elwood Mead advised President Franklin D. Roosevelt that a low dam for development of commercial power could be constructed at the Grand Coulee of the Columbia as a first-stage unit of the Columbia Basin Project. As regional power markets waxed and the nationwide glut of agricultural land waned, this dam would be followed by a superimposed high dam and appurtenant irrigation system. Three months later, on July 27, 1933, construction of a dam at Grand Coulee was formally defined as a federal Public Works Administration (PWA) project, under the authority of Section 202 of the National Industrial Recovery Act. And, finally, on December 15, 1933, 50 indigent local men hired under the auspices of the National Reemployment Service began removing the first of 23,000,000 cubic yards to be excavated from the dam site. Newly appointed construction engineer Frank A. Banks, Bureau of Reclamation, described the project's multiple facets and most immediate purpose:

In times such as these, a project of this character serves to start the wheels of industry, to provide employment for those who are idle in all parts of the country and, as economic conditions become normal, power at reasonable rates will be available for new and expanding industries and homes, with a means of sustenance available for some of those who for the past few years have been dependent upon relief for mere existence.

Mead's April recommendation and the ensuing federal funding and control of the massive Columbia Basin Project followed over forty years of "analytical studies, debates and animated controversy" over the feasibility of reclaiming the Columbia Plateau's arid Big Bend country with water of the Pend Oreille or Columbia rivers.

The Columbia River heads in the mountains of British Columbia, Canada, enters the United States at Boundary, Washington, and meets the Pacific Ocean at Astoria, Oregon on the Washington/Oregon border. In its 400-mile run through Washington, the river drops over 1,000 feet, a rapid descent strengthened by an extreme floodwater volume of almost 500,000 cubic-feet-

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2 F. A. Banks, "Columbia Basin Project is Described by Construction Engineer," Southwest Builder and Contractor, November 23, 1934, p. 9.

per-second (cfs) downstream of the Spokane River and 1,000,000 cfs downstream of the Snake. And yet much of the country through which this water flows is arid, screened from western Washington rains by the Cascade Mountains rain shadow and seemingly blocked from affordable and technologically feasible irrigation by the precipitous canyon that the Columbia cuts around the "Big Bend" country of east-central Washington (Figure 1).

The Big Bend is bounded to the north, west, and south by the circuitous course of the river, from its westward turn from a south-bound trajectory at the confluence with the Spokane River, to a brief northward turn at the confluence with the Grand Coulee, to its swing south-southeast from Pateros to Pasco where it is joined by the Snake and continues in a more orderly manner west through the Columbia Gorge to the Pacific. Deep and fertile sandy loam overlays much of the plateau's 12,780 square miles of land; deprived of water, the soil supports sage, mixed grasses, and an occasional crop of dryland wheat. Those who advocated Big Bend irrigation hoped instead to raise the more-profitable irrigated specialty crops of fruits, sugar beets, and truck produce, and to witness, and profit from, the rise of the towns that would inevitably follow and support the farmers (Figures 2 and 3).

The Grand Coulee that opens over 500 feet above the bed of the Columbia was central to one of the two primary irrigation schemes proposed for the region. This hanging valley, marking an ancient flood path of glacial Lake Missoula, is 4 miles wide, bordered to the north, east, and west by cliffs approaching 900 feet, and extends south for 50 miles through the Big Bend. In 1892, editors of the Coulee City News first proposed a plan by which the Columbia River would be dammed, and its water diverted to the coulee from whence it would be delivered by canal and feeder ditch to 1,200,000 arid acres (Figure 4). Soon thereafter, Laughlin MacLean of Spokane, Washington introduced a competing plan by which over 2,000,000 acres at the southern and eastern extremes of the Big Bend and neighboring Palouse region would be irrigated by gravity flow from the Columbia, Spokane, or Pend Oreille rivers.

* Within the United States, only the Mississippi River exceeds the Columbia River in volume. Although maximum recorded flow at the Grand Coulee Dam site is 489,000, the river is thought to have approached 725,000 cfs during the flood of 1894 ("Can the Columbia Be Controlled?", Earth Mover, June 1937).


* Memorandum, Mead to Secretary of the Interior, December 27, 1934, Folder: Columbia Basin Project, Board and Engineering Reports on Construction Features, July through December 1934, Box 527, Decimal Classification 301, Project Correspondence File 1930-1945, RG 115, NARA-Den.

* Pitzer, Grand Coulee, pp. 6-10. The technological evolution of the "pumping plan" (as the Grand Coulee proposal came to be known) and the "gravity plan" (as the Pend Oreille storage and canal proposal came to be known); the series of state- and federally funded studies; the acrimonious debate between competing interest (continued...)
By 1926, after considerable study and modification of the original proposals, officials with the Bureau of Reclamation reported publicly that while "the time will come when local and national interests will require the construction of [Columbia Basin Reclamation] works, and the utilization of these immeasurably valuable resources . . . this time has [not yet] arrived." Privately, BOR Chief Engineer R.F. Walter argued that "the [Columbia Basin Reclamation] project must unquestionably be deferred for a very long time and the work to date has already covered the essential features of the project sufficiently to indicate its difficulties and probable costs."

By 1929, however, the Bureau of Reclamation (burdened by over-budget reclamation projects and bankrupt farmers unable to repay the cost of reclamation) was actively promoting construction of "multiple use" dams, whereby revenue from the sale of hydroelectric-power would cover part of the cost of reclamation (Figure 5). Concurrently, Major John S. Butler of the United States Army Corps of Engineers ( Corps) concluded that the Grand Coulee pumping plan was preferable to the Pend Oreille River gravity plan and that power sales would produce revenue "sufficient to return with interest the cost of the dam and power plant over a 50 year period (Figures 6 and 7)." The Bureau of Reclamation agreed, noting that groups; and the evolution from state funding of construction costs, to a state-federal partnership, to federal funding are not addressed in this construction history. Please see Pitzer, *Grand Coulee;* William D. Miner, *A History of the Columbia Basin Projects;"* (unpublished Ph.D. dissertation, Indiana University, 1950); Bruce Mitchell, *Flowing Wealth: The Story of Water Resource Development in North Central Washington, 1870-1950, Wenatchee Daily World,* March 6, 1967; Michael James Schulthesis, *The Struggle for Grand Coulee Dam — Beginnings* (unpublished master's thesis, Gonzaga University, 1961) for a detailed discussion of the early history of the Columbia Basin reclamation project. Federal reports relative to the Columbia Basin are cited and briefly described in the annotated bibliography that concludes this report.

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preliminary studies . . . indicate that if the power can be absorbed at the rate of 100,000 kilowatts per year, the revenue from sale of commercial power . . . would be sufficient to repay the cost of the dam with interest within 50 years and leave sufficient surplus revenues to repay a very substantial part of the cost of the initial irrigation development. . . . It appears that the output of the proposed installation of 1,575,000 kilowatts at the Grand Coulee power plant could be absorbed by the power market within economic transmission distance within 15 years.12

In 1932, the Bureau of Reclamation prepared preliminary plans for the "highest possible dam producing maximum power" at the Grand Coulee site — a dam 350' high with two power plants producing a combined 1,575,000 kilowatts and a pumping station to lift water from the 150-mile-long reservoir (Lake Roosevelt) to the Grand Coulee storage basin/equalizing reservoir. Including the irrigation and power distribution systems, project costs were estimated at $400,000,000. The Bureau of Reclamation would construct the project for the state, for which it would be reimbursed over a 50-year period (Figure 4).13

Immediately on the heels of this temporary victory for pumping-plan proponents, the Great Depression dramatically changed the project's cost-benefit equation. First, growth of the power-market — fundamental to the economic feasibility of the project — stalled. Second, newly elected president Franklin Delano Roosevelt approved and the Public Works Board granted $31,000,000 to the U.S. Army Corps of Engineers for initial design and construction of a navigation and power dam on the lower Columbia River at Warrendale, Oregon (Bonneville Dam), further saturating the power market. Finally, Arthur Hyde, Secretary of Agriculture (in company with the Washington State Grange and the Farm Journal), argued that

[Agricultural plant] surpluses are at once the cause of low prices and our farm problem. . . . We need to reduce our present cultivated acreage by probably thirty or forty million acres. . . . The market is glutted with farm lands at depressed prices. There are no takers. It is plainly and indisputably against the interests of the farmers of Washington and of the adjoining States to undertake a project that would bring into production 12,000 more farms. . . . No farmer of the Northwest would, in his right mind, urge the Nation to undertake something that would add to already burdensome surpluses, depress prices of his products, reduce the value of his land, threaten his economic security, and lift huge sums out of the United States Treasury for the avowed purpose of agricultural expansion in an era when precisely the opposite policy is called for.14


12 "Grand Coulee Dam to Start Early in 1934," Pacific Constructor, August 19, 1933, p. 6; Pitzer, Grand Coulee, pp. 63-64.

13 Arthur Hyde, Secretary of Agriculture, to the Board of Engineers for Rivers and Harbors, War Department, January 30, 1942. See also "Columbia Basin Folly" (editorial), The Farm Journal, April, 1932, V. 56, No. 4, p. 10 (continued...)
The economic depression, however, also dramatically increased the need for employment opportunities. President Roosevelt demurred on support of the $400,000,000 high dam and appurtenant irrigation works, suggesting instead a more modest low-power dam, with "less initial outlay and less power to be absorbed in the market," while still providing immediate construction jobs for as many as 12,000 local men. The high dam, allowing development of the irrigation program and of large blocks of commercial power, would be developed later.\(^\text{15}\)

On April 26, 1933, after soliciting comment from BOR Chief Engineer R. F. Walter and Chief Design Engineer John L. (Jack) Savage, Mead reported that the Bureau could build a dam 145' high, with one power plant, for $60,000,000. Thus a project initially proposed (and most actively supported) by irrigation interests had been redefined, first as a maximum-yield power/irrigation project, and second as a low-power, make-work project "useful... for the immediate employment and materials and equipment market that they create."\(^\text{16}\)

Although continuing to maintain that "no development of the land and water resources of the arid region equals this in importance and in the beneficial results which would come," Mead defended the President's decision and his agency's new project: "there is not at present a demand for these farms or for the crops to be grown on them."\(^\text{17}\) On July 6, 1933, the Bureau of Reclamation and the Columbia Basin Commission, acting on behalf of the state of Washington, signed a contract whereby the Bureau would initiate $377,000 worth of preliminary work (including plans and survey), to be paid for from the state's $10 million relief fund. Cheered by over 5,000 people, and despite uncertainty over additional funding, the Columbia Basin Commission held ground-breaking ceremonies at the dam site on July 16. Eleven days later, the Public Works Board appropriated $63,000,000 for low-dam construction and on November 1, the state of Washington relinquished control of the project to the Department of the Interior/Bureau of Reclamation. On December 15, 1933 — prior to conclusive foundation studies and in the absence of a final dam design yet "in order to expedite the work to furnish early employment" — Goodfellow Brothers of Wenatchee, Washington, subcontractor under David H. Ryan, begin


excavation on the west side of the river, clearing overburden from the granite bedrock abutment of the "First-Stage Low-Dam.”

**FIRST-STAGE LOW-DAM:**
**BUREAU OF RECLAMATION SPECIFICATIONS NO. 570**

Drawing on "nearly six years of intensive research and study in connection with Boulder [Hoover] Dam," Bureau engineers in the Denver main office and at research laboratories in Fort Collins, Colorado experimented with 15 Grand Coulee dam designs, striving for a "safe and at the same time economical . . . structure" (Figure 8). Their task was complicated by diversion and care of the Columbia River — the "most difficult engineering feat to be encountered" in construction — and by the unique economic and political concessions stipulating that the initial dam be superimposed by a subsequent structure, raising the dam to an ultimate height of 370' and an ultimate length of 4290'. On December 1, 1933, Mead announced that Bureau engineers had concluded that they could not safely raise any of the hollow-core multiple-arch designs studied to

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The Columbia River runs north at the dam site, a direction counter to its predominantly south and west run to the Pacific (and a direction largely masked by the complicated and circuitous road network to the site). "Left" and "Right" directional clues are given looking downriver (i.e. the Right Powerhouse is constructed on the east bank).

Memorandum from Chief Designing Engineer J. L. Savage to Chief Engineer, re expedited program and winter program - Grand Coulee Dam, December 1, 1938, Folder: Columbia Basin, Dams and Reservoirs: Grand Coulee Dam, 1938, Box 535, Decimal Classification 301, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.

Jacob E. Warnock, Hydraulic Research Engineer for the Bureau of Reclamation, reported that "by the time the design and construction of the Grand Coulee Dam had been assigned to the Bureau of Reclamation, the practice of using hydraulic models as an aid in . . . design . . . was well established," having first been used in 1930 on the Cle Elum Dam, Yakima Project. At Grand Coulee, 1:15, 1:40, 1:120, and 1:184 full and partial scaled models constructed in Denver, Fort Collins, and Montrose laboratories informed design decisions re: scour at the toe of the overflow spillway, transverse wave and pool action; erosion of river bed; design of spillway training walls, crest, and drum gate; and river diversion. See "Models Guide Work on Western Dams; Found Indispensable in Design and Construction of Dams at Grand Coulee and Fort Peck," *Civil Engineering*, November, 1936; Jacob E. Warnock, "Experiments Aid in Design at Grand Coulee Dam," *Civil Engineering*, November, 1936, both in Folder: Columbia Basin, Dams and Reservoirs, Grand Coulee Dam, May 1935-December 1936, Box 535, Decimal Classification 301.1, Project Correspondence File 1930-1945, Columbia Basin Project, RG 115, NARA).

Press Release, 12/17/1936, File: Correspondence re Construction of Coffer-Dams, Box 538, Columbia Basin Project, Project Correspondence File, 1930-1945, Decimal Classification 301.14, Entry 7, RG 115, NARA-RMR.
date and were instead concentrating on more-expensive "gravity-type dam sections" upon which a subsequent dam could be securely appended.\footnote{Anonymous, "Report of a conference held at the office of the Bureau of Reclamation, Denver, Colorado, December 2nd and 4th, 1933, concerning the Grand Coulee Project," n.d. (received Feb. 14, 1934), Folder: Col. Basin, Board and Engineering Reports, January 1, 1933-June 30, 1934, Box 527, Decimal Classification 301, Columbia Basin, RG 115, NARA-Den; Pitzer, Grand Coulee, p. 78.}

On April 20, 1934 the Bureau issued invitations to bid on Specifications No. 570, a 145' concrete gravity dam. Plans for the diversion and care of the river were to be left to the contractor, subject to Bureau review and approval. Mason-Walsh-Atkinson-Kier (MWAK; Francis Donaldson, Chief Engineer), a four-company conglomerate, submitted a low bid of $29,339,301.50 and received official notice to proceed on September 25, 1934. Manley Harvey Slocum, "popular with working men . . . [yet with] little more than an eighth grade education and a troublesome penchant for heavy drinking" served as MWAK's construction superintendent: Slocum "knew how to build big things."\footnote{Silas H. Mason, Inc., Walsh Construction Co., Guy F. Atkinson Co., and the Kier Construction Co, composed MWAK. Six Companies of Washington, Inc. (affiliated with Six Companies, Inc., builders of Boulder [Hoover] Dam) submitted the unsuccessful high bid of $34,555,582. Pitzer, Grand Coulee, pp.99-101.}

Only three months later, the Bureau of Reclamation (in accord with many of their detractors and in resolution of an ongoing debate) concluded that the low dam was justified only as an economic-relief measure (with an indefensible man-hour to cost ratio). Mead and Walter further argued that the depth to bedrock and size (length) of the dam were both "too great in proportion to the head developed and . . . the cost involved in auxiliary features . . . [was] practically as much for the low dam as for the high dam; that the protracted drought had resulted in a mass exodus of farm families to the West, increasing the immediate need for reclamation of the Columbia Basin; that the hydraulic machinery in the power plant would of necessity be an uneconomical and unhappy compromise between the low and high head considerations; that construction of the high Grand Coulee dam, power plant, pumping plant, canals and laterals would provide employment for a "large number" of workers; and that the construction joint between the low and high dam had proved a "major engineering problem."\footnote{Mead to R. K. Tiffany, Executive Officer, Washington State Planning Council, September 19, 1934, Folder: Col. Basin Eng. Gen, Oct. 1931-Sept. 1934, Box 415, Decimal Classification 791, Office of the Chief Engineer, Denver, Colorado, General Correspondence Files 1902-1942 (Engineering), Columbia Basin, RG 115, NARA-Den; Mead to Senator Clarence Dill, quoted in "Power, Navigation and Irrigation in Two Projects on the Columbia," Engineering News-Record, November 29, 1934, p. 682; Walter to Mead, December 15, 1934, File 301, Columbia Basin, Board and Engineering Reports on Construction Features, July through December 1934, Box 527, Project Correspondence File 1930-1945, Columbia Basin Project, RG 115, NARA.}
Certainly, Mead had never fully supported the low-dam proposal (confessing that "I am not entirely happy at the change in plan. . . . I realize that we do not need the agricultural products at this time, but I believe we will in the near future. . . . It is a disappointment, therefore, to have the fruition of this dream indefinitely delayed"), nor had James O'Sullivan, Rufus Wood, Senator Clarence Dill, and other vocal supporters of the irrigation plan who had continued to argue for the greater social and economic benefits of the high dam. Moreover, the drought and depression had worsened, weakening the protests of the agricultural community while dramatically increasing the appeal of increased employment opportunities and raising the budgets, the stakes, and the public expectations of public-works projects.  

The Bureau's private correspondence reveals less hint, however, of substantial concern over the safety of the construction joint between the dams and little hint of the weight of this engineering concern in relation to the economic and political justification for construction of the irrigation project. As late as March 1934, Bureau engineers had reported that "in our opinion there is no doubt whatever that the enlargement, as contemplated, is an entirely feasible engineering undertaking." In December 1934 memoranda to the Secretary of the Interior, Mead and his chief engineers urged construction of the high dam yet failed to mention construction difficulties associated with two-phase construction.

Editors of Engineering-News Record effectively placed the engineering concerns within the larger context of a public-works "blunder," arguing that while the technical difficulties might be surmountable, the risk could not be justified in the face of the larger economic folly:

When construction of the Grand Coulee power project . . . was undertaken more than a year ago, immediate re-employment was the dominant objective and the details and purpose of the project were given little thought. . . . As the facts are coming to be better understood, they rank Grand Coulee . . .

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*a* Elwood Mead to Roy R. Gill, Chairman, Executive Committee Columbia Basin Irrigation League, August 27, 1933, Folder: Columbia Basin Board and Engineering Reports, January 1, 1933-June 30, 1934, Box 527, Decimal Classification 301, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.


"As contemplated," the design involved "the adoption of a downstream slope of the small dam of practically seven to ten . . . to be made coincident with the direction of the principal stress in the high dam under full water load . . . because along this plane no shearing stresses exist" (Morse et al. to Walter, March 31, 1934).

*b* Elwood Mead, J. L. Savage, L. N. McClellan, S. O. Harper, W. H. Nalder, B. W. Steele, to Secretary of the Interior, December 21, 1934; Mead to Secretary of the Interior, December 27, 1934; both in Folder: Columbia Basin Project, Board and Engineering Reports on Construction Features, July through December 1934, Box 527, Decimal Classification 301, Project Correspondence File 1930-1945, RG 115, NARA-RMR.
definitely as the prime blunder of the public-works campaign. . . . The present Grand Coulee dam is not the one that was under study for years as part of the Columbia Basin irrigation project. . . . In short, the Grand Coulee project as it stands today is an economic error of first magnitude. And further, because of the mistaken decision to build the low dam, it is complicated by technical doubts not easily dismissed. . . . Raising [of the low dam], an operation of unprecedented dimensions, goes well beyond the range of recognized engineering procedure. While technical skills may overcome them, as it has overcome many other grave difficulties, yet the hazard of the operation is one that should not needlessly be assumed.27

On June 7, 1935, the Bureau and MWAK signed Change Order No. 1 "setting aside the original plans for a first-stage, or low-dam development, and in lieu thereof, authorized a contract for construction of the foundation for the high-dam and power plants." Change Order No. 1 stipulated completion of foundation excavation and river diversion; concrete placement to a maximum elevation of 1010 in the abutment sections and to elevation 945 in the spillway section; and powerhouse foundations to elevation 948. MWAK completed Change Order No. 1 on March 21, 1938 and turned the foundation over to new contractor Consolidated Builders Inc., composed of MWAK, Six Companies Inc., contractor on Boulder Dam, and General Construction Co., contractor on Owyhee Dam.

Atop this foundation, Consolidated Builders Inc. would construct a straight, concrete-gravity central-overflow-spillway dam, 4,200' long, 550' high, 500' wide, composed of over 10,000,000 cubic yards of concrete. Sufficient concrete, BOR publicists said, to build a paved highway, 16' wide, from coast to coast (twice): the "Biggest Thing on Earth," "Larger than the Great Pyramid," "The 9th Wonder of the World." It became a source of both employment and carefully orchestrated public inspiration during a time of economic chaos and social disorder (Figure 9). Congressional passage of the Rivers and Harbors Act (Public Law No. 400, 74th Congress, H.R. 6732) formalized reclamation policy uniting power development with irrigation. It also "validated and ratified all contracts and agreements heretofore executed at Grand Coulee," assuring the legality and promising the continued funding of the $400,000,000 project.29

In the months prior to the change order, despite and in disregard for the continued private and public debate over final dam design, the Ryan Excavation contract continued, Lynch Brothers of


Seattle initiated core drilling at the foundation, and Rumsey and Company continued with testing of the area's gravel deposits. Assorted other contractors worked to bridge the Columbia River, to construct a water supply, to build two cities — one for government engineers, one for MWAK crews — to construct a haulage railroad from the Great Northern line at Coulee City, and to plan and construct trestles, gravel screening facilities, and other construction plant. The politically and economically significant change from development of a low-head power project to construction of a massive high dam meant little to those engaged in the on-going construction effort. The low dam had simply been redefined as a foundation; the process of, and difficulties associated with, overburden excavation and river diversion and care remained unchanged. From a design perspective, the change was momentous: Bureau of Reclamation engineers were charged with designing a massive monolithic concrete structure of unprecedented proportions while realizing "maximum economy compatible with entire safety." Upon completion of the final design, Chief Engineer Savage assured his construction engineer that

Specifications no. 757 covering the construction of Grand Coulee Dam are, I believe, the best-considered specifications for a major dam that the Bureau, or any other organization, has prepared to date. These specifications utilize all of the comprehensive knowledge and data acquired from the Boulder [Hoover] project and, in addition, the most searching consideration has been given in their preparation to the fundamentals of safe design and construction (Figure 10).

Work on the eight-year project proceeded in clearly defined stages, most identified as separate cost items within Specifications No. 570 (foundation) and Specifications No. 757 (high dam, power plant, and pumping station). Prior to cofferdam construction/river diversion, and as an immediate make-work measure, laborers under Specifications No. 557 cleared 2,000,000 cubic yards of unwatered, upper-elevation overburden from the east and west abutments. Core drilling and exploration and study of the quality and quantity in the Brett gravel pit proceeded apace with

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32 Memorandum from Chief Designing Engineer J. L. Savage to Chief Engineer, re expedited program and winter program - Grand Coulee Dam, December 1, 1938, Folder: Columbia Basin, Dams and Reservoirs: Grand Coulee Dam, 1938, Box 535, Decimal Classification 301.1, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.
dam design. Through 1937, cofferdam construction, excavation, foundation preparation, and concrete placement in the unwatered abutment areas dominated construction. On March 21, 1938, one year and 12 days ahead of schedule, MWAK completed Change Order 1. Concrete placement by new contractor Consolidated Builders, Inc. defined 1938-1939. Spillway, powerhouse, and pumping station construction was initiated and completed between 1939 and 1941. Finally, on June 1, 1942, during the peak of flood season, the Bureau of Reclamation staged a massive waterfall over the spillway, witnessed by an estimated 15,000 people and presented to the nation over a "coast-to-coast" radio broadcast.33

During the course of this construction, for the duration of the Great Depression, approximately 72,000 men found work at an average pay rate of $.86 per hour or $1,672 per year (Figures 11 and 12). As stipulated by the National Industrial Recovery Act, first preference in employment was given to qualified ex-service men with dependents; second preference to residents of the immediate project area; and third preference to residents of the state. This supply of labor proved "generally adequate" although "on occasion it was necessary to extend calls into neighboring states." Hours were worked in 7-hour shifts, run around the clock, with the remaining 3 hours of the day reserved for work inspections, equipment repair, and as insurance against overtime pay. These men, many with their families, lived in a scatter of makeshift construction camps or in MWAK's official company town, Mason City, located at the east abutment, on the other side of the river — and the other side of the tracks — from carefully designed, crafted and landscaped "Engineer Town" (Coulee Dam). Seventy-four men died between September 1933 and December 1941. Their deaths are tallied, but not described, in the Bureau of Reclamation's annual project reports, concluding in 1941 with a blunt assessment of the public benefits and the personal risk: "one fatality for every 776,438 man-hours worked or 1 fatality for every $1,944,926.68 spent."34

Manufacturing jobs throughout the nation were added to the economic benefits of direct employment at the dam site. By 1939, the BOR estimated that

six eastern states . . . sold from a million to three and a quarter million dollars' worth of goods to the project; Minnesota and New Jersey sold nearly a million each; Iowa nearly half a million; and nine other States over two hundred thousand each. Three western states were large beneficiaries,


California through oil sales, Washington and Oregon by selling timber, and all three through their agencies for eastern manufacturers."

**EXCAVATION TO BEDROCK**

Given the volume and length of the proposed Grand Coulee Dam, the suitability and strength of the foundation was of critical concern. An arched design, by which much of the total water load is carried to the abutments, was not "economically possible" at the Grand Coulee Dam site, where 4300' of river canyon divided the east and west abutments. All of the water load would be carried to the base of the structure."

Between September 1933 and March 1934, Bureau of Reclamation contractors completed 45,000 linear feet of core drilling, developed "several" test shafts and trenches, and, under agreement with the U.S. Bureau of Mines, completed bedrock exploration, using electrical resistance readings for measurement of depth to bedrock. They found a fine-grained, "almost white to somewhat pinkish" granite and a coarser-grained, more massive granite, standing in what seemed to be almost vertical sheets confined to narrow lines of movement, and presenting a remarkably level surface. BOR consulting geologist Charles P. Berkey concluded that this granite floor was "eminently capable of carrying . . . a great masonry structure of virtually whatever height other considerations may dictate" and placed the depth to bedrock at 60' to 170' below the normal low-water level of the river.

An estimated 21,000,000 cubic yards of sandy silt, residuary river drift, and terraced gravels comprised these 60' to 170' of overburden (Figure 13). All would have to be excavated from the deep canyon prior to concrete placement and most displayed a tendency to slump when oversaturated, undercut, or subject to moderate changes in load or removal of normal support:

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3 Memorandum from Chief Designing Engineer J. L. Savage to Chief Engineer, re expedited program and winter program - Grand Coulee Dam, December 1, 1938, Folder: Columbia Basin, Dams and Reservoirs: Grand Coulee Dam, 1938, Box 535, Decimal Classification 301.1, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.


once disturbed [the ultra-fine rock-flour glacial silt ground by the ice sheets] is unstable on any slope steeper than 4 to 1 even when comparatively dry. . . . When moistened and disturbed the material takes on the consistency of axle grease. When dry and pulverized it forms an impalpably fine dust. 

This tendency to slide would haunt excavation, cofferdam-construction, and tailrace-channel development, lending weight to construction engineer Bank's assessment that "the vast amount of excavation that must be done and the task of diverting the river," defined the "major and unusual" problems associated with Grand Coulee Dam construction. 

Like river diversion (see below), Bureau engineers defined overburden excavation and the danger of slides as "a real construction problem" yet of insufficient consequence to threaten the feasibility of the project: "after the excavation is completed and the dam established, it ceases to be of serious moment as far as the main structure is concerned." Methods of overburden removal (and, similarly, cofferdam construction), were thus largely the concern of the general contractors and their insurance underwriters.

Following award of the contract for low-dam/foundation construction (and in rejection of the expected and traditional truck-haul operation), MWAK construction engineers designed a large (60"), high-speed (620' per minute), large-volume (2500 cy per hour) belt conveyor, equipped with four- and five-yard electric shovels and 10- to 24-yard dump carts. Three to five tributary conveyors converged at a central hub where a surge feeder discharged the accumulation of "muck" into the main conveyor (Figure 14). Placed in operation on December 13, 1934, the conveyor system ran to a spoil dump in Rattlesnake Canyon, 425' higher and 1 1/4 mile east of the damsite. Work proceeded under huge floodlights, at a 24-hour average excavation rate of 52,000 cubic yards. By 1935, over a million cubic yards had been relocated and headlines proclaimed: "A Mountain has been Moved a Mile." 

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9 Grant Gordon, Associate Engineer, U.S.B.R, "Freezing Arch Across Toe of East Forebay Slide, Grand Coulee Dam," n.d., CB510.00, Engineering & Research Center Project Reports 1910-1955, Box 319 (old box 356-357), RG 115, NARA-RMR.

48 F. A. Banks quoted in "Can the Columbia Be Controlled?," Earth Mover, June 1937.


The short haul and gentle grade on the east side of the dam site facilitated overburden removal: a 30' roadway was located on a uniform 5 percent grade. over which a fleet of trucks hauling material approximately (continued...)
First in January, then March, then April, and again in November 1934, the overburden confirmed its tendency to slump, with extensive slides on both sides of the river. By 1936, contractors had relocated the railroad and highway, had excavated an additional 1,000,000 cubic yards of unstable overburden, and had dewatered the west forebay and tailrace slopes through a series of drainage wells and shafts.

Of equal concern was the east-side slide initiated in March, 1936 (Figure 15). Protected by the east-bank cofferdam, MWAK had exposed bedrock to elevation 850, had completed excavation of the tailrace slope, and had excavated the forebay slope to elevation 900. Here, conforming to test-drill results, they found a long narrow gulch, parallel to the river near the axis of the dam, that extended 120' below the average bedrock level. Soon after crews exposed bedrock in the bottom of the gulch, a large portion of the forebay slope gave way and slid to a slope of 2:1. When work at the site resumed in August (after the standard flood-water hiatus), the 200,000-cy slide resumed, at an average rate of 2' per hour. Excavation within the east-bank unwatered zone while the slide remained active "invited disaster"; to flatten the forebay slopes until stable would be expensive and time consuming; and the dispersed nature of water seepage precluded drainage.

Faced by this "critical emergency," BOR engineers "achieved an unprecedented solution" (or "expedient") that allowed continued construction at a tolerable cost. Drawing roughly on the method of F. H. Poetsch of Prussia, who had used frozen earth in sinking deep shafts, Bureau engineers erected an ammonia-brine refrigeration system in a galvanized sheet-iron building constructed above the slide (Figures 16 and 17). Using an existing concrete-arch dam and timber-crib support (constructed by MWAK when they reached bedrock and overrun soon thereafter by the slide) as a base, engineers defined an "arch" of earth through placement of 3" freezing coils. Between August and September the earth was frozen, restraining the sliding material long enough

"(...continued)
4,500 feet upstream to the spoil dump.


4 BOR, as quoted in USD1 BOR, Press Release, December 7, 1936, Folder: Columbia Basin, Dams & Reservoirs, Grand Coulee Dam, May 1935-December 1936, Box 535, Decimal Classification 301.1, Project Correspondence File 1930-1945, Columbia Basin Project, R.G. 115, NARA-RMR.

4 "No criteria existed from former frozen arches. The only information available about similar operations was meager and offered little that could be used (" Grant Gordon, Associate Engineer, U.S.B.R, "Freezing Arch Dam Across Toe of East Forebay Slide, Grand Coulee Dam," n.d., CB510.00, Engineering & Research Center Project Reports 1910-1955, Box 319 (old box 356-357), NARA-RMR."
to remove the desired overburden and to place concrete to sufficient height to protect the dam from subsequent slides. In April, 1937, following record-breaking concrete-placement efforts during low water, the ice plant was removed and the void between the slide and the east abutment filled "as an assurance against further hazard from the slide."\(^47\)

Against the cost of the frozen arch, the Bureau credited a direct savings of $30,000, associated with removal of a minimum of 30,000 cubic yards — "a small fraction of what would certainly slide" — and estimated total savings in time and excavation at two months and $200,000. Despite the economic victory, Bureau engineer Grant Gordon was cautious about defining the dam as a significant construction method: "It is difficult to imagine a duplication of conditions which would ever make a scheme exactly like this feasible again. Its interest then, lies chiefly in its being unique."\(^48\)

**ITEM 1, SPECIFICATIONS NO. 570: "DIVERSION AND CARE OF RIVER"**

United States Geological Survey (USGS) river readings, taken between 1913 and 1933 revealed that the Columbia River at the dam site normally varied in flow from 17,000 to 500,000 second feet, a volume that prevented construction of diversion tunnels (as at Boulder and Shasta dams). The river had to be diverted through open channels of ample size to pass the maximum anticipated floodwater. Maximum volume could be anticipated during May to August, with peak flows in June; between September and April, the river rarely exceeded 100,000 cfs. Prior to diversion of the river and unwatering of the foundation, this seasonal schedule defined the parameters of dam construction.\(^49\)

Dismissing construction of a new river channel as needlessly expensive, and after consultation with Bureau and consulting engineers, MWAK construction engineers proposed four cofferdams, constructed in three stages and designed to "turn ... [the river] to one side of the canyon for the construction of half the dam and then diverting [it] ... back through openings left in the dam, for construction of the other half."\(^50\) The first cofferdam, an 800' wide, 115' tall cellular steel-sheet structure running for 1/2 mile parallel to the west bank of the river near the low-water line, unwatered 9,000,000 cy and 68 acres at the west abutment. The smaller cofferdam on the east bank of the river, constructed first of earth (1934-1935) and then of timber, was of sufficient height and strength to unwater the east abutment for nine months of the year, or until the river discharge reached 200,000 second feet and compelled abandonment of the excavation area.

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\(^{48}\) Gordon, "Freezing Arch Across Toe of East Forebay Slide, Grand Coulee Dam."


During the final diversion stage, two cross-channel dams forced the river sharply west just upstream of the dam, where it flowed through four slots left in the west abutment of the dam before returning to its course (Figure 18).11

On January 1, 1935, MWAK crews drove the first sheet piling of the west-side cofferdam, "therewith beginning construction of the greatest, or at least the largest, river control structure thus far undertaken by the construction industry" (Figure 19).12 Although construction techniques varied slightly between the ten distinct cell groups (A-J), the cofferdam was generally of steel construction, cross-tied to timber framing with steel rods. Gravel, taken from excavation operations at the west abutment and conveyed to the cofferdam by shuttle conveyor, filled the circular 40' space between the front and back walls of each cell (Figure 20). Cell groups E and F were permanent, constructed of concrete and ultimately incorporated within block 40 of the Grand Coulee Dam. Cell group "clusters" D and G would tie to the cross-river cofferdams.13

To construction engineers and the men charged with cofferdam construction, size translated to a variety of problems, including transport of 18,000 tons of steel to the dam site prior to completion of the construction railroad and driving of 3,000 linear feet of steel pile to bedrock, through non-receptive compact glacial till.14 Surprised by the difficulty of reaching bedrock, and racing cofferdam completion prior to May floodwaters, MWAK modified their original construction plan to include use of four pile drivers, rather than one, at each of the 10 cofferdam cell groups. A tower gantry with 70' base, sufficient to span the cell structure, was supported on trestles constructed on either side of the cofferdam. This gantry provided full coverage via two movable 36" I-beams that spanned the structure and carried geared trolley hoists from which McKiernan-Terry pile hammers were suspended. Although "the tower gantry improved efficiency about 50 per cent and decreased the cost as compared with single hammers handled by long-boom hoisting rigs" the refusal point through the compact till remained at 40' to 65', considerably above bedrock. To provide adequate drainage and prevent excessive saturation of the clay, fifteen wells (paired with electric pumps) were constructed at 100' intervals along the inner berm.15 Forced to improvise more dramatically at the "river section" of the cofferdam (cell-group E), MWAK engineers modified the original construction plan to provide


a berm about 60 ft. wide between the inside of the coffers of the river section and the face of the excavation for the permanent concrete to be poured in the west cofferdam. . . . To accomplish this result a type of construction was used which required the placing of vertical needle beams with a three-segment timber arch between them. The essential feature of this design is that it will hold back the pressure of the material behind and allow prestressing of the supporting members of the pit while preventing any movement of the material. The method had been used previously in New York subway construction.  

High water came two-weeks early in 1935 and its peak of 344,000 cfs in June was 32' higher than normal. It found the clay as difficult to penetrate as had the piledrivers; save for a slow seep of 200 to 600 gallons per minute, removed by pump, the cofferdam held.  

One year later, in August 1936, MWAK crews began construction of the rock-filled timber-crib cross-stream cofferdams. Sections of dam were constructed on shore, floated into place and sunk with rock fill. In December, the last stop logs were put in place and "the cofferdam received the full force of the river, which it turned aside." Four months later, long after the jubilant celebrations over the river's successful diversion and two short months prior to maximum runoff, a leak developed in the west-side cofferdam at cell groups F and G, the "cloverleaf" where the west cofferdam/dam foundation formed a junction with the downstream cross-river cofferdam (and the unfortunate location of one of the towers carrying sand and gravel to the west-side mixing plant [see below]). By morning of March 18, 1937, small leaks noted on the previous evening had increased, appearing as jets through openings in the steel piles of cells F-8 and F-9 (Figure 21). Near noon, a sheet piling between F-9 and G-3 opened, releasing the sand fill and 30,000 gallons of water per minute while threatening to flood the entire enclosure and to undermine the central conveyor tower. In a desperate and improvised effort to avoid "disastrous delay" (and in striking low-tech contrast to the high-tech, carefully planned, construction effort), MWAK crews created an earth- and rock-fill crib outside the apparent source of the leak at cell G-5, in which they dumped straw, tumbleweed, sagebrush, clay, mattresses, sandbags, and fir-tree

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Press Release, 12/17/1936, Folder: Correspondence re Construction of Coffer-Dams, Box 538, Columbia Basin Project, Project Correspondence File, 1930-1945, Decimal Classification 301.14, Entry 7, RG 115, NARA-RMR.

Day letter, J. H. Miner to Reclamation Denver, March 18, 1937, Folder: Correspondence re Construction of Coffer-Dams, Box 538, Columbia Basin Project, Project Correspondence File, 1930-1945, Decimal Classification 301.14, Entry 7, RG 115, NARA-RMR.
mats. With the flood slowed, MWAK drove steel sheet pilings to support sand and gravel designed to disperse the flow of water from the ruptured cell group. Grout holes within this fill were injected first with sand, sawdust, wood shavings, and finally with cement, water, and bentonite — its first application on the project. By late April, the leak had slowed to 250 gallons per minute and financial catastrophe had been averted.

By August 1937, the dam had risen to sufficient height for removal of the upper portions of the disposable cofferdams. During subsequent construction, and prior to completion of the spillway, eight large portable (and temporary) gates, 52' wide and 35' high, controlled the passage of water through the diversion slots left in the dam foundation (Figure 22).

**CONCRETE PLACEMENT**

*Can every portion of such a tremendous mass of concrete be built into a monolithic structure that will not crack longitudinally and thus weaken a structure that is dependent for safety on its monolithic character? . . . If Grand Coulee Dam should fail, it would probably be due to shear failure along vertical longitudinal cracking that had destroyed the integrity of the monolithic structure. It is this consideration that makes so exceedingly important the construction of a dam that will not develop the characteristic vertical cracks that have been observed on less important dams designed and constructed prior to Boulder Dam.*

Diversion of the river from its course and excavation of the overburden and rock left in its wake was a task of gross proportions, realized with equipment of startling size: four-and five-yard electric shovels, ten- to 24-yard dump carts, stiffleg derricks, revolving cranes, crawler cranes, electric whirlies . . . In contrast, engineers described foundation preparation as a "manicure," a meticulous, detailed process by which bedrock was picked and scoured clean.

Natural seams and pockets were cut from the bedrock surface, allowing adequate bearing of concrete on granite. With a base width of 500' and a length of over 4,000' (including the massive abutments), the expanse of concrete/granite contact totaled 2,000,000 square feet, each of which was cleaned with hand picks and paving breakers to remove "all loose, fractured, soft, or disintegrated rock (Figure 23)." The foundation was then sandblasted to removed calcium

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* J. H. Miner, Acting Construction Engineer, to Chief Engineer, March 20, 1937, Folder: Columbia Basin, Correspondence Re: Construction of Cofferdams, Box 538, Decimal Classification 301.14, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.


* Memorandum from Chief Designing Engineer J. L. Savage to Chief Engineer, re expedited program and winter program - Grand Coulee Dam, December 1, 1938, Folder: Columbia Basin, Dams and Reservoirs: Grand Coulee Dam, 1938, Box 535, Decimal Classification Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.
deposits, "thoroughly cleaned" by brushing with high velocity jets of air and water, and dried with sponges and air siphons. The operation, "rather accurately described as 'manicuring,' cost about 75 cents per square foot."63

What preliminary core drilling had suggested was a "remarkably flat" granite foundation, overburden removal revealed to be remarkably contoured and irregular, particularly at the east abutment and along a lift seam near the center of the west foundation area. As bedrock was scaled along the axis of the dam, crews equipped with percussion drills and pneumatic jackhammers injected cement grout (cement and water) at low pressure (200 psi) into rock crevices and 682 grout holes (ranging in depth from 20' to 200'), hoping to create a curtain impervious to percolation or uplift. "The adopted procedure consisted of injecting the greatest possible quantity of grout of varying water-cement ratios under pressure in the shortest period of time, keeping the hole open as long as possible."64

On December 6, 1935, Washington governor Clarence Martin poured the ceremonial "first" of over 10,511,160 cubic yards of concrete at Grand Coulee, an event marked with remarkable pomp and circumstance and great public discussion of the enormity of the task ahead. Specifications for aggregate composition, drytime, concrete cooling, surface preparation, and joint adhesion for each of these ten million yards were exacting and enforced by government inspectors working around the clock: the maximum difference in elevation of any two adjacent panels of concrete was not to be greater than 15' perpendicular to the axis of the dam or 30' parallel to the axis of the dam; concrete was to be cooled to 45°, attainable only with a period of winter cooling; to facilitate concrete cooling and contraction-joint grouting, all panels in the areas separated by transverse construction joints were to be kept at a uniform elevation; within a block, no more than 5 feet of concrete ("5-foot lift) were to be placed in a 72-hour period; concrete, when poured, was not to exceed 85° or to drop below 40°; concrete placement was to stop during the winter months, unless these temperatures could be maintained through steam-heating.65 In response to contractors' requests to relax these restrictions, thereby speeding construction, BOR engineers Walter, Banks, Savage, McClellan, and Hammond argued:

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65 Walter, Banks, Savage, McClellan, and Hammond to the Commissioner, December 12, 1938, Folder: Columbia Basin, Dams and Reservoirs: Grand Coulee Dam, 1938, Box 535, Decimal Classification 301.1, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.
the restrictions and provisions of the specifications were not placed there as nuisances to impede construction progress, but on the other hand, were after careful deliberation, based on scientific study and experience, included in the specification to insure that a safe and durable structure would be the result. As between a safe dam and speedy construction, if both can not be obtained, there should be no argument.

Design of a rapid and efficient construction plant, operating within the parameters of a cautious and temperate construction methodology, was thus critical to the economically viable construction of the "largest structure ever built by man."66

In June 1934, after a year of study,67 the Bureau of Reclamation recommended the Brett gravel pit as the best source for concrete aggregates, adequate to supply over 9,000,000 cy of gravel; in contrast to other remote western dams (e.g. Shasta), where delivery of quality concrete aggregate over long distances to the construction site represented a significant construction cost, the Brett deposit was "advantageously situated" a mere 2 miles east and 700' above the dam site.68 An elaborate screening and washing plant was constructed below the gravel pit (Figures 24 and 25).69

A suspension bridge connected the screening plant with the Westmix plant, transporting aggregate westward by conveyor belt. The bridge crossed the canyon in two 1,437' spans, supported by a 325' steel tower secured to the west cofferdam (at cell group G), creating "a

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67 Technical testing and analysis of concrete were handled by the Concrete Control Department, headed by the Concrete Technician who reported to the Field Engineer. The main divisions of activity included "gravel pit inspection, control of concrete manufacture, pozzolanic investigations, and laboratory operations incidental to concrete control and related features." Three-shift inspection was carried on by a small group of technicians who inspected dam and power house concrete placing (and also supervised concrete cooling operations and control). At the Brett gravel pit and the gravel processing plant, inspectors were on duty "as needed" ("Annual Project History, Columbia Basin Project," Volume III, 1935, p. 85; "Annual Project History, Columbia Basin Project," Vol. V, 1937, pp. 77-78).

68 Bureau engineers, working from a "very complete" testing laboratory in the basement of the main Denver office, tested and graded concrete aggregate: "solid concrete cylinders as large as 3' in diameter are here tested to destruction in order to determine the characteristics of concrete made with various aggregates" (Anonymous, "Report of a conference held at the office of the Bureau of Reclamation, Denver, Colorado, December 2nd and 4th, 1933, concerning the Grand Coulee Project," n.d. (received Feb. 14, 1934), Folder: Col. Basin, Board and Engineering Reports, January 1, 1933-June 30, 1934, Box 527, Decimal Classification 301, Columbia Basin, RG 115, NARA-RMR).

spectacular finished assembly" (Figure 26). A simple timber trestle, approximately 1,500' in length, conveyed aggregate to the Eastmix plant.  

Fifty-thousand barrels of cement, sufficient for 45,000 cy of concrete, could be stored and blended at a plant 1/2 mile southwest of the dam, near the railroad tracks. After mixing "various brands of cement in desired quantity" (formulas based in part on extensive BOR research and testing of pozzolanic admixtures and concrete strength), cement was conveyed to the Eastmix and Westmix plants through pneumatic pipe, at a rate of 1000 barrels an hour, traveling over 100 miles per hour.

Those charged with placing an unprecedented volume of concrete at an unprecedented rate christened the Westmix plant the "House of Magic." Pneumatic pipes delivered cement to bins near the top of the 126' building, via a de-aerating tank, and the suspension-bridge conveyor belt delivered sand and gravel to a series of grade-specific bins located directly under the roof. Beneath the bins, organized in a "concentric zone design" whereby materials flowed toward the center of the plant, was the "Brain Chamber of the House of Magic," housing the dispatcher and batcher control rooms. Johnson automatic batch weighers, equipped with weigh-beams and selector air valves, weighed the seven different ingredients of concrete. From the batchers, material was conveyed by central hopper and swivel chute to one of four 4-yard 75-horsepower Koehring mixers where mixing time (improved from three minutes to two minutes over the course of the project) was automatically controlled and "interlocking mechanisms" held each operation to its "proper sequence" (Figure 27). From mixer, to conical hopper, to 4-yard placement buckets carried on flat cars of the elevation 1024 trestle, took an average of 25 seconds. The BOR's publicity department lauded the entire plant as a striking example of the economic savings associated with small efficiencies, employing BOR engineers' design improvements to the mixer blades as an example: "only a minute saved per batch, but a great savings made in the total time required for mixing - over two and a half million minutes on the job - half a year."

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72 Under the heading of special work, The BOR's concrete-control division had studied pozzolanic materials since 1934. In August, 1937, pozzolanic material, replacing 25 percent of the modified Portland cement, was used in five batches of 6" maximum mass concrete placed in the dam. By December pozzolanas were preblended with Portland cement ("Annual Project History, Columbia Basin Project," Vol. 5, 1937, p. 79).

The Bureau of Reclamation described the method of transporting and placing concrete:

Concrete trains, composed of a 10-ton Diesel-electric locomotive, and a flat car carrying four buckets... were pulled in under the mixing plant and the buckets were loaded directly from the discharge hopper. The cars were then hauled to the desired point on the trestle where the buckets were picked up by gantry cranes and lowered to the blocks in the dam as required (Figure 28).

During foundation construction, a trestle at elevation 1024 (14' above maximum height of the foundation) supported the gantry cranes. As the dam rose in height, CBI constructed a new trestle at elevation 1180, of sufficient width for four standard-gauge railroad tracks and on which larger and improved gantry cranes with a working span of 350' assured coverage of all but the right and left abutments. At the abutments, the contractor established stationary Lambert stiffleg derricks, for placement of concrete in the area beyond the trestle and outside the working range of the trestle cranes. With construction of this new trestle, both the east and west mix plants were re-assembled on the east bank of the river at elevation 1180, allowing removal of both the elevation 1024 trestle and the suspension-bridge conveyor (Figure 29).

Four-yard bottom-dump buckets released concrete for placement, first on "manicured" bedrock and finally on sequential blocks that formed the vertical tiers of the dam (Figure 30). These tiers varied in size from 50'x50' in the spillway area to 25'x34' in blocks opposite the powerhouses; many were traversed by octagonal penstock tunnels, outlet tubes, or interior galleries. Vertical and horizontal keys at the transverse and longitudinal joints "locked" each tier to its neighbor (Figure 31). In a meticulous process akin to preparation of bedrock, existing concrete surfaces, cured a minimum of 72 hours, were sandblasted clean prior to each successive pour. The wood placement forms were removed, areas of porous or fractured concrete (as identified by Government inspectors) carefully removed with chipping hammers and filled with a mortar patch, and all cooling, grouting, and drainage pipe placed.

Concrete was cooled to 45°, through a process first tested at Oregon's Owyhee Dam and first implemented at Boulder (Hoover) Dam: 2 to 4 gallons per minute of river water were piped through 2,116 cooling coils embedded in the concrete at 38 strategic cooling zones. This process was completed in two stages, first immediately after the concrete pour, and again during the

\[\text{\textsuperscript{19}}(\text{...continued})\]


\[\text{\textsuperscript{21}} \text{"Annual Project History, Columbia Basin Project," Vol. VI, 1938, pp. 230-231.}\]
winter when Columbia River water dropped sharply below its summer average of 55°. After final cooling, contraction joints between the vertical tiers were grouted through a pipe distribution system embedded in the concrete as it was being poured, "thus forming a solid monolithic structure." On the heels of the successfully improvised repair of the west-cofferdam leak (and in one of many Grand Coulee examples of the engineering maxim that "technical decisions [do] not always arise from scientifically optimizing studies") this grout was changed in October 1936 from Portland cement and water to a mixture of Portland cement, calcium chloride (to speed the curing process), and bentonite (to improve adhesion).

By 1939, concrete placement at Grand Coulee proceeded at an astonishing pace, breaking the monthly and yearly records established by MWAK during foundation construction and culminating on May 25, 1939 with a carefully planned and well-publicized single-day world-record pour of 20,684.5 cubic yards. CBI and the Bureau of Reclamation had reduced the volume of concrete laid during the previous week, thus assuring that much of the dam's surface was sufficiently cured for a new layer. The press was alerted, and at midnight CBI crews began placing concrete at a rate of one cubic yard every 4.18 seconds. The feat was never accomplished — or attempted — again and was incidental (if not detrimental) to the dam's design and subsequent use. It did, however, testify to the phenomenal capacity of the construction plant and added to the BOR and CBI's growing list of "fastest, greatest, biggest" accomplishments associated with Grand Coulee Dam.

On November 10, 1940, CBI suspended concrete placing for the duration of the winter, with a mere 33,000 cy (3 percent) remaining to be placed in the spillway bridge, elevator towers, sidewalks and parapets, and gate-guide extensions for the outlet works (Figure 32).


79 In contrast, the previous record of 15,000 cy, established by MWAK crews during foundation construction, had exceeded the previous record of 10,417 cy, established by Six Companies, Inc. at Boulder Dam ("All Records for Concreting Broken in Building Base for the Grand Coulee Dam," Southwest Builder and Contractor, January 28, 1938, n.p.).

80 Pitzer, Grand Coulee, pp. 204-205.
SPILLWAY

Optimal head for power generation and the anticipated needs of downstream irrigators dictated the minimum height of Grand Coulee Dam. The absence of an international treaty whereby water backed by Grand Coulee Dam could cross to Canadian soil dictated the maximum height: a reservoir level reaching no higher than elevation 1290 would extend 151 miles to the border. Within the central overflow spillway specified for the dam, 11 regulating drum gates (manufactured by the American Bridge Co.) maintain the reservoir at this level, releasing water in excess of power and irrigation demands along a 1,485' long spillway crest (Figures 33 and 34). Sixty gate-controlled (ring seal gates) 8.5' outlet tubes, located in lines of 20 at elevations 934, 1034 and 1134, release additional excess flow, to a maximum possible level of 1,000,000 cfs. (Figures 35 and 36).

By 1939, drum gates, ring-seal gates, and central spillways were common dam auxiliary features. A potential 1,000,000 cfs of water falling 280 and generating 31,800,000 horse power (hp) — 19,300 hp per foot of gross spillway crest length — was "unprecedented" (Figure 37). A "curious" reader of Engineering-News Record noted:

Relatively few dams have been built on large rivers with spillways on the main dam itself. . . . In such dams there has been preference for structures arched in plan so that the additional stability of wedding in the canyon would lessen any risk that might arise from vibration or from undermining of the downstream toe. . . . Certainly it will interest engineers to know just what the plans are for energy dissipation in or just below the Grand Coulee Dam."

Like the Army Corps of Engineers at Bonneville Dam, the Bureau of Reclamation began a series of photo-elastic experiments on to-scale bakelite models of the spillway section, investigating stress conditions during hydrostatic pressure on the upstream dam face and foundation and on the downstream face and spillway bucket during maximum flood. (The 1:40 model of the downstream face of the spillway was equipped with a glass panel 6' long, allowing visual inspection of flow conditions in the spillway bucket. Jacob E. Warnock, Hydraulic Research Engineer, wrote "regardless of the amount of data which may be obtained by other devices, none has proved as effective as this in affording a mental image of the true behavior of the water.") This data and mental imagery, evaluated in the context of site topography, location of the tailrace, and riverbed characteristics, suggested a spillway bucket, curved in section (50' radius) and placed at a very low elevation (Figure 38). Despite the care taken in spillway design, the wasted energy at the toe

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Letters to the Editor, "Overpour Hazard at Grand Coulee at Grand Coulee Dam," Engineering News-Record, September 6, 1934, p. 308.
remained considerable; Bureau engineers anticipated a degree of erosion and scour and included the installation of a permanent spillway drydock and caisson in their project design.

By 1943, after only two seasons of high-water passage over the spillway crest, the Bureau of Reclamation applied to the War Production Board for man-power and strategic materials sufficient to repair the "badly eroded" spillway and to construct the permanent maintenance facilities. "We believe," they argued, "that the cost of the repairs and the use of the required strategic materials is of small consequence as compared to the value of the electric energy now being delivered to vital war industries in the Northwest." The War Department agreed, and auxiliary outlets in the right powerhouse to bypass water during low-water season (thus avoiding all use of the spillway); a "submerging-type" caisson for unwatering 50' sections of the spillway bucket; and drydock facilities for erecting, storing, and maintaining the caisson equipment were constructed between 1942 and 1947.

Model studies also suggested that both the tailrace slopes and the immediate downstream river bank be riprapped to an average depth of 5' in order to mitigate erosion, undercutting, and earth slide. In 1937, Savage and members of the Bureau's board of consulting engineers expressed confidence that this riprap was "ample for any anticipated stream flow." Within three years, however, continued undercutting of the unstable banks ("a source of almost continuous trouble and great expense from the earliest days of the work") had generated substantial slides, threatening to block the right tailrace area and disrupt power generation from the left powerhouse. In 1940, the Bureau contracted for excavation of an additional 1,000,000 cubic yards of overburden from the west tailrace slope and in 1942 and 1943 government forces revised portions of both the east and west tailrace slopes and replaced the riprap.

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H.W. Bashore, Commissioner, Bureau of Reclamation, to Mr. J.A. Krug, Director Office of War Utilities, War Production Board, August 26, 1943, Folder: Columbia Basin, Engineering Reports, Siphons and Spillways, August 1943 through, Box 538, Decimal Classification 301.7, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.


PUMPING STATION

Both the pumping station and the power plant (see below) are auxiliary structures of Grand Coulee Dam, incidental to the dam's ability to hold the Columbia River and yet essential to the dam's function and use. The pumping station lifts water from Lake Roosevelt to the Grand Coulee and therefore marks the first stage of the water-distribution system that defines Grand Coulee as a reclamation dam (see Figures 9 and 10). Within the concrete pumping-station dam (tied to and constructed in-pace and in-kind with the main dam) are six 65,000 hp pumps and six 67,500 hp reversible pump/generators, each connected to one of 12 discharge pipes (Figure 39). Left powerhouse units L-1, L-2, and L-3 each supplies power to a pair of the pumps which can lift 1,600 cfs to the feeder canal located 280' above the dam site and 1/2 mile from the Grand Coulee (Banks Lake). The pump/generators can lift 2,000 cubic feet of water per second to the feeder canal. In 1981, the pumping units were modified to also serve as generators, powered by water from Banks Lake that is allowed to fall 280' back down the discharge pipes (used here as penstocks) whenever available water is in excess of irrigation needs and power demands are high.**

In 1951, princesses of the Washington State Apple Blossom Festival poured water collected from all 48 states into the main canal of the Columbia Basin project, initiating the first delivery to project lands. Completion of the entire system of canals, dams, reservoirs, lateral ditches, and ditches drawing water from Banks Lake for delivery to 500,000 acres (one-half the projected total) took over 20 years, at a greater cost than Grand Coulee Dam.***

POWER

Power production was a central component of the Grand Coulee Dam project, providing the means of pumping water from Lake Roosevelt to the Grand Coulee, providing power to project farmers and communities, and ideally allowing income generation sufficient for dam operation and maintenance and for the repayment to the United States for the cost of the dam and power plant and one-half the cost of the irrigation works. In an ironic conclusion to the power-market debate that had dominated the early years of project history, the United States' entrance into World War II dramatically escalated this heretofore-inadequate demand. Under contract modification, CBI installed four rather than two generators in the completed left powerhouse and through emergency appropriation rushed completion of the right powerhouse, where the penstocks had

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*** Pitzer, Grand Coulee, p. 364.
been installed and the foundation placed but final structural completion had waited development of a considerable portion of the irrigable area (Figure 40).

Power facilities integrated within the dam had of course been placed during the course of construction (Figure 4). In June, 1938 Western Pipe & Steel Company began construction of 18 pipe-steel penstocks 290' long and 18' in diameter (nine per powerhouse). In addition, Western Pipe & Steel constructed the 12 "comparatively short," 14' inlet pipes associated with the pumping plant (see above) and three 290' 7' diameter penstocks, which fed the small left-powerhouse generators that would provide "station-service" power for the gates and valves and for Engineer Town.

"The largest ever constructed," the 18' diameter units were too large for shipment to the dam site and were instead built in sections at Western Pipe & Steel's Electric City fabrication plant (3.5 miles from the dam, at the government railroad siding), using fusion-welding technology. Upon completion, the welds were examined by x-ray, hydrostatic tested, and the penstock section cleaned, washed, painted, and transported by truck and barge to the appropriate powerhouse. Here each was hoisted to the octagonal holes left in the dam and field welded to adjoining sections (Figure 42). These field welds were checked with portable x-ray equipment and the entire penstock checked for line and grade. Seventy-two-inch ring-seal gates were installed at the lower ends of the penstocks, immediately ahead of the turbines and, finally, all annular spaces were backfilled with concrete.

**In sharp contrast to the depression-era make-work effort, when men and materials were in abundant supply, war-time austerity measures affected right powerhouse construction. The Bureau reported that "this was particularly true of both structural and reinforcing steel, and metal pipe, as well as skilled labor. . . . One of the most important changes of this nature was the change in design of the right powerhouse roof. The original plans contemplated a structural steel purlin roof supported by steel trusses, as used in the left powerhouse. Structural steel was not available. However, by purchasing the contractor's salvaged steel girders formerly used in his construction trestle on the dam, a satisfactory support for the 'pan-type concrete slab and joints construction' was obtained" ("Annual Project History, Columbia Basin Project," Vol. 9, 1942, p. 134).

* USDIBOR, Memorandum for the Press, January 31, 1938, Folder: Columbia Basin, Correspondence re Construction and Operation of Penstock Tunnels, Box 538, Decimal Classification 301.61, Project Correspondence Files, 1930-1945, Columbia Basin Project, RG 115, NARA-RMR.


In the spring of 1940, Government forces began installation of the two 10,100 kw station-service units, using turbines manufactured by Pelton Water Wheel Co. and generators manufactured by Westinghouse Electric & Mfg Co. The Bureau announced that on March 22, 1940 the first power would be delivered from Grand Coulee Dam via a temporary tie line to the Bonneville transmission system: "After only 7.5 yrs of construction, with the dam yet a year from completion, the dam's power machinery, in the shape of two small 10,000 kilowatt units, began amortizing the investment of the United States."94

Substantial delivery of commercial power sufficient to meet the needs of war industries was not realized until October 4, 1941, following installation of a 150,000 hp hydraulic turbine, manufactured by Newport News Shipping and Drydock Co., a 108,000 kilowatt generator manufactured by Westinghouse (together composing unit L[eft]-3), and completion of a 115-kv switchyard and a 230-kv yard. Again, the nation celebrated:

When Grand Coulee's first great hydroelectric generator starts developing power this Saturday, it will be a little over 8 year since half a dozen Bureau of Reclamation engineers braved an infrequent Eastern Washington rainstorm to drive a simple fir stake amidst the sagebrush of the Columbia River valley... Between September 9, 1933 and October 4, 1941 the Bureau of Reclamation, its contractors, 70,000 workers, and modern construction machinery have built a massive structure of 21,000,000 tons, created a huge reservoir 133 miles long, constructed a powerhouse about 18 stories high and two city blocks long, and put into operation a 108,000 kilowatt generator, a third larger than any of similar type built heretofore... During 1942, The Grand Coulee Dam will contribute a major share of the power needed to manufacture one-fourth of the Nation's anticipated [aluminum] output of 600,000,000 pounds.95

Turbine/generator units L-1 and L-2 were placed in service early in 1942, followed by unit L-6 on August 9, 1943, unit L-5 on November 8, 1943, and unit L-4 on February 12, 1944. "In order to speed the development of generating capacity for war production," two 75,000 kw generators manufactured for Shasta Dam augmented this production; both the turbines and generators had been manufactured prior to the war and had been in storage at Hoover Dam, waiting completion of the Shasta powerhouse (Figure 43). With these six large units, two Shasta units, and the station-service units, Grand Coulee was able to generate 818,000 kw (Figure 44). Ironically, given the increased power demand generated by the war, wartime restrictions on material and labor prevented rapid completion of the remaining units: on October 27, 1942, the War

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95 USDI BOR Press Release, October 1, 1941, Folder: Columbia Basin, Dams & Reservoirs, Grand Coulee Dam, January 1939-December 1941, Box 534, Decimal Classification 301.1, Project Correspondence File 1930-1945, Columbia Basin Project, R.G. 115, NARA-RMR.
Production Board cut the priority for generators L-7, L-8, and L-9 and suspended work on the right powerhouse.

**THIRD POWERPLANT**

All eighteen Left and Right powerhouse units were placed in service by 1952, with a maximum generating capacity of 243,000 kw; this maximum, however, was obtainable only when sufficient water was available in Lake Roosevelt. During periods of high water (coinciding with periods of high summer-time power demand) power head was "wasted" over the Grand Coulee spillway. By 1966, following two-decades of domestic and international (Canada) negotiations and political wrangling, the BOR secured Congressional appropriation and Canadian approval for construction of upstream storage dams that would assure a consistent water level at Lake Roosevelt and that would allow construction of a massive Third Powerplant, ultimately capable of generating 9.2 million kw, using 12 600,000 kw generators fed by 40'-diameter penstocks. The 20-story Third Powerplant/forebay dam was located at the east abutment. Its construction (the largest contract ever awarded by the BOR) involved removal of the right powerplant switchyard and much of old Mason City; construction of a new cofferdam; completion of a massive new forebay dam stretching from the original dam along the east side of the river; and removal of 250' (blocks 92 and 93) of the original dam. To the undoubted satisfaction of those who had built blocks 92 and 93 (and of those living downstream), the existing concrete proved "amazingly hard and . . . took longer than anticipated to break up." A protective slot in the dam, excavated slowly by jackhammer and minor charges prevented the detonations from transmitting to the main dam structure (Figures 45-48).

**CONCLUSION**

In 1934, the Bureau of Reclamation described the Grand Coulee west cofferdam as "the greatest, or at least the largest," ever built. The ambiguous, and often forgotten, distinction between these two superlatives defines the difficulty of assessing the technological importance of Grand Coulee Dam. For Bureau of Reclamation designing engineers, Grand Coulee Dam presented few technological challenges not already faced at Hoover Dam (most notably content and cooling of large volumes of concrete). The Grand Coulee foundation was of sufficient strength to support a dam of "any height" demanded by the power and irrigation programs and the

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" This is of necessity a grossly abbreviated discussion of Third Powerhouse political and construction history. See Pitzer, *Grand Coulee*, pp. 333-354 for a political history, and Bureau of Reclamation Third Powerplant Project Histories, 1969-1974 for a discussion of powerplant design and construction.

" Only six of these generators have been installed to-date.
economic largess of the federal government during the 1930s lessened the need for technological innovation and risk in response to economic concerns: a traditional massive concrete gravity dam rather than a less expensive multiple-arch structural dam was possible in the cost-benefit equation of the times. In contrast, within the parameters of conservative design, economic expedients were central to construction methods. The construction-plant innovations realized during removal of an unprecedented volume of overburden and placement of an unprecedented volume of concrete established Grand Coulee Dam "among the construction classics . . . [showing] that in planning field execution creative engineering reaches as great heights as in the activities of the designing engineer." Although none of the major economic expedients at Grand Coulee (the ice dam, the west cofferdam, the conveyor belt system, the Westmix plant) were pioneering in concept, each, civil engineers of the time argued, was executed to a size and capacity "so far overshadowing earlier applications . . . as to represent radical innovations." Each established a precedent, redefining the engineering and construction community's understanding of what was possible, within a given timeframe and a given budget.

Size and greatness are more easily correlated when evaluating the historical impact of the dam on the Pacific Northwest region: Construction of the largest thing on earth allowed employment of over 70,000 men and created a stream of manufacture goods, dollars, and jobs that reached 45 states. This immediate employment during an era of nearly universal unemployment provided the final catalyst to construction of a politically untenable and economically suspect project, thus placing Grand Coulee with the major public-works projects of the depression era, representative of a significant new public/private social and economic contract. The unprecedented volume of water stored behind Grand Coulee Dam allows irrigation and cultivation of over half-a-million acres of land, a substantial impact on the economic and social history of the region and effective symbol of the Bureau of Reclamation's mission to make the desert bloom. By March, 1944, this unprecedented water volume, run through generators of unprecedented size, established a world's record for electrical production by a single plant in a month's time with a gross output of more than 621,000 kilowatt hours; this unprecedented output powered Pacific Northwest aluminum plants and other war industries (an estimated total of $1.5 billion of regional industrial

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installations) during World War II, allowing effective prosecution of the war effort, without disrupting the domestic power supply.\textsuperscript{101}


\textsuperscript{102} Pitzer, \textit{Grand Coulee}, pp. 247-249. Pitzer argues that contemporary and current claims that Grand Coulee and Bonneville dams "won" the war are dramatically overstated. The combined electrical output allowed aluminum manufacture \textit{without} disrupting the domestic supply: "Grand Coulee allowed the government to produce the aluminum and run Hanford, while not disturbing the day-to-day lives of most Americans. The government could have diverted power from domestic use but Grand Coulee, among other projects, made this unnecessary" (p. 249).
ANOTATED BIBLIOGRAPHY

■ Secondary Sources


Massive study of all phases of Columbia Basin Project construction and implementation, with focus on economic and legislative rather than construction history. Concludes with a valuable annotated bibliography. Pitzer conducted research in the James O'Sullivan papers, Gonzaga University, Spokane Washington; Columbia Basin Commission papers, Washington State Archives, Olympia, Washington; Warren Magnuson, Henry Jackson, and Willis Batcheller collections, University of Washington, Seattle; Frank Banks papers and Columbia Basin Project collection, Washington State University, Pullman; Bureau of Reclamation RG 115, NARA, Denver.

■ Technical Journal References to Grand Coulee Dam

(The following list is a compilation from a variety of sources. Not all articles were reviewed during the course of this study).

1920-1933


Adams, Fred A. "What is the "Scheme of Development Upon Which the Inland Empire is Based?" *Modern Irrigation*, October 1925, v. 1, pp. 15-16.


1934


"8,000,000 kw. Goal of Columbia River Development; utilization of generating facilities from power, navigation, flood control and irrigation projects." *Electrical West*, Feb. 1934, v. 72, pp. 16-17.

"Grand Coulee; the Key to Columbia River Power." *Electrical West*, Feb. 1934, v. 72, pp. 18-19.

"8,000,000 kw. is Columbia River Goal; P.W.A. Projects at Grand Coulee and Bonneville." *Electrical West*, Mar. 17, 1934, v. 103, pp. 409-410.


* The following five articles are from *Pacific Builder and Engineer*, April 14, 1934, v. 39, no. 15.


O'Sullivan, James. "The Conference of Consultants on Grand Coulee Dam, at Denver, March 29, 30, 31."


"Grand Coulee Project to Start." Newsweek, July 7, 1934, v. 4, pp. 6-7.

The following three articles are from Pacific Builder and Engineer, July 7, 1934, v. 40, no. 27.


"Inland Empire Celebrates Opening of Bids on Grand Coulee Project," pp. 16-17.

"Comparative Unit Bids on Grand Coulee Dam and Power Project," pp. 27-27.


"Developing the Columbia River Drainage Basin." Civil Engineering, Sept. 1934, v. 4, no. 9, pp. 443-459.


1935


Editorial Introduction, pp. 139-140.

Keener, Kenneth G. "Grand Coulee Project and Dam," pp. 141-143.


- The following three articles are from *Compressed Air Magazine*, Oct. 1935, v. 40.


1936


Bins, batching equipment, and four 4-yd mixers arranged in compact tower structure on west abutment; capacity of 6000 cu yd per day; placing trestles and methods described.


General review of plans for project and progress in construction at Grand Coulee.


Symposium of 2 papers: Excavation and Conveyor System; Grand Coulee Aggregate Plant.


Excavation of dams and gravel; crushing plant; aggregate screening an (sic) washing; delivery of refined aggregates; handling bulk cement; delivery of concrete to forms.


Operations involving placing 4,500,000 cu yd of concrete; data on foundation grouting, step-by-step review of concrete placing methods, form design, cooling system and contraction joint grouting; inspection.
Outline of design contemplating construction of U-Section cribs to permit gradual closure with stoplogs; cribs of different design in upstream and downstream arms; unwatering of present river channel set for latter part of December.

Riddle, C.D. "Construction Plant at Grand Coulee Dam." *Civil Engineer*, October, 1936.
Large-scale operations for cofferdam, excavation and for aggregate productions; earth handling on huge scale; schemes to save time; screening plant; airplane tripper with 75-ft wing booms.

Description of 2 cross-river cofferdams constructed to permit unwatering & excavation in main channel area; crib bottoms designed from 40,000 soundings taken in river channel; main cribs are 64 x 90 ft; cofferdam construction.

Young, H.W. "Compressed Air at Grand Coulee Dam." *Compressed Air Magazine*, December, 1936.
Examples of utilization of compressed air in construction of dam.

Use of ammonia brine refrigerating system for freezing arch dam 100 ft long 40 ft high & 20 ft thick to save removal of 30,000 cu yd of excavation; design of arch & refrigerating plant; method of installing freezing points; operation of system, etc.

Details of staging for work on concrete forms which can be hung up against forms when not in use, employed in construction of Grand Coulee dam.

Recent progress at Grand Coulee Dam; completion of preliminary work and preparation for concrete placing schedule of 440,000 cu yd per mo; changes in handling materials.

Construction problems, cofferdams, gravel plant and conveyors, application of oxyacetylene welding and welding in construction.

Methods used in demolition of cofferdam for construction of Grand Coulee Dam; excavation totals; steel sheeting pulled by cranes and timber cribs uprooted by power shovels.

Outline of plans for completion of dam in Eastern Washington to its ultimate height of 550 ft & length of 4500 ft, requiring nearly 6,000,000 cu yd of concrete in addition to 4,500,000 cu yd already in place; finances, etc.


Report on design and construction of Grand-Coulee dam.

Compilation of design and construction of Grand Coulee dam.

Progress report on construction of dam; rehabilitation of aggregate production system, dismantling of old concrete, placing trestles, moving mixing plants and improving camp; concrete placing cranes; penstock fabrication.

Survey of dam site and surrounding terrain, including geology and water resources; review of projected dam, hydroelectric power plant, and pumping plant.

Outline of Columbia River Basin reclamation project; possibilities relative to irrigation and power production; river diversion; removal of overburden; mixing and placing of concrete.

Use of 70-ton gates moved along dam crest to effect closure of gaps left temporarily in spillway section of Grand Coulee Dam.

Brabrook, R.S. "Erecting 3600-Ft Steel Trestle for Placing Grand Coulee Concrete." *Western Construction News*, February, 1939.
Construction of structural steel trestle, nearly 3600 ft long and 200 ft high, for placing 45,500,000 cu yd of concrete to complete Grand Coulee dam, being built by Bureau of Reclamation on Columbia River; erection procedure.

"Concrete Placing at Grand Coulee — from Gravel Pit to Forms." *Western Construction News*, June, 1939.
Progress report on construction of dam; concrete placing going forward at rate of about 12,000 cu yd every 24 hr; typical mass concrete mixes showing changes in proportioning to meet variation in production of aggregates; mixing plants, etc.

Description of A-frames for raising 25-ft for panels on Grand Coulee Dam made up with 2-in. pipe welded up on job.

Hutton, S.E. "Grand Coulee Dam and Columbia Basin Reclamation." Mechanical Engineering, September, 1940.

Peculiarities of Columbia River; geological, geographical, climatic, and economic features of western third of United States; energy available at Grand Coulee dam; power houses, turbines, penstocks, and coaster gates, generators and transformers, etc.


Grand Coulee power plant, when fully equipped will contain 18 15,000-hp main generating units and three 14,000-hp station service units, or total capacity of 2,742,000 hp; turbines are of vertical shaft single runner Francis type.


Methods and equipment used in preventing accidents on Grand Coulee Dam; safety rules and regulations.


Costing some $375,000,000, this project will produce practically double amount of firm power available at Hoover Dam and will provide facilities for irrigating 1,200,000 acres of land; notes on dam; power house; irrigation; cost of power.


U.S. Bureau of Reclamation project comprising low-head development of 1,575,000 kw. ultimate capacity & irrigation for area of 1,200,000 acres in central Washington; geology of Grand Coulee damsite on Columbia River; foundation grouting & drainage, etc.


Summary of unit prices bid on construction of dam in Washington, which is of concrete gravity section, 300 ft. in maximum height, with overflow section 1800 ft. long, and two non-overflow power-house sections 592 and 754 ft. long.

Schedule, specifications and drawings for construction of concrete-gravity dam on Columbia River, in Washington, about 300 ft. long, 300 ft., max. height, ultimate height 500 ft., including permanent cofferdam below main dam.


Engineering data of general interest on several proposed Grand Coulee dams; reservoir sites; potential water storage in Columbia River above Grand Coulee dam site; estimated cost data; irrigation by pumping; high dam vs. low dam.


Method of construction of sheet-pile cofferdam of cellular type; 7053 piles, involving more than 12,500 tons of steel and total length of about 791,000 ft were driven in 3 months; description of gravel and concrete plants.


Symposium on design and construction of Grand Coulee dam having proposed ultimate height of 540 ft., 1650 ft long, etc.

"Concrete Dispatching System." Engineering News-Record, September 10, 1935.

Description of electric signal boards to transmit orders, automatic control for aggregate combinations and comprehensive system for checking form blocks; concrete placing operations in west cofferdam; routing and placing of concrete.


Equipment an layout of gravel plant designed to meet rigid specifications for mass concrete.

"Concrete Mixing and Placing at Grand Coulee Dam." Engineering News-Record, January 23, 1936.

Description of first of 2 duplicate mixing plants, each with capacity of 320 cu yd per hr, having floor area of only 42 sq ft, but total height exceeding 250 ft; batcher floor and automatic-control equipment.


Ex. Document No. 308 - 69th Congress, First Session. Letter from the Secretary of War, transmitting report by Chief of Engineers, U.S. Army, and Executive Secretary, Federal Power Commission, showing all navigable streams upon which power development appears to be feasible and the estimated cost of examination of same, submitted in accordance with the requirements of Section 3 of the Rivers and Harbors Act of March 3, 1925, dated April 7, 1926.


House Document No. 103, 73rd Congress, First Session. Columbia River and Minor Tributaries - A general plan for the improvement of the Columbia River and minor tributaries for the purpose of navigation and efficient development of water power, the control of floods, and the needs of irrigation. Two volumes, March 29, 1932.


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S-3808 - 67th Congress, Fourth Session. Bill authorizing the Secretary of the Interior to investigate and report to Congress upon the Columbia Basin Irrigation Project. December 6, 7, and 13, 1922.
S-2663 - 69th Congress, First Session. Bill authorizing the Secretary of the Interior to cooperate with the states of Idaho, Montana, Oregon and Washington in allocation of the water of the Columbia River and its tributaries and for other purposes, and authorizing an appropriation therefor. February 2, 1926.


H.R. 7446 - 72nd Congress, First Session. Bill to provide for the construction, operation, and maintenance of the Columbia Basin Project in Washington, and for other purposes. May 25, 27, June 1, 2, 3 and 13, 1932.

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U.S. Department of Agriculture - Bureau of Chemistry and Soils


Reports by the State of Washington


Columbia Basin Project, by George W. Goethals and Company, Inc.; Dated April 7, 1922.

National Archives and Records Administration, Rocky Mountain Region

Bureau of Reclamation Record Group 115.
This record group is organized by projects and includes annual project histories; project reports; and correspondence files. The annual project histories include timelines, a list of important visitors, a synopsis of the Board of Consulting Engineers' reports; and a general discussion of the most important construction activities during the year, with statistics and graphic aids. See below for a general discussion of Columbia Basin Project annual histories, 1933-1945.

The Project Reports focus on "special features" of the project. They range in detail from, for example, an overview of the "Columbia Basin Project" to an "Analytical study of stress in pier gate of feeder canal, Grand Coulee." Assorted project reports re: the ice dam; cofferdam construction; and cement investigations were reviewed for this study. "Gault Report"; "Special features of Design and Construction"; "Report of Conferences with Banks"; "Analysis of Arch Dam at Grand Coulee;" and "Columbia River Pumping and Power Project," were also reviewed.

The voluminous correspondence files are organized by topic, and therein by year. Columbia Basin Project topics (decimal classifications) reviewed during the course of this study include: General Correspondence; Reports on Construction Features; Engineering, General; Dams & Reservoirs: Grand Coulee Dam; Publicity; Board and Engineering Reports on Construction Features; Correspondence re Construction of Coffer-dams; Correspondence re Construction and Operation of Penstock Tunnels.

**Bureau of Reclamation Grand Coulee Project Office, Grand Coulee, Washington**

In 1933, the Bureau of Reclamation established a Columbia Basin Project Photography Department "for the purpose of photographing work in progress and to perform miscellaneous photographic work necessary for publicity and court requirements." By 1938, three full-time photographers were employed on the project. The resulting 300,000+ black-and-white and color-slide images are on file at the NARA, Denver. The BOR project office also maintains a more manageable collection, composed of approximately 2,000 historic images (ca. 1900-1945) reproduced from the NARA collection, and an additional 70,000 images post-dating dam construction (with focus on construction of the Third Powerplant).

All annual histories and special-feature reports are also maintained at the project office.

**Bureau of Reclamation Annual Columbia Basin Project Histories, on file at the National Archives and Records Administration, Rocky Mountain Region and at the Columbia Basin Project Office, Coulee Dam, Washington**

All annotations are quoted from Chapter I of the project histories.

Volume I (1933) covers a summary of essential events leading up to establishment of the project, including a review of all reports of engineering and economic investigations; and historical reference to the Columbia River and its geographical description; a brief reference to early agriculture in the Big Bend area, and concludes with operations ending with the year 1933.

Volume II (1934) covers continued investigations of the project; preparation of specifications and plans for the "low" dam and power plant and awarding of the contract for its construction; surveys and contracts for construction of highway and railroad, the Government Camp (Coulee Dam) and other facilities, and
operations by the general contractor. It also includes a brief summary of principal events prior to the establishment of the project, and the listing of reports of investigations in a chronological order.

Volume III (1935) includes reference to the Order for Changes issued by Secretary Ickes in June 1935, where the concrete to be placed under the contract for the "low" dam was ordered placed as the base, or foundation, of the ultimate high dam; the action of Congress approving the project; the completion of the United States construction railroad and the Columbia River highway bridge; the building of additional residences and other housing facilities in Government Camp; the establishment of executive headquarters at Coulee Dam; the beginning of economic surveys in the irrigable area and a review of precise geodetic surveys. Also covered, is construction by the contractor, including the west cofferdam, excavation of overburden, uncovering bedrock in the west area; opening of the gravel pit, processing of aggregate, and constructing plant for manufacturing and placing concrete; ceremony of pouring the first concrete, and expansion of the general construction plant.

Volume IV and V (1936, 1937) covers progress by the contractor, the Mason-Walsh-Atkinson-Kier Company, who placed 1,860.832 cubic yards of concrete in the dam, mostly from the west abutment to block 40; the removal of the west cofferdam and construction of the two cross-river cofferdams, and erection of the east mixing plant; excavation of 1,787,575 cubic yards of common and rock in east and center sections and the placing of 170,032 cubic feet of grout in 787 holes in bedrock; surveys relating to relocation of highways and railroads in reservoir areas; geological investigation; and the drilling of 36-inch Calyx holes.

Volume VI (1938) describes the completion of the MWAK contract; the awarding of the new contract for completion of the dam, left powerhouse, and foundation for the pumping plant (Specification No. 757); the alteration and repair of construction plant equipment; initial placement of concrete using new construction plant.

Volume VII (1939) describes Consolidated Builders Inc. and Western Pipe and Steel contracts but also the activities of several contractors engaged on the migratory fish control features. The WPA clearing project activities, and initial work on highway relocation are also covered in this volume.

Volume VIII (1940) describes Consolidated Builders, Inc., Western Pipe and Steel Company, and by various contractors engaged in constructing the migratory fish control features. Also included in this volume are further activities in the reservoir area in connection with the WPA clearing project, highway and railroad relocation, bridge construction, and river channel improvements at the Little Dalles.

Volume IX (1941) describes completion, to contract height, of the spillway training walls, final cooling of concrete, construction of the spillway piers and bridges; installation of drum gates and other mechanical and electrical features; excavation and removal of overburden in the left (west) tailrace area; placing of riprap on the west tailrace slide area; and miscellaneous work at the left powerhouse. Volume also covers relocation of county and state highways and the Great Northern Railway in the reservoir area, and river channel improvements at the Little Dalles. Also included in this volume are the WPA clearing project in the reservoir, the construction of migratory and game fish control facilities, and the installation of generating units and switching features at Grand Coulee Dam.
Volume X (1942) describes completion of the Consolidated Builders, Inc. contract, including the right powerhouse and transformer deck. The installation of two main generating units, and the completion of four additional power-transmission lines by the Bonneville Power Administration.

