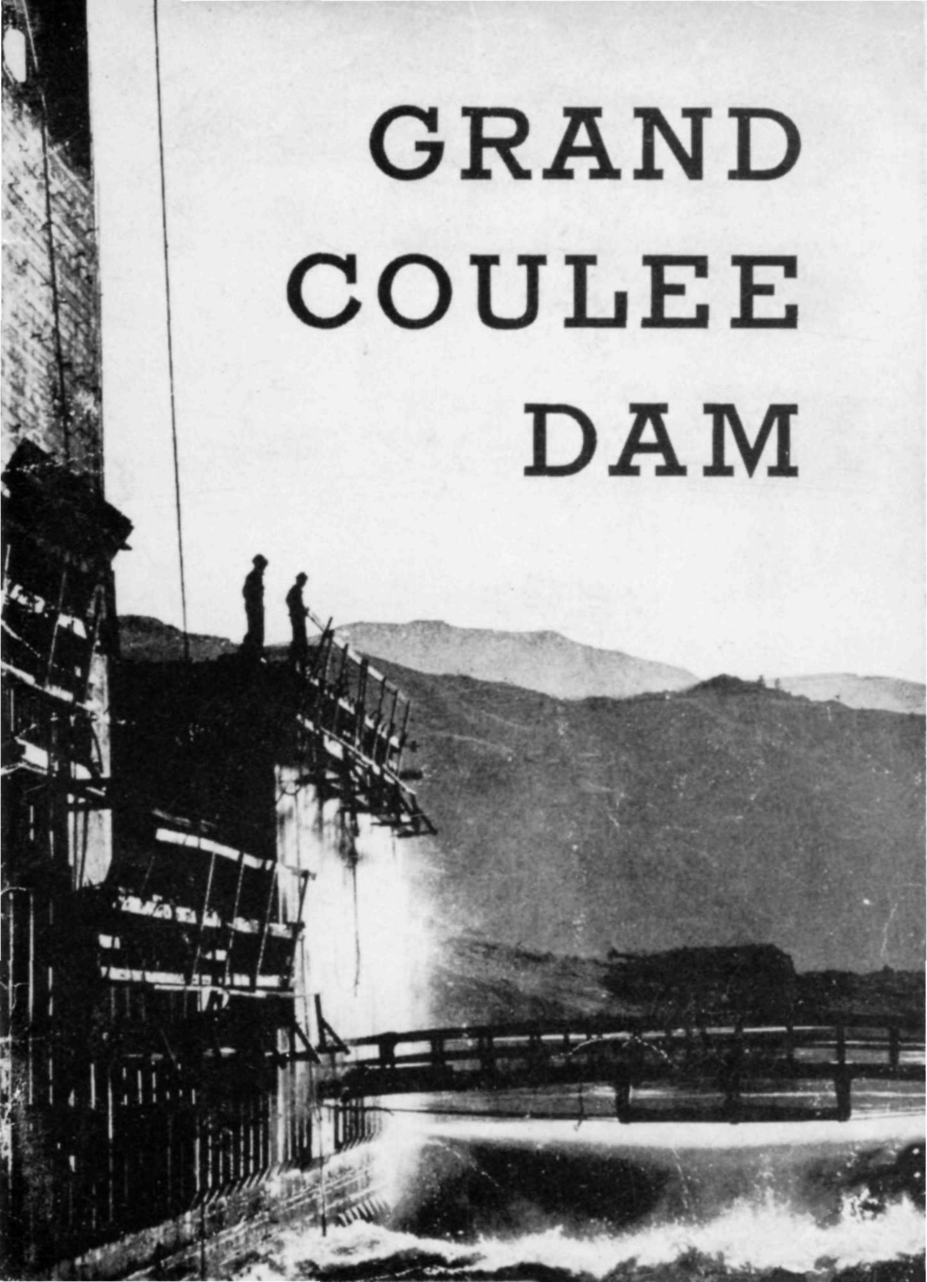
GRAND COULEE DAM



UNITED STATES DEPARTMENT OF THE INTERIOR
HAROLD L. ICKES, Secretary

BUREAU OF RECLAMATION
JOHN C. PAGE, Commissioner

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Photographs by the Bureau of Reclamation
Prepared by the Division of Information

THE GRAND COULEE DAM

and the Columbia Basin Reclamation Project

"The significance of the dam is not found alone in the magnitude of its dimensions, nor in the workmanship that has gone into its construction. It lies rather in the ends which are to be served."—Harold L. Ickes.

1937

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Franklin Delano Roosevelt
President of the United States

Frank A. Banks, Construction Engineer
U. S. Bureau of Reclamation

THE PRESIDENT REVISITS THE GRAND COULEE DAM

"Coming back to Grand Coulee after 3 years I am made very happy by the wonderful progress I have seen. We look forward not only to the great good this will do in the development of power, but also in the development of thousands of homes. There are thousands of families in this country who are not making good because they are trying to farm on poor land, and I look forward to the day when the valley is dammed up to give the first opportunity to these American families who need some good farm land in place of their present farms. They are a splendid class of people, and it is up to us as a Nation to help them to live better than they are living now. So, in a very correct sense, it is a national undertaking and doing a national good."

—President Roosevelt, Grand Coulee Dam, October 2, 1937.

THE COLUMBIA BASIN RECLAMATION PROJECT

PURPOSES OF THE PROJECT

A dream of 50 years, the irrigating of a vast tract of rich desert and dry-farming land in central Washington, is about to be realized through the construction of the Grand Coulee Dam, and a system of canals that, in time, will cover an area 60 miles wide, east and west, and 85 miles long, north and south, and bring to it the life-giving waters of the Columbia River.

When fully developed, the Columbia Basin Reclamation Project will reclaim over 1,200,000 acres of land, regulate the flow of the Columbia River for the benefit of downstream power plants and navigation, and develop electric energy to be used in pumping for irrigation and for other purposes, on the project and elsewhere.

SCOPE OF THE WORK

The enterprise involves building, in an isolated, sparsely populated district, a dam of unprecedented size, a power plant which will be, when completed, the biggest thing of its kind in the world, and a pumping plant big enough to pump dry, at least in their low-water seasons, any but a few of the largest rivers in the country. In the Grand Coulee, abandoned channel of the Columbia River, formed during the last Ice Age, a balancing reservoir 27 miles long will be formed; and on the project lands, hundreds of miles of main and lateral canals and numerous auxiliary power and pumping plants must be built as the project develops.

LOCATIONS

The Grand Coulee Dam, principal and outstanding engineering feature of the project, is located on the Columbia River just below the head of the Grand Coulee, where for a short distance the river flows north. It is 94 miles north and west of Spokane, and 259 miles by highway east of Seattle. It is 151 miles downstream from the Canadian border, and about 600 miles above the mouth of the Columbia at Astoria.

Although it is not at the narrowest point in the river's canyon, the site for the dam was chosen because, here, close to the head of the Grand Coulee, a granite barrier once lay across the river's course and extended from the Okanogan highlands far into the basalt plateau which forms the left bank of the river above and below the dam site. The remains of this granite barrier form exceptionally good foundation and abutments for the dam.

Grand Coulee Dam is accessible by motorcar or bus, over excellent hard-surfaced roads connecting with U. S. Highway No. 10 at Wilbur, Almira, and Coulee City. An excellent hard-surfaced road, passing spectacular Dry Falls, Park Lake, Blue Lake, Lake Lenore, and Soap Lake, traverses the lower Grand Coulee between Coulee City and the town of Soap Lake, and connects with State Highway No. 7, leading to points west of the Cascades by way of Snoqualmie Pass, Chinook Pass, and Mt. Rainier, and the Columbia River highways.

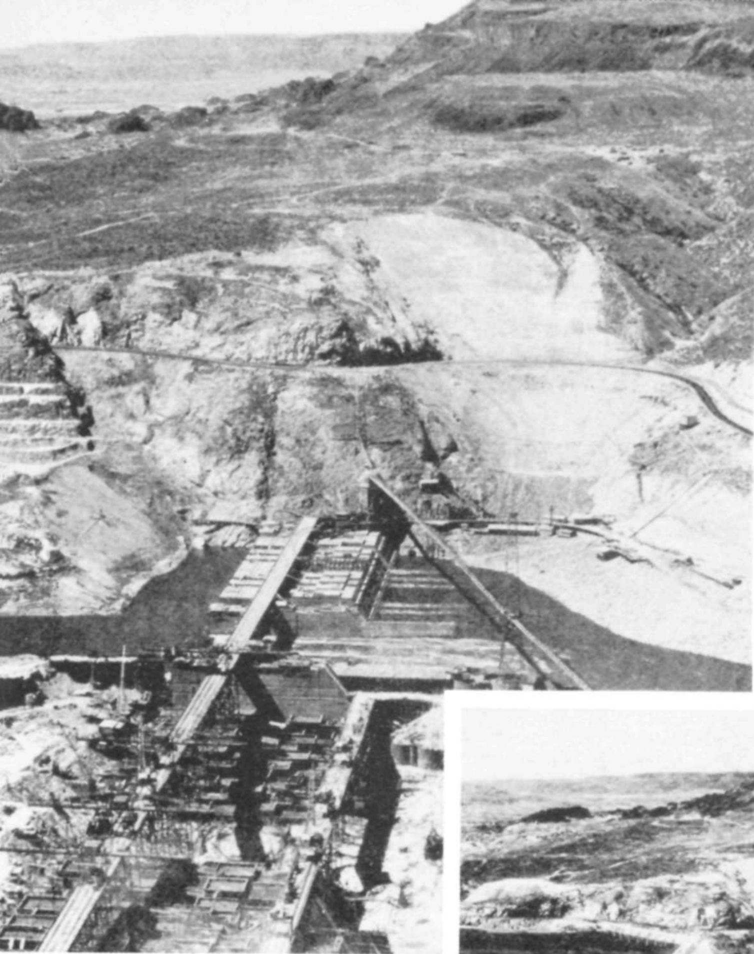
FACILITIES FOR VISITORS

Sightseers appear at the Grand Coulee Dam in such great numbers that, as a matter of safety as well as of convenience to them, special facilities for handling visitors have been provided. Only employees on shift are admitted to construction areas, but the topography at the dam serves the tourist's purposes admirably.

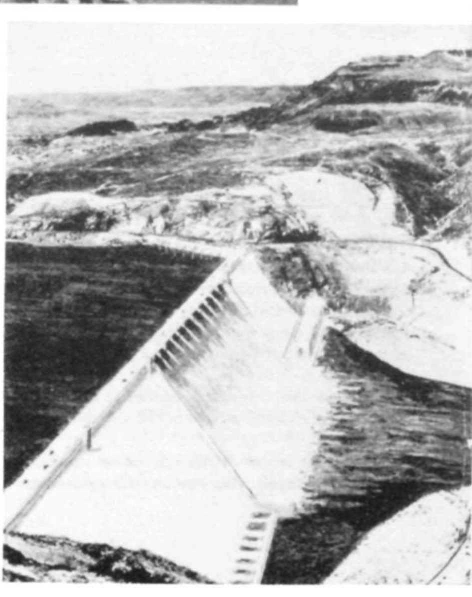
On each side of the river, extensive free parking areas accommodate large numbers of cars, and from positions high above and overlooking operations the visitor looks down upon the river and construction activities. Ample provisions are made for the safety and comfort of visitors.

Each week during the tourist season, thousands of visitors view with interest an accurate model of the dam located in the west vista house. There is shown, first, one six-hundredth actual size, the vicinity as it appeared before construction work was started, then the excavated area and several stages in the progress of the work, and, finally, the model of the dam, power-houses, and pumping plant as they will finally appear.

Signs along the highway entering Government property direct the visitor to the free Government parking spaces and vista houses.



Above: Activity at the Grand Coulee Dam was at its peak in the summer of 1937 with more than 7,000 men at work. The base of the dam was nearing completion when the above view, looking west into the Grand Coulee, was taken



Right: The finished dam as it will appear from the same viewpoint

Aerial view of Grand Coulee Dam, looking northeast over the construction area, the Government town, Coulee Dam (left), and the contractor's town, Mason City, in April 1937. (15th Photo. Sec., U. S. Army)

Section I. THE GRAND COULEE DAM

TYPE AND SIZE OF DAM

The Grand Coulee Dam is of the straight-gravity type, depending entirely upon the weight of the structure to resist the pressure of water behind it, tending to overturn it or to cause it to slide on its base. The river canyon is too wide for a dam of the arch type. At each side of the 1,650-foot centrally located spillway section, which is surmounted by control gates spanned by concrete arch bridges, will be a power-house and abutment section, each more than a thousand feet long.

The finished dam will be 4,300 feet long at the crest and about 3,000 feet long at the base. The base is 500 feet wide, and covers about 30 acres. The dam will be 30 feet thick at the crest, and will be surmounted by a 30-foot highway. From lowest bedrock, the height will be 550 feet to the crown of the roadway; and the water surface above the dam will be raised about 355 feet above low water-level. Galleries in the dam for inspection, gate control, cooling, grouting, drainage, and other purposes will have a combined length of about 8 miles.

ELEVATIONS ON THE PROJECT

The river bed at the side of the Grand Coulee Dam is approximately 910 feet above sea level. The low-water elevation in the river is about 933 feet, and the average high-water level about 978. Bedrock, under a deposit of clay and boulders forming the river bed, was found generally at about elevation 875, but three deep gorges, one extending to elevation 761.5, were found.

The general elevation of the floor of the Grand Coulee is about 1,500, and the walls of the coulee about 2,300 feet above sea level. The lands to be irrigated vary in elevation from

Only three families lived in the vicinity of Seaton's Ferry when excavating began at the site of the Grand Coulee Dam late in 1933

about 1,300 near Ephrata to 400 feet near Pasco.

The top of the dam will be at elevation 1,311.08, and the parapet at elevation 1,315. The crest of the concrete in the spillway will be at elevation 1,260, and the tops of the control gates at 1,288.

COMPARATIVE SIZE

The Grand Coulee Dam will be the largest in volume and the second highest of the masonry dams of the world, second in height to only the 726.4-foot Boulder Dam. Even the base of the dam, covered by the Mason-Walsh-Atkinson-Kier contract, completed in the winter of 1937–38, was the biggest man-made structure on earth, far surpassing the great pyramid of Cheops, which for thirty centuries was man's biggest structure, until the Boulder Dam was built. The finished dam will occupy more space than the entire population of the United States—men, women, and children—and will weigh more than twice as much.

