PART I-INTRODUCTION

CHAPTER I. HISTORY AND DESCRIPTION

1. COLORADO RIVER STORAGE PROJECT. The Colorado River Storage project provides for the comprehensive development of the Upper Colorado River Basin. The project furnishes the long-time regulatory storage needed to permit States in the upper basin to meet their flow obligation at Lee Ferry, as defined in the Colorado River Compact, and still utilize their apportioned water.

Water stored by the project will provide a portion for direct use in the upper basin and, in addition, will control sediment, control flooding, facilitate recreational development, and aid in fish and wildlife conservation. A significant amount of electrical energy is created through project development to meet the needs of the upper basin and adjacent areas.

The project includes four storage units as follows: Glen Canyon (the subject of this publication) on the Colorado River in Arizona near the Utah border, Flaming Gorge on the Green River in Utah near the Wyoming border, Navajo on the San Juan River in New Mexico near the Colorado border, and Curecanti on the Gunnison River in west-central Colorado. Authorized with and linked to the Colorado River Storage project, but not part of it, are a number of participating projects which will share in the power revenues of the larger project to help pay for irrigation construction costs. These participating projects are listed in Subsection (c). Figure 1 is a location map of the Colorado River Storage project while the frontispiece shows the completed Glen Canyon Dam.

(a) *Plan.*—The reservoirs formed by the four units of the Colorado River Storage project have a total capacity of nearly 34 million acre-feet. During periods of low streamflow, the stored water in the upper basin is released to meet the Lee Ferry obligation and, in exchange, upstream flow is diverted for use in the upper basin. Powerplants and other pertinent facilities are provided at each dam except Navajo, and a complex transmission system has also been provided. This transmission system will carry Colorado River Storage project (CRSP) power to key load points in the marketing area. The system is integrated with preference-user and private-company transmission lines to form the CRSP Interconnected Transmission system. CRSP hydropower is delivered to the preference-user organizations for distribution to their consumers as required by Federal Reclamation law.

2. UPPER DRAINAGE BASIN DEVELOPMENT. (a) *Early History.*—Settlement of the upper drainage basin began in 1854 when the early pioneers established Fort Supply in Wyoming on the Emigrant Trail and diverted water from Blacks Fork to the adjacent lands. Breckenridge, Colo., on the basin's eastern rim, was settled in 1859 by miners and prospectors pushing over the mountains from older mining districts on the eastern slope of the Continental Divide. Within the next decade, other mining camps were established nearby. Unsuccessful miners turned to farming and supplied agricultural products to the mining communities. Settlements grew downward from the mountains to the valleys, the advance being slowed somewhat by conflicts with the Indians who occupied the territory. Grand Junction, Colo., now the largest community in the upper drainage basin, was not settled until 1882. The greater part of the Uinta Basin in northeastern Utah was established as an Indian reservation in 1861, and lands unoccupied by Indians were not open to settlement until 1905. Most lands of agricultural importance in the San Juan River Basin in Colorado, New Mexico, and Arizona were once included in Indian reservations, and substantial areas are still under Indian control. Numerous tributary streams in the upper drainage basin have been diverted to irrigate meadows and mountain valleys and farmlands and broader valleys at the base of the mountains.

(b) *Investigations.*—Investigations of means to develop the waters of the Upper Colorado River system were started by the Reclamation Service (predecessor of the Bureau of Reclamation) in 1902, the year of its organization. Since that year, many of the larger irrigation projects within the basin have been undertaken with Federal assistance, and the Bureau of Reclamation has constructed, or is now constructing, 25 projects to utilize water in the upper basin. The need for the Colorado River Storage project was envisioned at the time of the Colorado River Compact of 1922. In dividing Colorado River water between the Upper and Lower Colorado River Basins, the compact set aside for consumption in the upper basin 7,500,000 acre-feet of water each year. However, this allocation is contingent upon the upper basin's delivering to the lower basin not less than 75 million acre-feet of water in any period of 10 consecutive years and delivering additional water for use in Mexico under certain circumstances. The dividing point between the two basins is at Lee Ferry, near the northern border of Arizona. Water allocated to the upper basin was further apportioned to the individual States of Arizona, Colorado, New Mexico, Utah, and Wyoming by the Upper Colorado River Basin Compact of 1948.