Volume XI (1943) describes installation of the fourth and fifth main generating units and two temporary Shasta units.

Volume XII (1944) describes a year of light construction in 1944, but one of maximum power output for war industries. The sixth main generating unit was placed in operation early in 1944 and all six main units plus two temporary units operating at nearly full capacity throughout the year.

Volume XIII (1945) describes another year of light construction. Maximum generation of power for war industries was continued until after the cessation of WWII in August. After this date, the demand for power decreased because of the shutdown of some war industries and the conversion of others from wartime to peace-time operations.
COLUMBIA BASIN PROJECT TIMELINE

Before 1902
U.S. Geological Service completes general reconnaissance of areas, elevations, artesian water supply, etc.

1896
Northern Pacific Railway Company completes preliminary engineering investigations of the Priest Rapids area.

1902 to 1916
U.S. Reclamation Service completes numerous surveys, reconnaissance and investigations for a water supply for various sections, including Palouse, Pasco, Priest Rapids, and Quincy areas.

1920
State of Washington finances engineering report and cost estimates by the Columbia Basin Survey Commission on an area of 1,753,000 acres to be irrigated by water diverted from Pend Oreille River and carried by a gravity canal 130 miles in length.

1921
Review by Board of Engineers, U.S. Reclamation Service, of plan proposed by Columbia Basin Survey Commission.

1922
State of Washington finances report by Engineer Willis T. Batcheller on power and pumping plans (at Grand Coulee) for areas ranging from 1,403,000 acres to 1,857,000 acres.

1922

1922
Federal Power Commission completes report on coordinating the efficient use of Columbia River water for irrigation and power purposes.

1924
U.S. Reclamation Service finances report on investigations by Engineer Homer J. Gault for irrigation of from 998,894 acres to 1,424,555 acres, considering both gravity and pumping plans.

1925
USDI finances review of previous reports and an independent engineering and economic investigation by Boards of Engineers appointed by Special Columbia Basin Commission, covering areas from 1,054,000 acres to 1,893,000 acres.

1925
Completion of report by the Special Columbia Basin Commission on the Gault investigation and the reports of the two boards of engineers.
**COLUMBIA BASIN PROJECT TIMELINE**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1927</td>
<td>B.E. Hayden, reclamation economist, cooperating with Professor George Severance of the State College of Washington, completes economic investigation of Columbia Basin project.</td>
</tr>
<tr>
<td>1931</td>
<td>Release of Army Corps of Engineers' comprehensive report of investigations covering a period of three years' work on the use of upper Columbia River for navigation, flood control, power and irrigation purposes.</td>
</tr>
<tr>
<td>1932</td>
<td>Chief Engineer Bureau of Reclamation reports on plan for irrigating about 1,200,000 acres in Columbia Basin by means of pumping from Columbia River at Grand Coulee.</td>
</tr>
<tr>
<td>March 3, 1933</td>
<td>Columbia Basin Commission is created by act of state legislature.</td>
</tr>
<tr>
<td>April 26, 1933</td>
<td>Elwood Mead advises President Roosevelt that a low dam could be constructed at Grand Coulee for $60,000,000 as a first-stage unit of the ultimate Columbia Basin Project.</td>
</tr>
<tr>
<td>July 16, 1933</td>
<td>Dedication ceremony marking the beginning of construction at Grand Coulee.</td>
</tr>
<tr>
<td>July 27, 1933</td>
<td>PWA includes the Grand Coulee Dam project in the program contemplated under Section 202 of the National Industrial Recovery Act and allocates $63,000,000 for the project.</td>
</tr>
<tr>
<td>September 16, 1933</td>
<td>Initial development of test pits and trenches.</td>
</tr>
<tr>
<td>December 1933</td>
<td>Goodfellow Brothers, of Wenatchee, Washington, subcontractor to David H. Ryan, initiates excavation at the dam site.</td>
</tr>
<tr>
<td>October 1934</td>
<td>Mason-Walsh-Atkinson-Kier Company (MWAK) commence active work at the dam site.</td>
</tr>
<tr>
<td>December 6, 1935</td>
<td>First concrete is poured in the Grand Coulee Dam.</td>
</tr>
<tr>
<td>April 17, 1936</td>
<td>Major slide begins in east forebay section.</td>
</tr>
<tr>
<td>August 24, 1936</td>
<td>Freezing operations begin at ice dam, at the toe of the east forebay slide.</td>
</tr>
<tr>
<td>March 17, 1937</td>
<td>Major leak develops in cell &quot;G&quot; of west cofferdam with inflow reaching 35 second feet. Flow is reduced to less than two second feet by April 30.</td>
</tr>
<tr>
<td>April, 1937</td>
<td>Ice Dam no longer needed and dismantlement begins.</td>
</tr>
</tbody>
</table>
Columbia Basin Project, Grand Coulee Dam & Franklin D. Roosevelt Lake
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(Page 55)

COLUMBIA BASIN PROJECT TIMELINE

May 1, 1937
Excavation of common overburden is completed and last yard transported on the conveyor system.

October, 1937
Final cleanup of bedrock in foundation area is completed

October, 1937
East Powerhouse substructure is completed.

February 7, 1938
Consolidated Builders, Inc. (CBI) is awarded the contract for Specification No. 757, covering completion of Grand Coulee dam, the left powerhouse, and pumping plant foundation, for low bid amount of $34,442,240.

March 21, 1938
The MWAK contract (foundation of high dam and power plants), is completed one year and 12 days ahead of schedule. Upon completion of contract, foundation excavation and river diversion were complete, concrete had been poured to a maximum elevation of 1010 in the abutment sections (just beneath the el.1024 construction trestle) and to elevation 945 in the spillway section with the exception of blocks 39 and 40 which were carried to elevation 1000. The power house foundations were completed to elevation 948.8 and the training wall to elevation 980.

June, 1938
Western Pipe & Steel Company begins construction of penstocks, at fabrication plant erected at Electric City (under Specifications No. 760).

1939
The Bureau of Reclamation reports that "in the construction annals of Grand Coulee Dam, the year 1939 will be outstanding because of the record-breaking concrete placing program... [and because] the control of the river at flood stage was successfully carried out by means of the spillway diversion channels."

April 22, 1939
Excavation is completed for pumping plant discharge tunnels.

May 25, 1939
CBI makes world-record concrete pour of 20,684.5 cubic yards in a continuous 24-hour run.

June, 1939
Excavation is completed at pumping-plant foundation.

September 20, 1939
For the first time, the entire flow of the Columbia River is diverted through the el. 934 outlet works.

October 6, 1939
First concrete pour in pumping plant foundation.

March 12, 1940
Installation of the 18' diameter steel penstock pipe is completed for the right powerhouse penstocks and the 12 14' inlet pipes in the pumping plant.
COLUMBIA BASIN PROJECT TIMELINE

May 31, 1940  
Installation of the 18' diameter steel penstock pipe completed for the left powerhouse penstocks.

August 2, 1940  
A number of blocks in the right abutment section of the dam are completed to their ultimate height at elevation 1311.06. The first cars drive along this completed portion of the roadway.

August 31, 1940  
Installation of the two 12,500 kv-a station service generators is begun at left powerhouse.

September 30, 1940  
Mining of raw aggregate at Brett pit is completed.

October 10, 1940  
Installation is begun on spillway drum gates.

October 31, 1940  
Atmospheric cooling tower is placed in operation to expedite concrete cooling.

October 31, 1940  
Contractor's mess hall at Mason City closes after six years of service.

December 10, 1940  
Bureau crews begin installation of the 150,000 hp. turbine at unit L-2 of the left powerhouse.

1941  
At close of 1940, approximately 98% of the required concrete is in place, with 35,000 cu. yds remaining to be poured. Tasks for 1941 include concrete placing for the spillway bridge, elevator towers, sidewalks and parapets, and gate-guide extensions for the outlet works; installation of spillway drum gates; removal of the overburden in the left tailrace slide area; and miscellaneous work at the left powerhouse.

March 22, 1941  
The two 12,500 kv-a station service units are placed in operation on the Bonneville transmission system. Celebration held for event.

April, 1941  
All concrete cooling and contraction joint grouting complete, except at twist adjustment slots.

July 15, 1941  
F. A. Banks, construction engineer for the Bureau of Reclamation, and Carl M. Smith, State Director of the Works Progress Administration, fell the last tree in the Columbia River Reservoir area.

April 26, 1941  
Excavation at the west tailrace slide area is completed.
COLUMBIA BASIN PROJECT TIMELINE

October 4, 1941  The first 108,000 kv-a generator (Unit L-3) is placed in operation on the Bonneville transmission system after a 6-day test period. The event is broadcast over the C.B.S. radio network.

October 14, 1941  Concrete placement of spillway bridge is completed, essentially marking completion of the dam.

October 16, 1941  Extra Work Order no. 42, providing for construction of the right powerhouse transformer deck, is issued to Consolidated Builders, Inc.

October 23, 1941  Consolidated Builders, Inc. begins dismantling the construction trestle on the downstream face of the dam.

December 12, 1941  Last concrete is placed under Specification No. 757.

December 29, 1941  Extra Work Order No. 44 (Right powerhouse construction) is issued to Consolidated Builders, Inc., as a wartime emergency construction project.

January 1, 1942  Consolidated Builders, Inc. turns completed Grand Coulee Dam turned over to the Bureau of Reclamation for operation and maintenance.
Appendix

Abbreviated Descriptions for Structures of the Columbia Basin Project
ABBREVIATED DESCRIPTIONS FOR STRUCTURES OF THE COLUMBIA BASIN PROJECT

Grand Coulee Dam is the key structure of the Columbia Basin Project, a multipurpose development utilizing waters of the Columbia River for power generation and irrigation. Irrigation works extend southward across the Columbia Plateau for 125 miles to the vicinity of Pasco, Washington, at the confluence of the Columbia and Snake rivers. In addition to the dam, principal project features include Franklin D. Roosevelt Lake; the Power Plant; the Pumping Station; Banks Lake and the feeder canal; North Dam; Dry Falls Dam; the Main Canal (including Pinto Dam and Billy Clapp Lake), West Canal, East Low Canal, and Potholes canals; O'Sullivan Dam; and Potholes Reservoir. In 1981, fifty years after initiation of work on Grand Coulee Dam, there were 333 miles of main canals, 1,993 miles of laterals, and 3,163 miles of drains and wasteways.

GRAND COULEE DAM AND THIRD POWERPLANT

Grand Coulee Dam is 5,223' long, 550' high, and (with the Third Powerplant) contains 11,975,000 cubic yards of concrete. The original dam was modified for the Third Powerplant by construction of a 1,170-foot-long, 201-foot-high forebay dam along the right abutment approximately parallel to the river. The spillway of the dam is controlled by 11 drum gates, each 135 feet long, and is capable of spilling 1,000,000 cubic feet of water per second. The dam also contains forty 102" diameter outlet tubes. Within the dam are 8.5 miles of inspection galleries and 2.5 miles of shafts.

FRANKLIN D. ROOSEVELT LAKE

The reservoir behind Grand Coulee Dam extends 151 miles northeast to the Canadian border and up the Spokane River, a tributary of the Columbia, to within 37 miles of Spokane, Washington. The total storage capacity of the reservoir is 9,652,000 acre-feet; of this capacity, 5,184,400 acre feet can be used to generate electricity.

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POWER PLANT COMPLEX

Power facilities at Grand Coulee Dam consist of a powerplant on both the left and right sides of the spillway on the downstream face of the dam, the Third Powerplant on the downstream face of the forebay dam, an 11.95/115-kilovolt switchyard, a 230-kilovolt consolidated switchyard, and the 500 kilovolt Third Powerplant cable spreading yard and switchyard located west of Grand Coulee Dam.

As constructed, the left and right powerplants contained a total of eighteen 108,000-kilowatt units, nine in each powerplant. Rewinding these units has increased the capacity to 125,000 kilowatts each. Three small station service units of 10,000 kilowatts each in the left powerplant increase the total to 2,280,000 kilowatts for the left and right powerplants.

The Third Powerplant has six units. The first three units are rated at 600,000 kilowatts each and the last three are rated at 700,000 kilowatts each, for a total of 3,900,000 kilowatts.

As modified in 1981, six of the 12 units within the pumping station (see below) are capable of either pumping water or generating power. In the generating mode, each of these units has a capacity of 50,000 kilowatts for a total of 300,000 kilowatts.

Prior to construction of the Third Powerplant and of a central 230-kilovolt, low-profile, consolidated switchyard, switchyards were located on each side of the river, with the right switchyard in the area now occupied by the forebay dam. From the new consolidated switchyard, power generated in excess of station requirements is delivered to the lines of the Bonneville Power Administration (BPA), a marketing agency for federally produced power in the Pacific Northwest.

PUMPING STATION

The pumping station lifts water 292' to 300' (depending on the level of the reservoir) from Lake Roosevelt to Banks Lake, via a 1.6 mile feeder canal (see below). Designed to accommodate 12 pumping units, only six were installed at the time of construction; each of these six units can lift 1,600 cubic feet of water per second. Between 1965 and 1981, an additional six pumping/generating units were installed, each of which can lift 1,700 cubic feet of water per second or, when reversed, produce 50,000 kilowatts of power (see Power Plant Complex, above).
BANKS LAKE AND FEEDER CANAL

Banks Lake, a 27-mile long equalizing reservoir, was created by building two rock-faced earthfill dams at the north and south ends of the Ice-Age channel of the Columbia River: the Grand Coulee. Major features forming and serving Banks Lake are the 1.6 mile feeder canal with a capacity of 16,000 cubic feet per second, North Dam, 2 miles west of Grand Coulee Dam, and Dry Falls Dam and Main Canal headworks near Coulee City, 29 miles south of Grand Coulee Dam. The feeder canal was reconstructed in the late 1970s, in association with the installation of reverse action pump/generators at the pumping station: the base width was increased from 50 to 80 feed and water depth reduced from 25 to 20 feet to accommodate wave action when the waterflow is reversed. The North Dam is 145' high and contains 1,473,000 cubic yards of rock and earth. The south dam (Dry Falls Dam) is 123' high and contains 1,658,000 cubic yards of rock and earth. The Dry Falls Dam headworks contain six 12'x18' radial gates.

MAIN CANAL

The 21-mile Main Canal begins at the headworks at Dry Falls Dam and ends at Billy Clapp Lake. It consists of unlined and concrete-lined sections. Two siphons, 1,038' and 1,041' long, and two parallel tunnels, 10,037' and 9,950' long, carry water to Billy Clapp Lake (maximum capacity of 19,300 cfs). This lake, approximately 6 miles long and formed by earthfill Pinto Dam, is a segment of the canal system. Below Pinto Dam, bifurcation works divide Grand Coulee Dam irrigation water between the West Canal and East Low Canal.

WEST CANAL

The 88-mile West Canal is one of two canals formed by the bifurcation of the Main Canal. It skirts the northwest edge of the project and is carried across the lower Grand Coulee through a large inverted siphon at the north end of Soap Lake. From Soap Lake, the canal continues around the upper margin of Quincy Basin to the northern base of Frenchman Hills where it passes through a 9,000' tunnel to the Royal Slope.

EAST LOW CANAL

The 82.4 mile East Low Canal also begins at the bifurcation of the Main Canal. It extends south in a contour course through the eastern uplands to a point just east of Moses Lake. As late as 1994, the Bureau of Reclamation anticipated extension of the canal to a point 8 miles northeast of Pasco.
O'SULLIVAN DAM AND POTHOLE RESERVOIR

O'Sullivan Dam, a large zoned earthfill dam, is located on Crab Creek 15 miles south of Moses Lake, Washington. The 27,800-acre/332,200 acre feet Potholes Reservoir collects return flow from irrigation in the upper portion of the project for reuse in the southern portion. A system of waterways on both the West and East Low canals provides a means of delivering water into Potholes Reservoir to supplement the natural and return flows.

POTHOLES CANAL

The Potholes Canal begins at the headworks of O'Sullivan Dam and extends 70 miles to the southwestern and south-central portions of the project. (Irrigation Blocks 2 and 3, comprising approximately 5,000 acres at the southernmost end of the South District, receive irrigation water pumped directly from the Snake (Block 2) and Columbia (Block 3) rivers.)
ADDENDUM TO: COLUMBIA BASIN PROJECT, GRAND COULEE DAM & FRANKLIN D. ROOSEVELT LAKE
Across Columbia River, Southeast of Town of Grand Coulee
Grand Coulee
Grant County
Washington

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
U.S. Department of the Interior
1849 C Street NW
Washington, DC 20240-0001
ADDENDUM TO: COLUMBIA BASIN PROJECT, GRAND COULEE DAM & FRANKLIN D. ROOSEVELT LAKE
Across Columbia River, Southeast of Town of Grand Coulee
Grand Coulee
Grant County
Washington

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

HISTORIC AMERICAN ENGINEERING RECORD
PACIFIC WEST REGIONAL OFFICE
National Park Service
U.S. Department of the Interior
333 Bush Street
San Francisco, CA 94104
ADDENDUM TO:

HISTORIC AMERICAN ENGINEERING RECORD

COLUMBIA BASIN PROJECT, GRAND COULEE DAM &
FRANKLIN D. ROOSEVELT LAKE

HAER No. WA-139-A

This report is an addendum to a 62-page report previously transmitted to the Library of Congress in 1997.

Location: Across Columbia River ¼ mile southeast of the town of Grand Coulee
Grand Coulee
Ferry, Grant, Lincoln, Okanogan, and Stevens Counties
Washington

Grand Coulee Dam is located between 47.953219 latitude, -118.989650 longitude and 47.960207 latitude, -118.976870 longitude. These coordinates represent the west and east termini, respectively, and were obtained December 30, 2013, using the Research Coordination Network UTM Converter.

Dates of Construction: 1933-42; forebay dam 1967-74

Engineers: Bureau of Reclamation

Original Owner: Bureau of Reclamation

Original Use: Dam

Present Owner: Bureau of Reclamation

Present Use: Dam

Significance: The Grand Coulee Dam is the most prominent component of the Grand Coulee Project, which was launched by the Bureau of Reclamation in the 1930s after decades of planning. It is the largest of a series of dams that controls the Columbia River and harnesses that river’s power to generate electricity. It also helps regulate the river’s flow to maximize power production throughout the system and plays a role in reducing flooding along the river. A pumping plant at the dam’s west end moves water up the steep walls of the river valley to irrigate arid but fertile farmland in eastern Washington State.
Grand Coulee reflects the aspirations, capabilities, and priorities of the United States through economic depression, war, and prosperity. It stands as a noteworthy monument to the minds and muscles of the thousands of people who created it. The Grand Coulee Dam, together with the Columbia Basin Project, have been in the international spotlight since the time they were conceived. As one indication of the project’s importance, it were named one of the top ten public works projects of the twentieth century by the American Public Works Association.

Project Information: This documentation study was initiated by the Bureau of Reclamation’s Pacific Northwest Regional Office in Boise, Idaho. Joseph Pratt was the contracting officer; Derek Beery, Mike Flowers, Sean Hess, Pei-Lin Yu, and Lynne MacDonald served as contracting officer representatives. Hess Roise and Company, a historical consulting firm based in Minneapolis, Minnesota, was the prime contractor for the project, with photography and delineation completed by subcontractor Clayton Fraser of FraserDesign, Loveland, Colorado. Charlene Roise, principal of Hess Roise, was the project manager and historian, with research assistance from staff historian Elizabeth Gales and staff researcher Penny Petersen. CH2M HILL’s Boise office provided editorial and other assistance, under the supervision of Mark Bransom, as a subcontractor to Hess Roise.

NOTE: Previous HAER documentation referenced only Grant County. This property is located in Ferry, Grant, Lincoln, Okanogan, and Stevens Counties.
1. INTRODUCTION

“The dam itself is the largest ever conceived. . . . In engineering scope it outranks the Panama Canal, and for sheer bulk is three times as large as the famed Gizeh Pyramid of Egypt, hitherto the biggest thing every built by man.”\(^1\)

The history of the Grand Coulee Project is long and complex. Any attempt to tell its story must choose a focus and let other facets go untold—or be doomed to never finish the tale. Since its conception, the project has spawned studies ranging from scholarly articles to popular histories to personal reminiscences. All have their place, adding to our understanding of this colossal undertaking.

The following report has been prepared for the Historic American Engineering Record. As a result, its emphasis is on the technological aspects of designing and building the dam, powerplants, pumping plant, and related facilities. This has required a look at things beyond the dimensions and capacity of structures and equipment to other factors that influenced the project’s construction—such as economic conditions that paved the political way for a federal investment that some saw as primarily a means to put massive numbers of unemployed men to work. Also relevant is the infrastructure needed to erect and operate the facility, including accommodations for the visitors who could spread the word about the project’s value.

2. THE GRAND COULEE

Fed by glaciers and melting snow, the Columbia River runs through Idaho, Montana, and Washington on the way from its source in British Columbia to its mouth in the Pacific Ocean. (See ILLUSTRATION 1: Columbia River Watershed.) Draining some 74,000 square miles upstream from Grand Coulee, the river displays dramatic fluctuation of flow, ranging from 17,000 to almost half a million cubic feet per second (cfs) (the number of cubic feet of water passing a given location during one second), and averaging about 109,000 cfs. Lakes along the way help to moderate these surges, keeping the river’s volume high throughout the summer months when water is needed for irrigation.\(^2\)

The river originally flowed south from what is now the northeastern corner of the state of Washington to the mouth of the Snake River. Millennia ago, lava flows forced the Columbia’s channel west below its junction with the Spokane River, creating the “Big Bend.” Land south of the bend was covered by a glacial lake, which deposited a thick layer of fertile soil, produced by volcanic ash. When the Cordilleran ice sheet temporarily changed the Columbia’s course, the river, swollen by water from the melting glaciers, carved out a long, broad canyon that became known as the Grand Coulee. These features—the river, the rich land, and the coulee—were to

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become the primary components of the massive irrigation and power project that took the coulee’s name. ³

The coulee comprised two sections divided by the “Dry Falls,” a geological oddity isolated by the changing course of the Columbia. (See ILLUSTRATION 2: The Grand Coulee.) As Harper’s Monthly Magazine reported in the 1930s: “The giant cataract was stranded as silent as the ages, its water-eroded walls telling, in the words of Dr. J. Harlan Bretz of the University of Chicago, ‘a heroic tale of vanished power and glory far transcending that of Niagara, and beggaring the leisurely story of the Yellowstone, the Yosemite, or even the Grand Canyon of Colorado.’ ” Above the falls was a canyon about thirty miles long, up to four miles wide, and 600' to 900' deep. At the falls, the coulee’s floor dropped by about 400' and the canyon broadened into a plain.⁴

The granite bedrock was covered by up to 200' of overburden lain down by glaciers. Beneath layers of sand and gravel was a thick bed of indurated—but unstable—clay. The Columbia cut through this clay, which had low shear strength, causing it to shift. Even after areas appeared to settle, disruptions to land in the vicinity could set the ground in motion again. Pockets of water trapped in lenses of sand and gravel within the clay amplified the movement.⁵ While the granite provided an excellent foundation for a dam, the instability of the overburden bedeviled the engineers and contractors working on the Grand Coulee Project.

The geological evolution produced rich soil, but unreliable rainfall made farming risky. This did not initially deter pioneers who settled in the area in the late nineteenth century. Soon thereafter, as the technology of hydroelectricity advanced, the farmers were joined by others who coveted the river for the power it could generate. Grand Coulee Dam was one of a series of dams planned to domesticate the wild Columbia. What set the Grand Coulee project apart from the rest was its scale. It would be one of the largest dams the world had ever seen, and the hydroelectric facility would be the world’s biggest. A colossal pumping plant would be needed to transport water from the river up the high, steep wall of the Columbia River Valley to a convenient landscape feature, the Grand Coulee, which would be dammed to serve as a reservoir for a massive irrigation project.

The dam that impounded the Columbia River would create a lake stretching 151 miles to River Mile 741, about four miles south of the Canadian border. With an average width of 4,650' and a shoreline of some 600 miles, the lake would hold 9.6 million acre-feet of water and flood about 70,500 acres of land. (An acre-foot equals the volume of water covering one acre to the depth of

one foot.) By the time the project was built, that land held “two railroads, three primary state highways, approximately 150 miles of county roads, eleven townsites, four sawmills, four telephone and telegraph systems, powerline facilities, and numerous cemeteries,” according to a Reclamation report. In the end, the cost to acquire the land was almost $5.7 million—the equivalent of almost $100 million in today’s dollars.\(^6\)

The project’s immense scale inspired superlatives from observers from the outset. Considering the 1.2-million-acre irrigation project, *Engineering News-Record* noted that “the development of this desert region will be equivalent to adding another state the size of Delaware to the Union.” A Reclamation publication proudly called it “the greatest, or at least the largest, river control structure thus far undertaken by the construction industry.”\(^7\)

Successfully designing and building these facilities demanded experience, discipline, creativity, and a modicum of luck. Reclamation staff and a host of consultants, contractors, and construction workers, have spent the past seven decades building and refining one of the man-made wonders of the world, the Grand Coulee Project. The seeds for the project, however, were sown much earlier.

3. COMPETING VISIONS FOR THE FUTURE

Grand Coulee’s history is inextricably tied to the larger context of the Columbia River Basin. The first Euro-American exploration of the Columbia was launched in 1804 by Lewis and Clark at the behest of President Thomas Jefferson. After reaching the river’s mouth in December 1805, they returned to broadcast the area’s potential. Captain Bonneville surveyed the region between 1832 and 1834, producing the first maps showing its hydrography. Further details were provided by other surveyors in the next decades. Particularly important was a map produced by Army engineer Lieutenant G. K. Warren in 1858 as part of planning for a railroad route to the Pacific Ocean. Intensive surveys directed by Army engineer Lieutenant T. W. Symons between 1878 and 1880 included Grand Coulee.\(^8\)

The potential of the Columbia for irrigation was obvious. The area was one of the first to be explored by the U.S. Reclamation Service after its establishment within the Department of the Interior in 1902. Investigations by Reclamation engineers on the feasibility of irrigating the “Big Bend” area of Washington were discussed in the agency’s earliest annual reports. They were not alone. By the 1910s, hardly a year went by without the appearance of at least one report on some subject related to irrigation—soils, geology, topography, vegetation, or water. The reports were prepared by a variety of experts and produced by an array of organizations in addition to

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\(^8\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 103-104.
Reclamation, including the U.S. Army Corps of Engineers, the U.S. Geological Survey, the Washington Geological Survey, the University of Washington, and the State College of Washington. Reports continued to proliferate in the following decade.⁹

The attention was welcomed by local residents. Large areas along the Columbia River had been settled during a period of heavy rainfall in the late nineteenth century, but many abandoned their farms during a subsequent drought, a more typical condition in the arid West. A dry-land farmer found graveyard humor in the abundance of water in a river so close but so inaccessible without a massive irrigation system: “That river is always a good place for a fellow to drown himself when he goes broke.”¹⁰

To sustain a stable population, local promoters were lobbying for an irrigation project by the early twentieth century. They got a major boost in the late 1910s when Rufus Woods, editor of the Wenatchee Daily World, began a tireless campaign to bring irrigation to the region. In 1919, the State of Washington created the Columbia Basin Survey Commission to study options for irrigation, make a recommendation for implementation, and push the federal government to proceed with the project. An appropriation of $100,000 supported the commission’s initial work. Two Reclamation engineers—D. C. Henny and James Munn—worked with the commission “as consulting engineers to cooperate in the study of general features of the work.”¹¹

The formation of the commission brought into sharp focus competing visions for the development of the upper Columbia River. The commission adopted the views of one camp, which advocated for a massive gravity irrigation system. On the other side were proponents of a dam and pumping plant at Grand Coulee. This alternative was initially favored by Reclamation as well as the U.S. Army Corps of Engineers. Underlying the conflict was the issue of waterpower. Most staff members of the Columbia Basin Survey Commission were employed by the Washington Water Power Company, the region’s electricity provider. They opposed the construction of a dam at Grand Coulee because it could create a competing hydroelectric facility. The prospects for Grand Coulee were further weakened by conflict between the two federal agencies that supported the development, with each vying for control. Federal hydroelectric development was traditionally the realm of the Corps, but Reclamation had increasingly incorporated hydroelectric plants into projects to support its core mission of irrigation.¹²

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⁹ Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 1-14, 68-69. The agency’s name was changed to the Bureau of Reclamation in 1923.


Not too surprisingly, when the commission’s report was issued in 1920, it proposed to irrigate some 1.75 million acres—potentially encompassing 20,000 to 40,000 farms, depending on their size—with a gravity system fed by the Pend Oreille River. To ensure that water would be available year round, concrete dams would be built to maintain the level of the Flathead Lake in western Montana and the Pend Oreille Lake in northern Idaho. Together, these reservoirs would provide about 2.6 million acre-feet of storage. A series of smaller dams would provide additional storage and control. Water would be transported and distributed through about 200 miles of existing waterways and a new network of concrete-lined main canals and tunnels extending more than 130 miles. Some elevation changes along the canal system could be used to generate hydroelectricity to power pumps for supplemental irrigation of about 90,000 acres, but hydropower was otherwise excluded from the project.  

The feasibility of a pumped irrigation system at Grand Coulee was considered in an appendix. The report found many things to criticize including an assumed cost of $60 million to $75 million, technological challenges inherent to the site, logistical problems related to constructing the dam and pumping plant, and the ongoing cost of operating the pumping system. The report ignored the potential income from the sale of power generated at Grand Coulee. In the end, the commission found that the construction of the dam was “impracticable and perhaps impossible” and dismissed the Grand Coulee alternative as inferior to the Pend Oreille gravity project.

Reclamation appointed a board of engineers—including Henny and Munn—to evaluate the report’s findings. The board took issue with some of the study’s assumptions. No interest expense was factored in during construction of the gravity system, for example, and the cost of raw land appeared to be underestimated. As a result, the engineers questioned the report’s conclusions, finding the cost per acre of the gravity scheme to be 9 percent too low and the cost of the pumping plan 5.5 percent too high. Reclamation did not publicly endorse either of the alternatives, but Grand Coulee was clearly favored by Arthur P. Davis, who had served as Reclamation’s chief engineer since 1907 and director since 1914. With a multipurpose dam, the generation of power helped support the cost of the entire project.

The Grand Coulee option retained momentum. One of the first actions of the state’s Department of Conservation and Development, which replaced the Columbia Basin Survey Commission in

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1921, was to conduct diamond drill investigations of the potential dam site to gain a better understanding of bedrock conditions. Although working with a limited budget of $50,000, the study produced fourteen test holes totaling 1,925 linear feet. Bedrock was discovered around elevation 880, some 40 feet below the center of the river channel.\(^\text{16}\)

At the same time, the new department was examining alternatives for providing power to the potential Grand Coulee pumping plant. Reclamation’s Henny was again tapped to serve on the oversight board along with consulting engineers Joseph Jacobs, J. C. Ralston, and A. J. Turner. Willis T. Batcheller, an electrical engineer, was retained in August 1921 to consider three locations on the Columbia River for the new powerplant. One was about fifty miles downriver from Grand Coulee, near Foster Creek. The other two were at Grand Coulee. One assumed that power would be generated at a plant at the dam and transmitted to pumps in a forebay, while the second envisioned turbines directly connected to the pumps. Batcheller analyzed the results of a number of different variables including the acreage to be area irrigated, the height of the dam, the size of storage, and the capacity of the turbine-generator units. All led to the same conclusion: any of the pumping alternatives would be more economical than the gravity plan if hydroelectricity was generated and sold commercially. He endorsed the construction of the power and pumping plants at Grand Coulee in a report submitted in February 1922.\(^\text{17}\)

Batcheller’s findings were cheered by landowners and business interests in the western part of the irrigation district who felt that they would be better served by the pumping plan. They formed the Columbia River Development League in 1922 to promote the Grand Coulee alternative, incorporating a powerplant to produce commercial power as well as the power needed for the pumping plant. Although Batcheller’s report was not published, its results were widely disseminated by the league and its tireless executive secretary, James A. O’Sullivan.\(^\text{18}\)

The matter, though, was far from settled. A subsequent study, also commissioned by the Department of Conservation and Development, buoyed proponents of the gravity plan. It was prepared by the George W. Goethals Company, whose principal was best known as the chief engineer of the Panama Canal. The study reassessed the findings of both the Batcheller and the Columbia Basin Survey Commission reports and concluded that the gravity plan offered the least expensive and least complicated alternative. Reclamation, which clearly favored the pumping option, cried foul: “General George W. Goethals arrived in the state, spent two days on the project and as many in the office, signed a report prepared by the office engineer for the former

\(^{16}\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 24-25.


Columbia Basin Commission in which the gravity plan was recommended, filing the report on March 30, 1922, for which he was paid $25,000.19

A change in the Department of the Interior’s administration soon reversed Reclamation’s course. Secretary of the Interior Albert Fall was forced out of office in early 1923 because of the Teapot Dome scandal. His replacement, Hubert Work, was a politically savvy physician whose assistant secretary, Francis M. Goodwin of Spokane, sided with the gravity plan backed by the Spokane-based Washington Water Power Company. Reclamation’s pro-pumping director soon found himself out of a job. It would be years before Reclamation’s administration would again back the pumping plan.20

By this time, a new agency, the Federal Power Commission, had joined the fray. Created in 1920, the commission almost immediately made the Columbia River basin a priority. In January 1921, it convened a board of engineers representing interested state and federal agencies: the U.S. Army Corps of Engineers, Reclamation, the U.S. Geological Survey, the Idaho Department of Reclamation, the Montana State Engineer, and the Washington State Supervisor of Hydraulics. The chair was Colonel J. B. Cavanaugh of the Corps, with D. C. Henny representing Reclamation. The board’s mission was to study the upper river’s current use and potential for navigation, irrigation, and power. Furthermore, the board was to “outline a program of development to harmonize any conflicting uses in a manner that would secure the greatest combined benefit from all,” and to evaluate the effects of the gravity and pumping plans on the river’s hydroelectric potential. In a report issued in June 1922, the board concluded that irrigation should claim the highest priority for the river’s use. It did not, though, come out in support of either gravity or pumping, saying either were feasible and that more information was needed to decide between the options.21

Yet another form of federal involvement appeared in March 1923, a few months before Davis was dismissed as the head of Reclamation. Congress created the Columbia Basin Commission, including the Commissioner of Reclamation and the Assistant Secretary of the Department of the Interior as members, and appropriated $100,000 to cover its costs. Some of these funds went into yet another study, this time directed by Reclamation engineer Homer J. Gault, with extensive fieldwork investigating soils, geology, and water supply for two options: the gravity system, utilizing Albeni Falls on the Clark Fork River, and the pumping plan at Grand Coulee. For the gravity system, the study looked at several locations for the main canals and the need for supplemental pumping and storage. A number of proposals that the study chose not to consider

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included the so-called “Southard Plan, which contemplated a dam in [the] Columbia River at Grand Coulee 400 feet above low water, or up to elevation 1,343 feet.”

Gault was assisted by experts from other agencies including Kirk Bryan, a U.S. Geological Survey geologist. Bryan evaluated sixteen proposed lakes or reservoirs and twenty-seven possible locations for a dam. He found seven reservoirs to be watertight, and ruled out six as having an unacceptable amount of leakage. Grand Coulee fell in neither category: the reservoir “will probably not leak seriously, but if leakage occurs, it cannot affect the stability of the dam, and will be localized in the area of the Coulee Monocline where blanketing is feasible at a large but measurable expense.” Likewise, the Grand Coulee dam site was “in part” situated on a desirable layer of “hard and relatively tight bedrock [that] can be reached within a practical working depth.”

Gault gathered information, but the responsibility for making conclusions was left to a reviewing board of engineers comprising A. J. Wiley, James Munn, and John L. Savage—all appointed by Reclamation’s chief engineer. The board endorsed the all-gravity plan, with water diverted from Clark Fork at Lake Pend Oreille. The Grand Coulee pumping option was rejected. In part this was because, despite Bryan’s findings, the board thought the reservoir might have substantial leakage, requiring an expensive, twenty-eight-mile canal to circumvent the problem area. Ultimately, though, the board concluded that none of the alternatives were economically viable. In the meantime, until conditions changed and the development became feasible, the board cautioned against the construction of powerplants that would restrict the plan’s implementation, and encouraged continued work on topographic surveys.

Gault submitted his report in March 1924, just as Reclamation’s leadership was undergoing another transition upon the departure of David Davis, who had replaced Arthur Davis only a year earlier. David Davis was a banker and politician in Idaho, serving as governor of the state immediately before taking the helm at Reclamation. His successor, Elwood Mead, had a stronger background for the job, earning a doctorate in civil engineering in 1883 and working for decades on irrigation-related issues in the public and private sectors. The debate over the fate of the upper Columbia would be resolved during Mead’s long tenure, which extended to 1936.

The decision was far from clear, however, in February 1925, when a board appointed directly by the Columbia Basin Commission issued a review of Gault’s study. The board included

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22 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 35-40. Albeni Falls was known as “Albany Falls” at that time.
representatives from states not directly involved with the project—Louis C. Hill of California, Charles H. Locker of Maryland, and Richard R. Lyman of Utah—as well as Joseph Jacobs, A. J. Turner, and O. L. Waller from Washington. All were apparently appointed by Assistant Interior Secretary Francis Goodwin. Again, the pumping and gravity plans were considered. The pumping plan included the costs of building and constructing the powerplant but did not consider income from the sale of electricity, making it far more expensive than the gravity plan, which the board favored. Like the board of engineers, though, it concluded that the project was not justified at the time.26

The Columbia Basin Commission conveyed the reports prepared by Gault, the board of engineers, and reviewing board to the secretary of the interior in August 1925. In its transmittal, the commission emphasized that the project was ultimately desirable, but that conditions were not yet right to proceed. Among other issues, the commission “felt that the Bureau did not have the information or experience to develop as costly and complex a program as the one outlined and advocated.”27

Numerous studies by Reclamation, the Federal Power Commission, the U.S. Army Corps of Engineers, and others followed. One of the problems with all of the studies, and a reason for the great divergence of financial conclusions, was that little was known about the agricultural potential of the area proposed for irrigation. With a small appropriation from Congress in 1926 supplemented by funds from the State of Washington, a committee with representatives from Reclamation, Washington’s Department of Conservation and Development, and Washington State College oversaw a study of six typical tracts within the project area. Among other issues, the study considered land classification (based on slope, depth of soil, fertility, topography, and drainage), land values, the costs for developing farms and their size, the types of crops that might be grown, the national demand for these crops, and the area’s transportation infrastructure. The team concluded “that surveys and investigations had not progressed to the point where reasonably accurate estimates could be made of irrigable area and construction cost.” The study did posit, though, that the gross crop value would be $32 to $40 an acre, resulting in a net income of $6 to $10 an acre.28

4. POWER SHIFT: THE BUTLER REPORT

The Corps of Engineers soon added a pair of reports to the growing library generated by the ongoing battle between the pumping and gravity interests. The Corps’s reports, however, were to prove among the most influential. Authorized by the Rivers and Harbors Act in March 1925, the first report examined the potential of the nation’s navigable streams and their tributaries for the

27 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 44.
additional uses of waterpower, flood control, and irrigation. On the basis of the findings of that report, issued in April 1926, Congress directed that detailed surveys be made of the rivers recommended in the initial study.  

Major John S. Butler, the Corps’s engineer for the Seattle-based Pacific Northwest district, deployed a host of professionals to prepare the report. From the Corps’s staff were two civil engineers, three hydroelectric engineers, an irrigation engineer, an electrical engineer, and a hydraulic engineer. They were joined by three consulting engineers, three consulting geologists, two consulting electrical engineers, a consulting economist, and the U.S. Geological Survey’s Pacific Northwest District Engineer.

The team’s findings and conclusions, commonly known as the Butler report, ran 1,845 pages and filled two volumes. More than 500 pages focused on the Columbia above the mouth of the Snake, including 240 plates, 25 photographs, more than 200 tables, and a 300-page appendix. Released in 1931, the report made its way slowly through the bureaucracy, finally reaching the House of Representatives in June 1933, where it was printed as House Document 103, 73rd Congress, first session.

Its preparation had taken slightly longer than Congress’s review. For the Upper Columbia, members of the team had conducted preliminary investigations on numerous irrigation alternatives between April 1928 and February 1929. In June 1929, the options were narrowed to seven for intensive evaluation—five using gravity (or gravity after initial pumping), and two with pumping and repumping.

Three of the gravity plans (Plans 1, 2, and 2-A) proposed to divert water from the Clark Fork of the Columbia River at Albany Falls, Idaho, near the Washington State border, or from a combination of the Clark Fork and the Spokane River. The water would be delivered some 130 miles through a series of open canals, 33 miles of tunnels, six reservoirs, inverted siphons, and a viaduct over the Spokane River to Ritzville, where it would be distributed to smaller laterals. Two of these plans would irrigate 1,519,890 acres, including 262,950 acres requiring pumping. Pumping was not in the third plan, which covered 1,256,940 acres. All of these options required storage reservoirs, which would be created from Pend Oreille Lake or Priest Lake in Idaho or Flathead Lake in Montana. A fourth gravity option (Plan 6-A), used two shorter canals to obtain

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water from the Clark Fork and the Spokane and Wenatchee Rivers. This alternative irrigated 1,449,700 acres, of which 243,120 acres were pumped.  

The other three plans centered on Grand Coulee. They featured many elements of the irrigation system that was ultimately built, revealing an early consensus among engineers about the project’s overall design. A pumping plant situated on a forebay just upstream from the dam would lift water to a 1.67-mile feeder canal, which would empty into a balancing reservoir with a capacity of 339,000 acre-feet. Extending about 23 miles and contained at each end by earth and rock dams, the reservoir “would replace an otherwise costly canal, 24.4 miles in length,” a project history explained. The main irrigation canal extended from the reservoir for 10.2 miles, then divided into East and West Canals. In Plan 4, repumping was used along both the 156-mile East Canal and the 101-mile West Canal, which increased the area served by 243,120 acres to a total of 1,449,700 acres. Plan 4-A shortened the East Canal and used a supplemental pumping plant at Bend, in central Oregon, just east of the Cascade Mountains, to obtain water from the Columbia to irrigate 140,250 acres in the vicinity, resulting in a total of 24,800 acres less than in Plan 4. Plan 3, a gravity option, involved no supplemental pumping and served only 980,340 acres.  

While engineers agreed on the general elements of the irrigation system, the inclusion of two alternatives for the dam’s height foreshadowed a debate that was to carry on even after the project was under construction. One camp advocated for a high dam with a normal forebay elevation of 1287.6 that would create a 151-mile-long reservoir extending almost to the Canadian border. The other group called for a low dam with a normal forebay elevation of 1157.6. Its pool would reach only to Kettle Falls, another potential hydropower site.  

Regardless of the dam’s height, the Grand Coulee pumping options appeared to be the cheapest by far. Per acre costs were $178.40 to $184.76 compared to more than $300 for the gravity alternatives. The Butler report concluded that the gravity plans were not economically feasible but that both of the pumping plans (4 and 4-A) were. Plan 4-A was preferred because it offered more flexibility for phased development.  

The Butler report concluded that irrigation improvements were not financially feasible without power development, which would help to subsidize the cost, and that the Columbia’s highest potential was for power generation. Irrigating adjacent lands came in second—even though, as a Reclamation report noted, “irrigation is considered a more beneficial use of water than power generation.” The good news was that they could have it all. “The unusual climatic conditions of the Northwest are largely responsible for the exceptional water resources of the Columbia and its

principal tributaries. The heavy precipitation in the high altitudes of the upper reaches insures ample water to meet all possible irrigation requirements and furnishes an abundant and well regulated supply for electric power, estimated to be about one-sixth of the potential power of the Nation.\footnote{37}

This assumed that the flow of the Columbia and its tributaries would be allocated efficiently. As Herbert Hoover observed in a speech in Seattle, when he served as U.S. Secretary of Commerce: “We must no longer think in single terms of single power sites, or single storage plants, or single land projects, or single navigation improvements, we must think (and thanks to science and engineering we can think) in terms of the coordinated long-view development of each river system to its maximum utilization.”\footnote{38}

The Butler report stressed that the development of the Columbia River should be approached holistically. The elevation of the “upper Columbia”—the section between the Canadian border and the mouth of the Snake River near Pasco, Washington—dropped 975’, providing many potential locations for dams. “After a large number of possible dam sites on the main river were investigated, ten sites were chosen as best meeting the essential requirements for a comprehensive scheme of improvement,” according to Thomas Robins, engineer of the Corps’s Pacific Division in San Francisco.\footnote{39}

Two of the dams would primarily serve navigation. They would be constructed “at points 14 and 40 miles above the mouth of [the] Snake River, when commerce would justify canalization up to [the] vicinity of Wenatchee.” There was little prospect for navigation further upstream, though. Numerous rapids, a swift current, steep banks, and sparse population of the surrounding area were among the factors discouraging waterborne commerce. “The steep slope in the Columbia—about five times that of the Ohio nor Tennessee Rivers—would make the cost of locks and dams high,” \textit{Civil Engineering} reported.\footnote{40}

The remaining eight dams had a broader purpose. While some would benefit navigation, they might also “permit irrigation of large tracts of land; and would reduce flood heights along the tidal section of the river.” More importantly, however, these dams could impound water for hydroelectric facilities. “The Columbia is the second largest river in the point of average annual run-off in North America and is the largest in the point of potential horsepower,” a Reclamation


\footnote{40} Butler, “Comprehensive Study,” \textit{Civil Engineering} 1 (September 1931): 1079.
report observed. “It can truly be considered as the greatest natural resource in the United States west of the Rocky Mountains.”

To take best advantage of this resource, the dams would be placed strategically at Grand Coulee, Foster Creek, Chelan, Rocky Reach, Rock Island, Priest Rapids, the Dalles, and Cascade Rapids. In forming the only significant reservoir on the system, Grand Coulee was the lynchpin in maximizing the river’s hydroelectric potential. By regulating the flow of the river, this reservoir could improve the performance of plants downriver: “With its regulation, the power capacity of these nine projects is increased from 2,558,000 kW [kilowatts] to 3,500,000 kW, and their installed capacity, if twice the power capacity, is raised from 5,080,000 kW to 7,000,000 kW.”

Engineers predicted that this arrangement would result in the use of 92.3 percent of the total low water fall of 1,288', with a total installation of 9.5 kilowatts meeting a demand for more than 41 billion kilowatt-hours (kWh) by 1960—at only a 50 percent load factor. This figure, which assumed a 1,000 percent increase in demand between 1930 and 1960, perhaps seemed overreaching to some; it was “more than half . . . the total amount of power used in the United States in 1932,” according to a contemporary article in Electrical West.

Of course, these dams could be used for irrigation as well, although “as a business proposition irrigation of the land is not feasible at this time, nor does it appear to be justified,” Engineering News-Record reported. The economics of hydropower, on the other hand, compared very favorably with steam-generated power. Steam came in at 4.51 mills with a 55 percent load factor and 3.62 mills with an 85 percent load factor, assuming that fuel oil cost $1 a barrel. The Corps calculated the equivalent figures at the Grand Coulee project were 1.52 and 1.38 mills.

There was, however, a downside to the large-scale vision of the federal agencies—particularly from the perspective of regional utilities. A key problem was demand—or, more specifically, a lack thereof. Colonel Robins of the Corps explained that “the great expenditure and the large blocks of power involved in developing these hydroelectric projects, particularly the larger ones, is an unattractive feature to power companies unless Federal financing is authorized. For many years to come these companies can find sites on tributary streams that will furnish cheap power in blocks more suitable to their market requirements.”

While the report’s conclusions related to power generation and irrigation raised controversy, there was virtually no debate when it came to navigation and flood control, two other issues that

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45 Robins, “Improvement of the Columbia River,” 566.
the Corps had been directed to consider. The report noted that in planning the Columbia’s
development, flood control was of minor concern, and not needed at all above the mouth of the
Snake River. As for navigation, only the stretch below the Snake River was considered worth
developing, and the two downstream locks would take care of that.\textsuperscript{46}

The Butler report was a watershed in the gravity versus pumping debate. This was underscored
by another report prepared under the supervision of Reclamation’s chief engineer, Raymond F.
Walter, that was included in the House document. In the report, which was issued on January 7,
1932, Reclamation did a remarkable about-face, coming out in favor of the pumping plan with a
major hydroelectric component, specifically Plan 4. \textit{Engineering News-Record} noted that this
endorsement “departs fundamentally from the bureau’s earlier reports in that the gravity supply
of irrigation water is abandoned for a pumped supply in which the development of power
becomes a major factor.”\textsuperscript{47}

In reviewing the Columbia Basin project, \textit{Electrical West} observed: “Cheap power is the
government’s primary consideration in this tremendous program. . . . The program as a whole
and in several of its component parts is larger than anything previously undertaken by the federal
government for social betterment. It appears to be a frank experiment designed to force
economic growth as marketing analyses will show. Whatever the results may be, no one can
question that they will have far-reaching effects on the people of the Northwest and perhaps on
our national social structure.”\textsuperscript{48}

An increased focus on power generation had come about gradually, paralleling the organization’s
transformation from the Reclamation Service to the Bureau of Reclamation in 1923. A decade
later, Reclamation’s Denver headquarters occupied “three top floors of the new United States
Customhouse.” A visiting engineer observed that “the organization in a comparatively short time
has grown to be the largest engineering body in the United States employing 460 engineers
where formerly about 60 served.”\textsuperscript{49}

A Reclamation engineer later reflected: “In the course of constructing its very earliest irrigation
projects, the Bureau built its first power plants. They were small, and were designed to provide
power during the construction period, and thus to reduce costs. Later, power developments were
undertaken to provide energy for pumps used in irrigation and drainage. In more recent years, the
development of power has, in some instances, become an inseparable part of the economic plan
of the projects. This has resulted from the fact that the projects to be undertaken have become

\textsuperscript{46} “Western Engineering Problems Discussed by Civil Engineers,” \textit{Engineering News-Record} 109 (July 14, 1932): 52; Robins, “Improvement of the Columbia River,” 563.

\textsuperscript{47} “Columbia Basin Project Reported Feasible,” \textit{Engineering News-Record}, June 30, 1932, 907; Bureau of

\textsuperscript{48} “8,000,000 Kw. Goal of Columbia River Development,” \textit{Electrical West} 72 (February 1934): 17.

\textsuperscript{49} A. F. Darland, consulting engineer (Tacoma), Columbia Basin Project, December 18, 1933 report on conference
at Bureau of Reclamation-Denver, December 2 and 4, 1933, page 1, with cover letter to E. F. Banker and J.
O’Sullivan, January 20, 1934, at RG 115, NRG-115-00-148, Box 1, Folder 510, NARA-RMR.
progressively more and more complex, and power revenues have been needed in some cases to reduce the charges against the land, and thus to make the projects economically feasible.” While noting that “the primary work of the BR is and probably always will be chiefly the development of irrigation water supplies, and the creation of new homes and communities in the arid West,” he added: “Where it is possible to develop power in connection with irrigation improvements, power must be considered.”

This change of mindset was epitomized by the Boulder Canyon Project on the Colorado River (now known as Hoover Dam). When Congress authorized the project in 1928, Reclamation had, for the first time, a green light to build and operate both a major dam and a major hydroelectric facility, as well as a substantial irrigation system. As historian William deBuys observed, “For the Bureau of Reclamation, now emerged from the chrysalis of the Reclamation Service, it was the start of a redefined mission and identity.”

Commissioner Mead later acknowledged that “until we came to the Colorado River, we never had nerve enough to think of terms of hundreds of millions of dollars of expenditures.” For the Columbia River, the gravity plan “was the cheapest plan to start,” but then “we came to realize that, while the greatest value to the country is the building of agricultural population, the best way to make it possible, without putting heavy burdens on irrigation, is to join power development with irrigation development. . . . The financial return from power in these works creates solvent investment for the Government and it has a social value in giving better light and power in farm houses and helping to pay the irrigators’ charges.”

Although Grand Coulee was a big step in Reclamation’s growing reliance on power, rather than irrigation, as the economic engine for its projects, Mead had embraced this conclusion before Reclamation’s report went public in 1932. In an October 1931 letter to James O’Sullivan, executive secretary of the Columbia River Development League, Mead confided: “I have always felt that power was destined to be the most important factor in determining financial feasibility” of the Grand Coulee project.

Reclamation’s change of heart was publically documented in Walter’s 1932 report, which included fifteen tables and nineteen drawings in its seventy-two pages. In addition to examining the Butler report and reviewing earlier reports completed in-house and by other groups, Reclamation conducted additional investigations. Existing information on foundation conditions at the dam site “was considered as too meager,” so Reclamation’s due diligence included

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50 Frank A. Banks, “Development of Power at Grand Coulee Dam,” 2, 9, speech at Reed College, Portland, Oregon, July 5, 1938, typescript of text at Frank A. Banks Papers, Washington State University, Pullman (hereafter cited as FAB Papers).
53 Elwood Mead to James O’Sullivan, letter, October 8, 1931, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 542, NARA-RMR.
“drilling 48 vertical holes, 8,400 linear feet; ten inclined holes, 8,000 linear feet; trenching 550 feet of open cut, and excavating four test pits averaging 150 feet deep.” Prior to such testing, there had only been sixteen diamond drill holes done to investigate the site, including only two by the Corps in 1930.  

The new tests, combined with data from earlier studies, resulted in a better understanding of the site: “It was believed that bedrock of a fine-grained dense, hard granite was at approximate elevation 880 across the floor of the channel, with side slopes of about 1-1/2 to 1 at abutments, and that it would be necessary to remove from five to fifteen feet of unsound rock from the floor and abutments. From twenty to seventy feet of fine-grained clay appeared to lie above bedrock at about elevation 880, affording a watertight connection for sheet piling in cofferdams. Above the bedrock was an overburden of clay, sand, and gravel from a few feet to 100 feet in depth.” Removing this overburden would be a major task in the project’s construction. Reclamation engineers also noted “two main depressions . . . in bedrock, about 100 feet in depth from [the] channel floor level, but no indications of faults.”  

These conditions caused Mead to feel confident in advocating for the construction of a 450-foot high, 4,100-foot long dam, which would raise the water 355' above the normal low water level and create a 5 million acre-feet reservoir stretching more than 150 miles to the Canadian border. The reservoir could be drawn down 80' in times of low runoff to power the fifteen turbine-generator units planned for the Grand Coulee powerplant, operating at an average head of 330'. Just over half of the 2.1 million horsepower generated by the plant would be sold at a rate of 2.25 mills per kWh to outside customers, while 1 million horsepower would be dedicated to irrigation pumping at a charge of $1 per acre. Firm power of 800,000 kW was assumed. If these predictions held true, cash flow after operations, maintenance, and depreciation charges would repay the cost of the dam and powerplant within fifty years, given an interest rate of 4 percent.  

Mead mentioned the project’s multiple functions in his cover letter transmitting the report to the Secretary of the Interior, describing it as “a combination of power and irrigation, with improvements of navigation and flood control as incidental features.” He made it clear, though, that the dam and powerplant would precede the irrigation program. The cost to construct the dam and powerplant was estimated at $185,890,000. Only after the dam and powerplant were in place would Reclamation consider the irrigation component, which encompassed 1.2 million acres—“the largest and finest body of unreclaimed land left in the United States.” Competing this phase would take $208,265,000, about $174 an acre.  

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57 Elwood Mead to the U.S. Secretary of the Interior, letter, January 14, 1932, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 542, NARA-RMR.
Mead concluded that the project was justified even though Reclamation’s assumptions about the demand for power were more conservative than those of the Corps. The Corps had predicted that demand would increase at a rate of 9.5 percent in 1930 but would decline thereafter, reaching a rate of 4.75 percent in 1960. During the same time span, Reclamation assumed rates of 8 and 4 percent, respectively. Even with these lower numbers, Reclamation projected that the existing supply of power generated by municipal and private utilities would be absorbed by 1940, and Grand Coulee would cover only half of the anticipated increase after its completion, with all of its power being absorbed in fifteen years. 58

Mead’s letter acknowledged that “the feasibility of the project depends . . . upon the demand for power and the ability of the power market to absorb the power within a reasonable period after completion of the dam and on the negotiation of contracts for this power before construction begins.” As planning for the project proceeded, assumptions about demand and a wide range of additional factors were modified. The phasing of the development and its ultimate size and configuration changed in response. 59

As of early 1934, Reclamation envisioned a completed facility with fifteen 105,000-kW main generating units, each “driven by a 147,000-hp reaction turbine at 120 r.p.m. Each unit will have an individual governing system, its own direct connected exciter, and each will feed its own transformer bank at 22,000 volts which voltage will be stepped up to 220 kV for transmission.” Initially, only three of the main units would be installed. Reclamation anticipated installing one additional unit a year, bringing the project up to its full capacity of 7 billion kWh in the twelfth year. 60

To supply the irrigation system, a pumping plant would be built on the left forebay of the dam. Five turbine-generator units in the powerplant would be dedicated to powering 33,000-horsepower motors direct-connected to single-stage pumps, rated at 800 cfs under a head of 370'. “The motors were of the synchronous type and of the same voltage as the generators, in order that the pumps could be operated at the most efficient speed under the varying conditions of head.” The facility would be designed to hold twenty pumps. 61

The pumps would lift water to a 1.7-mile canal that would feed a 329,000-acre-foot reservoir formed within the Grand Coulee. Using this natural feature would be far cheaper than constructing a canal, assuming that leakage was not major problem—an issue disputed by geologists. The reservoir could balance disparities between the supply of the pumps and demands of irrigation, and could be drawn down 15.2' if the pumps were out of service or the run-off level

59 Elwood Mead to the U.S. Secretary of the Interior, letter, January 14, 1932, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 542, NARA-RMR.
60 “Grand Coulee: The Key to Columbia River Power,” Electrical West 72 (February 1934): 19.
was low. The reservoir would be formed by constructing earth-fill dams on the north and south ends of the coulee that would rise 92' and 97', respectively. Featuring “unusually flat slopes,” the dams would be reinforced on the water side by 30' of rock riprap over 12' of gravel. Bank-to-bank cutoff walls formed from steel piling and concrete would provide further reinforcement. Twelve-foot embankment free-boards would be topped by a 3' concrete parapet wall. Stoney gates would control an emergency wasteway at the upper dam and the outlet to the main supply canal at the lower dam.62

A main canal would extend eleven miles from the reservoir, then branch into two supply lines that would feed a distribution system to the irrigated area—829,000 acres on the East Canal, 371,000 acres on the West Canal. Pumps would be required to raise water to about 219,000 acres of higher ground. All in all, the irrigated area would be twice the size of Rhode Island.63

By the time Reclamation’s 1933 annual report was issued, the cost of the dam and powerplant had dropped slightly to $168,366,000 from the previous year’s estimate of $185,890,000, while the irrigation project still stood at $208,265,000, for a combined total of $376,631,000. Quincy Flats, some 150,000 acres in the northwest corner of the irrigation project, was the first in line for irrigation. Blocks of 20,000 acres would be completed at a time, with the assumption that the first increment would be irrigated the year after completion of the dam at Grand Coulee.64

5. THE HEIGHT FIGHT

Adoption of the pumping plan ended that controversy, but another soon emerged over the height of the dam, which had implications for irrigation and power. It also presented different engineering challenges. Regardless of its height, the dam would be confronting a powerful force, a load flow of some 1 million cfs. “The kinetic energy of such mass of falling water—from 12,000 to 20,000 hp. per lin. ft. of dam—is believed to be without precedent,” Butler noted in an article in Civil Engineering.65

The Corps’s study had included two alternatives: “The low dam would have an average static head of 210.4 feet, a firm power capacity of 478,000 horsepower, and a projected installation of 1,230,000 kilowatts. The average head of the high dam would be 340.4 feet, the firm power

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64 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 64.

65 John S. Butler, “Comprehensive Study by Army Engineers,” Civil Engineering 1 (September 1931): 1080.
capacity, 773,000 horsepower, and the installed capacity, 1,575,000 kilowatts.” The crest of the low dam would rise to elevation 1135.6, while the high dam would top out at elevation 1266.6.⁶⁶

Reclamation came out in favor of the high alternative. In his 1932 letter transmitting Reclamation’s report on the Butler report findings, Commissioner Mead had supported a 450’ dam that would raise the level of the Columbia 355’ above normal low water level. The straight concrete gravity dam was to be 4,100’ long, including a central spillway measuring 1,918’. Discharge would be controlled by fourteen steel drum gates, each 124’ wide and 28’ tall; fifteen 22’-diameter penstocks; and thirty-six sluice gates. The Left Powerplant, the first to be developed, would hold fifteen 105,000-kW turbine-generator units, with the turbines rated at 147,000 horsepower at a head of 330’ and the generators at 120,000 kVA at 120 revolutions per minute (rpm) and 22,000 volts. Transformers would raise the voltage to 220,000 volts.⁶⁷

The decision to pursue this option had been reached only after heated debate within the agency. The engineering staff, including chief engineer Raymond Walter, took the conservative approach and preferred the low dam. They initially concentrated on that alternative. By November 1931, however, Commissioner Mead was strongly favoring the high dam. Walter protested against this on both functional and financial grounds. “From the physical standpoint and topography,” Walter wrote, “it would probably be feasible to increase the height of the dam, . . . but this is already a very high dam, especially so considering the fact that it is of the overflow spillway type and that the spillway must be designed to pass something like 1 million second feet and the energy which must be dissipated at the toe of the dam will be of the order of 30 million horsepower. This is considerably more energy per foot of spillway than is the case with any dam now in existence and consequently this problem will require very careful investigation.”⁶⁸

Walter conceded that a higher reservoir meant less cost for the pumping operation, but felt that the saving would be negligible in comparison to the increased expense to build the higher dam. While the Corps had estimated a $67 million cost differential between the two options, Walter asserted that the “increase of an additional 100 feet in the height of the dam might add something like $75,000,000 to the initial cost of the development. The increased interest charges on this additional investment which alone would amount to $3,000,000 per year would be a heavy burden on the power revenue during the early period. . . . Several years will be required for the power market to absorb this large block of power and there would be no likelihood of deriving any revenue from the additional power which the increase in height of dam would make available for a number of years, and consequently deficits would accumulate very rapidly during

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⁶⁶ Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 54; R. F. Walter, chief engineer, to Elwood Mead, commissioner, letter, November 17, 1931, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 536, NARA-RMR.
⁶⁸ R. F. Walter, chief engineer, to Elwood Mead, commissioner, letter, November 17, 1931, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 536, NARA-RMR.
the early years.” Despite these misgivings, Walter bowed to authority and agreed to continue developing plans for the high dam.  

Reclamation presented a united front on the feasibility of the high dam when Walter’s report appeared on January 7, 1932. On January 11, only four days later, identical bills supporting the dam’s construction and operation were introduced in the House (H.R. 7446) by Congressman Samuel B. Hill and the Senate (S. 2860) by Senators Wesley R. Jones and C. C. Dill, all representing Washington State.  

Within a short time, Walter’s qualms about expense proved justified. The project’s cost, including the development of the irrigation component, was around $394 million—about $20 million more than the Panama Canal. This substantial sum was a hard sell in light of the unprecedented economic depression gripping the country. In addition, Reclamation was having difficulty securing commitments from potential users of the great quantity of power that the project would generate. Last, but not least, President Roosevelt was very concerned about putting more land under cultivation at a time of significant agricultural surpluses.  

As a result, by spring 1933, the option of a low dam was back on the table, but this time proposed as the first phase of a development that would ultimately result in a larger structure. With a crest at elevation 1085, the low dam would be accompanied by an eight-unit powerplant with an installed capacity of 520,000 kW. Irrigation facilities would not be added until the height of the dam was raised.  

In an effort to maintain momentum for the project, Washington’s legislature established its own Columbia Basin Commission in March 1933 and appropriated $35,000 towards its operation. The commission was authorized to “promote the early construction of the Columbia Basin project by means of the Grand Coulee dam and power plant in [the] Columbia River and the orderly development of the power, water, and soil resources incident thereto, in accordance with the plans recommended by the War Department and the Department of the Interior.”  

While the depression hindered plans for the high dam, Grand Coulee’s potential to employ massive numbers of workers positioned the project as an obvious candidate for new federal relief funds. On April 17, 1933, Senator Dill and A. S. Goss, master of the Washington State Grange and a member of the Columbia Basin Commission, met with President Roosevelt and obtained

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69 R. F. Walter, chief engineer, to Elwood Mead, commissioner, letter, November 17, 1931, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 536, NARA-RMR.
73 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 8, 70.
his support for a $60 million loan from the Reconstruction Finance Corporation to Washington State for constructing the Grand Coulee dam and powerplant. Later that month, Commissioner Mead assured the president that the low dam and 520,000-kW powerplant could be built for $60 million.74

The effective turbine head produced by the low dam would be 150'. It appeared possible to subsequently raise the dam to create a 353' head without disrupting power generation at the hydroelectric plant. Reclamation backed up that assertion in a report issued in May. The report verified the feasibility of the low dam and analyzed the impact of completing the second phase—raising the dam to its ultimate height, expanding the powerplant, and developing the irrigation—in seven, twelve, or twenty years after the first phase was finished.75

By the end of June, the state’s Columbia Basin Commission was pursuing its mission by negotiating a contract with Reclamation to begin preliminary engineering for the project. The $337,000 contract, paid by the commission with funds from the Washington Emergency Relief Commission, acknowledged that the possibility of developing a high dam and pumping plant at Grand Coulee had been investigated, but that “under present economic conditions it may prove advisable to construct the Columbia River Dam in two stages.” The specifications had changed slightly from Reclamation’s report: the head produced by the low dam would be 145’, and the capacity of the powerplant would be 700,000 kW. The pumping plant would be built later along with the high dam, which would increase the head to 370’ and the pool elevation to about 1287.5’. The contract required Reclamation to conduct topographic surveys and test borings at the dam site, investigate sources for concrete aggregate, prepare plans and a budget for constructing the low dam, and investigate markets for the power that would be generated. The agreement was signed on July 11.76

A celebration to launch the beginning of the dam’s construction was held at Grand Coulee five days later. Some 5,000 people made the long journey to the site to witness Washington Governor Clarence D. Martin drive the first survey stake. Chief Jim James of the Sanpoil Tribe in ceremonial dress also participated in the event, which was attended by other members of the Colville Confederated Tribes as well. The honor of turning the first shovel of dirt was reserved for Senator C. C. Dill, who had played a pivotal role in promoting the project on Capitol Hill. Eleven days later, President Roosevelt approved the expenditure of $63 million, $3 million more

76 Contract between the United States and the Columbia Basin Commission, June 30, 1933, at RG 115, NRG-115-00-148, Box 1, Folder 510, NARA-RMR; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 8; Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 38.
than initially requested, under Section 202 of the National Industrial Recovery Act. “Because Grand Coulee Dam . . . was much in the limelight during the creation and organization, in 1933, of the Public Works Administration,” a contemporary periodical noted, “the project was one of the first to be approved by that body.”

The cheers that met news of the $63 million allocation were silenced several months later when politics intervened and much of the funding was rescinded. Only $15 million remained, enough to cover no more than the first of the project’s costs. From then on, it was a year-to-year struggle to get funding. (Another $19,800,000 was to come from the Emergency Relief Act of 1935, and Congress provided $20,750,000 for the 1937 fiscal year and $13,000,000 for the fiscal year that followed.)

In any event, after decades of dreaming, scheming, and planning, the Grand Coulee project was finally becoming a reality. This became even more apparent on August 1 when Frank A. Banks was named construction engineer for the Columbia Basin Project. Born in Saco, Maine, in 1883, Banks joined Reclamation in 1906 immediately after obtaining a Bachelor of Science degree in civil engineering from the University of Maine. His first assignment was in the Lower Yellowstone Project in Montana. After three years, he was became designing engineer for the Idaho division, where he worked on preliminary plans for Arrowrock Dam. Between 1913 and 1917 he managed the Jackson Lake Dam in Wyoming, which claimed the fourth-largest reservoir in the United States. He then worked as the construction engineer for the Minidoka and American Falls projects in Idaho. Beginning in 1927, he spent six years as head of construction for the Owyhee Dam, the world’s highest dam until Boulder Dam was erected. At Owyhee, he improved methods for cooling concrete, a major challenge in the construction of large concrete structures. This proved to be invaluable experience when he was appointed to oversee the Grand Coulee Project, a position he held for a decade until his promotion to director of Reclamation’s Northwest Region, covering Washington, Oregon, Idaho, and parts of Montana and Wyoming.

He faced many challenges during his tenure at Grand Coulee, some technical and some political. The latter included a last salvo from opponents of the high dam. The Washington Water Power Company still hoped to derail the Grand Coulee Project by building a hydroelectric facility at Kettle Falls, which was at the top of the pool for the low dam. The company had earlier obtained rights to proceed with this project from the State Supervisor of Hydraulics, but those rights were set to expire in July 1934. The company sought an extension, and also applied to the Federal Power Commission for permission to launch the project. Construction of the Kettle Falls plant would have forced Reclamation to abandon its plans for the high dam at Grand Coulee because

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79 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 8; biographical essay, typescript, October 4, 1945, in FAB Papers.
the reservoir created by that dam would have flooded Kettle Falls. When both the Federal Power Commission and the state denied Washington Water Power’s request, Reclamation had jumped a major hurdle in its plans for a high dam at Grand Coulee.80

With the final decision seemingly made, plans for the construction could be drafted. Selecting the low-dam/high-dam approach added layers of complexity to the design process. Engineers ultimately had to plan for the high dam, while ensuring that the low dam was built safely and economically. Reclamation’s project team included Raymond F. Walter, chief engineer; Sinclair O. Harper, assistant chief engineer; John (Jack) L. Savage, chief design engineer; W. H. Nalder, assistant chief design engineer; L. N. McClellan, chief electrical engineer; B. W. Steele, design engineer-dams.81

A contemporary journal remarked: “There was nothing new in two-stage construction, as it had been used with satisfactory results in the case of other dams of comparable design— notably among them being the Assuan Dam on the Nile, which has been raised twice, and the Sweetwater Dam near San Diego, Calif.” Even so, some Reclamation engineers were adamantly against this approach. In an attempt to change the course of the project, Chief Design Engineer Savage proposed dedicating the entire $63 million allocation to build part of the high dam, a wing on the west bank that could be constructed without diverting the river. The main function of this partially completed dam, he claimed, would be to speed appropriations for the remainder. This somewhat cynical suggestion was not endorsed by his fellow engineers.82

In addition to the two-stage construction, the dam envisioned in the 1932 Reclamation report and the design Congress endorsed with the 1933 appropriation featured a complex design. Rising about 251' above the foundation, the dam had two sections. Extending from the left abutment was a 1,100'-long concrete gravity dam, the same type proposed for the higher structure. This section would incorporate the foundation for the first powerplant. Projecting from the right abutment was a multiple-arch dam about 2,330' in length. Some 1,950' of this section would be an uncontrolled spillway with an ogee crest capable of discharging 1 million cfs with a 5' freeboard over the maximum water surface. Twenty 5'-8" x 10' sluiceways, controlled by hydraulic slide gates, would be at elevation 930.83

80 Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 9, 39.
81 A. F. Darland, consulting engineer, report on conference at Bureau of Reclamation-Denver (held December 2 and 4, 1933), December 18, 1933, page 2, with cover letter to E. F. Banker and J. O’Sullivan, January 20, 1934, at RG 115, NRG-115-00-148, Box 1, Folder 510, NARA-RMR; Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934. Spillway crests were at elevations 1085 and 1290, respectively.
Two types of multiple-arch dams were considered. One, modeled after a dam developed for the Union Valley project by Fred Noetzli, had an arch and buttress slab forming a deck, supported by monolithic gravity buttress walls. The appropriate size of the structure was developed by trial. Noetzli, a Swiss-trained engineer, had risen to prominence in the field in 1921 after publishing a major paper on arch-dam design in a journal of the American Society of Engineers. He contended that form was more important than mass in dam design, insisting that mass did not necessarily guarantee safety. This was an extremely controversial stance at the time and stimulated a great deal of discussion in the engineering profession for years thereafter. Ironically, Noetzli died in 1933, just as the Grand Coulee design was being debated.  

A second design was similar in shape to Noetzli’s, but the buttresses were “column units designed to take the first principal stress as uniform compression throughout and to eliminate the second principal stresses.” Because the stresses could be evaluated mathematically, using catenary arch formulas, Reclamation engineers preferred the second alternative.  

They were increasingly skeptical, though, about whether the multiple-arch design could be safely converted from a low to a high dam. When Alvin Darland, consulting engineer for the Columbia Basin Commission, met with Reclamation engineers in Denver in December 1933, he was “introduced to a group of perhaps ten men from the State of Washington who are engaged in design studies of dams for the Grand Coulee Project” at a hydraulic laboratory at Colorado State College. “According to their supervisors these men have developed into an efficient group of designers and computors [sic] and have completed an exhaustive study of the multiple arch, hollow dam. . . . The unanimous opinion of the engineers at the Bureau with whom the question was discussed is that the hollow type dam should not be used for this Project.” Instead, the engineers recommended a gravity dam. This followed Reclamation’s pattern of preferring gravity over arch structures—even the contemporary Boulder (Hoover) Dam, which appeared to have a concrete-arch form, was actually an arched-gravity structure.  

By early 1934, there was intense pressure to reach a decision so that design and construction could proceed. In March, Chief Designing Engineer Savage sent a memorandum to Chief

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85 W. O. McMeen, “Summary of Multiple-arch Dam Studies for Grand Coulee Project,” prepared by the Bureau of Reclamation, Denver, September 17, 1934, pages 1 and 85, at RG 115, Engineering and Research Center Project Reports, 1910-1955, 8NN-115-83-019, Box 319, NARA-RMR.  
Engineer Walter outlining fifteen options, which juggled a number of variables. Savage’s underlying assumptions were as follows:

- The low dam would rise to elevation 1116, the maximum reservoir water surface would be at elevation 1111, and the concrete spillway crest would be at elevation 1086. The spillway would contain no gates.
- The high dam would rise to elevation 1307.6 and the maximum reservoir water surface would be at elevation 1289.6. The spillway would have twelve 135’ by 28’ steel drum gates. When the gates were down, the spillway crest would be at elevation 1259.6.
- The first stage of the development would include “the dam or power plant or both.”
- The “future development” would complete the high dam and powerplant.
- For the first stage powerplant, two types of 105,000-kW high-head power units were being considered. One would be outfitted with special low-head runners rated at 34,300 kW that would be replaced when the high dam was completed; the other unit would provide the maximum efficiency with the high dam, without particular accommodation for operations during the low-dam period.87

Several of the options retained the multiple-arch dam with a gravity section at the left abutment by the powerplant. Power development was included in some of the options and not in others. Savage even included the alternative that bypassed the low dam in favor of constructing a portion of the high dam—the right abutment and one-third of the adjacent spillway. At $39.6 million, this had the lowest price tag. The most expensive option, at more than $183 million, included the high dam with a powerplant on the left side of the river holding eighteen main units and two service units. In the end, Savage was pragmatic, recommending a $62.4 million plan that would produce the low dam and “a portion of the downstream toe of the high dam to serve as a downstream cofferdam for future work.” The plan envisioned nine-unit powerplants on each end of the dam, but initially only the Left Powerplant would be built, outfitted with three high-head power units with low-head runners and two station service units. Penstocks for the six other units in the Left Powerplant and the nine units for the Right Powerplant would be installed and temporarily capped.88

When fully outfitted, the Left Powerplant would generate 520,000 kW with eight 65,000-kW units. The rated output anticipated a 135’ head, with the output dropping to 52,000 kW with the minimum head of 123’. When the dam was raised, the Left Powerplant could operate without interruption while a new plant was built to take advantage of the higher head. When the first plant was subsequently upgraded at a cost of about $15 million, most of its original equipment would be scrapped.89

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89 Bureau of Reclamation, “Preliminary Estimate and Design, Columbia River Dam and Power Development (Low-Dam Crest Elevation 1085), Columbia Basin Project,” Denver, Colorado, May 24, 1933, 10; A. F. Darland, consulting engineer, report on conference at Bureau of Reclamation-Denver (held December 2 and 4, 1933),
Alvin Darland, consulting engineer for the Columbia Basin Commission, submitted a report in January 1934 that questioned whether the Left Powerplant should be equipped with different turbine-generator units for the low and high dams. In meetings with engineers at Allis-Chalmers Manufacturing in Milwaukee, he learned that “designs of hydraulic turbines were evolved that show conclusively it is possible to secure as much as 65,000 h.p. output at 120 r.p.m. and 125 ft. head from equipment intended for ultimate use at the same speed but at a head of 330 ft. and an output of 147,000 h.p. This design is available at but slightly additional initial cost and at a very low conversion cost when the high dam is built.” The same was possible for generators. While cautioning that his opinion was “based upon a somewhat superficial examination of the evidence now at hand,” he was convinced that it would be “both economical and practical to install only hydroelectric equipment for the low dam development that will later be efficiently usable in conjunction with [the] high dam and with but few and simple changes.” Darland’s insights were apparently valued by Reclamation. He was hired as field engineer for the Grand Coulee project in April 1934 and remained with Reclamation until 1945, reaching the position of construction engineer.\(^9\)

Darland joined Reclamation shortly after the Board of Consulting Engineers convened at Reclamation’s headquarters in Denver in the end of March 1934 to approve a design for the low and high dams, the spillway, and the outlet works.\(^9\) Reclamation had assembled this group of experts from across the country to provide advice as the project progressed. The chairman was Charles H. Paul, a consulting engineer in Dayton, Ohio. Once a Reclamation employee, Paul had helped design some of Reclamation’s dams on Idaho’s Snake River. Another former employee was D. C. Henny, a consulting engineer based in Portland, Oregon, who had been hired shortly after Reclamation was created in 1902. Major Joseph Jacobs was a consulting engineer from Seattle. Dr. W. F. Durand, head of the Department of Mechanical Engineering at Stanford University, was responsible for writing the board’s initial report. In addition to serving on the...
board, geologist Charles Berkey, a prominent professor at Columbia University, came to Grand Coulee on a number of occasions at Reclamation’s request to evaluate specific issues related to the project’s construction. Most of these men served on the board for years, often “retiring” only upon their death.92

At its first meeting, the board considered staff recommendations for the two-phased project. In the first phase, the low dam would rise about 350' above bedrock, with its crest at elevation 1116. At a maximum water surface at elevation 1111, the 3,500'-long structure would create a reservoir of 1.3 million acre-feet stretching upstream about 75 miles. The capacity of the dam’s 1,800'-long central spillway was 1 million cfs. Ten pairs of 5'-8” by 10' outlet conduits located on the east half of the spillway at elevation 935 were controlled by tandem hydraulic gates, allowing a drawdown of 20', or 350,000 acre-feet.93

While the low dam would incorporate the substructure for powerhouses at both ends of the dam’s downstream toe, including eighteen penstocks for the nine main turbine-generator units in each plant, the superstructure for only three units and two service station units would be built initially. Thanks to Darland, the 105,000-kW generators and 147,000-horsepower turbines were designed for the ultimate head of 335', but an average head of only 150' was anticipated with the low dam. With a rated capacity of 520,000 kW, the plant was estimated to produce 2,200 million kWh of electricity for commercial sale. The earnings from selling the power would be dedicated to funding the project’s further development.94

The second phase would include the high dam, a straight gravity structure 4,300' long and 550' high, that would raise the water 355' above its normal low-water level; two powerplants, each with nine 105,000-kW generating units; a pumping plant with twelve pumps capable of lifting 16,000 cfs of water up 280' to a short canal leading to a 339,000 acre-foot balancing reservoir in the Grand Coulee formed by two earth dams 23 miles apart; and a canal system to supply irrigation to 1.2 million acres of land.95

The Board of Consulting Engineers endorsed the staff’s recommendations. While finding no problem with the concept of expanding the low dam into the high dam, the board urged that

92 Jacobs, for example, remained active on the board until dying after a heart attack in March 1942, an event noted in that year’s project history (page 27). Berkey’s age and periodic illness sometimes prevented him from attending meetings, but at the beginning of the project he often visited the site between board meetings to analyze geological issues. References: Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 18; L. Vaughn Downs, The Mightiest of Them All: Memories of Grand Coulee Dam, rev. ed. (New York: ASCE Press, 1993), 32.
special attention be given to the treatment of the joint between the two structures. It also felt that the width of the low dam’s base could be decreased, and encouraged Reclamation to reconsider this design element.  

6. RAMPING UP: EXCAVATION BEGINS

In late August 1933, C. B. Funk, Reclamation’s chief clerk for the Grand Coulee Project, set up temporary headquarters for the construction engineer in a former bank building in Almira, Washington. Funk had previously worked in the Kittitas Division of the Yakima Project. He and a stenographer he hired in mid-September constituted the entire clerical staff for months. By the last months of 1933, Reclamation’s field force averaged 67 men for Reclamation.

To justify funding for Grand Coulee, Reclamation had touted the project’s potential to provide jobs for large numbers of men unemployed by the Great Depression. As a result, there was intense pressure to get work underway. With the project office only beginning to get up to speed in the fall of 1933, it was clear that contracts for construction of the dam and powerplant would not be in place until the following summer. As a means of making progress on the project and, just as importantly, getting men to work, Reclamation made plans to begin removing 1 million cubic feet of overburden at each end of the dam site. While this was only a fraction of the total 13 million cubic feet required for the project, the material that could be removed immediately because it was on dry land. Interest in the contract was intense, with twenty-two firms submitting bids. It was awarded on November 20 to David H. Ryan of San Diego, California who submitted the lowest bid of $534,500, significantly less than the $1 million Reclamation had allocated from the Public Works Administration funds. Completion was scheduled for June 1, 1934. Most of the laborers at Grand Coulee—also known as PWA Project No. 9—were recruited from the swelling ranks of the unemployed. A temporary office building was erected for the National Reemployment Service representative to process job applications.