VOLUME OF CONCRETE

Nearly 12 million cubic yards of concrete, more than three times that required for the Boulder Dam, will be used in constructing the dam, power plant, and appurtenant works—sufficient to build a monument as high as the Washington Monument and covering six average city blocks.

With the same quantity of concrete a 20-foot pavement could be built about a quarter of the way around the earth, or two times from coast to coast. It would make a pyramid two blocks square and eight blocks high, more than three times the volume of the great pyramid of Cheops.

QUANTITY OF CEMENT

About 12 million barrels of cement will be used at the dam, a total of nearly 4 billion pounds or about 48,000 carloads. The daily use has exceeded 60 carloads, and a total of about 960 trainloads will be required. The making of the cement will require the quarrying, crushing, and grinding to a fineness exceeding that of flour, of about 3 million tons of limestone, and the consumption of enormous quantities of power, supplies, refractories, and fuel. The cement, ground into particles less than one four-hundredth of an inch in size, will expose a surface of over 150,000 square miles, an area more than three times that of the State of Pennsylvania.

SPILLWAY, GATES, AND OUTLETS

Between the power-house sections at the ends of the dam is a spillway section 1,650 feet long over which water not required for storage or for power generation or irrigation will be allowed to flow, forming a spectacular waterfall twice as high as Niagara. The rate of flow, and to a certain extent the quantity of water held in storage, will be controlled by 11 drum gates at the crest of the spillway, each gate 28 feet high and 135 feet long.

World's largest cofferdam, 300 feet long, enclosing 60 acres, completed, and the Government camp under construction, 1935

Columbia River diverted through base of dam built inside west cofferdam. Excavation under way in old channel, 1937

The spillway will have a capacity of a million cubic feet a second; and, if that capacity should ever be realized, it will be necessary to dissipate at the foot of the dam the energy of the falling water equivalent to 32 million horsepower. This will be accomplished, and erosion of the river below the dam will be prevented, by an upwardly curved bucket at the toe of the dam, where a trough 100 feet wide and 30 feet deep is formed behind a concrete wall across the river bed at elevation 900, 33 feet below low tail-water surface.

Through the dam there will be sixty 8½-foot gate-controlled outlet tunnels, twenty at elevation 934, the approximate level of low water, twenty at elevation 1,034, and twenty at elevation 1,134. The tunnels are arranged in pairs, and their entrances are protected by trashracks. The upstream ends of the outlet tunnels are lined with heavily ribbed semi-steel conduits, set in the concrete as protection against erosion and the effects of cavitation, which will be reduced or eliminated by the scientific shaping of the entrances to the tunnels. A ring-follower sliding-leaf valve, hydraulically operated, and an electrically operated "paradox" valve, with leaf and wedge on rollers, will control the flow of water in each tunnel for the purpose of regulating the flow of the river in seasons of low water, or emptying the storage reservoir. The 60 tunnels have a combined length of about 2½ miles.

The outlet tunnels will have a capacity of 253,000 cubic feet per second and the turbines fully loaded will pass 81,000 second-feet. These, with the spillway, will have a total capacity nearly three times the maximum recorded flow of the river, and nearly double the estimated flood of 1894.

FOUNDATION EXPLORATION

Diamond drill holes to the extent of about 33,000 feet were put down into the granite foundation on which the dam rests. Occasional holes were drilled to depths varying from 660 to 880 feet. In all instances there was found light-colored, dense granite, suitable, according to the board of consulting engineers, to bear any load that might be put upon it.

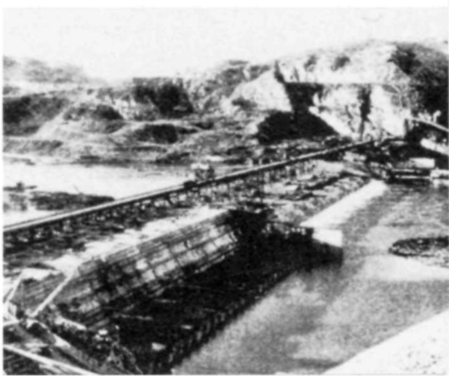
After uncovering bedrock, additional exploratory work was done with Calyx drills, extracting rock cores 36 inches in diameter, which permits a detailed examination to be made of both the core and the hole from which it was taken. Eighteen such holes were drilled to depths varying from 29 to 68 feet.

Bedrock is quite uniform in character, and in general was prepared for foundations by the removal of weathered surface rock to a depth of 6 to 10 feet.

FOUNDATION GROUTING

To seal the cracks and crevices in the granite bedrock under the dam, formed millions of years ago when the molten rock solidified and shrunk, grout of cement and water is forced

Foundation of dam completed, cofferdams removed, and the Columbia River flowing through low gaps in the base of the dam, 1938



down through holes drilled into the rock. Of such holes, 30 feet deep and 20 feet apart, five rows were drilled under the upstream edge of the dam and entirely across the river canyon. The rows were spaced 20 feet apart, and the holes in each row are staggered with respect to those in the next row. The 30-foot holes were grouted under pressures up to 250 pounds per square inch before any concrete was placed close to them.

After considerable concrete was in place on bedrock, a row of holes 75 feet deep and spaced 20 feet apart was drilled diagonally downward into the rock under the dam through the curved fillet of concrete which connects the upstream face of the dam with bedrock. An effectual seal against leakage under the dam will be created by the grouting of these holes and a single row of holes 150 feet to 200 feet deep, to be spaced 10 feet apart and drilled from the drainage gallery in the dam close to bedrock. Grouting pressures in the deep holes may run as high as 1,000 pounds per square inch.

As an added precaution against the uplifting effect of any leakage under the upstream edge of the dam, there will be one row of uplift pressure relief holes spaced 10 feet apart, permanently open into the drainage gallery at the base of the dam.

A 10-million-yard hole on the west bank to make room for dam, forebay, and tailbay

Thirteen million yards of overburden were carried away from dam-site excavations by this system of belt conveyors

THE COLUMBIA RIVER STORAGE BASIN

SIZE AND CAPACITY

A storage reservoir 151 miles long, averaging 4,000 feet in width and with a maximum depth of about 375 feet, will be formed behind the dam. It will extend up the Columbia River to the Canadian border, the elevation of which determined the height of the dam, and up the Spokane River 32 miles.

The reservoir will have an area of 82,000 acres (128 square miles), and a total capacity of about 10 million acre-feet of water—equivalent to 25,000 gallons for every inhabitant of the United States, nearly a 10-year supply for all purposes for the city of New York. The estimated annual evaporation from the reservoir will be 200,000 acre-feet.

The average annual rate of flow of the Columbia River would fill the reservoir in about 2 months, and the average flow in June or July would fill it in less than 1 month.

USEFUL STORAGE CAPACITY

The upper 80 feet of the reservoir capacity, something over 5 million acre-feet, will be utilized when necessary for power production and for the regulation of the river flow for the benefit of future downstream power plants, and for the improvement of navigation. Since the high-water and irrigating seasons coincide, stored water will not be required for irrigation, nor for power in pumping irrigation water.

SILT

The streams tributary to the Columbia are almost always clear and free from silt. Solid matter causing slight turbidity during part of the flood season is extremely fine, and practically all of it is carried in permanent suspension. Silt will have no detrimental effect on the utility of the reservoir.

LANDS ON THE RESERVOIR SITE

The high-water line in the reservoir will be 1,292 feet above sea level. All lands in the river basin upstream from the dam and below elevation 1,310 have been reserved for reservoir purposes. The greater part of such lands are privately owned. They have been surveyed and appraised and will be acquired by the Government. Chiefly cut-over timber lands, grazing lands, and pasture lands are affected. Two small towns and a little cultivated land are included within the reservoir area. Several miles of highway and railroad will be relocated, and several new bridges will be built to accommodate them.

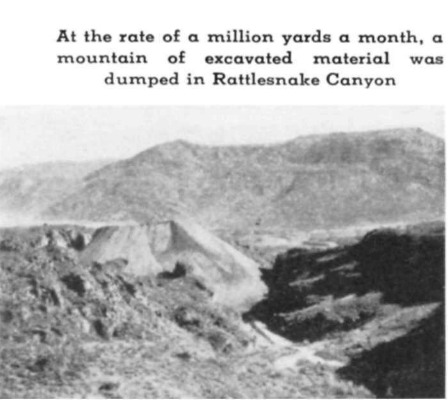
Kettle Falls and the nearby points at which fur-trading posts were established more than 100 years ago will be inundated.

POWER AND IRRIGATION

PROBLEMS INSEPARABLE

In irrigation projects of any considerable size, dams and falling water are involved, and the

At the rate of a million yards a month, a mountain of excavated material was dumped in Rattlesnake Canyon



Jackhammers and dynamite moved a million yards of rock to make a firm, clean footing for the dam

pumping of water for irrigation is frequently necessary. Consequently, problems of power generation and distribution are inseparable from those of irrigation. Many of the feasible undeveloped irrigation possibilities remaining in the United States are of such large scope, and so greatly affect stream flows, that they must embrace river regulation, power development, flood control, navigation, and in some instances domestic and industrial water supplies, as well as irrigation.

In some instances several of the agencies benefited by river conservancy and development works must cooperate, and participate in the cost, in order that any may be benefited.

POWER ON THE COLUMBIA BASIN PROJECT

Pumping will be done on the Columbia Basin Project as a matter of efficiency and necessity, hence some power must be developed. High-water periods fortunately occur at

Electric shovels and belt conveyors move 25 thousand yards of pit-run sand and gravel in a day

such times that secondary or seasonal power will take care of pumping needs, and all primary and much secondary power will be available for use on and outside of the project lands as demands for power develop.

POWER PLANT AT THE GRAND COULEE DAM

GENERATING CAPACITY

When fully equipped the power plant at Grand Coulee will be by far the largest in existence. It will consist of two separate but similar powerhouses, one on each side of the river, each to contain, when completed, nine generators of 105,000 kilowatts capacity. The total ultimate installed generator capacity, including three 10,000-kilowatt station-service units, will be 1,920,000 kilowatts. The capacity of the 18 large generators to be used for commercial prime power and for seasonal power for pumping and other purposes will be 1,890,000 kilowatts, equivalent to 2,520,000 horsepower. The largest generators so far built are those at Boulder Dam, each rated 82,500 kilowatts.

Capacities of World's Largest Power Plants
(Horsepower ratings of turbines)

Grand Coulee	2,700,000
Boulder	1,835,000
Dnieprostroy (Russia)	746,000
Wilson (Muscle Shoals)	610,000
Conowingo	594,000
Niagara (plants in United States)	452,000

TURBINES

Each of the 18 large generators will be driven by a 150,000-horsepower vertical hydraulic turbine, to which water will be delivered through 1 of 18 steel penstocks 18 feet in diameter, each provided with shut-off gates and trashracks.

The heads under which the turbines will operate will vary between 275 and 355 feet. At full load, water will pour through each turbine at the rate of 141 tons per second, enough passing in a day to provide 30 gallons each for nearly 100 million people. Through seven of the turbines, fully loaded, there will pass sufficient water to take care of the requirements of the entire population of the United States, at 150 gallons per person per day.

AUXILIARY POWER PLANTS

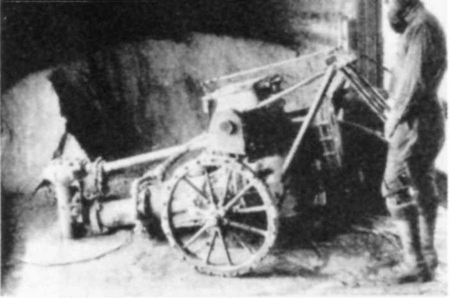
As the system of main canals is extended, it will be necessary to provide at a number of points "drops" in the canals because otherwise the gradient would produce undesirable and destructively swift currents in the canals. At a number of such points relatively small power plants will be built to utilize the energy of the falling water and generate electric power to be used in pumping water to lands above the main canals.

PUMPING ON THE COLUMBIA BASIN PROJECT

PUMPING PLANT AT THE DAM

The balancing reservoir in the Grand Coulee, to which all irrigation water for the Columbia

A conveyor 5,965 feet long carries washed sand and gravel from screening plant to stock piles at the dam



Bulk cement unloaded from boxcars by a machine that blows it through hose and pipe—as much as 60 cars a day

Basin Project is to be pumped, will be nearly 650 feet above the low-water level of the river. The dam will raise the water to about 355 feet and pumps will lift that required for irrigation the rest of the way.

The pumping plant will be located on the west side of the river, behind the dam, within the reservoir basin. There will be installed ultimately 12 pumps, each with a capacity of 1,600 cubic feet per second. Two of the pumps are regarded as "spares," the normal capacity of the pumping plant being 16,000 second-feet. Each pump would be able to take care of the domestic water requirements of nearly 7 million people. One pump will elevate sufficient water to irrigate 120,000 acres of land.

Directly connected to each pump will be a 65,000-horsepower synchronous motor, two motors being supplied with power directly from one generator in the power plant. Generator and motor speeds will be adjustable to the most efficient pump speeds at various heads. Ordinarily, pumping will be against a 280-foot head; that is, from a full storage reservoir behind the dam to a full balancing reservoir in the Grand Coulee.

Pumps will discharge through conduits 13 feet in diameter and about 800 feet long into a canal leading to the balancing reservoir in the Grand Coulee about 1.7 miles away.

AUXILIARY PUMPING PLANTS

Of the 1,200,000 acres of land in the project, 980,000 acres will be watered by gravity from the system of canals extending southward from the balancing reservoir. A total of about 220,000 acres of irrigable land is about 70 feet above the gravity canal system. Auxiliary pumping plants will be constructed to serve such plants as the project develops, power for them being derived from auxiliary power plants at canal "drops" on the project lands.

BALANCING RESERVOIR IN THE GRAND COULEE

SIZE AND CAPACITY

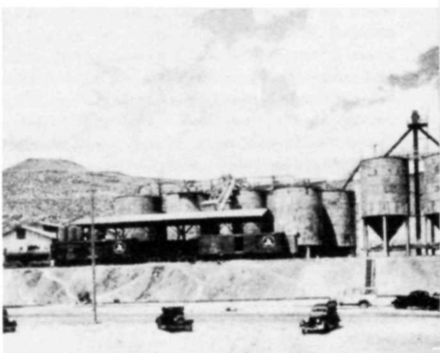
By means of two earth dams about 100 feet high, one 2 miles from the Grand Coulee Dam and the other near Coulee City, a balancing reservoir 27 miles long and covering an area of about 27,000 acres, or 43 square miles, will be formed in the upper Grand Coulee, its high-water level being 280 feet above that of the storage reservoir behind the Grand Coulee Dam. The maximum capacity of the balancing reservoir will be approximately 1,150,000 acre-feet, of which about one-half million acre-feet will be useful in regulating pumping and water consumption.