This compact also created the Upper Colorado River Commission, consisting of representatives of the Federal Government and each contracting State except Arizona.

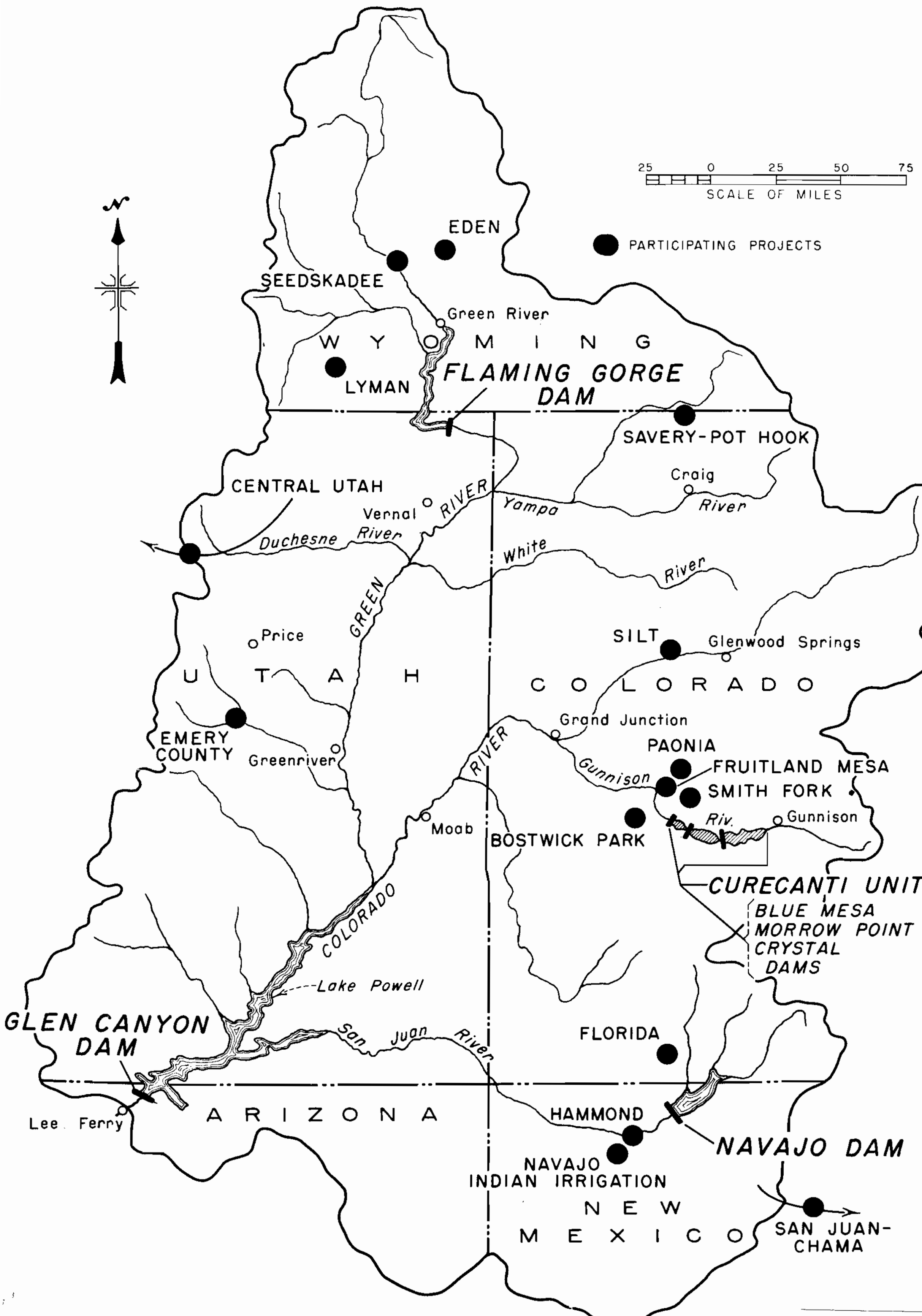

Figure 1.—Colorado River Storage project location map.