On December 13, 1933, a subcontractor to Ryan, Goodfellow Brothers of Wenatchee, began excavating at the west end of the site. According to Reclamation’s project history, this “date may be considered as the commencement of actual work on the dam.” Subcontractors Rowland Construction Company of Seattle and J. S. Ross of Los Angeles set to work on the east end shortly thereafter. Initial equipment included four steam shovels, fourteen trucks, two bulldozers, and two scrapers; three more shovels and dozens more trucks were quickly added. Soon crews were removing about 1,000 cubic feet an hour. Waste materials were dumped about half a mile upstream, in an area that would become the reservoir. By the end of March, the contract was more than halfway done, and Reclamation expanded the contract to include a total of 2.6 cubic

yards of common excavation and 50,000 cubic yards of rock. By the end of its contract in June, the company had excavated just over 3 million cubic yards of material.98

With construction underway, project account management was transferred from Denver to the field office in January 1934. By the end of that year the staff had grown to fifteen. In addition to managing construction, the office oversaw survey parties that scrutinized the Columbia River and canyon walls about 4,000 feet upstream and downstream from the anticipated axis of the dam. Crews verified property lines, developed cross-sections, and identified locations for drill holes, test pits, and trenches to check foundation conditions. Survey monuments were established for monitoring the dam’s construction. A private photographer from Spokane, Wallace Aerial Surveys, was hired to document the area that would be inundated between the dam and Hunters’ Ferry, about seventy miles away.99

Surveyors faced a daunting challenge because of the size of the project and the degree of accuracy needed. The reservoir’s flow-line was established at elevation 1310, and “a transverse of the flow-line contour involved running approximately 600 miles of line, as well as the retracement of a multitude of property lines bordering thousands of tracts of land which had to be acquired for reservoir purposes.” A standard aerial survey would not have provided results with sufficient accuracy. “Consequently, precise geodetic surveying methods were adopted, insofar as the major control system was concerned, leaving only the running of the flow-line traverse and the secondary ties to be made by simple transit and chain methods.”100

The contentious work of determining land values was given to an appraisal board appointed by the Columbia Basin Commission in September 1933. The board, with representatives from Wenatchee, Spokane, and Coulee City, convened for the first time in mid-October.101

The Almira office also monitored testing projects. In early September, Reclamation awarded contracts for doing core drilling and digging test pits and trenches to provide information on-site conditions to Reclamation’s engineers in Denver, who were preparing plans and specifications for the project. One of the contractors, Lynch Brothers, put four diamond drill rigs to work and by the end of 1933 had completed thirty holes extending 8,492’. Four of these holes, 74’ to 92’ deep, checked conditions at the proposed river bridge site. Others, sometimes drilled at an angle, went much deeper to examine bedrock around the dam location. By early September, 115 test holes “penetrated to a depth of 700 ft below low water,” Frank Banks reported. “Granite bedrock

100 Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 56-57.
of excellent quality, fulfilling every requirement for the foundation, is found at an average depth of about 70 ft below low water, the maximum depth so far disclosed being about 160 ft below low water in a pothole on the east side of the river. By the end of Lynch’s contract in September 1934, the company had completed 122 holes totaling about 21,200 linear feet.102

Seattle contractor Rumsey and Company dug test pits and trenches in the areas being considered for the dam abutments and the piers for a bridge across the Columbia below the dam. For the abutments, the company dug two trenches, each 6' wide and 20' deep, that extended a total of 550' on the axis of the dam. It also prepared six test pits 32' to 230' deep at the dam and two more 20' to 23' deep at the bridge. Rumsey had finished its work by the end of 1933. On the basis of this testing, Reclamation engineers estimated that approximately 15 million cubic yards of overburden, ranging from 40' to 275' in depth, would need to be removed from the bedrock.103

Reclamation used consultants to provide additional expertise in key areas. Consulting geologist Charles Berkey was involved with the project for years. His first visit was in September 1933, just weeks after the temporary construction engineer’s office opened in Almira. In his first report, dated October 10, 1933, he explained that “the chief purpose of this memorandum is to evaluate the exploratory program and indicate modifications of it if better or more economical results could be secured.” His second memorandum, completed in December, focused “on the character of the rock floor.” It analyzed fourteen corings from the Columbia Basin Commission and another two from the War Department that he had examined during his September site visit. By June 1934, bolstered by his observations and additional core drilling, Reclamation felt confident that the foundation rock was reliable.104

Berkey was also a member of the board, and his area of specialization made him particularly valuable during the planning phase of the project. Geology was a central factor in the search for a source for aggregate in the vicinity of the dam. In November and December 1933, a Reclamation crew dug six 120'-deep pits to investigate sand and gravel deposits at one of the most promising locations, known as the Plum site, on the west side of the river about six miles upstream from the dam location. Carloads of samples from these pits were sent to Reclamation’s Denver testing laboratory, in the basement of the U.S. Customhouse. The facility was described by a visitor in

103 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 80; Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 89.
1933 as “a very complete testing laboratory . . . used for the testing and grading of aggregate for concrete, including cement, and concrete products.”

Although the results were positive, the Plum site’s distance was a problem. The first phase of the project alone would require about 4.5 million cubic yards of concrete—slightly more than the entire quantity used for the Boulder Dam and powerplant. To complete the Grand Coulee high dam and west powerplant would take 10.5 million cubic yards. The cost and effort to transport sufficient aggregate for this volume of concrete by railroad, aerial tram, or another means was prohibitive.

“Fortunately,” Banks reported, “an extensive gravel pit of excellent quality, the surface of which lies 800 ft above the top of the Low Dam, has been found on the east side (right bank) of the river about 1-1/2 miles below, that is, north of the dam site. The material is largely hard basalt of high specific gravity with some granite in the sand. There is considerable excess of sand, which by wasting undesirable sizes, can be graded to the proper fineness modulus, that is 2.50 to 3.00. The location of the gravel pit automatically fixes the location of the sand and gravel plant and the mixing plant on the east side of the river, where favorable topography has already fixed the location for the contractor’s camp.” Known as the Brett Pit, this glacial deposit contained about 75 percent basalt and 10 percent granite. It contained sand and gravel to a depth of at least 300', more than enough to cover construction of the dam and west powerplant, and its elevated location would make it possible to utilize gravity to move the materials during processing. The Board of Consulting Engineers concluded that the Brett pit looked promising, based on initial findings, and recommended additional testing.

While Denver tested materials, much of the data from on-site surveys was put to use by the growing engineering staff in Almira. By the end of October 1933, Reclamation’s original project office was dedicated to administration and a nearby lodge hall had been commandeered for a drafting room and engineering. Four draftsmen and two tracers developed maps that showed land ownership and recorded drilling and other testing results. They also started to develop plans for Government Camp, the base for key Reclamation staff during construction and the facility’s operators when the project was finished.

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During 1934, the engineering staff grew from eleven to sixteen and was divided into four departments: architecture; structures, utilities, highways, and railroad; computing; and photography. The computing group worked on right-of-way and other surveys and calculated quantities of materials for specifications and payments to contractors. Photography to document construction work was initially a part-time assignment for one of the draftsmen. As the project accelerated in 1934, a full-time photographer and laboratory assistant were kept busy. The architectural work had become so overwhelming by May 1934 that the architecture group was transferred to Denver. During 1935, when the average staff numbered twenty, the “department of office engineering . . . functioned as an intermediary office between field operations and the directing engineering department at Denver.” Reclamation’s offices remained in Almira until they moved to Government Camp in March 1935, first locating in the schoolhouse. In June, the offices moved into the new administration building.109

The office’s challenge was daunting. (See ILLUSTRATION 3: Grand Coulee Dam and vicinity.) As Frank Banks observed, constructing a railroad, “together with the building of highways, telephone lines, telegraph lines, transmission lines, and housing facilities for 6,000 workmen and their families, constituting altogether a population of about 15,000 people, were all necessary preliminaries to the commencement of active construction on one of the world’s largest projects in a barren canyon occupied only by a ferryman and two neighbors, over 80 miles from the nearest city of any consequence.”110

One of the most basic needs was to provide electricity to the area until the powerplants were up and running. The few lines that were in place would be flooded when the reservoir was filled. It would be necessary to install a new transmission line extending thirty miles from the nearest feeder line.111

A rail line was essential for transporting materials and workers to the remote dam site. The rail line would see heavy use, transporting an estimated 12 million barrels of cement, 77 million pounds of reinforcing bars, and the penstocks, estimated to have a total weight of 16 million pounds. In 1933, two railroads considered building branch lines to a planned rail yard near the head of the Grand Coulee. Northern Pacific proposed a line extended from a siding in Odair, about two miles from Coulee City, while the Great Northern’s would start at Mansfield. Upon further analysis, the amount of grading required for the Great Northern route removed it from consideration. The Northern Pacific’s route was more suitable, and the railroad decided to develop a standard-gauge single track, about twenty-eight miles in length. The line would run to a rail yard about two miles from the dam site (now Electric City). There, cars would be

110 Frank A. Banks, “Development of Power at Grand Coulee Dam,” 7, speech at Reed College, Portland, Oregon, July 5, 1938, typescript of text at FAB Papers.
transferred to gear-type locomotives that could navigate the steeper grades and sharper curves in
the vicinity of the dam.\textsuperscript{112}

In early 1934, there was a hitch in the railroad’s plans. Bowing to pressure from trucking
interests, the state public utility commission denied the railroad’s request for the exclusive right
to haul most of the construction materials. As a result, in February 1934, the railroad refused to
build the line, putting a critical component of the construction project in limbo.\textsuperscript{113}

In April, Reclamation maneuvered around this obstacle by hiring Northern Pacific engineers to
plan the construction of the U.S. Construction Railroad, which would be owned by the federal
government. By the following month, the location surveys and property appraisals for the right-
of-way were completed. On May 17, Reclamation opened bids for constructing the single-track
line, as well as the delivery yard at Odair and a siding at Grand Coulee. Seattle contractor L.
Coluccio submitted the lowest bid, but David H. Ryan of San Diego, California, protested the
award, citing irregularities in the process. The comptroller general agreed, and ruled that the
contract should go to Ryan. Reclamation officially awarded the contract on July 17. By
November, Ryan had finished the grading and laid twenty-five miles of track. On December 8,
Governor Martin and Senator Dill participated in a ceremony to drive a “golden spike”
completing the line from Odair to the rail yard, a total of 28.33 miles. More details remained,
however, and Ryan was officially done with the contract in July 1935. Shortly thereafter,
Reclamation turned over the railroad to the general contractor for the low dam, which was
responsible for operating and maintaining the railroad for the duration of its contract. Again
Governor Martin was present for the festivities, this time dressed in an engineer’s uniform to
pilot the official first train from Odair to the rail yard.\textsuperscript{114}

The project also required a new highway. Developed by the State of Washington, the highway
shared a 48'-wide right-of-way corridor with the railroad for part of its length. By August 4,
1934, it was completed except for the final two miles to the dam site, which were traversed by
a narrow, winding construction road. For the 350' drop into the river valley, the highway and
railroad had different alignments. The railroad continued along the hillside on a grade of no more
than 5 percent, requiring several switchbacks and one underpass beneath the highway to reach
the site of the west powerhouse. The highway followed a steeper grade of up to 10 percent to
Government Camp and the site of a planned bridge across the Columbia. Crick and Kuney

\textsuperscript{112} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1933, 81; Frank A. Banks,
“Columbia Basin and Grand Coulee Project,” \textit{Civil Engineering} 4 (September 1934): 459; Frank A. Banks,
“Development of Power at Grand Coulee Dam,” 6-7, speech at Reed College, Portland, Oregon, July 5, 1938,
typescript of text at FAB Papers; Bureau of Reclamation, Annual Project History, Columbia Basin Project, First
Stage Development (Low-Dam Power Project), Vol. 2, 1934, 110.

\textsuperscript{113} “Three Big Dam Operations Begin in the Northwest,” \textit{Engineering News-Record} 112 (April 5, 1934): 443;
Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam

\textsuperscript{114} Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam
Power Project), Vol. 2, 1934, 10-11, 15, 31; Bureau of Reclamation, Annual Project History, Columbia Basin
Company, contractors from Spokane, won the contract to extend the railroad and approach highway into the canyon in April.\textsuperscript{115}

The start of the project was delayed, though, by the first of the slides that were to plague the project. On March 27, 1934, about 2 million cubic yards of earth gave way in a ravine on the west side of the river, near the dam’s axis. At the time of the slide, power shovels were working on either side of a ravine, doing grading for the highway and construction railroad. They had adopted a slope of 1-1/2 to 1 in the hope of avoiding a slide. One of the shovels, however, apparently disturbed a horizontal arch of stable earth stretching between the opposing rock faces of the ravine. This affected a lower stratum, a dense but sometimes unstable clay described by one report as “finely ground glacial rock flour.” “The material in the bench below the shovels,” Banks reported to Walter, “was too plastic to sustain, unassisted, the load of the surcharged slope,” and it oozed to the northeast, at an angle to the river. Fifteen men traveled about 100’ on the moving earth. “Engineers who happened to ride it down” observed that “many cracks opened and closed as the mass progressed.” The material heaved the ground beneath the shovels 20’ up, while 100’ away there was no sign of disturbance.\textsuperscript{116}

Engineers had been concerned about this possibility and had tried to minimize the risk by sinking six wells to divert groundwater. A perforated casing 10” in diameter was inserted in the 18”-diameter wells and the area outside of the casing was filled with gravel. Nine-inch drainage holes were bored at the base of the wells, which extended to bedrock at an average depth of 75’. The plan to pump water from the drainage holes, though, was foiled by the slide.\textsuperscript{117}

Rowland suspended its work on the east side and, with Goodfellow Brothers, immediately dedicated all crews and equipment to removing the material, which covered the highway and railroad corridor. The slide increased the amount of excavation needed by about 1.5 million cubic yards.\textsuperscript{118}

The slide occurred just before the bids for the road work were opened, forcing a realignment of the road and railroad. On May 9, Construction Engineer Banks sent plans for a new corridor alignment to Chief Engineer Walter in Denver. “The locations were projected with the object of


\textsuperscript{118}Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 99.
having both the railroad and highway, to the greatest extent practicable, built on ground that has not moved.” The plan, though, required significantly higher excavation costs, more than doubling the original contract with Crick and Kuney from $220,676 to $464,146.\footnote{Construction Engineer Banks to Chief Engineer Walter, memorandum on slide on March 27, 1934, May 9, 1934, pages 2-3, at RG 115, Project Correspondence File, 1930-1945, Box 536, Entry 7, NARA-RMR.}

Banks worried that “the heavy cost of the change in location raises a question as to whether we may not have been too conservative and taken unnecessary precautions to guard against future slides.” He pointed to ground water as one of the culprits behind the slide. An unusually warm winter had left the ground unfrozen, causing water from the spring thaw to be absorbed rather than running off. He recommended driving a drainage tunnel that would empty near what would be the west end of the tailrace, where excavation had recently begun. Because of this, Banks emphasized that a decision was urgently needed: “For the sake of safety, the drainage tunnel should be constructed before the main body of material in the tailrace is excavated.” Apparently, his sense of urgency was not shared by the engineers in Denver, to everyone’s later regret. During a site visit in mid-June, the Board of Consulting Engineers recommended a study of ways to drain the slope.\footnote{Construction Engineer Banks to Chief Engineer Walter, memorandum on slide of March 27, 1934, May 9, 1934, pages 3-4, at RG 115, Project Correspondence File, 1930-1945, Box 536, Entry 7, NARA-RMR; Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 37.}

The issue of the road alignment, though, was resolved more quickly. Crick and Kuney Company received notice to proceed with construction on June 30. Work was underway by the following month. The road was open from end to end in October.\footnote{Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 10, 12, 31.} Because the warning of the first slide had been unheeded, the road’s service was short. Mother Nature struck again in mid-November 1934, when the sand and clay in the unstable ravine began to move. This time it went more slowly, with large cracks appearing and expanding on the gradually sinking surface. In reporting on the event, the Omak Chronicle provided “three reasons . . . for the constant sliding of the earth at the west side area, first soap seams in the clay, which furnish a skidway much like a cake of soap sliding down the side of a bathtub, second, water pressure behind the mass, and third, the ‘gooeyness’ of the clay.”\footnote{“Second Big Slide Hits Coulee Dam,” \textit{Omak Chronicle}, November 23, 1934.}

The slide raised concerns about the overall stability of the site for the dam’s foundation. Charles Berkey was called in for additional analysis, and in September 1934 issued “Memorandum No. 8 on the question of rock quality and strength in the foundations of Grand Coulee Dam.” He wrote: “I am confident that the major portion of the foundation, and particularly the deeper portion of the gorge, will show much greater strength and that the average result, when adequately distributed tests can be made, will be eminently satisfactory on the point of strength and stability.” The sides of the gorge were more weathered and would need excavation “to a depth of a few feet, probably 6 to 10 feet, and rarely, especially in certain narrow zones, to a possible 15
to 20 feet. I am sure that it will not be necessary or advisable to set a definite, uniform excavation depth.”

D. C. Henny, another member of the Board of Consulting Engineers, issued a report in mid-December on alternatives in the wake of the slide. There was only a small strip of land not occupied by the dam and reservoir, making other alignments for the railroad and highway impractical, if not downright impossible. Stabilizing the slope would require a four-to-one grade, which was not feasible in the narrow corridor. A retaining wall was unlikely to prevent future slides and would probably be buried when one happened. Erecting a bridge over the ravine would be expensive—about half a million dollars—and the curved alignment would be difficult to design and build. Instead, it appeared that the only practical option was replacing the unstable earth—about 750,000 cubic yards—with rock fill.

Berkey addressed the same issue in a January 1935 memorandum on “Geologic Elements of the Slide in the Westside Gulch at Grand Coulee.” He began by describing the problem: “There is no doubt of the instability of a part of the overburden occupying this deep notch in the valley wall, for it has moved twice. Furthermore, it is likely to move again if material is removed from the lower toe slopes unless something can be done to stabilize or protect it.” He explained that “large portions of the overburden are less pervious than the jointed rock beneath and consequently may act as a blanket tending to prevent free escape of the water and pond it behind these overlying masses.” Given these conditions, he concluded: “It seems eminently proper to run a drainage tunnel beneath and parallel with the axis of the gulch for the purpose of lowering the water table and disposing of the ‘thalweg’ [lowest elevation and fastest] circulation.”

When the Board of Consulting Engineers braved winter conditions to meet at the dam site that January, stabilization of the west side, particularly the highway and railroad corridor and the powerhouse and tailrace excavation area, was a major agenda item. In addition to recommending the realignment of about 1,100’ of the railroad and highway corridor to more stable ground, they endorsed Berkey’s recommendation to install drainage wells. The area above the new transportation corridor was excavated between January and May. A larger initiative, starting in March, created a 1,136’ drainage tunnel “as near as possible to the bedrock surface and directly below the trough of the canyon in which the slides occurred.” The main tunnel extended westerly from the base of the slide, going up the slope and passing below the highway corridor. Some sections were unlined, but other areas were reinforced with timbering and, later, concrete. A 50’ vertical shaft connected the tunnel with the surface. Lateral shafts allowed the wells to drain into

the tunnel. A 5' by 8', 270'-deep access shaft was also excavated near the slide. Although the volume of water that drained from the tunnel was not large—typically no more than six gallons a minute—engineers hoped that this reduction in the ground’s saturation would be enough to stabilize the area.¹²⁶

It was not. On July 2, 1935, “a noticeable crack appeared in the highway pavement about 600 feet away from but directly above, the west tailrace,” according to a Reclamation report. “Investigation revealed that the crack extended for a considerable distance, indicating that a large area adjoining the tailrace was in motion.” If allowed to progress, the shifting earth would destroy not only the highway and rail line, but also the tailrace area. Immediate action was needed. On July 5, crews began digging three drainage shafts in the tailrace slope, ranging from 69' to 135' deep. Within three months, pockets of water that were destabilizing the slope were drained, and the crisis was averted.¹²⁷

While the battles with the slide raged, Reclamation was making progress on the bridge that would carry the highway across the Columbia after it descended into the valley downstream from the dam. Designed by the state’s highway department, the bridge would replace two ferries that provided the only crossing. During construction, the bridge would make it much easier to transport people, equipment, and materials across the river. After the dam was completed, the highway would traverse its crest, and the bridge would serve as a secondary crossing.

The highway department first proposed a suspension bridge about 2,000' below the dam’s axis. Tests revealed, however, that the foundation conditions were poor in that location, so the site was pushed another 1,000' downstream, and the suspension design was replaced by a steel, rigid-connected, cantilever Warren truss. The 550'-long, twenty-two-panel center span was balanced by 200', eight-panel anchor arms. With one concrete-girder approach span on the west and three on the east, the bridge extended a total of 1,165'. Its 20'-wide roadway was flanked by 4'-wide sidewalks cantilevered on 6'-9" brackets.¹²⁸

Reclamation was responsible for constructing the bridge. Because it took longer to prepare plans and specifications for the bridge superstructure than for the piers, the contracts were let separately, with a call for bids for the substructure issued early in 1934. The Western

Construction Company of Seattle, Washington, won the contract on March 17, and was notified to proceed on April 4.  

By the beginning of May, the first of many problems appeared with the arrival of high water. Water levels remained elevated for about two months, delaying installation of the cofferdam for the east pier (Pier 2) until the end of July. As a result, Western was unable to begin pouring concrete for that pier until August 22, using an open caisson to the bedrock about 67' below the water’s surface. A similar technique was adopted for the west pier (Pier 3) when work started on that in July. A partial failure of the sheet-pile wall flooded the caisson in December, delaying work for ten days, and the caisson was converted into a pneumatic design for the remainder of the construction. The piers were only about half finished by the end of the year despite “135 percent elapsed contract time,” a Reclamation report noted with frustration. “As the work progressed, it became evident that the Western Construction Company was encountering work for which it was entirely unprepared, as its construction plant and equipment was inadequate for the existing conditions. As a result, break-downs and delays were frequent.” Pier 2 was completed in April 1935 and Pier 3 in May, “198 days later than the required date for completion.”

In the meantime, plans for the superstructure went out to bid in August 1934. Eight firms submitted proposals by the October 18 deadline. San Francisco contractor J. H. Pomeroy and Company, which submitted the low bid of $258,978, was awarded the contract in November and received notification to proceed on December. Erection began the following spring.

Things went well until August 1935. The two cantilever arms that had been built from each pier were nearing connection midstream when the 150'-tall east pier began to tilt towards the river. It angled 9' off vertical before the contractor was able to stop the movement with jacks and cable braces. The culprit was an unstable layer of fine material beneath 20' to 30' of surface gravel, the same material responsible for the slides on the canyon’s west side. The ground’s equilibrium had been disturbed by a bench cut for a rail spur, creating cracks and a thrust that dislodged the pier from its granite foundation. After the movement had been stopped, the contractor was able to complete the connection of the cantilevered spans with minor adjustments in the expansion joints, but the pier remained out of alignment.

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A permanent fix for the pier was at the top of the agenda when the Board of Consulting Engineers met at the dam site in early September 1935. The board believed that the pier should be enlarged, but considered other alternatives and related costs as well. In the end, the pier was enlarged with sheet-piling and concrete, a process begun by J. H. Pomeroy and Company late in December. The bridge finally opened on January 27, 1936, but work on returning Pier 2 to its proper alignment continued into March. The final concrete to enlarge the pier was placed in the end of April.  

7. MWAK COMES ON BOARD

Specification No. 570 went out to bid on April 30, 1934, for the first stage of the project, the straight gravity concrete dam rising to elevation 1116, with the spillway crest at elevation 1085. The downstream walls of the future powerhouses at elevation 935 would serve as permanent cofferdams at the dam’s toe. Another permanent cofferdam below the spillway section, reaching elevation 920, would ultimately be incorporated in the toe of the high dam. The contractors were responsible for providing labor and equipment.

To control costs, Reclamation would supply “all permanent materials and equipment, . . . including cement.” It would also allow the contractor to mine the Brett deposits for aggregate, although Reclamation would continue to own the site.

Work on the contract was to be completed within 1,650 days from the notice to proceed. Reclamation retained the right, though, to change to rules midstream. “In case the government decides to build the high dam before the present contract is finished, it reserves the right to terminate the contract, and all work done to date of termination would revert to a cost plus basis, including all labor, material and equipment costs, with 10 per cent added. All equipment on the job would be taken over on this basis, and if the total of progress estimates paid exceeded the cost plus fee amount, the contractor and sureties would be held liable for the difference.”

Bids were due at the offices of the Columbia Basin Commission in Spokane by June 18. The award of the contract would be the last major responsibility of the Columbia Basin Commission. Once construction began on the dam, with Reclamation at the helm, the commission had little reason to exist. By 1936, secretary James O’Sullivan and a representative at the dam served “mainly as public relations representatives.”

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When the time came to open bids on July 16, 1934, only two had been received. One was from the Six Companies, a joint venture of the Morrison-Knudsen Company (Boise, Idaho), Henry J. Kaiser Company (Oakland, California), Utah Construction Company (Ogden, Utah), J. F. Shea Company (Portland, Oregon), McDonald and Kahn (San Francisco), and Pacific Bridge Company (Portland, Oregon). The team first formed to bid on the Boulder Dam project. After procuring and completing that job, it seemed the favorite to get the Grand Coulee project. Its bid of $34,555,582 was relatively close to the engineers’ estimate.\(^{137}\)

This proved to be $5 million more, though, than the bid from the Mason-Walsh-Atkinson-Kier Company—commonly known as the MWAK Company—of $29,339,310.50 (with no explanation for the 50 cents). The most expensive component was excavation: $11 million to remove 11 million cubic yards of earth and $1.6 million for 800,000 cubic yards of rock. Other costs included a lump-sum fee of $3.5 million to redirect the river, $1.8 to build 400,000 cubic yards of cofferdams, $880,000 for 97,000 cubic yards of concrete, and $250,000 to place 25 million pounds of reinforcing bars.\(^{138}\)

The lead of the MWAK joint venture was the Silas Mason Company, a family-owned New York firm. Established in 1827, it claimed to be the oldest contractor in the United States. The Walsh Construction Company was based in Davenport, Iowa, and the Atkinson-Kier Company in San Francisco and San Diego. Guy F. Atkinson, born in 1875, was almost predestined to go into the construction business: his father was a contractor and his grandfather was a stonemason. A profile of Atkinson in *Engineering News-Record*’s list of the “Top [125] People of the Past 125 Years,” compiled in 1999, noted “his revolutionary use of equipment and technique” which “often proved ingenious. On California’s Pardee Dam, he built an intricate web of towers, pipes and chutes to deliver wet concrete from a plant near the abutment to any part of the structure. He innovated the use of earthmoving shovels on Oregon’s Barview Highway and Monterey Harbor.” These accomplishments were good training for one of the company’s “landmark jobs,” Grand Coulee. Atkinson’s career continued for decades thereafter. He passed away in 1968.\(^{139}\)

MWAK’s low bid was accepted by Reclamation, which issued the notice to proceed September 25—setting the completion date at April 2, 1939. To meet this ambitious schedule, MWAK got underway before receiving the official notice. During August, the company set up temporary headquarters in Spokane and began planning construction facilities, leveling the site for the camp, and digging test pits to assess conditions at potential cofferdam. Progress was interrupted

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\(^{139}\) “Top People of the Past 125 Years,” *Engineering News-Record* 243 (August 30, 1999): 27.
by a visit from President and Mrs. Franklin Roosevelt, Secretary of the Interior Harold Ickes, and Secretary of War George Dern on August 4. The president’s dedicatory address at the dam site drew some 20,000 people.\textsuperscript{140}

The president’s support of the project was based in large part on the jobs it would create to alleviate the country’s massive unemployment problem. Because funds for the project came through the National Industrial Recovery Act, all labor was hired through the National Reemployment Service, which set up local offices in the counties closest to the project—Okanogan, Grant, and Douglas—and a main office near the construction site. Qualified veterans were given first preference, then residents in the three counties, and finally residents of Washington State. “The supply of labor residing within the State was, in general, found to be adequate,” according to Reclamation’s annual report for 1934, when the service processed nearly 6,800 applicants. Government rules limited the work week to forty hours to maximize the number of people employed. MWAK organized the work day into three shifts of seven hours each, separated by an hour. The hour between shifts was used by foremen to discuss progress and by machinery operators to maintain equipment. Also, if work was delayed during a shift, the entire crew could work the additional hour without running afoul of overtime or federal regulations.\textsuperscript{141}

Getting electricity to the site was an urgent priority. MWAK extended a 110,000-volt transmission line from the Washington Water Power Company’s distribution system at Coulee City to the dam site, a distance of thirty-one miles. The improvement was completed in November 1934, forty-two days after work had begun.\textsuperscript{142}

By October, MWAK had started excavation at the dam site and completed a temporary 672’-long wood-pile trestle across the river, just below the dam where a ferry had previously operated. This was the first of several bridges across the river, critical links between the banks. As one writer noted, “Until the railroad and the permanent truck and railroad bridge below the dam site were completed, cross-river communication and the transportation of supplies and equipment proved especially vexatious at times, and not infrequently necessitated changes in the construction program.” One of those “vexatious” periods was when the trestle was damaged by an ice jam in January 1935. MWAK erected a suspension footbridge with a span of 770’ just downriver from the dam site in just four days. After the trestle was repaired and put back in service (with “a


permanent ‘kink’ in its midsection”), the suspension bridge was moved downstream and elevated so that it would not be endangered by high water. The trestle served until the end of March when the contractor opened a more substantial bridge comprising four 152'-long Howe deck truss main spans with a 70' steel-stringer approach span on each end. The 30'-wide structure accommodated highway, railroad, and pedestrian traffic.\textsuperscript{143}

MWAK also built barges at its east-side wharf to haul equipment across the river that was too heavy or bulky to cross the bridges. A former ferry, \textit{Chief of Seattle}, was reconditioned and pressed into service to move the engineless barges. All in all, MWAK assembled fourteen barges, which carried equipment to pull piles, excavate the river bottom, pump out excavation areas, and other activities.\textsuperscript{144}

Before the end of 1934, MWAK had drilled almost 8,000 feet of exploration holes and excavated 1 million of the 12 million cubic yards of overburden that was estimated to cover the foundation bedrock. The contractor was on the verge of driving sheet piling for the west cofferdam. In describing MWAK’s initial work on the project, Reclamation’s 1934 project report noted that “activities throughout proceeded at a rapid gait.” Another report said that “the general status of the dam and power plant construction program . . . may be briefly described as ‘nicely started at the beginning of 1935.’” \textsuperscript{145}

8. TAMING THE COLUMBIA: THE COFFERDAM

With a record flow of almost 500,000 cfs and a flood season lasting almost half the year, from April to September, the Columbia was a mighty foe. Frank Banks called “the care and diversion of the river during construction . . . a major problem,” adding that this challenge was “probably the most difficult one to be met.” Another writer judged it a “man-sized job” and “one of the most important diversion jobs ever undertaken.”\textsuperscript{146}

The best method of diverting the river was one of the main items that the Board of Consulting Engineers considered when it convened at Grand Coulee in mid-June 1934, around the time that


\textsuperscript{144} Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 22-23, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148 Box 3, Folder 510, NARA-RMR.


bids were due for the first stage of the dam’s construction. A number of alternatives had been proposed. In the preliminary design that Reclamation outlined in 1933, the river would be diverted to the right with cellular sheet piling and timber crib cofferdams to enable construction of the dam’s left half above the low water elevation. Water would flow through slots in this section when cofferdams were placed on the right side to build the other end of the dam. When the dam was completed, these slots would be filled and the reservoir would be controlled by twenty hydraulic slide gates at elevation 930 in the multiple-arch section.147

This approach was modified after Reclamation hired MWAK, which was responsible for planning and carrying out the diversion of the river as part of its scope of work. In September 1934, Banks wrote that the option “now in favor seems to be two U-shaped cofferdams, one running out from each shore to within 500 ft of the other. Within these the two ends of the dam would be constructed, leaving alternate panels in the spillway section at an elevation about 15 ft below low water and carrying the other panels well above low water. The 500-ft gap in the center would then be closed above and below by cofferdams, and the water would be turned through the low panels and ten of the sluice gates. After the center section was raised above low water, the low panels left on each side would be bulkheaded during low water and carried up as rapidly as possible.”148

This is essentially what was ultimately done. MWAK brought a good deal of practical experience to the project. Its design team included Francis Donaldson, who had been the company’s chief engineer since 1926 and later became a vice president. He was at Grand Coulee as the company’s construction engineer until about the end of 1935. The cofferdam engineer and superintendent for river diversion was Robert L. Telford. In the 1920s, Telford had served as Mason’s resident engineer for the construction of cofferdams—designed by Donaldson—that were of unprecedented size and depth for the New Jersey piers of the George Washington suspension bridge over the Hudson River. Mason’s designing engineer was James Foster, with assistance from New York consulting engineer Silas H. Woodard.149

Despite the direct involvement of some of Mason’s top engineers and the contractor’s ultimate responsibility for the diversion, Reclamation remained closely involved with planning for this important step in the project. The proposal for the river’s diversion was under regular review by the Board of Consulting Engineers. A summary of its January 1935 meeting noted that the

engineers “were well impressed with the care with which problems of river diversion and control were being considered.”

To deflect the river’s velocity away from the site of the cofferdam, MWAK built a 375'-long rock-filled timber-crib jetty just upstream from the dam’s axis. The cribs were formed from 10'-long, 12" by 12" timbers. Most topped out at elevation 948, but some rose higher to hold stiff-leg derricks. A similar crib structure supported three stiff-leg derricks used in the preliminary construction of the cells. The derricks were then moved to another crib structure to start work on another cell cluster.

After the initial crib structures were in place, MWAK installed about 2,500 lineal feet of timber trestles to carry the heavy equipment for the cofferdam’s construction. Building the trestles “constituted a considerable portion of the contractor’s construction up to the end of the calendar year 1934,” according to field engineer Darland. The 72'-long, 36"-deep I-beam stringers were supported by pile bents spaced 18' apart, with double bents at the juncture of two stringers. The stringers carried 36'-long, 12" x 12" timber ties placed every 24". On top of the ties ran 90' rails spaced for gauges of 13.75' and 28.5' to accommodate the various rigs that MWAK had been able to procure on short notice: “two American steam revolving cranes mounted on tracks, with 85-foot booms, one 25-ton Browning crawler crane, two long-boom (100 foot) Marion gas-electric crawler cranes, two Marion gas crawler cranes with 60-foot booms, two Thew-Lorain crawler cranes with 60-foot booms, and four Clyde-Wiley electric whirleys with gantry mounting 30 feet above the tracks. The booms on the Clyde-Wiley whirleys were of alloy steel and were designed for the capacity of the rigs, that is 40 tons at a 45 foot radius boom or 11 tons at a 115 foot radius (flat) boom.” Lines to power the steam equipment were extended along the trestles and supplied by three 300-horsepower boilers and several smaller ones.

Getting the cofferdam constructed before high water arrived in the spring was a major priority. MWAK had started excavating overburden on high ground on the west side in October 1934, removing almost 1 million cubic yards of common and 3,205 cubic yards of rock by the end of the year. Much of the rock was removed by light dynamite blasting, hauled away by truck, and used to riprap unstable slopes. Given the far greater quantity of the common overburden, which was usually smaller in size, a more efficient method was needed to transport the material. In December, a 60"-wide belt conveyor began bringing the rock to fill the canyon along Fiddle Creek, which bisected the Government Camp.

151 Chief Inspector B. A. Hall to Field Engineer, memorandum on cofferdams and river diversion, March 20, 1937, 13, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-NR-115-00-148, Box 3, Folder 510, NARA-RMR.
This canyon, however, was far too small to accommodate the estimated 6 to 12 million cubic yards that would be excavated from the west side alone. The dam’s setting presented unique challenges for other options. “Due to the cliffs which form the left bank of the Columbia, no low-level dump was available within several miles,” explained MWAK’s Donaldson. “The cost of constructing and operating either a railroad or a truck road to such a dump was, therefore, prohibitive. Rattlesnake Canyon, however, provided an excellent dump for many million yards of spill within a mile or so of the excavation, but the floor of the canyon was 150 ft. above the river, and the rim of the canyon was most inaccessible from the pit due not only to a difference in the elevation of some 400 ft. but also the aforementioned cliffs.”

When Donaldson first saw the Grand Coulee site just before bids were opened in June 1934, “at once there came into [his] mind the experience of the Mason Co.’s organization in transporting, in Boston, soft clay to a distance of a mile and, at Fort Peck, broken shale up a steep hill to a dump fed by a movable stacker. A belt conveyor seemed to him to be the answer to the disposal problem.” The idea of employing a long conveyor to transport spoil material was not new. In fact, the Silas Mason Company had pioneered the use of conveyors for a similar purpose for the Boston Traffic Tunnel project in 1931-1932 and Fort Peck Dam in 1934. H. L. Myer, who had managed the Boston project and devised the conveyor concept there, was named MWAK’s general manager for the Grand Coulee project.

While the concept was not innovative, the scale of the Grand Coulee conveyor system was. “Conveyors have replaced trucks for this purpose in isolated cases before,” Engineering News-Record acknowledged, “but not on so large a scale or to so complete an extent.” The system was developed on-site through close collaboration between the contractor and the Jeffrey Manufacturing Company of Columbus, Ohio, which had provided similar equipment for the Boston and Fort Peck projects. It was “conceived, engineered, manufactured, and installed” in less than three months and had its inaugural run on December 13. “The contracting world now definitely has a new and reliable tool available, which Grand Coulee proves is economical, reliable and admirably adapted to high-speed operation in difficult situations,” the journal remarked. “In using conveyors for the major transportation and disposal of excavated dirt at Grand Coulee, the contractors have shown that the pioneering spirit of the West is still a vital American characteristic.”

In the excavation pit, seven electric shovels with 4- to 5-yard buckets and seven gas and diesel shovels with 1.25- to 2-yard buckets scooped overburden into self-propelled 12-yard dump trucks, 24-yard trailers with low-pressure pneumatic tires, or pairs of 10-yard tractor-wheel trailers. The trailers were pulled by Caterpillar tractors. All of the loads were dumped into “grizzlies”—steel grillages with 12" to 13" openings, which stopped larger boulders from damaging the conveyor belts. This had been a major problem in the first days of operation before the grizzlies were installed. Boulders were cleared from the grizzlies by bulldozers and hauled to the spoil pit with trucks. An observer noted that “a continuous circle of hauling equipment—from shovel to grizzly and back to shovel again—was so efficiently maintained that waits for either shovels or hauling equipment were rare indeed.”

The material that passed through the grizzlies, which were at grade, was funneled into feeders that moderated the irregular deposits of the trucks and trailers to ensure a relatively even loading of material on the steel feeder belts. The 65-ton feeder units were installed underground but could be moved by three tractors to remain in close proximity—ideally within 500’—of active excavation areas. While two feeder units were sufficient to supply the main conveyor, the operation included four units to provide coverage when units were being moved or were under repair.

The feeder belts were initially about 350’ long, but additional segments were needed as the excavation progressed. The four feeder belts converged at a hub, where their loads were transferred onto the main conveyor. An operator managed a surge feeder at this junction to make sure that the main belt, moving 620’ a minute, was operating at its highest capacity without being overloaded or unbalanced. With experience, workers made the system more productive, although they never reached the theoretical capacity of 2,500 cubic yards an hour, 52,500 cubic yards during the 21-hour work-day. The maximum that the system actually handled in a day was still impressive, reaching 43,000 cubic yards (about 73,000 tons) by July 1935 and almost 51,000


cubic yards by that October. It took 27 to 40 operators, mechanics, and carpenters every shift to run and maintain the conveyor system.\(^{159}\)

The main conveyor was actually a series of nineteen 60”-wide, eight-ply, 32-ounce canvas duck belts with a rubber cover. (See ILLUSTRATION 4: Diagram of conveyor system for Grand Coulee Dam excavation.)\(^{160}\) They ranged from 150’ to 450’ in length, depending on the grade, which reached a maximum of 14 degrees. The belts overlapped slightly where they met, with the load dumped from the end of one belt onto the beginning of the next one 6’ to 8’ below. A headhouse covered the control equipment and 200-horsepower motor that turned each belt, and a roof protected the main conveyor line from the brunt of the sun and weather. Starting the system took about ten minutes and required careful control, with the unit closest to Rattlesnake Canyon beginning first; when it was up to speed, the next belt started. The process went in reverse when the conveyor was shut down, with a load being dumped from one belt to the next before the empty conveyor was stopped. In the summer of 1935, the main belt extended 4,648’ and feeder belts added another 1,400’ for a total of over 6,000’. That dimension increased to over 7,000’ as the excavation deepened.\(^{161}\)

In the spoil dump at Rattlesnake Canyon, the main conveyor emptied onto an extendable conveyor, which could be expanded in 49’ increments until reaching a total length of about 300’. A telescoping unit advanced 49’ from the end of this conveyor, filling the area until another unit was attached. The telescoping unit led a 175’ boom conveyor, which discharged the spoil into the canyon in a 180-degree arc. This three-piece stacker was labeled the “crowning glory of the line” by a representative of the manufacturer. “Without this unit, which permits the uniform and continuous disposal of material on the dump, the system would be incomplete, and its disposal rate would be greatly devaluated.” Engineers estimated that by the time the excavation for the west side was completed, the spoils pile would be about 300’ high and over half a mile long, measuring 700’ across its base and around 350’ at its flat apex. The unstable slope conditions, though, sometimes interfered with this efficient operation. In March 1935, for example, a slide in Rattlesnake Canyon damaged the spreader boom, which incapacitated the conveyor system for several days until repairs were completed.\(^{162}\)

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The system worked reasonably well. It would carry 4,000 tons per hour—“which is approximately 2,500 bank-yards per hour, but this would vary considerably according to the amount of swell experienced in digging.” By August 1935, *Engineering New-Record* reported, “the best seven-hour shift performance is 17,478 bank-yards, and the best daily 21-hour output is 50,700 bank-yards.” During a twenty-one-hour day, the system was typically shut down for a total of about an hour, in one- to ten-minute increments, usually to remove large boulders that got past a grizzly. When the system worked to perfection, it reached a record of just over fifty-nine hours of continuous operation without a shutdown. During 1935, the conveyor transported about 8.5 million cubic yards of material from the west side. By October, the initial excavation was virtually completed.¹⁶³

By spring 1935, the excavation area was protected by the west cofferdam, which mostly paralleled the west riverbank. (See ILLUSTRATION 5: Plan of west cofferdam.)¹⁶⁴ Extending about 3,000', it was “by a good margin the world’s largest,” *Reclamation Era* claimed. “The nearest rival is the one built in the Hudson River for construction of piers for the steamships *Queen Mary* and *Normandy*, 2,100 feet in length.” The ends of the west cofferdam curved back to the riverbank, enclosing about 65 acres. In this area, about one-third of the dam could be constructed.¹⁶⁵

The cofferdam had several sections, most rising to elevation 990, high enough to hold back a half a million-cfs flood. The sections were known by letters. The sturdiest sections were D, E, F, and G, which would be used for both the east and west diversions. Sections E and F paralleled the river in the area where the dam would be built, flanking Block 40 near the center of the dam. Section E, which extended along the river’s natural west bank, would be the dam’s face for the first phase, protecting work on the west end of the dam as well as the west abutment and powerplant. It consisted of eighteen cells “each forty feet in breadth normal to the axis of the dam and 38.8 feet wide at the diaphragm. The outer walls of each cell were arcs of circles with 35.83 foot radii, making the total width between walls 51 feet.” Steel sheet piling was used for the entire circumference for the piling that was driving into the ground. The piling was continued up to elevation 990 on the river side, while about 37’ inland, 4”-thick timber sheeting formed the

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¹⁶⁴ Bureau of Reclamation, Annual Project History, Columbia Basin Project, First Stage Development (Low-Dam Power Project), Vol. 2, 1934, 182.

section’s rear wall. These walls were tied together with steel rods and the space between filled with gravel.  

Section F ran west of and parallel to Section E. A berm between these sections would protect the excavation for Block 40, directly to the west, the first area to be dug to bedrock and the first part of the concrete dam that would be poured. Plans originally called for Section F to be a single row of sheet piles extending between Sections D and G, which were mirror-image clusters of five main cells interconnected by smaller cells. These junction blocks would support the cross-river cofferdam at a later phase of the construction, when the river was pushed to the west. The clusters were supported by sheet-piling diaphragms up to elevation 965 and tie-rods for the top 25’.  

Section C, a 338’ line of nine cells similar to those forming Section E, arced upstream from Section D. Section H extended 602’ downstream from Section G, continuing the straight edge formed by the east faces of Sections G and E. Section H, which had seventeen cells, would be subjected to the river’s buffeting on its west side when the tailrace was excavated behind it. The cells on the south end of this section were about 90’ broad and 36’ at the rounded east and west ends. The breadth decreased further along in the section, with the cells nearly circular in plan at the north end.  

South of Section H were Section I, which was 216’ long, and Section J, an 80'-long shore arm. Situated on relatively high ground, these sections would have less contact with the river than most other parts of the cofferdam, and they would be removed when the river was diverted to the west. As a result, they featured relatively light steel-pile construction. The same was true for Section A, the 126.5’ upstream shore arm, and Section B, which extended about 575’ to Section C at the natural edge of the river. Sections B and I comprised a single row of standard 15” wide interlocking steel piles, reinforced with tie-rods attached to timber walls 37' behind the piles; gravel filled the area between the piles and timber walls. Lighter pilings were used for Sections A and J. Section I contained a 23' by 20' emergency floodgate with timber stop logs that could be opened to submerge the west excavation area if rising water threatened to overtop the cofferdam. 

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166 Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 6-7, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148 Box 3, Folder 510, NARA-RMR.
167 “Constructing the First Cofer Dam,” _Engineering News-Record_ 115 (August 1, 1935): 148-149; Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 7, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148 Box 3, Folder 510, NARA-RMR.
168 Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 6-9, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148 Box 3, Folder 510, NARA-RMR.
169 “Constructing the First Cofer Dam,” _Engineering News-Record_ 115 (August 1, 1935): 148-149; Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 6-9, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148 Box 3, Folder 510, NARA-RMR.
By the end of 1934, MWAK was clearing overburden from a 12'-wide trench for the west cofferdam. Sections that were underwater were dredged with a clamshell, “a slow tedious job requiring underwater drilling and shooting of many boulders whose sizes ranged up to 500 cu. yd.”

The pace continued to crawl when pile-driving started January 1, 1935, with subzero temperatures chilling the men and equipment. All in all, the west cofferdam required about 13,000 tons of steel piles. The west cofferdam was erected before the construction railroad was completed, so getting materials to the site was challenging. Trucks carried most of the materials from the closest railroad line in Odair, but thousands of timber piles were rafted down the river.

The contractor initially did not use a template to position the piles, which were 80' and 40' in length. MWAK was soon forced, though, to create a template of laminated timber and steel I-beams to keep uncooperative piles in alignment. To the same end, the pile driver worked its way around a cell, “adding some two to five feet of penetration for each round of driving, so that an entire cell was driven more or less simultaneously.” Fishtail guides held two adjacent piles in place so that a steam hammer could drive them simultaneously. Workers suspended in boatswain’s seats threaded the piles and welded extension joints between the piles. As Engineering News-Record noted, this was “a particularly disagreeable assignment during one cold period of two weeks’ duration in which the thermometer went as low as 20 deg[rees] below zero.”

Reclamation had assumed that the piles would be driven from the level of the river, at about elevation 935, to bedrock at around elevation 880, but “the hard till or young shale resisted the driving with remarkable stubbornness.” After most of the piles reached a depth of 40' to 65', the ground refused to allow further penetration, so they were driven only to that point. Although the piles could not reach bedrock, engineers felt confident that such a hard material would be a suitable bearing material, generally impervious to water infiltration. There was still concern, though, that water might travel through sand seams in the clay and undermine the cofferdam. To minimize this risk, fifteen wells were dug to bedrock to interrupt cross-flows. Water collected in the wells was removed by pumps powered by electric motors that were activated by float switches.

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171 Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 14, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148, Box 3, Folder 510, NARA-RMR.
The slow progress threatened the schedule, but “it was literally impossible to put any more boom units into the available space,” recalled C. D. Riddle, MWAK’s chief engineer. To accelerate progress, MWAK fashioned a movable timber gantry crane that spanned the cofferdam cells, supported on each side by a timber trestle. The crane held four steam hammers suspended from electric hoists, a compact arrangement that allowed the hammers to be moved as needed to any location beneath the crane. Using four hammers instead of just one on each cell increased efficiency by almost 50 percent, and actually put the project ahead of schedule.174

After the piles were driven, massive quantities of backfill material had to be placed inside and behind the cells before the spring floods. MWAK began filling cells in sections A and B with dump trucks on February 20. By the time that work started on cell C, the framework of the entire west cofferdam was in place. The dump trucks were not keeping pace, so MWAK concocted an ingenious system of three conveyors that could be adjusted to rush the material into position. A belt conveyor transported material from the west excavation to a hopper near the cofferdam. The hopper straddled a 1,600'-long track running about 200' inland from the cofferdam, feeding a 870' shuttle conveyor that traveled on the track. Two-hundred-foot boom arms extended from auxiliary hoppers at each end of that conveyor. The booms, equipped with 36"-wide conveyor belts, positioned 157,000 cubic yards of fill in the cofferdam, completing the work on April 10, 1935, in time to stave off the Columbia’s rising water.175

Some modifications were made to the design of the cofferdam during the course of construction. When contractors encountered large boulders in the riverbed, for example, they decided to move the location of the cofferdam 150' west, narrowing the berm between Sections E and F to only 60'. As a result, it was necessary to install something more substantial than a single row of sheet piles when work began on Section E in July 1935. Adopting a technique used in constructing the New York City subway system, MWAK spaced a row of vertical needle beams 10' apart along the west side of the berm. As material was excavated from around these 21" I-beams, three-segment timber arches were wedged between the beams, forming a scalloped west wall for the earthen berm. The I-beams were braced by timber struts running to a sheetpile wall 80' to the

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175 “Constructing the First Coffer Dam,” Engineering News-Record 115 (August 1, 1935): 150; Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 17, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148, Box 3, Folder 510, NARA-RMR.
west. Material between the wall and berm was excavated from 65' to 110' to bedrock, forming an open caisson 500' long. 176

In December 1935, the contractor began scaling this excavated area. Removing the overburden left a rough surface of rock, which had to be cleaned up to obtain a stable surface to receive concrete. The process of scaling, a Reclamation report explained, generally removed 3' to 10' of weathered rock, “and where fractured or soft rock was encountered scaling was carried to a sufficient depth to remove all undesirable rock.” Rather than sending this rock to the spoils pile, it was used to reinforce slide areas and as riprap for slopes, including tailrace areas. “The preparation of the surface, after excavation was completed, was an extremely expensive job because of the amount of handwork with pick or bar,” Engineering News-Record explained. Ultimately, the area where concrete and granite would come into contact at Grand Coulee was nearly fifty acres, over 2 million square feet. At a cost of $.75 a foot, the tab for this “manicuring” would be around $1.5 million. In March 1935, contractors started scaling bedrock on the west abutment between elevations 1100 and 1308. By September, scaling operations had moved to the west tailrace and powerhouse areas, a length of about 900’. 177

Right after areas had been scaled, the bedrock was consolidated by grouting. “At the time Grand Coulee Dam was constructed,” a Reclamation engineer recalled, “pressure grouting techniques were still somewhat in the development stage though extensive grouting had been performed at Boulder/Hoover Dam. . . . The contractor made numerous improvements in the grouting process, principally in high pressure pumps where replaceable hard surfaced liners and piston rods and rubber-jacketed pistons were used to maintain the serviceability of the equipment.” 178

Reclamation particularly wanted to target unstable areas for foundation grouting, but planned to grout extensively throughout the foundation. The objective of “B” or “blanket” grouting was to create “an impervious grout curtain thirty to fifty feet in depth along the axis of the dam” to solidify the upper layers of rock. Using pressure of 50 to 200 pounds per square inch, cement grout was injected into five rows of holes that were 1-7/8” in diameter and up to 30' deep. Wagon-type percussion drills and jackhammers produced the holes, which were placed 20' on center in staggered rows. Before grout was inserted, holes were cleaned “with air and water, admitted alternately at the bottom of the hole through a small pipe so arranged as to give an outflow at the top of the holes of at least 20 minutes of free or clear water flow.” 179

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“C” grouting would be applied with up to 400 pounds of pressure per square inch after at least 25' of concrete had been placed for the dam. This high-pressure grouting went deeper than “B” grouting to create an impervious curtain 30' to 135' to stop water from undermining the dam’s foundation. The depth related to the conditions of foundation rock in a given area. Drains would draw out water downstream from the grout curtain.\textsuperscript{180}

After grouting had been underway for about a year, \textit{Compressed Air} magazine reported that “where jointing was vertical there was little trouble in sealing leaks by caulking but in cases of horizontal jointing, there were several cases where sealing was quite difficult and could only be affected by reducing the pressures, or by diminishing the water-cement ratio”—normally five cubic feet of water to one cubic foot of cement for both “B” and “C” holes.\textsuperscript{181}

The first grouting challenge, however, came late in 1935 when scaling uncovered a 400'-wide lift seam, which had the potential to destabilize the dam’s foundation. A 60' drift was dug in December 1935 to explore the fractured zone, with plans for additional examination with a 36" Calyx drill and other tests. The tests revealed that the disintegrated granite and clay were not extensive. On the basis of the test, engineers decided that six rows of holes, 20' on center, should be drilled through to the other side of the seam. These holes would be used to wash out the seam and apply grout. Ultimately some 14,525 cubic feet of grout was needed for the seam, in addition to the standard grout that was anticipated as part of the dam’s construction. At a meeting in April 1936, the Board of Consulting Engineers concluded that the grouting work done on the seam had been done appropriately. Although the board found the rock’s structural condition to be “satisfactory,” it recommended that four additional Calyx holes be drilled for further testing of foundation conditions.\textsuperscript{182}

Calyx drilling was often used to plan for grouting, which restricted seepage that could undermine the dam. “Before the grouting operations are taken in hand,” \textit{Compressed Air Magazine} explained, Reclamation “planned to examine the site by drilling holes from 50 to 60 feet in depth at 200-foot intervals along the axis of the dam with a 3-foot ‘Calyx’ core drill. Into these holes geologists will be lowered, enabling them to study the rock at first hand.” Reclamation had purchased the 36" Calyx drill in 1935 at the recommendation of the Board of Consulting Engineers. The Calyx was “a comparatively new development in the field of core drilling,” according to a Reclamation report.\textsuperscript{183}

The board had identified a number of locations for drilling at its meeting in June 1935. Two holes were drilled by October. By the end of 1936, the Calyx drill had been put to use in thirteen locations to test questionable rock conditions. A project history noted: “This method of exploration was very effective as it permitted a visual inspection of bedrock to depths varying from 24 to 66 feet. Also, the large size cores gave a much better record of rock structure than did the smaller-size diamond drill cores.” Six more Calyx holes were completed by the board’s April 1937 visit. By the end of that year the nineteen holes totaled 785' in length. The contractor had drilled two additional holes for use as sumps.\(^\text{184}\)

**9. THE LOW DAM/HIGH DAM DEBATE CONTINUES**

As construction got underway, the debate over the dam’s height resurfaced with new vigor. From the outset, Reclamation engineers had expressed “some uncertainties concerning the effectiveness of the bond that could be made between the supporting surfaces of a completed low dam and the superposed concrete mass that would form the body of the high dam,” *Scientific American* reported. “It was feared that the vibrations that might be set up at flood stages, with the pool at its maximum elevation, would weaken and perhaps overtax the bond between the old and the new concrete.”\(^\text{185}\)

As early as July 1934, officials from Reclamation and the State of Washington met in Seattle “to consider matters relating to construction of the high dam.” By fall 1934, the ambivalence was hindering development of the design of key features. Writing in *Civil Engineering* in September, Frank Banks noted that a decision on the type of turbine-generator unit for the powerhouse “is being deferred until more is known of the prospects for proceeding with the construction of the High Dam.” Other elements were also in limbo, with an attempt to keep plans open to change: “All subaqueous excavation required for the High Dam will be done at this time, and its downstream toe will be constructed to serve as a permanent cofferdam during the work on the rest of the structure. . . . Arrangements have also been made to take over the contractor’s pump and immobile plant and equipment in case the construction of the High Dam is authorized before the Low Dam is finished.”\(^\text{186}\)

Political factors were a critical part of the equation. While engineering issues were central for Reclamation, Commissioner Mead realized that other arguments might be more compelling to leaders in Washington. He wrote to Senator Dill in October that “much attention has been given to the development of the Columbia Basin during the past two or three months. This is because of a continued recognition of how much more valuable this development would be if we returned

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to the original conception of a high dam and the irrigation of 1,200,000 acres of land.” He cited the employment that would be generated by the project’s construction.  

In addition, a prolonged drought was increasing the demand for irrigated land. This issue was at the heart of the debate. Irrigation was not feasible with the low dam because the facilities to pump the water came at too great a cost. At the same time, there was growing concern about the soundness of one of the primary rationales for the low dam, namely power. In November 1934, Engineering New-Record warned: “Without the people and new commerce that the irrigation project will bring, the present powerplant bids fair to become as great a white elephant as the plant at Muscle Shoals.” The Northwest power market, once underserved, was about to be oversaturated. The Corps of Engineers, defeated in its bid to develop Grand Coulee, was proceeding with the Bonneville Project further downstream. Bonneville included a lock and dam and provided flood control. These activities would subsidize the powerplant, making it able to sell hydroelectricity at a rate far below that of the low dam powerplant at Grand Coulee. The Pumping Plant associated with the high dam was essential to change the dynamics. “Irrigation has no official place in the present operations,” Engineering News-Record reported, “but it stands off-stage, as it were, at Grand Coulee, ready to step forward as the real justification for that great undertaking.”  

A Reclamation report a month later admitted that “construction of a low dam across the Columbia River at the Grand Coulee site was undertaken early in 1934 primarily as a work relief project. . . . The low dam is purely a partial power development and its only justification is as a work relief project.” Reclamation’s motives for helping out with the economic crisis were not entirely altruistic in 1934, but Grand Coulee’s capacity to employ thousands of workers continued to be a major theme by the end of 1935 as Reclamation stepped up its lobbying for the high dam and immediate development of one or more units of the related irrigation project. Chief Engineer Walter, once an opponent of the high dam, emphasized this in a report to Commissioner Mead in December 1934: “I know of no project that could be undertaken which would be as effective as a means of providing a large amount of work relief during the final year 1936 as the Columbia Basin project. The change from the low dam to the high dam at Grand Coulee would make it possible to purchase the large turbines, generators, transformers and other powerplant machinery as soon as the necessary specifications could be prepared and this would afford a large amount of employment in the factories in the East and the construction of the main canals and laterals of the irrigation development would afford a large amount of local

employment because such construction can be carried on simultaneously at a large number of points.”

Walter underscored the inefficiencies of proceeding with the low dam: “The hydraulic machinery in the powerplant must be an uneconomical compromise between the low and high head conditions which will considerable increase its cost.” He also repeated the engineering concerns: “The construction of the Grand Coulee Dam in two stages involves difficult problems in the design of both the dam and powerplant. The joint in the dam between the two stages of construction must unite the low and high portions of the dam into a monolithic structure and yet the joint must be drained to prevent the accumulation of hydrostatic pressure and to insure the safety of the dam.”

Walter’s report was the product of a two-day meeting of Reclamation engineering staff in Denver in early December 1934 that Commissioner Mead attended. The resulting recommendations for revising the scope of the first phase included increasing the area excavated, particularly around the two tailraces and the retaining and training walls; installing longitudinal joints and changing the method for placing concrete; installing a concrete cooling system and shafts and galleries to accommodate cooling and grouting operations; making revisions to the design of the cofferdam; moving the Left Powerplant closer to the river; shortening the dam’s spillway and modifying its design; eliminating steel penstocks; eliminating penstock trashracks, traveling and gantry cranes, and penstock gates; installing ring follower and paradox outlet gates; and postponing powerhouse construction above the turbine floor.

In transmitting the report to Secretary of the Interior Ickes, Mead and Reclamation engineers emphasized a variety of engineering, construction, economic, and social factors that supported expanding the Grand Coulee project, including the multiyear drought in the Midwest and West that was forcing many farmers from their land. Producing irrigated land would bring the project full circle, back to its initial purpose as “principally an irrigation project.” The most responsible thing to do under these changed circumstances, Mead’s letter argued, was to switch to the high dam and immediately proceed with the irrigation works. The current contract for the low dam could be easily modified: while the same amount of concrete would be placed, its location would be reconfigured to create the base of the high dam. When that work was finished, Reclamation could bid out the remainder of the project or complete the construction with its own forces. The ultimate project cost was anticipated to be $404 million.

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190 W. F. Walter to Elwood Mead, December 22, 1934, typescript, at Grand Coulee Administration Building Library.
During the same week, Mead wrote a private memorandum to the secretary of the interior that repeated many points from the report, but expressed his views more frankly. “For the past six months I have been increasingly dissatisfied with the plans under which the Grand Coulee project is being carried out,” he began. “Ever since your visit to the Northwest I have contemplated discussing this with you but have postponed it until I could have an opportunity of considering the matter with our engineering staff at Denver.” At that meeting, “there was a unanimous view that the plans of this project ought to be changed, that it ought to be built as a combined irrigation and powerplant.”

His arguments included both the positive reasons for a change of plans and the negative consequences of not doing so. Much of the initial work was needed for either alternative: “The preparatory expense, which includes the road, the railway, the removal of the overburden and unwatering the foundation, are as great for the low dam as for the high dam.” Between the power needed for the pumps and the electricity used by the new settlers on the land, “irrigation will go far to provide a market for the power generated at the dam.” In addition, the benefits would reach beyond the immediate vicinity: “There will be a reservoir 150 miles long, which will regulate the flow of the river, and equalize the discharge to the great advantage of all power developments along the stream below, including Bonneville.” And, during a time when economic hardship had lowered America’s morale, citizens could take pride in the accomplishment: “It will be the largest single irrigation development in this country, or in any country, except Egypt and India.” If Reclamation proceeded with the low dam, Grand Coulee was destined, instead, to be an embarrassment to all involved. The high dam would transform Grand Coulee from a Depression boondoggle into a project of real value: “From being a dubious enterprise it becomes an attractive one.”

Months passed, but Reclamation’s campaign ultimately met with success. On June 7, 1935, Secretary Ickes signed a change order for the MWAK contract. Instead of completing the low dam, MWAK would now be building the base for the high dam. In reporting the change, Engineering News-Record opined: “The present situation came about because the work was begun without studied design or purposeful conception of ultimate service value.”

Reclamation officially notified the contractor of the change on July 5, 1935. An article in Compressed Air reported: “While there is no official assurance that a new contract for its completion will be forthcoming when the existing contract is concluded, the sponsors of the project are of the opinion that activities will continue uninterruptedly until the dam has reached

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194 Elwood Mead, memorandum for the secretary [of the interior], December 19, 1934, pages 1 and 4, at RG 115, Project Correspondence File, 1930-1945, Box 527, Entry 7, NARA-RMR.
195 Elwood Mead, memorandum for the secretary [of the interior], December 19, 1934, pages 2-3, at RG 115, Entry 7, Project Correspondence File, 1930-1945, Box 527, NARA-RMR.
its full height.”

For the first phase, the dam would rise to elevation 940 and the powerhouse foundations to elevation 1000. Revisions to the original contract would include somewhat more concrete work and excavation to complete the wide base of the high dam, even though the height of the construction would be dropped 120’ to about 177”—just over one-third of the dam’s ultimate height. This reduction, as well as stopping construction of the powerplant at the turbine floor, would offset other cost increases.

Ultimately, the dam would top out at elevation 1311. As in the original plan, it would be 4,000' long, but near its west end, a 500' Forebay Dam for the Pumping Plant would angle to the southwest. Both sections would be straight gravity concrete structures, with a 1,650' spillway centered in the main dam. A road on the dam’s crest would be carried across the spillway by a concrete-arch bridge. The spillway would hold eleven drum gates, each 135' long and 28' high, which could raise the level of the reservoir from the spillway’s crest at elevation 1260 to elevation 1288. The addition of flashboards could increase that by another 2', bringing the reservoir to a maximum height of 1290. Just this 2’ increase would add 163,200 acre-feet to the capacity of the reservoir.

The Left and Right Powerplants would be supplied by 18’-diameter penstocks through the dam. Also penetrating the dam would be sixty 102”-diameter outlets. Located in the right two-thirds of the spillway, the outlets would be evenly divided into three horizontal tiers about 100' feet apart. The forty pipes in the top two tiers (elevations 1036 and 1136) would be lined with steel casings and each hold two 102” ring-seal gates set in tandem. The inlets could be closed with 12’ x 12” bulkhead gates. The conduits in the lowest tier (elevation 934) would be unlined, and would be equipped with one 102” ring-follower gate and one 102” paradox gate. The bell-mouthed intakes for the three tiers of outlets would be vertically aligned, with each column protected by a single 250'-tall semicircular trashrack with a horizontal radius of 22’.

10. A MATTER OF SCALE: MODEL TESTING

Engineers at Reclamation were relieved by the decision. They had been hard at work finalizing plans for the low dam, using models extensively to test design options. The testing program had been complicated by the need to develop a low dam that could be transformed into a high dam. This, in essence, meant designing two structures. The engineers realized, though, “that the hydraulic features of these two structures would be interdependent, and that the studies on both

should be conducted simultaneously.” This approach proved a tremendous advantage when the low dam was eliminated. “Tentative designs for the high dam had been ascertained. . . . The general shape and dimensions of the spillway were known and studies for the river outlets and specific parts of the spillway were in progress.”

Investing time and money on models was a relatively new trend at Reclamation. “Models were first used extensively by the Bureau in 1930 in the design of the spillway for the Cle Elum Dam of the Yakima project in Washington,” according to Jacob Warnock, a hydraulic research engineer for Reclamation. “By the time the design and construction of the Grand Coulee Dam had been assigned to the Bureau of Reclamation, the practice of using hydraulic models as an aid in the design of large hydraulic structures was well established.” In a report on “Hydraulic Laboratory Test No. 103: Spillway and Outlets for Grand Coulee Dam,” Warnock described the immense scale of the project, noting: “Hydraulic features of unprecedented proportions, such as these, introduce new problems in design and intensify the usual ones. Both require extensive and diversified investigations to insure dependable designs, which prompted a comprehensive program of hydraulic model studies for the design of the spillway and river outlets. These studies, conducted intermittently with those on other projects, extended over a period of several years.” Most of the models for the Grand Coulee Project were cross-sections with glass sides to allow visual observation, but a few included the entire structure. The model studies “were comprehensive and productive of results, which, though unanticipated in many cases, produced designs superior to any which might have been based on precedent alone.”

The design of the spillway seemed a particularly appropriate subject for model studies. Reclamation had anticipated the challenge of designing the spillway in its 1932 report to the secretary of the interior recommending construction of the dam: “Kinetic energy of the spillway water would be dissipated by a sloping apron designed to create a hydraulic jump, the final arrangement to be determined from model tests in a hydraulic laboratory.” Reclamation’s laboratory facilities were well respected, and their scope extended beyond in-house projects to dams of the Tennessee Valley Authority, like Wheeler and Norris, and Madden Dam in the Panama Canal Zone. A series of tests at its laboratory at Colorado University in Boulder in the early 1930s examined stresses and strains on slice models of maximum cantilever sections of Boulder, Grand Coulee, and Norris Dams. The models were made of a plaster-celite mix mounted on a reinforced-concrete frame.


The Grand Coulee model was based on one of the proposed designs for the high gravity dam. The scale was 1’ equals 20’. The force of water on the upstream side was simulated with a bag of mercury, held in place by wood blocks. The appropriate dead load was produced by lead weights hung from the model, adjusted by levers to approximate the actual resistance of a full-scale concrete structure to water. The test found that the maximum stress in the dam was about 350 pounds per square inch (psi). “No vertical tension was observed at the heel under full load,” Chief Designing Engineer Savage wrote. “The results clearly indicate that the stress distribution at the base is not linear. However, the measured curves are concave upward, whereas curves calculated on the basis of an infinite elastic plate are concave downward.” All in all, the engineers concluded that the models were useful for evaluating load deflections, general stress conditions, and special stress conditions at corners, galleries, and other locations, but gave “misleading stress curves in the foundation material” because the models were held rigidly.\(^{204}\)

Reclamation engineers chose a 1:184 scale for a model of the Grand Coulee spillway tested at the hydraulic laboratory of the Colorado Agricultural Experiment Station in Fort Collins, Colorado. While too small to produce accurate results, “this model did serve admirably in a qualitative way for the study of suggested designs and for the elimination of undesirable ones quickly and economically,” according to Warnock. The most important conclusion was that “the topography of the site, the tailwater-discharge relationship, and the condition of the river bed were such as to dictate the use of an apron, or bucket, curved in section and placed at a very low elevation.” He continued: “A further refinement of this design resulted in the addition of a dentated lip on the downstream edge of the bucket.” Engineers were concerned, though, about vacuums in this area that would cause premature wear on the teeth.\(^{205}\)

The model for the second test contained one gate and half a pier at each end plus the downstream face of the spillway and bucket. The 1:40 model, which was outfitted with a standard array of recording devices, also incorporated a 6'-wide, 3.5'-high glass panel on one side of the flume to permit visual inspection. Warnock called the glass panel “invaluable”: “Regardless of the amount of data which may be obtained by other devices, none has proved as effective as this in affording a mental image of the true behavior of the water.” The test confirmed the presence of a partial vacuum, sending designers back to the drawing board to seek alternatives.\(^{206}\)

Frank Banks reported in a 1934 article in _Civil Engineering_ that the design of the bucket at the bottom of the spillway “is the subject of experiments now being conducted on large-scale models in the hydraulic laboratories at Fort Collins and Montrose, Colo.” The Montrose testing facility was in a canal of an irrigation project, where Reclamation engineers developed a 1:15-scale


\(^{205}\) Jacob E. Warnock, “Experiments Aid in Design at Grand Coulee,” _Civil Engineering_ 6 (November 1936): 737.

\(^{206}\) Jacob E. Warnock, “Experiments Aid in Design at Grand Coulee,” _Civil Engineering_ 6 (November 1936): 737-738.
model of the dam. Warnock noted that “the testing on the two large models was carried on simultaneously, permitting direct comparison of data.” Findings from these tests provided crucial information. Regardless of how the design of the dentated lip was modified, for example, it appeared that the vacuum and wear from debris in the river would quickly damage the teeth, so this feature was ultimately dropped.\(^{207}\)

In the end, the models led engineers to design the bucket with a 50’ radius. Depending on the season, its downstream edge would be submerged 30’ to 75’ below the level of water in the tailrace. *Engineering News-Record* reported on the design, expressing a concern that would prove warranted: “This bucket has an optimum radius, determined by model studies, for the purpose of turning the water upward to form a high boil which is expected to dissipate the energy most effectively. Nevertheless, the large amount of power to be expended centers a good deal of interest on the condition of the concrete in the bucket after it has been some time in this service.”\(^{208}\)

The models also examined more systemic issues. The model-makers at the Fort Collins laboratory produced a 1:120 representation of “the complete ultimate development, including spillway, power houses, tailraces, and a half-mile of the river bed below the dam.” The model allowed for better observation of an unusual—and potentially, problematic—transverse wave that appeared on the spillway in other models. Engineers modified elements of the model in an effort to eliminate the wave. They met with success by increasing the depth of the tailwater and removing a spillway gate at the left end, which shortened the spillway’s length from 1,800’ to 1,650’. “This change permitted the shifting of the left power house to a position 150 ft. nearer the river,” Warnock noted, “a more favorable location, which will effect an appreciable reduction in construction cost.” The design of penstocks and outlets were also subjected to extensive testing, with fourteen models “representing designs from the embryonic to the final stage.” The first concept for the dam called for forty unlined outlets that were rectangular in cross-section, measuring about 6’ wide by 11’ high, and arranged in two tiers. The 1:120 model of the dam showed that this configuration resulted in severe scour in the river and erosion along the banks.\(^{209}\)

Model testing caught other problems with the two upper tiers of outlets as well. Warnock observed that without tailwater to create atmospheric pressure, “sub-atmospheric pressures which would have caused absolute zero pressure through a considerable length of the prototype conduit, prevailed in the model. Severe cavitation would have resulted, hampering or even


completely preventing successful operation.” In what was perhaps a slight jab at the engineers who drafted the design, he noted: “The fact that the frictional losses in the conduit were insufficient to overcome the accelerating force introduced by the slope of the conduit had apparently been overlooked.” Another issue with the outlets was the spray generated at their termini. This had turned into a major problem at the recently opened Boulder Dam, where outlet spray had created unpleasant atmospheric conditions and some physical damage to the powerhouse.210

“The subsequent redesign of the conduits for the middle and upper tiers at Grand Coulee was therefore based on three objectives,” Warnock wrote: “(1) prevention of sub-atmospheric pressures within the conduits, (2) minimizing the formation of spray, and (3) minimizing the river-bed erosion.” The best design appeared to be a horizontal conduit that was circular, rather than rectangular, in section. The dimensions of a bell-mouth inlet with a converging elbow were also refined using models, which were outfitted with trashracks to closely simulate actual conditions. At the downstream end, the outlet angled down, directing the jets parallel to the spillway face, which minimized spray and the potential for erosion. The hydraulic laboratory tested a number of elbow geometries, finally identifying a design that retained positive pressures for heads over 40’, the minimum anticipated when the dam was completed.211

With that resolved, Warnock continued, “the trough, or apron, portion of the outlets presented a problem of greater magnitude than originally anticipated.” Again, a number of options were tried, but “when the solution was found, it was quite by accident. Pressures in the elbow, cone, and upper portion of the channel were satisfactory; the jet of water was stable and undisturbed; the design of the conduit down to the end of the cone had been released to the design department for detailing; the simplicity of the design so far was encouraging. But what was to be done with this one remaining low-pressure condition?”212

The solution was found by a serendipitous observation: “One morning, after several weeks of study, the single-leg glass piezometer tubes were being replaced with U-tubes to eliminate the necessity of establishing a new datum plane after each change in the model. During the changing of the rubber connections, it was noted that the pressure downstream from any disconnected tube was increased. Air flowing into the disconnected tube aerated the low-pressure region. Why not install air vents for that purpose?” This discovery ended up providing the solution. The challenges were not yet behind the designers, though. “The supposedly final design for the


intermediate outlets at Grand Coulee Dam, which was developed under extreme urgency, did not have deflectors over the outlets, although consideration had been given to the excessive spray from the water dropping into the channel of the outlet.” As it turned out, deflectors were indeed necessary to eliminate spray when water was passing over the spillway and the outlets were closed. Installed at the top of the outlet opening, the deflector “was made parabolic in the direction of flow and was blended into the spillway face by reverse curves.”

Gates for the outlets, which faced extreme water pressure, were also analyzed. The models indicated that excessive force would be required to both raise and lower the gates. Through testing, the engineers concluded that “hydraulic balance was reestablished to a large degree by providing a vertical intercommunicating passageway behind the leaf in the gate bonnet and frame.” Warnock explained that “this allowed the excess pressure above the leaf to escape into the top of the conduit downstream from the gate and alleviated a condition which in the operation of the prototype would have been a source of grief.”

Engineers also wanted to identify the ideal turbine and related components for the project. “The unprecedented capacities of the proposed turbine units for the Grand Coulee Power Plant made it necessary to insure that every possible improvement be incorporated in their design,” a Reclamation testing report asserted. “The highest possible efficiency consistent with simplicity and sturdiness of design in these turbine units was especially desirable because of the unprecedented capacity of the units and the enormous investment involved.”

Engineers felt, though, that little improvement could be made on the efficiency of modern turbine runners, so model studies focused on the draft tube design. “In the case of Grand Coulee,” a test report explained, “the average velocity at the exit from the turbine runner for a discharge of 4,400 cubic feet per second will be 27.0 feet per second, which corresponds to a velocity head of 11.3 feet. As draft tubes are generally only about 75 percent efficient, the velocity head actually recovered is something like 8.5 feet, or 2.5 percent of the normal head on the turbine. An improvement of 10 percent in draft tube efficiency would therefore result in an increase of 0.25 percent in the over-all efficiency of the units. It was decided that this possible improvement justified a model study.” Pilot tests on a small model using a variety of draft tube designs led to the selection of three for testing on a 1:24-scale model, where different scroll case, speed ring, and fairwater cone designs were also analyzed.

216 “Grand Coulee Turbine and Draft Tube Studies,” Bureau of Reclamation-Denver, July 25, 1940, 1; L. E. Winkelhaus, D. J. Hebert, and D. A. Wigle, “Hydraulic Model Studies for Turbines at Grand Coulee Power Plant,
The model tests helped Reclamation design the project even as it was being built. When the Board of Consulting Engineers met in Washington, D.C., in late July 1935, shortly after the high dam had been approved, members tabled a discussion of most of the design changes until more detailed plans were available. The board did recommend the concept of a spillway bucket with a 50' radius, with its discharge lip at elevation 900. “The exact form and dimensions of the bucket lip,” it noted, would “be selected after completion of model tests.” The board also concluded that “with adequate permanent drainage and natural adjustments, there is good reason to anticipate an ultimate stable condition of tailrace slopes.”

The switch from the low to the high dam, which came as the cofferdam was under construction, had implications for the river’s diversion as well. Reclamation studied this with the 1:120 scale model at Fort Collins, which was built between November 1935 and January 1936. As testing progressed, the model was refined. The bents of the construction trestle were added, for example, to analyze the effects of various alternatives on the footings. The model tests continued through at least May.

These tests were closely monitored by MWAK’s chief engineer, C. D. Riddle, as well as Reclamation engineers, and they influenced the approach selected for diverting the river on the dam’s west end (Blocks 8 through 40). The workhorses for the diversion would be Blocks 32, 34, 36, and 38, which would remain at elevation 910, 23’ below the mean low water level, during much of the construction period. These slots, a Reclamation engineer explained, would provide “ample floodway for a flow of 50,000 cubic feet per second without any appreciable increase in the reservoir level.” When the water rose to elevation 950, it could pass through Blocks 13, 15, 17, 23, 25, 29, 30, 33, 35, and 37. The remaining blocks would be at elevation 1000 or higher.