Only a part of the irregular coulee floor will be flooded, but practically all of the railroad and much of the highway in the coulee will be inundated.

CANALS AND DISTRIBUTING SYSTEM

Through a canal of 15,000 second-feet capacity, water will be carried about 10 miles

"Modified" cement of five brands, blended here, is pumped by compressed air through a 6,200-foot pipe line to the concrete mixing plant



A record of 9,290 yards of concrete in a single day was established by this mixing plant

southwesterly from the balancing reservoir to the heads of the 150-mile east-side canal and the 100-mile west-side canal, from which it will be distributed to farms through numerous laterals. Several large tunnels, siphons, wasteways, headgate structures, and bridges, and a drainage system for collecting and using seepage water will be required.

LANDS TO BE IRRIGATED

OWNERSHIP OF LANDS

Much of the land on the project was homesteaded 30 to 40 years ago, and for a few years a number of small irrigation ventures and many dry farms were reasonably successful. Prolonged periods of drought and the overtaxing of stream flows and ground waters forced the abandonment of large areas of land and numerous small towns many years ago, but large areas are still devoted to the growing of grain on large tracts. In years of exceptionally heavy rainfall, they yield large crops.

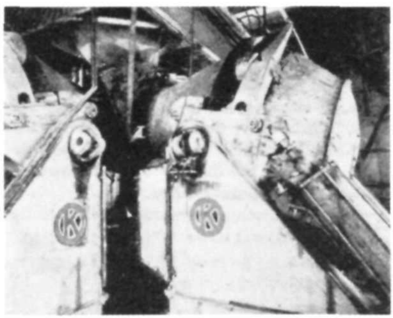
Practically all of the irrigable land is owned privately by individuals, counties, and railroads and other corporations, largely by former holders of mortgages on the land. Before water for irrigation of the land will be procurable from the Government, the land must be made available to settlers at reasonable prices.

CLIMATE ON PROJECT LANDS

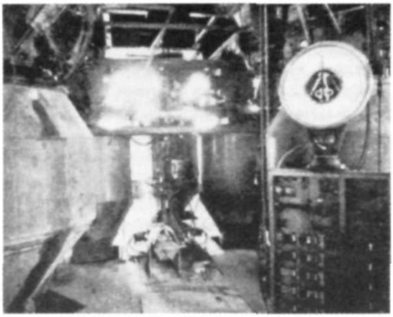
The mean annual temperature on the project lands is 50.4° F., and during the irrigation season from April to October, it is 62.2° F. The summers are characterized by hot days and cool nights. The average frost-free period is 159 days, considerably greater than that in many notably successful irrigated districts. The mean annual precipitation is 8.2 inches, but the mean for the growing season is only 3.6 inches.

SOIL AND CROPS ON PROJECT LANDS

The soil, deposited chiefly from turbid glacial waters that covered the land during the last Ice Age, is generally deep, and it varies from fine, silty loam to sandy loam. There are small areas of sandy soil underlain with gravel. In 1911 the Bureau of Soils of the Department of Agriculture after a partial survey reported the soil to be extremely rich, stating that, if irrigated, it would be produc-



Four massive mixers receive their 4-yard charges, mix them, and dump them by remote control



Cement, water, and aggregate for different concrete mixes are weighed out automatically by multibeam scales

tive. Subsequent more extensive soil surveys confirm such findings.

The crops may be any or all of those common to a temperate zone, such as hay, grain, beans, peas, other vegetables, and fruits. Since the land is to be held in relatively small tracts, intensive methods of farming will be followed, and no material additions will be made to "surplus" crops. Much of the land will be devoted to the raising of livestock and forage crops.

PROJECT PROBLEMS

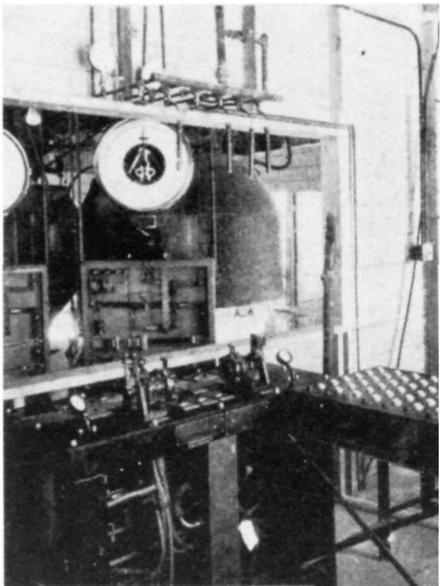
CONTROL OF SPECULATION

The development of speculative land prices on the Columbia Basin Project will be reduced to a minimum by means of the provisions of the Anti-Speculation Act of May 27, 1937. A similar policy was applied successfully on the Kittitas, Owyhee, and Vale Projects.

The principal requirements of this act are (1) that privately owned lands within the area to be served be impartially appraised to determine their present-day market value without reference to the proposed irrigation works; (2) that contracts for the repayment of the part of the cost of the project allocated by the Secretary of the Interior to irrigation, and for other purposes, be made with an irrigation district or with irrigation districts; (3) that private landowners agree to limit their holdings to 40 acres for an individual or 80 acres for a man and wife; (4) that landowners agree to sell lands held in excess of these minima at the Government-appraised price; (5) that in the event excess lands are sold at higher prices or are retained, no water shall be delivered to the lands involved; (6) that water may be obtained for lands which were purchased at prices above the Government appraisal, unless they were excess land so purchased, upon payment to the Government by the vendor of a portion of the excess price, varying from 50 to 100 percent with the length of time which has elapsed since the sale, this money to be applied in inverse order to the construction payments charged against the land; and (7) that the State of Washington by appropriate legislation shall authorize, adopt, ratify, and consent to all the provisions of the act which come within the jurisdiction of the State. Conditions under which water can be obtained for any tract of land run with the land as part of any title to it.

Copies of the appraisals of project lands made under the direction of the Secretary of

Operating bench (left), lamp signal table (right), and graphic recorder for the one-man control of the concrete mixing plant



Eight-ton batches of concrete are handled by huge overhead cranes, directed by telephone-signalmen "on location"

the Interior will be on file in county offices, and will be accessible to prospective buyers of land.

The collecting of annual installments for construction, and for maintenance and operation charges, through the taxing power of irrigation districts, will tend to prevent the holding of idle land for speculative purposes.

COST OF WATER RIGHTS

The exact costs of water rights and of annual maintenance and operating charges cannot be determined until the project is much further advanced. They have been estimated as follows:

The portion of the project costs chargeable to the reclamation of land is estimated at this time to be from $85 to $100 per acre, to be distributed over 40 years without interest. For operation and maintenance, including the cost of power for pumping, the annual charge is estimated at $2.60 per acre. On this basis the total indicated payments by the settler would be $2.60 per acre per year for operation and maintenance and nothing on account of construction for the first 4 years, and would be thereafter about $4.60 per acre per year for 4 years for operation and maintenance, and construction, and about $5.10 per acre per year for the next 32 years for operation and maintenance, and construction.

YEARS REQUIRED FOR COMPLETION

The irrigation of land in the Columbia Basin Project cannot begin until the Grand Coulee Dam, together with portions of the power plant and pumping station, is completed, and the Grand Coulee Reservoir and a system of canals to the northern boundary of the project lands are constructed. When that will be accomplished will depend upon the rate at which funds may be made available by the Congress.

From 25 to 50 years may be required for the completion and settlement of the whole project. The period will be determined by the rate at which extensions of the canal system will make water available. If the land should be brought under cultivation at the rate of only 25,000 acres each year, 48 years will be required to reclaim the entire area to be irrigated.

DEVELOPMENT OF THE UPPER COLUMBIA BASIN

A comprehensive plan for the development of the Columbia River, worked out by the Army engineers, contemplated the construction of 10 dams to utilize 92 percent of the available fall in the river between the international boundary and the Pacific Ocean. By far the largest and most important of these is the Grand Coulee Dam—largest because it uses 355 feet or 27 percent of the total available fall and includes an electric generating installation of 1,890,000-kilowatt capacity, which is larger than any existing development in the world today; and most important because it creates a storage reservoir of over 5 million acre-feet of usable capacity at the highest possible location on the river in this country, and affords the most feasible and practicable means of diverting the waters of the Columbia River out of its canyon and onto any considerable area of arid land.

The Grand Coulee Dam is often referred to as the "key" structure in the plan for the development of the Columbia River. The release of stored water from the reservoir behind the dam during periods of low flow not only will increase the minimum navigable channel depths by 2 feet below the Bonneville Dam and by 4½ feet below the Grand Coulee Dam, with corresponding increases at intermediate points; but it will also double the amount of firm power that can be developed at the six power sites on the Columbia River between Grand Coulee Dam and the point where the Snake River joins the Columbia, and increase by 50 percent the firm power that can be generated at the various sites below this point, including Bonneville.

THE EFFECTS OF IRRIGATION

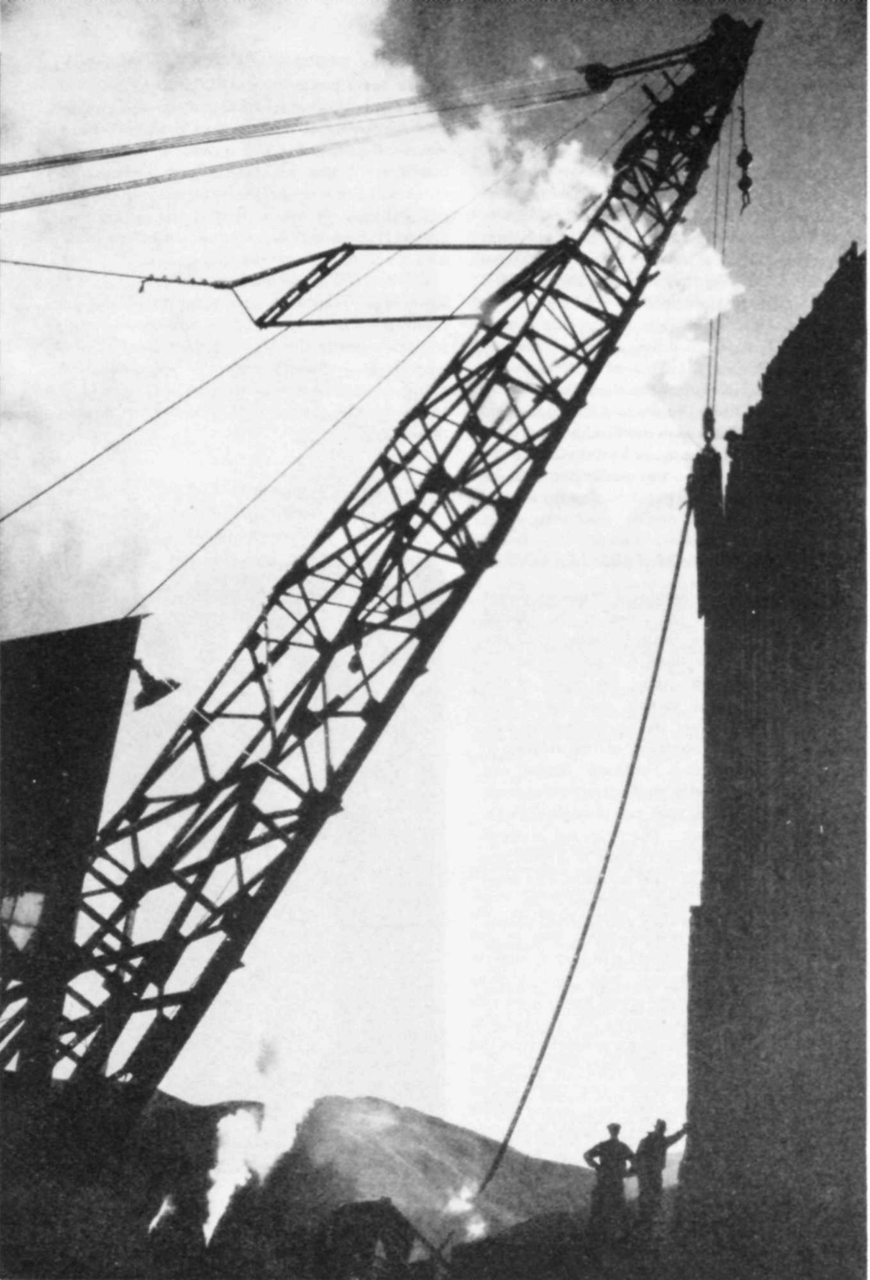
In the 11 arid and semiarid Western States are 39.5 percent of the area of the United States, a little more than 9 percent of the population, and less than 4.5 percent of the farmed and cropped area. So much of the land is in mountains, forests, and desert that these States can never be agriculturally self-sufficient. Great quantities of the staples of the Middle West and Southern States are shipped in, and chiefly protective foods, fruit, eggs, dairy products, and out-of-season vegetables are shipped out. The irrigated lands of the West supplement the ranges in producing feeder stock for Middle West farmers, and wool to compete with foreign producers in the American market, and they supplement rather than compete with Middle West and Eastern farms in producing a balanced national diet.

Statistics show greater stability and greater purchasing power in irrigated districts than in farming and industrial districts throughout the country. There is an insistent demand for irrigated land to replace the worn-out, eroded, and submarginal lands that are better suited to forestry and grazing than to cultivation.