The flow of the Colorado River is extremely erratic, ranging from 4 to 22 million acre-feet annually at Lee Ferry. There is a tendency for the high years or the low years to be grouped, thus accentuating problems of river regulation and use. In prolonged dry periods, there is not enough water to permit the upper basin to increase its use of water under the 1922 compact and, at the same time, make the required deliveries to the lower basin. In wetter periods, however, flows are more than sufficient for these purposes. Large storage reservoirs, that can be filled when flows are high and that can provide additional water when needed for compact fulfillment, are required. Favorable sites for such reservoirs are found in the deep canyons of the Colorado River and its principal tributaries in the upper basin. A plan for the Colorado River Storage project, including a series of dams and reservoirs to provide storage capacity in combination with power development and other services, was presented in a Bureau of Reclamation report in 1950, which was subsequently printed as House Document 364, 83d Congress, 2d session. The report was formulated in cooperation with other Federal agencies and with the Upper Colorado River Commission. An initial group of participating projects that would develop water for irrigation and other purposes in the upper basin and that would be linked financially with the Storage project was also described in the 1950 report. Following several years of congressional deliberation, the project was authorized in 1956.

(c) *Authorization*.—Construction of 4 storage units of the Colorado River Storage project and 11 participating projects was authorized by the act of April 11, 1956 (Public Law 485, 84th Cong., 70 Stat. 105). Additional projects have been added since the original legislation was adopted. Authorized developments are:

- Glen Canyon unit on the Colorado River in Arizona and Utah,
- Flaming Gorge unit on the Green River in Utah and Wyoming,
- Navajo unit on the San Juan River in New Mexico and Colorado, and
- Curecanti unit, consisting of three dams on the Gunnison River in Colorado.

Participating projects originally authorized are:

- Central Utah (initial phase), Utah,
- Emery County, Utah,
- Florida, Colorado,
- Hammond, New Mexico,
- La Barge, Wyoming,[1]
- Lyman, Wyoming and Utah,
- Paonia, Colorado (works additional to existing project),
- Pine River extension, Colorado and New Mexico,[1]
- Seedskadee, Wyoming,
- Silt, Colorado, and
- Smith Fork, Colorado.

The Eden project in Wyoming, by terms of its authorizing act of June 28, 1949, became financially related to the Colorado River Storage project as a participating project. In 1962, their authorizing legislation named the following two as participating projects:

- San Juan-Chama, Colorado and New Mexico, and
- Navajo Indian Irrigation (being constructed for the Bureau of Indian Affairs by the Bureau of Reclamation).

And in 1964, the following three projects were also named:

- Bostwick Park, Colorado,
- Fruitland Mesa, Colorado, and
- Savery-Pot Hook, Colorado and Wyoming.

(d) *Benefits*.—The Upper Colorado River Basin has a scarcely tapped potential of agricultural, industrial, and recreational assets. It contains tremendous quantities of uranium, coal, and other minerals. Realization of the potential in economic growth and contribution to the national welfare is dependent on maximum utilization of limited water supplies. The Colorado River Storage project and participating projects conserve the very limited precipitation which falls principally in the form of snow in the high mountains and utilize it for municipal, industrial, and agricultural growth. Project development provides municipal and industrial water supplies, flood control, extensive recreation, and fish and wildlife preservation.

3. LOCATION AND PURPOSE OF GLEN CANYON UNIT. Glen Canyon Dam was constructed on the Colorado River in north-central Arizona, about 15 miles upstream from Lee Ferry and 12 river miles downstream from the Arizona-Utah State line. The dam is a concrete-arch structure, 710 feet high above foundation and has a volume of 4,901,000 cubic yards. At the time of construction (1956-64) it was the second highest dam in the Western Hemisphere, exceeded in height only by the 726-foot-high Hoover Dam. The location of Glen Canyon Dam and the Glen Canyon Powerplant is shown on figure 2

The reservoir (fig. 3) impounded by the dam, named Lake Powell in honor of Major John Wesley Powell,

[1] Later found to be infeasible and deleted from the plan.

renowned explorer of the Colorado River and its tributaries, has a total storage capacity of 27,000,000 acre-feet and will extend 186 miles up the Colorado River and 71 miles upstream on the San Juan River, with 1,900 miles of shoreline. The reservoir is a major storage feature to provide the longtime regulatory storage needed to permit the States of the Upper Colorado River Basin to utilize their apportioned water and still meet their flow obligations at Lee Ferry, Ariz.,[2] under the terms of the 1922 Compact of the Colorado River (see sec. 2).