Even as the model studies were underway, important planning and design decisions were being made. On June 15, 1935, shortly after the major change order for the construction was announced, the Board of Consulting Engineers assembled at the dam site. The group considered various issues related to the high dam plan, including a drilling program to explore options for grouting, proposed changes to slopes in the tailrace and slide areas, and alternatives for penstock placement. The board approved the general design for the Pumping Plant, recommended that the drum-gates on the dam be heated to avoid ice build-up, and authorized an in-depth geological

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218 “Constructing the First Cofer Dam,” Engineering News-Record 115 (August 1, 1935): 148; J. E. Warnock to Chief Designing Engineer, memorandum on diversion of river through the west cofferdam area, April 9, 1936; J. E. Warnock to Chief Designing Engineer, memorandum on diversion of river through the west cofferdam area, May 8, 1936.
219 Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 26-27, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148 Box 3, Folder 510, NARA-RMR.
investigation to identify issues that might affect the Grand Coulee’s suitability for service as an equalizing reservoir.\textsuperscript{220}

As Reclamation engineers had recommended, the permanent downstream cofferdam, which had been intended to form part of the base of the high dam, was eliminated. Plans for any work on the penstocks and powerhouses above the turbine floor level were postponed, and the order for equipment was put on hold. The amount of excavation, though, was increased, and the contractor was instructed to clear out the area for the Left Powerplant tailrace and remove an additional 2 million cubic yards for the dam foundation. The original contract had not included any provision for development of the Left Powerplant.\textsuperscript{221}

Some engineers were disappointed at Reclamation’s final selection of a seemingly common straight-gravity design for the dam. Chief Designing Engineer Savage asserted, though, that “the design of Grand Coulee Dam is the boldest that the Bureau of Reclamation has approved to date for one of its major structures,” matched only by Shasta Dam. “It was only as a result of nearly six years of intensive research and study in connection with Boulder Dam that the Bureau engineers acquired the necessary personnel and technical knowledge required in the task of preparing a safe and at the same time economical design for a structure like Grand Coulee Dam.” While Boulder Dam’s concrete arch might appear more novel, its design was actually less complicated because two-thirds of the water load was carried by the abutments. This made it “a far safer structure than is economically possible for a long, straight-gravity dam,” Savage noted, where “all of the water load is carried to the base of the structure.”\textsuperscript{222}

\section*{11. CONCRETE PROGRESS}

Although the contractor targeted October 1, 1935, as the date to start placing concrete for the dam’s foundation, the official “first pour” did not occur until December 6, when Governor Martin tripped a ceremonial bucket of concrete to initiate the 50'-wide mass that would become Block 40. This was the first ”concrete” manifestation of the design that had resulted from intensive work by Reclamation engineers at the drawing board and in the laboratory.\textsuperscript{223}

MWAK had begun low-pressure grouting of the bedrock in November in advance of the pour, and began placing concrete in earnest on December 15, 1935. Problems related to placing concrete in cold weather were compounded by an incomplete delivery system. The railroad trestle intended to bring buckets from the mix plant to Block 40 was not finished, so the buckets


\textsuperscript{222} J. L. Savage to Chief Engineer, memorandum, December 1, 1938, appended to R. F. Walter, J. L. Savage, Frank Banks, L. N. McClellan, and John J. Hammond, to Commissioner, “Construction Program for Completion of Grand Coulee Dam,” memorandum, December 12, 1938, RG 115, Project Correspondence File, 1930-1945, Entry 7, Box 534, NARA-RMR.

had to be transferred to trucks for part of their journey. “As a result,” a Reclamation report observed, “concrete was delivered in a very stiff condition.” By the end of the month, railroad tracks had been installed down the tailrace slope to the cofferdam, greatly improving the delivery time.224

In addition, the maze of timber trusses bracing the walls around the excavated area “made concrete placement very difficult, particularly below the 900-ft. level,” according to a Reclamation report. “As a consequence much hand shoveling had to be resorted to.” The situation improved in mid-March when the block was high enough so that the braces could be removed. A month later, Block 40 rose to elevation 970.225

Built up in relatively small units, 5′ at a time, the dam would ultimately become a “25,000,000-ton mass” that one Reclamation document called “the biggest lump of concrete in the world.” Given the huge volume of concrete that was needed, the arrangements for preparing aggregate, storing cement, and mixing and delivering these materials were critical to the project’s timely completion. High quality was essential for the dam’s durability. As The Reclamation Era observed, “The permanence of this type of structure depends upon the quality of concrete used in its construction. This quality, in turn, depends upon many things—the kind and durability of the cement and aggregates, uniformity of concrete mixing, skill in placing, strength, and other factors.”226

Producing concrete was a challenge at the beginning of the project, before large mix plants were in service. Several small plants were established including one belonging to the Western Construction Company, the contractor for the bridge piers. The company screened and washed aggregate and produced concrete for other contractors as well as for its own use. Some contractors employed small portable concrete mixers. Most of the aggregate came from a screening and washing plant that the Ridge Construction Company had set up on the river’s east side. This and other plants were temporary, “and as a consequence the quality of aggregates produced was not always suitable,” a Reclamation report observed, “but through vigilant control, satisfactory materials were supplied.”227

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Only 12,418 cubic yards of concrete were placed in the dam during 1935, and another 11,570 cubic yards in bridge piers, sidewalks, building foundations, and other miscellaneous structures, a small-scale warm-up for the massive campaign to come: Reclamation anticipated placement of 2 million cubic yards in 1936. This initial period gave Reclamation a chance to ramp up the staff and facilities of the Concrete Control Department, which was responsible for everything from inspecting the gravel pit to running a testing laboratory to monitoring concrete production and placement.\(^{228}\)

O. G. Patch had been transferred to Grand Coulee from Boulder Dam to become chief concrete technician in July 1934. His first task was to build and equip the laboratory, which was in operation by mid-September. His initial staff of three had grown to seven by year’s end and to twenty-seven a year later. Patch was to serve as chief of the department until his retirement in 1949. The project history in that year extolled his achievements: “Mr. Patch was responsible for many improved techniques in mixing and placing concrete, and as a result of knowledge gained from his many experiments, he was able to produce for the Grand Coulee Dam a mass concrete averaging over 5,000-pounds compressive strength per square inch, with the use of only one barrel of cement to the cubic yard, an unparalleled feat even 10 years earlier. The saving in cement, thus effected on Grand Coulee Dam alone, was in the neighborhood of $10,000,000.”\(^{229}\)

Reclamation had determined that the aggregate for the dam’s concrete would come from the Brett pit, located downriver from the dam on a bluff about 700' above the east bank of the Columbia. MWAK had been given the undeveloped site, including an area for a screening and washing plant, when it was awarded the construction contract in July 1934. Subcontractor Rowland Construction Company used scrapers, Caterpillar tractors, and a bulldozer to begin stripping sagebrush and silt from the Brett deposit in May 1935. By the end of the year, about 380,000 cubic yards of overburden had been cleared from a 50-acre area. The pit was divided into five blocks, which were excavated sequentially.\(^{230}\)

The need to move large quantities of materials—around 2,500 tons an hour—with speed and efficiency led the contractor to adopt belt conveyors as a principal means of transport. (See ILLUSTRATIONS 6 and 7: Sand and gravel plants and conveyor system.)\(^{231}\) Material was removed from the pit by a 60"-wide conveyor which was extended as excavation progressed. The conveyor was supplied by two feeders, protected by grizzlies with 16" screens. (In 1937, a rock crusher was installed in the pit to reduce boulders larger than 16" for further processing.) Each feeder had a steel hopper over a 42" conveyor, which was supported by a 200' structural-steel boom. One end of the boom was mounted on a tractor that followed an electric shovel as it

moved in a semicircular arc through the pit. The other end rested on a gantry frame above the collecting conveyor, which was on a trestle that extended beyond the edge of the bluff. The material dropped off the end of the conveyor onto a raw stockpile far below, the first of several times that the process took advantage of gravity. The excavation system was set to go by October 1935 and in regular operation by December.\(^{232}\)

The Grand Coulee project required several types of aggregate: four sizes of gravel, ranging from \(\frac{1}{4}\)" to 6" in size, and three grades of sand, which were classified from the finest, No. 4 to No. 20 mesh, up to the coarsest, No. 48 to No. 100 mesh. Obtaining usable aggregate from the excavated material, which included everything from sand to large rocks, involved three steps in the screening and washing plant that extended down the slope from the raw stockpile. About 50 percent of the excavated material—mostly very fine or surplus sand—was wasted, ultimately resulting in a mountain of sand on the edge of Mason City.\(^{233}\)

The first-stage screening and crushing plant, situated directly downhill from the pit, received material from the stockpile by a 175'-long, 60"-wide conveyor. (See ILLUSTRATION 8: Gravel plant flow diagram.)\(^{234}\) The initial sorting was accomplished by two Trommel (scraping) screens, massive cylinders measuring 6' in diameter and 22' long, and weighing eighteen tons. As the horizontal cylinders rotated, material smaller than 6" passed through the holes in its walls. Larger chunks were sent to two 20" Telsmith gyratory crushers. The output from the screens and crushers was transferred by a 150'-long, 48"-wide conveyor to a “balancing pile”—a stockpile intended to provide a steady supply of material to the second-stage screening and washing plant.\(^{235}\)

Four feeders in the balancing pile fed two 42" conveyors. The conveyors took the material to the five-story, steel-frame, screening and washing plant, which a reporter described as “the ‘thunder house’ because of the ear-splitting racket within. In this house, amidst a din and rumble like a constant earthquake, the last speck of dirt is removed from sand and pebbles. There is an orderly confusion of conveyors, screens, chutes, water spouts and surprisingly few men.” In the upper level, the aggregate was drenched with wash water as the conveyors fed four 5' x 10' Symons double-deck vibrating screens, which retained 6" and 3" stone. The smaller material landed on eight double-deck vibrating screens, each also 5' x 10', on the floor below, which extracted the 1-1/2" and \(\frac{3}{4}\)" sizes of gravel. This was state-of-the-art equipment: a 1939 article in Civil


Engineering noted that “multi-deck vibrating screens are replacing the revolving type for general use because of the higher efficiency, economy, and compact arrangement possible with this type.” The four grades of aggregate were carried on separate stone ladders, moderately inclined to avoid breaking the 3” and 6” stone into smaller sizes, to temporary storage piles over a conveyor tunnel.\(^{236}\)

Water washed sand through all of the screens to drag-type sand dewaterers. Eight revolving rakes in the concrete dewatering basin removed the sand, some of which was sent to a classifier house. The remainder landed in the waste dump. A slurry of aggregate sand passed through three “bowl-and-rake type” Dorr classifiers, each with a different flow speed, causing the grades of sand to settle at different rates. After completing the cycle, the water was piped to two concrete clarifying tanks, one a circle 125’ in diameter, the other an oval measuring 125’ x 250’. Cleaning and grading the aggregate and sand required an immense volume of water: the plant was designed to use up to 20,000 gallons of water a minute. The clarifiers made it possible to reclaim about 85 percent of the water for reuse in the plant. Fresh water was obtained from the river.\(^{237}\)

The facility, like the rest of the construction operation, ran three seven-hour shifts. It was designed to produce 1,000 tons of washed and graded sand and gravel from 2,500 tons of raw materials every hour—“probably more than double that of any existing plant,” according to an engineer with the Jeffrey Manufacturing Company, which produced some of the equipment. The disparity between the quantities of raw and final product was due to the substantial oversupply of sand in the Brett deposit. About 15 million cubic yards of unneeded sand would be the byproduct of preparing the 15 million cubic yards of aggregate for the dam.\(^{238}\)

Each class of sand and gravel was segregated in a stockpile area that could hold a total of about 13,000 tons of material. Beneath the stockpiles was a laminated timber tunnel protecting a conveyor that ran about 4,000' to the live-storage piles by the dam’s east end, in the vicinity of where one of the projects two mix plants (“Eastmix” and “Westmix”) was constructed. The tunnel’s roof held a hydraulically operated gate beneath each pile of material, which could be opened to feed the conveyor. The gates were remotely controlled by a “bin man” at the top of the Westmix plant 6,000' away. When the material arrived at the main storage area, which had a capacity of 77,000 tons, it was directed into the appropriate pile by an “airplane tripper”

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consisting of a pair of winged belts extending sideways from a gantry frame mounted on a 441' track.\footnote{239}

From the storage area, sand and gravel were delivered to the Eastmix plant by a 1,500'-long conveyor on a timber trestle. To get to the Westmix plant, materials were carried on a 36"-wide, 4,100'-long conveyor that passed over the river on a 3,500'-long suspension bridge. It could transport up to 700 tons an hour. The bridge’s two main spans, each 1,437' long, were supported where they intersected by a tower resting on one of the west cofferdam’s cell clusters.\footnote{240}

The suspension bridge also carried an 11"-diameter pipe through which bulk cement was pumped 4,200' from the blending plant to the Eastmix plant. The pipe came in 40' sections that were welded together in the field: “A station was erected on a level with the conveyor belt crossing, and the welding was done from that station. As each length of pipe was welded, the whole pipe was pushed across on rollers.” The same type of pipe conveyed cement 2,200' to the Westmix plant.\footnote{241}

Reclamation, rather than MWAK, purchased the bulk cement, contracting with five different companies to get sufficient quantity. MWAK was responsible for the cement from the time it arrived at the construction railroad in Odair, Washington, until it was placed in the dam. When railcars of cement reached the construction area, they were unloaded pneumatically into eight 5,000-bbl steel silos at the rail yard on the west side of the river, about two miles southwest of the dam site. (See ILLUSTRATION 9: Cement storage and blending plant.)\footnote{242} The facility was designed to accommodate up to sixty carloads of bulk cement daily. The cement was blended as it was transported from the silos to two additional silos of the same capacity by a helicoid screw conveyor that was 20" in diameter and 160' long. The blended cement was then piped to the mix plants with the assistance of a 3,000 cubic-foot air-compressor plant. Altogether, the facility could store 50,000 barrels of cement, a three-day supply for the Westmix and Eastmix plants if both were running at maximum output.\footnote{243}


Reclamation considered a variety of cement supplements to improve the performance of the concrete, to tailor the characteristics of the concrete for specific locations, and to save money. One material that particularly intrigued engineers was pozzolan, named after Pozzuoli, Italy, where Romans had discovered a siliceous material they incorporated into the concrete used in aqueduct construction. Volcanic in origin, pozzolan “includes pumice, ash, cinders, basaltic tuff, and basalt” and natural sources were found around the world, with a number of deposits in close proximity to Grand Coulee. The material had no adhesive quality on its own, “but when mixed with hydrated lime exhibited cementitious properties which were highly desirable.” The cement industry had done enough research on pozzolan to verify its potential, but more investigation was needed to determine if the material’s use was practical and economical. Reclamation decided that “with the unprecedented concrete construction program underway at Coulee Dam, . . . [it] was in a good position to give this subject thorough study.”

In November 1934, Reclamation engineers W. T. Moran and W. H. Dumke transmitted the results of preliminary tests on twenty-one samples of pozzolanic materials that had been procured by Frank Banks. The tests examined the reaction of the samples in a solution of saturated lime water, a measure of how the material would perform when combined with Portland cement to make concrete. Five samples, mostly diatomaceous earth from the Yakima Valley, were the most “active,” absorbing more lime and forming loose masses. All samples were evaluated after twenty-four hours, forty-eight hours, and seven days.” The best were scrutinized for fourteen days.

Despite promising results, Reclamation did not adopt pozzolan, but it did not drop the idea either. Testing was revived in August 1937, this time on the dam, with pozzolan replacing 25 percent of the cement in five batches of concrete. Another series of experiments was run in December, when pozzolan was substituted for 20 to 30 percent of the cement. More tests were done in 1938. A total of seventy-eight batches of pozzolan concrete, each comprising four cubic yards, were placed on the top lift produced by the initial contract for the dam. Thirteen batches of standard-mix concrete were placed in the same area as a control. The performance of both was regularly inspected until the next phase began.

Ultimately, “more than 500 samples of such material, obtained in this vicinity, were chemically tested, and thousands of small concrete cylinders were made for compression tests at the field laboratory. The best samples were more exhaustively tested in the Denver laboratory. In the end, though, “although the results of the tests proved to be satisfactory,” taking a chance with this new material on the massive and high-profile Grand Coulee Project seemed too risky, so the idea

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245 W. T. Moran and W. H. Dumke to R. F. Blanks, memorandum on preliminary investigation on pozzolanic materials, November 20, 1934, at RG 115, Engineering and Research Center, Project Reports, 1910-1955, 8NN-115-85-019, Box 290, NARA-RMR. Diatomaceous earth is also known as diatomite, “a light friable siliceous material derived chiefly from diatom remains and used esp. as a filter” (Merriam-Webster’s Collegiate Dictionary, 10th ed.). Diatom is a simple algae.
was shelved. In addition, engineers were not convinced that pozzolan would add sufficient benefit. Some theorized that the fine rock flour in the Brett deposit, which was included in the aggregate for the concrete, served a similar function to pozzolan.247

Even without pozzolan, the state-of-the-art cement facility was a subject of interest and was widely covered by the engineering press. It undoubtedly influenced other facilities just as MWAK had learned from other projects, as a 1938 article in *Scientific American* noted: “In handling bulk cement, the contractor profited by what had been done earlier at Boulder Dam.” MWAK’s education continued as the project was underway, and it made modifications to the facility as a result. In July 1937, for example, an eleventh silo was added to the cement plant. Around the same time, a 9” pipe was added to supplement the 11” pipe delivering cement to the Westmix plant. By that time, the facility was well broken in. It had been functional by the end of September 1935 and received its first shipment of production cement on November 1.248

Because the initial phase of construction focused on the west side, work began on the Westmix plant first. The plant “was early christened the ‘House of Magic’ by a lay public,” a Reclamation report observed, “a name which it fittingly deserves.” Rising to a height of 126’, the plant was just downstream from the west end of the dam. Its octagonal steel frame was 42’ in diameter, with walls sheathed in corrugated metal. Work was underway on the foundation by June 1935 and the plant was completed on November 15. It operated almost constantly until January 1938, except when winter temperatures prohibited concrete placement.249

Excavation for a bench for the Eastmix plant was started in December 1935. Construction began the following February and was completed by April. The plant did not go into operation, however, until October. It remained in service until November 21, 1937, when the Westmix plant took full responsibility for producing the small amount of concrete that remained for the contract’s completion.250

Both plants utilized gravity to move materials. The suspended conveyor that brought aggregate from storage piles across the river emptied into the top of the Westmix plant, as did the delivery

pipe from the cement plant. (See ILLUSTRATION 10: Concrete mixing plant.)\textsuperscript{251} Air that had infiltrated the cement as it was being pumped was removed as it entered the mix plant. The cement and various grades of sand and gravel were stored in bins beneath the roof until needed. It took only a few minutes to transform 17,000 pounds of raw ingredients into concrete. The process was overseen by the plant’s dispatcher, who received and tracked orders for specific amounts and types of concrete. He and the batch operator were located on the third floor—known as the “Brain Chamber of the House of Magic.” The batch operator was responsible for ensuring that the right materials in the right proportions were assembled for an order. The batchers, which were manufactured by the C. S. Johnson Company, were filled automatically, usually in accordance with one of five preprogrammed concrete formulas. There were an additional forty-five mixes, though, that Reclamation had approved. MWAK selected a mix based on the supply of materials from the aggregate plant, which the plant dispatcher communicated with regularly, or from special needs at the dam. The general formula for mass concrete was 1 part cement, 2.7 parts sand, and 7 parts coarse aggregate. The aggregate comprised four sizes in about equal proportion: between 3” and 6”, between 1.5” and 3”, between 1.5” and 0.75”, and between 0.75” and a No. 4 screen.\textsuperscript{252}

After receiving a signal from the mixer operator that a mixer was available, the batch operator emptied the batchers into one of the four 4-cubic-yard Koehring mixers. At first, Reclamation required a mixing time of four minutes. Experiments in Denver and on-site improved procedures and reduced time in the mixer to 2.5 minutes. The timing of the four mixers was staggered, so that one disgorged into a central hopper every 45 seconds. Reclamation and MWAK continued to experiment with the process, reducing the mixing time to two minutes in 1937 by replacing the six to nine blades in each mixer with three long blades that paralleled the mixer’s axis. They also improved the way materials were put into the mixers. When both the Westmix and Eastmix plants were operating at maximum capacity, they could theoretically supply dam workers with an average of one cubic yard of concrete every seven seconds.\textsuperscript{253}

After the materials were blended, the concrete was dispensed into 4-cubic-yard Blaw-Knox buckets. The buckets were transported by 36’-long flatbed railroad cars running on two steel trestles, one at elevation 1024 and the other at elevation 950, that paralleled the dam’s axis. The high and low trestles were extended first from the Westmix plant, then from the Eastmix plant. “As fast as foundation rock was exposed,” a Reclamation project history reported, “tower

footings were poured for the two concrete-placing trestles.” In July 1937, the last girder was riveted into position linking the east and west sections of the high trestle, which rose above the elevation that the dam would reach in the first phase of construction. The lower trestle was used to place concrete in the powerhouse foundations and spillway buckets. Altogether, the trestles required some 10,000 tons of structural steel. The legs of both trestles were subsumed by the dam as the concrete rose; only the deck girders were ultimately salvaged.254

Buckets carried by cars on the high trestle could be filled directly from the mix plant hopper. For the low trestle, a skip car shuttled concrete down a cantilevered ramp to a hopper above the railcars. Each of the trestles was 30′ wide and held three standard-gauge tracks for the railcars, which were pulled by a fleet of ten 10-ton Davenport diesel-electric engines. The tracks were straddled by rails for Whirley and hammerhead cranes. The railcars and engines could run below the cranes, allowing all equipment access to any point along the dam.255

The buckets, each holding about 11 tons of concrete, were taken from the railcars and moved into position by a crane operator, who was guided by a signalman near where the concrete was to be placed. Most concrete was destined for 50′-square forms, although form size ranged from 50′ x 63′ on the high end to as small as 25′ x 44′. The 5′-tall prefabricated formwork, designed to be easily anchored on the bottom and sides, was reused after the pour had set. When the bucket was positioned over the form, a laborer pulled a lever that opened an orifice in the bucket’s base and the concrete flowed out. A placing foreman managed a crew with three shovel men, who were responsible for pulling the bucket lever and spreading the concrete evenly over the block, and five laborers operating single and two-man electric vibrators to compact the concrete. A “pour” for a 5′ lift required 465 cubic yards of concrete and took about seven hours, the length of a shift. A lift had to cure for at least 72 hours before the next pour was allowed. If it was not covered with another lift soon thereafter, the concrete was kept moist for fourteen days to ensure that it would cure properly.256

About two hundred men were occupied as concrete finishers. The smallest surface voids, known as “bug holes,” were a product of the air bubbles that were inevitably incorporated as concrete

was poured. Workers used folded burlap to rub slightly moist mortar into the holes. For larger voids, such as those created by formwork bolt holes or poorly distributed aggregate, uneven concrete was chipped out to make a clean opening that was filled with dry-pack cement or, if large, with reinforcing and a more substantial patch. For concrete that would be visible on the interior of the dam or powerhouses, two methods were used to finish floors and other horizontal surfaces. Areas that might at times be covered with water and become slippery were slightly textured by “applying a trowel lightly and lifting it to create a light suction on the finish,” The Columbian explained, while other areas were simply hand-troweled. “Troweling was done a minimum of five times,” according to the 1941 project history. “As soon as the surface would permit, it was covered with curing paper with all laps glued to assure a tight seal. The curing paper was left in place for a period of 14 days, after which it was removed, and three coats of floor hardener were applied.”

For the mass concrete, a completed lift had to be approved by a Reclamation inspector before the block was released for another pour. MWAK had a crew of “O.K. men” who were responsible for directing the inspectors to lifts that had reached the obligatory 72 hours. The concrete surface had to be clean and smooth to receive approval. Once approved, the lift was covered with grout, a mix similar to the concrete used throughout the dam but without the large aggregate, in anticipation of the next pour.

To track changes throughout the 500' x 1,200' construction area, MWAK’s concrete schedule engineer maintained a small wood model of the evolving dam, adding a block of wood every time a 5' lift was completed. When establishing a sequence of pours, MWAK had to heed rules established by Reclamation. On the dam’s long axis, the difference in height of adjacent blocks could not be more than 25'; that was later increased to 30'. For neighboring blocks perpendicular to the axis, the variance could only be 15'. This procedure facilitated the initial concrete cooling to minimize cracking. It also reduced the risk of vertical cracks, which were likely to develop when large vertical faces were exposed for a period of time. The danger of cracks in the structure was emphasized by Chief Designing Engineer Savage: “If Grand Coulee Dam should fail, it would probably be due to shear failure along vertical longitudinal cracking that had destroyed the integrity of the monolithic structure.”

The dam’s design attempted to minimize cracking. Engineering News-Record reported: “To control the contraction of such a large mass of concrete, the dam will be constructed with vertical

257 “Coulee Dam’s Facial Performed by Finishing Crews,” The Columbian 6 (May 29, 1940): 1, 3; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 257.
transverse and longitudinal contraction joints, so formed that the resulting rectangular blocks or columns will be keyed together. The joints will be provided with a pipe and outlet box grouting system, and metal grout stops will be installed across the joints near the faces of the dam, the grout to be applied under pressure after the concrete has been cooled to its future average temperature.” The vertical longitudinal contraction joints ran at 50' intervals, dividing the blocks that were used to identify sections of the dam.260

While the low dam’s concrete mass, with a maximum dimension of about 260', would have been small enough to cool without assistance, supplemental cooling was essential for curing the concrete in the high dam. “Under ordinary conditions of concrete placement in massive structures,” Reclamation Era explained, “the largest element of volume change results from the expansion of the concrete while it heats during the hardening process, and from subsequent contraction as the concrete slowly cools. . . . The natural cooling of a very large mass of concrete, such as Grand Coulee Dam, would take approximately 100 years; and during that time the concrete would continue to contract, and tend to crack in various unexpected and undesired ways.”261

These problems could be counteracted by artificial cooling, which would greatly accelerate the curing and allow more control over its effects. The plans for Grand Coulee were revised to introduce cooling “coils” throughout the structure. The coils, typically about 650' long but sometimes stretching to 1,200', were a network of horizontal 1"-diameter metal pipes placed every 5'-6" to 5'-9". All told, some 20,000 miles of pipe was embedded in the dam. The pipes “were laid on top of each 5-foot lift of concrete after it had hardened, and they were anchored by wire loops buried in the concrete while it was still plastic,” according to Reclamation Era. “A low-cost expansion coupling, designed by and manufactured especially for the Bureau of Reclamation, was used to join the lengths of tubing and at all points where the 1-inch cooling pipes cross a contraction joint.”262

Supply mains, located in longitudinal galleries, fed subheaders in transverse galleries. Risers extended from these subheaders through 42” cooling shafts to manifolds at each 5' lift. The manifolds, which had valves to control the flow, were connected to the cooling pipes with rubber houses. Pumping equipment on barges next to the dam supplied the system with water from the river at a rate of two to four gallons a minute. The goal of the cooling was to lower the concrete’s temperature to 45 degrees, requiring water of 40 degrees or less. The river’s temperature ranged from 32 to 65 degrees, with the coldest months from December to March. Ideally, the final

cooling would occur during this period. The water had to be artificially chilled during the remainder of the year.\textsuperscript{263}

Because the concrete shrank slightly as it cooled, leaving about a 1/10" gap between the rises, construction grouting was required. The joints would be cleaned with alternating blasts of air and water before grout, a mixture of fine cement and water, was pumped into pipes that had been inserted into each block. The process was described by a project history: “Sections, 50 feet high, are grouted through supply headers of 2-inch and 1-1/2-inch thin-wall tubing, extending from the galleries. Grout is supplied to the joints through ½-inch outlets, so located that each will cover an area of about 60 square feet.”\textsuperscript{264}

At Boulder and Owyhee Dams, Reclamation had installed copper horizontal grout stops between each lift. The contractor experienced “considerable difficulty” in installing the stops “in such a manner as to be 100% effective,” particularly at Boulder. “The grout stop was bent and distorted as the concrete was poured against it. When the joints were being grouted, leakage often occurred through or around the horizontal grout stops into the lift above sometimes plugging the headers in the next lift.” As an alternative, Reclamation engineers designed a horizontal grout groove that was triangular in section for use at Grand Coulee. “The grout will be carried and distributed to the joint by pipe headers and risers with grout outlets in the same manner as at Boulder Dam except that there will be no return header at the top. A metal grout stop will be placed across the joint close to faces of the dam, around the galleries, along the foundation in the transverse joints and vertically at the ends of each longitudinal joint.” The groove joint would substitute for a grout stop on top of the lifts. When grout was fed into the joint, “air and water will escape from any part of the joint into that groove joint,” effectively eliminating voids in the grout.\textsuperscript{265}

\textbf{12. MOVEMENT ON THE EAST SIDE}

While the main focus was on the west side in 1935, the Guy F. Atkinson Company, one of the MWAK partners, had started removing the overburden on the river’s east side that February. Plans had called for the construction of a steel-pile structure similar to the west cofferdam, about 720' to the east. With manpower and equipment stretched thin and the west cofferdam the top priority, however, this strategy was reconsidered. As a substitute for the steel-pile structure, an embankment was left unexcavated along the bank as workers dug below the level of the river. When the rising water approached the top of the dike in May, workers moved to higher ground.


\textsuperscript{264} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 5, 1937, 152.

\textsuperscript{265} Hays and Hammond, memorandum to chief designing engineer about substitution of a grout groove for the horizontal metal grout stop, September 13, 1935, and A. M. Simonds, memorandum to chief designing engineer about grouting of contraction joints, November 1, 1937, 10, 13, both at RG 115, Dam, Grand Coulee-Contraction Joints and Keyways, General, 1935-1940, NRG-115-00-148, Box 3, Folder 510, NARA-RMR.
Two 10" pipe siphons had been installed in the berm in an attempt to control the pit’s flooding, but the river rose rapidly and overtopped the structure, washing out the dike’s top 15’ for a distance of about 100’—a problem that MWAK planned to remedy with a more substantial structure and larger pipes. The process to dewater the excavation area started in mid-July and was completed on August 2.266

Work quickly resumed in the lower area. In September, construction started on a 1,130'-long, 20'-wide timber-crib cofferdam to replace the berm. (ILLUSTRATION 11: Revised plan for the east cofferdam and cross-river cofferdams.)267 Three-inch wood planks in a tongue-and-groove configuration—known as Wakefield sheet piling—faced the river side of the structure, which was reinforced with steel tie rods, filled with gravel, capped with concrete, and braced from behind with earth. Reaching elevation 965, it was designed for use only during periods of low water. When the river’s level rose, the gates sealing three 36" corrugated-iron pipes that ran through the cofferdam could be opened to flood the pit. This would reduce stress on the structure’s timber piles, which were driven to a depth of only 10’. The light structure was justified because the east cofferdam was to serve for only a year. By late 1936, cross-river cofferdams would direct the river over the newly finished west foundation, and construction would start on the center section of the dam. As planned, MWAK started removing the concrete cap, timber backwall, and fill in mid-October 1936. The Wakefield piling, which had little salvage value, was burned in place in December.268

Although Atkinson had planned to install a conveyor similar to the one on the west side, the grade and bank conditions made it relatively easy to construct a road to a spoil dump about 4,000' upstream. A fleet of twenty-four trucks hauled out about 10,000 cubic yards of material a day until mid-August 1935, when the lower pit was dewatered. At that point, MWAK extended a conveyor across the river to connect with the conveyor on the west side so that east side overburden could be transported to the Rattlesnake Canyon spoil dump. Progress was slower on the east side than on the west because, “the exposed rock surface was considerably more broken and irregular” and required more scaling. Even so, by the end of 1935, “bedrock had been exposed down to elevation 850, the tailrace slope was practically complete, and the forebay slope was finished down to elevation 900,” a Reclamation report announced.269

The excavating and scaling on the east side in 1935 had exposed a worrisome feature, a substantial crevice running parallel to the river below the forebay slope. Diamond drill borings had identified the dimensions of the crevice and the characteristics of the mucky material within it. About 120’ deeper than the average level of bedrock at the dam site, the crevice was to prove a substantial challenge in the following construction season.\textsuperscript{270}

MWAK started 1936 with fifteen months of work behind it. While that was 28 percent of the total time projected for the project, the company had already completed 40 percent of the scope. The chill of winter, though, slowed excavation and concrete placement in January and completely stopped concrete work in February. The respite was short, and soon workers were back at their jobs. When the spring thaw arrived and the river rose, MWAK opened the gates in the low east cofferdam on April 27 to flood the excavation area as planned. The river overtopped the dam in May, and it was not until July that the water level had dropped sufficiently for the contractor to begin pumping water from the pit.\textsuperscript{271}

Other things, however, were not going according to plan. While engineers seemed to be winning the battle against slides on the west side, even though some sections remained unstable, the area around the crevice on the east side proved more intractable. Excavating the overburden between the steep walls of the crevice, which were only 100’ apart just upstream from the dam’s axis, was a slow process. At the bottom of this gulch, Reclamation engineer Grant Gordon explained, “the filling was removed by dragline and power shovels. To reach the bottom a steep ramp had to be built, and the muck hauled laboriously up the ramp in trucks towed by caterpillar tractors.”\textsuperscript{272}

When the excavation seemed nearly finished, the forebay slope began sliding into the crevice, “pour[ing] through the narrow formed by its vertical walls like a flood of molten lava,” according to Gordon. When the slide paused, MWAK quickly installed a concrete-arch dam across its toe to impede future movement. “The concrete arch was built 20 feet high,” a Reclamation report noted, “and above it a bulkhead was built up another 15 feet with timber cribbing” to elevation 815. MWAK planned to build the arch higher, but on April 17 “the slide suddenly became active and immediately overtopped it, filling the gulch and forcing the shovel to retreat.”\textsuperscript{273}
In describing the material that was the source of the problem, Gordon observed: “When moistened and disturbed the material takes on the consistency of axle grease. When dry and pulverized it forms an impalpably fine dust.” He added: “Undisturbed, and in its original horizontal bedding, it will stand indefinitely in a vertical face of moderate height, but once disturbed, it is unstable on any slope steeper than 4 to 1 even when comparatively dry.” Excavation plans were modified accordingly. Slopes in the area around the crevice had been designed originally with a 1-1/2:1 profile. That ratio was changed to 2:1 when the problems with the slide became apparent, and 4:1 when the slide proved even nastier than it first appeared.274

Attempts to solve the problem were abandoned as the river rose. With the east excavation pit flooded at the lower elevation, the contractor’s focus shifted to higher areas—and to analyzing options to counteract the slide. After the river’s level started to drop and MWAK began pumping water from the excavation area, the slide became active again, crushing any hopes that it was a temporary condition. The need to address it, though, was short term: the area had to be stabilized only long enough to complete excavation and construction of the dam’s foundation. When the concrete rose higher than the slide area, the problem would be eliminated.275

Engineers came up with the novel idea of freezing the toe of the slide using an arch form that echoed the muck-covered concrete arch. Exposed timber cribbing on top of that arch was used for the foundation of the frozen arch. Working from the dimensions of the crib and the adjacent rock walls, which would support the arch’s thrust, engineers designed the arch with a 105’ radius. To add an extra measure of safety, the arch would be 20' thick, double the 10' required by normal engineering standards. “Little data existed regarding the mechanics and strength of frozen ground,” a Reclamation report observed. The only precedent for the concept was a deep-shaft freezing method invented by Prussian engineer F. H. Poetsch, but “available information on operation and costs offered little basis for comparison.” As a result, Gordon noted, “design and cost data for the entire setup were required to be worked up from scratch.” Despite the unanticipated expense, “the cost of the arch as roughly estimated would be covered by the saving in excavation which it afforded, beside the saving in time and money which it afforded the contractor.” 276

The plan was implemented in August. A refrigeration plant was installed at elevation 855. The arch was formed by 377 “freezing points”—pipes 40' long and 3" in diameter, capped at the bottom and placed 30" apart. The pipes were driven by a drill rig on a barge floating in the still-flooded excavation pit. A 1-1/2" pipe was placed inside each 3" pipe. As the system went into operation, ammonia brine was pumped into the smaller pipe. When the brine reached the bottom,

it rose through the space between the inner and outer pipes, exiting through a tee connected to a rubber hose that extended to the next freezing point. Two refrigerating machines operated at full capacity for six weeks, starting August 24, to chill the ground to 32 degrees Fahrenheit. After the temperature had dropped below that level, one machine was able to maintain the frozen condition.277

Pumping to dewater the east excavation area had stopped while the freezing system was being installed. By September 18, the contractor felt that the arch was stable enough to resume pumping, but Reclamation engineers on-site were not completely convinced that the frozen earth could be trusted. In early October, Banks wrote to Acting Commissioner of Reclamation Raymond Walter: “Although this method of procedure appears to be the best that could have been adopted under the circumstances, and also appears to be successful at this time, there is, as you know, considerable hazard in connection with a structure of this kind and consequently we have not thought it wise to give a great deal of publicity to it until we were more certain that it would be successful.” 278

Banks continued: “One of the things which we most fear, of course, is that there may be some slight movement in the slide in the future that would cause the breaking of a sufficient number of pipes, which are already brittle because of the low temperature, which would release the brine and possibly prevent us from keeping the dam frozen in the vicinity of the frozen pipes.” The good news was that “cold weather is now coming on and the problem of keeping the dam frozen is continually decreasing.” Excavation below the frozen arch would be finished by mid-October, but it would be several months before the concrete of the dam would rise high enough to make the temporary structure obsolete—and “most anything might happen during that time.” 279

Despite Banks’s concerns, excavation beneath the arch proceeded and was almost finished by November. Concrete placement in the adjacent dam made steady progress, except for normal winter shutdowns. The Board of Consulting Engineers examined the area in April 1937 and concluded that concrete placement “in the east portion of the dam, between Blocks 61 and 82, was quite satisfactory, about two-thirds of the blocks having been poured to various heights, including satisfactory filling in the deep gorge, about Block 64, the top being at about the same level as the top of the frozen-arch dam.” The board approved a plan to fill the void between the

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dam and ice dam to guarantee that slides would not cause trouble in the future. The ice dam had served its purpose by May, and the refrigeration plant and pipes were removed.  

As Gordon had predicted, the frozen dam proved economical. Although the arch required a change order totaling nearly $37,000, it saved, “possibly, several hundred thousand yards of excavation, at the contract price of $1.00 per cubic yard, and saved several months’ time in preparing foundations and concreting in the area excavated.” In terms of lessons learned, he found it of limited value: “It is difficult to imagine a duplication of conditions which would ever make a scheme exactly like this feasible again. Its interest, then, lies chiefly in its being unique.”

13. NOT JUST ANOTHER JOB

The slide happened shortly after a significant change in the project’s administration. MWAK’s general project manager since the start of construction had been H. Leslie Myer, who served as vice president of the Silas Mason Company from 1927 to 1943 and was the mastermind behind the conveyor system at Grand Coulee. In March 1936, Myer was replaced as project manager by George Atkinson, the son of Guy Atkinson—whose company was the “A” in MWAK.

Regardless of who held the title of manager, the principals of all four firms were personally involved in the Grand Coulee project. A Reclamation worker later recalled that “Silas Mason, Tom Walsh Sr., Guy F. Atkinson and E. L. and W. E. Kier were there and down on the job frequently enough for us to know who they were.” Silas Mason took a particularly close interest. Instead of monitoring progress from the corporation’s headquarters in Boston, he built a house on the outskirts of Mason City. It was to be his last residence. He died suddenly on April 14, 1936, at the age of fifty-seven.

Reclamation Commissioner Elwood Mead had preceded him to the grave on January 26. He was seventy-six. Under his leadership as commissioner, a job he began in 1924, “the Bureau of Reclamation emerged as a supplier of hydroelectricity and municipal water to the urban West.” Chief Engineer Raymond F. Walter became the acting commissioner.

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Casualties also occurred among the laborers at Grand Coulee. MWAK attempted to maintain a safe workplace, but accidents on such a massive construction project were inevitable. Reclamation’s 1936 project history provided a tally of reported injuries including 136 “abrasions, lacerations, and contusions,” 114 “sprains and strains,” 112 “falling objects,” and 100 “falling workmen.” Through the end of 1936, MWAK had 964 injuries and 28 fatalities—which worked out to a grim ratio of “one fatality per 514,691 man-hours.” Another seventeen died in 1937, when there were also “770 compensable, and 5,018 non-compensable accidents.”

The dangerous work conditions did not immediately foster the formation of unions. In the initial years, a Reclamation history noted, “no concerted effort had been made to organize labor on the project. . . . It is doubtful if the total membership in all unions was over 15 percent of the Contractor’s forces.” In the spring of 1937, though, “agitation for labor organization had become acute” with passage of federal labor legislation and organized labor’s efforts to promote unionization around the country. The Committee for Industrial Organization (CIO) and the American Federation of Labor (AFL) aggressively sought members, leading MWAK to sign a closed-shop agreement in the end of July with the AFL. The agreement maintained the status quo for wage rates, labor classifications, and work rules. Not all of the workers were enthusiastic about joining the union, and some did not: “While some pressure was put on the employees by both the contractor and the unions, resulting in most of them becoming members, no effort was made to replace non-members with union men, due to the short time remaining until completion of the contract.”

The hourly average wage for MWAK workers in 1937 was $0.86. With an average work week of 37.3 hours, this provided an annual salary of about $1,700. The wage rates and maximum hours that anyone could work in a week were largely dictated by federal depression-era labor policies. Virtually the entire workforce was Caucasian. Reclamation worker L. Vaughn Downs later recalled: “In 1933 black people were not numerous in the counties adjacent the damsite if indeed there were any, and the few within the state of Washington lived in the coastal cities principally. Also, few black men were employed in craft skills at that time when the dam was started. The native Americans on the adjacent Colville Reservation were ranchers or loggers or worked in the sawmills as their main lines of employment. So, it was a number of years before I noticed some black men and a few native Americans in the crews working on the dam. As I look back to those years, the impression I have is that ‘minority’ workers were usually employed in unskilled tasks.” Although Reclamation received pressure to have African Americans working on the project, and in turn applied pressure to MWAK to hire them, the average number of African American employees in 1937 was fifty. Other than providing space for local Native Americans

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to sell crafts at the East Vista House, project histories are silent on the number of Native Americans employed on the project.\textsuperscript{288}

While the majority of men on the project were common laborers, workers with special skills were also needed. Equipment breakdowns could result in costly delays. Because of the project’s isolated location, MWAK had to maintain and repair equipment on-site. Three maintenance crews, each with a foreman, two mechanics, and two helpers, provided around-the-clock coverage for repairs in the field. For major work, MWAK set up a 75’ x 150’ repair shop on the east bank that had “lathes, millers, shapers, blacksmith and babbiting departments, steam hammer, bending rolls, punch and shears, 250-pound hydraulic press, and complete welding equipment,” according to a reporter from \textit{Excavating Engineer}. “It could handle repairs, construction of most necessary parts, and even some complete machines.”\textsuperscript{289}

Because of the great demand for welding, a special facility employing fifty welders and helpers was dedicated to that use, with a 50’ x 60’ building and an adjacent fabricating platform. Among the welders’ many responsibilities was maintaining the teeth of the shovel buckets doing the excavation. The shop received an average of fifty teeth a day for repair. “The buckets seem to be constantly teething,” the foreman explained, “and the arc-welding machine is the only form of pacifier that will keep them contented.” One journal noted that the welding crew on call for repairing the concrete mix plants “is similar to that of a hospital staff.”\textsuperscript{290}

14. EXCAVATION’S GRAND FINALE: THE MAIN CHANNEL

As engineers struggled to address the slide on the river’s east bank, the dam was beginning to take shape. By spring 1936, the west side of the dam was beginning to rise above the river. When the board of consulting engineers met at the site in April, they “found that placement of concrete was being carried out in a very efficient manner, and that vibrating of concrete was well planned and executed, and test results and exterior appearance indicated concrete of very superior quality.” They expressed “full confidence in the strength of horizontal joints” based on work to date. These surfaces were cleaned with air and water jets between pours. The engineers noted that “best results [are] obtained where surface is kept wet and when little time elapses between cleanup and next pour, so as to avoid accumulations of extraneous matter.” When the surface dried, as the board learned at its next meeting, it became coated with a tough “grayish film” of calcium carbonate, which was formed when soluble calcium hydroxide percolated from the concrete and interacted with carbon dioxide. The contractors initially resorted to sandblasting to remove the film, later discovering that its formation could be prevented by covering the surface with 2” of moist sand.\textsuperscript{291}

\textsuperscript{291} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 4, 1936, 36, 38, 40.
On August 14, a celebration marked the placement of the 1-millionth cubic yard of concrete. All of the concrete was provided by the Westmix plant, which was pushed to its maximum production—up to 8,434 cubic yards in a day—until the Eastmix plant went into operation in October.  

When Block 40 was of sufficient height, the longitudinal galleries were bulkheaded. To fill in the gap between the concrete in Block 40 and cell cluster F to the north, a sheet-faced timber crib structure was installed. The 10'-square cribs were made with 12" x 12" timbers connected by 1" drift pins and filled with gravel. Section E was reinforced by the addition of fill to elevation 970. All of this was done in anticipation of the next phase of construction, when the river would be diverted over the west side of the dam. At that point, the west cofferdam, including the east side of Block 40, would be transformed into the eastern edge of the channel and the contractor would pour 50' sections east from there.

When the Columbia’s flow was shifted to the west, it would pass through eleven slots left open in the dam’s left foundation. Most would go through four slots at elevation 910, with the overflow handled by seven slots at elevation 950. The river would then return via the west tailrace to its regular course. The diversion would remain in place until some 1.2 million cubic yards of overburden had been removed from the main channel.

On July 17, 1936, when the river had dropped to about elevation 960, MWAK began the first stage of excavation for the river diversion channel. (ILLUSTRATION 12: Plan of river diversion.) Shovels removed some 384,000 cubic yards of material to create a trench about 450' wide that would form the upstream end of the new channel. A 30'-wide berm rising to elevation 945 was left behind the cofferdam for reinforcement. As the river level dropped, about 280,000 cubic yards of material supporting Sections B and C of the cofferdam was excavated to elevation 920, and another 200,000 cubic yards of fill and overburden were removed from the downstream alignment of the diversion channel.

Sections D and F of the cofferdam would remain in place at the ends of the concrete Block 40, forming the east side of the diversion channel. The remaining sections of the cofferdam were deconstructed, starting with the top course of the shore arms. During the first half of August,

297 Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 23-24, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148, Box 3, Folder 510, NARA-RMR.
MWAK cut 15" x 24" holes at 10' intervals at elevation 960 in the sheet-piling of Sections B, C, H, and I, and began washing the fill out of the cells with hydraulic jets. The sheet-piling and timber backwall was then removed to elevation 960 and the process continued, while draglines removed the rock toe fill to elevation 910. By mid-December 1936, only cells C1 through C6 blocked the river at the diversion channel’s upstream end. The river, however, had already pushed its way in. By early November, MWAK had stopped the pumps that kept the area behind the cofferdam dry, and water soon encroached.297

The upper cross-river cofferdam would extend southeasterly from cell cluster D and the lower one northeasterly from cell cluster G. MWAK had originally proposed to copy the design of the west cofferdam and install sheet-pile cells for the structure, but a timber-crib design was substituted. This type of construction “was not unusual,” according to a Reclamation report, “but the magnitude of the job and the uncertainties involved in pushing the Columbia River out of its normal channel were probably without precedent.”298

Construction of the cross-river cofferdam was initiated in August 1936 on the 1,004'-long downstream arm, beginning at the east shore: “There first will be 200 ft. of Ohio River-type cribs (vertical sheetings, horizontal walls and tie rods), then 336 ft. of built-in-place cribs followed by 448 ft. of cribs with a U-shape cross section floated into place and sunk.” The long dimension of the 90' x 64' cribs paralleled the current, with the low notch serving as a sluiceway to reduce pressure on the structure until it could be adequately secured. To ensure the cofferdam’s soundness, the bottom of the cribs had to closely conform to the bottom of the channel, with a maximum deviance of only 1'. Since Reclamation had taken soundings in fall 1934, the riverbed had experienced some 15' of erosion, probably because the channel had been narrowed by the west cofferdam. To assess the modified terrain, MWAK took about 52,000 soundings as cribs were assembled in a dry area behind the upstream arm of the west cofferdam.299

When the cribs were ready, the area where they sat was flooded and they were floated into position. The first crib was installed on November 13, 1936. The cribs were connected to a row of interlocking steel piles with tie-rods. Pockets in the cribs were filled with gravel to facilitate

298 Chief Inspector B. A. Hall to field engineer, memorandum on cofferdams and river diversion, March 20, 1937, 33-34, at RG 115, Dam, Grand Coulee, Diversion of River, General, 1936-1939, NRG-115-00-148, Box 3, Folder 510, NARA-RMR; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 4, 1936, 18, 100-102, 140.
sinking. Placement of the cribs shifted part of the river’s flow through the low (elevation 910) blocks in the dam’s foundation. As more cribs were placed, more and more of the current shifted to the diversion channel. Sluiceways were retained in the cribs until December 9, when all units in the downstream cofferdam were installed. On December 15, a barge began fitting stop logs in the sluiceways, forcing the river’s entire volume into the diversion channel. “The placing of the stoplogs and final total diversion will be . . . quite gradual and as far as I can see will offer no spectacular picture,” Banks wrote to Acting Commissioner Walter, who aggressively sought opportunities for publicizing the project. When the stoplogs were all in place, a row of steel sheet piles was driven to support the downstream side of the cribs and tied to them. Fill was placed in the cribs and behind the sheet-piling.300

After the diversion channel was completely open and the river was at its low stage, the upstream arm of the cross-river cofferdam could be installed in still water. Measuring 1,004’ long like its downstream partner, the structure was also similar in design, although the length of the Ohio River crib section was shorter (180’) and the built-in-place cribs longer (376’). The seven cribs that were to be floated into place, though, were not U-shaped in plan like the downstream version. instead, they resembled “a dumb-bell with square corners.” A line of steel sheet piles was again utilized for downstream reinforcement. Both cofferdams rose to about elevation 990 to withstand spring floods, although the taller (elevation 950) slots in the dam foundation where the river was diverted were anticipated to keep the water level well below that point.301

About 70 acres of riverbed would be exposed when the area between the cofferdams was dewatered. Pumps set to work on January 3, 1937, and within a week the central section was mostly dry and excavation had begun, despite more than 14” of snowfall and temperatures dipping to minus 13 degrees Fahrenheit. Winter conditions had forced the discontinuation of concrete placement in the end of December 1936, resulting in layoffs of about half MWAK’s workforce. Some were put to work in February removing Section E of the west cofferdam, which now stood in the dewatered area and was no longer needed.302

Components of the legendary conveyor system were reassembled to carry out the lion’s share of the excavated overburden from the river channel, although this time the terminus was the Atkinson dump on the east bank. Four feeders in the excavation area converged at a central feeder. The main 3,450’-long conveyor extended to a stacker unit in the dump. The first feeder was in place by January 22, 1937, and the entire system was operating a month later. It had removed about 1 million cubic yards of overburden by the time its work was done at the end of

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300 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 4, 1936, 18, 100-102, 140; F. A. Banks to R. F. Walter, memorandum, October 10, 1936, at RG 115, Project Correspondence File, 1930-1945, Entry 7, Box 555, NARA-RMR.
301 “Program for Grand Coulee’s Second Cofferdam,” Engineering News-Record 117 (October 1, 1936): 466.
April. On May 1, workers began disassembling the central feeder and main conveyor. Reclamation’s project history observed that “this marked the end of a world-famous conveyor belt system which, during its comparatively short life, transported over 11,000,000 cubic yards of overburden or ‘pay-dirt’.”

Excavation of rock went less smoothly. “Numerous boulders were found in the old river bed,” Reclamation’s project history noted. “Some were basalt erratics of large size and very difficult to drill.” MWAK concentrated crews and equipment in the area starting in April 1937 to try to keep on schedule, finishing the excavation in July. Rock excavation on the east side also proved challenging.

An even bigger threat to the schedule had appeared on March 17, when the cells in Section G of the west cofferdam sprang a major leak, apparently from water penetrating a seam of sand some 70’ below the riverbed. Pumps fought the rushing water—about 800 gallons a minute—that threatened to inundate the excavation area to the east. If the area flooded, it would take months to dry and the foundation rock would have to be cleaned again, significantly delaying the project. Such “a catastrophe . . . might well have cost the contractor an enormous sum,” according to Engineering News-Record. In addition, the torrent was undermining the foundation of one of the tall steel towers that supported the suspension bridge carrying the aggregate conveyor and the concrete supply pipe.

MWAK’s first response was to build a cofferdam within the cofferdam in an effort to contain the water. The inadequacy of this approach became apparent two days later when a vortex formed outside of a downstream cell, accelerating the rate that water surged into the cofferdam to 35,000 gallons a minute. The temporary dike would be filled to overflowing in short order. To add to the excitement, some of the cells were beginning to fail, as Engineering News-Record noted: “Steel sheet piling in cells of the downstream cluster were badly distorted, some cells settled out of plumb and internal pressure became so great that here and there a vertical riveted seam was ripped open like a zipper.” Frank Banks rushed back from an East Coast trip as the contractor attempted stopgap measures: “Hundreds of trees from the forests on the adjoining Indian reservation were cut, weighted with steel, and sunk. Sand bags—timbers—everything was done in an effort to fill the gap. . . . Huge pumps, several of them brought up from the Bonneville project, were kept steadily at work to keep pace with the inrush. A veritable army of trucks were put into service rushing dirt and dumping it outside the cofferdam on the downstream side to form an extra barrier.” Soon granite riprap was being substituted for the dirt.

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A turning point came when workers began plugging voids in the rebellious seam with bentonite grout. The bentonite, mined in eastern Wyoming, swelled from ten to thirty times its original size when exposed to water, forming a gelatinous mass. “This unusual clay,” Earth Mover reported, “seems to have won the battle.” Water infiltration slowed to a relative trickle of 250 gallons a minute by late April.  

At the same time as MWAK worked to stop the leaks, it also strengthened the cofferdam. New sheet-piling was driven to bedrock to replace damaged cells and reinforce other areas. The conveyor-belt tower’s foundation was reinforced with four concrete piers, which were inserted next to the existing concrete piers that carried needle-beam spans at the tower’s base.  

Despite the setback from the cofferdam breach, concrete placement was going full speed. The conduits at elevation 934 were unlined except for a section from the intake to 12’ beyond the downstream gate, where there were 1.75”-thick, heavily ribbed metal castings. As the dam rose, these were embedded in the concrete. All of the segments, which were manufactured by the Hardie-Tynes Company of Birmingham, Alabama, had been delivered to the site by October. The segments arrived on flatcars and were moved into position at the dam by a crane on the trestle at elevation 1024. They were temporarily supported by timber cribbing, concrete piers, or I-beams. The 1937 project history noted that “the use of I-beam supports proved the most satisfactory and was adopted for the majority of the liner installations.” Workers ringed the liners with reinforcing steel and sealed the joints between the segments before encasing them in concrete. The lower ends projected about 18” into blockouts measuring about 27’ wide, 30’ long, and 58’ deep where the gate-body castings could be installed when they arrived. Wood bulkheads were fitted on the ends of the conduits to keep the river at bay.  

The cooling system was inaugurated in the end of 1936. The cooling process followed the dam’s construction, starting at the bottom and moving up. Cooling was typically begun one or two days after pipes were covered with a 5’ rise of concrete. Water was circulated through the pipes for 60 to 90 days thereafter.  

In March 1937, MWAK began cooling the concrete in the east abutment. The upper cross-river cofferdam was still in place, so a pump barge was positioned just upstream from its east end and connected to supply and return mains. Pumping for the abutment section began in the end of April and continued the remainder of the year. Cooling did not start on the west side until September 23, using a pump barge located near Block 40. Hundreds of thermometers were

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307 “Can the Columbia Be Controlled?” Earth Mover, June 1937, 3-4.
embedded in the concrete and placed in the cooling shafts to monitor the concrete’s temperature.311

Operation of the cooling system did not go smoothly. While the 2.2 million feet of cooling pipes experienced few blockages, “most of the coils were leaky to some degree,” a Reclamation report observed. Because of the volume of water used for the system—which reached 1,700 gallons a minute by December 1937—the leaks threatened to overwhelm the sump pumps that MWAK had installed, forcing a reduction in the rate of pumping. “Factors causing this leakage are as yet undetermined,” Reclamation’s 1937 project history noted, “since rigid inspection and testing were required during the installation of the pipe.”312

In the end, the cooling system proved beneficial, despite its troubles. In 1941, Reclamation Era reported that “as a result of cooling, the contraction joints opened uniformly from one-sixteenth to one-eighth of an inch, as indicated by surface measurements and by the uniform acceptance of an average of 1 cubic foot of cement grout for every 100 square feet of contraction joint area.”313

Leaks also affected grouting operations, a problem compounded by poor connections in that system. “The greatest defect in the grout system as installed,” a Reclamation engineer wrote, “was the interconnection between longitudinal and transverse joints in a given area, and the leaks into the cooling system. . . . The leaks through the cooling coils caused the greatest trouble. . . . Of 1,502 cooling coils installed in the west end of the dam, 1,265 leaked into the contraction joints.” Workers had to cap leaking coils in a section where grouting was underway.314

Despite these challenges, MWAK completed the first phase of construction grouting, which went from bedrock to elevation 900 in Blocks 10 through 40, in June and July 1937. As the process continued, the contractor explored materials that offered better performance. In October 1937, Reclamation gave MWAK permission to use a grout comprising Bentonite and calcium chloride, as well as cement, which produced “a strong grout with very little shrinkage and a saving of cement.”315

The big construction push required a big labor force, numbering more than 7,000 by the end of May. Even during the Depression, though, some could not or would not do the job: the project history observed that “turnover [was] averaging 50 men per day.” Total employment had risen to

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314 A. M. Simonds, memorandum to chief designing engineer about grouting of contraction joints, November 1, 1937, 10, 13, at RG 115, Dam, Grand Coulee, Contraction Joints and Keyways, General, 1935-1940, NRG-115-00-148, Box 3, Folder 510, NARA-RMR.

about 7,800 by the end of August when MWAK broke world records for concrete volume, placing 15,844 cubic yards in one day and 377,133 cubic yards that month. All told, MWAK placed more than 2.6 million cubic yards of concrete in 1937, requiring some 2.7 million barrels of cement and 4.8 tons of aggregate.\(^{316}\)

Some of the concrete went into the diversion slots at elevation 950, which MWAK filled to their final contract height after the spring flood. This left the slots at elevation 910 to carry the river for the duration of the diversion. Progress on the east end of the dam allowed MWAK to start removing the cofferdams in July, taking down sections as the river dropped. “The units of the coffer walls were so solidly founded and closely interlocked that they had to be actually wrenched to pieces,” *Engineering News-Record* reported. The cribs and sheeting of the downstream cross-channel cofferdam were removed by November 24. Enough of the upstream structure was out by December 10 to allow the river to resume its original course. By the end of the month, 90 percent of the cofferdams had been removed. This left only the shore arms and some sections of timber cribbing and steel sheeting that were difficult to extract, including some small cribs in the spillway bucket area in Blocks 39 and 40. Another problem spot was where emergency fill had been placed when the cells in Section G had begun to fail. After the cribs were removed, the contractor worked until early March 1938 to clean out the debris that had nearly filled the bucket during the construction period.\(^{317}\)

With the river back in its channel, the low sections in Blocks 32, 34, 36, and 38 were no longer needed for diversion. Because the slots were at elevation 910, lower than the normal low-water elevation of about 935, MWAK had to install temporary gates on both ends of the slots and pump out the water before placing concrete up to the level of the rest of the dam. The contractor began assembling four gates, each measuring 54' x 52'6" and weighing 150 tons, in August. The compression members of the arch-shaped gates were made of 8" x 18" timbers covered with 3" x 8" wood planking that was caulked to form a watertight shell. Tension members were steel. A deflated linen hose was installed beneath rubber belting that edged the sides and bottom of the gates. When the gates were in position, the hose was inflated with a pressure of 140 psi, forcing the belting against the slot’s concrete walls and floor to create a seal.\(^{318}\)

At the end of September 1937, MWAK began floating the gates into place, two upstream and two downstream. Each gate had three air tanks to provide buoyancy, but this proved insufficient; the addition of a fourth tank helped maneuver the gates into position for Blocks 36 and 38. By October, these blocks were dewatered and work had begun on placing concrete. When the concrete reached elevation 935 in December, the gates were moved to Blocks 32 and 34 and the


process repeated. With all of the slots at elevation 910 closed by the end of 1937, the river was directed through four channels at elevation 935 and another eleven channels at elevation 945.\(^{319}\)

15. LAUNCHING PHASE TWO

Despite the record-breaking pace of construction, it was clear by the end of 1937 that some of the work planned for the first contract would not be completed in the allocated time. Some of the delays were the fault of the contractor: MWAK ran behind in applying coal-tar paint to rebar dowels, trashrack sections, and other metal components, for example, even after assigning eighty men to this task in March. In other instances, a supplier missed a deadline, triggering a sequence of problems at the construction site. The Hardie-Tynes Company, for example, failed to supply the ring-follower and paradox gates for the dam’s outlet works at elevation 934 in 1937 as promised.\(^{320}\)

In any event, Reclamation began gearing up to let the contract for the next phase of construction, despite the fact that the initial $63 million allocated to begin the work on the dam would be largely expended by the end of 1937. Reclamation’s 1937 project history highlighted the ongoing wrangling over funding, which was essential not only for construction but also to conduct fieldwork and prepare plans and specifications: “The principal need of the project is, as usual, the annual Congressional appropriation of funds to carry on for the fiscal year of 1938 at a rate that will insure the completion of the present contract as scheduled and beginning of the new contract early in the calendar year.” A cause for hope was a visit from President Roosevelt in October. His short speech in Mason City drew a crowd of 10,000.\(^{321}\)

On November 2, despite unresolved funding issues, Reclamation released Specifications No. 757 for bid. This phase covered the completion of the dam to its full height, construction of the Left Powerplant, and installation of the Pumping Plant foundation. The contractor would be responsible for placing 6 million cubic yards of concrete and installing outlet control structures, steel penstocks, spillway gates at the dam’s crest, and a 1,650'-long concrete-arch highway bridge over the spillway section. In the beginning, the river would be diverted through low slots in the spillway section. As these and adjacent blocks were built up, the reservoir would rise above the level of the outlets at elevation 934, which would then become responsible for diverting the river. Work was to be completed in 1,450 days, with a daily penalty of $2,000 for missing the deadline.\(^{322}\)

As with the initial contract, Reclamation would supply cement, steel, and the equipment that would be incorporated into the powerplants, dam, and Pumping Plant. The government could also exercise its option with MWAK to acquire Mason City, the transmission line, and other facilities, and make these available to the winning bidder. This provision was seen as a sign that MWAK was not guaranteed the second phase. “There has been much speculation as to whether the present contractor will be the successful bidder for the next concreting contract,” Engineering News-Record had reported in July. “Other bidders are encouraged by a clause in the present contract which provides that the government holds an option to buy for $100,000 all equipment installed and used by the present contractor in concreting operations.”^323

Despite this effort to stimulate competition, Reclamation had received only two bids by the December 10 deadline. Still, the opening was a major event broadcast nationally over the radio, with more than 1,000 people converging on Spokane’s Civic Building to witness the event in person. One of the bids was from Pacific Constructors, a consortium of eight firms from the West Coast that had worked on the Colorado River Aqueduct and the All-American Canal. At $42,195,802, it was significantly higher than the bid of $34,442,240 from the group that MWAK had joined, the Interior Construction Company. The team had expanded to include the General Construction Company of Seattle, which had headquarters in Oakland, California, and the Six Companies, which MWAK had underbid to get the first phase at Grand Coulee.^324

The prize went to the Interior Construction Company, which subsequently changed its name to Consolidated Builders, Inc. (CBI). Reclamation officially awarded the contract to CBI on February 7, 1938, and gave the company notice to proceed on March 21. This started the clock ticking on the contract, setting a deadline for completion of March 20, 1942.^325

In the meantime, MWAK’s work on the first phase was wrapping up. At its meeting in November 1937, the Board of Consulting Engineers “discussed design and suitability for purposes of work performed by the contractor and repeated formal approval of the various features, including character of general construction work, particularly concrete placed and the treatment of rock calling for special attention, expressing full confidence in the security of structures and its effective services as the first stage of the ultimate project.” MWAK completed the final concrete placement for its contract—which constituted about 40 percent of the concrete for the entire project—on January 10, 1938. A Reclamation report observed that this was “exactly 2 years, 1 month and 4 days after the first pour” on December 6, 1935.^326

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^326 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 5, 1937, 48; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 31; A. A. Merrill and J. R. Murphy,
Reclamation deemed MWAK’s contract complete on the same day that CBI’s contract began. The contractor had used only 77 percent of the allocated time, coming in a year ahead of schedule. During the course of the contract, MWAK had racked up some impressive statistics. It had excavated more than 17 million cubic yards of overburden and rock. The majority—14.7 million cubic yards—was common overburden for the dam and powerhouses. The volume of concrete was also mammoth: more than 4.5 million cubic yards, with the lion’s share—4.2 million—going into the dam.\footnote{Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 31, 97, 121-122, 126.}

MWAK felt that it had gone above and beyond the original requirements of the contract, at the request of Reclamation, and presented claims for additional payment of about $5.3 million for the first contract soon after the second contract was awarded. MWAK contended that “government inspectors wrongfully and arbitrarily exceeded their authority,” requiring work outside of the project’s specifications. The dispute eventually ended up in court. It appeared to be settled in January 1940 when the Federal Court of Claims dismissed MWAK’s petition for the additional reimbursement from Reclamation, a decision that the 1940 project history proclaimed “of outstanding importance.” MWAK responded, though, by filing an amended petition, which prolonged the disagreement.\footnote{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 23, 54; “Testimony by Inspectors—MWAK Claims,” n.d., and “Extracts from Special Finding of Fact in the Case of MWAK Company vs. the United States,” Court of Claims Case No. 48906, n.d., both available at Grand Coulee Administration Building Library.}

It did not, however, delay the launch of the new contract. Although the contractors did not have to start from scratch, the new phase of construction required some preparatory work before concrete could be placed. CBI began removing the high construction trestle at elevation 1024 in late May, recycling about 3,200 tons of the structural members that had not been encased in the dam for a new trestle at elevation 1180. The Bethlehem Steel Company supplied the additional 5,700 tons of steel needed for the structure and began erecting it in June. A hammerhead crane was installed on the trestle by the end of the following month. CBI purchased three new hammerhead cranes from the Colby Steel and Engineering Company, which also rebuilt four of MWAK’s hammerhead cranes and three Clyde Whirley cranes for ongoing use. The cranes ran on runway rails edging the deck of the trestle, which held four standard-gauge railroad tracks. By mid-September, the steelwork for the trestle was completed. The structure’s east end, which was situated 140’ downstream from the dam’s axis, curved to reach the new concrete mixing plant, also at elevation 1180, near the right abutment.\footnote{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 32, 33, 129, 137.}

The new plant was essentially a consolidation of the two old plants. Disassembly of the Westmix plant began on March 31. The components were relocated to the east side of the river, where

\textit{“Some Engineering Features in the Construction of the Grand Coulee Dam,” General Electric Review 41 (November 1938): 474.}
they were completely overhauled. The old Eastmix plant at elevation 1024 was taken apart from mid-June to mid-July and, after refurbishing, was set up next to the reassembled Westmix plant. The combination was dubbed “a Siamese-twin unit” by Excavating Engineer. The partially completed facility began production in July and was going around the clock by the end of August. The parallel plants were completely operational by October. As in the first phase, the contractor used flatcars pulled by diesel locomotives to transport the buckets of concrete from the mix plant to the construction area. The original Blaw-Knox buckets were repaired and reused, augmented by ten “Insley” buckets. The new buckets also had a capacity of four cubic yards, but had a wider mouth.\(^{330}\)

The increased pace of concrete placement in the second phase required Reclamation to contract with four new cement suppliers, three in California and one in Montana, in addition to the five in the State of Washington that were retained from the first phase. The same cement storage area was used, with some minor upgrades to equipment. Cement was transported to the new mix plant by a 14”-diameter pipe suspended below the floor of the trestle at elevation 1180. In 1939, an 8” pipe was added to transport modified cement. The trestle also carried a 12” water line, 10” air line, 6” steam line, and 1100-volt, three-phase power line. The suspension span, which had carried the cement line during the first phase, was no longer needed and was removed.\(^{331}\)

The Board of Consulting Engineers had examined the Brett pit in November 1937 to determine whether it would be adequate to supply the aggregate for the 5.8 million cubic yards of concrete in the final stage of the project. Feeling confident that the deposit was sufficient, the board concluded “that it would not be necessary to contemplate investigation of other sand and gravel deposits.” About a month after receiving the notice to proceed, CBI restarted mining operations at the Brett pit and fired up the aggregate plant for fifteen days to get sufficient material for the short term. It then closed the plant for remodeling, including a complete reconstruction of the sand classifying and blending plant. New screening equipment was installed in the aggregate plant with essential the same screen sizes that were used earlier. The conveyor to the storage piles about 5,000' away was rebuilt as a continuous, 48”-wide, 10,000'-long belt with a capacity of 2,750 tons an hour. Although the renovation was not entirely finished by August, the plant was put back in service as concrete production accelerated. In the following year, to keep pace with the demand for aggregate, additional shovels were added in the Brett pit and trucks supplemented the conveyor system that collected the excavated material.\(^{332}\)


On the west side, CBI installed an inclined skipway to transport materials from the construction railroad to the trestle, a drop in elevation of about 130'. The system, which went into operation late in October 1938, could carry a loaded railcar weighing up to 76 tons.\textsuperscript{333}

Concrete was again placed in 5' lifts, with each lift built up layer by layer. Before the first layer was poured, workers spread a coating of grout half an inch thick over concrete, three-quarters of an inch thick over rock. This was topped with concrete in 15” to 18” layers, which were compacted by crews operating electric vibrators. When the lift was finished, a project history explained, “workmen wearing ‘snow shoes’ embedded the necessary anchor bolts, pins, and stubs for supporting forms, cooling pipe, etc. in the succeeding lift.” The specifications had allowed for alternatives to clean up the blocks, a contentious subject in the project’s initial phase. Reclamation’s engineers emphasized “that the restrictions and provisions of the specifications were not placed there as nuisances to impede construction progress, but, on the other hand, were after careful deliberation, based on scientific study and experience, included in the specifications to insure that a safe and durable structure would be the result. As between a safe dam or speedy construction, if both cannot be obtained, there should be no argument.” Nonetheless, Reclamation inspectors sometimes allowed rules for concrete placement to be temporarily ignored to expedite construction. Successful experiments provided justification for changes in procedures. At its March 1938 meeting, for example, the Board of Consulting Engineers concluded that “chipping and wet sandblasting after final set and immediately before placement of concrete in succeeding lifts should prove effective and fully satisfactory.”\textsuperscript{334}

For the cooling pipes, a new type of expansion coupling was introduced in an effort to avoid the earlier leakage problem. The drainage system for the blocks was similar to that used in the first phase, but with an innovation that avoided the cost of embedding vertical drainage pipe in the concrete. Instead, CBI introduced removable formwork—a collapsible steel pipe—for the 8” vertical riser that drained transverse headers into a sump. The holes were later grouted.\textsuperscript{335}

While great care was taken to fill in the grout holes and drainage pipes to maintain the monolithic quality of the dam, some penetrations were necessary. Porous concrete drain tile 5” in diameter was embedded in vertical columns about 13’ back from the upstream face of the dam. The columns were spaced about 10’ apart. The drain tile was manufactured on-site by the Columbia Concrete Pipe Company, a subcontractor to CBI, using cast-iron molds. The molds were filled with concrete, which was dried in a kiln for about half an hour, then released from the molds and spray cured for two weeks or more.\textsuperscript{336}

\textsuperscript{333} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 138.
\textsuperscript{335} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 233, 243.
\textsuperscript{336} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 7, 1939, 173; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 139-140.
During cold weather, CBI used firepots and sand to protect the dam’s concrete while it was curing. Once cured, the concrete was cooled using the system developed during the first phase. Because the winter of 1937-38 had been mild, resulting in warmer than usual water temperatures in the river, the cooling process went slowly. In April 1938, CBI took over cooling operations from the previous phase. Cooling was suspended during the summer months.\(^{337}\)

Excavation during the year was minor. Smaller projects included digging a 520'-long, 7'-diameter drainage tunnel from the Pumping Plant to the Left Powerplant. A rock outcropping known as the “Dragon’s Tooth,” which occupied the future location of the Pumping Plant parking lot, was removed. A tapered recess, about 41' wide at its base, was carved in the left abutment for the dam’s future gantry crane and was later lined with concrete. The following year, a similar feature was completed in the right abutment for the second crane planned for the dam.\(^{338}\)

Excavation for the Pumping Plant foundation would begin in earnest in 1939. This was the biggest excavation task associated with CBI’s contract, requiring the removal of more than 300,000 cubic yards of granite between elevations 1170 and 1280 adjacent to the dam’s left abutment. To prepare the site, CBI blasted and cleared a series of benches beginning in May 1938. After getting below elevation 1203, it also began excavating the 21'-diameter pump discharge tunnels in the back wall.\(^{339}\)

Plans had called for the first 36' of the tunnels to be excavated initially. Due to modifications in the schedule, though, the contractor excavated the entire length of the tunnels to a diameter of 17' by April 1939. None of the tunnels had the same length or slope. CBI used drilling jumbos to excavate the horizontal section of the tunnels, which extended 61' to 141'. The tunnels then curved upward at angles ranging from about 44 to 60 degrees, reaching the surface between elevations 1480 (Tunnel No. 1) and 1535 (Tunnel No. 12). To remove the debris from the sloped sections, CBI installed a bin and a dock-high gated chute at the angle in each tunnel. Small dump trucks backed into the tunnels to collect the materials that had accumulated in the chutes.\(^{340}\)

As the excavation for the pumping plan foundation proceeded, a lift seam was discovered around the area planned for pumps 3, 4, and 5, and the seam continued up the back wall of the excavation. The precarious condition of the rock in this location proved to be one of the most challenging issues that confronted engineers during this phase of the project’s construction. As a Reclamation report explained: “The foundation and the backwall of the pumping plant are, for the most part, composed of two distinct types of granite which are commonly referred to as

coarse- and fine-grained. Results of ancient geological forces which have been applied to this rock are exemplified by the presence of numerous joints and fractures. The principal feature of concern is the shear zone which roughly parallels the backwall of the pumping plant, its related lift seams, and the possible movement of the overlying rock which might be expected in [the] event of [a] severe earthquake, internal hydrostatic pressures due to seepage flow, and/or pumping operations.  

“B” hole grouting for the Pumping Plant foundation proved to be a delicate task to avoid damaging the fragile rock. The rock was closely monitored for movement during the grouting, which filled horizontal holes first, then vertical holes. During the process, Dr. Berkey examined the seam and advised that grouting be continued to consolidate the lift-seam rock, but at a lower pressure of 40 psi rather than the 200 pounds used previously. By early October, “B” hole grouting at the Pumping Plant was finished. “C” hole grouting began in August and was done, without incident, by late October.

There was less consensus about how to deal with the unstable rock wall around the tunnels, which would be exposed until construction of the Pumping Plant was well advanced. While the most certain way to eliminate the problem was to remove the rock above the seam, the cost of doing so was prohibitive. At its April 1939 meeting, the board of engineers preliminarily endorsed a temporary measure—imbedding a single or double row of 2”-diameter prestressed steel dowels in the rock—rather than grouting. At its November meeting, the board examined the initial dowels that had been placed and concluded that the doweling was not effective. As an alternative, the board recommended that the area between the wall and the pumping house should be backfilled with concrete. Reclamation engineers objected to this approach, however, asserting that the concrete would provide little support. They advocated instead for doweling as a more reliable option. As a compromise, government forces sprayed a 700-square-yard area with two layers of gunite, each about 3/4” thick. There was no work beyond this “temporary” solution until after World War II because of the high cost of the alternatives, the lack of consensus about the best option, and concerns over delaying the contractor’s work on the wing dam.

CBI completed excavation for the Pumping Plant foundation in June 1939 and began concrete placement in early October. A stationary derrick on the left abutment transferred concrete from the 1180 trestle on the downstream side of the dam. Space in the foundation area was confined, so hoppers and “elephant trunk” downspouts of rubber or metal were sometimes used to place the concrete.
To protect the heavy power lines providing electricity from the bus gallery in the Left Powerplant to the Pumping Plant, a bus structure was installed on the left abutment. Preliminary work on the structure began in 1938, but concrete placement for the box-like gallery was not started until the following year.\textsuperscript{345}

\section*{16. NECESSARY BREACHES: OUTLETS AND PENSTOCKS}

While CBI worked on the Pumping Plant and the dam, Reclamation moved forward on ordering key components for the new phase. It awarded a $1.5 million contract for penstocks and pump inlet pipes to the Western Pipe and Steel Company, San Francisco, in January, and gave notice to proceed in March. The contract included eighteen 18'-diameter penstocks for the main units, three 6'-diameter penstocks for the station service units, and twelve 14'-diameter pump inlet pipes. Altogether, these items required 16 million pounds of plate steel. Western agreed to produce and install the station service penstocks by April 1939, the pump inlet pipes by July 1940, and the main unit penstocks by November 1940.\textsuperscript{346}

While the smaller penstocks could be shipped in complete sections by rail, this was not possible for the main penstocks and pump inlet pipes. The steel for the colossal pipes and elbows could be formed into components that could fit on railcars, but the components had to be assembled close to the dam. Western subcontracted the work of making the plate-steel components for all of the penstocks and pipes and fabricating the station service penstocks to the Chicago Bridge and Iron Company. Sections were shipped from that company's plant in Birmingham, Alabama, to Electric City, where Western had erected a prefabricated building 270' long, 70' wide, and 45' high. In addition to housing an assembly area outfitted with fusion welding equipment, the building contained facilities for radiographic, mechanical, and hydrostatic testing.\textsuperscript{347}

The radiographic machines produced X-ray images of welds that Reclamation staff reviewed, along with field inspections, to verify the quality of the connections. Sections that were rejected had to be welded again. While this process ensured the safety of the end product, it caused delays in the schedule. An enterprising Western employee began substituting X-rays of good welds for some that were possibly defective. A Reclamation engineer later recalled how the ploy was discovered: “The work of assembly had advanced substantially before one of the engineers or technicians recognized that some of the pictures, while coded differently, were actually of the same weld. Because the welds are as distinctive and identifiable as fingerprints, the contractor’s fraudulent scheme came to light and the entire assemblage had to be re-X-rayed and defective welds repaired.” Reclamation also requested “a few changes in personnel.”\textsuperscript{348}

\textsuperscript{345} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 7, 1939, 173.

\textsuperscript{346} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 31, 259-260, 263.

\textsuperscript{347} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 31, 259-260, 263.

Despite the delay caused by this indiscretion, Western made good progress on assembling the outlet liners. The contractor installed the station services penstock liners, each measuring 6' in diameter and 40' in length, by the end of June 1939, two months ahead of schedule. The company began placing the penstock liners for the Right Powerplant in late September.

Getting the colossal sections of the main-unit penstocks from Electric City to the powerhouse entailed complex logistics. After running a dummy section on the rail line to ensure that there were no obstacles, Western began delivering sections by flatcar to the Government Warehouse at the top of the bluff, where they were transferred to a heavy-duty truck trailer. Truck tractors were attached to both the front and back of the trailer to provide sufficient braking capacity for descending the steep grade to the riverbank downstream from the Left Powerplant. The sections were then put on a barge, which was propelled by cable drum hoists, and floated to the powerhouse turbine pits.

Cranes placed the first upstream section in each penstock tunnel and these sections, which were sealed by hemispherical bulkheads, were encased in concrete. The other sections were then positioned from the downstream end. Western laid a railroad track in the penstock tunnels and loaded penstock sections onto transfer cars in the turbine pits. A section was shuttled up the tracks to its destination, where it was lifted from the car with jacks and lowered onto supports at the proper alignment. After the sections were welded together, concrete was pumped into the annular space to incorporate the pipes in the structure’s mass. The procedure was basically the same for both the station service and main unit penstocks, although some accommodations were made for the difference in scale. The railroad track was narrow gauge in the station service tunnels, for example, but had to be wide gauge to handle the main unit sections.

By the time Western’s duplicity with the X-rays was discovered, most of the main unit penstock sections had been placed in the Left Powerplant, with the twelve stiffener rings in each penstock braced with spiders composed of 4" pipe. The pipes were repaired in place, delaying CBI’s start of backfilling around the liners by about a month to late February 1940. CBI plugged the lower end of each void between the liner and the concrete foundation with a bulkhead, then pumped concrete to fill the void. Because the construction in the Right Powerplant was not as far along, some of the concrete could be placed directly from buckets. By early June, backfilling was completed for both powerhouses.

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In the meantime, the Hardie-Tynes Manufacturing Company of Birmingham, Alabama, delivered the long-awaited gates for the outlets at elevation 934 in late winter. Each of the conduits was to be outfitted with a ring-follower gate and, slightly downstream, a paradox gate. Chambers above the gates provided access to the mechanisms for maintenance. The hydraulically hoisted ring-follower gates were to be used only when the paradox gates downstream failed or needed maintenance. The leaves of the ring-follower gates were moved by 30.5" pistons activated by oil pressure.\(^{353}\)

Like the ring-follower gate, the paradox gate’s cylindrical opening was closed by a leaf, but the leaf’s design was more complex. As a project history explained:

> There extends from each side of the paradox leaf a vertically tapered flange with its thicker end up and its inclined plane facing downstream. Between the tapered flanges and the inner (downstream) surface of the gate frame are assembled two long, steel wedges with their small ends upward. The leaf is raised and lowered by a hoist mechanism consisting of two motor-driven screws which are attached through a common lifting beam to the upper ends of the two wedges. In raising the leaf to open the gate, the hoist mechanism draws the wedges in between the diagonal leaf flanges and the gate frame, thus forcing the leaf horizontally upstream away from its seat. This initial movement of the wedges causes the leaf to clear its seat by approximately 3/16 of an inch. The wedges and leaf then travel together as a unit to the upper or open position of the leaf. Each wedge assembly is enclosed in an endless chain of stainless steel rollers, and resembles a caterpillar tread. These rollers travel on stainless steel tracks or guides within the gate frame. A train of rollers is also installed between each wedge and the tapered flange on the leaf, against which it bears. The wedges are thus enclosed on both sides by roller trains which reduce friction to a minimum.\(^{354}\)

CBI began installing the ten gate bodies on April 1, 1938, anticipating the completion of six before spring floodwaters crested two months later. Flatbed railcars transported the three sections of each gate body—a frame and a lower and upper bonnet—onto the concrete-placing trestle. Two revolving cranes with a common lifting yoke carried the assemblies, some weighing as much as 39,000 pounds, from the railcars to structural steel pedestals that had been installed in the blockouts to temporarily support the gates. “The ring-follower gates were the first to be installed,” an article in *Reclamation Era* explained. When the lower bonnets and gate frames had been assembled and put in position, “they were adjusted for height by means of shims on the supporting pedestals, so that the bores of the gate frames coincided with the bores of the conduit.


linings which had been previously embedded from the blockouts to the upstream face of the dam.” The downstream section of liner was bolted to the opposite side of the gate frame. The liner’s other end was bolted to the paradox gate frame after its lower bonnet and frame were in place, and this, in turn, was bolted to the embedded liner section that served as the outlet. After the upper bonnets were attached, the gate bodies were embedded in concrete.

CBI met its goal of completing six gate frames before the annual high water period. After the rest were finished later in the summer, the gate leaves and hoists were installed. The paradox gates “were the heaviest assemblies in the entire installation, weighing 53,300 pounds.” When the gate installation was completed, formwork for the gate chambers and connecting galleries was erected, and the blockouts were filled with concrete.

The elevation 934 outlets were ready for use by spring 1939. The first was activated on May 2, using water pressure to unseal the ends of the conduits: “With the paradox gate closed, the ring follower emergency gate was opened, and this section of the conduit was filled with water under pressure from the contractor’s water main to force off the bulkhead at the upstream entrance of the conduit. To remove the bulkhead at the downstream end, the paradox gate was opened, and the flow of water through the conduit dislodged the bulkhead.” The same procedure was followed for the other conduits, and on May 14, the twenty gates were opened together for the first time. On September 20, the last diversion slot was closed and the entire river was diverted through these outlets. The surface of the reservoir stood at elevation 1024.

The quality of the installation impressed Columbia Basin Project engineer Lloyd Froage. Writing in Reclamation Era in August 1940, he said that “each paradox gate has been opened and closed many times, each operation requiring about 8 minutes. During a brief period while opening or closing a gate, the flow of the water causes a snapping or crackling sound, but when the gates are fully open they operate so quietly that no sounds can be heard even when one inspects them by stopping his ears and holding a sounding rod in his teeth. It consequently becomes necessary to look at the indicator to tell whether a gate is open or closed.”

The gates at elevation 934 were designed to be either fully open or fully closed and to operate under heads of 250’ or less. It was anticipated that these outlets would be used very rarely. The two upper tiers of outlets were at elevations 1036 and 1136. Each was capable of discharging up to 225,000 cfs of water. Together with the spillway gates near the dam’s crest, the upper outlets would be the workhorses for controlling the reservoir’s elevation. They passed through the dam horizontally, turning down sharply just before reaching the dam’s downstream face to discharge

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almost parallel to that face. The lower outlets “descend through the mass concrete in a parabolic curve which emerges from the downstream face of the dam on a tangent to the curve of the bucket section of the spillway.” 359

The 102”-diameter conduits for the upper tiers were completely lined with 5/8”-thick welded plate steel except for an exposed concrete section at the discharge end. The cast-steel liners were manufactured by the U.S. Pipe and Foundry Company. Each conduit comprised five sections. “The upstream opening for all of the outlets was bell-mouthed to facilitate smooth water flow and discourage cavitation,” a project history reported. Two straight sections led from the intake to the upstream gate. A short section between the gates included a manhole for access to the conduit interior from an adjacent gallery. The final section extended from the downstream gate to the unlined section near the outlet. 360

By the end of 1939, CBI had installed the conduit liners and gates for the outlet works at elevation 1036 and started on the liners and gates at elevation 1136, finishing the latter task in 1940. Placement of the massive gates was an exacting process, with a deviation of only 1/16” allowed vertically and 1/8” horizontally. Reclamation modified the design of the downstream sections of the twenty conduits in Blocks B, C, D, and E while the dam was under construction, outfitting them with welded-plate steel liners. The Puget Sound Machinery Depot in Seattle manufactured the seven sections of 5/8” plate required for each conduit. 361

For the upper tiers, Reclamation substituted ring-seal gates for ring-follower gates. “The general design and installation requirements are substantially the same for ring-seal gates as for ring-follower gates,” an engineering source explained. “The principal difference is in the wheels, roller trains, and seals which have been added.” Ring-seal gates had not been used on the outlets at elevation 934, according to The Columbian, because the design “was developed after the lower tier had been installed.” The reason for switching to the ring-seal gates was also straightforward: “They are more desirable from the standpoint of cost and size of installation chamber required in the dam.” Credit for the ring-seal concept was given to Reclamation engineer P. A. Kinzie, who sought an alternative to the operating constraints associated with the ring-follower gates that were typically used in large installations up to that time. 362

Grand Coulee’s ring-seal gates were manufactured by the Joshua Hendy Iron Works and the Consolidated Steel Corporation, both based in California. Each gate’s frame had a cylindrical opening (“ring”) that matched the conduit’s 102” diameter, allowing the water to flow

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361 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 7, 1939, 190, 196, 201-204.
unimpeded. A leaf was housed in a bulkhead above the conduit when the gate was open. The leaf dropped across the opening to close the gate, guided by a slot in the frame. A tight seal was provided by a 102”-diameter bronze “seal ring,” which “floats in an annular slot machined in the upstream face of the bulkhead section of the gate leaf,” according to a project history. “A companion bronze seat ring of the same diameter is made part of the gate body or gate frame casting. Water under pressure is admitted through a tube to the slot behind the floating ring to force it into water-tight contact with the seal ring of the gate frame.”

This seal design, known as a diaphragm, was not the only option for a ring-seal gate. “Both diaphragm- and ‘grommet’-type seals . . . have been used on ring-seal gates,” the Handbook of Applied Hydraulics reported. From the author’s perspective in 1969, “the ‘grommet’ type is simpler and operates better. It is also cheaper to make because of the fewer parts and the relatively low rubber-molding costs as compared with the diaphragm type.” Seals were often the weak link of a gate, however, and the author concluded that “a number of designs seal well enough to be called satisfactory,” but “the perfect seal has not yet been designed.” Reclamation was not initially enamored of the grommet design, having tried hydraulic hoists with grommet-type seals for two 126” gates at Boysen Dam before selecting the other alternative for Grand Coulee. In doing so, Reclamation made history. According to the Handbook, “The major initial use of the ring-seal type of gate was for the 40 outlets in the two upper tiers at Grand Coulee Dam.”