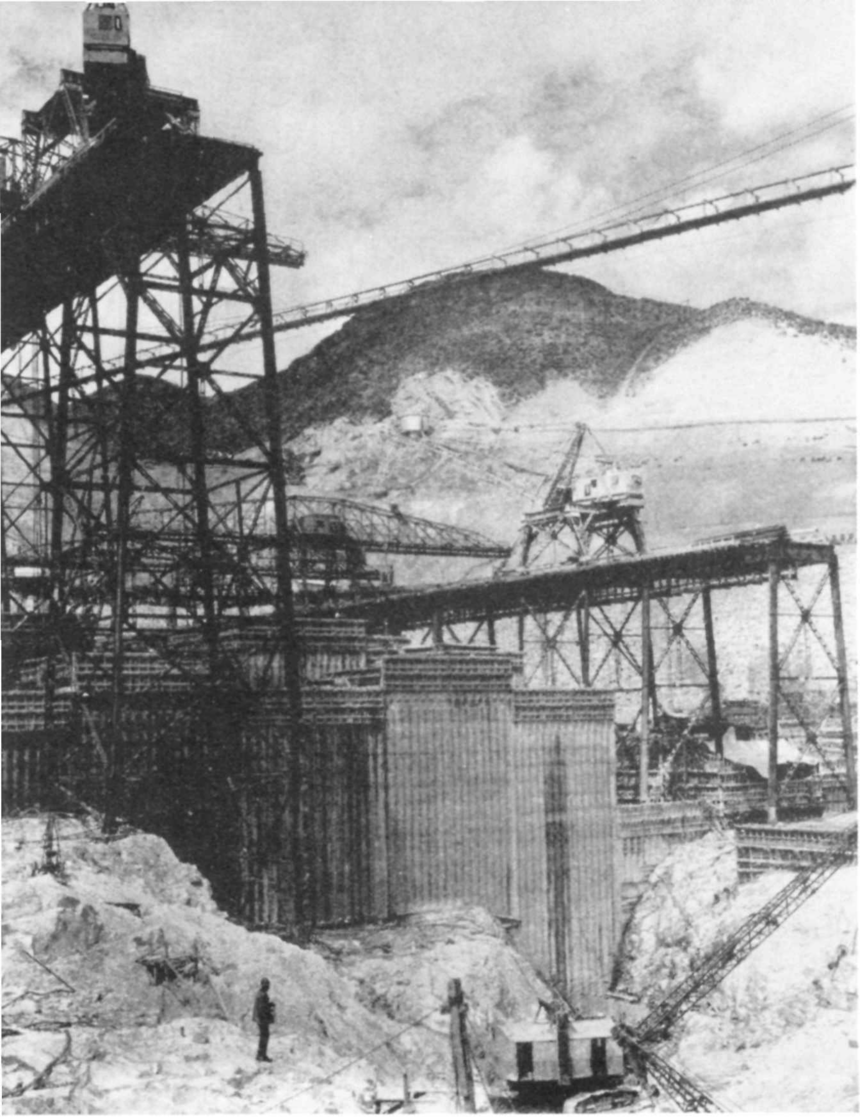
The Columbia Basin Project will bring about within a period of 25 to 50 years the establishment of 25,000 to 40,000 new farm homes, with a farm population of 100,000 to 200,000 people. In the gradual building, equipping, and improving of those homes there will be a steady demand for the products of eastern industry. Along with the farms, towns and cities will grow up on the project lands with a population as great as that of the farms, and material growth may be expected in the cities and towns in the surrounding area.

It has been the experience of the past that for every family on an irrigated farm there is also one in the towns that are developed on the project to serve the farming districts, and still another in the more distant cities and towns engaged in the manufacturing and transportation of the things that the project people must buy.

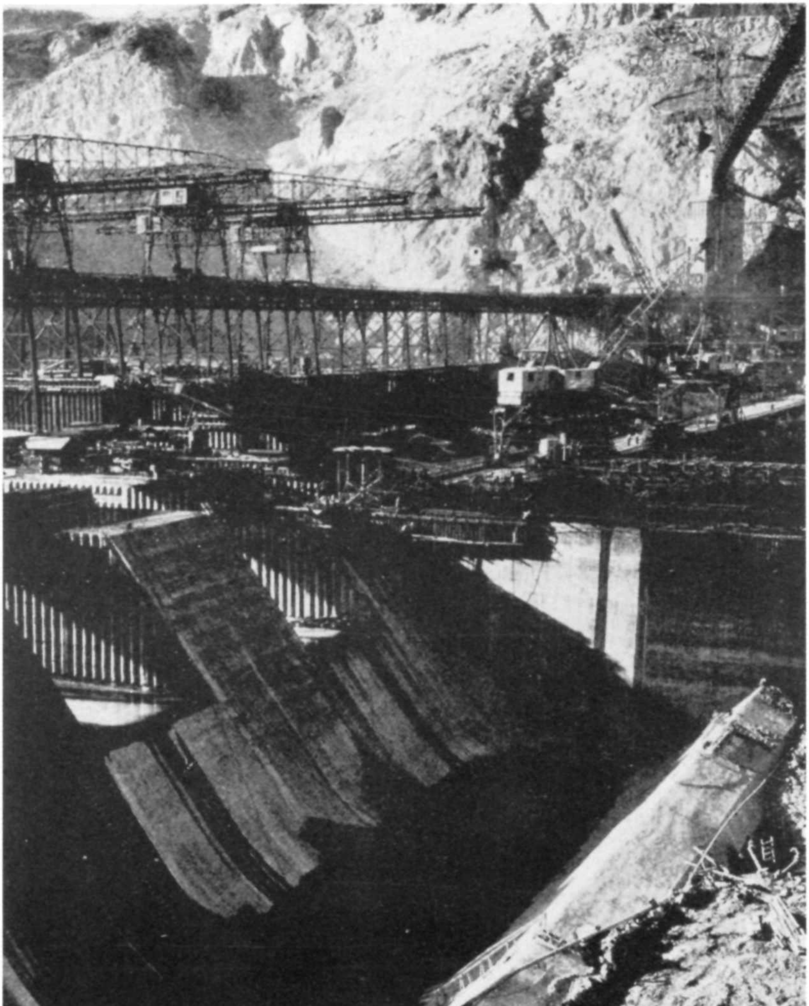
"Vibrators," thrust into the stiff concrete, cause it to spread without segregation of components



Above: Under powerful lights covering an area 3 miles long, work on the base of the dam went on day and night without interruption
Left: 127 miles of heavy steel sheet piling was driven in the west cofferdam by powerful steam hammers



As firm, clean bedrock was exposed, high steel trestles were built out from abutments, and from them long-arm cranes placed concrete in "lifts" 5 feet thick and 50 feet square



Inside the west cofferdam were built the base of the west power-house and part of the spillway section of the dam, with low gaps through which the river was later diverted

Section II. CONSTRUCTION OF THE GRAND COULEE DAM

BRIEF HISTORY OF ORIGIN

The problem of applying the water of the Columbia River to the rich but arid land of central Washington has engaged the interest of settlers and engineers since the days of original settlement. Numerous schemes were conceived, and at least two of them have undergone extensive engineering and economic investigation by State and Federal agencies during the past 30 years. Eleven engineering reports had been made prior to 1933.

In the summer of 1933 preliminary engineering work, financed by a grant of emergency relief funds, was begun under the direction of the Bureau of Reclamation. In November 1933 the building of the Grand Coulee Dam was made a Federal Public Works Administration project (No. 9), and in December the first contract for construction work, the moving of about 3 million yards of overburden, was awarded. The contract for the construction of the base of the dam was let to the Mason-Walsh-Atkinson-Kier Co. by the Secretary of the Interior on July 13, 1934, and on September 25, 1934, the contractor was directed to proceed with the work. Numerous other contracts for railway, highway, grading, building, and other work were let within the year.

AUXILIARY CONSTRUCTION

In order to provide adequate transportation facilities, highways leading to the dam site were regraded, widened, and hard-surfaced by the State; a hard-surfaced road from the Grand Coulee to the dam site was built by the Government; bridges across the river replaced a primitive ferry; and 32 miles of standard-gauge railroad from Odair, on the Northern Pacific Railway near Coulee City, to the mouth of the Grand Coulee and into the river canyon were built by the Government, to be operated by the contractor. A 110,000-volt transmission line, 31 miles long, was built from the Washington Water Power Co.'s lines near Coulee City to Mason City by the contractor. Telephone and telegraph lines were built in by the Pacific Telephone and Telegraph Co. and the Western Union Telegraph Co.

Left: Rockmen drilled, blasted, and barred down thousands of tons of weathered and loose rock from abutment areas

TOWNS AT THE GRAND COULEE DAM

To house the workers at the Grand Coulee Dam two towns were built, one on the west side of the river, Coulee Dam, commonly known as "Engineers' Town," by the Bureau of Reclamation, and one on the east side, Mason City, by the contractor.

Coulee Dam is to be a permanent town for the accommodation of employees on the Columbia Basin Project. It is provided with paved streets, concrete sidewalks, and appropriate water, sewer, and street-lighting systems, and is composed of 77 residences of 6 standard types and sizes, 2 large dormitories, administration building, schoolhouse, post office, garage and shop, fire station, and extensive warehouses and storage yards. To the north

Thirty miles of railroad, highway, and transmission line were built up the Grand Coulee to the dam site

of the town site are 4 temporary dormitories and 57 temporary court-type 3-room houses for the use of Bureau employees.

Mason City was designed for only temporary service and is to be dismantled when the dam is finished. Consequently its houses and street improvements are of a less substantial character than those in Coulee Dam; but reliable and efficient water, sewer, and street-lighting systems were installed. There are 3 standard types of small houses, of one, two, or three rooms, with baths and kitchens or kitchenettes, 60 cabin-type dormitories to house 1,360 men, 2 dormitories for women employed in Mason City, a hospital, a hotel, schoolhouses, 2 churches, a laundry, stores, recreation buildings, office buildings, shops, warehouses, and storage yards, and a mess hall capable of seating 1,360 men at one time.

The school system includes a high school and a grade school in which the first three grades are taught. For the succeeding five grades the children of Mason City attend a Government school in Coulee Dam. The younger

Coulee Dam, the Government's permanent town, and Mason City, the contractor's temporary town, located below the dam site

children from Coulee Dam, and those of high-school age, go to the Mason City schools.

The low rate for electrical energy and the temporary character of the contractor's town are responsible for the use of electricity for house and dormitory heating, as well as for lighting and cooking, in Mason City.

At some distance from the dam site numerous towns have sprung up, and many of the workers on the project live in them. The total population in the vicinity of the dam in 1937 was about 15,000.

EXCAVATION

One of the major tasks on the project was that of excavation. Under a contract, let in December 1933 for the purpose of providing employment quickly under the emergency relief program, David H. Ryan moved about 2 million yards of overburden, using power shovels, heavy trucks, and large scrapers drawn by caterpillar tractors. Subsequently, the same contractor moved about a million yards of material dislodged in slides on the west side of the river.

The MWAK Co. moved more than 15 million cubic yards of common and more than 1,300,000 yards of rock by January 1, 1938.

Removing from the old channel of the diverted river deep beds of clay deposited during the last Ice Age

Excavation on and adjacent to the dam site will exceed 22 million cubic yards. That at the gravel pit, for the completed dam, will be even greater.

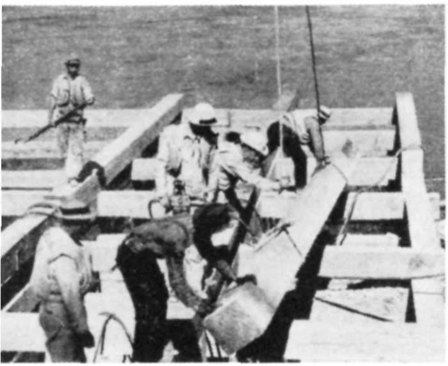
CONVEYORS

With the exception of rock, practically all material was transported to spoil banks by the MWAK Co. on belt conveyors. Material, dug by large electric shovels, was hauled by 8-yard to 10-yard trucks and in 12-yard to 20-yard buggies drawn by caterpillar tractors to grizzlies—gratelike structures on the ground, where boulders over 13 inches in diameter were pushed off and other material broken up and forced through the grizzlies by bulldozers. Feeders under as many as four grizzlies delivered the material over 60-inch belt conveyors to the surge feeder on the 60-inch main-line conveyor, which carried more than 13 million cubic yards of it a mile away into Rattlesnake Canyon, and dumped it at an elevation of 500 to 600 feet above the point of origin. A part of the material excavated on the east side was carried by belts 4,000 feet across the river and thence into Rattlesnake Canyon. After excavating was completed on the west side, the conveyor system was moved to the east side of the river.

The main-line conveyor was made up in sections, long or short, depending on the grade at any point, each section driven by a 200-horsepower motor. In excess of 5,000 horsepower was at one time required to drive the conveyor system. The average daily capacity was 40,000 yards and the maximum daily output 50,839 yards in a 21-hour day. More than a million yards were moved in a month.

Hundreds of cutters and welders cut off battered ends of cofferdam sheet steel piles and welded on extensions

Ten and a half million board feet of heavy timbers went into the cofferdam cribs



COFFERDAMS AND RIVER DIVERSION

A cofferdam is a temporary dam, built for the purpose of excluding water and water-bearing materials from areas in which construction work is to be carried on. Those at this site were constructed by driving interlocking steel piling into the ground to form a watertight fencelike structure, which is protected against collapse by timber framing or cribs, and filling or embankments of sand and gravel.

In constructing a dam, it is necessary to lay bare firm bedrock on which to build the structure, and to divert a stream while the founda-

High water flooded the low east cofferdam in 1935, but the west cofferdam kept a 60-acre working area dry

tion is laid in its bed. In narrow canyons and for smaller rivers, tunnels are sometimes driven around the dam site, and cross-river cofferdams are used to divert the river through them. The topography at the Grand Coulee Dam site and the size of the Columbia River are not suited to such a plan, with the result that several huge cofferdams were built, that on the west side of the river, the largest ever built, being 3,000 feet long parallel to the river. It was built in 90 days.

From the 60-acre area enclosed, about 10 million cubic yards of material were removed, and within it blocks 40 to 8, inclusive, about a third of the dam foundation, were built from the west bank of the river to the abutting rock wall to the westward.

In constructing the west cofferdam, 15,462 tons, 800,000 lineal feet, 151 miles of interlocking steel piles 15 inches wide and in lengths of 40 to 80 feet were driven into the hard clay deposits on bedrock by steam hammers handled by long-boom cranes.

A chain of joined cells, averaging 110 feet in height, approximately cylindrical, and about 50 feet in diameter, filled with sand and gravel, formed the west-side cofferdam along the river. Timber cribs with steel-sheet pile facings formed the shore arms.

Block 40, at the river's edge, and block 39 next to it, each 50 feet wide, were built immediately inside the west cofferdam to the height specified in the foundation contract. Blocks 32, 34, 36, and 38, each 50 feet wide, were built up only to a point about 23 feet below normal low-water level, and the alternate blocks 33, 35, and 37 were built only 40 feet higher. These and several other low gaps nearer the west end of the dam base were provided to pass the river water while the middle section of the dam was under construction.

Water was admitted to the diversion channel November 5, 1936. On December 9 the last crib was placed in the downstream cross-river cofferdam, within 30 hours the openings left in it were closed with stop logs, and by December 12 the entire river was flowing through the diversion channel and through the four 50-foot channels over the low blocks 32, 34, 36, and 38.

The upstream cross-river cofferdam was completed, and unwatering of the 55-acre area enclosed was begun January 3, 1937. In 6 days 80 million gallons of water were pumped out, and on January 9, 2 months ahead of schedule, actual excavation began.

The west foundation completed, water was admitted to the diversion channel through it, and construction of the cross-river cofferdams started in 1936

With the diversion of the river accomplished, the excavation of the river channel and east side were carried out in the summer of 1937

The construction of the cross-river timber crib cofferdams required 10,500,000 board feet of lumber, enough to build 500 eight-room houses, and the timber cribs on the faces of blocks 39 and 40, 130 feet high, 200 feet long, and 100 feet wide, required 3 million board feet. Timbers 12 by 12 to 16 by 24 inches in cross-section and 40 to 60 feet long were used. Nearly a million cubic yards of gravel were used to fill them. Steel sheet piling used to face the water sides of the cofferdams totaled 2,200 tons.

THE ICE DAM

Unique in the history of the building of dams was the use here of a temporary frozen earth dam.

Threatened with delay and great expense by a body of more than 200,000 yards of plastic clay which, in spite of timber cribs and concrete barriers, moved toward and repeatedly filled a deep crevice in the bedrock at the east end of the dam, Bureau engineers conceived the idea of freezing the toe of the sloping mass of clay to form a dam across the crevice.

Six miles of pipe, 3 miles of inch and a half pipe inside 3 miles of 3-inch pipe, were driven in an arc between the walls of the crevice. Brine at 0° F. circulated through the pipes, froze a portion of the clay into an arch-type dam, 20 feet thick, 45 feet deep, and with a span of 110 feet.

From August 1936 to April 1937 an 80-ton ice plant kept the ground frozen, and the ice dam held back the clay while excavation of the crevice was completed and the base of the dam built up above the toe of the clay slope.

Movement of the clay, as soon as the ice dam was allowed to thaw out, proved that the expenditure of $35,000 on the ice dam had saved many times its cost, and much valuable time.

CONCRETE

CONCRETE MIXES

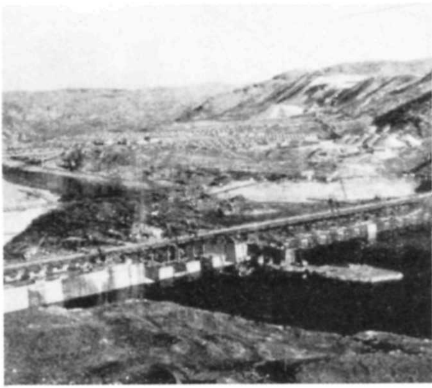
The job of greatest magnitude on the Grand Coulee Dam is that of making and placing concrete—20 million tons of it.

To serve various purposes and to suit a variety of conditions, mixes of two classes are used:

Class A, maximum size aggregate ¾, 1½, or 3-inch depending upon position; water-cement ratio 0.90 by volume; strength 3,000 pounds per square inch at 28 days.

Class B, mass concrete for interior of dam

The removal of cofferdams late in 1937 allowed the river to flow through low gaps in the completed foundation



and toe; maximum size of aggregate 6-inch; minimum cement content 1 barrel per cubic yard; maximum water-cement ratio 1.00 by volume; strength 2,800 pounds per square inch at 28 days.

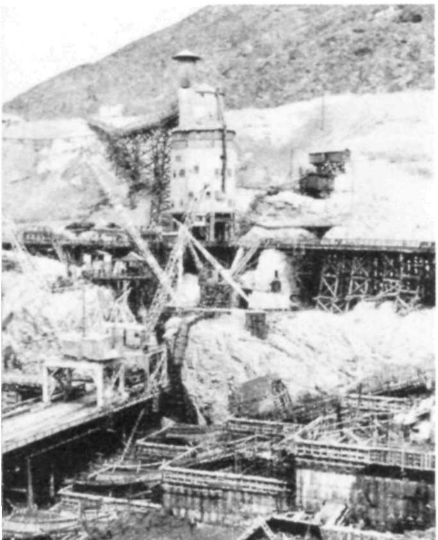
Two and a half miles of cylindrical forms will be required for the 8½-foot outlet tunnels

CONCRETE AGGREGATE

Sand and gravel are obtained from a pit furnished by the Government and operated by the contractor, a mile and a half below the dam site on the east side of the river and 800 to 1,000 feet above it.

Pit-run material is delivered by electric shovels, through grizzlies which reject boulders too large to be handled on a belt, to an extensible system of belt conveyors by which material can be transported from any part of the pit to a raw stock pile above the processing plant.

In columns 50 feet square, the concrete is built up in terraces of 5-foot lifts in movable forms



The washed gravel, separated into four size ranges, 6 to 3 inches, 3 to 1½ inches, 1½ to ¾ inches, and ¾ to $\frac{3}{16}$ inches, and the sand, ranging in particle size from 100-mesh to $\frac{3}{16}$ inch, are stored in separate piles below the plant, and moved as required over a 48-inch belt conveyor to stock piles near the east end of the dam 5,965 feet away. The aggregate required at the west side mixing plant was transported across the river on a 36-inch conveyor carried, during the constructing of the base of the dam, by a suspension bridge about 4,000 feet long.

The pit contains a large excess of sand, and about 50 percent of the material excavated is rejected. In furnishing aggregate for the contract for the base of the dam, about 3 million yards of sand went to waste. On the completed dam, the excess sand to be handled will exceed 10 million yards.

CEMENT

Cement, purchased by the Government, is shipped in bulk in boxcars from five cement plants in Washington, unloaded through hose and pipe lines by means of cement pumps, stored in 11 steel silos with a total capacity of 55,000 barrels, and blended for uniformity in color and other characteristics before being used. Mixed with air under pressure, it is transported from the blending silos through an 11-inch pipe to the concrete mixing plant 6,200 feet from the blending silos. During the construction of the base of the dam, the cement pipe line crossed the river on a suspension bridge which also carried the belt conveyor supplying sand and gravel to the west mixing plant.

CONCRETE MIXING PLANTS

Concrete is mixed in two plants, octagonal towerlike structures 44 feet wide and more than 100 feet high, one originally located on each side of the river. At the top of each plant are two bins for cement, one for sand, and one for each of the four sizes of gravel used.

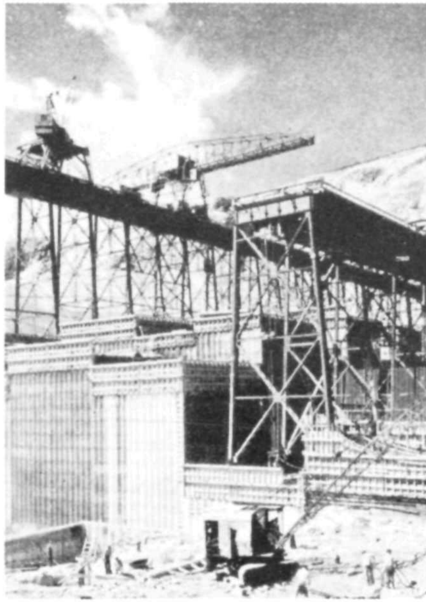
By means of electrically operated devices, under push-button control by one operator, water, cement, sand, and gravel of each size, in quantities appropriate to the mix required, are automatically weighed out for each batch and delivered to one of four 4-yard mixers in each plant, graphic records of all components and the consistency of each batch being automatically recorded.

CONCRETE PLACING

Mixers deliver their charges into 4-yard, bottom-dumping buckets, which are hauled away by 10-ton Diesel-electric locomotives, four to a car on standard-gauge railway tracks on steel trestles. Huge cranes, with a reach of 115 feet or more traveling on the same trestles, remove the buckets from the cars, swing them out over the rising structure, and lower them into the forms, where workmen dump them through specially shaped hopper bottoms and ingenious valves, designed to prevent the segregation of coarse and fine aggregates, and to control the rate of deposition.

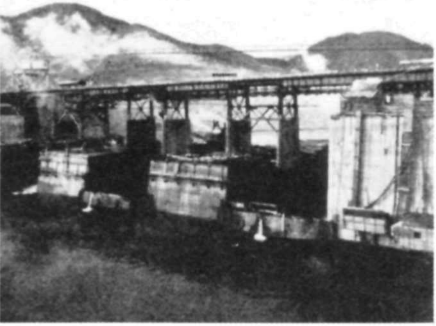
As the dam grows, in 5-foot "lifts," placed in any column at intervals of not less than 72 hours, the steel trestles are buried, and forever lost.

The placing of concrete in the Grand Coulee Dam was started in December 1935. Seven hundred thousand cubic yards were placed by June 30, 1936, 2 million yards by April 15, 1937, and more than 4 million yards in less



Two 3,000-foot steel trestles averaging 95 and 175 feet in height were used in placing concrete in the foundation

A hundred and fifty-seven welders, cutters, and helpers were employed at one time on repairs and construction



Closed with massive gates 50 feet square, diversion gaps were filled with concrete after the central section of the base was finished

than 2 years. As much as 9,290 cubic yards were placed in 1 day from one mixing plant. The maximum record for a day was 15,844, and for a month, 377,135 yards. With two mixing plants running at full capacity, concrete could be placed at the rate of 1 cubic yard every 5½ seconds.

COOLING

The reaction which takes place between water and cement in concrete always results in the evolution of heat. During a large part of the year relatively warm materials are used in making concrete. The dam must ultimately reach a temperature close to that of the river bed, practically constant throughout the year, and considerably below that of the concrete when placed.

Unless the heat of cement hydration is dissipated as it is liberated, a massive concrete structure will rise in temperature and expand in size over a period of months. As the temperature afterwards falls toward its ultimate value, contraction occurs and shrinkage cracks appear. Structural weakness may be caused, and leakage will result if shrinkage cracks remain unsealed.

In order to prevent damage from expansion and subsequent shrinkage, and in order to permit the final sealing of all contraction joints by grouting before the dam is completed, more than 2,000 miles of 1-inch, thin-wall steel tubing is being set in the concrete, and cooling water is circulated through it. The pipes are set 5 feet apart vertically and 5 feet 9 inches horizontally, and are parallel to the faces of the dam.

The cooling water circulated through the dam will carry away heat in excess of that liberated in burning 30,000 tons of coal. The maximum temperature reached within the dam is 55 to 65 degrees above that of the concrete when placed. The final temperature of the dam will be about 50° F.

CONSTRUCTION FEATURES

Although the dam will be a monolithic struc-

Water that flowed placidly into the wide forebay became a raging torrent in the narrow diversion channels

Six miles of refrigerating pipe were driven into the toe of a 200,000-yard mass of moving clay

ture, it is constructed in blocks 5 feet thick and varying in area from 50 feet square in the spillway section to 25 by 34 feet at some points in the power-house sections, successive lifts in any column being placed at intervals of not less than 72 hours. Adjacent columns are locked together by a system of vertical keys on the transverse joints and horizontal keys on the longitudinal joints.

GROUTING

After the concrete is cooled and shrunk grout of cement and water is forced into the contraction joints, opened between the columns by the contraction of the concrete, through a pipe distribution system embedded in the concrete as it is being poured, thus forming a solid, monolithic structure. The shrinkage of the concrete, though it opens a crack only three thirty-seconds of an inch wide between adjacent blocks, aggregates about 8 inches in the length of the dam.

WHERE THE MONEY GOES

Over 6,000 men have been employed on the project at one time, at an average wage rate of 83 to 90 cents per hour. Employment is limited to a maximum of 8 hours per day and 40 hours per week.

In the first 37 months of construction operations, the contractor paid out $18,615,617.48 in wages. In the first 15 months after beginning operations, the firm spent for equipment and supplies $11,413,628.63, of which 56½ percent went directly to points east of the Rocky Mountains. Of the remainder, large parts passed through the hands of western jobbers to eastern manufacturers, and thence to their employees, and through western corporations to eastern stockholders and manufacturers. Much of the wages of all western workers goes east for the purchase of staple foods, clothing, automobiles, household equipment, and miscellaneous requirements.

The Government expenditures during 1935 and 1936, for materials, equipment, and supplies for the project, went directly to 23 States east of the Rocky Mountains and to 5 States

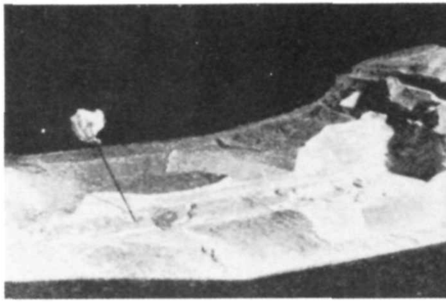
A frozen-earth dam 100 feet wide protected a deep bedrock excavation for 7 months from a flood of plastic clay

west of the Continental Divide. In 1937 Government purchases for the dam were made in 34 States. Indirectly, the funds expended probably reached every State in the Union.

DESIGN, SUPERVISION, CONSTRUCTION

The Grand Coulee Dam was designed, and the Columbia Basin irrigation works are being designed, by the Bureau of Reclamation, United States Department of the Interior.

The contractor on the construction of the base of the dam was the Mason-Walsh-Atkinson-Kier Co., made up of the Silas Mason Co. with headquarters in New York, the Walsh Construction Co. of Davenport, Iowa, and the Atkinson-Kier Co. of California, and commonly known as the MWAK Co.



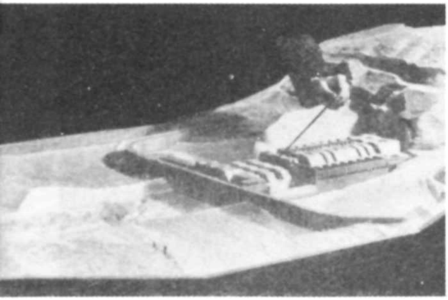
Three deep gorges and numerous minor irregularities were found at the bottom of the 18-million-yard excavation

Through each 18-foot penstock water will pass at a rate of 141 tons per second to drive a loaded generator

The contract for the completion of the dam was let by Secretary Ickes on January 28, 1938, to the Consolidated Builders, Inc. It is composed of the members of the MWAK Co.; the Morrison-Knudsen Co., Boise, Idaho; J. F. Shea Co., San Francisco; McDonald & Kahn, San Francisco; Pacific Bridge Co., San Francisco; Henry J. Kaiser, Oakland, Calif.; and Utah Construction Co., Ogden (the firms included in the Six Companies, which built the Boulder Dam); and the General Construction Co., Seattle, which built the Owyhee Dam.