The hydraulic hoisting mechanisms were also innovative. As the size of gates grew, their operation pushed the limits of mechanical equipment. It was already common to replace sliding connections with wheels or roller trains on gates with capacities of 100 to 150 tons or more. While this made it easier for the mechanical hoists to move the gates, the introduction of hydraulic hoists brought a noteworthy improvement in performance. The hydraulic unit was also more durable because “the connection to the gate is made by a series of large stem sections which are easily protected by painting and are not materially weakened by corrosion of a degree which would seriously impair a wire rope. The wire ropes on mechanical hoists must either be made of stainless steel or, if made of carbon steel, be replaced frequently to ensure the safety of gate operation.” In an emergency or otherwise, hydraulic gates were lowered by gravity, with the speed regulated by controlling the flow of oil from below to above the piston. Speed was less critical when the gates were raised, often taking up to thirty minutes to complete the operation, so motors and pumps were usually small.

There were problems when the outlet works gates at elevation 1036 were placed in service in 1940. Seals leaked water, hoist mechanisms leaked oil, and high humidity in the galleries disabled switches. Repair work continued into 1941. Similar problems were experienced with the

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outlet works gates at elevation 1136, especially after temporary operating mechanisms were replaced by permanent electrical equipment in January 1941. The gates went into service over the course of the winter and spring as conduit linings were welded and grouting was completed. All were in operation by May. By December, the gates at elevation 1136 were undergoing repair. The repairs were facilitated by the bulkhead gate that traveled on guides permanently installed in the dam’s upstream face.366

The roller chains for the ring-seal gates at the elevation 1036 outlets at had a tendency to get kinked after turning at the top or bottom of their run, stopping the gates. In 1942-1943, Reclamation installed 6” guide angles at both the upstream and downstream ends of these outlet tubes to prevent this problem.367

Reclamation specified coaster gates for the penstocks. Lewis Smith, assistant engineer in Reclamation’s Denver office, oversaw the development of the design for the gate leaf and frames. He described them in an article in The Reclamation Era: “The gates and their hoisting mechanism are unique in almost every respect, both in view of new and older operating features that appear on this type of gate for the first time.” Each 15’ x 29.65’ gate leaf was built up from heavy horizontal girders framed into vertical end girders, with a watertight steel-plate sheathing on the downstream side. Endless roller trains, like caterpillar treads, on each side of the gate ran on tracks in gate slots to raise and lower the gate. The roller trains spread the intense horizontal thrust of the 264' operating head over a large area. “This is believed to be the first instance where roller trains have been placed completely around the flanges of the end girders of a gate leaf of this size,” Smith reported. Even so, given the gate’s height, they had to use a pair of roller trains aligned end to end, rather than a single one.368

Smith explained that “the gate ‘coasts’ or lowers from its position of rest just above the penstock orifice to the closed position by virtue of its own weight, and is raised to the open position by the pressure of oil forced under the lower side of the hoist piston” in the hydraulic hoist, situated at elevation 1302.42. The hoist’s piston stem was connected to the gate by a knuckle-joined hoist stem. Smith added: “A novel control arrangement is provided whereby if the gate should for any reason become stuck during lowering, the controls automatically reverse and the gate and hoist piston will, in effect, remain suspended at the point where the gate sticks. After repeated automatic trials of the gate to lower it, should it become dislodged, then lowering will be resumed; if not, the gate may be raised by switching the controls to the raising cycle.” A hydraulically activated seal, similar to that used on ring-seal gates, sealed the closed gate. If a gate was inoperable, emergency stoplog gates could be slid into guides in front of the frames. If a gate had to be removed, it could be placed in one of the coaster-gate transfer structures at blocks

21 and 74. Transfer structures for hydraulic hoist cylinders and stems were at Blocks 23 and 72.  

*The Columbian* explained that the coaster gates provided “a solution for several important design considerations: (1) ability to close the gate rapidly, (2) ability to remove the entire unit with the reservoir at the maximum level, and (3) ability to control by a completely dependable automatic means.” In an emergency, the 250,000-pound gates could be closed, primarily relying on the force of gravity, in a speedy two minutes.  

Reclamation ordered gates for only three of the main units (G-1 through G-3) and two of the station service units in 1940. In the following year the supplier, the American Bridge Company, delivered each gate in three main sections, which were assembled by CBI in an erection frame at the dam’s west end.  

Moving the massive gates into place required a powerful hoist. Reclamation had ordered a 150-ton gantry crane from the Star Iron and Steel Company of Tacoma, Washington. In May 1941, the company began delivering sections of the structure, which was to ride on rails flanking the roadway on the dam’s crest west of the spillway. The crane’s framework had been bolted together by the end of the month, and the connections were riveted by mid-June. The arrival of the main hoist, though, was delayed. This threatened to upset Reclamation’s schedule for testing Unit G-3 because the bulkhead sealing the upstream end of the penstock could not be removed until the coaster gate was in place. CBI borrowed a hoist with a 75-horsepower motor, then tried one with a 150-horsepower motor; neither could lift the gate. The hoist from Star Iron finally arrived June 22 and was installed with haste, before the crane structure was entirely finished.  

Each of the hydraulic hoists had “a steel cylinder 30 inches in diameter, in which a piston operated with a working stroke of 31 feet, 6-1/2 inches.” The Consolidated Steel Corporation had won the contract to provide the first three hoists and delivered them to Reclamation’s storage yard at Electric City in early 1941. CBI transferred the first one to the dam in mid-June, placing it in the roadway at Block 18. When the gantry crane was finally functional, “the gate was lowered on the gate guides by the . . . crane, and was temporarily supported by the erection frame and hoist stem yoke while each succeeding length of hoist stem was attached.” The project history observed that “when a gate was lowered to its closed position and came to rest on the stops, the hoist stem continued to descend an additional four inches to operate the valve for inflating the gate seals.”  

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372 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 135-139.  
373 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 139-140.
With the first gate in place, the erection frame was returned to the west end of the dam, where work started immediately on gate G-2. By the time that it was ready for installation in mid-August, the assembly of the gantry crane was essentially complete, although it was not until November that Reclamation forces replaced the crane’s temporary wiring with a permanent installation. As soon as gate G-2 was in place, the erection frame pressed into service for gate G-1, which was installed in Block 14 by early October. Because of problems with the hoisting mechanisms, gate G-2 was not functional until mid-December; the bulkhead behind it was removed before the end of the year. Gate G-1 was put into operation in the following year.374

Like the upper conduits, the penstocks were also equipped with emergency ring-seal gates that were designed to be either fully open or fully closed. The 72" motor-operated gates were installed immediately in front of the turbines.375

17. MAKING WAVES

Gates of yet another kind were needed during construction to fill in slots that had been used for the river’s diversion. The spring flood in 1938, which was nearly two months in duration, overtopped the fifteen lowest blocks in the spillway section of the dam at elevations 935 and 945. As the waters receded, CBI planned to begin placing concrete in six of these sections, bringing them to elevation 965. These slots would then handle the river’s flow while five of the remaining low blocks were raised to elevation 980 and the remaining four to elevation 995.376

The slots had to be closed and drained before concrete could be placed. The timber gates that MWAK had used to accomplish this for the lower slots proved cumbersome, so CBI hired two engineers from the Aluminum Company of America to design a more functional model. The engineers patterned the 70-ton steel gates, which measured 52’ wide and 35’ high, after the permanent gates at the Bonneville Dam. Each gate was formed from nine horizontal plate girders secured to side girders and sheathed on the upstream side with steel plates. Twenty 16"-diameter cast-iron rollers on the vertical sides of each gate fit into tracks on portable guide frames. Brackets at the top of the frames hooked over anchor bolts in the dam. The weight of the frames and the pressure of the current held the frames in place against the dam. A gate was lowered into the frame by a hoist barge, which was maneuvered to the slot by heavy cables anchored upstream. A Reclamation worker asserted that the “river jockies” [sic] responsible for “handling the gates into and out of position had some of the most dangerous and important work on the entire undertaking. And they did it with only minor mishaps.” Rubber belting and tubes sealed the edges of the gates. A water-tight chamber at the bottom of each gate could be filled with water to help weigh down the gate when it was lowered. Releasing the water lightened the gate to raise it. The Pacific Car and Foundry Company of Seattle fabricated eight gates and nine

374 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 139-142.
375 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 77.
roller-path gate guide frames. The extra guide frame could be positioned at an open slot to facilitate the transfer of a gate to that location. The first gate was installed on August 10, 1938. Because moving gates was tedious and there were only eight of them, CBI sometimes pushed the limits of diversion practice. A Reclamation report worried: “The contractor worked on such a small margin of clearance between the upstream river level and the construction work that the river was constantly threatening to overtake the construction work. On one occasion it was necessary to use sandbags to prevent the water from topping the closure gates. Fortunately, weather conditions favored the contractor as no hard rains fell to cause a sudden rise in the river.”

Some of the gate closures created rapid fluctuations in the surface of the tailwater—up to 2 to 4 feet within a two-hour period. This caused “considerable movement of the east and west riverbanks,” raising concerns about further slides in these unstable areas. In response, Reclamation required CBI to close the gates more slowly to maintain the tailwater within half a foot of its normal daily variation. It took 34.5 hours to close the gate in Block 44 and 58.5 hours for the one in Block 50. This tedious process was accelerated in May 1939 when the outlet gates at elevation 934 were placed in service. Thereafter, a day before a closure gate was placed, paradox gates were closed sequentially until they blocked as much flow as the closure gate would. Then, as the closure gate was positioned, the paradox gates were opened to compensate for the loss of flow, allowing a closure gate to be dropped within minutes.

The effect of the closure gates on downstream water levels stoked Reclamation’s ongoing fears about slides, especially in the vicinity of the highway into Government Town along the west tailrace. “Much effort has been put into the task of stabilizing the ground,” a 1939 report by Dr. Berkey noted. “Test holes, wells, shafts, drifts and tunnels, both in the clay-sand overburden and also in the rock floor, have been resorted to in a long drawn out, though somewhat intermittent, program which was urged on from time to time by apparent danger of new movement in the mass of sand and silt deposits still resting on the rock floor and clinging to the side walls of the gorge.” While Reclamation attempted to improve existing conditions rather than just stabilize

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them, the ground “is still believed to be sufficiently unstable at certain periods to claim continued attention.” He recommended that additional tunnels be dug at higher elevations to release any pockets of water lurking there.380

The situation seemed better after the completion of a drainage shaft near the West Vista House in January 1940, but the problem soon returned. “Intermittent settlement along a 140-foot section of the U.S. Construction highway became especially severe,” a project history explained, “and resurfacing of the highway and raising of the guard rail posts became regular work.” The cause seemed the same: “In general, it has been observed that earth movements occur when the equilibrium between the river bed and the banks is disturbed. This unbalanced condition may result from the scouring action of the river at the toe of slopes, or by the introduction of moisture into the material involved. When earth movements do occur, the angle of repose of the material may change from 45 degrees to the surprisingly low value of 14 degrees.”381

The west slide area was on the agenda for the meeting of the Board of Consulting Engineers in March 1940, which Berkey missed because of illness. Surcharge had been added in an attempt to stabilize the area. The board now thought that the surcharge might be doing more harm than good, but decided to observe the area through the summer rather than call for the immediate removal of the material, a costly prospect. In the meantime, though, the board recommended that staff do preliminary plans for that process. The board also considered the right slide area, deciding that “no attempt be made to control the earth movements in this area as it would probably become stable before the right powerhouse was placed in operation.” CBI did, though, have to move some of its shop buildings and equipment that were being undermined by the shifting ground.382

The board’s decision only delayed the inevitable. When it met again in September, it “advised with regret that the year’s cycle of events had not been encouraging, and that it would be necessary to excavate and unload the west slide area” at an estimated cost of $510,000. “There was danger of the sliding material blocking the left tailrace channel, which would be a major catastrophe should it occur during operation of the power plant.” In addition to the excavation, the board recommended using large rock to riprap about 1,300’ along the toe of the slide above the left tailrace area. In November, Reclamation issued an extra work order to CBI to excavate and remove about 1.3 million cubic yards of overburden, reinforce the tailrace with 50,000 cubic yards of riprap, and relocate about 1,450’ of the highway and 1,300’ of the rail line about 200’ back into the hillside. A 1,300’ rail spur on the tailrace would receive a new foundation. The work, which was underway by the next month, included reopening the Brett pit, where CBI blasted to dislodge rocks ranging from 4 to 25 tons for the riprap.383

381 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 110, 113, 117.
By the time the Board of Consulting Engineers returned in May 1941, the work to unload the tailrace slope and install the riprap beyond the tailrace’s mouth was almost completed. “The appearance of the reconstructed slope appeared quite reassuring,” a reported observed, but “the real test of the adequacy of the work is not likely to come until after one or more seasonal cycles of the rise and fall of the river.” As a precaution, the board recommended that rock be stockpiled in case additional riprapping was needed.\textsuperscript{384}

While the engineers sought a solution for the tailrace area, another slide just upstream from the Pumping Plant became active. Although this vicinity had experienced minor movement in 1937, Reclamation was surprised by several major slides in 1940, including one in late October that destroyed part of the highway and about 100' of a stone wall that had been installed by the Pumping Plant parking lot. A temporary bridge had to be built to carry highway traffic over the ravine that formed. By December, crews were working around the clock on the excavation. Removal of common material was completed in April 1941 and of other materials in July. All in all, some 1.5 million cubic yards of material was excavated. The area was re-graded to accommodate the highway and railroad tracks, and traffic began flowing again in late August. A new retaining wall along the highway was completed in July and August.\textsuperscript{385}

The campaign to stabilize the left bank continued into 1942. In the tailrace area, the year started off well, with workers removing about 40,000 cubic yards of earth from the slide area between elevation 980 and the highway in February and March and placing riprap in April. A bench at elevation 980 was covered with a 5' layer of riprap to create a future parking lot for the Left Powerplant.\textsuperscript{386}

The Columbia, though, seemed intent on counteracting these efforts. Flowing at about 300,000 cfs in June 1942, the river scoured out some 15,000 cubic feet of riprap by the west tailrace. Reclamation engineer J. L. Savage suggested two alternative responses. The first was to let the river continue to enlarge its channel for several years, and then install heavy-duty riprap. “This will result in additional slides that may be extensive, costly, and unsightly,” Savage predicted. Even so, it would probably be less expensive than the other option, “a heroic plan of protective works using large concrete blocks. The blocks might be fastened together by heavy chains and placed in rows normal [perpendicular] to the river.” Salvage cited a similar installation by the Aluminum Company of America in Canada.\textsuperscript{387}

\textsuperscript{384} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 42.
\textsuperscript{387} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 10, 1942, 47-48; J. L. Savage to chief engineer (S. O. Harper), memorandum regarding “Conclusions form discussions at Coulee Dam, July 9, 1942, 3-4,” at RG 115, Project Correspondence File, 1930-45, Entry #7, Box 536, NARA-RMR.
By the time that the Board of Consulting Engineers met in late September, the 15,000 cubic feet of riprap lost in June had been replaced, with another 11,000 cubic feet added for good measure. Still, the board did not trust the riprap to withstand the river’s torrents, which could reach 500,000 cfs, and recommended “a moderate widening of the river channel” to accommodate a greater flow. To this end, some 22,230 cubic yards of existing riprap was removed from the east bank between December 1942 and mid-January 1943. Additional excavation was initiated in August. A 3:1 slope was established on the bank, with the excavated material dumped in a ravine northeast of Mason City to level an area for the town’s future expansion. In other reaches, the river was allowed to erode lower areas of the banks, with stockpiled riprap as “a second line of defense” to stabilize upper slopes as needed. The channel was also enlarged by dredging directly below the spillway, beginning in December 1943. 388

Acting Reclamation Commissioner H. W. Bashore summarized the inconclusive results of stabilization efforts as of July 1943: “Since completion of the powerhouse tailraces, approximately $1,000,000 has been expended in attempting to stabilize the left slide area by drainage, riprapping, and unloading methods. Even with this protection movements have in the past threatened to invade the powerhouse tailraces with large masses of earth. Extraordinary movements within the slide area follow closely rapid downward fluctuations in the tail-water surface.” This had onerous implications for the facility’s operations: “Sudden loss of load in the power plant will cause a rapid drop in the tail-water surface of considerably greater magnitude than any that has occurred to date with consequent danger of a major slide movement. A major slide would undoubtedly block the left tailrace channel and result in wholly eliminating or reducing power generation for a considerable period of time.” He noted that valves in the Right Powerplant could control sudden fluctuations in the tailwater elevation, and could also divert water from the spillway to retard deterioration of the bucket. In a more immediate effort to stabilize the west slope, Reclamation extended the west-slide drainage tunnel. A new adit was excavated by March 1944, and related concrete work was completed the following month. 389

18. REACHING NEW HEIGHTS

As the dam rose, CBI was also making progress on the Left Powerplant, which would measure 765' long by 84' wide and rise 182.5' above the draft tube floor at elevation 896. MWAK had finished the structure to about elevation 949—high enough to avoid the need for a cofferdam for the remaining construction. The turbine pits were within this foundation. Temporary timber bulkheads filled the 15’ x 17’ openings where the turbine draft tubes would discharge. 390

389 H. W. Bashore to J. A. Krug, July 9, 1943, draft of letter attached to memorandum from S. O. Harper to acting commissioner (Bashore), July 9, 1943, regarding repair and maintenance of spillway bucket, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 539, NARA-RMR; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 12, 1944, 25.
Before construction could begin, CBI had to dewater and clean out the turbine pits and draft tubes, a process that began after the 1938 spring floods subsided and took almost two months. The timber draft-tube bulkheads were repaired as needed. Eight reinforced-concrete bulkheads in the gallery openings at elevations 921 and 934 “were of no further use,” the 1938 project history reported, so they “were dumped into the river channel downstream from the dam.”^391

CBI planned to use the powerhouse’s transformer structure at elevation 1015 as a staging area because the structure’s rising walls would soon be beyond reach of the cranes on the construction trestle at elevation 1024. Reclamation had initially planned to prepare the drawings for the transformer structure later, but agreed to finish them by mid-June 1938 to accommodate the contractor—“although this required a complete reversal of the Government’s schedule for design plans,” the project history observed.\(^392\)

The structure of the powerhouse was more complex than the dam and required a significant amount of reinforcing steel, conduits, piping, and other materials. This meant that the formwork would be complicated. CBI retained a specialist in form detailing to design it, and these drawings were approved by Reclamation before construction began. “This practice resulted in first-class formwork,” a project history noted, “and saved the contractor a considerable amount of time and money.” The forms for the superstructure’s tall walls, for example, required unusual bracing of steel I-beam posts and heavy timber beams. The draft tubes presented the greatest challenge: “From a 16-foot diameter circle at the turbine location, the draft tube curves downward to branch out into three 16’ x 13’ exits.” CBI initially proposed using wood forms for this feature, but ultimately retained Commercial Boiler Works of Seattle to produce two forms of steel. Each had twenty separate pieces made of ¼” plate metal on a framework of angle irons.\(^393\)

CBI placed the first concrete for the powerhouse on July 23, reaching elevation 1015 in October. By the end of November, it had installed a timber deck on the transformer area to hold a set of crane runway rails for three whirley-type gantry cranes and three sets of railroad tracks. A truss carrying a double set of tracks extended from a hopper on the timber deck to the construction trestle. Cars on these tracks transported concrete from the trestle to the hopper in 4-cubic-yard Blaw-Knox buckets. Practices for placing concrete were similar to those used on the dam, but the concrete was poured in shallower layers 8” to 12” deep. When space was too tight to dump the concrete directly from the buckets, it was funneled through “elephant trunk” downspouts. The concrete was somewhat finer than that in the dam, with a maximum aggregate size of 1.5” in most of the powerhouse and 3” in the turbine pits.\(^394\)

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More than 4.4 million pounds of reinforcing steel were placed in the powerhouse during 1938. The intersections of the bars were insulated with rubber hose so that they would not become conductors for induced currents when the plant went into service. As another precaution, the bus gallery was reinforced with high-silicon bars, which were much less susceptible to becoming conductors than standard billet steel. Standard bars were used in most other locations, although high-tensile steel bars were specified for the generator structure.\(^{395}\)

By the end of 1938, the transformer structure was completed and most other sections of the powerhouse rose to elevation 951. Although cold weather in January 1939 forced a hiatus in construction that lasted more than a month, CBI was again placing concrete by the end of February. When the walls had reached full height, two gantry cranes moved the steel roof trusses into position. “It usually took about four hours to set the trusses in one unit, twelve hours to set purlins and belt up, and about three days to drive the rivets,” according to the 1939 project history. By the close of the year the plant “had assumed to a large extent its final appearance in regard to architectural outline.” The exterior walls and the roof slab for the main units were finished. The bay walls in the station service area were nearly done, while those in the control area had reached elevation 1018. Inside, most of the initial draft-tube concrete in the turbine pits was at elevation 926.\(^{396}\)

Significant progress on the dam was made in 1939. Construction had been interrupted by cold weather between January 10 and February 20, and work on the spillway section was stopped by spring flooding between mid-April and mid-June. For the rest of the year, though, construction proceeded apace. During the winter of 1938-1939, the river had been diverted through six slots that remained at elevation 985. When concreting resumed in the spring, five lower blocks were raised to elevation 980, eleven to elevation 995, and one to elevation 1010. These slots accommodated the river at flood state because the outlets at elevation 934 could not handle the entire discharge. The diversion slots were sequentially closed as the waters receded, with the lowest closed by the end of June and the rest by the end of September, leaving the outlet works at elevation 934 fully responsible for maintaining the level of the reservoir, which was beginning to fill. “Although only a fraction of the ultimate storage of 10,000,000 acre feet of water was contained therein,” the 1939 project history noted, “backwater effects were being observed 38.5 miles away.” \(^{397}\)

At the beginning of 1939, the left abutment stood at elevation 1040, the right abutment at 1070, and some sections of the spillway at 1015. A year later, the right and left abutments were within 100’ of elevation 1311, their ultimate height. The spillway section was still below elevation

1180, but construction was ahead of schedule: 44.5 percent of the contract time had passed and the project was 68.5 percent completed. 398

The experience gained from the first phase greatly enhanced productivity. In addition, the contractor pressured Reclamation for changes in some of the specifications to accelerate concrete placement. As lifts were poured, Reclamation had not allowed the height difference between adjacent blocks to be more than 50' in the spillway, 30' in the remainder of the dam, and 175' between the spillway and abutments. CBI wanted to increase those distances to 75' in the spillway, 50' elsewhere in the dam, and 225' between the spillway and abutments. CBI also proposed to create blockouts for the outlet works at elevations 1036 and 1136, which would enable placement of concrete above these elevations before the equipment for the outlet works was delivered. Reclamation engineers expressed grave doubts about these changes, fearing that the monolithic integrity of the dam might be compromised. “A number of conferences were held with the contractor’s officials to discuss the proposed changes,” according to the 1939 project history. “Representatives from the project office and Consolidated Builders, Inc., then journeyed to the Denver office for further discussion of the proposed program with the Chief Engineer.” CBI finally prevailed on March 11. 399

The impact of these changes was illustrated on May 25 when the contractor placed 20,684.5 cubic yards of concrete in a twenty-four-hour period, setting a new world record. It set another record in October, producing 536,264 cubic yards of concrete in a single month, an average of about 17,300 cubic yards a day. That quantity of concrete, one observer wrote, was enough “to build a 2-lane, standard, concrete highway 250 miles long.” The concrete was transported from the mix plant to the dam at a frenetic pace. “During the peak of operations,” the project history reported, “ten regular and four auxiliary placing cranes were used and as high as 1,500 round trips were made in one day by the concrete trains operating on the elevation 1180 trestle.” By December 11, 9 million cubic yards of concrete had been placed in the dam. 400

As the weather got colder, CBI implemented special procedures to keep the concrete at a minimum of 60 degrees when placed and above freezing throughout the initial curing process. During the winter of 1938-1939, Reclamation’s chief concrete inspector, Bert Hall, reported that oil-burning “salamanders were used within the forms to raise the air temperature. Gasoline torches were used to remove any ice that might occur on the forms and the embedded materials.” Instead of stripping forms after thirty-six hours, the standard practice, CBI left the forms in place for at least forty-two hours. In January 1939, however, Hall discovered significant areas of

superficial scaling and spalling in the concrete that had been laid since the first freezing temperatures two months earlier.\footnote{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 7, 1939, 145; Bert A. Hall, Chief Inspector, to field engineer, Bureau of Reclamation, memorandum on survey of spalled concrete on the downstream face of the dam, January 13, 1939, at RG 115, 1935-1942, Dam Grand Coulee, Concrete: Dam, NRG-115-00-148, Box 1, Folder 510, NARA-RMR.}

The following winter, the minimum time before forms could be stripped was raised from forty-two to forty-eight hours. This, a Reclamation engineer maintained, “will provide most of the protection needed for a large percentage of the mass concrete placed in cold weather,” assuming that the concrete contained a small amount of calcium chloride to accelerate the curing process from twenty-one to eight days.\footnote{R. F. Blanks, Engineer, to chief engineer, memorandum regarding recommendations for cold weather concreting at Grand Coulee Dam, November 6, 1939, 2-3, at RG 115, NRG-115-00-148, Box 1, Folder 510, NARA-RMR. CBI added between 0.6 and 1 percent calcium chloride during the winter to speed the setting of concrete from twenty one to eight days. Calcium chloride had fallen from favor by 1947, when the project history noted: “Since the Denver office has cautioned about extensive use of calcium chloride, this project has restricted its use to minor structures where early form removal or early loading is desired, but without sacrifice of curing in keeping with standard practice.” (Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 15, 1947, 262.)} CBI installed a steam heating system to warm water at the mix plant and, when necessary, to pump steam through the aggregate. A “steam spray curing method” was used for the newly poured blocks, which were blanketied with 2” of damp sand and covered with canvas. Live steam jets were inserted between the sand and canvas, creating a layer of warm air at least 6” deep. Small service lines ran from the blocks to headers that were supplied by seven boilers on a large floating barge known as the “Iron Duke.”\footnote{R. F. Blanks, Engineer, to chief engineer, memorandum regarding recommendations for cold weather concreting at Grand Coulee Dam, November 6, 1939, 2-3, at RG 115, NRG-115-00-148, Box 1, Folder 510, NARA-RMR; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 7, 1939, 145, 155-158.}

Ironically, at the same time that the contractor worked to keep the curing concrete warm, it was cooling other sections of the dam. By mid-March 1939, areas below elevation 1000 in the abutments and 950 in the spillway had been sufficiently cooled. As the year progressed, the accelerated concrete placement forced an upgrade of the equipment on the cooling barges, which were supplied with booster pumps to increase the operating head from 220' to 330'.

Cooling and curing were facilitated by Reclamation’s application of low-heat cement in this phase of the project. “All of the cement used during the first contract . . . was of a modified type, while during the second contract a low heat cement was used for mass concrete, and a modified cement for walls and other thin sections,” Reclamation engineer Oscar Dike explained. “The basic differences between the modified and low-heat cement were in the speed of early chemical action or hydration and the total amount of heat generated. The two types were not composed of different materials but of different proportions of the same materials.” A low-heat mix worked well for mass concrete, causing less cracking due to shrinkage. It was responsible, though, for
the longer times that formwork was kept in place because it set up more slowly than modified cement. Both types reached essentially the same strength after curing for ninety days.  

19. FORESTS AND FISH

By June 1939, the reservoir had reached a depth of 100' by the dam, with water backing up for miles upstream. Working ahead of the slowly but steadily advancing water, Reclamation cleared about 50,000 of the 81,000 acres that would be flooded, the largest clearing project that Reclamation had ever undertaken. Reclamation emphasized that this task was “very suitable for a large scale WPA [Works Project Administration] project”—reinforcing a major justification for Congressional funding for Grand Coulee. The WPA “would furnish all labor to perform the clearing work, build the camps, and operate mess halls,” while Reclamation “would furnish equipment and material for field operations and camp construction.” In October 1938, the WPA established the headquarters for the project at Davenport, Washington, with twenty-five workers. The anticipated population of the facility, christened Camp Lincoln, was three hundred. It was later expanded to more than six hundred. On December 20, a ten-man crew initiated clearing operations.

The following year, the WPA moved its headquarters to Creston and set up six additional camps along the reservoir’s 150-mile length. “Camp Ferry,” designed to reach more remote locations, comprised three 24’ x 64’ barges with sleeping, dining, and administrative facilities for 128 workers. “This was the largest WPA project in progress in the State of Washington and one of the largest in the nation,” according to Reclamation’s 1939 project history.

Sometimes entire communities had to be moved. A New York Times reporter gave a colorful summary of the process: “As the Columbia has surged higher and higher behind the dam, an ark-like craft called the Paul Bunyan has moved slowly upstream. At each settlement, workers have left the Paul Bunyan and shifted the buildings to ground beyond the level of the lake. They have dragged and rolled schools, stores, post offices, houses and barns out of the water’s reach. Even cemeteries have been moved.”

Roads that would be inundated also had to be relocated. Reclamation had been working on surveys for new routes since 1935. In 1939, the State Highway Department agreed to take on the responsibility of building the new state roads, with funding from Reclamation, and quickly let five contracts. Three were completed by the end of the year. Reclamation finished the last

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surveys for the relocated highways early in 1940, and the highway department soon advertised for bids for the remaining routes. For relocated county roads, Reclamation directly oversaw the construction. A forest highway was reconstructed by the Public Roads Administration and 14.2 miles of relocated rural roads in the Colville Indian Reservation were completed by the Colville Indian Agency. In all cases, Reclamation footed the bill.\

While automobiles can handle a wide range of grades, trains are less adaptable. Reclamation had difficulty identifying an acceptable new alignment for the tracks of the Great Northern Railway. Although surveyors started mapping out alternative routes in 1935, they had not completed that work until early 1940, and Reclamation did not come to an agreement with the railroad until that July. Because precious little time remained before summer 1941, when the reservoir would inundate the existing line, Reclamation called for bids for the line’s construction even before it had finalized the agreement with the railroad. It awarded a contract of just over $1 million to J. A. Terteling and Sons of Boise, Idaho, in June 1940 to reconstruct the 15.3-mile Nelson branch from Kettle Falls to Williams and the 13.1-mile Republic branch from Kettle Falls to Boyds. Reclamation contracted out other sections as well, and did some of the work with its own forces.\

The more routine part of the clearance was removing trees and other vegetation that could float downstream and clog turbines. Marketable trees were chopped down and purchased by the Lincoln Lumber Company, which had a mill on the Columbia about 35 miles upstream from the dam, and the rest were burned. The work was 79 percent complete by the end of 1940 and officially finished on July 15, 1941, when Carl Smith, the state director of the WPA, and Reclamation’s Frank Banks ceremoniously felled the last tree in the reservoir. In reality, though, the project was not entirely finished until December.\

By this time, Banks had left his position as construction engineer of the Columbia Basin Project, which he had held since construction at Grand Coulee began in 1933. In 1939, he had been appointed acting administrator of the Bonneville Power Project. Established by Congress in 1937 to market the electricity generated by federally operated powerplants, the agency was intended as a short-term solution until a regional authority could be established along the lines of the Tennessee Valley Authority. When it became clear that politics would prevent this from happening, the agency was rechristened the Bonneville Power Administration in 1940 by an executive order and given responsibility for a number of things, including marketing Grand Coulee’s power.\n
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410 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 25, 238-239, 244, 249.
While the clearing was going on upstream, there was also drama downstream. The dam’s effect on fish had been of official concern to Reclamation since at least the 1932 report of the chief engineer that recommended Grand Coulee’s construction. The report suggested that to facilitate fish migration to spawning grounds upstream, a flume and mechanical elevator might be part of the dam’s design. As plans were developed, however, the prospect of this option waned. “The question of handling migratory fish in the Columbia River looms large, in that it appears impracticable to build suitable facilities to permit fish to go above the dam,” the 1934 project history reported. “This problem does not enter for the immediate present, but a solution must be found before the dam is built above the foundation stage.”

With the decision to construct the high dam in 1935, the matter became pressing. The stakes were substantial—“the little matter of the $10,000,000-a-year salmon industry of the Columbia River,” as an article in *The Nation* put it. The article, written by muckraker James Rorty, added: “Not even the dodo is as extinct as the Columbia salmon industry will be in a few years.” A fishway or hoisting devise that seemed impractical with the lower dam was completely out of the question for the higher structure. By the end of the year, the plan that looked the most feasible involved trapping salmon below the dam and transporting them to holding pools at hatcheries until spawning season. Then, the eggs would be artificially hatched. After the fry have matured, they would be returned to the river.

There was no resolution to the issue in September 1936, though, when Reclamation met with the State Department of Fisheries to discuss alternatives. Reclamation launched a survey of fish populations in October 1936. By the end of the year, it submitted a draft plan to state and federal conservation agencies that entailed trapping salmon at the Rock Island Dam near Wenatchee, about 130 miles downstream, then trucking the fish about fifty miles to new facilities near Leavenworth to spawn, hatch, and mature. Reclamation had initially considered having the hatchery near Grand Coulee Dam, but rejected this idea as inefficient and ineffective. Reclamation had begun negotiations on the use of existing fishways at the Rock Island Dam with the dam’s owner, the Puget Sound Power and Light Company.

Other agencies apparently wanted additional studies before finalizing a plan. Winter forced a cessation of the fish surveys, but the work began again in April 1937 when Reclamation retained the State Department of Fisheries “to supply the necessary biological and experimental information as required, to determine the best means of protecting and continuing the

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propagation of migratory fish.” The report was to be completed in early 1938. As a temporary expedient, fish ladders were installed at the ends of the spillway (Blocks 32 and 62) in October 1937. Reclamation agreed to keep these sections low enough to allow the salmon to pass until the fish had completed their annual run in October 1938. The hatchery at Rock Island was slated to be in operation by the following year.⁴¹⁶

Reclamation received the state’s recommendations for migratory fish control in January 1938. The report “presented an elaborate plan for maintaining and increasing the present salmon runs in the Columbia River,” a Reclamation project history reported. “Briefly, the plan involves the trapping of the salmon on their upstream migration at the Rock Island Dam, and the transportation of the trapped fish to a hatchery station to be constructed near Leavenworth, Washington. At this station the fish will be retained in special holding ponds until ready for artificial spawning. The fry will be hatched at this station, and will be reared to a fingerling size suitable for planting in the tributaries of the Columbia River. Based upon the well established law that mature salmon will return to spawn in the stream where they began life, the salmon formerly spawning above Grand Coulee Dam will by these means be permanently transferred to the four tributary streams below the dam, which they can thereafter reach without obstruction.”⁴¹⁷

In May 1938, Reclamation set up an office in Ephrata to survey potential locations for trapping and hatchery facilities and to begin preliminary design work. In August, though, “acting upon orders from the chief engineer,” the office was closed and design work suspended, with the assumption that future work would be done in Denver. The issue had become high profile. In September, Secretary of the Interior Harold Ickes appointed a board “to review problems, and recommend procedure in regard to migratory fish control problems.” The board comprised three “disinterested experts”: R. D. Calkins, a professor of economics at the University of California, Berkeley; W. F. Durand, a retired professor of mechanical engineering; and Willis H. Rich, a biology professor at Stanford University. Their report was anticipated in March 1939. ⁴¹⁸

In April 1939, Reclamation Era announced that the secretary had approved a plan that essentially adopted the recommendations of the State Department of Fisheries. The $2.5 million fish control project was to be ready by the 1940 chinook, steelhead, and blueback salmon runs. “The 1939 runs will be handled on a temporary but adequate basis,” the publication reported. “They will be trapped at Rock Island Dam . . . and transported by means of a fleet of specially designed tank

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trucks to tributaries which enter the river below Grand Coulee Dam.” Reclamation also agreed to keep some blocks at elevation 980 until the end of the fish run in 1939.419

In addition to the fish traps at Rock Island Dam, the plan included the construction of “holding ponds at Icicle Creek; Icicle pipe line; a large hatchery at Leavenworth, equipped with screen chamber, rearing ponds, a fish-food plant, garages and a warehouse, an incinerator, and a hatchery building; the Wenatchee Canal, by which water to supplement the water taken from Icicle Creek will be provided; the necessary residences, right-of-way, and landscaping, walks and fences, water, sewerage, and drainage; a hatchery on the Entiat River, the Methow hatchery, the Okanogan hatchery, and necessary transportation equipment.” Secretary Ickes asserted that, while “the program may be experimental in some respects, there seems to be ample assurance that at least the present runs of migratory fish in the river will be protected and probably that the runs will be increased in the future.”420

In the meantime, Reclamation received approval of the overall concept for addressing the fish issue from the State Department of Fisheries in February 1939, and set up an office for a resident engineer in Wenatchee in June to begin surveys and planning for various components of the project that were assumed to be required. In November, contractor Kera and Kibbe began constructing fish traps and related structures at the Rock Island Dam. The following month, Reclamation laborers started excavating a 2,500' tunnel to obtain water for the Leavenworth hatchery and holding ponds from Snow Lakes. The tunnel was completed in October 1939.421

The Federal Bureau of Fisheries approved Reclamation’s fish program in March 1939. That agency would operate the facility after Reclamation constructed it. In August, Reclamation gave notice to proceed to MacDonald Construction Company of Seattle for the Leavenworth hatchery building and to the Norris Brothers of Burlington, Washington, for the associated diversion canal and holding ponds.422

During summer 1939, a fleet of eight specially designed trucks carried the fish from the three traps at the Rock Island Dam to the Leavenworth hatchery. Each truck held a 1,000-gallon fish tank and a compartment that could hold 1,200 pounds of ice. The ice cooled water that was circulated through the tank by a 125-gallon centrifugal pump, gradually dropping the

419 “Plans for Control of Migratory Fish at Grand Coulee Dam Approved,” Reclamation Era 29 (April 1939): inside cover; R. F. Walter, J. L. Savage, Frank Banks, L. N. McClellan, and John J. Hammond, to commissioner, memorandum on construction program for completion of Grand Coulee Dam, December 12, 1938, 1 at RG 115, Project Correspondence File, 1930-1945, Entry 7, Box 534, NARA-RMR.


temperature during the course of the trip to help the fish adjust to the cooler water at their destination. The Leavenworth facility, which went into operation in 1940, was only about forty miles away, but during 1939 the fish were driven as far as 155 miles to lakes and streams that had been approved by federal and state fisheries departments.423

The U.S. Fish and Wildlife Service released a report in 1948 that evaluated the success of Grand Coulee’s fish maintenance project, which had cost around $3 million. The report concluded that a primary objective of the project, relocating the upper-river salmon and steelhead runs from the main channel of the Columbia to the tributaries below Grand Coulee Dam, “has been successful and the general level of production during the initial phase of the program has been satisfactory.” The report continued on a less optimistic note: “The outlook for rehabilitating the salmon populations of the Grand Coulee Area through adequate protection, natural spawning, and effective artificial propagation appears possible but difficult. Many of the factors responsible for the original depletion of the Okanogan, Methow, Entiat, and Wenatchee salmon runs still remain in effect. In addition, the up-river salmon runs must eventually face a series of major multiple purpose water-use projects—one of which is now under construction. Whether the early-running Columbia River salmon races—which are dependent upon a suitable fresh-water environment for a significant fraction of their life-span—successfully can surmount the increasing development of the Columbia River and its tributaries is questionable.”424

20. LET THERE BE LIGHT

In the meantime, progress continued on the dam that was the cause of the salmon’s distress. CBI started 1939 with what the project history described as “one of the most difficult tasks assigned to the contractor during the year”: removing the remaining cofferdam cells, a three-month ordeal. “All equipment had to be transported to the island by boats or barges and with the exception of some power shovel excavation, drilling, and blasting, the work had to be carried out from the decks of barges. . . . The river currents in this area were a source of considerable trouble. . . . On several occasions the contractor almost lost some of the floating equipment.” A diver who inspected and sometimes cut off stubborn steel pilings worked in difficult conditions, with “water velocities estimated from 5 to 8 miles per hour; water temperatures from 34 to 38 degrees F.; and steel piling in very unstable equilibrium.”425

On land, work was more routine. As with most previous excavating, only light blasting was allowed to avoid fracturing nearby rock and expanding existing seams. In working on the right abutment, CBI exposed a badly sheeted area that ran diagonally across the foundation. To avert the possibility of leakage, the contractor dug a 6'-wide, 30'-deep cut-off trench, filled it with

423 “Uncle Sam to Nurse Forty Million Little Fish,” Compressed Air Magazine 45 (June 1940): 6174-6178.  
concrete, and sealed it with grouting. Also in the right abutment, CBI excavated a 7’ x 9’, 647’-long horseshoe-shaped drainage and grouting tunnel at elevation 1100.\textsuperscript{426}

Grouting followed the pattern established by the first phase: low-pressure grouting in 20’ to 50’ “B” holes to stabilize surface rock before concrete placement was started, and then, when the concrete had reached a certain thickness, intermediate-pressure grouting in 30’- to 125’-long “C” holes and high-pressure grouting in 30’- to 500’-long “A” holes. In 1938, CBI only grouted “B” holes in the right abutment. Three regular government crews and a relief crew were responsible for grouting the “A” holes. They began in late September 1939 and worked in three shifts, seven days a week, starting with bedrock areas below elevation 900. Lynch Brothers of Seattle drilled the holes. Most were 150’ deep, but some extended 500’.\textsuperscript{427}

CBI undertook other excavation in 1939 as well. A 1,700’ section of the west approach highway was lowered as much as 10’ to align with the Pumping Plant parking area and crane recess. A corridor more than 4,000’ long was excavated and graded for the east highway. Reclamation issued an extra work order for excavating a channel 25’ deep, 100’ wide, and 200’ long for the right tailrace through a bar of clay and gravel. The shore side was riprapped, while the river side was left exposed in the hope that the peninsula that had been created would eventually erode away. CBI also added more riprap to a 1,000’ section of the still unstable left tailrace slope. Rock for the riprap was procured from the Pumping Plant excavation.\textsuperscript{428}

As the end of 1939 approached, CBI rushed to have projects ready to do during the winter when concrete placement would stop. The contractor’s goal was to have the spillway sections containing outlets—the odd-numbered blocks from 43 to 63, excepting Block 53—poured to elevation 1130 to permit installation of the conduit liners and ring-seal gates. At the Pumping Plant, having the foundation reach elevation 1171 would facilitate installation of the 14’-diameter pump inlet pipes. CBI reached its goal for the Pumping Plant foundation and surpassed it on the spillway, where some sections rose to elevation 1145.\textsuperscript{429}

Western Pipe and Steel Company installed the 14’-diameter, 56’-long inlet pipes for the Pumping Plant in February and March 1940. The two sections for each pipe, one 30’ and the other 26’, were initially set on timber cribbing. When properly aligned and tack welded, they were supported by permanent steel struts and ties. After final welding and cleanup, the pipes were embedded in concrete. During the same period, Western placed the 18’-diameter steel penstock pipes for the Right Powerplant, completing this last task under its contract with Reclamation by the end of May.\textsuperscript{430}

\textsuperscript{426} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 6, 1938, 190, 193.
\textsuperscript{430} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 23-24, 180.
CBI had started to dewater the turbine pits in the Left Powerplant in April 1939. By the following April, construction had advanced to the point where the draft tubes and turbines could be installed, tasks that Reclamation had elected to do with its own forces. Senior engineer C. P. Christenson and master mechanic James E. Wallace relocated to Grand Coulee from Boulder Dam to oversee the work. Their staff included three associate engineers, three assistant engineers, one junior engineer, and two clerks. In addition to a general foreman, specialized foremen were in charge of rigging, pipefitting, electrical installation, and machinist work. Altogether, Reclamation had more than one hundred skilled and unskilled workmen on the job.

“Some of the rooms and galleries of the service and control bays were equipped for offices, tool rooms, and machine, conduit, electrical, and carpenter shops,” the 1940 project history reported. “An old building outside and near the powerhouse was obtained from the contractor and equipped for use as a blacksmith shop and a rigging loft.”

The work was facilitated in June when two 350-ton traveling cranes, each spanning almost 73’, became fully operational. “Each crane carries two trolleys of 175 tons capacity and two 30-ton auxiliary hoists,” an article in *Mechanical Engineering* explained. “Through a heavy H-shaped equalizer, the two cranes can lift a 700-ton load.” Their installation was supervised by a representative from the manufacturer, the Whiting Corporation. The components were partially assembled in the Electric City rail yard before being delivered to the powerhouse. By this time, Reclamation forces had installed three power conductor rails and runway rail stops. Two additional cranes were installed at the powerhouse. The Bedford Foundry and Machine Company supplied a 50-ton overhead traveling crane with a 12-ton auxiliary hoist for the station service generator room, while the Cyclops Iron Works produced a 14-ton single-leg gantry crane for the draft tube bridge deck on the plant’s downstream side to move bulkhead gates.

Reclamation forces installed turbines in two service station bays (LS-1 and LS-2) between April 24 and October 19. The vertical, Francis-type reaction turbines were manufactured by the Pelton Water Wheel Company and rated at 14,000-horsepower at 330' head with 90 percent efficiency guaranteed at 11,500 horsepower. The 58-1/2”-diameter runners were mounted on 14”-diameter shafts. The turbines were direct-connected to 60-cycle, 3-phase, 6.9-kV generators. Each generator unit was connected to “a Woodward governor mechanism completely enclosed in a steel cabinet and beside it a generator control panel.”

Parts for the generators began arriving in the end of June, along with an erecting engineer from the manufacturer, the Westinghouse Electric and Manufacturing Company. The concrete jack

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piers for the generators were not finished until August, though, so the installation could not begin until that time. It was completed by the end of the year except for the control cubicles, which had not yet arrived.\(^{434}\)

The beginning of operation of the two 10,000-kV station service units was eagerly awaited. These units would provide electricity to heat, light, and operate the powerhouses, dam, and Pumping Plant, as well as the buildings in Government Town. Perhaps even more important, though, was the symbolic value of seeing the first payback from the country’s massive investment in the project.\(^{435}\)

The initial test of the first station service generator occurred on January 22, 1941. With the production of power from the station service units anticipated in March 1941, Reclamation rushed to connect these generators into the Bonneville power grid. In late 1940, the generators were temporarily rigged to the G-3 main unit transformers, from which the 115-kV transmission line No. 1 ran about a mile to the nearest Bonneville tower. A Reclamation project history described the long-anticipated event: “On March 22, during a ceremony featuring a radio broadcast, both station-service generators were synchronized with the Bonneville transmission system, and commercial delivery of power began.” Reclamation’s construction engineer, A. F. Darland, had the honor of closing the synchronizing switch.\(^{436}\)

The occasion was noted by President Roosevelt, who sent a message to Frank Banks: “I want to congratulate the Bureau of Reclamation upon putting the great Grand Coulee Dam to work 2 years ahead of schedule. It is a fine job well done.” With the country gearing up to support allies in the expanding war across the Atlantic, Roosevelt emphasized the project’s importance “in two emergencies. It served to provide much useful employment at a time 8 years ago when it was important that we find at once a means of avoiding complete economic stagnation, and it will serve now to provide the power to make aluminum for airplanes and otherwise to speed our protective arms.”\(^{437}\)

The amount of power that was generated was inconsistent at first because of operational issues, including a low water level in the forebay because of ongoing construction. These issues had been resolved by May 22, when the units started sending power to Coulee Dam and the government-owned section of Mason City.\(^{438}\)

\(^{434}\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 25, 77.
\(^{437}\) Roosevelt quoted in “Grand Coulee Powerhouse Goes to Work,” Reclamation Era 31 (May 1941): 133.
\(^{438}\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 30-31, 184, 247.
The station service units were a good warm-up for the installation of the much larger main units. Reclamation forces started installing the draft tube liner for the G-3 turbine in October 1940. That task was completed by December, when the first section of the G-3 scroll case was lowered into place under the watchful eye of Frank Malarkey, an erecting engineer sent by the Newport News Shipbuilding and Drydock Company, the turbine’s manufacturer. Each scroll case comprised fourteen cast-steel sections each weighing 20 to 30 tons and totaling 291 tons when assembled. After the first section was fastened to the draft tube liner, a foundation ring was installed on blocking below. All except one of the remaining sections of the scroll case were then put in place on small concrete piers, which were outfitted with screw jacks and bolted together. The sections were milled to fit very snugly. To insert the final section, the bolts holding the two sections flanking the gap were loosened, creating a clearance of ¾”. When all sections were in place, the bolts were prestressed to 24,000 psi. A photograph caption in the 1941 project history noted: “Bolts holding the sections of a scroll case together are actually stretched so as to make them exert a greater force than that of the water. . . . The increase in length, determined by micrometer, is a measure of the force exerted by the bolt.”

With the scroll case in place, the crown plate and a test ring were temporarily installed for hydrostatic testing. A bulkhead blocked the end of the scroll case, which was filled with water at a pressure of 175 psi to detect leaks. After any leaks were repaired, the scroll case was imbedded in concrete. The first of four concrete lifts for Unit G-3 was started February 25, 1941, with the final pour completed on March 9. The scroll case remained filled with water under the normal operating pressure of 145 psi during the concreting, with the pressure maintained by a discharge pipeline. The circulating water was cold to facilitate concrete cooling. After the concrete and grouting were finished, the bulkhead was removed and replaced with an expansion joint to connect the scroll case and the penstock. The blockout in this location was subsequently filled with concrete.

Between March 18 and April 15, 1941, workers poured seven lifts of concrete to create a column between elevations 951 and 991 to support the G-3 generator. The generators, measuring 45’ in diameter and weighing more than 2 million pounds, would rise 22’ above the operating floor. All of the second-stage concrete in the Left Powerplant reached elevation 991 by October 1941.

Next came the installation of the G-3 turbine. Like the station service units, the Left
Powerplant’s main units had Francis reaction-type turbines, but on a larger scale. Each massive
steel runner measured 6’ high and 16'-8” in diameter and was formed in a single casting. “Water
will pass through a fully loaded main turbine at the rate of about 140 tons per second,” according
to Reclamation engineer S. E. Hutton. In an article in Mechanical Engineering, he gave the vital
statistics of the turbines, which were “rated 150,000 hp at 330-ft head, and 90,000 hp at 263 ft.,
at a speed of 120 rpm. The water entrance diameter is 15 ft, and the scroll case, normal to the
entrance, is 51 ft 5-1/2 in. wide. Runners are 16 ft 5 in. in diameter, with an entrance height of
34-3/8 in. An efficiency of 90 per cent is guaranteed at outputs of 120,000 to 130,000 hp.” 442

The 74'-long, multi-segment shafts were supported by three adjustable, segmental-shoe, oil-
lubricated bearings. The first bearing, located below the turbine, covered an area of 3,450 square
inches and was pressure lubricated. The second was below the generator rotor. The third,
enclosed in a common oil reservoir with the thrust bearing, was above the generator. The
generator bearings each had a bearing area of 600 square inches and were self-lubricating.
Engineering News-Record provided further details: “Guide bearings are located above and below
each generator rotor. The one above has 16 shoes and the one below 8 shoes, both using the
principle of thrust bearings in which an oil film separates the rotating from the thrust-
receiving elements. The third and heaviest guide bearing is in the crown plate of the turbine.” The article
noted that “these bearings, although larger than any before built, use the usual principle of oil
film between the rotating bearing plate and the segmental stationary blocks that carry the load.443

The Kingsbury-type thrust bearing was 45" in diameter and 41.5" deep. Reclamation engineer S.
E. Hutton explained that “each thrust has approximately 5,250 sq. in. of bearing surface, giving a
unit pressure of 400 psi with a load of 1300 tons.” Electrical West described it as “an 8-ft. cast
iron thrust collar, attached to the end of the generator shaft by means of a steel hub, and eight
babitted steel thrust shoes supported on pivots.” A Reclamation report used simpler language,
giving the main components as “eight ‘shoes’ and one 8-foot iron and steel ‘doughnut.’” The
report observed that “weeks of machine work and polishing are put into making the thrust
runner, the face of which must be as nearly a true plane as men and machines can make it, for it
must distribute over the eight shoes the 900-ton load of the rotating parts of the generator and
turbine. Final hand scraping, on the job, is necessary to remove from the babbited faces of the
shoes microscopic high spots that would pierce the oil film between the rotating collar and the
stationary shoes.” 444

442 “Grand Coulee: Its Story in Pictures,” Electrical West 87 (November 1941); S. E. Hutton, “The Grand Coulee
Dam and the Columbia Basin Reclamation Project,” Mechanical Engineering 62 (September 1940): 653.
443 S. E. Hutton, “The Grand Coulee Dam and the Columbia Basin Reclamation Project,” Mechanical Engineering
62 (September 1940): 653; “Grand Coulee Dam Nears Completion,” Engineering News-Record 127 (September 11,
1941): 92.
444 S. E. Hutton, “The Grand Coulee Dam and the Columbia Basin Reclamation Project,” Mechanical Engineering
Assembling the components of the unit was a complex process. The shaft was installed in sections. The turbine runner was attached to the first section with eighteen 5-3/4"-diameter bolts before it was lowered into the scroll case. The 1941 project history explained that “these bolts, which were ground about one and a quarter thousandths oversize, were cooled to 24 degrees below zero Fahrenheit in dry-ice, so that they could be readily inserted.” The bolts had securely united one shaft and runner by April 26, when they were moved to the G-3 bay by the powerhouse’s overhead crane. When the crane attempted to lower the shaft and runner into position, though, “it was found that insufficient clearance had been provided in its manufacture.” The 1941 project history reported that “it was necessary to remove the runner and grind a ¾" chamfer around the lower skirt,” which was to rest on the foundation ring.

After this modification was completed, the wicket gates, crown plate, and bearing bracket were installed. “The turbine crown plate, Electrical West explained, “carries the upper bronze bushed bearings for the 9-in. shafts of the 24 wicket gates, the stuffing boxes for the shafts and a central section with a tapered seat for the 45-in. lower main shaft guide bearing.” Fourteen fixed vanes on the spiral case speed ring would direct water to the twenty-four adjustable wicket gates on the runner. A ring controlling the gates was adjusted by pairs of oil-pressure hydraulic servomotors that extended from the walls of the pit lining. “Under an oil pressure of 250 pounds per square inch and under maximum operating head conditions, [the servomotors] are capable of causing a full opening or closing stroke of turbine vanes in four seconds,” The Columbian reported. That, at least, was what they were supposed to do. The servomotors and gate-shifting ring for the Unit G-3 did not initially cooperate. “The eccentric pins provided had insufficient throw to permit satisfactory adjustment of the gate contacts,” according to a project history, so Reclamation had to install new pins of the correct length.

The servomotors were controlled by governors manufactured by the Woodward Governor Company of Rockford, Illinois. The governors were “of the actuator type with speed-responsive elements actuated from 3-phase magnetic generators connected to generator shaft tops.” The speed of the governors could be varied, based on conditions, typically opening or closing the turbine gates in four to twelve seconds. “Each governor is complete with an oil-pressure system. This includes two pressure-controlled 40 horse power motor driven pumps and a sump tank located within the actuator; a pressure tank is located adjacent to the actuator which is at one end of and forms a part of the control board in the governor gallery.”

The 60-cycle, 3-phase, star-connected generators were at the top end of the shaft. An article in Mechanical Engineering in September 1940 explained that the generators “will run at 120 rpm and generate 13,800 volts. . . . Guaranteed generator efficiencies range from 93.4 per cent at

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quarter capacity to 97.4 per cent at full load.” The article noted that “rotors will be about 31 ft in diameter, and will have flywheel effects of 150,000,000 lb at a one-foot radius. On the lower side of each will be a brake ring. Air-operated brake cylinders will bring the rotors to a standstill from half normal speed in 7-1/2 min. The brake cylinders can be made to serve as hydraulic jacks to lift the rotors sufficiently to permit the removal or adjustment of thrust-bearing parts.” To transform the brakes into jacks, oil was substituted for air in the cylinders. *Electrical West* provided additional details: “Inorganic insulation to stand an operating temperature of 120 deg. C. was specified as a means of insuring overload capacity and long life. Short-circuit ratio is 1.75 or more. Stator windings are connected 11 coils in series and 12 coils in parallel in each phase. . . . Stator frames are 37 ft. in diameter and are fabricated of welded steel plate in quadrants. . . . Power for excitation is supplied from motor-generator sets driven by the station service units. They consist of 600-hp. Synchronous motors driving 400-kw., 240-volt d-c generators with a direct-connected pilot exciter.”

Westinghouse Electric and Manufacturing Company started assembling the 108,000-kVa generator for Unit G-3 in February 1941. Work began first on the rotor at a temporary erection area in Bay G-9 at the east end of the powerhouse. The hub of the rotor spider was a single casting weighing 50 tons. After the hub was heated to expand its clearance around the shaft from 0.015" to 0.045", a crane slid it into position on the shaft. It was locked in place when the metal cooled. Next, the spider arms were attached. Starting March 31, the rotor rim was heated to allow keys to be driven between the rim and the ends of the arms. The rim was comprised of about 12,000 35-pound plates. By mid-May, the poles had been assembled on the rim and the 527-ton rotor was completed. It was stored in an adjacent bay until Unit G-3 was ready to receive it.

The four welded-steel-plate sections of Unit G-3’s 37'-diameter stator frame were assembled in Bay G-7 between March 5 and May 10, 1941. The thrust-bearing bracket was assembled in Bay G-6 in late March and placed atop the stator in mid-May. The lower bearing and the stator sole plates were installed in Bay G-3 in early May. The sole plates soon supported the stator, which was aligned with the intermediate shaft on May 20. The 1941 project history described the next step, when the rotor was eased inside the stator’s circumference:

The rotor was lowered into place on June 4, and shimmed up on the depressed rotor jacks until there was a ¾" clearance between the coupling flanges of the generator and intermediate shafts. The upper bearing bracket was replaced on June 6, and the thrust bearing shoes, which had been scraped to conform to the bearing surface of the thrust runner, were placed on June 19. The generator shaft and intermediate shaft were then coupled together, the bolts having been shrunk by cooling, before being placed. The nuts were sledged to stretch the bolts an average of 0.014 inch. The weight of the rotor was then transferred to the thrust shoes, and the remainder of the dowels were placed between

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the upper bracket and the stator. The shaft was centered to provide uniform clearance between the turbine runner and the seals, and was aligned vertically.\textsuperscript{450}

The installation was finished by July 1. By July 17, the G-3 generator was ready for initial testing, which proved disappointing when the thrust bearing shoes and thrust bearing runner were damaged by heat. Replacement components were appropriated from Unit G-2 and a higher viscosity oil was tried for a second round of tests. These started well at a lower speed, but the bearing was damaged again when the unit approached its normal speed of 120 rpm. Before the third try, Reclamation made a few modifications to yet another bearing: “The bearing runner was very carefully stoned to a high polish, and the thrust shoes were scraped so as to be slightly recessed in the centers.” Also, “before starting the unit, the rotating parts were lifted by means of the brakes, acting as hydraulic jacks, to admit oil to the contact surfaces of the thrust bearing.” This time, no problems were encountered. On September 26, Unit G-3 was connected to the Bonneville transmission system for testing, and on October 4, it was officially placed in operation on the system, an event covered by a special nationwide broadcast by CBS.\textsuperscript{451}

Although the unit was up and running, testing continued. Reclamation’s acceptance tests included “resistance of field and armature windings, no load saturation, and short circuit saturation,” \textit{Reclamation Era} reported. Tests conducted in the last months of 1941 delivered “varying loads of electricity . . . over the power line to permit adjustment of the generator governor, the machine which must maintain proper control of the speed of the dynamo under all conditions. Fluctuating speeds would disrupt systematic distribution; a generator turning too slowly, for instance, would cause all clocks on the system to lose time.” During an overspeed test on April 18, 1942, the unit was unscathed at 194 rpms, well above its normal operating speed of 120 rpms. The thrust bearing shoes, though, would continue to cause operational headaches for years thereafter. The 1949 project history reported that “many of these shoes have suffered failure in only a few months’ time. . . . Westinghouse has devoted much time and research to locating and rectifying the trouble and is now manufacturing a new design believed to overcome the weakness.”\textsuperscript{452}

While work progressed on Unit G-3, the neighboring bay was also a center of activity. Workers began installing the draft tube lining for the G-2 turbine in December 1940. The process that was followed for installing Unit G-3 was basically copied for Units G-2 and G-1, which were completed in December 1941 and March 1942, respectively. Testing of Unit G-2 began January 2, 1942, and on January 29, it was synchronized with Unit G-3 and began supplying power into

\textsuperscript{450} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 203, 209.
\textsuperscript{451} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 30, 32, 33, 189, 203-204.
the Bonneville grid. Testing of Unit G-1 followed on March 21, and it joined the grid on April 7. 453

As the generator units were being installed in 1941, a small but critical flaw in the plant’s design was discovered: it did not have an auxiliary power system, and the main units were completely dependent on the station service units to activate motor-driven exciter sets. The 1941 project history explained the potential dilemma: “In case damage occurred to one of the station service units while the other station service unit was shutdown, with the penstock or draft tube gates closed, there would be no power available to open the gates to put the other unit in operation. The whole plant would be down and unable to start.” Reclamation located a 50-kVa diesel engine-driven generating unit that was no longer needed by WPA crews clearing the reservoir, and this became a back-up power source for the plant. 454

Assembly of the turbine-generator units occurred in the middle of a busy construction zone for the powerhouse at large. During 1940, the control bay, transformer bus gallery, and fan room were finished. The slab for the station service bay roof was poured and a Wiley-Whirley crane was situated on the roof to place concrete in the control bay. Laborers used concrete buggies and wheelbarrows to bring concrete to locations not accessible by the crane. Glass blocks began to fill the window openings. “The eye cannot see through them,” The Columbian explained, “yet they will admit the maximum amount of light and will be good insulation against temperature changes.” 455

The fall of 1940 saw the arrival of twelve transformers for lighting—six 50-kVa and six 100-kVa—and twelve 500-kVa transformers for auxiliary power. Work on installing and connecting these transformers was almost done by the time parts for the “36,000-kVa, 13,800 to 132,800/230,000-Y-volt” transformers for Unit G-3 began arriving on December 28. Writing in Mechanical Engineering, Hutton explained that “the transformers are to be out-door type, oil-immersed, water-cooled, gas-filled, designed for delta-star connection, with high-voltage neutrals grounded.” Electrical West noted that “connections with generator leads are made through I.T.E. enclosed isolated phase buses. Four mats of bare copper cables 200,000 to 500,000 circ. mil section, one under each power house and one under the riprap of each tailbay, provide connections for all electrical equipment.” Hutton added that the mats were “connected by bare cables in the concrete with 750,000-circular-mil insulated ground buses in the powerhouse.” 456


454 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 224.


Rails were installed on the transformer deck, which was located between the powerhouse and the dam, for the transfer car that delivered the transformers. A hand-operated winch moved the transformers from the car onto structural-steel portal frames spanning the transfer-car track. When assembled and ready for operation, the components of the transformer—a 94,000-pound core, a 48,000-pound tank with fittings, and 108,000 pounds (14,000 to 15,000 gallons) of oil—weighed about 250,000 pounds. The oil to insulate the transformers was stored in two 17,000-gallon tanks in the control bay, which also held two intermediate storage tanks and two 5,000-gallon oil tanks for lubrication and the governors. Pumps circulated the oil from the tanks to the transformers and back.457

The General Electric Company manufactured the transformers for the first three main units and supervised their installation by Reclamation forces. A Reclamation report described the installation of the first one in January 1941: “The two sections of the tank had been previously welded and tested, and the core was placed back in the tank after being exposed to the air only 8 hours. After this, a vacuum pump was connected to the tank, and the pressure was reduced to 4 millimeters of mercury, absolute pressure. This vacuum was maintained for 8 hours before oil was admitted to the tank, and was maintained during the filling. Nitrogen gas was then admitted to the space above the oil, and the space was flushed, until the oxygen content of the gas was reduced to 0.5 percent.” The same process was used for the other two transformers, all of which were ready for testing by February 21.458

The portal frames holding the transformers also supported lightning arrester disconnecting switches from the Bowie Switch Company. The General Electric Company supplied the lightning arresters, which stood on concrete pedestals on the dam’s downstream face. The portal frames also anchored the circuits running from the transformers to the take-off towers, which had been installed on the powerhouse’s roof in 1940. Structural-steel towers to carry the circuits between the take-off towers and the switchyard were erected between July and September 1941, and conductor stringing for circuits No. 2 and No. 3 was finished by the end of the year. Work did not start on circuit No. 1 until 1942.459

The bus structure for Unit G-3 was installed during the summer of 1941 under the supervision of an erecting engineer from the manufacturer, the I.T.E. Circuit Breaker Company. Work on the bus structure for Unit G-2 commenced in August and was completed by late November. Battery storage, charger sets, and direct-current control boards were also installed during this period.460

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458 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 236-238.
459 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 238-239.
460 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 80-81.
The Allis Chalmers Manufacturing Company had delivered the 6,900-volt station service switchgear in 1940 and it was partly in place by the end of that year. The installation was slowed, though, by a number of problems, including a runaway crane that damaged some components. By November 1941, the switchgear was mostly in place.461

21. TOPPING OFF THE DAM

As assembly progressed on the turbine-generator units and transformers, the dam continued to rise beside the powerhouse. When a number of blocks in the right abutment reached their ultimate height of elevation 1311.08 in early August 1940, this milestone was marked by a brief ceremony. By this time, construction had risen above the reach of the seven hammerhead cranes on the 1180 trestle. All had been removed by mid-September, leaving the two Clyde Wiley cranes, with their booms extended from 126' to 150'. Even these cranes could not serve the top levels of the abutments, so two side-hill bracket cranes were installed on gantries, using the 1180 trestle for the lower rail. A new upper rail was inserted in a recess in the downstream face of the dam at elevation 1215. The upper blocks of the right abutment were still beyond reach, so concrete was transported by truck to a dumping ramp and placed by a stiff-leg derrick. One of the side-hill cranes was later mounted on an elevated base atop one of the hammerhead crane traveling mechanisms to reach the highest sections of the dam, as well as the spillway bridge and the piers for the drum gates. For some of the more intricate pours, such as the trashrack structures, elevator towers, and drum gate piers, concrete was distributed by rubber trunks fed by portable concrete hoppers.462

As the height of the dam increased, it became narrower in section with less surface available to receive concrete. As a result, the volume of concrete placement for the dam, powerhouses, and Pumping Plant dropped to 1.4 million cubic yards in 1940. This led to cutbacks in operations at the double mix plant, and the east side was permanently shut down in early August.

“Considerable special concrete was produced during the year,” the project history reported, including “cold weather concrete containing from 1 to 1-1/2 percent of CaCl2, concrete for the pumpcrete operations in connections with backfill of the penstock tunnels and the twist adjustment slots, porous concrete for the control cable gallery extension, and high strength concrete for the road surface on top of the dam.”463

Five twist adjustment slots had been incorporated into the dam to ease deflection from water pressure as the reservoir filled. Two were in the left abutment (between Blocks 7 and 8 and Blocks 9 and 10) and three were in the right abutment (between Blocks 77 and 78, Blocks 81 and 82, and Blocks 87 and 88), locations where twisting action was the most likely to occur because of substantial changes in bedrock elevations. From west to east, the bottom of the slots were at elevations 1120, 955, 1005, 1065, and 1120. The sides of the 6'-wide slots, which ran

transversely through the dam, were connected by cantilevered sections about 7’ thick on the upstream side and 3’ thick on the downstream side. The dam’s movement could be absorbed by 1”-wide slits sealed with Celotex, which ran vertically through these cantilevers. Horizontal cantilevers at approximately 50’ intervals served as floors for sand fill.464

The sand was removed from the twist slots as the reservoir rose and replaced with concrete, starting at the bottom lift and working up. In early July 1940, sand was sluiced from the lowest lift in the slot by Block 9. When concrete had been pumped to within 10’ of the horizontal cantilever capping that section, sand was removed from the section above, and concrete placement began in that section after the lower concrete had set for at least twenty-four hours.465

Another milestone was reached on September 30, 1940, when raw aggregate mining operations at the Brett pit were terminated because CBI had sufficient aggregate on hand to supply the remaining concrete. The gravel plant was dismantled by the end of the year. The conveyor that carried aggregate from the plant to the storage yard near the dam was retained into the following year because the storage yard could not accommodate sufficient sand for the concrete, as well as for sandblasting and other needs. By May 1941, CBI began disassembling the conveyor, and in September the airplane tripper in the storage areas was removed.466

With only about 35,000 cubic yards of concrete still to be placed, CBI suspended concrete work for the winter on November 10 rather than going to the extra effort to protect the fresh concrete in winter conditions. By this time, the dam’s left and right abutments and the Pumping Plant had reached elevation 1311.08 and the spillway was at elevation 1260, the final height for these sections. CBI had completed grouting the final fourteen “C” holes in the right abutment and begun construction of the piers for the bridge over the spillway. While work on the bridge and other details, such as the elevator towers and parapet walls, remained for 1941, the contractor could claim that the project was 68.5 percent complete in 44.5 percent of the time allocated under the contract.467

While the pace of concrete installation dropped during 1940, other substantial tasks were undertaken. Concrete was allowed to cure for a year before construction joints were grouted. Because 1939 had been a record-breaking year for concrete placement, Reclamation crews had a big task before them in 1940. The work was completed by April of the following year except in a few locations, including the twist-adjustment slots.468

467 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 27, 91, 140, 147.
Before the joints were grouted, they were cleaned with pressurized air and water. Grout was pumped into horizontal supply pipes feeding 5' risers, which were connected to a return line. The grout was pumped into the transverse joints from the longitudinal galleries and into the longitudinal joints from the transverse galleries. The galleries were stacked at 50' intervals. Grouting proceeded bottom to top in these 50' zones, with horizontal and vertical copper stops keeping the grout from infiltrating neighboring sections. “The basic idea behind the actual grouting of the joints is simple,” according to The Columbian. “Take some little blocks, group them together, encase the group in metal, leave an opening at the bottom and one at the top. Then force water and cement through the bottom opening. When all the space within the case is occupied, any further water and cement will force an escape through the top hole.” In a dam containing some eight hundred not-so-little blocks, the process was much more challenging than it was in theory.\footnote{469}{“Coulee Dam’s Biggest Season of Block Grouting Under Way,” The Columbian 6 (February 22, 1940): 1, 3, 5, 9.}

Concrete cooling remained an important activity. By April 1940, the Pumping Plant foundation was cooled to elevation 1170, the abutments to 1150, and the spillway to 1100. The spillway lagged because its construction had been delayed to facilitate the salmon runs through 1939. By early 1940, engineers began exploring alternatives to accelerate cooling of the spillway to avoid delaying the construction schedule—the spillway gates could not be installed until the concrete was cooled and grouted. It was not until September, though, that Reclamation gave CBI authorization to purchase a 5,500 gallon-per-minute deck-type atmospheric cooling tower and erect it on the right abutment, several hundred feet upstream from the dam’s axis. The “tower” was actually a long rectangular box measuring 15’ x 162’ and rising only 30’ high. It rested in a 3’-deep basin of slightly larger dimensions. By October 31, a barge in the river was pumping water to the tower. The cooled water was dedicated exclusively to the spillway section, but to little effect, according to the 1940 project history: “Delayed erection of the cooling tower resulted in its use during much unfavorable weather, when its operation was inefficient.”\footnote{470}{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 27, 129-131.}

With the completion of the top tier of outlets at elevation 1136 by summer 1940, many sections of the related concrete trashrack structures were installed on the dam’s upstream face by the end of that year. A single 250’-tall trashrack structure protected the intakes for a vertical tier of three outlet works. The semicircular structure had a radius of 22’. The trashrack structures held metal trashracks, which were delivered to the dam in sections. Trucks hauled most sections from storage in Electric City to a boat landing in the east forebay area, where they drove onto a barge. The barge traveled to a floating crane, which unloaded the trucks and installed the sections. During 1940, CBI installed 1,722 trashrack sections by the intakes for the outlet works, main units, and station service units.\footnote{471}{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 176, 180; Lloyd V. Froage, “Outlet Works at Grand Coulee Dam,” Reclamation Era 30 (August 1940): 215.}

An ice-prevention system, which extended across the upstream face of the spillway crest, was incorporated into the trashrack beams at about 25', 50', and 75' below the maximum water
surface. Nozzles dispensing compressed air at these locations would discourage ice formation. This was one part of a four-part ice-deterrence system that continued to the left and right abutments and Pumping Plant dam. Although the system was interconnected by a 4” air header, each section had its own rotary vane, direct-connected air compressor, supplied by the Fuller Company of Catasauqua, Pennsylvania. Valve assemblies consisting of copper tubing and nozzles extended from the header along the concrete frames of the trashracks, which had horizontal, semicircular beams spaced 12’ apart. Angle irons were installed to protect the tubing. Some of the system was installed in 1940. By April 1941, all of the trashrack structures on the dam and Pumping Plant were outfitted with nozzles and crews were installing them across the spillway section.\textsuperscript{472}

Construction in and around the trashracks led to a conflict between Reclamation and CBI. In spring 1941, Reclamation discovered that large amounts of debris had passed through the outlets at elevation 934 and damaged the paradox gates. The clearance between the gate seals on the body and leaves was 0.25” when the gates were closed and 0.065” when they were open, so the damage happened when the gates were partially opened and the clearance was greater. Investigators examined a number of the gates, considered possible sources of the debris, and concluded that “the contractor has been grossly negligent in his efforts to prevent construction materials from entering the trashrack structures and that such materials have caused extensive damage to the paradox gates.” Reclamation asserted that CBI had ignored instructions to keep construction debris away from the inlets. As a result of the damage, Reclamation engineers warned, “it is conceivable that the effect of the increased head against the gate leaves may result in complete failure of the gates to operate, either due to the breakage of some of the parts or due to the motors being inadequate to deliver the greatly increased amount of power to operate the gates with the rollers and tracks roughened . . . and/or in contact with foreign materials.”\textsuperscript{473}

CBI was forced to dismantle two of the gates (43-west and 57-west) in the spring of 1941. Representative links of the roller chains were sent for analysis to Reclamation’s Denver office, which concluded that two-thirds of the rollers would need to be repaired or replaced. Other problems were identified in four other gates (43-east, 61-east, 55-east, and 59-east). Reclamation continued to use the functional gates until June 1941. At that point, the reservoir surface was reaching the maximum 250’ head for which the gates were designed, so all were closed. A Reclamation report explained that “later, it was decided that the gates might not be opened for several years, and in the interest of safety, the ring-follower gates were also closed.” After the United States entered World War II in December, “the ring-follower gates were made inoperative by removing the intake manifold from the oil pump which operates the gates.”\textsuperscript{474}

\textsuperscript{472} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 180-181; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 146-147, 151.

\textsuperscript{473} W. I. Morgan and L. V. Downs to chief inspector, memorandum regarding outlet works control gates damaged during construction operations, May 8, 1940, at RG 115, NRG-115-00-148, Box 4, File 510, NARA-RMR.

\textsuperscript{474} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 127-128.
Problems with the various gates continued to emerge, and not all were attributed to debris. Chief Designing Engineer J. L. Savage conceded that the issues were “no doubt due to the unprecedented size and type of gates and also to the pressure under which they were designed and manufactured. Both design and construction defects are involved.” He praised the efforts of field staff at addressing these issues: “Mr. Banks and his engineers have done an excellent job in directing this work and Mr. Morgan has proved indispensable in planning and carrying out the difficult task of handling the work under high-water operating conditions.” Savage recommended that a representative of the designing engineers visit the project to learn from the problems and alternative solutions.475

Gates of a very different type were planned for the spillway’s crest, which had been set at elevation 1260 to ensure that the reservoir’s backwater would not cross the Canadian border some 150 miles upstream. The spillway was also to serve as a safety value in the event of extreme flooding. Its capacity of 1 million cfs was more than twice the greatest recorded stream flow at that location. Both of these functions could be maintained if gates were installed in the spillway to raise the reservoir’s level by 18'. This had the substantial benefit of increasing the reservoir capacity by 2.4 million acre-feet. Without the gates, a project history explained, “the storage capacity of the reservoir would be 30 percent less than at elevation 1288, and the firm power capacities of the power plants at Grand Coulee and at other dams below it would be greatly reduced.”476

In October 1940, the contractor began fabricating three of the eleven massive drum gates that would together extend for a length of 1,485’. A sense of the scale of the material for the gates, which was supplied by the American Bridge Company, was provided by The Columbian: it would take “nearly 250 railroad cars—2-1/2 miles of train—to bring in all the parts.” Steel girders formed the framework for the 135’ long, wedge-shaped gates, which weighed in at some 500 tons apiece. The girders were assembled on-site and sealed with a riveted and welded steel-plate skin that was air-tight and water-tight, making the gate buoyant. The gates were designed to be operated in unison, with each gate pivoting on a series of forty hinges in its upstream edge. The anchor hinge castings in the spillway’s crest were secured by 160 anchor bolts that were 3'' in diameter and 18' to 20'-5'' long. Reclamation carefully monitored the installation of the anchors, since slight deviations in alignment could cause significant problems with the operation of the gates. Flexible stainless-steel plates formed seals vertically on the ends of each gate and longitudinally along a gate’s downstream face. As a project history explained: “The seals are designed to bear lightly against their contact surfaces, thus preventing the flow of water from the reservoir around the ends of the gates, and preventing the escape of water from the gate

475 J. L. Savage to chief engineer (S. O. Harper), memorandum regarding conclusions from discussions at Grand Coulee Dam, July 9, 1942, 4, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 536, NARA-RMR.

The operation of the gates was described by a project history:

The gates are raised by hydrostatic force of water admitted into the gate chambers from the reservoir. In operation, the gates can be set to control and maintain the reservoir level at any point within their range of 28 feet. Three controls are provided, the first being an automatic control by which, if the reservoir begins to rise, a float-actuated mechanism will cause the drum gate to lower slightly, to compensate for the rise in reservoir elevation; and, as the reservoir elevation drops to the normal elevation for which the control has been set, the automatic control will cause the gate to rise and thereby maintain the reservoir elevation at any desired elevation, with only a variation of a few inches. The second means of control is manual; and the third is by means of a motor-driven unit which has a remote control, so that any or all of the drum gates can be raised or lowered independently of the automatic control.\footnote{478 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 160, 162.}

The controls opened and closed a 57” butterfly valve at the head of the gate’s 58” cast-iron intake, which was embedded in the pier directly west of each gate. The gate chambers were drained by 24” pipes that emptied into a 60” header extending along the entire length of the spillway.\footnote{479 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 8, 1940, 163-164.}

Because of their metal construction, the pier plates and gate seats were susceptible to icing up in the winter. It was critical that the gates remain operable at all times of the year, so Reclamation engineers devised an induction heating system for the gates using copper cables and metal plates—“a comparatively new method of electrical heating,” according to \textit{Reclamation Era}. In contrast to the direct heat transfer provided by radiant heating, the cables created an electromagnetic field that heated the plates but left the cables relatively cool. “More than 9 miles of electric heating cable and nearly an acre of steel plates are being placed along the top of the great dam,” \textit{Reclamation Era} reported. “The largest of the 11 plates will be 135 feet long by 8-1/2 feet wide. There will be 22 pier plates also, one on each end of each gate, which will contain approximately 875 square feet each.” The spillway ledge heating plates were manufactured by the Schmitt Steel Company of Portland, Oregon, and installed from March to May 1941. Power was provided to each drum gate by two 150-kVa transformers, which stood in the drum gate
gallery below the gate chambers. Together, the twenty-two transformers might use “in the neighborhood of 2-1/2 million watts... for a really tough defrosting job.”

Although Reclamation was well aware of the need for extreme care with the gate installation, the engineers considered a shortcut that CBI proposed in the rush to complete the project. The specifications had required that the concrete be cooled and grouted before the gates were installed. The reasoning for this was sound. Each gate spanned three construction joints and its hinge anchors rested on four concrete blocks. If the concrete shifted before a gate was assembled, the gate would be permanently out of alignment. To speed construction, though, Reclamation allowed CBI to start installing the gates if it followed a strict methodology. After the parts were bolted together, prior to riveting, Reclamation would inspect the hinges. If the alignment was acceptable, CBI would stitch-rivet the joints immediately to prevent any movement before driving the 43,287 rivets that each gate required.

This approach proved fallible. When the cooling and grouting were completed in early February 1941, the hinges were out of alignment for all four gates installed prior to this date. The adjustment was apparently minor, however, because the gates were in proper alignment before the end of March. CBI rushed to finish the first seven gates before the high-water season in 1941, when Reclamation planned to lower the gates to allow floodwaters to pass.

During the peak of activity, two shifts of up to eleven crews of riveters worked on the gates. After sections were riveted together, the gates were sealed watertight with about 2,600 lineal feet of welds. Modifications were made to the welding specifications after Reclamation inspectors examined the first three gates and noted “that the welds could be located to better advantage for obtaining a water-tight structure,” according to the 1941 project history. “The Denver office revised the location of welds on the drum gates, and Gates 4 through 11 were welded in accordance with revised drawings.” Additional welding was done on the first three gates to match the improved design. CBI wanted to have sixteen welders on the day shift and eight on a swing shift, but had trouble retaining qualified workers. To meet the demand, it set up a training school that graduated forty-eight welders.