Supervision and inspection of the work are under the direction of Secretary Harold L. Ickes of the Department of the Interior and Commissioner John C. Page of the Bureau of Reclamation, and are carried out by Chief Engineer Raymond F. Walter of the Bureau of Reclamation, with headquarters at Denver, represented by Construction Engineer Frank A. Banks in charge of the field office at Coulee Dam, Washington.

Among the activities of the Bureau has been a surveying project of extraordinary magnitude. The reservoir flood-line and the taking-line at elevation 1,310, each nearly 400 miles long, were established, property lines were relocated, and new locations for highways and railroads within the reservoir were worked out. *Surveys on project lands have included, so far,* section-line retracement and the setting of monuments on more than a million acres of



The purpose of the west cofferdam and the design of the diversion gaps on the west side are explained

land, control-leveling on more than three-quarters of a million acres, and topographic surveys of nearly as much.

THE BUREAU OF RECLAMATION

The Bureau of Reclamation of the Department of the Interior is the Federal agency organized in 1902 to carry out the provisions of the Reclamation Act, "Appropriating the receipts from the sale and disposal of public lands in certain States and Territories to the construction of irrigation works for the reclamation of arid lands."

In the 35 years of its existence the Bureau has built 138 storage and diversion dams, 24 power-houses, 2,344 buildings, 19,116 miles of canals, ditches, and drains, 72½ miles of tunnels, 4,367 miles of telephone lines, 267 miles of dikes and levees, 6,041 flumes, 18,694 culverts, 13,166 bridges, and 182,964 other irrigation structures.

Living on the land made productive by these structures are 210,466 persons, and in the towns on the projects 653,441, served by 859 schools and 996 churches. The estimated gross value of the crops produced on Federal reclamation projects in the calendar year 1936 was $136,502,480. The average crop value for each of the 2,901,919 acres of land for which the Bureau of Reclamation furnished water in 1936 was $47.10.

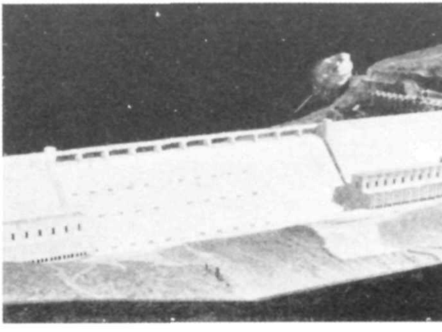
Since 1906, when the first Federal project went into operation, the grand total value of crops produced on these projects has been $2,311,983,242, or approximately 10 times the cost of the Federal irrigation works serving the lands. The return obtained by the farmer on Federal reclamation projects for each acre worked during 1936 was two and a half times that received by the average farmer the Nation over.

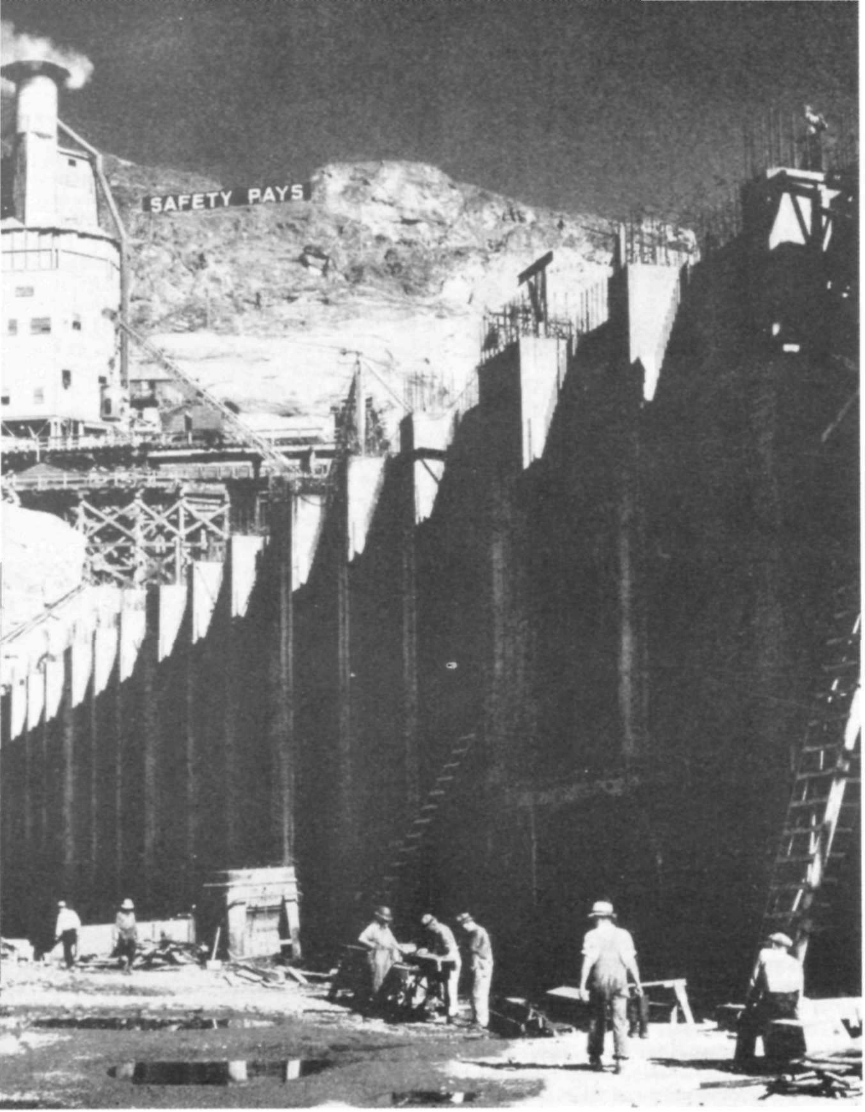
Although the 1936 production from Federal reclamation projects was only 1.1 percent of the value of all the crops harvested from farms in the United States, approximately 864,000 people, on 48,773 farms and in 257 towns and cities which have sprung up in these areas, were supported by the projects.

With the exception of some fruits and vegetables, the products of irrigated western farms do not reach eastern markets. More than half of the area is used in the production of hay and forage which is consumed on the farms, and is an important factor in the support of the livestock industry of the Western States.

★

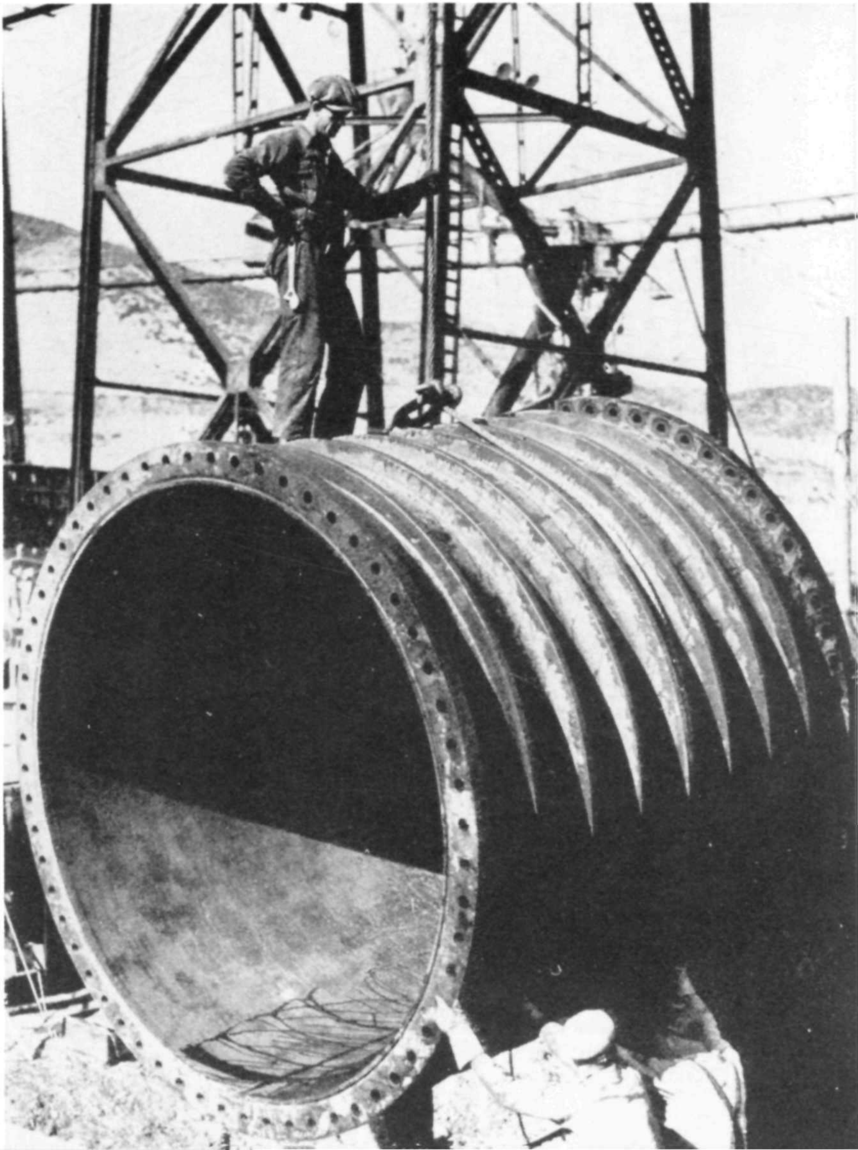
Its tremendous size is illustrated by showing scale models of motor stages and freight trucks on the dam

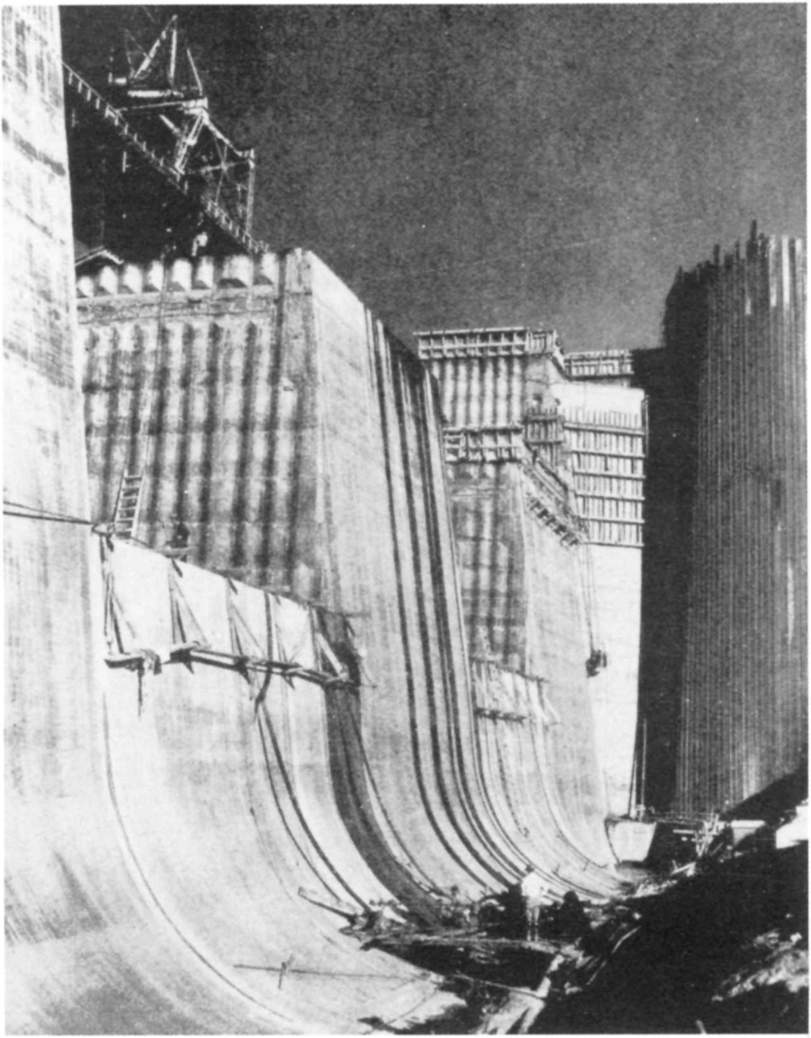




The finished dam will tower 300 feet above this massive base for the east power-house, now almost completely submerged in the tailbay into which nine huge turbines will some day discharge spent water

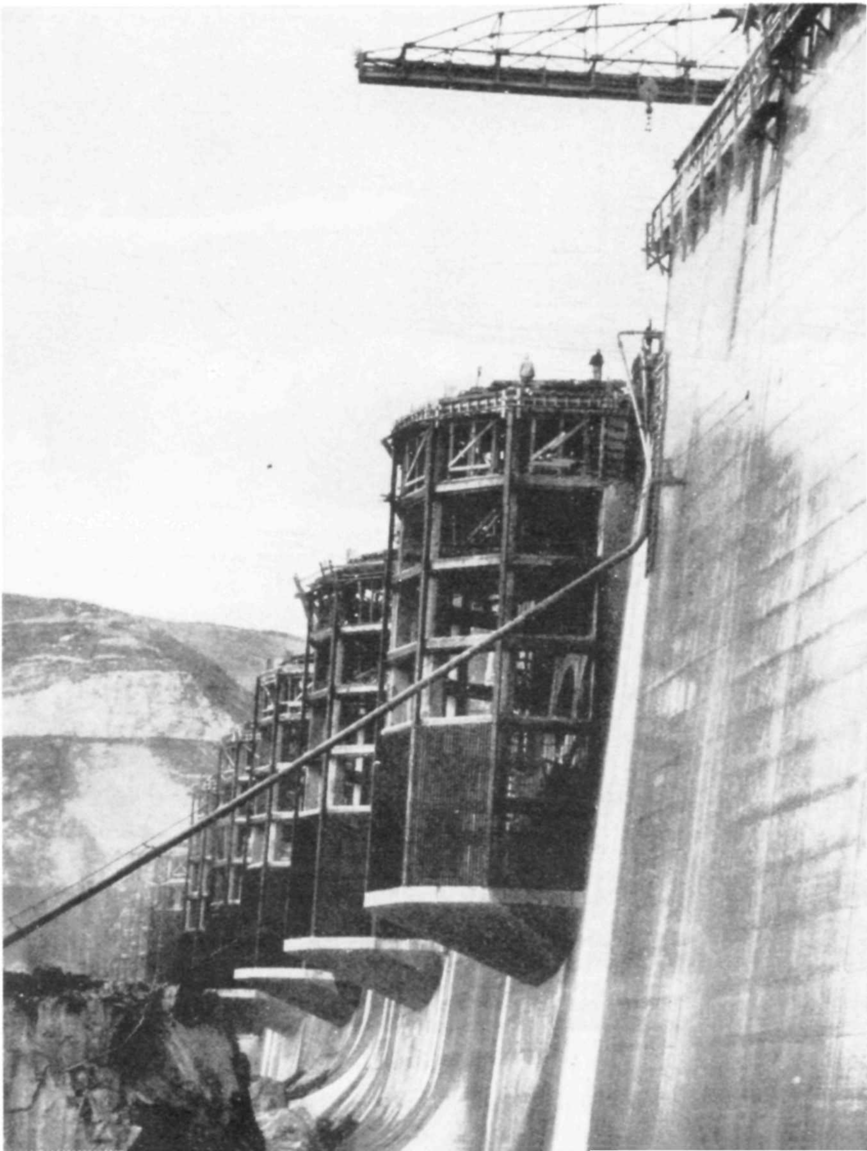
Heavily ribbed semisteel conduits line the entrances to outlet tunnels, the first flared out in a mathematical curve to prevent erosion. Two mammoth valves will control the flow of water in each tunnel

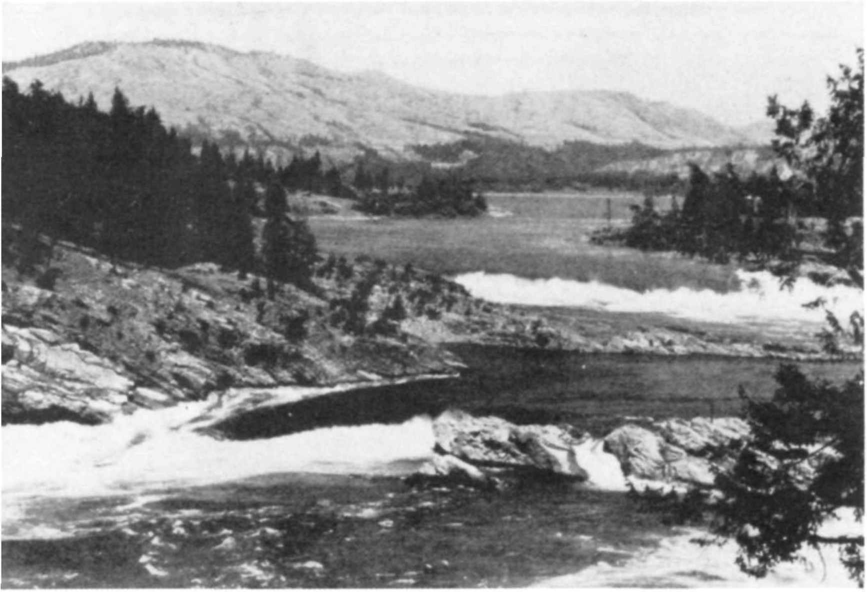




Blocks are interlocked with vertical keys along transverse joints and with horizontal keys at longitudinal joints. Grout later fills and seals openings formed at such joints when blocks are cooled and shrunk.

Heavy steel trashracks, supported on reinforced concrete frames on the upstream face of the dam, will protect outlet tunnels from debris. Similar and larger racks will cover the entrances to penstocks





Kettle Falls, 112 miles above the dam, marks a spot of scenic and historic interest in the reservoir area which is generally surrounded by low timber-covered mountains. The 30-foot falls will be submerged

Section III. THE COLUMBIA RIVER AND ITS WATERSHED

THE COLUMBIA RIVER BASIN

EXTENT OF THE COLUMBIA RIVER WATERSHED

The drainage basin of the Columbia River covers an area of 259,000 square miles. It includes almost all of Idaho, the greater parts of Washington and Oregon, and parts of British Columbia, Montana, Wyoming, Utah, and Nevada, an area equal to practically four times that of the New England States.

The Columbia Basin Project is concerned with the 74,100-square-mile area above the Grand Coulee, drained by the Columbia and its upper tributaries. Of this area, 39,000 square miles are in Canada.

THE COLUMBIA RIVER

The Columbia River, second in flow only to the Mississippi and greatest in potential power among the rivers of North America, rises in Columbia Lake at an elevation of 2,650 feet in the southeastern part of British Columbia, flows northwesterly 195 miles, between the high timber-covered Rocky and Selkirk Mountains, thence southward 270 miles, entering the State of Washington 151 miles, by river, above the mouth of the Grand Coulee and the site of the dam. It contributes about 37 percent of the flow at the dam.

THE KOOTENAI RIVER

Among its principal tributaries above the dam are the Kootenai, Clark Fork, and Spokane Rivers. The Kootenai has its source about 75 miles north of that of the Columbia, but flows in an opposite direction 180 miles into Montana, thence into Idaho; and, after making a 167-mile loop in the United States, returns into British Columbia through Kootenai Lake, and joins the Columbia 30 miles north of the international border.

The Kootenai River drains an area of 19,450 square miles, 14,550 square miles of which are in Canada. Its average annual flow is about 34,000 second-feet, and its average run-off 25,300,000 acre-feet, about 31 percent of the run-off above the dam.

THE CLARK FORK RIVER

Clark Fork of the Columbia River rises on the west side of the Rocky Mountains near Butte, Mont., and not far from the headwaters of the Missouri River, and the Snake River, largest tributary of the Columbia. Its course is generally to the northwest through Montana about 360 miles into Pend Oreille Lake in the panhandle section of Idaho. Thence its course is northerly nearly 100 miles, through Idaho and northeastern Washington into Canada, where it empties into the Columbia about one-half mile above the international boundary. The Clark Fork basin covers 25,820 square miles, only about 1,200 of which are in Canada. Its

Below the dam site, the river is bounded by rugged, arid hills extending back on the right bank to the Okanogan and Cascade Mountains, and on the left to the Columbia Lava Plateau

Blockaded by ice, this canyon was for thousands of years filled to overflowing with turbid glacial water

average annual flow is about 25,000 second-feet, and its average annual run-off 19,300,000 acre-feet. It brings into the Columbia about 23 percent of the water passing the dam.

THE SPOKANE RIVER

The Spokane River is, relatively, a minor tributary, its drainage area being only about 6,600 square miles, and its average annual flow only about 8,000 second-feet. Its source is Coeur d'Alene Lake in Idaho, which receives its water supply chiefly from the Coeur d'Alene and St. Joe Rivers, rising on the western slopes of the Bitter Root Mountains. The lake is a valuable regulator of the flow of the Spokane River. The average annual run-off of the Spokane River drainage basin is about 5,800,000 acre-feet.

COLUMBIA RIVER ABOVE GRAND COULEE

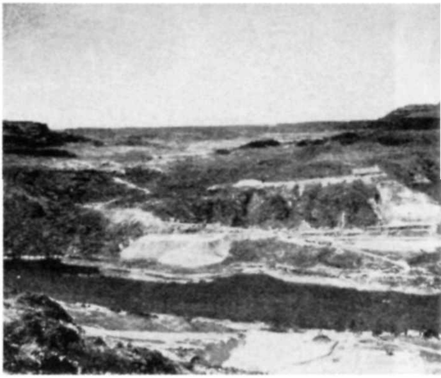
At the dam site the Columbia flows in a channel 700 to 850 feet wide, in a canyon 2,000 feet wide at the bottom and a mile wide at the top. The average elevation of bedrock is about 875, of the river bed about 910, and of the low stage water level about 933. The average high-water mark over a period of years was 978, but in the flood of 1894 it is believed to have reached elevation 1,003.

The drainage basin above this point covers 74,100 square miles, 39,000 of which lie in British Columbia. Particularly in Canada the headwaters of the Columbia rise in high mountain snows, glaciers, and lakes, which have the effect of regulating the river flow and bringing high-water periods in the months of June and July which will be highly advantageous to both irrigation and power development on the Columbia Basin Project.

The mean flow of the river at the dam site during the past 23 years was 110,000 second-feet. A minimum of 17,000 second-feet and a maximum of 492,000 second-feet have been recorded, and it is estimated that in the flood of 1894 a flow of 725,000 second-feet was reached. By means of the Grand Coulee Dam it will be possible to regulate the flow to a minimum of 35,000 second-feet.

The average annual run-off of the Columbia Basin above the Grand Coulee Dam is 80 million acre-feet. At an estimated maximum

Entrance to the Grand Coulee, prehistoric diversion channel, cut by a torrential glacial Columbia in the last Ice Age



Forty cubic miles of hard basalt cut out of the Columbia Lava Plateau left the Grand Coulee

annual requirement of 5 feet of water for each acre of land to be irrigated, only 6 million acre-feet will be diverted from the river. The run-off at the Grand Coulee Dam is five times as great as that of the Colorado River at Boulder Dam.

THE COLUMBIA LAVA PLATEAU

THE ORIGIN OF THE PLATEAU

Millions of years ago many successive floods of highly fluid basaltic lava poured out through fissures in the earth's crust and spread over the surface of central and eastern Washington, northeastern Oregon, and southwestern Idaho. These floods of lava cooled and solidified to form the generally horizontal rock strata of basalt which characterize the Columbia Lava Plateau. As the lava flows spread northward and westward they gradually pushed the Columbia River out of its ancient course from the Colville Valley toward Pasco, and forced it to detour far to the west around the edge of the lava flows where they met the older igneous rocks of the rising Cascade Mountains and the Okanogan Highlands. Thus was formed what is popularly known as the "Big Bend" region of the Columbia River. In this region of the Columbia Lava Plateau, one of the two largest lava flows now exposed on the earth's surface, are 1,200,000 acres of rich soil to be irrigated from Grand Coulee Dam.

In its new position the river eventually cut for itself a canyon as much as 1,600 feet deep, in many places bounded on one side by precipitous cliffs of lava and on the other by granite hills. At the site chosen for the Grand Coulee Dam granite is exposed on both sides of the river and forms the abutments and the base of the dam.

THE GRAND COULEE

The Grand Coulee is a prehistoric river bed, 52 miles long, 1½ to 5 miles wide, and at places nearly 1,000 feet deep. It is one of a number of southwest-trending channels which were cut in the lava plateau of central Washington by the displacement of the normal Columbia River drainage during the period of the last great Ice Age.

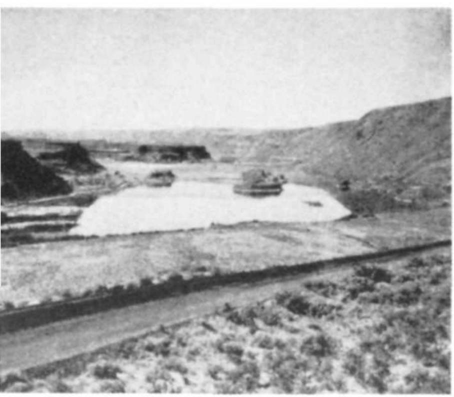
Thousands of years ago, during the Ice Age, a thick sheet of ice moved southward into northern Washington. A portion of this ice

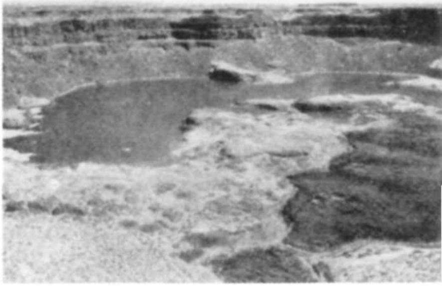
Two miles long and 900 feet high, Steamboat Rock is a spectacular landmark in the upper Grand Coulee

sheet crossed and completely filled the gorge of the Columbia River at some point west of the site of Grand Coulee Dam. As a result of this ice obstruction, the upstream part of the gorge was converted into a great lake whose rising, turbid waters laid down hundreds of feet of sediment in the river canyon and ultimately spilled over through several low points in the south wall of the gorge, and flowed southwestward across the Columbia plateau. This temporary overflow swept away accumulations of surface soil, cut a complex series of channels into the lava sheets, and deposited millons of acre-feet of fine material in the lake created south and east of the Big Bend of the Columbia. In this manner were formed the scablands which are a prominent and interesting feature of geology of eastern Washington. The Grand Coulee, largest of these channels, is one of the scenic wonders of the Western United States.

A short distance north of Coulee City the generally horizontal lava flows of the plateau dip sharply to the southeast, forming an immense wrinkle in the plateau surface before they again flatten out at a lower elevation. It is believed that the waters of the glacial Columbia River, flowing down this steep surface, initiated a waterfall which gradually cut

An excellent public highway skirts the chain of four beautiful lakes that occupy the greater part of the lower Grand Coulee





Dry Falls, head of the lower Grand Coulee, was the site of a cataract two and a half times as high and five times as wide as Niagara Falls

its way northward and formed the rock trench known as the Upper Grand Coulee. Steamboat Rock is a remnant of the plateau surface, 2 miles long and ½ mile wide, left as an island as the falls retreated northward.

Eventually these ancient falls died out as they ate away the last of the rock barrier which separated them from the valley of the Columbia River. As a result the upper coulee intersects the south wall of the valley of the Columbia River about 1 mile south (upstream) from the site of Grand Coulee Dam. At this point the floor of the coulee hangs about 500 feet above the level of the present river.

THE DRY FALLS OF THE COLUMBIA

The lower Grand Coulee was formed in a similar manner by retreating waterfalls which originated in the vicinity of Soap Lake. When the ice obstruction which had dammed and diverted the waters of the Columbia River finally melted away, the river resumed its old course and left at the head of the lower Grand Coulee a relic of its former might—the Dry Falls of the glacial Columbia River. They are located in the Dry Falls State Park a few miles south of Coulee City, on the road to Soap Lake. Here, from the roadside or from a vista house in the park, one can look at the site of the ancient waterfalls, more than 400 feet high and 3 miles wide, whose northward retreat cut the channel of the lower Grand Coulee. They are two and a half times as high and five times as wide as Niagara Falls, and according to some authorities the torrent of silt-laden water which poured over them is estimated to have had a volume as much as 100 times that of the present Niagara Falls.