When the welding was done, the gates were painted. This was “the largest single item of work undertaken by the contractor’s painting department,” the 1941 project history observed. “In addition to the large area involved (820,000 square feet of metal surface receive three of more coats of paint), the work had to be done in a limited time, between late winter and the flood stage

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481 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 151.
482 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 156-158.
483 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 151, 155-156.
of the river, in June.” CBI took on this challenge with gusto: “Soon after starting the drum gate painting on March 25, the contractor scheduled the work on a twenty-four-hour day. There were eighty-five to ninety men of the contractor’s organization assigned to the drum gate painting.” They used welding torches to shoot 5,300-degree flames over the metal, which efficiently cleaned off rust and scale prior to painting. Some days, Reclamation needed to provide twenty-three inspectors to keep up with the progress.484

After the gates were painted, the chamber below each gate was filled with water. Jacks raised the gate to allow removal of the erection platform on which the gate had been assembled in an upright position. The jacks then slowly lowered the gate into the water until it floated, and the jacks were removed. This step was completed for all of the gates in May 1941.485

Work began on the reinforced-concrete, deck-arch bridge over the spillway in the following month, and all of the concrete had been placed by October. The eleven spans echoed the rhythm of the gates, with the bridge piers rising from the concrete walls between the gates. Constrained by the small clearance between the elevation of the flood water over the gates and the elevation of the roadway on the non-overflow sections, the arches of the 135' spans were relatively flat. The roadway was 30' wide between curbs. It was flanked by sidewalks that were 6' wide on the downstream side and 2'-11" on the upstream side, cantilevered out from the 11"-thick deck slab. An indirect lighting system was to be incorporated into the top rail of the horizontal-bar, metal railing. Shortages of materials delayed the installation of the metal railing until 1950; a temporary wood railing served until that time.486

The bridge’s deck slab was supported by the concrete piers, the extrados of the arches, and 10"-thick vertical posts in the open spandrels. A Reclamation report explained that “the open spandrel-type of structure was adopted largely because it permits greater flexibility of the arch barrel in adjusting itself to load changes and, consequently, smaller stress concentrations.” Aesthetics were considered as well: “It is believed that when viewed from the downstream side of the dam the bridge will stand out in pleasing contrast to the great bulk of the dam below it.” A caption for a Reclamation photograph of three spans, taken shortly after the formwork was removed, crowed: “The crest of the Grand Coulee Dam spillway has become a thing of beauty.”487

485 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 158-159.
486 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 31, 33, 102; Archie K. Hill and Milton R. Parrish, “Design and Stress Analysis of the Grand Coulee Dam Spillway Bridge,” Denver, July 16, 1942, 1, at RG 115, Records of the Bureau of Reclamation, Engineering and Research Center, Project Reports, 1910-55, 8NN-115-85-019, Box 312, NARA-RMR. It was not until June 1950 that E. E. Settergren was awarded a contract for $67,110 to install the lighted aluminum crest railings. Even then, delays in material deliveries and “certain design changes” that “were found necessary” slowed the work for a couple of months. The installation was finally completed in 1951 (Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 18, 1950, 114, 152, and Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 19, 1951, 15).
The crest also held penthouses for four elevators. The spillway was flanked by two freight elevators in Blocks 31 and 64. Two passenger elevators were near the dam’s west and east ends, in Blocks 11 and 84, respectively. There were also two elevators in the control building that was part of the Left Powerplant. All of the elevators were powered by electricity. Constructing the elevator towers was a challenge, as a Reclamation report noted: “The concrete placing schedule was slow and irregular, due to the difficult formwork required for the heavily reinforced walls.” All of the towers were completed, except for interior finishing, by the end of 1941.488

The Otis Elevator Company of San Francisco began installing guideways for the elevators and doors in the dam and Left Powerplant in July 1941. Delivery of the cabs and machinery, however, was delayed by other manufacturing priorities as the country was increasingly drawn into the conflict overseas. By the end of the year, the elevators for the left control building and Block 11 were at hand and partly installed. The passenger and freight elevators in the control building were operable by May 1942. In October 1942, the elevator in Block 11 was the first of the four in the dam to go into service. Its companion in Block 31 was completed by the beginning of February 1943. Otis Elevator did not start installing the elevators in Blocks 64 and 84 until 1947; the elevators went into service the following year.489

The elevator towers stood in the path of the downstream rail for a 150-ton gantry crane that was equipped with an overhanging hoist to raise and lower gates. The pair of 170-pound rails, separated by 27”, edged the roadway on the dam’s crest. Because the crane could not reach the spillway section to raise and lower the bulkheads for the outlet works, a 25-ton shuttle crane—not included in the original design—was added to the plans in spring 1940. Shuttle-crane transfer storage structures were installed in Blocks 31 and 64 to move the crane between the upstream and downstream rails.490

After concrete placement was finished for the bridge, CBI began dismantling the construction trestle on the dam’s downstream face. Blockouts for trestle legs were backfilled. The contractor, though, did not place the last concrete under its original contract until December 12, 1941. By this time, the final section of the dam, Blocks 64 to 84, was completed. In October, CBI began final cleanup on the dam, working from east to west: “A small crew of men using ‘slicks’ and

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hand scrapers, and suspended on the downstream face on ropes, removed the grout, concrete slobbers, etc.” They were finished by the end of the year.⁴⁹¹

CBI had begun removing equipment from the east half of the mixing plant in the fall of 1940 and finished the task in February 1941. The west half continued to operate throughout 1941, although with only one or two shifts a day. When the construction trestle was removed, the pipes that transported cement from the storage area on the left bank were cut, so cement was transported to the mix plant by dump trucks. Some of the plant’s last output went to the concrete training walls that flanked the spillway, a task completed in November. The end of concrete placement also foreshadowed the end of concrete cooling operations. Most of the cooling was finished during the winter of 1940-1941, but mass concrete cooling continued in targeted areas until March 3, 1942. All told, the cooling process at Grand Coulee cost about $1.5 million.⁴⁹²

On June 1, 1942, about 15,000 people gathered to watch a historic event: the first water passing over the spillway. Those unable to attend could participate by listening to a coast-to-coast radio broadcast. To maintain a consistent flow downstream, the discharge of some 200,000 cfs of excess water was gradually transferred from the forty outlet conduits to the gates at the crest of the spillway.⁴⁹³

It was immediately apparent that the left training wall needed to be higher to deflect spillway spray away from the Left Powerplant’s transformers. The wall’s height was raised by a foot between October 1942 and April 1943. Unfortunately, this did not fix the problem, and in 1946-1947 the wall was raised by an additional 5’.⁴⁹⁴

22. WAR BRINGS CHANGE

By the time the station service units began operating in March 1941, the country’s focus had clearly shifted from the depression to war. This was reflected in a Reclamation Era article on Grand Coulee that month: “Putting this colossal structure to work two years ahead of schedule will aid materially in the national defense program.” Aluminum, a critical wartime material, was spurring an industrial boom in the Northwest. It took a substantial quantity of power to produce aluminum, making Grand Coulee a strategic asset.⁴⁹⁵

In September 1941, Engineering News-Record reported that “power-generating equipment in the west powerhouse is being hurried into serviceable condition presumably as a means of making energy available for defense industries.” At the same time, “no plans have been announced for

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⁴⁹¹ Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 9, 1941, 34, 71, 125.
awarding contracts for the proposed pumping plant . . . or going farther at the present time with the two dams in the Coulee or other parts of the irrigation development.” This component was clearly not a priority: “In those phases of the project pertaining to irrigation, surveys and studies are about all that are expected until there is some decrease in the urgency of national defense expenditures.”

Grand Coulee’s role in the war effort was being considered internally well before this time. On July 3, 1940, Secretary of the Interior Harold Ickes sent a memorandum to Reclamation Commissioner John Page requesting an update on the status of Grand Coulee’s development. Ickes also inquired about the feasibility of accelerating the schedule. Page responded in late August after consulting with the field office, reporting that the dam and Left Powerplant would be completed in early 1942 and the first three units would come on-line sequentially in October and November 1941 and April 1942. “It is not possible, apparently, to hurry this work and to advance these dates.”

While this was not the answer Ickes wanted, Page did offer some good news: “Without any consideration for developing national defense needs,” Reclamation had included $1 million in its $20.2 million fiscal year 1942 budget to begin work on the fourth unit. There was a substantial cost and significant lead time associated with a new unit—“one can be put into operation for about $3,000,000, and . . . each normally can be on the line within 30 to 35 months of the day on which shopwork first begins”—but “the time might be shortened through the making of special arrangements with the manufacturer.” Page concluded: “With the probability that a large amount of additional power will be required for war industries and Navy construction in the Puget Sound area in the next few years, it would seem wise to me . . . for the Bureau of Reclamation to proceed to purchase and install three additional main generating units (instead of one as now planned).” Distribution of the additional power could be easily handled by an upgrade to the transmission lines that the Bonneville Power Administration was undertaking.

Reclamation increased its order to three turbines in July 1941, and “Secretary of the Interior Harold L. Ickes . . . hinted that more such units might be needed soon.” Reclamation Era added: “It is becoming increasingly apparent that the completion of Grand Coulee Dam this year is most fortuitously timed.” Engineering News-Record reported that the schedule for installing the new units, G-4 through G-6, was aggressive: “The contract covering the first three units now going in allowed 1,050 days for construction and installation. On the second group of three units duplicating this first order, the time allotment is only 650 days for the first unit, 710 days for the

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496 “Grand Coulee Dam Nears Completion,” Engineering News-Record 127 (September 11, 1941): 91.
497 John Page to secretary of the interior, memorandum, August 1940, at RG 115, Project Correspondence File, 1930-45, Box 529, Entry 7, NARA-RMR.
498 John Page to secretary of the interior, memorandum, August 1940, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 529, NARA-RMR.
second and 770 days for the third.” The bid was won by the Westinghouse Electric and Manufacturing Company, which had supplied the first three units. 499

The reason for the rush was apparent by the following July, when a Reclamation press release announced that the Bonneville Power Administration “now powers about a quarter of the national output of aluminum.” Grand Coulee was responsible for a large share of the electricity that fueled this industry, which had hardly existed a few years earlier: “The production of this silvery airplane metal in the Northwest today exceeds that of the entire country in 1939.” The significance of this accomplishment was highlighted by Reclamation’s 1943 project history: “Northwestern electric power has become a vital unit in the war effort. Aluminum plants, airplane factories, shipyards, the chemical plant at Hanford, and many smaller enterprises, have taken the energy output of each new Coulee Dam unit as rapidly as it was made available, and still more power could be advantageously used.” 500

Even before the country had officially entered the war, Grand Coulee’s strategic significance raised security concerns. In October 1941, a unit of the Federal Guard was organized to protect the dam and related facilities. The army supplemented this force with thirty-three soldiers in January 1942, shortly after Japan attacked Pearl Harbor. The number of soldiers soon grew to sixty-one. The road across the dam was closed to the public. Ten-foot-tall metal fences were installed at each end of the dam and encircled the powerhouses, and other fences ringed the switchyards. Access to secured areas was restricted by fifteen guard houses at strategic locations, and physical deterrents were installed as well. “Concrete bulkheads were placed in galleries of the dam at critical points to prevent flooding of the powerhouses,” the 1942 project history reported, “and metal and wooden doors equipped with strong locks were installed in all points of entry to the dam, elevator hoist-way adits, and elevator tower.” U.S. Coast Guard boats patrolled the river above and below the dam looking for signs of enemy sabotage. 501

The war also affected staffing. During the 1930s, the amount of time a laborer could work was strictly limited in an effort to spread jobs among the largest number of men. In March 1942, with a shortage of workers and a pressing need to get power to wartime industries, the work week was extended to forty-eight hours, with men paid time and a half for the eight hours of overtime. This was at first implemented as a seven-day week. By mid-April, however, Sunday was again a day of rest. 502


With many male employees entering military service, Reclamation had little choice but to hire women to fill open clerical positions. This trend had started before the country entered the war, as a caption on a Reclamation photograph from August 1941 observed: “One of man’s last strongholds, large construction jobs, is just a little weaker at Grand Coulee Dam this week as the result of its ‘invasion’ by the four women who operate the Bureau of Reclamation’s new powerhouse telephone switchboard.” By the end of 1943, Reclamation employed 155 women.

Most of the women “had very little recent experience,” a project history noted, “and considerable time and much effort were required to fit them into the organization, with a consequent diminution in efficiency.”

Women were not allowed, though, to do construction jobs. As the war advanced and many CBI supervisors were transferred to the Kaiser Company’s shipyards on the West Coast, Reclamation took an unorthodox but pragmatic step to maintain progress at Grand Coulee: the government’s “engineers and inspectors supervised the work directing the contractors’ workmen—a most unusual arrangement.”

23. RAMPING UP THE POWER

As Reclamation sought to speed up installation of new units at Grand Coulee, the units that were in place also demanded attention. During the testing of Unit G-2, Reclamation had observed the same problem that G-3 had displayed during high water periods: “At certain gate openings in the neighborhood of 0.3 of full gate, disturbances in the draft tube would cause some hammering, load swings, and vertical bounce of the unit.” At other openings, “a pronounced vibration of about 38 cycles per second occurred.” Tests on G-2 showed that the vibration was caused by “a ‘Kerman Vortex Street,’ a sheet of eddies, rhythmic in nature, which originated at the blunt trailing edges of the turbine runner vanes, and at certain frequencies were in tune with the frequency with which the runner vanes pass the wicket gates.” The remedy, ultimately applied to the first three units, was to sharpen about half the trailing edge of the runner vanes.

Although this solved the problem of high-frequency vibration, Unit G-2 continued to experience hammering and load swings, so “four baffles or ‘booster fins’ were installed” in the draft tube, the 1942 project history reported. “These produced some improvement in the performance of the turbine, but results were not conclusive.” As G-4, G-5, and G-6 came on the line, vibration plagued both the existing and new units. Attempts to address the problem continued into the winter of 1945-1946, when Newport News installed four baffles in each draft tube and added permanent rotary air compressors for each of the main units.

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The turbines were not the only equipment with defects. The governors that Reclamation had specified were supposed to be adjustable for speeds between 50 to 60 cycles, but “the ballheads supplied to cover this speed range were too sluggish, and they had to be replaced with standard ballheads in order to obtain satisfactory response.”

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In February 1942, only seven months after Reclamation had ordered Units 4, 5, and 6, it turned again to Westinghouse to obtain Units 7, 8, and 9. Despite efforts to accelerate the manufacturing process, however, a lag of many months was unavoidable. In the interim, Reclamation resorted to “loaners,” two 75,000-kW units that it had in storage at Boulder City, Colorado. Allis-Chalmers had manufactured the turbines, governors, and a back-up 25,000-kVt transformer, while the General Electric Company produced the 75,000-kW generators and six 25,000-kVt transformers. The units were intended for the Shasta hydroelectric plant near Redding, California, but it would be at least two years before the facility was ready for them. They were soon on their way to Grand Coulee for temporary service in the Left Powerplant.

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The substitution was not an easy one, however, because the Shasta turbines rotated counterclockwise, the opposite of the Grand Coulee units. Reclamation engineers had to quickly determine how to modify the wheelpits in Bays 7, 8, and 9 to accommodate this disparity. They decided to install the units in Bays 8 and 7, with improvised elbows directing water from the penstock in Bay 9 to the unit in Bay 8 and from the penstock in Bay 8 to the unit in Bay 7. This required cutting out massive chunks of concrete from the 8’-thick crosswalls between the wheelpits, a task accomplished between April and June 1942. Turbine parts began arriving at the project in late May. The erecting engineer from Allis-Chalmers arrived in mid-June to oversee the installation, starting with Shasta Unit A in Bay 7.

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Reclamation selected a design for the draft-tube liners after testing models of alternatives, then hired Western Pipe and Steel Company to fabricate them. Even at an expedited pace, this was a lengthy process, and by the time the liners arrived at Grand Coulee, the installation of Shasta Unit A was well advanced. The liners were cut into sections, eased through a blockout to the elevation 921 gallery that had been left for this purpose, reassembled, and welded back together.

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A crew from General Electric began assembling the generator rotor for that unit in early July:

> The steel punchings for the magnetic circuits were weighed individually, and were distributed in piles in which the punchings did not differ in weight more than one pound. This was done so that the weight could be distributed evenly around

the rotor during the stacking of the punchings. The rotor shaft was then set up, and the eight spider arms were bolted to the hub, which had been shrunk on the shaft at the factory. The punchings were then stacked to form the rim, and compressed with belts, which were welded when the stacking had been completed. The poles were then inserted and keyed into slots on the ring and by October 20 the assembling of the rotor was complete, and it was ready for installation. The final driving of keys between the spider arms and the rotor rim was not accomplished until immediately after the dry-out run.\textsuperscript{511}

The stator for Unit A was assembled during the same period. Concrete placement in the bay was finished by November. Low-strength concrete, in which fine silt was substituted for part of the cement, was used for the temporary installation. The rotor had been moved into Bay 7 by the end of November, and before the year’s end most of the bearings and related equipment were in place.\textsuperscript{512}

Components of the 36,000-kVa transformer for Unit G-6 arrived in early December, and by the end of the month the assembled transformer was moved to the transformer deck. Reclamation planned to use this temporarily for one of the Shasta units. The first of the Shasta unit’s 25,000-kVa transformers arrived in late December, though, much sooner than anticipated, so the complications of adapting the 36,000-kVa transformer were avoided. The three 25,000-kVa transformers for Shasta Unit A were put in place on the transformer deck in January 1943, and the three for its twin in the adjacent bay had followed by April.\textsuperscript{513}

The shuffling to get the Shasta units in operation resulted in the positioning of steel portal frames intended for units G-4, G-5, and G-9 at Bays 6, 7, and 8. The portal frames were produced by Gate City Iron Works. Similar juggling was done for the lightning arrester supports and roof takeoff towers.\textsuperscript{514}

Shasta Unit A was placed on the line on February 25, 1943. It ran until May, when it was shut down for inspection. At the same time, a timber that had become stuck in the gate seat was removed. The official turbine acceptance tests performed by Allis-Chalmers revealed that the unit “developed a peak efficiency of approximately 92.5 percent and was 12 percent above rated capacity.”\textsuperscript{515}

While the unit performed well for the most part, the governor was beset with problems. Over the course of 1943, a new regulating valve, screens, compensating dashpot, springs, weights, and

\textsuperscript{511} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 10, 1942, 211, 221.
\textsuperscript{512} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 10, 1942, 30, 119, 15, 221.
\textsuperscript{515} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 11, 1943, 37, 153.
pilot rods were installed and the oil was filtered, all to no avail. Finally in December, “new pilot rods were installed in the governor ballhead and relay valve, the speed indicator was rebuilt, new bearings were installed in the hand control bracket, the speed droop was adjusted, and a new relay valve was installed.” This finally did the trick.\(^{516}\)

Although some of the initial concrete work in Bay 8 was started in summer 1942, a major push to pour the concrete for Shasta Unit B did not begin until October, when its neighbor was almost finished. One advantage of this delay was that the draft tube liner could be installed in the standard way by being lowered through the center of the scrollcase before the runner and cover plate were placed, rather than in pieces through a blockout. The installation of Unit B proceeded relatively quickly and smoothly, although the governor experienced problems similar to Unit A. Although the unit was placed on the line on May 7, 1943, it was necessary to substantially rebuild the governor in November.\(^{517}\)

Despite shutdowns related to the governors and other issues, the two units contributed a total of 923,284,000 kW-hours of power to the war effort in 1943. Each unit had an overload capacity of 90,000 kW, but they were operated closer to 80,000 kW to avoid roughness in the draft tube when the gates were near full aperture.\(^{518}\)

Controls for Units A and B had been transferred to the main benchboard, located in the governor gallery at elevation 951, by August 1943. The main benchboard was assembled and installed after arriving at the project in mid-December 1941. Units G-3 and G-2, which had been connected to temporary benchboards when they were placed in service, were transferred to the main benchboard in March 1942. Unit G-1 was hooked up to the main switchboard from the outset.\(^{519}\)

By early 1942, crews were installing cable from the control bay to a breaker in the 230-kV Left Switchyard, which was also a work in progress. General Electric had delivered six 230-kV, 1,200-ampere oil circuit breakers in 1941, but only one was placed in service that year. The rest followed in the first half of the next year. The 1942 project history reported that “work on the control circuits of the switchyard circuit breakers continued throughout the year as cable allocations arrived from the Denver office, or as cables were needed for operations.”\(^{520}\)

Initially, the switchboard was only linked to the 230-kV Coulee-Midway Line No. 1. By May 1942, two 115-kV lines to Spokane had been added. A second 230-kV line to Midway and a 230-kV line to Covington were energized in July. Connections continued to be made in 1943.

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The 230-kV Spokane Line No. 3 went into service in mid-April, and a fourth line followed on May 1. A second line to Covington was established in October 1944.\(^{521}\)

The introduction of the Shasta units forced revisions to the overall construction schedule, but progress continued on Units G-4, G-5, and G-6, which were installed in 1942-1943. Reclamation crews placed the reinforcing steel and concrete for these units using concrete produced at the government mixing plant on the right bank. Semi-trailers hauled 4-cubic-yard buckets of concrete to the Left Powerplant, where the powerhouse cranes positioned the buckets for pouring. Elephant trunks funneled the concrete into the bays.\(^{522}\)

Reclamation started installing Unit G-6 in October 1942, and it went into service the following summer. The rush to get the unit into operation was “indicative of the conditions under which the plant was operating during the year. The unit was placed on the test run August 8, placed on commercial service the following day without coming to a stop, and was in continuous operation for the following six months, during which time it generated 522,000,000 kWhr of energy.” When it went on the line, the project history reported, “some erection details were not quite complete.”\(^{523}\)

Early in March 1943, work commenced on Unit G-5. It was ready for testing by early October, and the three associated transformers followed later in the month. The unit went on the line in November.\(^{524}\)

The General Electric Company produced the six 36,000-kV\(a\) core-type transformers for Units G-6 and G-5. The Westinghouse Electric and Manufacturing Company fabricated the three 36,000-kV\(a\) transformers for Unit G-4, which were of shell-type construction. The 1943 project history explained that “the chief difference is the more compact construction of the force-cooled shell-type construction.” Work on Unit G-4 had begun in mid-1943 and the transformers were in place by December. The unit began commercial operation on February 12, 1944.\(^{525}\)

In addition to installing the units, Reclamation forces were also responsible for finishing many architectural components of the Left Powerplant. Beginning in 1943, they applied lath and plaster to the walls and ceilings, installed metal doors, cover plates, grates, and grilles, and

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\(^{522}\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 11, 1943, 107, 133.
placed more than 13,000 glass blocks in the ten 40’ by 17’ windows in the plant’s downstream wall. The glass blocks were manufactured by the Owens-Illinois Glass Company.\textsuperscript{526}

Reclamation crews finished most floors with a concrete topping or terrazzo. Workers began installing terrazzo on the generator floor of the station service units in February 1944 and in the visitors’ gallery in Block 11 in January 1945. The design of the terrazzo was usually undistinguished, but the 1943 project history described a notable exception: “One unusual job was the elaborate design in the floor of the reception room of the control bay at elevation 1012.5 wherein the relations of turbines and generators was graphically depicted in the colors of the floor, so that visitors could get a clearer idea of how power is generated at Coulee Dam.” This project was apparently not finished until 1949, when a photograph of the intricate terrazzo appeared in Reclamation’s project history. The caption for the photograph, dated June 24, read: “Completed Terrazzo Design of the working parts of a turbine as shown on the design. The design is in the service bay of the West Powerhouse and is to be used to explain the working of the turbines to sightseers visiting the dam.”\textsuperscript{527}

Other architectural elements were more utilitarian. Reclamation workers salvaged pipes from construction to form handrails. The pipes were sandblasted to a bright finish, smoothed with sanders, and bent and welded into railings. A coat of clear lacquer preserved and enhanced the metal’s luster.\textsuperscript{528}

Not all of the finish work on the plant was done by Reclamation crews. By fall 1943, for example, contractor C. A. Grenell had lined the lobbies and stairways of the elevator towers, as well as the corridor, lobby, and vestibule of the control bay at elevation 1012.5, with travertine. Grenell also faced the front of the elevator towers in granite.\textsuperscript{529}

There were also advances, in fits and starts, on the Right Powerplant. Wartime power demands prompted a sudden push to develop the facility many years sooner than Reclamation had anticipated. With the work on the dam and Left Powerplant almost done and idle equipment set to be moved elsewhere, Reclamation seized the opportunity to redeploy the equipment at Grand Coulee.

On October 16, 1941, Reclamation issued Extra Work Order No. 42 authorizing CBI to erect the Right Powerplant’s transformer deck. This was the first step in the construction of the powerhouse, “one of the largest concrete buildings in the West,” a Reclamation press release

\textsuperscript{528} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 12, 1944, 90.
\textsuperscript{529} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 11, 1943, 40, 112, 131.
claimed. The building “will be 743 feet long, 84 feet wide and more than 200 feet high, containing about 80,000 cubic yards of concrete. One section of the building, known as the control bay, will contain several dozen rooms, including a control room, switchboard room, oil storage room, compressor and pump room, lockers and showers, reception room, guide room, first-aid room, lobby, corridor, file room, fan room, battery room, offices, machine shop, electrical laboratory, cable-spreading room, and terminal board room” CBI began placing concrete on November 3. Even though a Reclamation report complained that “progress was rather slow due to difficulty in obtaining the required materials for embedment in the concrete,” by the end of the year the transformer deck was 85 percent complete.\textsuperscript{530}

By then, the next phase had been launched. On December 15, the undersecretary of the Department of the Interior signed the “Adjustment for Compensation No. 2, Order for Changes No. 5, and No. 44, providing for construction of the right (east) powerhouse.” On December 29, Reclamation issued Extra Work Order No. 44, which gave CBI authorization to erect the powerhouse. Construction commenced on January 1, 1942.\textsuperscript{531}

Although plans called for the structure to be ready by late 1942, the 1941 project history acknowledged that progress “will be dependent upon the availability of reinforcing steel and other materials” given wartime restrictions. CBI and Reclamation had to be creative with whatever supplies could be obtained. A large-scale challenge was the roof, which was supposed to have had steel trusses and structural steel purlins like the plant it mirrored on the left side. Steel was in short supply, the 1942 project history reported, but “by purchasing the contractor’s salvaged steel girders formerly used in his construction trestle on the dam, a satisfactory support for the so-called ‘pan-type concrete slab and joists construction’ was obtained.” The roof was covered with five-ply membrane roofing in 1943. “Many structural items, such as rivets and pipe fittings, had to be manufactured locally. The shortage of skilled labor became so acute that local schools were established to train promising unskilled laborers for those higher positions.”\textsuperscript{532}

Supplies and labor were not the only things that delayed progress on the Right Powerplant. A major setback came in October 1942 when the War Production Board downgraded the project’s priority. Although the control bay had not been started, most major components of the Right Powerplant were in place when Reclamation suspended construction a few weeks later.\textsuperscript{533}


During this interruption, Reclamation established a concrete mixing plant, which was in operation by mid-November 1942. Designed by Reclamation’s Concrete Control Department and erected under Reclamation’s supervision, it was located about a mile below the dam and about a mile inland from the river’s right bank. The plant’s two-cubic-yard mixer could produce around 45 cubic yards of concrete an hour. Operating six days a week and usually with two shifts, but sometimes three, the plant produced 1,366 cubic yards of concrete by the end of 1942, 21,874 cubic yards in 1943, and 39,882 cubic yards in 1944. There was less demand for concrete in 1945, when only 3,945 cubic yards were produced, mostly for installing needle valves in the Right Powerplant. Special batches, such as that used for the terrazzo in the powerplants, were produced in portable mixers.534

Cement was initially obtained in sacks and stored at the mix plant. When construction accelerated in 1944, Reclamation returned to bulk cement. In December 1947, the mix plant received its first bulk cement from a 120-barrel tank truck, which transported the material from two 3,000-barrel silos at the reactivated cement plant in the Industrial Area.535

In an article published in Reclamation Era in March 1941, Reclamation engineer Oscar Dike explained that “all of the cement used during the first contract, when approximately 4,500,000 cubic yards of concrete were produced, was of a modified type, while during the second contract a low heat cement was used for mass concrete, and a modified cement for walls and other thin sections.” By conducting less heat, low-heat cement lowered the final temperature of the concrete. A low-heat mix worked well for mass concrete, causing less cracking due to shrinkage. The trade-off, however, was that it set more slowly, which required the formwork to remain in place longer than usual. Dike noted that “the basic differences between the modified and low-heat cement were in the speed of early chemical action or hydration and the total amount of heat generated. The two types were not composed of different materials but of different proportions of the same materials.” Both types reach essentially the same strength after curing for ninety days.536

The still-substantial stockpile generated by CBI’s aggregate plant provided sand for the concrete. Until July 1943, aggregate came from a reprocessing plant that CBI had established in 1942 near the Eastmix plant stockpiles. As that source became exhausted, Reclamation engineers designed another facility, which was erected between April and October 1943. The new plant, conveniently located near Reclamation’s mix plant, processed raw materials that could be obtained in the immediate vicinity. A feeding structure fed the material into a primary screening

and crusher structure, where pieces larger than 1.5” were processed in a gyratory reduction crusher. A secondary screen graded the materials into several sizes, which were stored in separate bins. Processed concrete was delivered to the work site by skips on a two-track trestle. A stiff-leg derrick moved it from the trestle to a concrete train that served the Right Powerplant.537

24. WEAR AND TEAR

Although the dam was completed and the powerplant was generating electricity, engineers had many unanswered questions about the facility, particularly about its maintenance and operation. One of the most pressing pertained to the condition of the spillway bucket, which had been pummeled by objects ranging from concrete buckets to steel bars during the construction period. In addition, the spring floodwaters that were diverted through slots as the dam rose produced eddy currents. These currents kicked up debris from the riverbed, leaving deposits up to 8’ deep in the spillway bucket. With water flowing through the outlets and over the spillway, the bucket was subjected to an intense beating, causing the materials in the bucket to scour the concrete. This type of action was an inherent problem of the “roller bucket” design—“a circular bucket . . . submerged below tail water so that the issuing jet does not spring free.” The Handbook of Applied Hydraulics explained that “one of the hazards of roller-bucket operation is the abrasion of the concrete caused by rock being entrained in the roller. Heavy abrasion damage and costly repair were experienced in the Grand Coulee Dam roller bucket.”538

Before repairs could be undertaken, Reclamation had to better understand the condition of the bucket and the causes of deterioration, but it was extremely hazardous for divers to conduct inspections or undertake repairs. This could be more easily accomplished in a dry area, so Chief Designing Engineer J. L. Savage proposed the construction of a floating caisson to unwater the dam’s spillway bucket. To develop the caisson’s design, he wanted to build a 1:60-scale, concrete, hydraulic model of the dam, including the river half a mile downstream. While the model could serve a number of research needs and also be incorporated into a vista house for visitor education, Savage asserted that it was “absolutely necessary” for developing the design of the caisson, which he called “one of the most important and most difficult features that this office has ever been called upon to design.” He reinforced his point by referencing a comparable situation that Reclamation undoubtedly did not want to repeat: “Any serious damage to the

bucket may be expected to start erosion and cavitation of the concrete, which can, as we know form the Arizona spillway at Boulder, result in a costly and very dangerous situation.\footnote{539}

Savage’s urgent plea, however, did not yield quick results. A change in the location of the model caused a delay early on. Engineers first planned to place it in a parking lot by the bank of the river downstream from the dam, near the anticipated anchorage of the caisson. The design of the model and site preparation were well along when the project was transferred to a park upstream from the dam by the West Vista House, where it would be more accessible to visitors after its testing role had ended. “This required a complete redesign of the model foundation dependent upon the vista house location and architecture,” a later report noted. It was not until March 1942 that the revised plans were available for construction.\footnote{540}

Savage then ran into roadblocks from Reclamation management. In a memorandum to the chief engineer in June 1942, Savage wrote with frustration: “It is unfortunate that this matter is being delayed. The plan was to have this model in operation so that full advantage could be had of this summer season for model testing. Also it was hoped that the design could be completed so that, if serious trouble is disclosed by diving or other methods, following this flood season, the caisson could be constructed and put to work during the fall and winter of 1943.” His final paragraph highlighted the intensity of his concern: “Do you approve immediate construction of the model? If not approved, I desire copies of this and my memorandum of May 5, 1942, filed in the Washington, Denver, and project offices and in my personal files.”\footnote{541}

The delay had apparently been caused by someone at Grand Coulee. On June 12, 1942, Chief Engineer S. O. Harper wrote to the supervising engineer: “In my letter of March 10, 1942, . . . you were advised that although construction of the vista house should be deferred until after the present emergency, the hydraulic model for the caisson would be required and should be built as soon as possible.” He added: “Construction of the model should be undertaken by Government forces. This may take three months and likely six months, or even longer, will be consumed in making the hydraulic tests. Construction of the caisson and dry docks, along with the purchase of gates for the latter, will take approximately 20 months. Under such a program, which probably cannot be shortened, it will be November 15, 1944, before any portion of the bucket may be inspected and repaired. Thus it is urgent that the model for the necessary hydraulic testing be

\footnote{539} J. L. Savage to chief engineer, memorandum regarding construction of 1:60 scale hydraulic model of Grand Coulee Dam, May 5, 1942, at RG 115, Office of the Chief Engineer, General Correspondence Files, 1902-42 (Engineering), FAC 115-54A081, New Box 439, NARA-RMR.


\footnote{541} J. L. Savage to chief engineer, memorandum regarding construction of 1:60 scale hydraulic model of Grand Coulee Dam, June 9, 1942, at RG 115, Office of the Chief Engineer, General Correspondence Files, 1902-42 (Engineering), FAC 115-54A081, New Box 439, NARA-RMR.
commenced and completed at the earliest possible date.” In the meantime, he added, a diver should be hired to inspect the bucket.542

The dangers of diving, even after the high water period, prompted Savage to consider other alternatives for interim inspections. One idea “would involve the lowering of a vertical steel tube from a cable-held barge to close proximity of the spillway bucket. The bottom end of the tube would be closed and provided with glass windows and powerful lights. The tube might be large enough to permit a man to be stationed at the bottom of the tube for observation purposes, or the tube might be only 18 or 24 inches in diameter and arranged for field glass observation and photographic recording.” If these ideas were tried, they were apparently not successful. In March 1943, two divers spent three weeks investigating the spillway bucket.543

They did not have good news to report. The bucket had clearly suffered damage. Some areas were roughened by high water velocities with an uneven flow, a condition called cavitation. The bucket’s surface was also abraded by sand, gravel, and boulders trapped by eddies created when the water was being discharged over only part of the spillway. To cure these problems, Reclamation engineers recommended that water should be introduced more evenly across the spillway and that scroll cases should be installed in two bays in the Right Powerplant to divert water when repairs on the bucket were undertaken. Instead of holding turbines, these outlets would be controlled by needle valves. Further investigations of the damage were conducted in November when another pair of divers spent ten days assessing the bucket’s condition.544

The March findings were apparently the catalyst that gave the caisson project momentum. In May 1943, J. W. Ball arrived from Reclamation’s Denver office to oversee the model’s construction at a site in Vista Park, about one-quarter mile upstream from the dam’s left abutment. By the end of August, the model was sufficiently completed to allow Ball to begin testing. It had to modified a year later because the water supply system was inadequate, but after this task was accomplished in September 1944, the model was immediately returned to use.545

Tests related to the caissons were completed by December and the results issued in June 1945 in Hydraulic Laboratory Report No. 174. Most of the tests were conducted at the 1:60 model at

542 S. O. Harper, Chief Engineer, to supervising engineer, Coulee Dam, memorandum regarding construction of 1:60 scale hydraulic model of Grand Coulee Dam, June 12, 1942, at RG 115, Office of the Chief Engineer, General Correspondence Files, 1902-42 (Engineering), FAC 115-54A081, New Box 439, NARA-RMR.
543 J. L. Savage to chief engineer, memorandum regarding conclusions from discussions at Coulee Dam, July 9, 1942, 3, at RG 115, Project Correspondence File, 1930-45, Entry 7, Box 536, NARA-RMR; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 1, 1943, 37.
Grand Coulee, using two models of the caisson that had been fabricated at the same scale by the Denver office. Additional tests were “performed in the Denver hydraulic laboratory on a 1 to 20 scale working model of the floating caisson with its operating barge and powered hoists, a 1 to 42 model of the caisson drydock and gate slab, a 1 to 60 model of the base of the right training wall and bucket section, a 1 to 24 model of the Grand Coulee turbine scroll case and draft tube, and a 1 to 30 model of an 84-inch needle valve and turbine draft tube.” Testing also included the tailrace slopes and riverbanks to analyze options for avoiding deterioration.  

The tests identified the optimal combination of discharge between the spillway gates, river outlets, and powerhouses to provide the least disturbance when the caisson was at work. The caisson would be seated on the deteriorated bucket with a steel frame, which measured 106’ x 62’. The frame comprised “two principal side girders with bottom skin plates 5 ft. wide, shaped to the theoretical sectional dimensions of the spillway bucket, and an end frame conforming to the theoretical shape of the apron downstream from the lip of the bucket,” *Civil Engineering* reported. “An A-frame was provided for attachment to anchorages on the face of the dam, and towers at the four corners extend from the side girders to a point above the normal water surface. The A-frame serves the function of precisely locating the seat frame in a lateral position in the bucket, and the towers are used to control the adjustment of the frame to exact vertical position.” The caisson would be stored in a cylindrical concrete drydock 163’ in diameter.

Well before the tests were completed, Reclamation began arranging for the necessary materials to build the caisson and drydock. The Denver office opened bids for puller machines for the floating caisson in mid-August 1944 and for a two-leaf miter gate for the drydock and structural steel for the caisson in September.

Even earlier, excavation had started for the drydock. Engineers had considered three locations for it: at the end of the right tailrace, on the right side downstream from the highway bridge, and on the left side downstream from the contractor’s railroad bridge. Ultimately, a site near the right tailrace was selected.

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549 J. L. Savage to chief engineer, memorandum regarding construction of 1:60 scale hydraulic model of Grand Coulee Dam, May 5, 1942, at RG 115, Office of the Chief Engineer, General Correspondence Files, 1902-42
In September 1943, a contractor started two shifts of laborers to excavate the outer edge of a circle about 200' in diameter at this location. By the end of the year, large dump trucks had hauled out some 672,000 cubic yards of material. By the end of May 1944, when the first phase of the excavation was completed, that quantity had risen to more than 1.2 million cubic yards.\(^{550}\)

At the beginning of the next month, workers started placing concrete for the drydock’s 163'-diameter, 16'-thick cylindrical shell, which had a steel cutting edge at its base. In late July, when the shell’s concrete walls had reached 33' in height, crews began using stiff-leg derricks and bulldozers to remove earth from around the cylinder’s exterior edge and from its interior. With that excavation and the addition of more concrete to the shell’s walls to aid the force of gravity, the cutting edge dug the massive cylinder to bedrock. The engineers had done well in selecting the location: the shell came to rest only 1.5" out of level.\(^{551}\)

After the bedrock was cleaned, a thick concrete ring was poured around the shell’s interior to reinforce the cutting edge. Four 10'-square concrete piers were formed near the drydock’s center. The rest of the interior was filled with a layer of gravel 10' deep. The columns and gravel supported a 16'-thick floor slab that was poured in December, the base of the floating caisson’s erection pedestal.\(^{552}\)

In March 1945, four concrete anchor blocks were poured. By the end of April 1945, engineers initiated a test of the drydock. Because the channel was not yet completed, they used a 12" pipe to flood the enclosure. The test proved prudent: the water undermined one of the four anchor blocks, causing it to tilt. It was righted and stabilized after the water was pumped from the drydock in mid-August. Crews then worked on finishing touches, which included grouting joints between the wall, the foundation concrete, and the floor slab. The drydock was ready for use by late September.\(^{553}\)

Excavation for a channel between the drydock and the river went hand in hand with the excavation for the drydock. The section above the river level was completed first. By the end of November 1944, an earth-filled dike had been extended into the river. During 1945, shovels and draglines worked intermittently on the section from the river to the drydock, while a floating derrick barge dredged the channel in the river. The work continued between the fall of 1946 and March 1947, removing about 23,500 cubic yards of material. Riprap to line the channel was

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\(^{552}\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 12, 1944, 28-29, 220.

provided, in part, by salvaged concrete from the bays of the Shasta units, which were removed after World War II.\textsuperscript{554}

The opening in the drydock that would allow the caisson to get to the river was to be sealed with a two-leaf miter gate. When it was time to inspect or repair the bucket of the dam, the gates would be opened and water would enter the drydock to float the caisson. Installation of the miter gates began in the fall of 1945. The American Bridge Company had been awarded the contract for the structural steel in November 1944 under the First War Powers Act, and the first steel was placed in late November 1945. Most was installed by the end of the year.\textsuperscript{555}

In January 1946, Reclamation began assembling the floating caisson, a steel structure that would weigh about 1,600 tons. According to an article in \textit{Civil Engineering}, the caisson “consists of a series of compartments which are used for buoyancy; ballast and trim tanks to facilitate floating and submergence; and an open-bottom working chamber which fits the general shape of the bucket of the dam.” It was designed to dewater a section that was more than 50' long to provide access to an entire concrete block and adjacent construction joints. The caisson was moved into place by puller machines on the riverbanks with the aid of two wood fender barges. The barges were anchored to the dam with flexible connections before they lowered the caisson into place with hoisting lines.\textsuperscript{556}

Workers started constructing the barges in January 1945 and they were ready for service by April.\textsuperscript{557} Work on the caisson was suspended from May to July during the flood season. By the end of December, erection and painting were essentially done, most of the hoists and other equipment were in place, and a majority of the electrical work was completed. The caisson—maneuvering puller machines and associated deflection sheaves for the cable hoists were secured on their foundations on the riverbanks—although a slide led Reclamation to move puller machine No. 5, a task was not undertaken until 1947. In December 1946, footings were poured for some of the puller-line support towers.\textsuperscript{558}


\textsuperscript{556} J. L. Savage to Chief Engineer, memorandum regarding “Construction of 1 to 60 scale hydraulic model of Grand Coulee Dam,” June 9, 1942, at RG 115, Office of the Chief Engineer, General Correspondence Files, 1902-42 (Engineering), FAC 115-54A081, New Box 439, NARA-RMR.

\textsuperscript{557} L. Vaughn Downs, “Floating Caisson Facilitates Repair of Grand Coulee Spillway Bucket,” \textit{Civil Engineering} 20 (April 1950): 256; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 13, 1945, 164; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 14, 1946, 220. The Downs article gives the caisson’s weight as 1,200 tons; Reclamation’s 1945 project history provides the 1,600-ton figure.

\textsuperscript{558} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 14, 1946, 213, 221.
Tests of the floating caisson began in February 1947. Leaks inside the downstream girder tank caused the caisson to list by 2'. Problems in the caisson’s performance continued, and it was not until 1949 that it was put to use.\(^{559}\)

25. NEEDLING PROBLEMS

While tackling repairs to the bucket, Reclamation also pursued ways to minimize future damage. One was to establish temporary outlets in the Right Powerplant to provide an alternative to releasing excess water over the spillway during low-water periods, particularly when repairs on the bucket were underway. The Board of Consulting Engineers had advised putting needle valves in the bays. The board also called for the river channel to be dredged for 200' below the dam to remove rock and gravel that might otherwise swirl into the bucket.\(^{560}\)

The channel dredging went faster than the caisson construction. Between mid-December 1943 and late April 1944, an area as wide as the spillway and extending 200' downstream was dredged to elevation 885. More dredging was done during low water periods at the beginning and end of 1946, again going to elevation 885, but this time reaching about 300' below the spillway. Material was collected by a clamshell bucket, dropped on a derrick barge, taken downstream, and put back in the river.\(^{561}\)

The needle valve installation was more complex, and options were extensively analyzed with the model testing that began at the dam in 1943. While plans initially called for two needle valves, the project had a chance to borrow eight 84" needle valves from Boulder Dam, where they were ultimately destined for canyon wall outlet houses. Their temporary home would be Bays 11 through 18 of the Right Powerplant. A funnel-shaped tube known as a penstock reducer would make the transition between the larger penstock orifices in the powerhouse and the smaller needle-valve intakes, while a cast-steel elbow curved at a 41-degree angle would direct the flow to the needle valve. The end of the valve was outfitted with a steel discharge elbow.\(^{562}\)

Reclamation’s Denver office issued instructions for installing the valves in December 1943. The penstock reducer would:

- be delivered in five pieces, which must be welded together in the field and then welded in place in the end of the penstock. The cast steel elbows will be delivered completing machined, and will only require bolting in place, the drain pipe connected, and the concrete anchor No. 1 poured around it to absorb the lateral thrust from the flowing water. . . . The needle valve will be bolted to the elbow

\(^{562}\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 12, 1944, 97, 155.
and will be supported on a concrete pier. The air manifold is attached to the
downstream end of the needle valve and provides a means for admitting air to the
water stream to reduce disturbance and cavitation. . . . The discharge pipe is to be
bolted to the manifold and will then be embedded in the reinforced concrete
anchor No. 2, which is anchored to the old concrete and is designed to resist the
dynamic force of the water acting against the discharge pipe.\textsuperscript{563}

The concrete anchors and piers that would support the needle valves were a critical component
of the installation. A Reclamation crew spent several months installing reinforcement dowels for
the anchors and piers. By the end of 1944, the reinforcing steel and concrete were in place to
elevation 927 for all of the piers and No. 2 anchors. All of the anchors and piers were in place by
June 1945.\textsuperscript{564}

In the meantime, the discharge elbows and air manifolds for the needle valves had begun arriving
in July 1944, and the components were assembled and installed in the bays as available. On May
25, 1945, operation tests were initiated on the needle valve in Bay 18, the first to be completed.
The project history reported that the results were not auspicious: “This test operation produced
considerable vibration.” More issues appeared when a second test was conducted on June 5:
“After making several runs of varying lengths of time and at different valve openings, it was
discovered that the operation had caused a material pitting and erosion of concrete surfaces in the
draft tube throat and invert.” These areas were repaired by the end of the year. Engineers had
concluded that the problem could be eliminated by adding more air venting on the valve’s
discharge side, so they had a 36” calyx drill add vents in the No. 2 anchor block of Bays 13 to
18, where the discharge elbow was embedded. In August, tests proceeded with the needle valves
in Bays 13 and 14.\textsuperscript{565}

The needle valves continued to misbehave in 1946. Finding solutions was complicated by the
availability of only one penstock coaster gate, so only one unit could be tested at a time. The
needle valve in Bay 18 was tested a number of times, for varying lengths of time, in January
1946. The tests convinced engineers that it would be beneficial to install a 15’-long steel plate in
the draft tube invert to reduce concrete cavitation. More tests were launched after the plate was
installed and damaged concrete was chipped out and patched. During a 48-hour test in early
April, a steel nose on the draft tube’s west pier came loose and turned at an angle against the
flow of the water. This caused a good deal of damage to concrete in the vicinity, which was not

\textsuperscript{563} Bureau of Reclamation, “Instructions for the Installation of the Spillway Bypass Pipes, Needle Valves, Concrete
Supports and Anchors in the Right Powerhouse at Grand Coulee Dam,” Denver, December 1943, at RG 115, Design
Construction and Operation and Maintenance, Dams-Spillway Bypass, 1943-1944, NRG-115-00-148, Box 6, File
510, NARA-RMR.

\textsuperscript{564} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 12, 1944, 93; Bureau of

\textsuperscript{565} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 12, 1944, 27; Bureau of
completely repaired until January 1947. During this time, the needle-valve tests were suspended.\footnote{566} It was not until March 1947 that a project history could report: “The needle valve in bay R-9 [G-18] of the right powerhouse operated successfully during the month at 100 percent gate opening.” In addition to repairing the damage to the draft tube caused by cavitation, reinstalling the metal pier-noses, and adding to 36” vent holes, the diameter of the air vent to the discharge jet was expanded from 18” to 24”. The 1947 project history noted, with undoubted relief on the part of everyone involved, that “these extra vents, plus careful polishing of certain areas in the draft-tube inlet, so reduced the amount of cavitation that a subsequent 900-hour test showed only negligible erosion.” Based on this success, the same modifications were undertaken on the valves in Bays 13 through 7 in April 1947. Most of the work had been done by August 1 when a budget shortfall forced Reclamation to reduce its employees. As a result, the five needle valves remained out of service for the rest of the year. The problems and delays with the needle valves had caused Reclamation to cancel its plans for the needle valves in Bays 11 and 12 by the end of July 1947.\footnote{567}

The plan to install the needle valves had forced Reclamation to proceed with some work on the Right Powerplant. In the end of 1943, a 75-ton Shaw-Box overhead crane arrived from Boulder Dam, and by February 1944 it had been temporarily installed in the main generator room. A 14-ton gantry crane was set on rails on the draft tube bridge deck, and two dewatering pumps were put to work. It was also necessary to erect the gantry crane on the east abutment to remove temporary draft tube bulkheads and place permanent steel coaster gates. The structure of the 150-ton gantry crane, which was fabricated in the field, was erected between March and June 1944. It was equipped only with a pair of 11-ton electric hoists, which could handle the coaster gates. Other electrical and mechanical equipment was not needed until generator units were ordered for the powerhouse.\footnote{568}

Further development of the Right Powerplant did not seem imminent. The Left Powerplant was transitioning from start-up to standard operation and meeting all expectations. Between March 9 and April 27, 1944, it used all of river’s flow to produce power for an extended period for the first time. It set a production record on December 27, generating 952,000 kW an hour.\footnote{569}

For the first time since the project started producing power, no new capacity was added in 1945. This was fortunate because demand dropped dramatically with a decline in defense manufacturing in anticipation of the war’s end. During the first half of the year, the average daily peak load went from 900 MW to 600 MW. The trend continued, albeit at a slower pace, through the remainder of 1945, with a particular dip in September following V-J Day in mid-August. By

\footnote{569} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 12, 1944, 25, 29.
the end of the year, the average daily peak load was about 500 MW. The lower demand reduced the operational impact of a fire in May, which was caused by the failure of testing equipment being used by Westinghouse employees. The fire resulted in substantial damage in Bay 4. Repairs ranged from scrubbing soot off of walls in several galleries to replacing 40 percent of the finish on the concrete floor in the switch gallery. It was not until December that Bay 4 was returned to its pre-fire condition.\textsuperscript{570}

With the war over and demand for electricity dropping, Reclamation staff decided that the Shasta units had served their purpose at Grand Coulee and should be sent to their intended destination. In early December 1945, Reclamation shut down the unit in Bay 8 and began excavating concrete from the pit liner and from the adjacent Bay 9 wheel pit. The 1946 project history described how the “temporary concrete surrounding these units was removed, insofar as possible, by line-drilling large blocks, cutting the reinforcing steel, and then breaking the blocks out with hydraulic jacks. Blocks of concrete in excess of 80 tons in weight were removed in this manner, and loaded on flat cars by the powerhouse cranes.” The technique was so effective that only a very small amount of the concrete—1.25 percent—had to be chipped out.\textsuperscript{571}

The disassembly of the turbine unit in Bay 7 began in January 1946 and was completed by August.\textsuperscript{572} Disassembly of the transformers began in October. By December 31, “practically all the turbine and generator parts and four of the transformers have been shipped to Shasta Dam. The concrete excavation in bay 7 has been completed, and the removal of concrete from bay 8 is nearing completion.” Reclamation was poised to install new units in Bays 7, 8, and 9 when the Shasta units were gone.\textsuperscript{573}

\textbf{26. POLITICS AND PUMPING}

The relative calm of the post-war period did not last long, thanks to a nationwide housing crisis. There had been little residential construction during the economic downturn of the 1930s and virtually none during the war. The country’s aging housing stock was woefully inadequate to meet the demand from returning military personnel, who wanted to start families and bury memories of battle in the garden plots of new houses. The government’s slow response led veterans to hold massive protests in Washington, D.C., soon after the Armistice. As a result, housing became a federal priority, and Grand Coulee’s irrigation project suddenly became a priority as well.

Reclamation’s commissioner set the ambitious goal of irrigating 400,000 acres by 1950-1951 to support 10,000 new ranch houses, primarily for veterans. “The need for new, fertile, supervised,

\textsuperscript{570} Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 13, 1945, 124, 268.  
irrigated farms is imminent,” the 1945 project history noted, “and applications to Bureau offices for such farms are numerous and are increasing.”

The Pumping Plant was critical to the irrigation initiative. As with almost everything associated with the Grand Coulee project, the Pumping Plant would break new ground. It would raise about 5 million acre-feet of water annually from the reservoir to a canal on the bluff, requiring lifts of 295’ to 370’. The plant’s main features fell into four categories, a Reclamation report explained: “(1) the intake, which includes trashracks, piers, gates, and gate slots, (2) an elbow which connects directly to the pump, (3) the pump, and (4) the discharge conduit.”

The design of these features had been worked out well before the war’s end. Reclamation engineers followed methodology similar to that adopted for the dam, testing various concepts for the Pumping Plant with hydraulic models. A report issued in August 1939, for example, described tests of three alternatives for the intake components including “the trashracks, the entrance through the gates, the conduit, and the elbow under the pump.” The study examined three options for elbows and two for inlets. While these variables proved similar in terms of energy loss, “from the standpoint of velocity distribution in the conduit, the circular entrance was slightly superior to the rectangular one.” In the end, though, engineers selected a rectangular rather than a circular bellmouth for the intake, with the design combining “the functions of a modified bellmouth, a transition, and a 10-degree bend.” Not only did the design perform efficiently, it also required smaller—and less expensive—bulkhead gates and trashracks.

The elbow design was more of a challenge because of the desire to avoid, as much as possible, an unsymmetrical distribution of velocity as water flowed into the pump. This challenge was compounded by the elbow’s short radius. The 1939 tests found significant differences in the elbow models. (See ILLUSTRATION 13: Model study for pump intake, elbow, and siphon discharge.) One had a “circular entrance which changed progressively to an elliptical section at the outflow end.” The second had a “constant radius elbow with a gradual convergence from the intake pipe up to the pump inlet flange.” The third, labeled the “vane elbow,” was “a miter bend with a section containing vanes inserted at the intersection of the two segments.” The latter design was becoming common in aerodynamic applications for turning air, but its potential for hydraulic use was just beginning to be explored. “The vaned elbow,” the test concluded, was “definitely superior” to the other alternatives. Options for the turning radius were also evaluated: “After models of several elbow designs were tested in an effort to obtain minimum energy loss and optimum velocity distribution with the least possible radius of turn, an elbow of 100 degrees

575 Bureau of Reclamation, “Grand Coulee Pumping Plant,” July 25, 1940, 1, at RG 115, Engineering and Research Center, Project Reports, 1910-55, 8NN-115-019, Box 329, NARA-RMR.
577 “Pump intake, elbow and siphon discharge, model study,” 1940, Drawing 222-D-6090.
of turn, with a rapid acceleration of the water reducing to zero acceleration just before it enters the pump, was adopted.”

The water entered the base of a vertical-shaft pump. The pump runner had to be below minimum water level, but Reclamation wanted to minimize costly rock excavation. Operating at 60,000 horsepower at a 295' head with capacity of 1,600 cfs, the single-stage pumps would be exponentially larger than the 27,000-horsepower, 350' head, 423-cfs units at the Black-and-White-Sea pump storage plant in France, the world’s largest at that time. The Coulee pumps would easily best the 11,000-horsepower, 444' head, 200-cfs pumps at the Hayfield Plant on the Colorado River Aqueduct, the country’s largest. While doing most model testing for Grand Coulee in house, Reclamation turned to the California Institute of Technology for the pump studies.

Tests on the centrifugal pump were conducted in Pasadena between January 1938 and June 1940. The primary purpose of the tests, according Reclamation engineer D. P. Barnes, was to provide “a broad experimental background upon which to establish sound specifications.” The tests focused on two types of casing that seemed the most promising: “the double volute and the fixed vane diffuse ring,” with the tried and true single volute as a control. Barnes explained that “the most clear-cut advantages expected of them were the elimination of radial thrust and the structural economy supposed to result from the utilization of the additional tongue or of the diffuser vanes as tension members.” He added, though, that “the general hydraulic properties of neither of these types had been explored or could be reliably predicted.”

Barnes observed that although the tests were not definitive, they “demonstrated that balanced radial forces, wide operating range, small diameter, and good turbine performance can be achieved without sacrifice of efficiency and without hazard of instability.” All in all, “the diffuser ring pump and the double volute tested both provide adequate hydraulic properties and balanced radial thrusts on the impellers (approximately).” The final report cautioned: “To assure optimum performance of the final pumping unit the inlet structure and the pumps should be designed and tested together.”


The final design challenge was the siphon elbow at the end of each discharge conduit. A Reclamation report explained that the elbow, which would remain submerged in the feeder canal, “is designed similar to a draft tube, which accomplishes the twofold result of recovering velocity head and releasing the water with a low velocity into the canal.” When a pump was stopped, a solenoid-operated air valve at the elbow would break the vacuum to prevent a reversal of flow. Reclamation engineers built a 1:24 scale model of the elbow and air valve to test design options.\textsuperscript{582}

The ultimate number of pumps that would be installed was also a factor in the design. Reclamation had to make this decision before land surveys were completed, so it erred on the cautious side in estimating water needs and provided space for twelve pumps in the plant. A report in 1952 observed that “ten may prove to be sufficient, on account of planned economies in the use of water.”\textsuperscript{583}

Construction work on the Pumping Plant foundation had resumed in 1946 after a four-year hiatus. In anticipation of this, in May 1945, engineers had again begun debating the best way to deal with the lift seam and fragile rock structure above. A modified approach to doweling was proposed, using 61 rather than 177 dowels. Instead of the 2” diameter of the earlier scheme, though, the proposed “dowels” were actually bundles of six 70-pound steel rails, which would fill a 12” hole to a depth of 30’ to 40’. This proposal had a significant negative side effect in requiring the partial or complete demolition of the road above, the main public highway along the west side of the river.\textsuperscript{584}

As this plan was being developed, Reclamation authorized further diamond drill holes as part of an intensive study of the questionable area. The results were reassuring: except in the event of a severe earthquake, the rock appeared to be “relatively stable and quite safe.” In response to this news, the doweling plan was again revised, this time with the assistance of A. W. Simonds from Reclamation’s Denver office. It called for forty-six 6” composite dowels with an average length of 40’. Forty-three would be horizontal and three vertical. The placement of the holes was to be established in the field. A Reclamation report explained: “A dowel, fabricated from eight 1-1/4-inch and two 1-inch square reinforcing bars, with a ½-inch diameter grout pipe extending the full length of the dowel, was to be inserted into each of the holes and later to be grouted in place under low pressure.” The plan was successfully implemented—without a major impact to the highway above—between November 1945 and April 1946.\textsuperscript{585}

\textsuperscript{582} Bureau of Reclamation, “Grand Coulee Pumping Plant,” July 25, 1940, 2, at RG 115, Engineering and Research Center, Project Reports, 1910-55, 8NN-115-85-019, Box 1042, NARA-RMR.


With this work accomplished, Reclamation crews began low-pressure grouting of the Pumping Plant’s backwall, a process that had been started in 1939 but was interrupted until the doweling issue was settled. The maximum pressure of 40 psi was sometimes reduced even further to avoid displacing rock and opening seems. Reporting on the grouting in 1946, the project history observed “(1) that rock generally accepted a small amount or no grout at depths of 10 feet or more; (2) that grout travel was, in most instances, traceable only a very short distance from the hole being grouted; (3) that there are a few cases, to date, of grout seams appearing in cores from adjacent holes that were drilled subsequent to grouting; (4) that in some instances grout leaks were reported as much as 100 feet from the hole; and (5) that there were numerous surface leaks through which a large percentage of the injected grout was lost.”

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On the opposite side of the excavation area, Reclamation began removing rock in March 1946 by drilling and blasting, protecting the hemispherical bulkheads at the pump inlet pipes with sand-filled timber cribs. The waste rock was removed from the bottom of the excavation with Whirley gantry cranes that were erected on the wing dam starting in February. When the first crane was completed in April, it facilitated the erection of the second crane, was in operation by the end of May. These cranes were workhorses during the construction of the Pumping Plant. The four permanent cranes were not installed in the plant until 1950.

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During 1946, Reclamation completed the excavation of elevator shafts and inspection chambers on the backwall and the foundation for an administration building at the plant’s south end. Work also progressed on “the removal of the rubble wall along the top of the backwall and the benching of the rock, prior to the placing of a concrete retaining wall conforming to the revised grade of the adjacent highway.” In addition, “the downstream parapet wall along the pumping plant dam roadway from P-1 to P-7, inclusive, was removed to accommodate a revision in plans for the proposed pumping plant superstructure.”

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There were also improvements to the highway adjacent to the Pumping Plant. The road between the northern border of the community of Grand Coulee and the west abutment of the Grand Coulee Dam cut through the heart of the project’s Industrial Area. While this was a handy alignment during the early construction phase, it was increasingly problematic—and dangerous—to have the main public arterial running through the project’s mushrooming complex of warehouses and shops. The reoriented road would curve around the outside edge of the Industrial Area, keeping tourist and local traffic from disrupting operations and providing a scenic vista for drivers.

North of the Industrial Area, the road would return to its original trajectory but would be widened, requiring the removal of rock from the cliff edging its west side. The cliff was blasted

with the aid of fifteen to thirty drillers and the loosened rock was salvaged for use as riprap along the riverbanks downstream from the dam. The excavation started in 1945, and was almost completed by June 1946. Storm drains and a sewer-effluent line for the City of Grand Coulee were installed beneath the surface of the roadway. During the same period, the access road to the Right Powerplant was improved and a new access road was created from the highway to the Feeder Canal headworks and the Left Switchyard.589

The highways would carry visitors as well as local residents, so Reclamation, ever mindful of the importance of public relations, made plans to improve tourist facilities. A new vista area was developed on the east side downriver from the dam, near the caisson drydock. Work to excavate and grade the area began in May 1946. After a long hiatus of construction in the summer and fall, when the equipment was needed for work on the Feeder Canal, the project resumed in late November.590

The Feeder Canal disgorged into a reservoir created by two dams blocking the ends of the Grand Coulee. Reclamation opened bids for constructing the South Dam in 1946. Work had begun on the foundation of the North Dam early in 1942. The reservoir (later named Banks Lake) and the Feeder Canal, like the Pumping Plant, were crucial components of the irrigation project. Good progress was being made on the irrigation works through June 1947, when excavation of the Pumping Plant’s backwall was completed.591 Then in July, in an abrupt reversal, Congress slashed Grand Coulee’s budget with the start of the new federal fiscal year. The sharp drop in funding forced Reclamation to lay off 642 employees. By September, the workforce had dropped by 924 from its June peak at 2,685. This prompted leaders of the AFL union to come to Grand Coulee in October to investigate—just as another 100 employees were given pink slips. Yet another reduction in Reclamation’s labor force came in July 1948. “Henceforth practically all new construction work will have to be done by contract,” the project history announced. This made it difficult for Reclamation to improve minority hiring, an important goal in the post-war era. The 1946 project history reported that “eighty-six Negroes were employed on the Project during April.” For the entire year, “the number of Negroes employed out of a total of 2,442 employees, was 107, or 4.4 percent.”592

The reduction in Reclamation’s forces brought work on the Pumping Plant to a virtual halt. The only activity in the new fiscal year in 1947 was at the south end of the plant, where work continued sporadically on a drainage tunnel using crews that had time between other projects.593

By 1948, the pendulum had swung back again and funds became available to move forward with the Pumping Plant. In the fall, Reclamation awarded a $13.3 million contract to a joint venture of the Morrison-Knudsen Company and Peter Kiewit Sons’ Company to produce concrete, complete the Pumping Plant, excavate the Feeder Canal, install the pump discharge pipes, erect the Siphon Breaker Building, and other items. The team had received a $2.8 million contract earlier in the year to complete some work on the Right Powerplant and to construct the Right Switchyard and related transformer and tie circuits.594

The contractors took over operation of the government gravel plant and mixing plant, producing concrete for the Pumping Plant and for other contractors involved with construction at the site. In March 1949, the joint venture opened a new mixing plant, and some of the other contractors subsequently produced their own concrete.595

By 1949, completing the Pumping Plant was again a high priority, although the initial goals for irrigation had again dropped and the introduction of new acreage was staged. Instead of delivering water to 216,000 acres by 1952, the plan called for serving about 80,000 acres that year, with 60,000 acres added in each of the following years through 1958. The project history justified this approach: “These added irrigated lands as scheduled are needed to furnish food for the rapidly growing population of the Northwest and Nation, and incidentally, to sooner begin repaying their development cost to the Federal Treasury.”596

While the on-again, off-again funding had set back progress on the numerous components of the irrigation system, the deadline to open the Pumping Plant in 1952 had not budged. In fact, the Pumping Plant, Feeder Canal, and North Dam had to be ready by early 1951 so that the reservoir could be partly filled and the canals tested in advance. “Facilities in the ‘West’ and ‘East Low’ canals will be sufficiently developed in Fiscal Year 1951 to carry trial heads of water to prime the canals for regular duty the following year,” the 1949 project history asserted.597

To meet this aggressive schedule, Reclamation had to expedite contracts with contractors. It modified terms for the Pumping Plant contract with Morrison-Knudsen and Kiewit in September 1949. The project history that year noted that “two exceptionally cold long winters were hard on the contractor’s progress schedule and slowed down his operations materially, but if no serious contingencies arise in 1950, the work will be completed on schedule.”598

The concrete was poured for the plant’s substructure by April 1950 and for the intermediate structure by December. The first of the reverse-flow coaster gates was installed at the P-2 recess in August 1950. The concrete lining for the backwall was in place by June 1950, which allowed

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the structural steel for the ramp and parking area to be installed by October. The steel for the storage and service building roofs was also erected by that time.\textsuperscript{599}

Although the Pumping Plant had room for twelve pumps, only six would be installed initially. Reclamation had awarded contracts for the pump motors for Units P-1 through P-6 in 1946, ordering four from the Westinghouse Electric Corporation and two from the General Electric Company. All of the 3-phase, 13,800-volt synchronous motors ran at 200 rpm, with a horsepower rating of 65,000. Two motors shared a single generator. The powerful machines had the task of moving 1,600 cfs of water up the 280’ rise to the Feeder Canal.\textsuperscript{600}

General Electric was the first to deliver, installing the pump motors for Units P-1 and P-2 between November 1950 and July 1951. Westinghouse began work on the other four motors in the following month. The six pumps for these units were manufactured by a joint venture between the Byron-Jackson Pump Company and the Pelton Water Wheel Company.\textsuperscript{601}

Consolidated Western Steel Corporation, a subcontractor to Morrison-Knudsen and Kiewit, was responsible for installing the twelve discharge pipes for a fee of $1.2 million. The stiffener rings were attached at the Electric City storage yard, and the pipe sections were then transported by truck to the tunnels. “Installation began from the bottom of the tunnel up the steep incline to ‘combined bend No. 2,’ and from ‘combined bend No. 3’ downward to meet ‘combined bend No. 2.’” When the pipes were positioned, concrete was pumped to fill the space between the pipes and the excavated rock in the tunnel section. Reinforced concrete formed substantial anchor blocks over the bends at the crest and covered exposed sections of the pipes between combined bend No. 3 and the Siphon Breaker Building, which provided a transition from the cylindrical form of the pipes to the rectangular outlets into the trapezoidal-section feeder canal. Installation of the pipes started in March 1949, and Tube No. 1 was finished by the end of the year.\textsuperscript{602}

By May 1950, all of the pipes were in place. In the same year, installation was completed for the plant’s four cranes—a 60-ton bridge crane, a 70-ton gantry crane, and two 100-ton cranes on the south and north bridges—and for main Unit P-2. By June 1951, Morrison-Knudsen and Kiewit were virtually finished with the Pumping Plant, Siphon Breaker Building, and related construction.\textsuperscript{603}

During the same period, a memorial was being developed at the east abutment of the dam honoring President Franklin Roosevelt, one of the project’s major champions. Dedication of the memorial was supposed to coincide with a proclamation by President Truman on May 11, 1950, naming the reservoir behind the dam Franklin D. Roosevelt Lake. The memorial was designed by the George V. Nolte Company. Although the Nolte’s firm, which specialized in civil engineering and land surveying, was based in California, the founder was originally from Bellingham, Washington. The company apparently maintained an office there and was involved in a variety of infrastructure projects at Grand Coulee during the same period. Government forces crafted the concrete pedestal for the sculpture and landscaped the area. The bust of Roosevelt, though, did not actually arrive on-site until March 1953.\(^{604}\)

By that time, the world’s largest Pumping Plant with the world’s most powerful pumps had been in operation for almost two years. Unit P-1 was placed in service in May 1951, and P-2 followed in July. Both units continued to run until the end of the pumping season on September 20, and then were put back to work when the season was extended through October. Together, they filled the balancing reservoir with 671,000 acre-feet of water. A Reclamation report explained that the motors “are started as induction motors, and brought up to speed as synchronous motors. With a generator running at about half normal speed, and the corresponding motors at rest, the circuit breakers between generator and motors are closed. As the accelerating motors and decelerating generator approach synchronism with one another, the motor fields are closed. Then the synchronized combination is brought up to speed.” The report added: “Pumping units can be run above or below their normal 60-cycle speed, to lift water from a drawn-down reservoir or to increase output, or at synchronous speed when surplus generator output is to be delivered to commercial loads.”\(^{605}\)

By the end of 1952, Unit P-4 was in operation and Reclamation was supplying water to over 1,000 farms covering 27,000 acres, with the capacity to irrigate about 73,000 acres. A year later, 1,183 farms in the initial twelve irrigation blocks—63 percent of the total farms in these areas—had used the project’s water during at least some of the season, which ran from May 18 to July 24. The season was cut short because of a canal failure.\(^{606}\)


Reclamation let a $563,939 contract to install the pumps for Units P-5 and P-6 to the Eichleay Corporation in 1952; the work was completed by May of the following year. By the end of 1954, water was accessible to some 185,300 acres that were either developed or in a testing period.607

27. REPERCUSSIONS ON THE RIGHT

The Pumping Plant’s massive pumps demanded a good deal of power, which was provided by three units in the Left Powerplant. Since the demand for electricity was expected to rebound when the post-war economy stabilized, Reclamation planned to replace these units by installing units in the Right Powerplant. First, though, it brought the Left Powerplant up to its full capacity. Orders for turbine-generator Units G-7, G-8, and G-9 had been placed in 1941-1942, but their manufacture was delayed by the war. In 1945, the orders were reissued, with plans to bring G-7 on the line in October 1947, G-8 in January 1948, and G-9 in May 1948. Work would then concentrate on the Right Powerplant with Units G-10, G-11, and G-12 going on the line in 1949, joined by Units G-13, G-14, and G-15 in the following year.608

The accelerated plans for the Right Powerplant meant an end to the furtive experiment with needle valves at Grand Coulee. Although some concrete work had been started for the installation of needle valves in Bays G-11 and G-12, neither had received a valve, and Bay G-10 had not been modified at all, so preparing these bays for new turbine-generator units was relatively easy. Crews next moved to Bay G-13 where the concrete was cut into large blocks as it had been for the Shasta units. Weighing up to 35 tons, the blocks were recycled as riprap along the riverbank. By the end of 1948, the needle valves had been removed from Bays G-13 and G-14 and returned to Hoover Dam. The installation of needle valves in Bays G-16, G-17, and G-18, however, continued. Needle valve G-18 was ready for use first, followed by G-16 and G-17 in August 1949. Their service was brief. By the end of November the needle valve in Bay G-16 had been removed.609

Progress on the Right Powerplant went in fits and starts, with regular modifications to the schedule because of political influences and changing federal priorities, the resulting increases and decreases in funding, and swings in anticipated demand for irrigation and power.

Worker shortages after the dramatic reduction in federal funding delayed projects both big and small, including the modification of a section of the gallery in the Right Powerplant between Block 11 and the Pumping Plant at elevation 1250. Reclamation had started to create a combined visitors’ gallery and control-cable gallery in this area in early 1947, erecting a concrete-block wall to divide the two functions. Although terrazzo for the floor of the visitors’ gallery and

adjacent elevator lobby was placed by June and the initial grinding was completed by the end of July, there was no progress on the final grinding and finishing for the remainder of the year.\(^{610}\)

On a larger scale, the funding uncertainty and delays created a predicament for Reclamation. Although the optimistic plans to irrigate 400,000 acres by 1951 had been scaled down to a more realistic goal of 216,000 acres by 1952, the time frame was still tight. The 1947 project history emphasized that “to deliver any water at all to this land on that date requires the completion of all the major construction features. . . [including] the additional generating units in the Coulee Dam powerhouse, the pumping plant, the feeder canal, the equalizing reservoir, the main canal, and the lateral system serving the area to be placed under irrigation.” It warned: “The omission, or the failure to construct any one of these items, means a failure of the entire program.”\(^{611}\)

Still, the project was making progress. During 1948, installation of Units G-10 and G-11 was well advanced, with initial work started on G-12. Reclamation opened bids for the turbines for Bays G-13, G-14, and G-15 in December 1947, and Newport News Shipbuilding and Drydock Company of Newport News, Virginia, won the contract. The solicitation for the generators followed, with the Westinghouse Company winning the bid in March 1948. The coaster gates and most of the trashracks for the Right Powerplant were installed by 1949. The gates for Units G-16 through G-18 were in place in 1948, for G-9 through G-13 in 1949, and for G-14 and G-15 in 1950.\(^{612}\)

Unit G-10 went on the line in May 1949 after repairs that were required as a result of two successive coil failures during testing. Unit G-11 followed in July and Unit G-12 in September. With these additions, the generating capacity at the dam jumped from 992,000 kW to 1,316,000 kW. The project history observed that “the units are capable of producing about 23 percent above their rated capacities, when the water supply is ample and the available head is close to the maximum.” High tail water during flooding, however, reduced the head by as much as 50’, significantly affecting the output.\(^{613}\)

While the first three turbines were to make up for power being diverted from the Left Powerplant by the Pumping Plant, the order for the second group of three turbines was prompted by an abrupt increase in projected power consumption, a surprising turnaround from the downward trend during the period immediately after the war. The 1947 project history emphasized that “marketing studies and load forecasts by the Bonneville Power Administration, based on current demand and future indicated industrial development, signify a demand for the energy from all 9

\(^{613}\) Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 17, 1949, 36, 38, 42, 328.
main units in the right powerhouse as rapidly as they can economically be manufactured and installed.”

Although the full build-out was not initiated immediately, there was a growing sentiment that generating equipment should be installed in the three remaining bays of the Right Powerplant (G-16, G-17, and G-18). The fifteen units that would soon be in place at Grand Coulee would capture nearly all the power that could be obtained from the drawdown of the reservoir behind the dam, but a new factor would soon come into play upstream: Hungry Horse Dam. While the Hungry Horse project included a powerhouse, its significance to Grand Coulee was the massive reservoir the dam would create—some 3.5 million acre-feet of water—almost 3 million of which was active storage. This water could be used to even the flow of the Columbia River, allowing for a more efficient use of the turbines at Grand Coulee.

The three final units in the Right Powerplant were estimated to generate an additional 160,000 kW, assuming a 75 percent load factor. The additional power was primarily needed for peak loads, especially during two seasons. The first was winter, when water levels were low. The second was when the river was flooding and high tail water reduced the output of plants downstream including Bonneville and Rock Island.

The anticipated budget to place the units in service was $16.5 million—about $13.2 million for the machinery and equipment in the powerhouse and the remainder for transformers, transmission lines, and switchyard equipment. As of the end of 1949, the schedule called for G-16 to be operational by April 1951, G-17 by July 1951, and G-18 by October 1951. These would be preceded by Unit G-13 in April 1950, G-14 by July 1950, and G-15 by October 1950—a year behind what had been anticipated in 1946, but still far ahead of earlier projections. In addition, the third station service unit in the Left Powerplant was to be in operation by June 1950.

President Truman authorized construction of Units G-16, G-17, and G-18 in January 1949. In the following month, Reclamation awarded contracts for three 108,000-kVa generators to the Westinghouse Electric Corporation for $5.3 million, for three hydraulic turbines to Newport News Shipbuilding and Drydock Company for $2.5 million, for three governors to the Woodward Governor Company for $129,435, and for nine 43,000-kVa transformers to the General Electric Company for $906,819.

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615 Commissioner of Reclamation, “Supporting Data, Units R-7, 8, 9, Grand Coulee Powerplant,” December 1948 (advance copy), 3-5, 10, at Bureau of Reclamation-Boise, third floor.
616 Commissioner of Reclamation, “Supporting Data, Units R-7, 8, 9, Grand Coulee Powerplant,” December 1948 (advance copy), 3-5, 10, at Bureau of Reclamation-Boise, third floor; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 17, 1949, 56.
617 Commissioner of Reclamation, “Supporting Data, Units R-7, 8, 9, Grand Coulee Powerplant,” December 1948 (advance copy), 3-5, 10, at Bureau of Reclamation-Boise, third floor; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 17, 1949, 56.
The start-up of Unit G-13 in April 1950 raised Grand Coulee’s capacity to 1,424,000 kW, and another 108,000 kW came on the line when Unit G-14 was activated in July. The start of Unit G-15 in October brought the facility to 1,640,000 kW. The units continued to surpass the nameplate capacity by 23 percent under the most favorable conditions. The average load for the year was 1,314,300 kW, with a low of 683,000 kWh and a high of 1,886,000 kWh. Although the Korean War delayed and sometimes stopped the delivery of materials, requiring a search for substitute products, the final three units came on the line in 1951 on time or slightly earlier than expected: G-16 in April, G-17 in June, and G-18 in September. The final station service unit in the Left Powerplant, LS-3, was also put into service during the year, raising the facility’s capacity to 1,974,000 kW. Unit LS-3 was similar but not identical to its older siblings: the slightly more powerful 14,500 horsepower Francis turbine drove a generator rated at 12,500 kVa operating at 400 rpm.\(^{619}\)

With the installation of these units and the initial test of the Pumping Plant and irrigation works, 1951 was a watershed year. The project history remarked on “the final achievement of some of the long waited for goals. During this year the last of the generators was completed and placed on the line, ten years after the first one. Thus the goal was reached five years earlier than predicted by Mr. F. A. Banks in 1940, and certainly a long period ahead of the time many thought would be possible.” In addition, the launch of the Pumping Plant on June 14, 1951 “mark[ed] the beginning of a new agricultural era for the Columbia Basin.”\(^{620}\)

### 28. BANKS, BUCKET, AND BACKWATER

In the meantime, nature seemed to conspire with Congress to wreak havoc on the schedule. In May and June 1948, the Columbia delivered the fourth-largest flood on record, discharging at a rate of about 1 million cfs. The deluge claimed fifty-one lives and caused damage of over $100 million. The flow over the Grand Coulee spillway was more than 600,000 cubic cfs. The river flooded the floating caisson’s drydock, destroyed roads, and accelerated slides. Damage was particularly intense in the vicinity of the tailraces, where blocks of rock weighing as much as four tons were disturbed and banks were undercut by as much as 25’. As a result, Reclamation decided to install even more substantial riprap and to reduce the slope of some sections of the riverbank to a 6:1 angle, far flatter than the 3:1 ratio that model tests had indicated would be adequate. Some of the riprap was placed later in the year under emergency procedures in anticipation of a comparable flood in 1949.\(^{621}\)

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The floods highlighted a tenacious thorn in Reclamation’s side: the unstable ground along the riverbanks and bluffs. Some in-house and consulting engineers, including Charles Berkey and Frank Banks, had been leading the charge to combat this problem since before construction of the dam began. In January 1949, they participated in yet another meeting of the Board of Consulting Engineers that focused on the issue and possible solutions: “The three primary causes of instability of these side benches are (1) undercutting at the river edge, (2) heavy overburden load, and (3) excessive sub-surface water. Remedies in general are (a) protection of the toe portion by riprap against serious erosion by the river, (b) removal of a portion of the overburden, (c) removal or control, by adequate drainage provisions of the underground waters.”  

Worries about the impact of floods in 1949 proved justified. In response to the damage from that torrent, Reclamation undertook a major initiative in December 1949 to stabilize and reinforce both riverbanks below the dam. The project entailed relocating utilities, removing the tracks of a tourist railroad that Reclamation had developed between the west vista house and powerhouse after World War II, flattening the slope of the west bank for a distance of 2,500’, and installing reinforcing on both banks. On the west bank, about 182,000 cubic yards of material was removed between the highway bridge and the powerhouse. The new slope was protected by a 30” gravel filter blanket topped by a minimum of 5’ of riprap and, finally, a 5’ layer of armor rock. Most of the rocks in the top layer weighed 3 to 6 tons, but the largest tipped the scale at 53 tons. A similar approach, but without the filter blanket, was adopted for the east side, with the rocks averaging 4.5 to 6 tons. By the time the project was completed in April 1951, the contractor had placed 768,421 tons of riprap and 339,904 tons of armor rock.  

Another response to the flood was a postmortem by Reclamation’s hydraulic laboratory in Denver, culminating in a report issued in 1952. The “Study of Height and Frequency of Waves Acting on Tailrace Slopes and Riverbanks during [the] 1949 Flood Season” came to the not-so-surprising conclusion that “the wave action generated by the spillway flow in the Columbia River immediately below Grand Coulee Dam is irregular.” The report added: “The frequencies vary from 0.6 to 1.5 waves per second and the heights from 3 inches to 7.5 feet for flows in the neighborhood of 300,000 cfs. . . . Waves between 15 and 20 feet high can be expected . . . during a capacity flood of 1,000,000 cfs.” The waves dislodged riprap along the riverbanks: “Rocks up to 6 inches will be tossed together with logs and other debris into windrows along the shore. There will be considerable readjustment of larger material particularly where the slopes are steep or piles of the material exist. Much of this readjustment will take place as a result of the smaller material being washed from between and beneath the larger, causing the latter to roll down the slopes.”  

The floods also gave the spillway bucket a beating. Reclamation had started to address this damage before the 1949 flood, awarding a contract to repair the bucket and dredge the river channel to the Pacific Bridge Company of San Francisco in January. The first step was to install concrete seats to anchor the caisson to the damaged spillway. The caisson was moved from the drydock and tethered in the channel in late August so that Pacific Bridge could complete the final assembly an A-framed seat frame, which held the formwork for the seats, in the dewatered drydock. About a month later, when the seat frame and forms were ready, the drydock was flooded. A specially designed scow picked up the frame and floated it to the spillway. The plan was to secure the frame to the dam, carefully level the seat forms directly on the bucket, force “Prepakt” concrete into coarse aggregate in the forms, and grout the seats, using a patented intrusion method.\footnote{L. Vaughn Downs, “Floating Caisson Facilitates Repair of Grand Coulee Spillway Bucket,” \textit{Civil Engineering} 20 (April 1950): 256-257; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 17, 1949, 130.}

The first trial of the installation began in September at Block 58: “The frame was . . . accurately lowered into position. The area to be covered by the seats was first cleaned by jetting and was then formed off by driving wooden sheathing down the sides of the frame onto burlap bags, ropes of oakum or bags of grout. After most of the caulking was completed, grout was introduced on October 11.” Numerous leaks resulted in the use of about four times as much grout as predicted, an ominous sign. After allowing the seat to cure for five days, the frame was removed. The result was disappointing: “Eighty percent of the seat had failed to bond, and had broken off when the seat was lifted.” A second attempt at Block 56, however, met with success: “The seat was left in very good condition for the floating caisson, and a tight fit was anticipated.”\footnote{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 17, 1949, 133, 140.}

Although the seats in Block 58 were not ideal, they were considered acceptable enough to accommodate the caisson when they reached a strength of 3,500 psi. The caisson was moved into position for its first operation in October. Cables controlled by hoists on shore guided it to Block 58, where it was lowered. The block was unwatered by October 24 and the contractor began repairing the spillway bucket a week later. Within a month, the deteriorated concrete had been removed and replaced.\footnote{L. Vaughn Downs, “Floating Caisson Facilitates Repair of Grand Coulee Spillway Bucket,” \textit{Civil Engineering} 20 (April 1950): 258; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 17, 1949, 44; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 18, 1950, 113-114.}

The repair of Block 56 was tackled in December and completed by the end of January 1950. Greater deterioration required more time to fix Block 54, but that work was done by the end of March. Reclamation awarded Pacific Bridge a new three-year repair contract in the fall of 1950 for almost $2.7 million. The contractor completed three blocks before the end of the year, when work was stopped by unseasonably high water levels.\footnote{L. Vaughn Downs, “Floating Caisson Facilitates Repair of Grand Coulee Spillway Bucket,” \textit{Civil Engineering} 20 (April 1950): 113-114, 258.}
The process of positioning the caisson and completing the repair work was carefully choreographed. Before the caisson was lowered, divers cleaned the seats to ensure a good connection. Rubber seals 6" thick and 12" wide created a watertight connection between the seat and the caisson, which was pumped dry in three to five hours. Pumps and piping for dewatering and to control ballast were in two of the caisson’s four shafts. Another held an elevator that delivered workmen to the spillway surface some 70’ below the waterline. There, in areas that had 1" or more of erosion, they removed concrete to a depth of at least 18". Steel anchor dowels measuring ¾" in diameter were inserted into the remaining spillway concrete to a depth of 30" or more in rows 18” apart, on 3’ centers. Bars of the same dimension on 18” centers formed a reinforcing mat 5" below the surface of the new concrete that filled the void. It took three to four weeks to install a complete set of seats. Between each set, the frame was brought back to the drydock to replace the sheathing.629

When conditions allowed it, the contractor ran three shifts a day, seven days a week, and employed up to 213 men, with an average force of 160. “The contractor carried out all phases of the repair work with vigor, using a well-balanced organization,” Civil Engineering observed. “The contractor is to be commended for the safe practices employed; considering the character of the work, the safety record has been good.” The article added that “special mention should be made of the successful work performed by divers. Their inspection of conditions in the bucket under rather hazardous circumstances over a period of years is noteworthy, and the eminently satisfactory construction of the caisson seats and the repair of the right training wall by underwater Prepakt methods were remarkable performances. Their work as individuals and as a craft warrants special commendation.”630

A face caisson was used to inspect and repair areas on the face of the dam that were below water, yet too high to be reached by the floating caisson. The face caisson was 59 square feet, weighted 250 tons, and rose 9’ high. Its interior held an unobstructed working chamber about 4’ high. Assembled between June and November 1949 by Morrison-Knudsen and Kiewit, the face caisson was immediately leased to the Pacific Bridge Company. After divers caulked substantial leaks in the caisson, it was dewatered and Pacific Bridge workers began repairing spalled areas.631

While Reclamation could find solutions to physical problems created by the dam, it was not as successful at combating issues introduced by outside forces—such as the Corps of Engineers. The animosity between Reclamation and the Corps over Grand Coulee had been dormant since Reclamation won the right to develop the site. It was reignited in 1949, though, when the Corps

proceeded with plans to develop Chief Joseph Dam only fifty miles downstream. The backwater from the dam would affect the operation of the Grand Coulee plants. The challenge was to set a pool level that would optimize the power production of both facilities. “The solution is complex and no definite conclusions have been agreed upon in 1949,” Reclamation’s project history observed. “The Chief Joseph pool elevation has been tentatively set by the Army Engineers at 940 feet above sea level . . . which elevation would cause some loss of head at Grand Coulee Dam at all river stages.”

29. TUNE-UPS AND OVERHAULS

Operations had settled into a routine until March 14, 1952, when a major disaster was narrowly averted. Contractors were in the process of painting steel liners in the outlet conduits at elevations 1036 and 1136. An operator who was opening downstream gates to drain water from the conduits accidently opened an upstream gate in Block 55 at elevation 1050 at the same time. The river surged into the 102"-diameter tube at great force, popping open a manhole cover. Water streamed into the 1050 gallery through the manhole and poured down shafts into the turbine pits, washing out oil from the lower guide bearings and causing malfunctions. Just before noon, Unit G-9 was shut down, followed shortly thereafter by Units G-7, G-8, G-15, G-16, G-17, and G-18. The units were carefully restarted during peak demand hours, then shut down again for servicing. In the meantime, Reclamation employees Norman Holmdahl, Don McGregor, and Milton Berg were braving the water’s force to reach the controls for the gate in Block 55. They finally succeeded, saving equipment from further damage and ending a potential threat to the structural integrity of the dam.

To prevent such an incident from reoccurring, Reclamation designed bulkheads and doors to close off galleries within the dam. Contractor Hazen F. Willett of Brewster, Washington, completed the installation between January and August 1954. Reclamation apparently put an additional seven aluminum bulkheads in place in transverse galleries in November and started work on another seven in December. A further safeguard came a decade later, when Reclamation ordered eight motor-driven pumps from Fairbanks-Morse and Company for draining the powerhouses in an emergency.

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632 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 17, 1949, 65. The elevation of the pool would remain a source of contention: it was raised in the 1970s and again in the 1980s, ultimately reaching elevation 956.
634 Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 22, 1954, August monthly report, 1, November monthly report, 2, December monthly report, 3, and annual progress report, 7; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 32, 1964, monthly progress report for July, 1, monthly progress report for October, 1, and monthly progress report for December, 1, 3; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 33, 1965, monthly progress report for April, 4. When the first motor for the emergency pumps in the powerhouses was tested at the Fairbanks-Morse manufacturing plant in Beloit, Wisconsin, in July 1964, it failed. The delivery date for the motors was supposed to be August 24, but the project was only 85 percent complete by the end of October. The pumps were finally shipped from Beloit in the end of
The project was hit with another accident in December 1952, this time in the Pumping Plant, where fire damaged the P-5 discharge pipe. “Scaffolding and canvas wind breakers, ignited by sparks from a welder’s torch set fire to the coal-tar enamel paint in the discharge pipe,” the project history reported. “Traveling quickly up the pipe the fire escaped through the siphon breaker and, fed by the stack-like draft, burned off the enamel, warped the pipe in places and cracked an anchor block.” Reclamation held the contractor responsible for making necessary repairs, which were apparently completed by the following spring.\(^635\)

Most maintenance and repair work, however, was completed without incident. The hard-working equipment had to be taken out of service on a periodic basis for a major overhaul, which in the mid-1950s included “installation of a new type seal on penstock coaster gate, repair of damaged paint areas in penstock, repair of cavitated areas on water wheel, replacement of seal ring inserts, wicket gate bushings; stainless steel bushings on lower wicket gate stems; repairs to stator windings and replacement of rigid amortisseur and field pole connections with flexible connections; and many minor details of repair to piping, coolers, permanent magnet generator, bearings, governor, and other items.” Unit G-6 underwent an initial overhaul 1956, followed by Unit G-5 in 1956-1957, Units G-7 and G-9 in 1957, and Unit G-18 in 1957-1958. The rest were tackled in subsequent years, with the Left Powerplant completed before work on most of the units in the Right Powerplant began.\(^636\)

Other projects aimed to improve the facility’s operation. In 1956, for example, Reclamation hired Marine and Industrial Supply of Seattle to install a centralized grease lubricating system for the turbines. The contractor started in the Right Powerplant and then moved to the Left Powerplant, finishing in April 1957. A more substantial upgrade for the thrust bearings was launched in 1962. Reclamation negotiated a $400,000 contract with the Westinghouse Electric Corporation that included several items: providing seventeen high-pressure thrust-bearing lubricating systems and eighteen multiple support thrust-bearing systems; reconditioning babbitted shoes to work with the multiple support systems; and furnishing other parts for related pumps and lubrication systems. Unit G-12, the first to be overhauled, was ready to be tested in March 1963. After being stopped and started 114 times, the bearings were inspected and found to be “in excellent condition,” according to the project history. Five additional units were completed by the end of the year and two more were underway.\(^637\)

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Reclamation also monitored repairs that had been done previously, such as the major initiative to fix the spillway bucket in the early 1950s. When divers investigated the repairs in 1960, their findings were positive, for the most part: “The bucket was clear of foreign materials except for a small accumulation of sand and gravel in Block 62.” However, “there appeared, for the first time, erosion on the surface of blocks repaired by Pacific Bridge Company prior to 1953. The surface mortar had been removed in many areas and aggregate was appearing in relief to depths of 1/8-inch, with a few isolated areas showing a depth of 1/2–inch. The ‘Prepekt’ patch in the west face of the right training wall was partially gone, and there was increased erosion in the ‘Prepekt’ repaired area of the bucket apron adjacent to the training wall.” Another round of examination by divers in 1961, however, determined that the damage was not as severe as feared.638

Some projects were accomplished by in-house workers. A long-term project to repair the ring-seal outlet gates at elevations 1050 and 1150, for example, was completed by small crews when schedules allowed. By the end of 1958, the crews had finished ten gates, including three done during that year. Five more were added to the tally in 1959. A total of forty-two were done by the end of 1963, fifty-one by the end of 1964, and sixty-eight by the end of 1965, including all forty gates at elevation 1150.639

The concrete at the end of the steel liners of these outlet tubes received attention in 1959 when engineers became concerned about cavitation. A repair program was launched the following year, with several types of epoxies used as bonding agents and in mortar mixes to fill the cavitated areas. To avoid repetition of the problem, a groove was cut into the trough wall of each tube just downstream from the liner in an attempt to change the flow’s trajectory. The idea proved effective: “One repaired tube, without groove, was operated for a period of 1,800 hours and then opened for inspection. It was found that the repaired patch was gone and considerable new damage had occurred to the concrete in the trough invert. A companion tube, with groove and same hours of operation, was in excellent condition.”640

Other modifications were not so quickly implemented. Putting flashboards on the drum gates, for example, took nearly a decade of consideration. Between 1952 and 1954, Reclamation’s commissioner, regional director, chief engineer, and others evaluated the merits of installing flashboards to raise the elevation of Lake Roosevelt by 2’. Although a relatively small change, the flashboards would increase the storage capacity of Lake Roosevelt by about 163,000 acre-feet. Engineers evaluated four main issues: structural modifications required for installing the

Flashboards, functional concerns related to the facility’s operation, legal factors associated with land edging the reservoir, and political issues dealing with the biggest upstream property holder, Canada. After lengthy analysis, the regional director recommended proceeding with the flashboards. They were not installed, though, until mid-August 1961, and then it was in response to a request from the Atomic Energy Commission, which operated the Hanford nuclear facility downstream. Although the facility had not been completed during World War II, when it had been established to produce plutonium for atomic weapons, its construction continued into the Cold War era. The Atomic Energy Commission put several of the plant’s reactors into operation between 1950 and 1955, and began installing the ninth reactor, the first to produce steam for generating electricity in addition to plutonium, in 1959.

Water from the Columbia was used to cool the giant reactors. Beginning in the late 1950s, the Commission asked Reclamation to release water through outlet tubes to lower the river’s temperature. Given the existing storage capacity in Lake Roosevelt, this meant diverting water that could otherwise be used to spin Grand Coulee’s turbines. Both needs could be satisfied with the extra storage created by the flashboards. The Atomic Energy Commission was quick to take advantage of the new flashboards, requesting 192 gate operations in 1961 compared to only 6 in the previous year. The total duration of the openings likewise jumped from 908 to 5,277 hours. The numbers dropped to 30 gate operations and 2,381 hours in 1962, 15 gate operations and 2,644 hours in 1963, and 20 gate operations and 3,544 hours in 1964. The outlet tubes were used periodically for thermal control for the Hanford project until the mid-1970s, by which time only one reactor remained in operation.

The operation of the flashboards, which was overseen by the Bonneville Power Administration, was sometimes complicated by natural factors. In December 1963, for example, crews were unable to remove the iced-in boards. The project history speculated: “In the future severe icing conditions may become more of an operational problem because of higher reservoir levels extending into the normally colder winter months. This problem is currently being studied for possible action to reduce the leakage between the flashboards which contributes to windblown spray and ice formation.”

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During the long period when the installation of flashboards was under analysis, the demand for electricity—and the related output of Grand Coulee—experienced some ups and downs. In 1955, the peak month was August, when 1.4 billion kWh of electricity was generated. The maximum daily production that year, almost 51 million kWh, was reached on August 30, and the maximum hourly production of 2.27 million kWh was on September 27. In 1956, the peak hourly load of 2.278 million kWh occurred early in the year, on January 31. August was again the highest month, although its tally of 1.35 billion kWh was slightly down from the previous year. The same was true for the total annual generation of 13.7 billion kWh. Peak loads were lower in the following year, although Grand Coulee broke a world production record for the month of August 1957, generating 1.56 billion kWh. This bested its previous maximum, also a world record, by almost 43 million kWh. The total generation for the year was about 13.5 billion kWh.\(^{645}\)

Power generation at Grand Coulee was lower in 1958. At the end of the year, the total stood at about 11 billion kWh, with 1.23 billion kWh in September, the peak month. Production rose slightly in 1959 to 11.5 billion kWh, but was still well below the plant’s record. While the drop was influenced by milder weather and less demand from industry, the main factor was new capacity at other locations in Bonneville’s system. Grand Coulee’s 1959 project history explained that the “installed capacity in the new Federal plants has been considerably greater than the increase in power requirements for the system.”\(^{646}\)

The 1960s started with the pattern of lower demand that was established in the late 1950s. Although the 12.3 billion kWh produced in 1960 was a noteworthy increase from the previous year, the project history reported that “generation at Grand Coulee was largely determined by downstream water requirements and maintenance outages.” Generation was around 12.5 billion kWh in 1961 and 1963, about 715 million kWh more than it was in 1962, and reached only 1.5 billion kWh in 1964. The trend changed in subsequent years, though, with output jumping to just over 13 billion kWh in 1965 and 14 billion kWh in 1966. It was in anticipation of ongoing increases that Reclamation had laid the groundwork for a major expansion earlier in the decade.\(^{647}\)

30. PUMPING FOR POWER

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In the early 1960s, the Pumping Plant seemed to be holding its own with the six pumps that had been installed. When the 1964 irrigation season started in late April, for example, only three pumps were needed to maintain the level of Banks Lake. All six pumps ran from May 1 to July 23. For the next couple of months, “pumping continued periodically to meet irrigation demands.” Around 2.1 million acre-feet of water were pumped during the season, with the pumps powered by 723,763,000 kWh of electricity from the Right Powerplant. By 1966, the hard-working pumps had seen enough service to merit overhauling. Unit P-5 was the first in line because it had some structural cracking that could not be fixed in place.648

By this time, plans were advancing to expand the plant’s capacity in anticipation of future needs. In the early 1960s, Reclamation had begun exploring the feasibility of installing the six additional pumps that the plant could accommodate—and the possibility of installing a different type of unit. According to a report entitled “Justification of Accelerated Construction of Pumping Units P-7 and P-8”: “Consideration has been given to construction of the remaining 6 pumping units as reversible pump-turbine units which could be used to help meet peaking power requirements when such peaking capability is required in the relatively near future.” That report was issued in August 1963. By September 1964, Reclamation had gone well beyond “consideration” with a “Plan of Development”: “Power demands in the Pacific Northwest will justify the installation of units P7 and P8 as pump-turbine units.”649

The pump-turbine units would supplement the main turbine-generating units when demand surged: “During the operation of an electrical power system there are periods throughout the day when the demand for power is at a peak. One method of providing electricity to meet the peak load is by a pumped-storage operation. Briefly stated, the principle of a pumped-storage operation in a hydro-power generating plant is to pump water from a low level source to a high level storage reservoir by using off-peak energy, and then releasing the stored water through hydraulic turbines for power generation during the periods of peak loads.” This operating cycle would increase the fluctuation of the water level in Banks Lake, but only by a few inches a day during regular operations. A maximum drawdown of 2’ was anticipated.650

Reclamation was eager to proceed, but timing was a question. Canada was developing a plan for storage on the Columbia River and was negotiating a related treaty with the United States. Installation of pumping Units P-7 and P-8 was scheduled for April 1973 based on anticipated irrigation demand, but there might be justification for bringing them on line as early as 1968 under various scenarios related to Canadian storage and power production. Reclamation planned

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to install Units P-9 and P-10 in 1980 and P-11 and P-12 in 1986 as more land was cultivated. Together, these six units would be rated at a capacity of 291,000 kW and could actually produce 207,800 kW. Studies found that this increased capacity was “justified and feasible,” even in light of something far bigger on the horizon—a third powerplant.  

In the end, the installation schedule was not accelerated, but when plans for the six new units went ahead, they were pump-generators. Reclamation called for bids for P/G-7 and P/G-8, the first two units with reverse-flow wheel mounted gates, in 1971. The Scott Buttner Corporation of Oakland, California, won the contract with a low bid of $1.9 million. This covered supplying and installing the pumps, turbines, and related equipment, and modifying the discharge line outlets. The units would be manufactured by Nydquist and Holm Aktiebolag (NOHAB) in Trollhatten, Sweden. Both units were essentially the same, although Reclamation experimented with two different types of steel for the runners: “Swedish 2RM2” for unit P/G-7 and “Number 18-8” in P/G-8. Supplying the generator/motors was not part of the contract; Reclamation purchased these directly from the Westinghouse Electric Corporation. Buttner, though, was responsible for structural and finish work in the plant that was related to the pumps’ installation.

The contractor began modifying the Pumping Plant in January 1972. On May 2, the draft tube in Bay 7 was dewatered, allowing work to start on installing the makeup section. The scroll case was in position by early July. Hydrostatic pressure testing revealed leaks, forcing modifications to the grout vent pipe system. The grouting of the draft tube and scroll case was not completed until the end of August, which delayed preparation of the foundations. This, in turn, delayed Westinghouse’s installation of the motor/generator for Unit P/G-7. Installation of the pump/turbine was also behind schedule because the shaft did not arrive until late September. The shaft was positioned and bolted to the runner, which was already situated in the scroll case, after the second-stage concrete was placed. The work was almost finished by the end of the year. Outstanding items—“systems for electrical controls, excitation, automatic lubrication, wheel-mounted gate operation, and unit cooling water”—were done by August 1973, and tests of the unit were initiated. By early November, the unit was ready to go.

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The setbacks with Unit P/G-7 caused a chain reaction, putting Unit P/G-8 behind schedule. The unit’s draft tube was dewatered just a few days after its neighbor, but its scroll case was not installed until mid-August and not tested until the end of October. In early November, the pump/turbine and motor/generator shaft arrived. After Westinghouse started installing the P/G-8 motor/generator in January 1973, though, work progressed quickly and almost caught up with Unit P/G-7, being substantially complete by late November.\(^654\)

The units served as pumps during the 1974 irrigation season. The generators were tested that September using 5,515 acre-feet of water from Banks Lake, with Unit P/G-7 generating about 1 million kWh of electricity and P/G-8 about 6,000. In 1975, their first full year in service, the units generated 4.9 million kWh of electricity using 18,770 acre-feet of water and pumped 20,072 of the entire plant’s 2.2 million acre-feet total. This was despite the “discovery of a serious mechanical problem” with both units in April. “Since the acceptance tests were completed last December,” the 1975 project report explained, “the P/G-7 voltage regulator had never functioned properly,” and the regulator failed shortly thereafter. “Preliminary investigation indicated that the C-phase intelligence current was 180º out of phase with C-phase voltage.”\(^655\)

A Reclamation engineer was sent out from Denver in late February 1975 to investigate the equipment. While he was able to make modifications to temporarily correct the problem on Unit P/G-7, “P/G-8 was a different story.” A ripple produced by a power bus supply module caused a stabilizer to malfunction, and changing out the module led to problems elsewhere. Ultimately, NOHAB decided that necessary repairs could best be done in its Swedish factory. In June, Unit P/G-7’s twenty servomotors, twenty pilot valves, and related components were packed in eight crates, weighing a total of over 42,000 pounds, and sent to Seattle, where they were loaded onto a ship. The repaired units were back at Grand Coulee before the end of the year. Then, the servomotors and pilot valves from Unit P/G-8 made the voyage to Sweden.\(^656\)

Although “NOHAB provided completely redesigned and fabricated servos and wicket gates for the two units,” the problems continued into 1976. This was especially true for Unit P/G-7, which was used intermittently for pumping starting in mid-January. The unit was scheduled to be inspected in mid-April, but that date was pushed up to March 22 after the unit produced excessive vibration and noise. Some unexpected wear was visible during the March inspection, but the unit was returned to service until “graveyard shift April 2, [when] P/G7 was shut down


due to the loss of oil in the governor system and excessive vibration and noise that caused the personnel in the turbine pit to feel nauseous after a relatively short exposure."657

Engineers from Reclamation’s Denver office and NOHAB conducted tests to develop limits within which the unit could be operated safely, and it was again returned to service. The next scheduled inspection in October revealed that eleven of the wicket gates were structurally damaged and several others had moderate damage. Reclamation staff attempted to weld cracks in the wicket gates and repair other damaged areas with the equipment in place, but they were skeptical about the outcome. This proved well justified, as “malfunction of both units persisted.”658

The fate of the units remained in limbo until mid-1977, when Reclamation and NOHAB negotiated an amendatory agreement. Buttner, serving as a subcontractor to NOHAB, started installing new wicket gates and making other modifications for Unit P/G-7 in October and Unit P/G-8 in early 1978. Reclamation tested the reconstructed units in June and July. Both appeared to be fixed. Unit P/G-7 was put to work pumping for most of July until it was shut down because of oil leaks in wicket gate pilot valve oil return lines. This time, the wicket gate stem seals had to be replaced. The 1978 project history remained optimistic regarding progress in the upcoming year: “All P/G-7 and P/G-8 corrections were expected to be completed by the end of January, with final adjustments to be made when the units were in operation during the 1979 pumping season.”659

Still, the equipment was far from perfect. An entry on Unit P/G-8 in the 1978 project report is illustrative: “The greasing system wouldn’t work. There were two completely different wiring diagrams and one schematic for it; none of them were correct. They appeared to be for some system other than that on either P/G-7 or -8. The greasing system could be made to work by placing the interrupt switch in the wrong position—‘OFF’—unless the ‘ON’ position was incorrect, making ‘OFF’ the correct position. But if this was the case, then P/G-7 was wrong. Whichever the situation, the interrupt switch was not shown on any of the drawings.”660

In January 1979, grease relief headers were installed on both units, and wicket gates and other turbine components were adjusted. The test came in May when the units were activated. While they performed pumping until October, the project history reported that “unresolved problems

remained at the end of 1979. One was the relief pipe grease and water mixture, which water pressure forced from the wicket gate bushings. Another (revealed in an inspection after the 1979 pumping season) was the development of cracks in the P/G-7 wear ring liner welds,” an area where repairs had been undertaken in the previous year. Reclamation looked forward to the completion of P/G-9 through P/G-12, when the two recalcitrant units could be disassembled.  

The older pumps were less troublesome but were not without an occasional issue. Unit P-6, for example, was shut down in June 1977 “when a cyclic metallic banging noise began in the turbine pit.” An examination using a fiberscope found that “the east plate had separated from the crown plate,” but the cause of the failure could not be determined until the unit was disassembled. Then, “the inspection revealed that the original broken fastener ends on the outer bosses and the outermost stiffener studs had been worn down by contact with the rotating plate.” The unit was repaired and plans made to inspect Units P-1 through P-5 for similar problems.  

31. INTERCONNECTIONS AND UPGRADES  

Federal and other power generators in the Northwest signed the Pacific Northwest Coordination Agreement in 1964, unifying the operation of all the reservoirs on the Columbia River and its tributaries. This enabled the most effective use of the entire system to maximize the power potential of its hydroelectric plants.  

With the increased production anticipated from the pump-generating installation and the growing sophistication of transmission equipment and system management, Grand Coulee became even more closely linked to the Bonneville Power Administration. During the early 1960s, load and frequency control equipment was installed in federal powerplants along the Columbia River, including Grand Coulee’s Right Powerplant in 1962. This equipment allowed BPA’s dispatch office to operate the plants from a remote console in Portland, Oregon. Components of Grand Coulee’s control system were modified in conjunction with this change, and a number of system monitors and alarms were added. Some equipment, such as the main unit penstock drain valves, was converted from manual to motor operation.  

Another step came in June 1963 when Reclamation ordered a central control board, console desk, and auxiliary equipment for the Left Powerplant from the North Electric Company in

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Galion, Ohio. The equipment, which cost $57,800, arrived the following March and was installed in the plant’s main control room next to the dispatcher.\footnote{665}

The process of converting Grand Coulee to centralized control went slowly but steadily. Although the stop-start control circuits for Unit G-4 were tested in 1965, the circuits were not yet installed on all of the main units. Plans called for the system to be in place, tested, approved, and in use by March 1966. Installation of controls for the Pumping Plant went much more quickly, with the centralized power control system in operation for the entire 1965 season.\footnote{666}

Within two years, weaknesses in the equipment became apparent, and it was clear that the system would be inadequate when the plant was intertied with the national power grid. Grand Coulee’s 1968 project history reported that “experimental models of a newly designed electronic voltage regulating system were installed on generators L-1 [G-1] and L-4 [G-4] in an attempt to evolve an improved system with a quicker and more closely controlled response than on the original equipment.” This experiment was unsuccessful, leading Reclamation to consider “a more extensive and exacting approach that will require major modifications to the unit excitation system.” In the meantime, new controls for the 115-kV Switchyard and the Consolidated 230-kV Switchyard were in place.\footnote{667}

While the transition to a consolidated control system was underway, a dramatic fault served as a deadly reminder of the inherent dangers of working with electricity. On the afternoon of August 18, 1964, when maintenance work was being done on the Right Switchyard and on generator G-12, an operator accidentally reenergized the G-12 transformer too soon. Current rushed into the generator bus, “resulting in heating and arcing. The arcing immediately involved the bus housing, resulting in a three-phase to ground fault. The tremendous arc soon vaporized the generator disconnect switch, the bus housing, portions of the copper bus, the supporting steel structures, and the generator surge protective cubicle located directly below the disconnect switch.” The heat was so intense that the steel floor grating above the generator bus gallery melted, producing a 2’ x 6’ hole. During the forty-second duration of the fault, the main power transformers caught fire and one was totally destroyed; “the other two are in a highly questionable condition.” In the meantime, “a dense, toxic smoke from the heated fluid in the capacitors and potential transformers was so thick that lights in the gallery could not be seen.”\footnote{668}

A board of inquiry charged with investigating the incident concluded that “the actual sequence of events following the fire is difficult to reconstruct accurately.” A primary cause of the incident, though, was easier to identify: “The plant Operating Section is currently understaffed and . . . this

\footnotesize{\begin{itemize}
\item \footnote{665}{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 31 1963, monthly report for September, 2; Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 32, 1964, 40.}
\item \footnote{666}{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 33, 1965, 49, 52.}
\item \footnote{667}{Bureau of Reclamation, Annual Project History, Columbia Basin Project, Vol. 36, 1968, 53.}
\end{itemize}}
has, in part, contributed to the operating error.” In anticipation of the central control system, the staff had been cut by more half—from 113 in 1960 to 51 four years later—and further reductions were projected. As a result, morale was low: “As one of those interviewed stated, ‘The men used to be happy and fun to work with—now they are grouchy and have no interest in their work.’” In addition, information on operating procedures was not adequately communicated to new staff: “The lack of printed station instructions that would be available to all operators for their continued study and review has been a major factor in contributing to this case of trouble.”

While the board found that “emergency work during the fire proceeded with commendable efficiency,” there was one exception: “We are quite concerned with the hazards to and difficulties encountered in handling the tourists within the plant at the time of the fire.” Although employees quickly ushered the visitors out of the plant, some insisted on returning and had to be removed again.

Soon after the event, Reclamation crews worked to remove damaged sections of the bus structure and cubicle. New equipment was ordered immediately, and was anticipated to arrive in January 1965.

In addition to upgrading control systems, Reclamation embarked in the late 1960s on a campaign to rewind all of the stators in the units to raise their output from 108 MW to 125 MW, planning to do two units a year. By the end of 1970, six of the stators in the Left Powerplant had been rewound. The effect was immediately apparent: Grand Coulee’s output rose to 15.4 billion kWh in 1970, an increase of almost 1 million kWh over the previous year.

Work on Units G-4 and G-8, the fifth and sixth stators to be rewound, was initiated in 1970. Reclamation made several improvements to its earlier process. The project history reported “considerable time and money savings” by employing a critical path chart to plan and implement the projects and “by use of old parallel rings and Westinghouse configuration rather than Allis-Chalmers.” Unit G-4 was shut down on August 30. With crews working two ten-hour shifts a day, it was back in service on October 28. The downtime was an opportunity to do related

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maintenance. With the upstream penstock stop logs in place, the coaster gate was removed and a spare gate was installed; the old coaster gate was repaired and retained as a spare. The gate hoist and stems, penstock interior, turbine wheel and wicket gates, coaster gates, and other components were cleaned and repaired. Similar work was done on other units when their stators were rewound.673

Westinghouse rewound Unit G-18 between May and July 1971, and started on Unit G-1 in September. During the process, research engineers from the company performed a series of stator tests on the original winding. This was one of many tests that contractors and Reclamation engineers performed when units were down. “A good deal of interest is being generated throughout the electric utility industry in the research and testing that the Bureau has been performing on Grand Coulee units,” the project history noted. “There are a number of other utilities in the United States and Canada doing similar testing and all are attempting to develop these tests into a maintenance tool that can be used to evaluate stator insulation systems.”674

Reclamation also tested new equipment when units were down for periodic maintenance. In January 1971, for example, Unit G-8 received an experimental dead stop/unit creep detection system. The control circuit was intended to bring the “governor speed level control to speed-no load position” when an air circuit breaker was tripped. It proved successful in tests, taking just over a minute to get the unit back on the line. “When this modification is effected on all units,” the project history reported, “the time required to get them back on the line after system break up will be greatly reduced.” By mid-year, all of the units had received the dead stop/unit creep control circuit modification, and Unit G-15 had a new prototype electronic governor.675

Reclamation had established a sequence for rewinding the stators, but the schedule was subject to change in response to unanticipated circumstances. When Unit G-17 had a sudden outage in November 1971, the winding intended for Unit G-2 was redirected to the already out-of-service Unit G-17. The Westinghouse Company completed rewinding Unit G-17 in February 1972, and the process of rewinding Unit G-2 began the following October. By that time, Reclamation had turned to another contractor, the National Electric Coil Company, which was a division of the McGraw Edision Company. The same company also rewound Unit G-3 between August and November. By the end of 1975, all of the units were completed in the Left Powerplant and only two remained in the Right Powerplant. Unit G-10 was the last to be undertaken. The Epoxylite Corporation, which had been hired to furnish and install the generator winding in 1978, completed the armature rewinding between May and June 1980. During initial energization tests in August, though, the rewound element failed. “Discussions to establish responsibility and

methods of repair were held in November,” the project history reported, with repairs beginning in January 1981.676

32. ROOM FOR THREE

A third powerhouse had been anticipated in the early plans for the Grand Coulee Project. Operation of the Left and Right Powerplants had barely become routine by 1952 when Reclamation began conducting exploratory drilling around a potential intake site. Engineers initially considered three locations for the plant. One was on the left bank at the base of a steep bluff downstream from the existing dam, just north of the town of Coulee Dam. The plant’s ten 108,000-kW generating units would be supplied from Crescent Bay or Lake Roosevelt by a pressure tunnel 56.5' in diameter and 8,500' long. The second option was an 864,000-kW plant on the right bank located underground “in the granite mass below the existing dam,” the Wenatchee Daily World reported. “The water would have been carried into the waterwheels through penstock tunnels completely underground,” an arrangement similar to the first option. The third alternative, also on the right bank, placed the plant at a perpendicular alignment directly downstream from the Right Powerplant.677

Reclamation issued a report analyzing the three options in February 1954, favoring the above-ground plant on the right bank. The long tunnels required for the other options would result in significant head loss, and construction costs would be extremely high. The report anticipated that the third plant would be completed in three phases, starting with the installation of four 108,000-kW units and construction of four additional bays for future units. The latter units would be added in the second phase, along with a new switchyard by the dam’s right abutment to replace the one dislocated by the plant’s construction. This would bring the plant’s capacity to 864,000 kW. At some later date, the plant would be expanded to house four more units. Water to power the turbines would come from intakes just upstream from the dam’s right abutment. The tailrace of the Right Powerplant would be enlarged to handle the new plant’s discharge.678


While considering locations, Reclamation was also evaluating the justification for building the plant. The demand was clearly growing: “A rapidly expanding power market and recurring winter power shortages in the Northwest demonstrate the need for additional power supplies. Power requirements for defense industries in the area are so vital that, with the occurrence of power shortages in the fall of 1951 and the fall of 1952, interruptible power commitments were cut off and voluntary cutbacks in other classes of power use were requested by the Defense Electric Power Administration.”

Despite these positive indicators, though, the report concluded that current and anticipated economic conditions could not justify the construction of the third plant at Grand Coulee in the foreseeable future. The report recommended “that further action on [plans for the plant] be held in abeyance until such time as prospective requirements for capacity, and energy resulting therefrom, provide definite prospects for financial feasibility.”

In the following decade, it was politics as much as anything that made the third plant a reality. To justify the construction, there had to be both a sufficient supply of water to turn the turbines and a substantial market demand for additional power. The Columbia River Treaty, long under negotiation between the United States and Canada, was signed in 1961 and finally ratified in September 1964. Under the terms of the treaty, Canada would build, operate, and maintain three storage dams to control the river’s flow. Holding a total of 15.5-million acre-feet of storage—nearly triple the amount previously available—the new reservoirs would reduce flooding and provide a greater and more dependable supply of water to hydroelectric plants downstream. As compensation, Canada would have rights to half of the additional energy that went into the Pacific Northwest grid as a result of the increased storage. Another 5 million acre-feet of storage would be created by the Libby Dam, which the United States agreed to build in northwestern Montana.

Grand Coulee, the first hydroelectric plant in line south of the border, would be a major beneficiary of the new Canadian reservoirs at Duncan Lake, Arrow Lakes (later known as Hugh Kennaehside), and Mica Creek, which were scheduled for completion in April 1968, April 1969, and April 1973, respectively. Grand Coulee’s existing capacity, however, could not utilize all of the increased water supply, even during periods of low flow. The Third Powerplant would solve

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this problem, but create another: where was a market for the surplus power that would be generated? 682

That issue was addressed by the Pacific Intertie, which would connect the distribution grids of the Pacific Northwest and the Pacific Southwest through four circuits (two 500-kV alternating-current and two 750-kV direct-current). If the northwest system did not need all of the power allocated to Canada under the Columbia River Treaty, the excess could be sold in the southwest United States. The intertie received Congressional approval in August 1964. 683

Harold Arthur, Reclamation’s chief designing engineer, described the Pacific Intertie as “the most extensive single electrical transmission development ever undertaken in the United States. It will connect public and private electrical systems from Vancouver, B.C., and Seattle, Wash., to Phoenix, Ariz., and points in California.” More specifically, “the Intertie will consist of four long-distance extra-high voltage transmission lines having a total capacity of approximately 5,000,000 kW. Three of the lines will extend from the Columbia River Power System to the load centers of California; the fourth will run from the Columbia River Power System to Hoover Dam.” 684

Not long after the intertie was approved, Reclamation launched its campaign for the Third Powerplant. Grand Coulee was already the largest power producer in the Northwest, accounting for almost 30 percent of the generating capacity on the Columbia River and its tributaries. Between 1938 and 1964, it had generated some 224 billion kWh of energy, about 48 percent of all of the power that had been produced on the system during that period. With the prospect of greater storage and a broader distribution area—as well as the technological advances in the decades since the first two plants had gone on line—plans for the third plant had grown more ambitious. The size of the twelve generating units had jumped from 108,000 kW to 300,000 kW. Plans for the intake structures had also changed. Initially, they called for six pressure tunnels, each serving two generating units. Over time, engineers came to prefer an open-cut channel forming a forebay in the right bank, with a separate penstock for each unit. 685

By 1965, plans to get approval for the Third Powerplant were in motion. Senator Henry “Scoop” Jackson, who represented the State of Washington in Washington, D.C., had made an announcement three years earlier that Reclamation would be requesting approval and funds for

the project. When preliminary plans were ready and the Senate’s Interior Committee held hearings on the project in April 1965, Jackson was the committee chair, essentially guaranteeing that the conclusion would be favorable. President Lyndon Johnson was also a big booster of the project, urging Congress to pass legislation to construct a 3.6 million kW plant, estimated to produce about 4.6 billion kWh of electricity annually. Nearly twice the capacity of either of the existing plants, the new facility would boost Grand Coulee’s total output to almost 5.6 million kW. Reclamation justified the estimated $364 million cost by a projected benefit-to-cost ratio of 3.24 to 1. “Its economic stimulus will be felt in many parts of the nation,” Arthur asserted. “The power plant will more than pay for itself as a unit of the Columbia River Federal Power System, and will enhance the economic and financial feasibility of the system.” He anticipated that the first unit could be in operation within eight years after funds were appropriated for the project.

The plant was to have twelve 300,000-kW units, although Arthur observed that “the bill . . . provides sufficient flexibility for reasonable design modifications, particularly as to size and number of units.” The concrete gravity Forebay Dam extended downstream from the east end of the existing dam at nearly a right angle. A 28’-diameter steel penstock with two 14’ x 30’ wheel-mounted emergency gates would control the flow of water to each of the units.

The plant would have a steel structure with concrete walls, although Arthur noted that “alternative superstructure designs that will achieve an appearance most compatible with the existing facilities and the natural surroundings are being studied.” In addition to the twelve bays for the units, plans included erection bays at each end, with the one on the north also serving as a service bay. “Two large capacity cranes would be required to handle the rotor, and a smaller traveling crane would be used for handling the runner and lighter equipment. The smaller crane would be used for early installation work, deferring purchase of the two large-capacity cranes until after award of the generator contract when a more accurate estimate of rotor weight will be available.”

The initial installation was to include only four units. Penstocks would be imbedded in the dam for the remaining eight units and bulkheaded until the addition of more capacity was justified. The substructure, intermediate structure, and superstructure for the entire plant would be completed in the first phase before any of the units went into operation. An area of compacted backfill would create a terrace between the existing and new plants on the right bank.

Granite bedrock offered a strong foundation for the forebay, Forebay Dam, and plant. The unstable soil that had plagued many elements of construction at Grand Coulee, though, was a potential problem in the tailrace area. As a countermeasure, engineers proposed to place a row of concrete-filled steel cells along the channel’s northern edge during the initial phase of construction, when the cells could also serve as a cofferdam and roadway. The roadway would provide a temporary connection to the Right Powerplant, since the road that served that function crossed the site of the new plant and would be obliterated. A permanent access road to the Right Powerplant would be installed across the draft tube gate deck of the Third Powerplant.  

Further downriver, riprap would be expanded to stabilize the slopes as needed. In the Mason Terrace area of the Town of Coulee Dam, for example, existing riprap protected the banks from daily fluctuations of 4’ to 6’ before the new plant was built. With the new plant, the level of the river could jump 21’ in a day, so it was necessary to regrade the slope and install riprap to a higher elevation.

The project required the demolition of tourist facilities on the right bank that had hosted some 300,000 visitors in 1963. Visitation was expected to rise by about 50 percent as a result of the new plant, so the facility would be designed to accommodate tours of the plant, including the generator floor, and provide good views of the dam and spillway.

By far the most challenging displacement, though, was the Right Switchyard, which stood on land that would be excavated for the Third Powerplant and Forebay Dam. Initially, Reclamation considered relocating it on the right bank (for a detailed discussion of this subject, see “Columbia Basin Project, Switchyards,” HAER No. WA-139-I). In the end, though, the project proved an opportunity to combine switching for both the Right and Left Powerplants in the Left Switchyard—a change that had to be accomplished before the Right Switchyard could be deactivated.

Plans called for installing oil-filled, oil-cooled cables in galleries in the dam and tunnels to carry electricity from the generators to the switchyards. For the existing plants, these cables would replace the overhead circuits that ran to the switchyards. The three 10"-diameter cable-circuit pipes for the Right Powerplant would run west on the face of the dam to the spillway training wall, then follow the wall up to an inclined gallery linked to an existing gallery at elevation 1200, about 160' below the crest of the dam. After running through this gallery for about 2,500', the circuits would enter a horseshoe-shaped, concrete-lined tunnel excavated in the rock by the
left abutment. From the tunnel, measuring 1,370'-long and approximately 12' wide by 16' high, the conduits would pass through a cut-and-cover structure to the enlarged Left 230-kV Switchyard. The cable circuits from the Left Powerplant would join those from the right plant in the tunnel, running first through the existing bus structure along the face of the dam. A new 100' tunnel about 40' below the crest of the dam would connect the bus structure and the tunnel.  

An environmental impact statement touted the aesthetic advantages of the putting the cables underground: “Removal of the overhead circuits and takeoff structures at the powerplants eliminated the clutter of electrical facilities at the damsite and also contributed to the improvement of the overall appearance of the powerplants and surroundings.”  

Several locations were considered for the switchyard for the Third Powerplant. Initial plans envisioned it “in an area behind the right abutment of the dam, on a bench several hundred feet above the lake.” This area, known as the “Crow’s Nest,” was first considered for the relocated Right Powerplant switchyard. When Reclamation decided to convert that plant’s transmission from overhead lines to oil-cooled circuits, making it feasible to combine switchyards for the original plants on the left bank, the Crow’s Nest site became an option for the Third Powerplant’s switchyard. 

As of 1968, plans called for transmitting power to the switchyard from the plant’s first three units with 525-kV cables, which would pass through tunnels under the Forebay Dam and up a vertical shaft to a spreading yard. “These extra-high-voltage cables will be the first at this rating to be installed in the United States,” Reclamation engineer Arthur reported. Overhead steel towers would carry the circuits from the spreading yard to the switchyard. Arthur signaled, however, that the selection of the Crow’s Nest site was not finalized: “The means of connecting the remaining three units of the initial six-unit installation with the switchyard is under study.” 

Soon, the Crow’s Nest site received its second rejection. Consolidating all of the switchyards on the left bank had become a possibility with the availability of oil-filled, oil-cooled cables. This proximity was ideal for operations and maintenance, so it was the obvious choice. The power from each unit in the Third Powerplant would be transmitted through three single-phase

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transformers, which stepped up the voltage to 525 kV. Each set of transformers was connected to three single-phase oil cables, which ran through a special gallery behind the Third Powerplant. Following the same arrangement as the Right Powerplant cables, the high-voltage cables would pass through the dam and a tunnel to the spreading yard, which was just north of the 230-kV Switchyard. Overhead tripod towers would carry the lines from there to the 500-kV Switchyard.698

The Right Switchyard, although a major obstacle, was not the only thing that literally stood in the way of the Third Powerplant project. Fifty-seven houses and commercial buildings had to be moved or demolished. The Forebay Dam would consume the landscaped area on the east abutment that had been created in the early 1950s around the bust of Franklin Roosevelt. Before construction of the third plant began in earnest, the bust was removed for safekeeping. In 1968, the *Spokane Daily Chronicle* noted that it “now rests in a Bureau of Reclamation warehouse.” It would stay there for a number of years, returning to public view in 1974 on the other side of the river, in a landscaped area just above the Pumping Plant.699

### 33. COLOSSAL TURBINES AND THE CONCRETE TEMPLE

On June 14, 1966, President Lyndon Johnson signed Public Law 89-448 authorizing construction of the Third Powerplant. It was amended by Public Law 89-561 on September 7. An appropriation of $3 million for preconstruction planning and the beginning of construction was included in the government’s 1967 fiscal year budget.700

A goal of preconstruction planning was to consider the appropriateness of the proposed size and features of the plant. Engineers soon concluded that the plant, if built as initially specified, would have to be enlarged as early as 1985. By January 1967, the political process was underway in Washington to substitute six 600,000-kW units for the six 300,000-kW units that had been approved, making the initial installation 3,600,000 kW. The dimensions of the plant would be increased to accommodate the later addition of another six units, making the plant’s total capacity 7,200,000 kW. The cost to build out the forebay for the six future units would increase the project’s price by about $21 million, but this was almost completely offset by substituting the larger units for the smaller ones, which saved about $20 million. With power from the twelve 600,000-kW units added to the existing units, Grand Coulee’s capacity would be 9,174,000 kW, larger than any power facility in the world. *Electrical World* remarked that the Third Powerplant alone “exceeds the total capacity of all 50 power plants the Bureau has constructed.”701

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This power would not be needed on a regular basis. “Of the 4,600,000,000 kwhr to be produced annually by the 12-unit plant, nearly 3,900,000,000 kwhr or 84% would be produced by the first four units,” a Reclamation engineer explained. “The capacity of all twelve units is needed, however, to provide peaking for the prime hydroelectric production and the nearly 9,000,000 kw of thermal capacity necessary to help carry the Pacific Northwest baseload by 1982, as well as to provide flexibility in the system after the Treaty reservoirs and the Intertie are built.”

The massive size of the project was also justified by Cold War sparring. The United States had not only been stung by the launch of Sputnik in 1957, it had lost bragging rights to the world’s largest hydroelectric facility two years earlier when the Soviets completed the 2.3-MW Kuibyshev Powerplant on the Volga River. With more Soviet plants on line by 1958, Grand Coulee sank to fifth-largest. The Third Powerplant would redeem the United States’ top rank. The scale of the equipment as well as the scale of the project would set new records. At the time, the eight 112,500-kW units at Glen Canyon were Reclamation’s largest. They would be dwarfed by the 600,000-kW units proposed at Grand Coulee.

Producing these behemoths would be no easy task. “Design of the 7,200-Mw installation requires new advances in hydropower technology,” Electrical World reported. “The generators, turbines, and governors, the 500-kv cable circuits needed to conduct power to the switchyard, the new switchyard itself and its equipment, the unusually large penstocks, and other essential features all impose major problems in design.”

This was acknowledged by Reclamation engineer Arthur. “The size of the third powerplant and its generating units are unprecedented in Bureau of Reclamation experience,” he observed. “The resourcefulness of the Bureau’s engineers will be challenged to solve the many difficult design and construction problems inherent in the development of the power plant.” To meet this challenge, Reclamation adopted a new technology: the computer. “Bureau engineers have developed a system of digital computer programs to perform the wide variety of analyses,” Arthur explained. “An indeterminate-analysis program will be used to compute the moments and forces in the rigid space frames found in the service and erection bays, and in the rigid planar steel and concrete frames found throughout the plant. The program will also be used to determine the distribution of stress in massive members using the finite-element method of analysis. The tall vertical piers on the downstream face of the plant will require this type of analysis.” In addition, “a computer program applying the general principles of the trial-load analysis method of arch-dam analysis will be used to determine the bending moments and forces in the walls and

slabs with nonuniform thicknesses, varying loadings, and/or openings.” Computers were also used to assess stability factors and to quantify how much reinforcing steel would be needed for the concrete structures.\(^{705}\)

In November 1968, Arthur published an article in an engineering journal that described the general configuration of the plant:

The building for the initial six-unit installation will be 1,129 ft. long, 156 feet wide, and 258 ft high above its foundation. It will be of reinforced concrete construction and will have a 126 ft wide concrete superstructure. It will comprise the six unit bays, each 119 ft long, a 267 ft long generator-erection bay at the north end of the building, and a 148 ft long turbine-erection bay at the opposite end of the building (near the Right Power Plant).” He also provided the general specifications for the equipment: “The turbines will each have a nameplate rating of 820,000 hp, 285-ft head, and 72 rpm. Specific speed of the units will be 55 rpm. Each turbine will deliver approximately 1,000,000 hp when it is turning the overload capacity of the generator. The nameplate rating of each generator will be 615,385 kva (600,000 kw) 97.5% power factor, 15,000 v. and 72 rpm. Despite their high kilowatt rating and enormous physical size, the generators, in most respects, will not have unusual electrical characteristics.\(^{706}\)

The gravity-type Forebay Dam would rise about 200' about the foundation, with its crest at about elevation 1310. To ensure the stability of the foundation, the rock below would be consolidated with pressure grouting and pierced with drainage holes, and faults would be treated. As with the main dam, the Forebay Dam would be formed from vertical blocks that were built up in a sequence of lifts and grouted after the concrete cooled. A service elevator and a network of galleries and adits would be incorporated within the dam.\(^{707}\)

Two service yards adjacent to the new plant and almost three miles of access road would be paved with asphalt. It was also necessary to build a new retaining wall along Marina Way in the forebay area. A new tunnel through the right abutment and a cut-and-cover section under the south service yard would be linked into tunnels in the existing dam for the extra-high-voltage transmission cables.\(^{708}\)


34. MASTER OF MID-CENTURY MODERN: MARCEL BREUER

Scale was not the project’s only novelty. The design of the dam and original powerhouses had put function first. The Streamline Moderne style that was popular at the time was well-suited for an industrial setting and is reflected in the project’s details and massing, but the design is understated. The Third Powerplant was to break from this mold. “With the design, construction, and operation of the Third Powerhouse, the Grand Coulee Dam complex will achieve new magnitude in the public mind,” a Reclamation report explained. “It is one of the great engineering accomplishments of all time and there is concern that a proper setting and environment be provided for public accommodation. Consequently, the Bureau of Reclamation contracted with the renowned architectural firm, Marcel Breuer and Associates, for architectural concepts for the Third Powerhouse.”

Breuer was one of the major architects of the mid-twentieth century. He never formally studied architectural history, design, materials, construction methods, or drafting, and his self-education in these areas was influenced by his interests in modern painting, sculpture, and furniture design. Born in Hungary in 1902, he enrolled in the Bauhaus school, which did not yet have an architecture program, in the early 1920s. After graduating, he moved with the school when it relocated to Dessau and became responsible for running its furniture workshop. As biographer Isabelle Hyman remarked, “From his Bauhaus days through the end of his career, he was committed to a sachlich [functional] architecture determined more than anything else by the expression of use.”

Hitler’s rise to power prompted Breuer’s move to London in the mid-1930s. In 1937, he arrived in the United States. Over the next decade, he influenced up-and-coming designers as a member of the architecture faculty at the Harvard Graduate School of Design. By the 1950s, Breuer had devoted himself to private practice and established a thriving international business based in New York City. His clients included the United States government, for which he built an embassy in The Hague. In the following decade, his office designed new headquarters buildings for the Department of Housing and Urban Development (HUD) and the Department of Health, Education and Welfare, both in Washington, D.C. “Both of Breuer’s federal buildings were admired within the profession for their structural innovations and creative technology,” according to Hyman. His popularity justified the expansion of his office from East Fifty-seventh Street to a larger space on Madison Avenue. He also set up an office in Paris.

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710 Isabelle Hyman, Marcel Breuer, Architect: The Career and the Buildings (New York: Harry N. Abrams, 2001), 14, 17. Modernists adopted the German term “sachlich” to denote architectural design that was based on utility rather than aesthetics.
His practice spanned almost six decades and produced designs for around 150 buildings on four continents. This success came at a personal price, and Breuer’s health began to suffer as he grew older. Despite several stays in the hospital, long periods of prescribed rest, and a greatly restricted travel schedule, though, he remained active in the firm until his retirement in 1976 and continued design work until his death in 1981.  

The HUD project is particularly noteworthy in relation to Breuer’s work at Grand Coulee. HUD was created by Congress in 1965, marking a significant change in federal housing policy. This innovation merited an equally groundbreaking headquarters. The HUD Building, begun in 1966 and completed in 1968, represented an early use of precast concrete for a federal building. In addition to being economical, coming in millions of dollars under budget, it was considered an aesthetic success. “The architectural press regarded the commissioning of the HUD building to Breuer as an example of a government effort to improve the quality of federal architecture,” according to Hyman. This initiative had been launched in 1962 by President Kennedy, who “issued to heads of all federal agencies a directive, ‘Guiding Principles for Federal Architecture,’ calling for ‘designs which embody the finest contemporary American architectural thought.’” The principals were first outlined in an essay by Daniel Patrick Moynihan, who was assistant secretary of labor at the time.  

This cause was subsequently taken up by Lady Bird Johnson. It was not an easy task. As one of her biographers explained, “Within the federal government itself, Lady Bird Johnson did not confront an overt sluggishness about the merits of beautification; few bureaucrats or agencies wanted to be in direct opposition to the president’s wife. Instead, she had to struggle against the perception that even though her goals were worthwhile in an abstract sense, they should not outweigh the more practical and realistic needs of busy men in the White House or the executive branch.”

Those “busy men” sometimes ignored her at their peril. “As environmental controversies flared during the Johnson administration, interested groups sought to obtain the First Lady’s endorsement of their position. Most of the time her staff deflected these initiatives to the government agency responsible for the policy decision. In the case of the Grand Canyon and the Redwoods, however, Mrs. Johnson had to express herself.” She sided with the Sierra Club and other environmental groups who opposed Reclamation’s plans for dams in these locations. “Instead of simply referring the protest mail that poured into her office to Interior, Mrs. Johnson instructed her staff to answer the mail themselves. . . . Some of her correspondence became

public, and the extent to which she made protest legitimate underscored her role in supporting the movement to preserve the Grand Canyon.”

This tangle likely led to Reclamation’s decision in 1967 to appoint a Board of Artistic Consultants to provide advice on design issues for major projects. Reclamation Commissioner Floyd Dominy “enlist[ed] members of national repute,” and the board soon set to work. “I was delighted, but not too surprised, when the board came back from a survey trip to assert that many of our dams were things of sculptured beauty,” he reflected. “But they added that some appurtenant structures and surroundings left something to be desired. We took them at their work and have contracted with Marcel Breuer and Associates of New York to furnish architectural concepts for our biggest single job now underway.”

Breuer’s association with Reclamation apparently began in September of that year when Associate Chief Engineer William Wolf visited Breuer’s Manhattan office to discuss a negotiated contract for work on the project. Tician Papachristou, an architect on Breuer’s staff, wrote a letter to Wolf the following week summarizing what had been discussed and adding: “Mr. Breuer has asked me to convey to you again his strong personal interest in this commission.” The scope of work included “the design of all visible parts of the proposed construction, including the Forebay Dam, the Third Power Plant, visitors’ facilities, etc., with particular attention to color, form, surface, choice of materials and lighting.” Papachristou continued: “It is understood that we will not be involved with elements of the project which, by their specific technical nature, have already been fully defined. Our work may also involve studies of circulation and arrangement for those portions which have not been determined by engineering requirements (for instance, facilities for visitors).” He concluded that “generally, we see our office as an instrument at your disposal to provide necessary consultations in questions of architectural or aesthetic nature. . . . We assume, of course, that all engineering will be provided by you.”

The design process would have three phases. The first was “Conceptual Studies,” which included developing basic architectural concepts, analyzing structural systems, and making an initial selection of materials. The contract noted that “the design concepts shall be based on schemes relative to the general comprehensive planning of both the initial 6-generating unit installation and the future expansion of the 6-generating unit to a 12-generating unit installation.” The second phase, “Preliminary Design Development,” involved planning for the design, structure, and materials in more detail. Final plans and specifications were prepared in the third phase.

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After the initial meeting with Wolf, Breuer’s office did some preliminary fee calculations. The total for hourly costs “at the flat rate of $16.00 per hour for all technical personnel involved in the project, including the two principals,” ranged from $160,000 to $320,000, with a recommendation “that a sum of $300,000 be set aside for this portion of the architectural costs.” In addition, there was a “professional fee” of $100,000 paid over eighteen months in increments of $5,000, with the balance of $10,000 due after shop drawings were accepted. Reimbursable expenses were anticipated to run $20,000, with half of that going to models and renderings and $7,200 to cover twenty-four round-trip, first-class flights from New York to Denver, Spokane, or Seattle. Subcontractors, including structural, electrical, and acoustical engineers, added another $65,000.  

Many of these numbers changed after months of negotiation with Reclamation. Breuer’s official proposal, dated February 12, 1968, included a profession fee of $100,000, but it was disbursed in three parts: $50,000 at the end of the first phase and $25,000 at the end of each of the final two phases. Expenses were left at $20,000, with an additional $2,000 for per diem costs. The total for hourly work dropped to $96,000, with only $32,000 allowed for subcontractors. All in all, the contract added up to $250,000.

Reclamation, which intended to issue the prime contract in June 1969, initially hoped that plans could be ready in 130 days—a lightning-fast turnaround of just over four months. Breuer’s office estimated that it would take seventeen to twenty months to prepare design documents, “barring . . . unforeseen delays along the way.” After discussing the schedule with Wolf over the telephone in February 1968, Papachristou wrote a memorandum to Breuer and Smith: “Mr. Wolf explained that the schedule had been cut short because of delays in their appropriations. He felt that the Bureau would be flexible however in accepting a longer design period and would take the matter up today with his colleagues. He definitely agreed to the 3 month period for Phase I.” The day after the telephone conversation, Reclamation drafted a supplement to the proposed contract that provided for completion of the first two phases within 180 calendar days of the contract award, with the third phase finished 110 calendar days later.


Reclamation remained responsible for preparing the engineering concept and working drawings, and for overseeing construction. Architectural Record explained the relationship: “Working with the 450-man A/E staff at the Bureau’s Engineering & Research Center in Denver, Breuer’s office . . . strove to give this massive and highly complex project a visual harmony with its setting and a sensitivity to user need.”

On Breuer’s end, Hamilton P. Smith served as the partner in charge, with Thomas Hayes as associate architect. Paul Weidlinger was the structural consultant. A few years earlier, Smith had overseen the design of the Whitney Museum of American Art in New York, which opened in 1966. The Whitney was greeted with generally positive reactions, although some balked at its uncompromising modernism. Another Breuer project a few years later, around the time the firm was hired for the Grand Coulee project, was more universally criticized—a tower atop New York’s Grand Central Terminal. A second version, which replaced the station’s facade, was considered even less acceptable. The Grand Central battles eroded the enthusiasm that architecture critics and the public felt for Breuer.

Hence, the Grand Coulee design dates from the peak of Breuer’s career.

Progressive Architecture lauded Reclamation’s decision to retain Breuer as “an action believed to be without precedent.” In an April 1968 article, the magazine described the architect’s purview as “all parts of the complex—dam, penstocks and anchor blocks, gate deck, elevator tower, and the like—with particular attention to color, form[,], surface, choice of materials and lighting.” In an interview in Architecture Plus, though, Breuer asserted that his charge “is not directed toward cosmetic application but toward the very anatomy of the project.”

At one point, Reclamation considered extending the new design themes to the existing powerhouses and dam. It approved a change order to Breuer’s contract in April 1970 authorizing the architect to “develop and propose concepts for modifying the appearance of the existing plant facilities to provide an architectural design compatible with the new Grand Coulee Third Powerplant and existing Grand Coulee facilities.” Breuer’s office was then to consult with Reclamation “designers to assure structural, operational, and functional integrity of the proposed architectural design modifications of the existing powerplant facilities.” This initiative was allocated a total of 400 man-hours. In the end, it did not result in any changes to the older structures.

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The concept design was well along by December 1968, when *Progressive Architecture* published a small, preliminary drawing of the plant: “Features of the Breuer concept, which may still be modified before construction, include an inclined elevator, a glass-enclosed cab moving up and down the face of the dam’s 475' high penstocks. The elevator will stop midway along the incline to give visitors access to a platform cantilevered out of the rock cliff supporting the Forebay Dam, where a cross-over bridge spanning the transformer deck will lead to the powerplant. Visitors will enter the generator hall of the powerplant at a level above that of the bridge crane, and will be able to cross the gallery at this level to a balcony from which they may view the powerplants, the spillway, and the Columbia River itself.” Visitors could also ride to the bottom of the elevator shaft to see the turbines up close. Breuer’s office had to obtain authorization from Reclamation before hiring subcontractors and, not surprisingly, one Breuer’s first requests had been for a $2,000 subcontract to the Otis Elevator Company “for feasibility studies in connection with the inclined elevator.” Reclamation had approved this in June.  

The idea for the elevator had been conceived by Kenneth Brooks, a Spokane architect, before Breuer became involved with the project. Brooks was born in Cedarvale, Kansas, in 1917, and studied architectural engineering at the University of Illinois at Champaign-Urbana, receiving an undergraduate degree in 1941. After gaining experience with the Corps of Engineers and Marines, he went back to Illinois for graduate school and obtained a masters degree in architecture in 1948. He had a seven-month post-graduate fellowship in Europe, where he worked with Swedish planner and architect Sven Markelius. When Brooks returned to the United States, he settled in Spokane where he founded an architectural practice in 1951. One of his first projects was the award-winning Coulee City High School, built in 1952-53. As his practice grew, he gained commissions for designing a number of prominent buildings in the region including the Intermountain Gas Company in Boise, the Rogers-Orton Dining Hall at Washington State University-Pullman, and the Washington Water Power headquarters in Spokane. He was also involved in significant planning projects including the “A Place in the Sun” plan for Spokane’s downtown and preparations for the 1974 World’s Fair.  

Reclamation had given Brooks a $75,000 contract in 1967 to develop a master plan for improving visitor facilities at the dam. A year later Reclamation asked him to expand the project to include the entire area around the project. As part of the process, “fifty-six governmental agencies and 21 private companies were asked in letters to give their views” on long-range planning for the dam and vicinity. In June 1969, Brooks presented the plan to an advisory panel including representatives from Reclamation and local community leaders. The plan was

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COLUMBIA BASIN PROJECT,  
GRAND COULEE DAM AND FRANKLIN D. ROOSEVELT LAKE  
(Grand Coulee Dam)  
HAER No. WA-139-A  
(Page 269)

christened the “Ecouleegia.”  

Intended to “serve as an imaginative guideline for the development of the area,” according to a later environmental document, “this plan envisions an elaborate system of tour and visitor facilities and lighting effects which could be constructed by the Bureau of Reclamation at and around the dam.” It also made recommendations for improvements, such as upgrading recreational facilities and roadways, that could be made by other government agencies or private groups.

Breuer’s striking Third Powerplant was one of the dominant features in this environment. Some have speculated that Breuer’s Brutalist design was influenced by Fort Peck Dam in Montana, particularly an image of it under construction taken by Margaret Bourke-White and featured on the cover of the first issue of Life magazine in November 1936. Breuer himself, however, credited a much earlier source, describing the plant’s giant concrete form as having “dimensions truly Egyptian.” As one of his biographers observed, “Breuer had a deep interest in the monumental architecture of Egypt and its formal constructs—the ramps, the battered walls of the pylons, the flat-topped inclines of the low-lying mastabas, the trapezoidal masses of heavy stone, and the serial repetition of individual elements, all of which found their way into his work.”

Concrete was an obvious choice of materials for the Third Powerplant for aesthetic as well as practical reasons. Architectural Record reported that the firm’s “extensive experience with concrete was one of several factors that led to the selection” of Breuer for the project. Breuer had great enthusiasm for that material. In a 1969 speech in Brussels, Belgium, sponsored by a major concrete producer, Cimenteries Cementbedrijven, he noted the advantages of concrete—its capacity to be molded “into practically any form, any shape,” its resistance to fire, its ability to “be used for structure and enclosing skin at the same time.” He also acknowledged disadvantages, both aesthetic (staining and streaking) and structural (shrinkage and cracking). Prefabrication, he asserted, could eliminate the structural issues, and creative texturing of surfaces could improve weathering characteristics. Concrete’s stature was rising because of a “change in contemporary architecture,” with “abstract space, all inclusive glass” being “replaced by solid enclosure, partly.” He felt this change was prompted by aesthetic reasons (“critical feelings against all around reflectiveness”) and technical reasons including “maintenance, control of climate, of sun, view and privacy.” Dissatisfaction with glass curtain wall structures “prepared the way for a more radical search for a satisfactory universal building material,” a role concrete could perform. “While we are by no means on the end of the road, we can say that our findings lend us a hopeful mood.”

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730 “Power Station, Bureau of Reclamation,” Architectural Record 164 (December 1978): 126-127; Marcel Breuer, “Reinforced Concrete,” notes for a talk given before Cimenteries Cementbedrijven, Brussels, Belgium, October 13,
Breuer was fascinated by the aesthetic potential of the material: “I believe the architect can fully express himself as an artist by means of concrete.” He elaborated: “The greatest esthetic design potential in concrete . . . is found through interrupting the plane in such a way that sunlight and shadow will enhance its form, while through changing exposure a building will appear differently at various moments of the day.” This potential was clearly achieved by the folded forms and textured surface of the Third Powerplant.

Breuer was also intrigued by the interior spaces created by massive concrete walls, finding spirituality in secular as well as religious structures. In an interview in 1979 about a recently completed project, the Saint Francis de Sales Church in Muskegon, Michigan, Breuer was asked how he “arrive[d] at the concept of a religious space, as opposed to an office space or an ordinary meeting hall.” He responded: “I have the feeling . . . that any space which is larger than necessary and higher than necessary, and in which the structure and the whole building of the space is visible, . . . that this space created is simply automatically religious.” Although not a religious man, he felt a sense of spirituality “in a big hydroelectrical power plant in Switzerland,” adding: “We have built a rather large one, the expansion of the Grand Coulee Dam. I have not seen it yet because I cannot travel much, but I think that this must also have this feeling. It is an enormous empty space carried by monumental concrete walls, folded. Everything is dustless and spotless, there is no daylight, only artificial light, there are no people, only the heads of twelve turbines visible, of which each produces enough electricity to operate the whole city of Denver.”

His vision of the interior apparently included the longer building holding the full complement of generating units that were planned, rather than the structure that was actually built. Even in the smaller configuration, the plant is generally considered a masterpiece of modern design. As biographer Hyman noted, “Breuer and concrete construction came together with colossal force at the third power plant and forebay dam sited at Grand Coulee against the imposing backdrop of the Columbia River basin.” She added that four of his designs—Grand Coulee Dam, the Saint Francis de Sales Church, the Whitney, and the Cleveland Museum of Art’s Education Wing—“hold a significant place in American late modern architecture, a period generally lacking creative vitality.”

35. FROM PLANNING TO IMPLEMENTATION

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Months before Reclamation contacted Breuer, preliminary site work was underway. On January 3, 1967, Reclamation opened a construction office for the project in the Right Powerplant. It was not until months later, however, that Reclamation appointed a construction engineer. On November 18, 1967, the *Spokane Daily Chronicle* announced: “J. Roscoe Granger: Role of Construction Boss Achieved after 40th Year.” The article described him as “a slim bespectacled man with a penchant for bow ties.” Born in 1903, he was clearly influenced by his engineer father, who had worked on developing many irrigation canals in the Northwest and had given his name to Granger, Washington. Roscoe joined Reclamation in 1926 after attending the U.S. Naval Academy for two years. He was involved with a variety of projects in the West, serving as assistant construction engineer at the Flamingo Gorge Dam and Powerplant in Utah and the Yellowtail Dam and Powerplant in Montana before moving to Grand Coulee.734

A number of projects had been launched before Granger was appointed. In the spring, Reclamation had let the first contract for drilling an exploratory tunnel 5’ wide, 7’ tall, and about 200’ long, with three side adits. The contract also included ten 3’-square test blocks, half deep inside the tunnel and the remaining five near the tunnel’s portal. Bids were opened on May 16, and on June 9, the J and S Drilling Company was awarded the contract with a bid of $40,576. The contractor started on June 13, the day it received notice to proceed, and had completed the scope by early October.735

A contract for exploratory drilling was awarded to a Boise firm, the Justice Core Drilling Company, in August 1967. The contract called for the installation of porous tube piezometers at a number of levels in three vertical holes that were 100' to 300' in depth. The holes were backfilled after the piezometers were in place.736

Reclamation also conducted drilling with government crews. In 1967, in-house forces drilled 151 holes with a combined length of 24,557 linear feet. The project history for that year listed the areas that were investigated: “Forebay, Forebay Dam, Cofferdam, staging powerplant, tailrace, new 500-kv Switchyard, cable spreading yard, proposed Office Building, temporary tour center, and downstream area.” Other crews collected and analyzed aggregate samples from potential pit locations downstream.737

At the same time that Reclamation was obtaining information essential for designing the project, it was also establishing the infrastructure for its construction. In May 1966, even before President Johnson signed the bill authorizing the project, Reclamation began “planning for the impending

influx of Third Powerplant personnel,” with a task force evaluating space needs. Implementation began in 1967. To house construction workers, Reclamation leased temporary structures from the Motor Investment Corporation of Boise. The first group comprised ten 12' x 55', two-bedroom mobile homes and fifty three-bedroom portable houses. The latter were intended to serve as family housing and contained 1,120 square feet or more. Reclamation hired another firm, Convention Cities of Seattle, to prepare the site for the temporary community and provide garbage collection, electrical and water service, a sewage disposal system, a play area, and other necessities.738

At the freight yard at Odair, about 3,100 linear feet of railroad tracks needed rehabilitation. In December 1967, Reclamation hired Lampson Railroad Contractors of Kennewick, Washington, to raise the track, add ballast, lay new ties, and install new asphalt and plank crossings. The company bid $29,829 to do the project.739

During the summer of 1967, specifications for the project’s first major contract, modifying the Right and Left Powerplants and the Left Switchyard, were issued. Bids were opened June 23, and a $10.1 million contract was awarded on July 12 to a joint venture of Jelco Incorporated and the Gibbons and Reed Company, both based in Salt Lake City. In January 1970, when the work was completed, the Right Switchyard would be permanently decommissioned and all switching operations would be transferred to an expanded Left Switchyard. To accomplish this, the contractor would install equipment and metalwork in the two powerhouses, including generator voltage switchgear assemblies, and remove transformer circuits, related steel structures, and tie circuits. A 165'-long, 7' x 8' cable gallery would be excavated in the dam’s concrete. Some 1,550' of one-, two-, and three-compartment tunnels would be excavated and lined with concrete. A 1,400-long cut-and-cover, reinforced-concrete cable circuit structure, including a building for 115-kV cable equipment and vaults for 230-kV cooling equipment, would be installed. Equipment and steel structures in the existing Left Switchyard would be removed and the new 230-kV Switchyard and 115-kV Cable Spreading Yard would be outfitted with new steel structures and equipment, a maintenance and shop building, and a 230-kV cable oil pump building. Also, the puller houses would be relocated.740

The contractor began excavating the tunnel for the cable circuits the day after receiving the contract and was placing concrete in the cut-and-cover section by September 20. All of the tunnels were excavated and lined with concrete by mid-1968. The next step, installing the cables, literally hit a snag in the summer of 1969. The 3.5''-diameter 250-kV cables that were to transmit electricity from the Right Powerplant to the expanded switchyard on the left side were proving difficult to thread through the pipes in the tunnels and dam galleries. Until the Right Switchyard

could be removed, an event originally scheduled for spring 1969, excavation for the new powerplant would be restricted, and the Right Switchyard could not be removed until the cables were activated between the Right Powerplant and the Left Switchyard. To speed up the process, Nat Harrison Associates, a Florida-based subcontractor to the Jelco/Gibbons and Reed joint venture, reversed the original process, which involved pulling the cable up the 700' rise to the switchyard. In addition to fighting gravity, the cables were impeded by five bends along the way, and the tension at these bends threatened to damage the cables. Starting at the switchyard rather than the powerplant proved to be a more efficient approach.\textsuperscript{741}

The subcontractor also ordered a custom-made hydraulic pulling rig with a pulling capacity of 70,000 pounds from the Lucker Manufacturing Company in Philadelphia. Measuring 28' long and 4' wide, the rig had a hydraulic ram with jaws that grabbed a 1-1/8" pulling line and advanced it 8' before releasing it to a second ram. A hydraulic take-up reel then took the line, which moved at a rate of 20 to 40 feet per minute. The rig was positioned at the east end of the gallery. When the leading end of the cable had cleared the gallery, a 100,000-pound anchor winch pulled it the remaining 800' to the powerplant.\textsuperscript{742}

The cables, up to 2574' in length, were produced by the Japan-based Furukawa Electric Company. They were delivered on 51 steel reels each weighing around 48,000 pounds and measuring up to 12' in diameter and 9' wide. Even a short delay in their installation could result in deterioration, as representatives from the manufacturer explained: “POF [pressurized oil-filled] cable has stable properties when once laid in pipes, filled with oil under vacuum and pressurized properly. Before that, it may be called a solid cable with no airtight sheath. It is therefore possible that the impregnating oil drains (usually accompanied by moisture absorption) before oiling is done at the site of cable installation, causing change in its electrical and mechanical properties.” To combat such decay, the ends of the cables were hermetically sealed to stop oil drainage, the cable was stored in an air-conditioned warehouse, and the reels were flipped 180 degrees on a regular basis.\textsuperscript{743}

During the installation, three cables were fed into a 10"-diameter, pre-stressed, lined, steel pipe, formed from 40' lengths that were welded together. Before the cables were introduced, the pipe was cleaned and filled with nitrogen to maintain low temperature and humidity. To reach from


\textsuperscript{742} “Narrow, Flat Hydraulic Rig Key to HV Cable Pull,” \textit{Electrical World}, August 4, 1969, 32; Bureau of Reclamation, Annual Project History, Grand Coulee Third Powerplant, Columbia Basin Project, Vol. 2, 1968, 43.

the switchyard to the plants, all of the cables needed splices—two for each of the nine cables from the Right Powerplant, and one for those from the Left Powerplant. *Electrical World* reported that “each splice is a painstaking operation, taking up to seven 24-hour days.” When the cables were installed, polybutene oil was pumped into the pipe to pressurize the cables and equalize temperatures. The ongoing cooling of the high voltage cables was taken care of by a conditioning system in the galleries, which was mostly in place by the end of 1968.\(^\text{744}\)

In the meantime, there was progress at the Left Switchyard. In late September 1967, the contractor started excavating to enlarge the switchyard. By mid-October, it had completed compacting a section of embankment for the new yard. A milestone came on December 11 when part of the Left Switchyard was de-energized. The contractor had removed the electrical equipment, bus work, and steel structures in four bays by the end of the year.\(^\text{745}\)

One of the more challenging tasks completed in 1967 was cutting 16’ x 20’ openings in the “E” line wall of the Left Powerplant for air-circuit breaker switchgear assemblies. A subcontractor, the Concrete Coring Company of Hawthorne, California, “used a lifting beam which was counter balanced at one end with three attached concrete blocks weighing approximately eight tons each,” the project history explained. “With the use of the 350-ton overhead crane, the beam was attached to the sawed concrete panel with bolts and the panel was removed . . . and transported to the service bay where the beam was detached and the panel was loaded on a truck and hauled to the disposal area.”\(^\text{746}\)

The contractor met the January 1970 deadline for most of the tasks and the facilities were officially transferred to the Grand Coulee Dam Operations Office in March. In the end, the work cost about $11.2 million, with twenty-one change orders resulting in an increase of over $1 million from the initial contract.\(^\text{747}\)

The second major contract let in 1967 was for work on the first phase of the Forebay Dam. Tasks included excavating some 7.5 million cubic yards of rock and common material for the Forebay Dam and channel and the cable spreading yard; removing Blocks 92 to 96, a total of about 260 lineal feet, at the right end of the original dam; removing concrete in the right crane recess; and a variety of electrical work, including installing a 2.3-mile-long, 11.95-kV, 4-wire construction power line and about 4,900’ of coaxial TV cable. This phase also involved constructing a 1.7-mile access road, a steel sheet-pile cofferdam, and a bridge on top of the cofferdam. Reclamation issued specifications for the work on September 24, 1967. The Green Construction Company of

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Des Moines, Iowa, won the contract in November with a bid of about $12.5 million and had started work by December 20.\(^748\)

Green began excavation for the four-cell cofferdam upstream from the dam’s east end in January 1968, placed reinforced concrete for the footings of the cells between March and May, and began erecting the cells in April. To facilitate the construction, Reclamation drew down the reservoir. It reached elevation 1201.08 by May, the lowest level since its creation. After the cells were filled with free-draining material, sandblasted, and caulked, the contractor produced and pressure-grouted 88 drill-holes extending a total depth of 10,535 linear feet. By the end of September, the road and steel bridge were installed atop the cells and carrying one-way traffic.\(^749\)

The cofferdam retained the reservoir during the removal of a 260' section of the dam’s east end that contained some 130 million pounds of concrete. The most delicate task was demolishing Block 92. Block 91, immediately to the west, would be the point of connection for the new Forebay Dam. The contractor created a vertical slot with a maximum width of 15' by carefully extracting the west edge of Block 92, lift by lift. When the slot was completed, large sections could be toppled by blasting because there was less danger of affecting the dam to the west. The contractor started at the east end of the section to be removed, and worked up to the slot.\(^750\)

The technique for blasting was described in an article in the *Spokane Daily Chronicle* in June 1968. An engineer working for Green “explained the principles of the so-called ‘pre-split’ method of blasting being employed. . . . A battery of horizontal holes, 3 to 5 inches in diameter and 45 to 50 feet deep, is drilled into the target area. Two-foot lengths of charges are packed into the holes. They then are set off. The charges . . . are not set off together, but milliseconds apart. If the charges exploded simultaneously, the blast ‘would rip the dam apart.’ . . . The side-by-side holed-in charges work in concert, pushing the rock together, then . . . forcing the material in a vertical fashion.” The article noted that “a recent 30,000-pound explosion moved about 30,000 cubic yards of sand and rock.”\(^751\)

Although the contractor was careful to keep debris from landing on the nearby Right Powerplant, it became increasingly dangerous to reach Reclamation’s construction office there. In August 1968, eighty staff began moving into thirteen 20'-wide temporary housing units in Coulee Dam that were converted into offices until a permanent administration building was erected. The


\(^750\) “How to Shorten Grand Coulee Dam,” *Western Construction*, December 1969, 62-64.

relocation was a diversion from the intense workload, given that Reclamation had awarded contracts valued at more than $81,000,000 by September.752

Green subcontracted installation of the construction power line to a Spokane company, Power City Electric, and the excavation work to Asbury Contractors of Los Angeles. Asbury started in the forebay area, but suspended that effort in mid-March 1969 to concentrate on the inlet channel just upstream, where an unanticipated problem had emerged. Earth and rock were left in place along the bank of the lake to serve as a cofferdam for the inlet channel excavation. It had been assumed that the materials would be relatively watertight and pumps could easily remove any seepage, but the seepage was greater than anticipated when the excavation went below the lake’s waterline. The contractor dumped clay and silt to reinforce the wet side of the dike to no avail, so the sump area was expanded and pumps were added, bringing the total to nineteen. The contractor hurried to drill and blast the rock, which was scooped into dump trucks with electric shovels and front-end loaders. With two ten-hour shifts running seven days a week, the area was excavated by mid-May and the dike was breached, bringing water into the inlet channel.753

The focus of the excavation returned to the forebay and powerplant. Sections of the valley wall were drilled and blasted. Loose rock was scaled, and rock bolts and wire safety mesh were installed on the newly exposed slope. Two electric shovels and front-end loaders scooped the shot rock into thirteen end dump trucks, which carried it to the staging area.754

In the more level area, excavation was slowed by delays in decommissioning the Right Switchyard. By September 1969, though, two ten-hour shifts were hard at work. Bulldozers pushed common material to hoppers over two 60" and one 48" conveyor belts. The belts filled the thirty bottom-dump trailers on the job, each capable of holding 22 cubic yards of overburden. Kenworth tractors pulling two or three of the trailers “stop briefly under a conveyor belt and then slowly crawl ahead as the material falls into the open top of the conveyance,” the Wenatchee Daily World observed. “A loudspeaker tells the trucker he’s full up and off he dashes downriver to dump the material along the shoreline” for riverbank stabilization. During 1969, about 5.6 million cubic yards of common material and over 200,000 cubic yards of rock were removed.755

By mid-summer 1969, enough material had been cleared from the vicinity of the Forebay Dam foundation to permit Reclamation to conduct detailed geologic mapping. The area was cleaned by blasting it with compressed air, and a grid of 10’ x 10’ squares was laid out as reference

points. Of particular interest was a fault, which was further explored with core drilling. Reclamation engineers also scrutinized a fault in the forebay backslope.\textsuperscript{756}

Bids for the third major contract were due in July 1968. The scope included excavating about 11,000 cubic yards of rock and common material for the new plant, placing concrete for an anchor block between the Right and Third Powerplants, installing a steel sheet-piling cellular cofferdam with a concrete foundation in the tailrace area, and erecting a timber-crib roadway over the cofferdam. The cribbing, running adjacent to the cellular dam, would serve as a retaining wall for backfill for the dam.\textsuperscript{757}

Reclamation received ten bids ranging from $12.5 million to $15.9 million. The contract was awarded to Gordon H. Ball, a company based in Danville, California. The contractor started work on-site in the end of August, with completion scheduled for January 1970. Clearing the site of existing buildings and installing a 7' fence around the perimeter of the construction site were straightforward tasks. More complicated was the underwater installation of rock bolts for the anchor block. Most of the inundated benches were covered with a dense clay that resisted removal with draglines and clamshells, so a 5-ton spud was deployed. Divers cleaned up the benches with water jets and siphons. The condition of the granite that was to serve as the anchor block’s foundation was not ideal: “Throughout the site, very closely spaced joints dip at low angles (30°±) northwest toward the tailrace. These loosen quite readily; and, in combination with more-widely spaced high-angle joints, cause a pronounced slabby or flagstone-like condition.” Because of this “unfavorably oriented jointing,” it was impossible to make the benches level at elevations 950, 955, and 960.\textsuperscript{758}

The shifty soil that bedeviled early construction at Grand Coulee provided further complications. As the contractor excavated in the anchor-block and cofferdam areas, slides appeared on the exposed slopes. The condition was inadvertently aggravated by the location of a muck pile near the top of a slide area. Slides began to occur in November 1968, but movements were minor until early the next spring. By this time, excavation for the cofferdam slurry trenches had removed much of the material at the toe of the slide, and rising tail water submerged the area. On May 3, destabilized clay and silt surged down on the first cell being placed in the cofferdam by the anchor block: “The slide mass moved rapidly some 100-150 feet, shearing one leg of a cell template and buckling several others,” according to the project history. Willamette-Western Corporation of Portland, a subcontractor responsible for installing the cofferdam, had to replace some of the sheet-pilling and backfill around the foundation to stabilize the cell before

\textsuperscript{758} Harold G. Arthur, “Transporting Equipment for Grand Coulee Third Plant,” \textit{Journal of the Power Division, Proceedings of the American Society of Civil Engineers} 94 (November 1968): 140; Bureau of Reclamation, Annual Project History, Grand Coulee Third Powerplant, Columbia Basin Project, Vol. 2, 1968, 18-19, 110-120, 132. A spud is a heavy metal bar or cylinder that is pounded against the clay to break it up; the clay can then be excavated.
completing the other two main cells and the connecting cells. Although slides continued to be active north of the cofferdam, most of the material had been slated for excavation and was removed within months. The access road over the cofferdam, which had been opened to limited traffic when it was partially completed in October, was finished and opened to two-way traffic the following month, with the cells filled and capped, and the timber cribbing and guardrails installed.759

An 8' x 9' adit for access to the anchor block was created by sawing through the concrete of the Right Powerplant “A” line wall. The contractor began placing concrete for the anchor block in February 1969. A framework of H-beams and channels held the wood formwork for placing the concrete underwater utilizing the “tremie” method. An article in the Wenatchee Daily World described the process: “The fresh mix is being dropped inside [an] enclosure to form the base for a 12,000-cubic-yard concrete anchor block. . . . Gordon H. Ball Co. has lowered a pipe to bedrock and the concrete is forced down it out of a hopper by gravity. The pour must be continuous into the center of the growing underwater deposit to keep water out of the mix. Pouring will continue uninterrupted until the concrete is above the water surface.” The work was finished in April.760

The deadline for Ball’s contract had been extended because of delays beyond the contractor’s control. By the end of 1969, though, Reclamation had decided to compress the extended schedule and have work substantially completed by midsummer. To comply, the contractor added sixteen self-loading scrapers, fifteen bulldozers, two 48” belt loaders, four bottom-dump trailers, eight end-dump trucks, and other equipment. When progress was slowed by muddy conditions on the haul road to downstream disposal areas as a result of snow and rain in January and February, the contractor built a new, all-weather haul road, which greatly improved the operation’s efficiency. Between January and July 1970, Ball cleared some 1.1 million cubic yards of rock, 5.5 million cubic yards of common material, and 1,844 cubic yards of unclassified material.761

36. THE PRIME CONTRACT

“The period between 1968 through 1970 was largely involved with modification and excavation,” a Reclamation report noted, with Jelco and Gibbons and Reed working under a modified contract and the Green Construction Company busy removing some 22 million cubic yards of common materials and rock. The stage was set for the next phase in December 1969

when Reclamation issued a call for bids for the project’s prime contract. The main items in the scope, a project history explained, were construction of “a concrete forebay dam, six 40 foot-diameter concrete-encased penstocks, a powerplant, visitor facilities, and service roads and service yards.” By February 15, 1972, the contractor was to have the rails for the 50- and 275-ton overhead traveling cranes in place and have Bay 19 finished to elevation 1092. This would allow the turbine contractor to begin installing the spiral case for that unit. Bay 20 was to follow by June 15 and Bay 21 by October 1. All tasks were to be completed by December 1, 1974. 762

When bids were opened on February 10, 1970, the totals ranged from $112.5 million to $144.9 million. The low bid came from a joint venture, Vinnell-Dravo-Lockheed-Mannix (VDLM). It was a cross-continental, multinational group. The Vinnell Corporation was based in Alhambra, California; the Dravo Corporation in Pittsburgh; the Lockheed Shipbuilding and Construction Company in Seattle; and Mannix Construction in Calgary, Alberta. The contract was the largest single contract that Reclamation had ever awarded. 763

The contractor’s first task was to clean the forebay foundation to allow geologic inspection and mapping. A total of 9,250 square yards was air-blasted by May. More substantial excavation was needed in other areas. The penstock slots, powerplant, and tailraces involved removal of some 1.4 million cubic yards of rock and common material. 764

Like the Right Switchyard and the Visitors Center, the floating caisson was a casualty of the construction. The site of its drydock would be consumed by the new project, and Reclamation concluded that the caisson was no longer needed. The drydock was dewatered in the fall of 1971, the caisson was cut into pieces with torches, and a crane removed the pieces. The drydock, however, remained in place until 1974 when it was blasted with 15,700 pounds of explosives during the removal of the downstream cofferdam. 765

By fall 1970, activity was transitioning from demolition and excavation to concrete placement. The first official pour was marked by a ceremony in Bay 19 of the Third Powerplant’s substructure on October 21. Concrete placement in the Forebay Dam began on October 27,
beginning in Block 107. It went slowly at first, and work was suspended from mid-December to mid-February because of cold weather. By the end of February, with only 91,000 cubic yards placed, the contractor was more than 100,000 cubic yards behind schedule. Workers were soon making up for lost time as they gained experience, reaching an average of 3,700 cubic yards a day in March and 4,200 cubic yards in April. By the end of 1971, VDLM had completed over 50 percent of the concrete placement in its contract, with 440,955 cubic yards in the Forebay Dam and 265,000 cubic yards in the new powerplant. The intermediate structure of the turbine erection bay was virtually finished, and the concrete in Bay 19 rose to elevation 942.12. Concrete placement for Bays 20 to 24 began in 1971, and ranged from elevation 860.0 to elevation 919.37 by the end of the year. Work had also commenced on the generator erection bay.766

Aggregate for the concrete was excavated and processed by subcontractor Curtis Construction Company, Spokane, at a site on the river’s west bank about one mile downstream from the dam. A crusher and sorting plant produced aggregate ranging in size from 6” chunks to sand. A tunnel beneath the stockpile held a 30”-wide belt, which extended across a 930’-long conveyor suspension bridge to steel storage bins on the east bank. Dump trucks transported the aggregate to the batch plant at the construction site.767

When the weather was warm, another step was added. Before going to the batch plant, the aggregate was placed on belts and run through a 250’-long cooling building where it was sprayed with 37-degree water and, sometimes, chilled with cold air. A 36’-wide belt then conveyed the aggregate 400’ to the batch plant, where four 4-cubic-yard mixers could together produce 230 cubic yards of concrete an hour. The mixture often contained pozzolan, which had been too novel for use in the earlier construction but was now a common substitute for part of the cement. Reclamation’s Materials Engineering Branch had begun exploring nearby sources of natural pozzolan in 1968, sending six samples from central Washington and one from Oregon to the Denver test laboratory for further examination.768

All in all, the project required 1.3 million cubic yards of concrete. Nearly half of that was dedicated to the construction of the Forebay Dam, which was erected with essentially the same process used for the original dam. The concrete was poured in twenty-one vertical sections, each 50’ to 70’ wide. While the lifts in the original dam were 5’, though, the standard for the Forebay Dam was 7.5’. The depth of the new 200’-high dam tapered from 130’ at the base to 30’ at the crest.769

Six hydraulically driven donkeys hauled cars with five 4-cubic-yard buckets of concrete from the batching plant in the forebay area. These trains went a short distance before traveling onto a 775'-long service trestle that extended across the construction site. This trestle was flanked by two other trestles, each outfitted with two revolving gantry cranes with 150' to 200' booms. The 1,055'-long forebay trestle sat a higher elevation, while the other, measuring 890', was lower. The cranes plucked the buckets of concrete from the cars and maneuvered them to pour crews of five to seven men. There were also two revolving gantry cranes on grade in the tailrace area. In addition, the carpentry yard rated a crane because of the volume and scale of the formwork for the draft tubes and forebay structure. “More lumber will be used in one [draft tube] form than would be required for several homes,” Engineering News-Record observed.\textsuperscript{770}

According to the same journal, the train trestle delivery system was a big factor in VDLM’s winning the contract. Other bidders “were thinking of rubber-tired equipment to truck the concrete into the forebay and powerhouse areas.” Having “the service trestle, bringing concrete on a straight line from the batch plant to the center of the work area, is credited with some $2 million of the $8-million spread between the winning bid and the next proposal.” Like any system, however, this approach had weaknesses, which were highlighted in October 1972 when the cranes were temporarily out of service because the trestles had sustained structural damage.\textsuperscript{771}

The service trestle’s novel construction “incorporates wood in places generally reserved for steel. The towers for all the trestles are built of steel on 119-ft. centers, but cantilevered, laminated-timber beams support the service trestle’s deck.” The 32’-wide trestle was comprised of 50' and 68' sections, with the 50'-long sections centered on the towers. The 68' beams were dropped into steel hangers on the ends of the 50' beams and the connections were bolted to create a continuous girder. Six parallel rows of these 66''-deep girders held the 12' x 12' and 6' x 12' decking carrying three standard-gauge railroad tracks and other equipment.\textsuperscript{772}

The Forebay Dam reached elevation 1310 in mid-August 1973 and was nearing completion that fall. By the end of 1973, all of the trashracks for the intake structures and the penstock stop log seats, guides, and wheel-mounted gates were installed. By December, only the parapet walls remained unfinished, and Reclamation began drawing down Lake Roosevelt in anticipation of the removal of the upstream cofferdam and the 700,000 cubic yards of rock that had kept the reservoir water at bay during construction. Blasting to remove the cofferdam began in late December. Reclamation reduced the lake level 1.5' to 2' a day from December until March 11, 1974, when it reached elevation 1160. VDLM kept pace, removing sections of the cofferdam steel sheeting and rock as the water dropped. The reservoir hit a low of 1156.74 on April 25—

\textsuperscript{770} “Concreters Set Pace at Coulee Powerhouse,” Engineering News-Record 186 (April 29, 1971).