Two of the five largest recesses in the 3-mile northern brink of the extinct cataract are within view from the vista house. In the plunge-pools at the foot of the first are Fall Lake and Perch Lake. In the second alcove is an alkaline lake, or an alkaline flat in dry weather. Opposite the point separating the first and second horseshoe falls is Umatilla or Battleship Rock, and beyond that the left wall of an extensive section of the Coulee extending eastward, and providing a bed for Deep Lake, a mile and a half long. Near the east end of Deep Lake are two alcoves on the north and one on the east.

LOWER GRAND COULEE

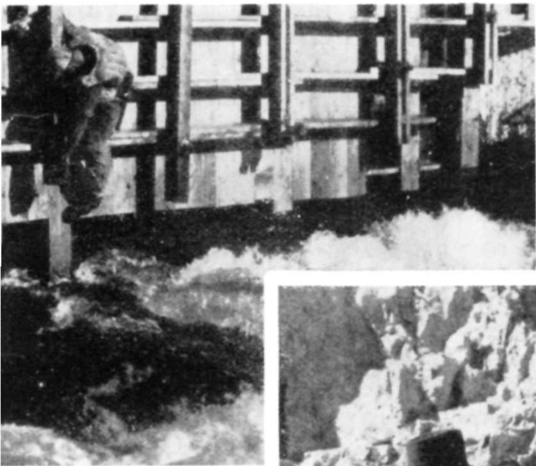
Along the State highway below the Dry Falls are Park Lake, Blue Lake, and Lake Lenore, each overflowing into the next in high-water periods, and all finally into Soap Lake which, having no outlet, is highly alkaline.

In the Coulee walls there are visible at least seven lava flows. The time intervals between some of the flows were so long that surfaces disintegrated into soil, and vegetation flourished. On the shores of Blue Lake below the sixth flow, are casts of huge trees buried by the lava as it flowed over the land. In the soils between lava strata, explorers have found fossil remains of the ginkgo tree, which now grows only in the Orient, of the Sequoia, now growing only in California, of oak, elm, yew, cypress, gum, and of other varieties of trees now growing elsewhere, proving that long periods elapsed between successive flows, and that sometimes semitropical climates existed here millions of years ago.

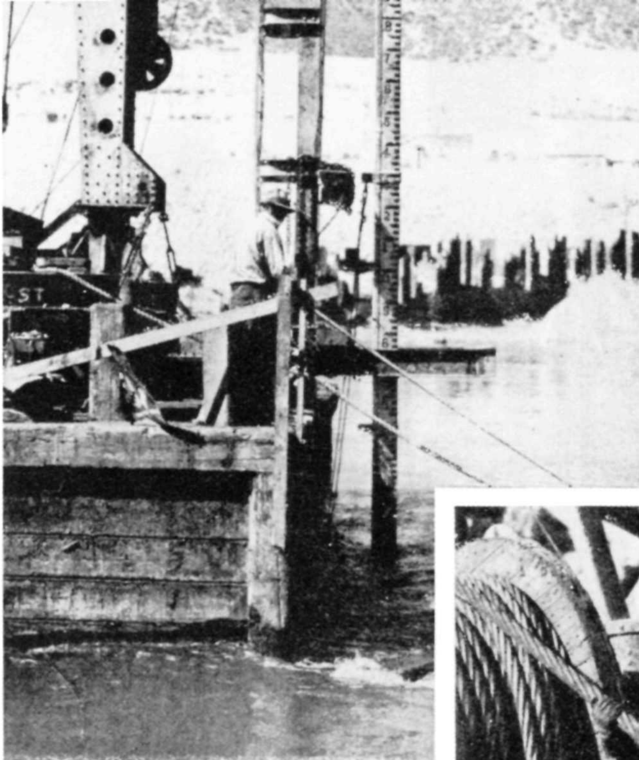
Glacial floods removed deep soil from hundreds of square miles of the Columbia Lava Plateau, and from the Grand Coulee alone cut out and carried away 40 cubic miles of hard basalt. Some 25 cubic miles of such materials are estimated to have been deposited in a 250-square-mile lake in the Quincy Basin. This lake disappeared when a southerly outlet to the east of Frenchman Hills, and three westerly outlets to the Columbia, one now traversed by the highway to Vantage Bridge, were worn down below the level of the lake bottom, and left part of the land which is to be irrigated by means of the Grand Coulee Dam.

The construction of the base of the Grand Coulee Dam across the Columbia River channel nears completion in the fall of 1937

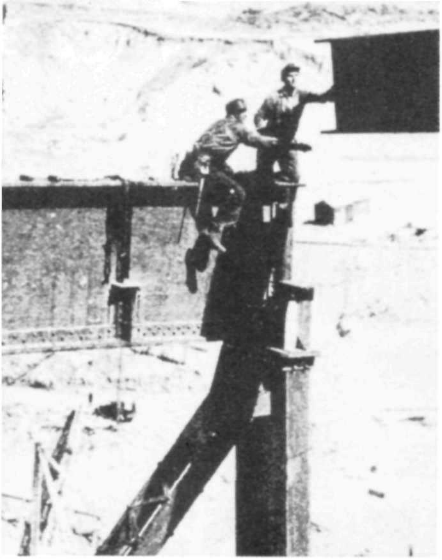
The river now flows through low gaps in the dam in many low cascades that will, in time, grow into a 350-foot waterfall



In spite of the unprecedented use of machinery and power, men of a great variety of crafts were employed, and much manual labor was required in building the base of the dam. Final clearing of bedrock was done by hand



The contours of the river bed were determined accurately by soundings, and cribs for the cross-river cofferdams were built to fit them. Riggers, with their ropes and cables, were indispensable figures in the construction crews



Two steel trestles, 3,000 feet long and averaging 95 and 175 feet in height, were built across the canyon—and buried in the concrete they carried. Over 75 million pounds of reinforcing steel will be required

Four-yard batches of concrete, in huge steel buckets, were lowered into the forms by long-arm cranes. After at least 3 days, each lift was scrupulously cleaned with sandblast, air, and water before another was laid on it

The topography of more than a million acres of land must be taken as a guide in designing irrigation works

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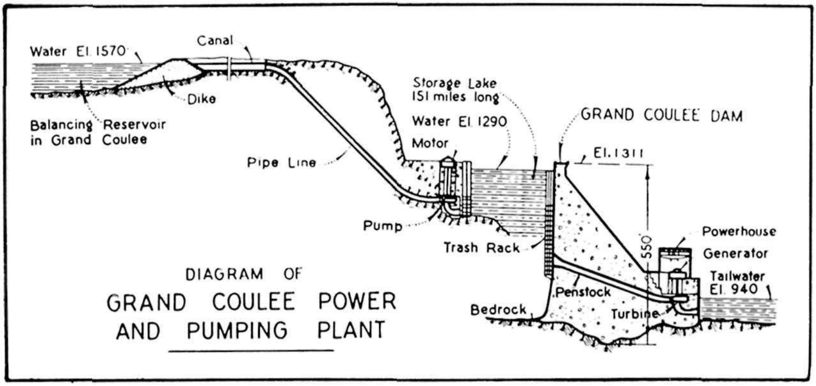
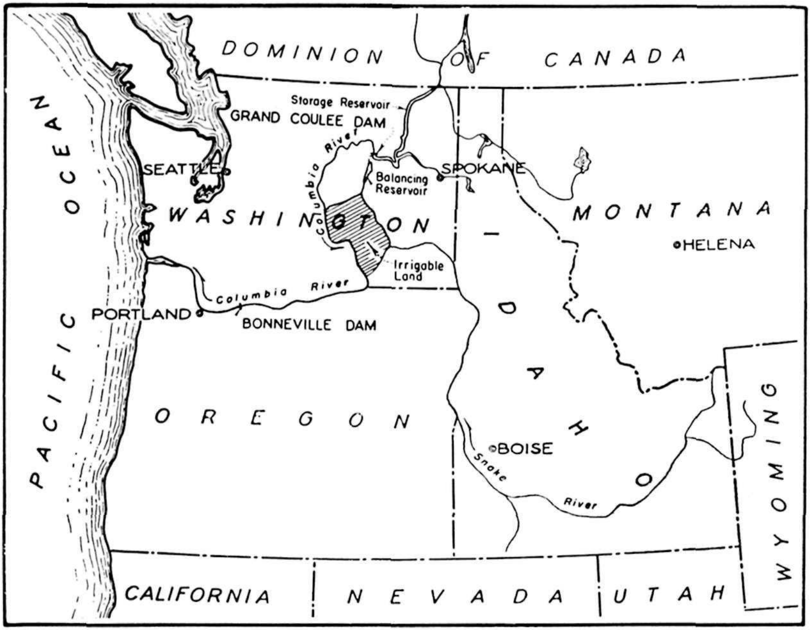
THE COLUMBIA BASIN PROJECT AND THE GRAND COULEE DAM

Marks, buried under years of growth of witness trees, guided surveyors reestablishing property lines in the reservoir area


Water El. 1570
Canal
Dike
Balancing Reservoir in Grand Coulee
Storage Lake 151 miles long
Water El. 1290
Motor
Pipe Line
GRAND COULEE DAM
El. 1311
Pump
Trash Rack
550'
Powerhouse
Generator
Tailwater El. 940
Penstock
Bedrock
Turbine
DIAGRAM OF
GRAND COULEE POWER
AND PUMPING PLANT


DOMINION OF CANADA
Storage Reservoir
GRAND COULEE DAM
Columbia River
SEATTLE
SPOKANE
Balancing Reservoir
PACIFIC OCEAN
WASHINGTON
MONTANA
HELENA
Irrigable Land
Columbia River
PORTLAND
BONNEVILLE DAM
IDAHO
OREGON
BOISE
Snake River
WYOMING
CALIFORNIA
NEVADA
UTAH

Pay day at Grand Coulee Dam

BUILDING A BETTER AMERICA

An army of men, reaching so far a maximum enrollment of more than 7,000 in the front rank at the dam site, is building Grand Coulee Dam. Behind those in the front rank are other battalions which cannot be seen from the vista houses on the rim of the Columbia River Canyon. They work in forests providing lumber; in mines and steel mills providing pipe, piling, reinforcement bars, etc.; in foundries and factories making machinery and equipment; on farms producing the food for these workmen; and for railroads which pour the products of all their labors through the funnel and into Grand Coulee Dam.

An amazing number of things go into the construction of such a dam. They range from tacks to dynamite caps, from divers' helmets to turbines, and they are gathered from almost every locality within the United States.

So, while Grand Coulee Dam is the principal structure of a great, long-term undertaking of tremendous social significance, its construction has an immediate social value in that it gives millions of man-hours of work at prevailing wages throughout the country. It has sent an army of men marching back to work each day since the dam was started, back to work at the job of building a better America.

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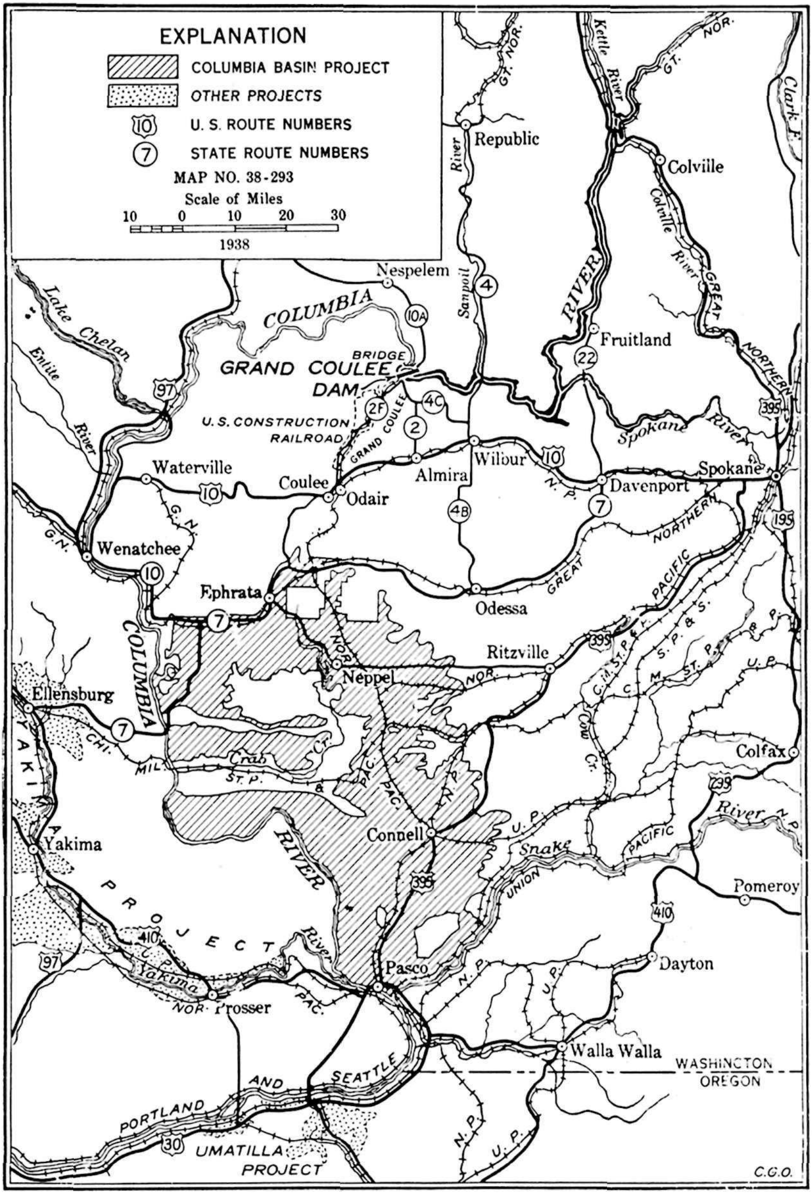
EXPLANATION
COLUMBIA BASIN PROJECT
OTHER PROJECTS
U. S. ROUTE NUMBERS
STATE ROUTE NUMBERS
MAP NO. 38-293
Scale of Miles
10 0 10 20 30
1938
GRAND COULEE DAM
BRIDGE
U.S. CONSTRUCTION RAILROAD
COLUMBIA RIVER
Republic
Colville
Nespelem
Fruitland
Waterville
Coulee
Odair
Almira
Wilbur
Davenport
Spokane
Wenatchee
Ephrata
Odessa
Ritzville
Neppel
Ellensburg
Colfax
Yakima
Connell
Pomeroy
Pasco
Dayton
Prosser
Walla Walla
WASHINGTON
OREGON
YAKIMA PROJECT
UMATILLA PROJECT
PORTLAND AND SEATTLE
Lake Chelan
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Crab Cr.
Cow Cr.
Clark F.
C.G.O.