\textsuperscript{772} “Concreters Set Pace at Coulee Powerhouse,” Engineering News-Record 186 (April 29, 1971).
133’ below its full elevation, the lowest level since the facility had gone into operation in 1941. After the dike was breached, bringing water into the forebay, the elevation was allowed to rise quickly, reaching 1285 in late June and 1290 in the following month. Aerial photographs were taken during the drawdown to update survey information of areas usually inundated.\textsuperscript{773}

After the forebay area was submerged, attention turned downstream. About 736,000 cubic yards of material had been excavated from the tailrace area between January and November 1973. Some of the material was used as fill for the north service yard parking lot and other areas around the new powerplant. The rest was hauled downstream and added to sections of the riverbank that Reclamation sought to stabilize. After the upstream cofferdam was removed, there were sporadic efforts, sometimes interrupted by high water, to remove the tailrace dike and cellular cofferdam as crews were available. The downstream dike was breached in August and the cofferdam in November 1974. The cofferdam was removed by February 1975 and the dike by late May. VDLM finished excavating the tailrace channel in 1975.\textsuperscript{774}

VDLM was also responsible for completing the EHV cable tunnel and grading the 500-kV Switchyard and cable spreading yard. When bids were opened on May 12, 1970, the company had submitted the low bid of $4,660,576; the highest bid was more than $5.7 million. The contract was awarded on June 8, and the contractor began work on-site in July. Tasks included earthwork for the switchyard and cable spreading yard and installation of the concrete-lined EHV cable tunnel.\textsuperscript{775}

The tunnel comprised a 1,609’-long two compartment section, a 575’ single compartment section, and a 531’ cut-and-cover section. Subcontractor Kemper Construction Company was responsible for excavating the two-compartment cable tunnel. It used the latest technology—an “Alimak Raise Climber”—which was guided by a laser “as it drills a pilot raise shaft on a one to one-half or 32º slope up the 900 foot long inclined portion of the tunnel. . . . This raise climber, manufactured in Sweden, rides with gears powered with an air driven motor up a rail securely fastened to the rock. The rail carrying a water pipe and three air pipes, is built in sections two meters or 78 inches in length. The drills are mounted on the climber platform for drilling the face


of the tunnel.” By April 1972, VDLM and its subcontractors had substantially finished the tunnel and preliminary grading for the 500-kv Switchyard and cable spreading yard.776

The contract to complete the 500-kv Switchyard, cable spreading yard, and transformer circuits went to City Manson Osberg, a Seattle joint venture, which submitted a bid of $6.4 million. The Donald W. Close Company, a subcontractor of British Insulated Callender’s Cables (BICC), was responsible for installing three-phase, self-contained 525-kV extra-high-voltage oil cable systems through a corridor in the dam and up the inclined tunnel to the cable spreading yard. The nine cables, three for each circuit, would transport the power generated by Units 19, 20, and 21. Close had begun working on the systems offsite in April 1971, but the company’s work was suspended from November 1972 until January 1974 because Reclamation had not determined the exact length of the cables. BICC manufactured the cables in England. Close began pulling the cables in September 1974. The circuit for Unit 19 was finished by the following summer and passed testing in late September, followed by the circuit for Unit 20 in December. All of the cables were installed and tested by spring 1976.777

37. THE BIG THREE

Reclamation had ordered the turbines and generators well in advance to ensure that they would be on hand when the Third Powerplant was ready for them. Although initially hoping to use a single contractor to provide and install both the turbines and the generators, Reclamation ultimately split the order into two contracts. This meant that two contractors would be working in the bays simultaneously, as Arthur explained: “The turbine contractor will have the spiral case installed, tested, and embedded before the generator contractor starts placement of the stator components. It will be necessary for the turbine contractor to continue to work in an area below the generator contractor.” Reclamation decided “to permit the assembly of the generator rotors in the generator-erection bay and to provide a . . . hydraulic-hoist gantry within the plant to transport and set the assembled rotors in the unit bays.”778

Reclamation awarded a $19.5 million contract for the first three turbines (G-19, G-20, and G-21) in July 1968 to the Bingham-Willamette Company of Portland, Oregon, a subsidiary of an earlier contractor at Grand Coulee, Guy F. Atkinson. The 820,000-horsepower turbines had Francis-


type runners measuring 32' in diameter, almost twice the diameter of the 16'-8" runners in the Left and Right Powerplants, and they weighed 550 tons compared to the 62.5 tons of the smaller turbines. Each was rated 600 MW under 285' head at 72 rpm. In August 1968, the Westinghouse Electric Company received a $22 million contract to manufacture and install the three 600,000-kW generators, each weighing 1,900 tons and having 68'-diameter rotors. The hollow, cast shaft was made in Japan in two parts. The section for the turbine was 8' in diameter, almost 22' long, and weighed 193 tons. At 122 tons, the generator shaft was lighter even though its diameter was 4" greater and it extended 23'.

Transferring the massive turbines, generators, transformers, and other equipment from the manufacturers, which were primarily located in the East and Midwest, required creativity. The Rocky Mountains presented a formidable obstacle, and then came the Columbia River—the plant was on the east side, while the closest rail connections and best roads were on the west side. Railroad clearances restricted the shipment of items larger than 13' wide or tall. While trucks could handle slightly larger dimensions, they faced limitations on weight; railroads could, with special planning, manage loads of up to 300 tons. Reclamation engineer Arthur explained that many of the plant’s components would “greatly exceed” these limitations, so they “may have to be shipped by water up the Columbia River through the locks of the dams on the lower reach of the river to the Pasco or Richland areas” using “‘land-type sea-going vessels,’ e.g., the LST craft used during World War II.” From there, the equipment would be loaded onto multi-axle trucks for transport to the construction site on “good but not heavily-traveled secondary roads,” with bridges specially reinforced if necessary.

One of the key bridges on the route was over the dam’s spillway. Reclamation engineers conducted laboratory tests and used computers to evaluate structural stresses to see if the bridge could handle loads of 250 tons net, 350 tons gross. “We were going to beef it up with steel beams to get the bigger pieces across,” office engineer T. R. McCollough told *Engineering News-Record*. Remarkably, the bridge proved strong enough without the reinforcement. Even so, Reclamation required contractors to request permission to cross with any load over 50 tons.

While the Christenson Electric Company did not have to contend with the bridge, it still faced a challenge in getting electrical equipment to the remote Grand Coulee site. Among the items in the company’s $423,759 contract was installing three 200-ton 230/525-kV autotransformers to tie the existing 230-kV Switchyard into the Bonneville grid and link that switchyard with the 500-kV Switchyard when the latter was completed. The Shaughnessy Trucking Company, as a


subcontractor to Christenson, built a special carrier with 7' high support beams with dollies that rolled on 80 airplane tires. The autotransformers were installed after their successful delivery and were activated on December 18, 1971.782

To ameliorate the transportation problem, the fabrication for some items was finished at the construction site. The penstocks, for example, were produced by the Chicago Bridge and Iron Company under a $17 million subcontract from VDLM. Most of the 15,000 tons of plate steel for the penstocks, which varied in thickness from about 1” to 2”, was produced in Japan, then formed into quarter-cylinder sections at a Chicago Bridge plant in Salt Lake City. The segments traveled by train to Spokane and by truck to a 400' x 600' work space at the construction site. There, the plates were welded into cylindrical “cans” 40' in diameter, 10' to 20' long, weighing up to 60 tons. *Engineering News-Record* reported that “to stress-relieve the welds . . . annealing ovens were built on the floor of the 7.5-million-cu-yd rock niche carved from the river’s right bank, called the forebay.” A section of penstock was lowered into the furnace and outfitted with thermocouples to ensure that temperatures were uniform throughout. Nine burners raised the furnace’s temperature to 1,100º F and maintained it at that level for three hours. Subsequent cooling was done under controlled conditions.783

To get the cans from the fabrication yard to their final position, the company put in rail tracks on the upstream side of the Forebay Dam and down the penstock slots. A stiff-leg derrick loaded the cans onto a steel-frame “ditch car,” that rode atop a transfer car. The transfer car went as far as the penstock slot. The ditch car carried the can into position in the penstock. A Skagit hoist, anchored by a concrete block behind each penstock slot, controlled the movement of the ditch car. Eight 50'-ton jacks lifted the can from the ditch car and, after the car was moved away, lowered the can onto concrete pedestals.784

The first can was put in place on February 27, 1971 for G-19, the southernmost in the plant, and by the end of that year 60 percent of the penstocks for the first six units were installed. The cans were welded together manually at first and later by automatic welders. Two shifts a day worked on fabricating and installing the cans. The welds were subjected to X-ray testing during the graveyard shift. Upon being cleared, the tubes were sealed, filled with water, and put under pressure for another round of testing. After the penstocks passed this inspection, they remained filled with water during placement of the 55,000 cubic yards of concrete that encased them. By

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the end of April 1972, Chicago Bridge had finished installing the penstocks, each measuring about 427' in length.\textsuperscript{785}

In December 1971, the Bingham-Willamette Company began delivering components for the turbines to the staging area. The components were brought to the Odair Siding by railcar, and transported from there to the site by truck. By the end of 1972, all of the runner bands, stay rings, crown sections, and turbine blades for the three turbines had arrived at the staging area.\textsuperscript{786}

There, subcontractor General Electric joined the components for the 39'-diameter turbine runners with field welds 2" to 10" thick. The runners were then stress-relieved in a steel-frame, propane-fired annealing furnace that was capable of reaching a temperature of 1,200 degrees. The company assembled the furnace in the forebay area between March and May 1972. The welding jig and related equipment did not begin arriving on-site until February 1973. Electroslag welding for the runner-band seams for the Unit 19 turbine was completed in April, and the first of the turbine’s thirteen blades was welded to the runner band in June. On December 12, the final blade-to-crown weld was completed. Unfortunately, however, “ultrasonic inspection of the blade-to-band electroslag welds revealed defects in nine of the thirteen welds.” The problem was not easily remedied. If the runner remained on the jig, the schedule for assembling the Unit 20 runner would be delayed, “so it was decided to move the runner to the stress relief furnace [and] complete repairs there.”\textsuperscript{787}

General Electric moved the runner to the furnace on January 10, 1974. The project history reported that “the subcontractor started working a second 12-hour shift, six days per week, to accelerate the weld repair of the runner. Weld repairs and blade shaping on the runner were completed on March 5, 1974 and preparatory work for stress relieving the runner was started immediately. The stress relieving was complete on March 11, 1974.” Much to everyone’s relief, the welds had no defects, so the runner was transported back to the turbine erection bay for machining. “The contractor’s milling machine was designed and constructed especially for the work under the contract. The main components of the machine were mounted on top of the runner with the cutting head rotating around the runner on an arm. After the milling machine was


mounted on the runner, numerous adjustments and corrections were necessary.” The equipment was finally ready to go on June 21, and the machining was done on November 5.  

38. THE NEW PLANT

The 540,000 cubic yards of concrete required for the powerhouse nearly equaled that for the Forebay Dam. The concrete was delivered to the site in buckets on flatbed trailers pulled by diesel-powered tractors. Seven large gantry cranes, most on trestles and some with 175'-long booms, had hooks to grab the buckets and lift them into position. The crews, Engineering News-Record reported, “complain[ed] about the 1-in.-slump mud’s incompatibility with the more than 61 million lb. of rebar in the powerhouse.” The bars were mostly 1" to 1-3/8" in diameter.

The article continued: “Although the huge structure’s . . . lower levels that house the unit’s embedded parts are heavily laced with big bars, ironworkers are just now getting to the really difficult rebar placement—the building’s folded, stiffened concrete walls, designed by New York City architect Marcel Breuer and Associates, to provide ‘continuity, visual interaction and structural integration’ with the dam.” In addition, “the 84-ft-high walls must be capable of supporting a pair of 275-ton bridge cranes, so there’s a nightmare of ever-changing rebar configurations involved.” The concrete sections stood 85' tall and were from 12" to 54" thick.

VDLM began placing concrete for the superstructure of the turbine erection bay in March 1972. By the end of the year, placement was finished for sections of the exterior walls and the remaining section rose to elevation 1054.17. The prestressed, precast roof tees were fabricated by the Central Pre-Mix Concrete Company, which began producing them at its Spokane facility in May 1972. By September 15, the company had placed concrete for every roof tee. The first tee was delivered to Grand Coulee in July. By the end of the year, all 122 tees were at the jobsite and 14 were in position over the turbine erection bay. The remaining tees were stored nearby until needed.

A new service/warehouse building was under construction in the 500-kV Switchyard at the same time and also featured precast, prestressed roof tees. Contractor Ace Concrete Company of Spokane began casting the tees in mid-July and had completed all of them by early August. The tees were in place by October, when rigid urethane foam insulation was installed.
The bay for Unit 19 was the most advanced among the three first bays constructed, with intermediate stage concrete placed to elevation 1012.5 by the end of October 1972. Work on the superstructure had begun a month earlier, and the transformer structure concrete had been in place since June. By the end of 1972, the concrete substructure for Bay 20 was finished and the intermediate structure stood at elevation 957.50, while the intermediate structure of Bay 21 was around elevation 1000. Work had begun on the intermediate structures in Bays 22 and 23 and the generator erection bay, but not yet on Bay 24.793

Despite the progress, VDLM was behind schedule by fall 1972. The 1973 project history reported: “By letters of October 31, 1972, and February 27, and March 2, 1973, the contractor filed a claim entitled ‘Powerplant Impossible to Construct within Contract Milestone Dates.’” In June 1973, Reclamation and VDLM had reached an agreement giving the contractor additional compensation to cover the government’s share of the “increased costs because of the difficulty of constructing the powerplant within the time allowed by the contract.” The completion dates for a number of items, particularly the generator erection bay and Bays 22, 23, and 24, were extended for more than a year. As a result, those units were expected to come on the line in April 1977, October 1977, and April 1978, respectively.794

Regardless, the project continued to experience cost overruns and delays. By the summer of 1974, the contractor had submitted claims for over $30 million, a substantial increase from the original $112.5 million contract, because of delays that the contractor claimed were beyond its control. This resulted in cash-flow issues for one of the joint venture partners, Vinnell. After experiencing a loss of $5.8 million on the project, the company turned over the lead role on the joint venture to Dravo.795

This loss was despite economic incentives that Reclamation provided to speed construction. In 1973, Reclamation issued an acceleration order “to meet target dates established for commercial operation of Units 19, 20, and 21.” By the end of the following year, the contractor had received additional payment of nearly $2.6 million due to this order, under which “the contracting officer could direct the contractor to work his employees in excess of a normal 40-hour work week, employ additional men, and furnish additional materials and equipment to accelerate performance of the work.” This was implemented mostly to speed up the placement of second-stage concrete to complete the powerplant superstructure. Bay 19 had been finished on schedule in April 1973; with the acceleration, Bays 20 and 21, both targeted for completion in January 1974, were done in November and December of 1973, respectively. By the end of 1973, all of the penstocks and draft tube liners were encased. Concrete was in place for all of the intermediate structure and, with the exception of Bay 24, the superstructure. The latter had been delayed by

793 Bureau of Reclamation, Annual Project History, Grand Coulee Dam Third Powerplant, Columbia Basin Project, Vol. 6, 1972, 48-49.
the failure of formwork in the northeast corner of the tailrace area, which caused the deck to drop about 2’ and required reconstruction of the area.\textsuperscript{796}

The last concrete was placed for the superstructure on January 18, 1974, and VDLM had completed “all precast concrete members for the powerplant structure . . . with placement for crossover bridge panels” on February 11. Part 6 of VDLM’s contract that covered the construction of Bays 22, 23, and 24 and the generator erection bay, including placement of the roof tees and crane rails, was substantially complete by March 1. Later that month, Thermoguard Insulation Company, the roofing contractor, installed flashing, and spent the summer applying a silicone rubber base coat and spraying on urethane foam insulation. Application of the silicone top coat was interrupted by bad weather in early November, delaying completion of that task until the following spring.\textsuperscript{797}

The plant’s cranes had to be operable to facilitate the installation of the turbine-generator units, and the plant’s superstructure had to be completed before the three overhead, traveling cranes could be installed because the columns for the rails were incorporated into the building’s concrete walls. An observer later noted that this design ensured that “the walls of the powerhouse will be kept as aesthetic inside as they are outside.” The turbine erection bay was appropriated to erect the two 275-ton and one 50-ton overhead traveling cranes. By the end of 1972, the cranes were in place but not tested. Each spanned 110’, all running on the same rails. The two 275-ton cranes, working together with a lifting beam, could pick up the 500-ton assembled turbine runners, while the smaller crane was for lighter loads and to help place concrete during construction.\textsuperscript{798}

Although powerful, these cranes were dwarfed by the 1,900-ton, self-propelled gantry planned for the plant. The crane was “of special design using four hydraulic cylinder hoists with 25 foot lifts for handling the generator rotors only,” according to a contemporary engineering report. Unlike the other cranes, it ran on steel tracks spaced 95’ apart that extended for the entire length of the plant’s main floor. Although the largest machine of this type in a Reclamation facility, the gantry would be capable of delicate operations, handling lateral movement of as little as 2” to precisely align a rotor into a stator.\textsuperscript{799}


\textsuperscript{797} Bureau of Reclamation, Annual Project History, Grand Coulee Third Powerplant, Columbia Basin Project, Vol. 8, 1974, 18, 43-44.


This behemoth had been slated for activation at the same time as the other cranes. Reclamation originally planned to issue the contract for supplying the gantry in spring 1970, with erection to begin in the fall of the following year and be completed by summer 1972. The solicitation did not go out until fall 1970, however, with a December 1 deadline for bids. The R. A. Hanson Company, a Spokane manufacturer, came in with the low bid of $1,095,000. The name of the model of the crane, the RAHCO 2000T, was derived from the initials of the company’s name. Reclamation gave Hanson notice to proceed on January 7, 1971, assuming completion 690 days later on November 27, 1972. Ultimately, it was much later than that, through no fault of the contractor. VDLM was supposed to have the crane’s main runway rails and conductors, which were integral parts of the installation, in place by July 15, 1972, but missed this deadline by months. The crane contract’s completion date was pushed back a day for every day that the rails and conductors were not available. Hanson ended up storing parts of the crane from April 1971 to June 1973. It assembled major components at its shop between July and November 1973 and was finally able to begin delivering sections to the Third Powerplant and installing the gantry in the generator erection bay in December. 800

Reclamation was well aware that the architectural quality of the powerplant could be undermined by an unsightly crane, since this mechanism was a dominant element on the interior. As a result, the bid documents had insisted that “care shall be used in the design of the gantry to produce a pleasing appearance. Drawing No. 3 (1222-D-1859) indicates the general architectural treatment that is considered an essential feature of the gantry. Drawings that are submitted for approval will be evaluated on the basis of good structural appearance as well as structural integrity.” 801

The crane was essentially completed by mid-January 1974, except for painting and load testing. The delay was not without benefit. According to the 1975 project history, “In the interim between substantial completion of the work and the availability of a rotor assembly to perform the load tests, . . . it was determined that the name plate capacity of the gantry could be increased from 1900 to 2000 tons.” This was made official after the tests were performed in June and the gantry successfully carried over 2,530 tons. 802

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In the meantime, assuming that the overhead cranes would soon be available, Reclamation notified Bingham-Willamette on August 18, 1972, that the turbine pit for Unit 19 would be ready for installation of the draft tube liner on November 1. Because the overhead cranes were not yet functional, subcontractor Chicago Bridge and Iron used a stiff-leg crane with a 90’ beam in the Unit 19 draft tube pit area to hoist the first section of the draft tube liner into place on November 28. By late January 1973, the installation was finished and the ball was back in VDLM’s court to do the concrete embedment. The bay for Unit 19 was finished to elevation 1092 by mid-April, and the focus shifted again to Bingham-Willamette and Chicago Bridge, which were responsible for installing the spiral case with the aid of the recently functional overhead traveling cranes. Work on Units 20 and 21 was underway concurrently, as was concrete placement for Bays 22, 23, and 24.  

Reclamation anticipated the start of hydrostatic testing of the spiral case in Bay 19 in November. When the last section was placed in the pit on October 19, however, there was an unexpected 30" gap between two sections. It took several weeks to fabricate and install a dutchman to close the gap, and it was not until early December that the spiral case was welded to the stay ring. Cracks in the weld further delayed the testing, which did not begin until early in 1974.

The Westinghouse Electric Corporation began assembling the rotor and stacking the stator laminations for G-19 in 1974. The process was expedited in anticipation of having the unit on the line by May 18, 1975. An ironworkers’ strike delayed completion of the generator foundation for fifty-eight calendar days, extending the deadline to July 15.

Yet another contractor arrived on the scene after Reclamation awarded Wismer and Becker Contracting Engineers of Sacramento, California, a contract for “Stage 01 Completion” late in 1973. This contract “consisted generally of work required to provide station-service and auxiliary facilities needed for Units 19, 20, and 21 and completion of major portions of the Third Powerplant and Forebay Dam visitor facilities.” Specific work tasks included installation of three 4,600,000 foot-pound governors, one for each unit; the electrical, heating, air-conditioning, ventilating, and plumbing systems for the plant; and ten single-phase, 15 to 525-kV 236,000-kVa power transformers. The company had submitted the lowest bid, $10,834,388, which was $915,122 over the engineer’s estimate.
The company began setting up facilities at Grand Coulee in late January 1974. One of its first priorities was installing piping systems, electrical controls, and related equipment to enable the start-up of G-19, which at this point was projected to occur on April 9 of the following year. By the beginning of 1975, however, it was obvious that the deadline would not be met, despite the contractor’s diligence. A project history explained that the “work had been delayed by previous labor strikes, contract changes, late drawings to be provided by the Government, lack of adequate access to the site, and interference with the contractor’s work by the operations of other contractors and the Government.”

The contractor completed installing the 525-kV power transformer for G-19, along with related lighting and electrical work, in May, then rushed to follow suit with the other units. Delays continued with the installation of G-20 and G-21, though, because the generator contractor was behind schedule. A six-month strike by pipefitters working for a plumbing subcontractor also caused complications.

Finally, though, came the long-awaited start of the first unit in the Third Powerplant, G-19. As the project history reported, the initial run did not last long: “Initial start-up of the unit occurred at 3:01 p.m. on August 25, 1975; however, the unit was shut down at 4:23 p.m. by a false overspeed indication. The spiral case was drained and work was performed on the wicket gate stem seals on August 26 and 27, 1975. On August 27, 1975, the unit was restarted and a two hour bearing run-out was satisfactorily complete.” Testing and inspection continued until September 26, when the unit was released for service. By the end of the year, it had generated nearly 1 billion kWh of electricity.

Delays with G-19 had a ripple effect on the completion of the other two units. Contributing to the problem was a bottleneck inside the powerhouse, where little space was available to maneuver the giant components for each unit and the assembly had to follow a strict sequence. The original schedule called for the nonembedded turbine parts for Unit 20 to be placed in the pit by August 1973, but the second-stage concrete work for the unit was not completed until April 1975, with Unit 21 following in August. In March 1975, Reclamation extended the contractor’s deadlines to November 24 for unit 20 and May 24, 1976, for Unit 21. “Delays due to the unavailability of the work area and other causes” pushed the deadline for the nonembedded parts for Unit 20 back to December 9, 1975. The contractor and its subcontractor, Halvorson-Mason Constructors, rushed to have them in place by October 31, earning a bonus of $370,000 after Reclamation offered incentives to accelerate the process. In September, before completing its

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work on Unit 20, Halverson-Mason embarked on the installation of the nonembedded parts in Unit 21.\textsuperscript{810}

Unit G-20 finally came on the line on April 8, 1976, and G-21 followed on December 4. The project’s annual production jumped almost 5.7 billion kWh from the previous year’s level, reaching 22.7 billion kWh. The three units in the Third Powerplant, operating at much less than full capacity, were responsible for about 7.2 billion kWh of that total—almost as much as the nine-unit Right and Left Powerplants, which each generated about 7.6 billion kWh. The two pumping-generator units contributed another 18.6 million kWh.\textsuperscript{811}

In 1977, production plummeted by 6.2 billion kWh to 16.5 billion kWh due to a combination of factors. One was an extreme drought, with precipitation 60 percent below the normal rate. Another factor was equipment outages because of a fire that started in the Third Powerplant on the evening of Saturday, November 19, and raged for several hours. The fire began inside the air housing of the G-21 generator. The deputy director of design and construction described the situation after the fire was extinguished: “The damage was serious and extensive. The stator winding and connections above the core were very badly burned over about one-half the circumference of the unit.” Fortunately, “the heat was confined to the upper part of the stator. There appears to be no sign of structural damage to the concrete, soleplates, stator positioning beams of the stator iron.” He estimated that repairing the stator, which would require removal of the rotor, would take approximately twelve months and cost from $1 million to $4 million. The tab ultimately totaled about $3 million, but the repair was to take longer than anticipated.\textsuperscript{812}

As a result of the fire, all three units were placed on construction status. G-19 and G-20 were functioning again within a month, but G-21 was out of service through 1978. In January of that year, the upper bracket was removed and workers started cleaning the stator winding connections and thrust bearing areas. In March of that year, the rotor was moved to the generator erection bay and stator core loss tests were conducted. By mid-May, the stator core had been removed. Many of the parts were cleaned by blasting them with ground corncobs and walnut shell fragments. \textsuperscript{813}

With G-21 still down for repair, operators juggled G-19 and G-20 to facilitate repairs and construction. In December 1978, G-19 was taken off the line for planned maintenance: “Government forces repaired Unit 19 turbine runner cavitation and put large dowels in a servomotor connecting rod pin. Rotor poles 89, 90, and 91 were removed for better access to stator windings. The contractor’s investigation revealed indications of corona damage and loose wedges at several locations around the stator.” A temporary fix for this condition allowed G-19 to go back on the line in March so that G-20 could come off the line and work in the 500-kV Switchyard could be undertaken. G-20 was back at work in May, and both units were active during the summer.\(^{814}\)

In late September, G-21 returned to service. Shortly thereafter, work began on rewedgeing the stator for the G-19 generator. For a few weeks in November and December, G-21 was working solo while G-20 was shut down for inspection and minor repairs. G-20 was soon back on the line and “was expected to remain in service in 1980 (with monthly inspections) until the unit could be shut down and permanent repairs made similar to those in progress on Unit 19.” The stator winding repair work for G-19 was finished in August and testing began in September. The unit was reassembled by early November, returning to service by the middle of that month. The disassembly of G-20 began in September and repair work proceeded rapidly, with reassembly started in January 1981.\(^{815}\)

39. THE BIGGER THREE

By this time, plans for the Units 22, 23, and 24 were well along. Before Reclamation issued a request for proposals in spring 1973, engineers had determined that the unit capacity could be greater than 600 MW, perhaps as much as 700 MW. Because the bay dimensions were already established, there could be little change in the size of the spiral case and draft tube cone, so this increase would have to be gained by accelerating the speed to at least 80 rpm. Reclamation left it up to the manufacturers to propose a solution for the turbine design, which could have an output of 820,000 to 960,000 horsepower given a 285' net head.\(^{816}\)

In August 1973, the Canadian General Electric Company, Ltd., won the contract to provide and install turbine-generators for the three units, beating out several other contractors with a bid of about $57.8 million. A project history explained that “work under this contract is divided into Parts A and B: Part A includes furnishing, installing, and testing the turbines and generators; and Part B involves work or material applicable to construction at the site, primarily the concrete spiral case encasement second-stage concrete, and embedded materials.” The contract called for


The company planned to fabricate and oversee installation of the generator parts, using subcontractors to complete the rest of the work. One of the subcontractors, S. J. Groves and Sons Company of Minneapolis and Pasco, Washington, was responsible for the concrete work, which included furnishing and placing reinforcing steel. To produce the concrete, Groves retained two Spokane companies that had recently provided roof tees for the project, Acme Concrete and Central Pre-Mix Concrete Company. The companies established a batch plant two miles downstream from the dam on the right bank.\footnote{Bureau of Reclamation, Annual Project History, Grand Coulee Third Powerplant, Columbia Basin Project, Vol. 8, 1974, 134-138; Bureau of Reclamation, Annual Project History, Construction Division-Grand Coulee Third Powerplant, Grand Coulee Dam Project Office, Columbia Basin Project, Vol. 1, 1975, 102.}

Allis-Chalmers Corporation of York, Pennsylvania, was the subcontractor for manufacturing and installing the turbines and installing the generators. It, in turn, gave a subcontract to the Eagle Construction Corporation of Loveland, Colorado, to fabricate and install the draft tube liners and spiral cases and install the turbines and generators. The latter operation took over the south service yard with a turbine fabrication building and a stress relief furnace.\footnote{Bureau of Reclamation, Annual Project History, Grand Coulee Dam Third Powerplant, Columbia Basin Project, Vol. 8, 1974, 134-138; Bureau of Reclamation, Annual Project History, Construction Division-Grand Coulee Third Powerplant, Grand Coulee Dam Project Office, Columbia Basin Project, Vol. 1, 1975, 102.}

For strategies to up the capacity, Allis-Chalmers examined the track record of its earlier high specific-speed turbines. It also compared notes with a collaborator, West German manufacturer J. M. Voith. The most relevant model was the Paulo Afonso Plan on the Rio San Francisco in Brazil, where Allis-Chalmers and Voith had installed turbines in the 1950s. “The excellent performance and smooth operation of these units,” a company representative later wrote, “together with improvements in subsequent model designs demonstrating even lower values of critical sigma led us to the decision to offer 700 MW units operating at 85.7 rpm for Grand Coulee.”\footnote{David Burns and James Meyers, Allis-Chalmers, “The 700-MW Turbines at Grand Coulee Dam,” paper presented at the Hydraulic Power Section of the Canadian Electric Association, Montreal, March 25-28, 1974, 5. Allis-Chalmers and Voith had established a technical license agreement in 1971.}

Enlarging the units was not simply a matter of increasing all components proportionally, which would have resulted in too much weight and an unacceptable amount of deflection. The company’s engineers subjected all major components of the units to “the finite element method of stress analysis, wherein a component is modeled using structural elements of finite size. The component is then subjected to such forces as pressure, weight, temperature distribution or
centrifugal load to obtain a static or dynamic analysis yielding exact stress levels and displacements at almost any point within the structure.” One of the most significant changes from standard design that resulted was for the head cover: “With its mass centered over the high pressure area between the upper runner seal and stay ring, the outer head cover design provides exceptional rigidity, reducing deflection under operation and insuring proper clearance between wicket gates and head cover. The lower profile inner head cover permits locating the shaft guide bearing nearer the runner center of gravity, reducing the effective bearing load.” In addition, “this head cover design has also permitted placing the gate operating servomotors within the outer head cover, eliminating the normal large alcove in the pit liner.”

In addition to design challenges, the fabrication of these massive components pushed the envelope. The overall size of the stay ring, an Allis-Chalmers article noted, “exceeds the dimensional capacity of our largest vertical boring mill. This component will be positioned outside the mill, with a drawbar containing the tool itself mounted on the rotating table.”

To make the shaft easier to transport and handle, the company made it of rolled plate steel rather than adopting a solid- or hollow-forged design. A number of other components were also formed from plate steel instead of being cast. This was feasible in large part because of innovative electroslag welding techniques, which created a weld of up to 20” thick in a single pass. Even so, some of the sections were massive, “measuring up to 17' high and weighing over 100 tons,” and requiring the use of specially designed rail cars for transport. Each of the outer head cover and bottom-discharge rings were shipped in four sections, while the stay ring was in six sections, the pit liner in eight, the draft tube liner in thirty-two, and the spiral case in eighty-four.

The contractors then faced the challenge of assembly and installation. There was no room in the powerhouse for assembling Units 22, 23, and 24 because the first three units were being installed, so Allis-Chalmers erected a temporary facility beside it equipped with automatic welding equipment, a propane-fueled stress-relieving furnace, machining fixtures, and a 60-ton crane that could lift the heaviest individual component of the 32.5’-diameter runner, which had a completed weight of 450 tons. The automatic welding positioner was rated at 450 tons at 9’ from its table and had 360-degree ring tilt gears. “Consequently,” company engineers noted, “the completed runner weldment can be turned into its normal running position and lowered through the use of hydraulic jacks onto a transport car without the use of a crane.”

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Subassemblies of draft tube liners and spiral cases, which had been transported to the site in sections, were also connected in advance of installation to speed the process. Reclamation promised financial incentives—$8,400 a day—for each unit that was activated before the target dates in the specifications. Instead of having Unit 22 in place sixty months after the contract award, with Units 23 and 24 following at six-month intervals, the company strategized to shrink the schedule by sixteen months. Allis-Chalmers accomplished this, in part, by ordering critical materials immediately after receiving the contract and using more than one source for many of the components. In a departure from traditional procedure, the company did not do a trial assembly of the turbine spiral cases before shipping them to Grand Coulee because “the use of highly accurate numerically controlled flame cutting equipment and improved plate rolling techniques has entirely eliminated the need for large spiral case preassembly.” The tape-controlled flame cutter was “capable of cutting plate steel segments up to 10 inches thick within an accuracy of a few thousandths of an inch.” When the components reached Grand Coulee, installers worked three shifts a day. There were duplicate sets of erection spiders to allow work on more than one unit at a time.825

The confined space and multiple activities within the Third Powerplant sometimes forced modifications in plans. The draft tube liner intended for Unit 22, for example, was installed in Bay 23 between August and December 1974 to avoid conflicts with other work in the Bay 22. Installation of draft tube liners for Units 22 and 24 started that December.826

In 1975, Sumitomo Shoji America (SSA) began installing the 525-kV medium-pressure oil cable systems that would serve Units 22, 23, and 24 in the Third Powerplant.827 Upon submitting the low bid of about $6.9 million, SSA had been awarded the contract in September 1974. The company delivered conduits and brackets to the site in October and November 1975. Installation began early in 1976 by subcontractor Donald W. Close Company, which had also installed the 525-kV cable system for Units 19, 20, and 21. The dates for completing the systems for Units 22, 23, and 24 were April 10, 1977, October 7, 1977, and April 5, 1978, respectively. By the end of 1976, all phases of the cables for G-22 had passed testing, and the system for that unit was accepted as substantially complete in June 1977. Testing of the cables for Unit 23 was finished by September and for G-24 by November.828

Reclamation received ten bids for Stage 2 electrical work and awarded the project to Seattle contractor Holert Electric in November 1976, with completion scheduled for March 1979. With a bid of $3.6 million, the company was responsible for installing government-supplied governors for three turbines, fire-protection equipment, metal piping systems and other metalwork, air-conditioning systems, and electrical control equipment and lighting. Reclamation’s optimistic deadlines were quickly extended, with the deadline for G-22 pushed from August 1 to December 1977, for G-23 from February 1 to June 3, 1978, and for G-24 from August 1 to December 1, 1978. The deadline for work on the conduit and controls the EHV cable cooling system was shifted from August 1, 1977 to April 1, 1978.829

Holert met the new deadlines for the EHV cable cooling system and G-22, which was ready for an initial start-up on February 13, 1978. After going through a series of tests, on May 23, it was the first of the 700-MW units to go into service. Hopes that the other units would come on line soon were dashed in October 30, when workers discovered that stator winding bars had been gouged. The damage, the New York Times reported, “involved 12 coil bars, and ranged from scratched paint to severely gouged insulation.” Vandalism was suspected, as it appeared a chisel or crowbar might have been used. The unit, which had been temporarily stopped for maintenance when the tampering had occurred, now faced lengthier downtime. Unit G-24, still under construction, was found to have six damaged coil bars. The commissioning program for G-23, except for mechanical tests, was stopped. By November 7, though, the initial start-up of G-23 went forward. Reclamation allowed deadline extensions because of the damage, with G-22 to be completed on February 1, 1978, G-23 on July 31, 1978, and G-24 on January 27, 1979. Each coil bar cost about $30,000, so engineers estimated that about $500,000 would be required to fix the units.830

The contractor’s winding specialists began repairing the damaged stators in G-22 in January 1979. By March 9, the new and refurbished bars were installed and the unit was back in operation. In March and April, the crew fixed the vandalized stator bars in G-23. Problems during start-up testing forced additional repairs, delaying its return to service until November. The bars in G-24 were repaired while other work on its installation proceeded.831

In the meantime, Holert Electric had completed its work on G-23 by October 1978, but the vandalism delayed progress on G-24. During 1979, while waiting for the repairs to be done on that unit, Holert “completed installation and testing of piping systems, installed thermocouples in

the EHV tunnel, worked on modification of control and protective circuits, installed a new annunciator system, and did other miscellaneous work.”

Unit G-22 was back off the line in January 22, 1979, to allow modifications to the thrust bearing oil reservoir tube and wicket gate shift ring. During the process of that work, damage to the rotor poles was discovered. The modifications and repairs kept the unit out of service until the following January. G-23 was periodically out of service for inspection and minor repairs in the first months of 1980. After June 4, though, when the rotor rubbed the stator and failure of stator coil insulation produced a phase-to-ground fault, the unit was down for the rest of the year.

By May 1980, it had become apparent that all of the newest units needed rotor modifications, while G-19, G-20, and G-21 required stator winding repairs. As Regional Director L. W. Lloyd explained to Reclamation’s commissioner: “When we speak of stator winding repair and rotor modifications, the generators are completely disassembled down to the turbines” The schedule called for at least two generators, and sometimes three, to be disassembled at any given time over the next fourteen months. “During the period when a unit is down . . . the powerplant is congested with generator components and activities that go on during this time. The powerplant has the appearance that it is still under construction.” As a result, Lloyd recommended postponing the official dedication of the Third Powerplant until after the repairs were completed. That recommendation was echoed by others, and as a result, the dedication was not held until the latter part of 1981.

40. PREPARING FOR VISITORS

With the activity created by the construction, it was difficult to accommodate visitors. The roadway over the dam was closed to the public in January 1968. The Visitors Center on the right bank, in operation since 1957, was dismantled in September 1968 as part of site preparation for the Forebay Dam and Third Powerplant. It was replaced by a temporary facility on the west bank, completed by late June 1969, that included a trailer with a small visitor orientation area, restrooms, and a large parking lot. Tours of the powerhouse and dam were suspended until the end of construction.

Self-guided tours of the Left Powerplant were restarted in 1970. A doorway was installed at elevation 1012 in the building’s west wall, just to the right of a large existing door, to give visitors access to the balcony above the generator floor. Because the route passed through the

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834 L. W. Lloyd to Commissioner of Bureau of Reclamation, memorandum regarding generator repair and modification schedule, May 27, 1980, in Bureau of Reclamation-Boise files.
station service bay, a removable aluminum railing was installed to keep visitors from getting in the way of operations. A drinking fountain was added for their use.\(^{836}\)

By the mid-1970s, VDLM was wrapping up the installation of visitor facilities in the Third Powerplant. A major component was the three-stop inclined elevator that linked a parking area on the Forebay Dam with the powerhouse below. The 1974 project history explained: “The top station will provide a shelter and an excellent overall view of the area. From it, the elevator will carry tourists to a midway station. Here they will find rest room facilities and a crossover bridge leading to a cantilevered balcony with a commanding view of the Columbia River and the spillway section of the dam. Returning to the midway station, tourists will again enter the elevator and descend to the bottom station where a gentle ramp will lead them to a viewing area from which they may observe the 100-inch-diameter shaft rotating at 72 rpm from the force of water plunging 200 feet through 40-foot-in-diameter penstocks through 820,000 horsepower turbines.”\(^{837}\)

Like the plant’s roof tees, the elevator hoistway panels were precast at the Spokane plant of the Central Pre-Mix Concrete Company. The hoistway bridge panels were installed in January 1974. The stairs were cast in place, starting with the midstation section in the same month. Work on the lower section could not begin until the next month when one of the long construction trestles was removed from the area. Work progressed on the stations through the summer. The Western Gear Corporation of Everett, Washington, was subcontracted by VDLM to furnish and install the elevator. Western Gear subcontracted the work to Cam Industries of Kent, Washington, which apparently manufactured the elevator. The Western Elevator Corporation was responsible for installing it. Western Elevator started their work in July. By December, most of the rails and part of the elevator car were in place.\(^{838}\)

Unfortunately, “problems with the operation of the inclined elevator were encountered.” While VDLM and its subcontractors finished removing the tailrace dike and cellular cofferdam and other clean-up tasks during 1975, the elevator remained an issue on December 3, when Reclamation accepted the contract as essentially complete. Problems with the elevator, the project history for that year noted, “were to be corrected by the contractor as soon as possible.” This was easier said than done, as a terse entry in the project history for the following year testified: “Adjustments on the inclined elevator were made during the year, with problems still evident at year’s end.” The elevator remained a challenge in March 1979, when Reclamation negotiated a contract for $19,950 with Elevator Industries for removing “the exiting mechanical crank and slotted-disc door-operating mechanism, and furnishing and installing motorized door-

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operating equipment to operate five hoistway door assemblies independent of, but simultaneously with, the car doors.” The completion date was supposed to be June 15, but the work was not finished until the end of July.  

Although the elevator was not functional, Reclamation wanted to make the Third Powerplant accessible to visitors and developed an interim tour route from the Right Powerplant in 1977. It hired the Chicago firm Herbst/Lazar Design in February 1978 to prepare exhibits for the Third and Right Powerplants, the Pump/Generator Plant, and the Visitors Center. Planning to erect the latter building had been underway for years, but budget constraints delayed the start of construction and reduced the center’s size. Like the Third Powerplant, the Visitors Center was a product of the office of Marcel Breuer and featured an eye-catching design (see “Grand Coulee Dam Visitors Center,” HAER No. WA-139-G). The cylindrical concrete structure opened to the public in 1978.

The project received more exhibits after Reclamation gave a $570,000 contract to Design and Productions of Alexandria, Virginia, in September 1979. In the following year, the visitor areas in the Third Powerplant were modified when it was discovered that noise levels exceeded OSHA guidelines. To reduce the noise, Reclamation constructed stainless-steel and glass viewing enclosures by one entrance to the turbine pits of Units 19 and 20. It also installed insulated doors at the other entrances to these units and at both entrances of the other units. OSHA had also found problems with the Pump/Generator Plant in 1979, so Grand Coulee’s Engineering and Resources Division prepared plans to modify exhibit areas, restrooms, and a stairway to comply with life safety requirements.

41. THE PITFALLS OF PIONEERING

Grand Coulee’s Third Powerplant and related modifications to other parts of the project introduced innovative technology on a massive scale. Occasionally, engineers pushed too far and the technology pushed back.

The oil-filled cables were a case in point. In late 1974, the Donald W. Close Company, which was on-site installing the 525-kV extra high voltage cables, rigged up a shoofly and overhead 230-kV cable circuit bypass for emergency switching so that the oil-filled cables running to the

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230-kV Consolidated Switchyard could be repaired. “Once again,” the 1974 project history observed, “overhead wires were prominent on the top of Grand Coulee Dam.” The sharp incline in the tunnel between the powerhouse and the switchyard had caused the heavy oil-filled cables to stretch, which would have led to a fault if allowed to continue. The problem had been revealed by X-ray photographic studies in 1973 and 1974. Reclamation had met with the cable manufacturer, Mitsui/Furakawa, to discuss a solution, and in the meantime had lowered the temperature of the cable cooling system from 60 degrees to 55, and later 50, degrees. Investigatory work was done in fall 1974 on Circuit No. 4, the most damaged, to gain a better understanding of the problem before tackling the repair work.  

The overhead bypass circuits were tested in March 1975. In May, Reclamation received six bids to undertake the repair work, with the contract going to low bidder UTEC Constructors of Danvers, Massachusetts. After receiving notice to proceed with the $621,726 project in June, UTEC started repairing the nine cable circuits, one by one. The contractor initiated the process, the 1975 project history explained, by “removing and storing the cable circuit oil and opening the pipes at the splice and trifercator assemblies for inspection. If repair was necessary, the cable was cut, tensioned and respliced. Additional supports were then installed where required. The pipe was then evacuated, by the use of vacuum pumps, and refilled with oil. Next, the assembly was cleaned and the protective coating applied to the pipe. The circuit was then released to the Government for reenergization.” Numbers 2, 3, and 7 were finished by the end of the year, with the remainder done by mid-1976. The repair, however, proved only temporary. The 1977 project history reported: “Preliminary radiographic evidence showed that the repaired cables were still ‘unstablized’ and continued to migrate downhill.”

There were also new environmental challenges, triggered in part by increased awareness of dangers that had not been recognized in earlier years. In the 1980s, for example, Reclamation considered replacing the transformers on the Third Powerplant, apparently because of concerns over the polychlorinated biphenyls (PCBs) they contained. Because the transformers were a custom design, it would have been costly to replace the almost new units. Reclamation decided, instead, to do a retrofit, which promised to be half the price and require significantly less down time. In April 1986, Acting Regional Director John W. Keys III wrote to Ralph Bower, the regional director of the Environmental Protection Agency: “With the recent advancements made in the technology of retrofitting PCB filled transformers and the successes being recorded in reclassifying them, we have decided to attempt a retrofit of our Third Powerplant excitation transformers in lieu of replacing them.”

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42. ONGOING OPERATIONS

G-24 first went into service May 30, 1980. Even before then, though, Grand Coulee was setting new standards for a single hour of generation, producing 3,987,000 kWh on January 4, then breaking that record only two days later with 4,125,000 kWh. The year’s total production of almost 19 billion kWh, however, was slightly less than in the previous year, with about 6.6 billion kWh coming from the Left Powerplant, 6.3 billion kWh from the Right Powerplant, 5.9 billion kWh from the Third Powerplant, 10,000 kWh from Pumping/Generating Unit 7, and the rest from the station service units.  

The new units fed into an interconnected power grid that was increasingly complex. The Pacific HVDC Intertie occasionally experienced outages, which caused sudden load swings that had the potential to destabilize generating units feeding the system. To counteract this problem, the Bonneville Power Administration asked Reclamation to install transient excitation boosting (TEB) for the six generators in the Third Powerplant, as well as the 500-kV Switchyard. The two agencies signed an agreement in 1987 stipulating that Reclamation would have TEB equipment operating on four units by June 1989 and the remaining two units by the following March. Reclamation engineers were responsible for designing and installing the system. The process apparently took longer than anticipated: Reclamation conducted the commissioning tests in May 1991.

Bonneville Power, for its part, agreed to upgrade aging and obsolete transmission lines. It announced plans in 1993 to improve the 115-kV line from Grand Coulee to Spokane, described as an “82-mile bottleneck.” Because of the time needed for planning and environmental review, construction was not scheduled to start until 1997. When the $144 million project was completed in 1999, the power output would rise to 3,900 MW. In 2002, Bonneville announced “the Pacific Northwest’s most ambitious transmission system improvements in half a century”—a $182 million project for 155 miles of new 500-kV transmission lines. The longest section was between Grand Coulee and Spokane, replacing an 84-mile-long 115-kV line. The Energy Services Delivery division of Duke Energy, from Charlotte, North Carolina, won the contract.

The newest units at Grand Coulee, G-22, G-23, and G-24, were important contributors to the power grid, but they remained temperamental after being put in service. Engineers had been frustrated in attempts to identify the cause of the early problems. By the fall of 1989, they...

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“speculated that the early unexplained failures were probably the result of undetected water leaks.” The solution was to replace the armature windings in the units, one by one. The process was expected to take six years and cost more than $34 million.⁸⁴⁸

It was not until 1992, though, that Reclamation ordered new water-cooled armature windings, stator cores, and associated equipment for the three units from the Siemens Power Corporation. By then, the cost was lower—$28 million—and the installation was faster. Siemens tried an innovative approach: supplying a new stator frame for the first unit to be overhauled. “The new frame, core and winding will be assembled in the powerhouse erection bay,” *Power Engineering* reported. “A specially designed lifting device will remove the existing stator in one piece, allowing the rotor to remain in place. The new frame with core and winding will be placed on the foundation, a lift of 700 tons. The existing stator will then be stripped of its core and winding, modified, and used for the second unit. The stator from the second unit will similarly be modified and used for the third unit.” Requiring only seventy days of downtime per generator, this approach was remarkably faster than the hundreds of days needed if starting without the new stator. To improve the stability and efficiency of the stators, the new cores had 540 slots, an increase from the 486 slots in the original units.⁸⁴⁹

In addition to making the units more reliable, the project increased the ratings of the 700-MW units to 805 MW. “This makes the three machines the highest output single-unit hydroelectric generators in the world,” *Power Engineering* marveled. In July 1996, G-22, the first to be installed, attained an output of 836 MW with an efficiency of 98.73 percent. The stator for G-23 was returned to its bay in October 1997. By the end of the year, G-24 was back in place and Siemens had completed its contract.⁸⁵⁰

The first units of the Third Powerplant were barely in operation in October 1975 when Reclamation released a report entitled “Background of Studies Investigating Desirability of Enlarging the Third Powerplant at Grand Coulee Dam, Washington.” This had been preceded in the previous year by another document, “A Background for Studies of Extension of the Third Powerplant,” and by planning conferences at the Boise regional office and Grand Coulee. Reclamation’s Third Powerplant Study Team was charged with evaluating a number of issues related to a possible expansion: “Installation of either four, five, or six units; individual generating capacity; river crossing for power transmission; disposal of excavated materials; and downstream riverbank stabilization.”⁸⁵¹

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⁸⁴⁸ Notes from meeting regarding rewinding Units G22-G24, September 19, 1989, and undated memorandum from Chief, Electrical and Mechanical Engineering Division (Denver) to Regional Director (Boise) regarding stator windings for GE Canada Units 22, 23, 24, both in Columbia Basin-Grand Coulee, Box 651, Powerplants and Equipment, Third Powerplant, November 1989, Bureau of Reclamation-Boise.


During the same period, the Committee for Completion of the Columbia River System was formed by Reclamation, Bonneville Power, the Corps of Engineers, several county utility districts, and private consultants. With the peak power needs of the Pacific Northwest predicted to triple to 60 million kW within two decades, this task force was charged with assessing current conditions and exploring future hydropower development on the Columbia River, either by modifying existing facilities or through new development. According to a Reclamation synopsis of the resulting studies, “It is apparent that Grand Coulee with its higher head and vast storage has the greatest potential for increased peaking capacity of any existing plant on the river.”

In 1977, though, after the initial investigations were finished, future work was suspended. A decreased load forecast, due largely to conservation efforts, made it prudent to delay thoughts of expansion for at least a decade.

Environmentalists were relieved. They were already concerned about the greater fluctuation of water levels downstream due to increased peaking capacity at Grand Coulee. The massive units of the Third Powerplant made it difficult for operators to maintain the river downstream at a constant level. Rapid fluctuations presented a major problem, though, by increasing the probability of movement of the slide-prone soil. Grand Coulee engineers began exploring the possibility of installing flashboards on the drumgates to control the flow. In 1978, they requested assistance from the Denver office to analyze the effectiveness of current procedures for operating the gates and seasonally installed flashboards, improvements that could be made to increase the spill capacity of the gates, and the feasibility of installing permanent flashboards that could be collapsed by remote control when more spilling was needed.

To monitor the effects on the river’s banks, Reclamation developed a Ground Water Data Acquisition System in the mid-1970s. When completed, the 1976 project history explained, the system “will automatically collect and transmit data from ground water piezometers to the CYBER computer system in Denver.” The piezometers and gas-bubbler transducers, which measured variations in pressure with changes in water level, were installed in holes that were drilled in various locations, including nine along the riverbank directly downstream from the dam. Twelve stations automatically collected data from these instruments and radioed the results to a central computer at the dam, which forwarded it on to Denver. When the system went into operation in 1977, “an intensive effort was required to troubleshoot and resolve technical problems with data communications.” Efforts to debug the system continued into 1978. The

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project history that year reported that “the system was providing reasonably reliable data by year’s end, but required intensive maintenance work.”  

Concerns further downstream with the perpetually unstable riverbanks led Reclamation to install a series of seven drainage wells on the left bank. The wells were 24" in diameter to a depth of 150' and 10" in diameter below that. The contract was awarded to Holman Drilling Corporation of Spokane, one of only two bidders when the bids were opened in February 1974. The completion deadline was extended 138 days, to June 3, 1975, because of a nationwide shortage of steel pipe. Still more time was added when Reclamation decided to add two wells to the scope, bringing the total to nine. All wells were in place by fall 1975.

Reclamation also undertook a river channel degradation study to consider how different flow conditions affected the banks and to identify the most effective stabilization techniques. Launched in 1977, the study involved the construction of a 1:20 scale model as well as computer modeling. Baseline material was gathered from maps, photographs, and a river bottom survey by the Pacific Northwest Region’s dive team.

Holman Drilling was back in March 1978 to drill two drainage wells with submersible pumping units downstream from the dam. Drilled into granite at a depth of about 260', both were finished by October. Holman was retained again in June 1978 to drill another five drainage wells, each a maximum of 400' deep, to stabilize the area downriver from the bridge’s east abutment. Holman, the only firm to respond, was given the contract and started the work in August. The project was essentially completed a year later.

The last drilling campaign had just been initiated in June 1978 when six slides disturbed the east bank on one weekend. One was right at Coulee Dam, extending north some 1,300' from the State Route 155 bridge abutment. The slides had been triggered by a failure in one of the units in the Third Powerplant, which had caused a sudden 15' drop in the water level of the tailrace.

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Investigations of this area continued into 1980 when Reclamation hired Murphy Brothers to excavate twenty-two test trenches, requiring the removal of about 91,000 cubic yards of material. The contractor also had to build a sampling platform that could be moved from trench to trench, and to place samples of materials from the trenches on the platform for Reclamation’s inspection. In the same year, Reclamation retained Schneider Equipment to drill three test wells and assist with pumping tests at these sites, and Wyman Construction to drill and case forty holes in locations between the highway bridge and Peter Dam Creek some four miles downstream. Wyman had to pull core samples from the holes, which penetrated 20' into the granite bedrock. 860

The fragility of the downstream shores limited the operation of the Third Powerplant, restricting operators from taking full advantage of the plant’s peaking capacity. This gave urgency to Reclamation’s efforts to find a solution acceptable to the increasing large and diverse group of interested parties. An important advance came in 1982 when Reclamation issued a final environmental impact statement for a proposed downstream riverbank stabilization program. 861

Outreach to the general public had not been much of a concern in the dam’s early years. Reclamation’s relationship with local tribes, too, changed over time. When Grand Coulee was initially developed, the tribes had little influence over how their land was managed. The Bureau of Indian Affairs had represented them in 1946, signing an agreement with Reclamation and the National Park Service covering the oversight of the Coulee Dam National Recreation Area. The agreement gave Reclamation the main responsibility for administering the area. It also permitted the general public, under the auspices of the National Park Service, to use the freeboard and slide area lands around Lake Roosevelt, including those controlled by the tribes. This agreement was challenged in 1974 by an opinion from the Solicitor’s Office of the Department of the Interior affirming the authority of the tribes to manage hunting, fishing, and boating in tribal areas. 862

In response to the solicitor’s opinion, the Colville Confederated Tribes asserted that “lands owned by the Bureau between 1290 and 1310 elevation should be returned to the Tribes.” The tribes raised other issues as well, believing that “they should be compensated for the suffering that took place when Tribal members were moved from the reservoir area.” They also maintained that “gravel used for construction of the Dam was taken illegally from Tribal lands.” Most significantly, though, “they felt they had been given claim to the stored water overlying the original river bed to the center of the river and thereby a claim to power generation.” In other words, they wanted a share of the revenues from the Grand Coulee and Chief Joseph plants. This

position was formally outlined in a letter from the Coleville Confederated Tribes to the Department of the Interior’s Solicitor’s Office in April 1976.863

The Colville and Spokane tribes began demanding mitigation for the loss of fish and wildlife that had resulted from the construction and operation of the Grand Coulee Project. With the assistance of the Desert Research Institute of the University of Nevada, Reno, the Colville Confederated Tribes prepared a proposal for a five-year study of the effects on fish and wildlife as well as alternatives for managing Lake Roosevelt and its tributaries. In March 1976, Colville representatives brought their concerns to the Congressional and Senate Subcommittees on Appropriations of Public Works. As a result, the Senate Committee on Appropriations directed Reclamation to study the tribal claims. Congress had also asked Reclamation to prepare a plan “to develop the best possible fishery on the Lake.” The 1976 project history observed that “the two separate issues were interrelated, considering that the implementation of a total management plan to develop the best possible fishery in FDR Lake may mitigate Indian claims.” A committee representing a broad range of interests, including the tribes and Reclamation, issued a report in January 1977 in response to the Senate mandate.864

The first result was an interim agreement in 1977 that made Reclamation, rather than the National Park Service, responsible for managing certain activities on tribal freeboard land. The tribes reiterated their demand for revenue from Grand Coulee at meetings in Spokane in August 1978: “The Tribes maintained the position that they own the resources and the United States owes them considerable payment, including interest, for use of this resource in the past, present and future.” The meeting resulted in the creation of a committee with representatives of the tribes, Reclamation, and several federal agencies to examine alternatives for compensation. Reclamation drafted a report presenting five options for determining valuation that was discussed at a committee meeting in September. The committee revised the draft and presented it as a formal report to the Solicitor in December.865

During the same period, the tribes worked, apparently without assistance from Reclamation, on reburying the skeletal remains of some one hundred Indians that were removed when the dam and reservoir were created. Reclamation had transferred the bones to the Eastern Washington State Historical Museum in Spokane. They remained there until 1975 when the tribes hired Dr. Roderick Sprague, a member of the anthropology department at the University of Idaho, to analyze the collection. “He says he tried to get funds from the Bureau of Reclamation to study and rebury them,” the New York Times reported, “but was turned down.” Instead, the tribes

provided about $15,000 to have Sprague complete his work. The remains were reburied on the Coleville reservation on Memorial Day 1979.  

43. MORE MODIFICATIONS

With the Third Powerplant diverting water that had once gone over the spillway, the need for outlets on the dam was diminished. In 1970, Reclamation decided to remove the elevation 950 outlets from service and hired a contractor to place concrete plugs in the ends of the outlets, with the paradox gates sealed on the downstream side. By the end of 1971, sixteen tubes were plugged, but the gates at 43E, 43W, and 57W were uncooperative. Reclamation allowed the contractor to use a different approach, which involved “drilling and tapping eight ¾-inch diameter holes in the upstream face of the paradox gate and screwing ¾-inch diameter threaded rods into these holes. The rods were secured with angle iron at the ring follower gate slot,” and the slots were plugged with concrete. The remaining ring follower gates were removed and the outlet tubes sealed by October 1972.  

During the same period, Reclamation engineers sought a better solution for operating the bulkhead gates of the remaining outlet tubes. Since the dam’s construction, the gates had been raised and lowered by a steam-crane barge, which was scheduled for decommissioning. In the mid-1970s, the project acquired a new 80-ton mobile crane and placed it on top of the spillway bridge.  

A major energy crisis strained the country’s power sources in the early 1970s as construction of the Third Powerplant was underway. In July and August 1973, all available generating units were pressed into service at the request of the BPA, forcing the delay of scheduled maintenance. Reclamation stopped the spillway lighting program to reduce energy use. This did not disappoint as many people as it normally would have because visitation numbers had dropped significantly—down 18 percent in July 1973 from what it had been a year previously. “An unsettled economic picture and shortage of petroleum products were deterrents to vacation trips,” the project history observed.  

Other changes in 1973 were more pragmatic, often resulting from wear and tear on the facilities as they aged. The operation manager’s office, for example, was provided with baseboard heat

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and a dropped grid ceiling. This was done, according to the project history, “to replace 30-year old obsolete equipment.” It also noted that “the large and cumbersome aluminum folding door giving vehicle access to the Right Powerhouse was replaced with a motor operated steel rolling door.” Workers fabricated a ramp to facilitate vehicle access to the Right Powerplant’s transformer deck. Reclamation hired the Otis Elevator Company to modernize and rehabilitate the two passenger elevators in the Left Control Bay. Specifications were developed for a prefabricated portable guard station to replace the original station on the west end of the dam—“an obsolete wooden structure, over 30 years old.”

Changes in subsequent years were often prompted by troublesome equipment. The air housing mercoids, for example, often malfunctioned, resulting in equipment shutdowns. New thermostats and mountings were tested in 1978, with a prototype placed in the G-12 air housing: “There were two sensors for each cooler, one mounted in close proximity to the cooler and the other about 3 feet away. All four sensors were wired into a separate alarm on the annunciator.” A test trip at 115º F “did not affect the normal ‘cooler failure’ alarm.” In addition to being more reliable, in large part because of they had no moveable parts, the thermostats were one-tenth the cost of a mercoid.

Modification of the elevator in Block 10 began in January 1979 when Reclamation retained Unidymanics/Saint Louis to demolish the existing work platform and to install “one freight and personnel elevator which is a special man-hoist and work-platform arrangement.” In October, the Washington State elevator inspector approved the new elevator for service. With a capacity of 1,500 pounds, the elevator rose vertically about 178' at a speed of 50' a minute.

Energy concerns continued to foster modifications to the plants. Overhead lights in the generating room of the Left Powerplant were replaced with more efficient units in 1979. In April of the same year, a federal mandate required lowering the settings on hot water tank thermostats. Safety issues also prompted changes. In 1979, for example, “a request was made for Third Powerplant draft tube drain valve access ladders with cages because of current safety requirements and increased employee awareness of safety needs.”

A more significant intervention was required for the three station-service turbine wheels in the late 1970s. In faithful service since the plant had opened, the blades had begun to display major cracking in the late 1960s. Reclamation had undertaken repairs in the early 1970s, but continued deterioration and concerns over the potential failure of the wheels justified planning for
replacement a few years later. In upgrading the turbine and generator units, Reclamation wanted to switch from the existing fifteen-blade wheels to stainless-steel models with fewer blades. At the same time, adding a third transformer to the existing pair would use the power produced by the units more effectively. Initial estimates put the cost of the upgrade at $1.8 million.  

Even the new Third Powerplant was not immune from change. The six wheel-mounted gates in the Forebay Dam, each measuring 29' x 43.5', were not sealing properly. An inspection of the gate for Unit 19 in January 1978 revealed leakage of about 6,000 gallons per minute. The top seals appeared to be the main source of the problem. “The water pressure actuated seals are mounted on the upstream face of the gate and are intended to seal against the stainless steel seal seats embedded in the concrete,” the inspection team explained. They discovered, though, that there was a gap of about 3/16" in the middle of the top seal because “the horizontal beams and skinplates across the top of the gates are deflecting downstream more than the pressure actuated seals are moving upstream.” There was also “excessive corrosion . . . at the joint between the seal base bars and the skinplates.”

In 1979, Reclamation hired the R. J. McCarthy Company to do modifications to improve the performance of the gates. The contractor was required to inspect the hydraulic gate hoists and repair oil leaks, and also to replace the hydraulic drain valve cylinder operators and control systems in Units 19, 20, and 21 with pneumatic units. The contractor worked on one gate at a time, with Reclamation providing and placing one set of stop logs. The contractor had finished the project by August 1980.

In 1992, Reclamation awarded a $30 million contract to Siemens to rehabilitate the generators in the Third Powerplant. Plans had originally called for replacing the water-cooled stator windings with similar equipment. A new design with fewer connections, however, was anticipated “to reduce total electrical losses by 9 percent.” Siemens also proposed an innovative procedure for installing the replacements that was estimated to cut downtime from 300 days to only 70 days per unit.

**44. INTO THE COMPUTER AGE**

In June 1974, the Third Powerplant Construction Office and the Grand Coulee Dam Operations Office, which had been established in 1967 and 1970, respectively, were consolidated. Between 1954 and 1970, the dam had been managed by the Power Field Division of the Columbia Basin

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875 Third Powerplant Construction Engineer to Assistant Commissioner, Engineer and Research, memorandum regarding modification of 29' by 43.5' wheel-mounted gates in units 19 through 24, August 25, 1978, in Bureau of Reclamation-Boise files.
Project Office in Ephrata. The new operations office reported directly to Reclamation’s Pacific Northwest Regional Office, which was based in Boise. The reorganization acknowledged the increased prominence of the Grand Coulee Project and was heralded by the project history as “the most far reaching organizational change in the history of the Grand Coulee Dam.” The office gained personnel, program coordination, and safety staff “to increase the self-sufficiency of the organization.”

The offices were located in the Administration Building in the Industrial Area (see “Columbia Basin Project, Industrial Area,” HAER No. WA-139-H). The construction and operations offices had moved to the facility in February 1970 while the Third Powerplant was being erected. The building was equipped with the latest technology, including “a high-speed electronic computer” to schedule the delivery of essential components and track the progress of design and construction. Office engineer T. R. McCollough asserted that during the plant’s construction, “we saved several man-years with computerization in design.” Even so, the scope of the project was daunting: “By the time we’re through, we’ll have 30,000 drawings.” The computer also helped Reclamation implement an innovative process, the Critical Path Method (CPM), which the U.S. Navy had developed in the previous decade to monitor submarine construction.

Computers were gaining a greater role in operations as well. In 1971, Reclamation decided to install “advanced Programmable Master Supervisory Control (PMSC)” at the dam. The PMSC, which would “contain all the logic . . . for total control of the plant,” was to be located in the new master station on the eighth floor of the Left Control Bay, requiring the relocation of direct-current and other equipment from there to the twelfth floor. A dispatch center would be on the eighth floor of the Right Powerplant. “A remote terminal unit (RTU) will be associated with each generator, pump, dam control, and switchyard. The RTU will contain a limited programmable computer and hard wired logic,” and “will function independently upon command and monitoring by the PMSC and Dispatch Center.” The 1971 project history observed that with the system, which was expected to be activated early in 1975, “human interface and involvement will be greatly reduced in scope and volume.”

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At least some parts of the system were in place by that date. Introduction of the PMSC system forced an upgrade to the remote control equipment on the drum gates at the spillway’s crest, with Gate 10 serving as the prototype. By 1975, the new drumgate control system was in place and connected to the PMSC system. “Closed-loop control and indication of drumgate elevation to within 0.1 foot is now operational from the Dispatch Office,” the project history remarked. Control equipment for the outlet gates was also modified. Operation of the new control system, however, was far from perfect. The 1977 project history reported that “the drumgate control circuits were serviced and tested. Many problems occurred and failures remained the norm instead of the exception.”

In the meantime, physical alterations to accommodate the new technology were underway. B & C Contractors of Bend, Oregon, submitted the lowest price, $493,934, when Reclamation opened three bids for architectural modifications to the Left Powerplant Control Bay in July 1975. The project included demolition of concrete, terrazzo, and other materials and construction of new rooms and finishes, including a raised metal floor system and suspended acoustical ceiling. The contractor was also responsible for installing plumbing, heating, air conditioning, and fire detection systems. The modifications were almost finished by the end of April 1977.

That January, the John A. Carlson Electric Company of Seattle won the bid to install and connect the PMSC equipment cabinets and connect solid-state protective relays for the Third Powerplant and switchyards. Although the specification had given a completion date of January 1978, the work was only about half finished by the end of 1977 because of delays in equipment delivery. With a 201-day contract extension, the work was substantially complete in August 1978.

Developing and installing the hardware and software was a much greater challenge, the source of most delays. The process of designing the system forced a hard look at the organization of the plant’s operations, as the project history noted: “A detailed examination of the Grand Coulee dam basic operating philosophy and functional requirements has been started with the objective of determining a specific points list for all plant functions.” It also involved close coordination with the Bonneville Power Administration, which had recently created the Dittmar Control Center.

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The threat of delays in implementing the PMSC appeared in 1973 when a shortage of manpower and reduced travel budgets limited collaboration between the Operations Office at Grand Coulee and Reclamation’s Engineering and Research Center in Denver. “The project is of sufficient magnitude and complexity that the manpower presently involved in this project is inadequate to the need,” a project history complained. “Comparison of the Bureau effort with the approach of private enterprise to similar projects makes the above conclusion quite evident in the opinion of Operations Office planners.” To compound the pressure, the projected cost of the system was rising.

Staff did their best to make progress nonetheless. In 1974, the eighth floor of the left control bay was cleared by moving the remaining occupants, the electronics shop and the employees’ lunchroom, to the fifth and sixth floors, respectively. Specifications were prepared for the new control room and computer system, but until it was ready, technicians hired to operate the system were ensconced in temporary facilities on the fourth floor. Personnel and Safety offices, which had been located on the seventh floor, were moved to the new Administration Building in the Industrial Area.

Reclamation’s Denver office decided that bidding for the PMSC computer “should be a two-step process. First, computer companies were asked to present proposals for a desired computer, after which a negotiation period would occur to allow the Bureau to include the proper hardware necessary for the computer, after which a final money bid would be submitted by the companies.” Only two firms, Boeing Company and Rockwell International, expressed an interest. After analyzing their proposals, Reclamation sent each company a “lengthy questionnaire” with a request for verbal responses at meetings in January 1975. In June of that year, Reclamation awarded the contract to Rockwell International which bid $5.1 million, substantially less than Boeing’s $8.9 million proposal. The master station, responsible for monitoring “over 20,000 inputs,” consisted of “dual redundant Xerox 550 computer systems with associated peripherals.” The master station was connected to thirty-four remote terminal units, each with an Interdata 7/16 minicomputer. The system was to be up and running by the end of 1978. In the meantime, an interim computer system was installed in the Right Powerplant to control power and voltage at the Third Powerplant.

Rockwell’s software was tailored to the Xerox 550 model. After Rockwell and Reclamation had been working for a year on designing Grand Coulee’s PMSC system, Xerox announced that it was phasing out that model and selling its computer division to Honeywell. Reclamation

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considered jettisoning the substantial work that had been done to date and starting anew with another system, but elected instead to proceed with the Xerox equipment, knowing that the computers would probably have to be replaced within a decade or so, much sooner than planned. By 1976, Honeywell had started training the system’s operators, anticipating that the system would be in operation by the end of 1978.888

Reclamation soon faced disappointment again, and this time responded more aggressively. It had sought a cutting-edge system that would update computer displays within two seconds of a change in conditions. Rockwell believed that this speed was unrealistic, but did not relay its concerns to Reclamation engineers, who discovered that the system was slower during factory acceptance tests (FAT). The relationship quickly deteriorated. “In October 1977,” the project history reported, “the Government directed Rockwell to suspend delivery of equipment and service. A long and expensive litigation followed, with Rockwell claiming we were requiring something beyond the present state-of-the-art; the Bureau of Reclamation expressed knowledge of systems elsewhere presently meeting the requirements.” The 1978 project history explained that “equipment delivery was postponed until the FAT showed the system performance would meet specifications.”889

Throughout 1978, Rockwell continued to test the PMSC’s central processing unit at the manufacturing facility, and it continued to fail the tests. In June 1979, a final test “confirmed that the PMSC system did not meet the specification requirements for age of data, new display call-up time, communication with Bonneville Power Administration, and processor idle time.” Reclamation ultimately decided to accept the system at a reduced price. By the end of the year, the equipment had arrived at Grand Coulee and the central processor had been installed. It joined several RTUs that had been installed in 1978. More were placed in 1979, and almost all were operational by the end of 1980.890

45. THE LAST OF THE PUMP-GENERATOR UNITS

By 1976, Reclamation received authorization to install Units P/G-9 through P/G-12, the final four pump-generator units. The annual use of the units was expected to be 3,500 hours for pumping and 800 hours for generating. Seven bids to supply the units had arrived by the July

1976 deadline. The award went to Mitsui and Company (USA), a contractor based in San Francisco, for about $6.8 million.\(^\text{891}\)

By the end of the following year, Reclamation issued a solicitation for bids for preliminary work for installing the units. The scope included removing temporary concrete slabs and steel supports in the plant, placing second-stage concrete to encase the draft tubes and spiral cases, pouring foundations for the generator/motors, and completing mechanical, electrical, and other work related to the installation. After considering four bids, Reclamation awarded the project to Venture Construction of Auburn, Washington, in April 1978 for $2.2 million.\(^\text{892}\)

Eagle Construction Corporation, a subcontractor to Mitsui, started removing the test heads and existing draft tube liners in the following month. By June, assembly of the new draft tube liner for P/G-9 had begun, and sections for other units were installed throughout the rest of the year. The project hit a bump in mid-September, though, when union laborers refused to install Japanese-manufactured pipe in the second-stage concrete. “This was contrary to a decision by representatives of the International Union,” the project history observed.\(^\text{893}\)

Work soon resumed, but was disrupted in December by another pipefitters’ dispute. This was resolved by late January 1979. Installation of draft tube sections continued and the hydrostatic tests were completed for P/G-9 in June, P/G-10 in July, P/G-11 in September, and P/G-12 in November. The spiral cases for P/G-9 and P/G-10 were embedded by the end of 1979 and for P/G-11 and P/G-12 by May 1980. In February 1980, the project history noted, “as part of the contract, the P/G-9 runner and turbine shaft were installed separately to be sure that the two-piece headcover could be removed without removing the shaft. Once this was proved, the runners for the other three units could, and were, installed with the shaft already attached.”\(^\text{894}\)

During the same period, the foundation for the P/G-9 generator/motor was ready. Hitachi America, Ltd., had been selected as the supplier of the vertical-shaft generator/motors for the four units in August 1977 with a bid of about $5.5 million. The machines were specified to run at 53,500 kVa when operating as a generator and 70,000 horsepower as a motor. Hitachi’s erection engineer oversaw the installation, which began March 10. In April, Reclamation hired Harder Mechanical Contractors to hook up the 285,000 foot-pound governors and related equipment and complete other concrete, mechanical, and electrical work. By the end of the year, “the P/G-9 and P/G-10 rotors and stators were installed, generator/motors were coupled to their pump/turbines,

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the air housings were installed, and piping and wiring were in progress.” In addition, “P/G-11 rotor pole installation had been completed and work on series connections had started.” Progress on P/G-12 was delayed because one of the stator sections had been damaged in transit. All of the units were in service by 1979.

46. STILL MAKING HISTORY

Grand Coulee continues to evolve. Modifications to the facilities are inevitable as buildings and equipment deteriorate, needs change, and technology advances. These factors have influenced the project’s course throughout its history.

Reclamation’s first challenge came long before construction began as it faced off against the Corps of Engineers in a gentlemanly but fierce battle over responsibility for the facility’s development. At the same time, engineers, local boosters, and politicians sparred over where the facility should be built and its design. Controversy about the design—specifically, the high and low dam alternatives—continued to plague Reclamation even after its hold on the project was secure.

Transforming big dreams into reality was the next hurdle. Reclamation took on the herculean task of preparing the plans for the dam, power plants, equipment, and other facilities. Engineers adopting the most advanced tools that were available as the project progressed—models at various scales in the early years, new-fangled computers in the mid-twentieth century.

Contractor MWAK had to ramp up America’s biggest construction project, employing thousands of men in an isolated, often inhospitable, setting. The earth-moving process was a major campaign that required innovative techniques and drew international press. Reporters also marveled at the massive mix plants spewing out a relentless stream of concrete that, bucket by bucket, built up the dam. “Conventional equipment and normal processes were, of course, available to the constructors and fully within their knowledge and experience,” Engineering News-Record observed. “But while accustomed methods could have been made to serve, these men recognized in the peculiar conditions of the job a demand for approaching all operations as something to be devised anew. This approach did not look to new and strange devices but to an extension of existing devices to new horizons of application.”

There was better infrastructure in place for subsequent phases of the construction, but CBI, VDLM, and other contractors still had to deal with logistics on an unprecedented scale. Suppliers puzzled over ways to transport super-sized equipment to the site, often from across the country. Labor issues—including concerns over minorities and women in the workforce—had a greater influence.

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Environmental concerns forced a substantial salmon relocation effort during the project’s initial development, and the power of environmental regulations grew as the decades passed. Other issues that had been of little concern in the early years, such as the treatment of local American Indian tribes, became increasingly prominent. Aesthetics had been an outgrowth of the utilitarian design of the dam, plants, and other buildings until the 1960s, when Marcel Breuer was brought in to design the Third Powerplant and related structures. The eye-catching facade of the Administration Building, also dating from this period, is another reflection of the sea change in Reclamation’s attitude about the appearance of its facilities.

While construction drew the most attention, it was only the start of the story. Maintenance was an issue from the moment water began flowing over the spillway as construction debris scoured the bucket. Evaluating the damage requiring daring on the part of inspection divers, while the challenge of repair brought out the creativity of the engineers behind the design of the floating caisson. Near disasters, such as the flooding inside the dam in 1952 and several fires, resulted in changes to equipment and operations. Less dramatic was the routine maintenance that sometimes improved the project’s productivity, such as when the output of generators was boosted when stators were rewound.

Nature did not surrender easily to the human intrusions in the rugged landscape of the Columbia River Valley. The unstable soil produced slides that bedeviled both construction and ongoing operations. The river tore at cofferdams and sometimes succeeded at dislodging them. Bitter winter weather and spring floods forced temporary work stoppages. Through it all, though, the engineers and construction workers persevered, irreversibly altering the river and the irrigated area that the project serves. While opinions regarding the merits of these accomplishments are mixed, the Grand Coulee Project clearly reflects the aspirations, capabilities, and priorities of the United States through economic depression, war, and prosperity. It stands as a noteworthy monument to the minds and muscles of the thousands of people who worked on its construction.

**AUTHOR’S NOTE**

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