The 900,000-kilowatt Glen Canyon Powerplant will provide the principal portion of the electrical energy generated by the Colorado River Storage project. Surplus revenue from sale of this energy will assist irrigators in the Upper Basin to repay costs of constructing the participating projects which were authorized by the Congress in 1956 to be developed with the Colorado River Storage project.

4. GENERAL DESCRIPTION OF GLEN CANYON FEATURES. (a) *Dam.*—The dam is a constant-radius concrete arch with fillets. It has a structural height of 710 feet and a crest length of approximately 1,560 feet. The crest of the dam is at elevation 3715, 583 feet above the riverbed, and accommodates a 35-foot-wide roadway which is a service road for the dam and provides access between the spillways.

A general plan of Glen Canyon Dam and Powerplant is shown on figure 4 and elevation and sections are shown on figure 5. Figures 68 and 69 show the general arrangement of the gallery system of the dam and the access to mechanical equipment in the dam.

(b) *River Outlets.*—Four 96-inch-diameter steel-lined river outlets are installed near the left abutment, extending from the upstream face of the dam to a point approximately 150 feet downstream from the machine shop. Each outlet is provided with a 96-inch hollow-jet valve at the downstream end, for regulation, and a 96-inch ring-follower gate located in the dam at elevation 3374 for shutdown emergency closure. One bulkhead gate is provided to close off one outlet at a time for inspection and maintenance of the four ring-follower gates and the outlet pipes upstream from the ring-follower gates. The intakes for each pair of outlets are protected by a trashrack structure on the upstream face of the dam. General plan and profiles of the river outlets are shown on figures 109 and 110.

(c) *Spillways.*—One spillway is provided on each abutment. Each spillway consists of an approach channel, intake structure, spillway tunnel, and deflector bucket. Discharges are controlled by two 40- by 52.5-foot radial gates in each intake structure. The deflector bucket flips the water downstream from the spillway and away from the canyon to prevent undercutting of the canyon wall. General plans and profiles of the spillways are shown on figures 100 and 101.

(d) *Power Waterways.*—Water is conveyed from the reservoir to the hydraulic turbines by eight 15-foot-diameter penstocks, extending from the upstream face of the dam to the powerplant. The intake to each penstock is protected by a trashrack. A 13.96- by 22.45-foot fixed-wheel gate is provided at the face of the dam for emergency closure and for inspection and maintenance of each penstock. Water from the turbines is collected by the draft tubes and carried to the tailrace. Bulkhead gates are provided at the downstream end of the draft tubes for unwatering the draft tubes. General plan and profiles of the penstocks are shown on figures 129 and 130.

(e) *Powerplant.*—The powerplant is an indoor-type structure with eight generating units, a service bay, a machine shop bay, and a control area located on top of the powerplant over unit bays 1 and 2. Each generating unit has a capacity of 125,000 kilovolt-amperes at 0.9 power factor. The turbines, of the Francis type, are rated at 155,500 horsepower at full gate opening when operating at 150 revolutions per minute under an effective head of 450 feet. The effective head on the turbines may range between 341 and 560 feet.

The control area consists of a control room, cable spreading area, and office space. The control area is designed to provide fallout protection for the operating personnel. Because of the remoteness of assumed targets relative to Glen Canyon, residual radiation from fallout should be very low; therefore, full-time occupancy by the operating personnel of the powerhouse for the usual 14-day period should be unnecessary in the predictable future.

The powerplant structure is of reinforced concrete construction in the substructure and intermediate structure, with a superstructure of exposed structural-steel columns and reinforced concrete wall panels. The general arrangement of the

[2] The Colorado River Compact provides principally for a division of the available water of the Colorado River system between the "Upper Basin" and the "Lower Basin" at Lee Ferry, which is defined as a point on the Colorado River 1 mile below the mouth of Paria River. The nearest stream gage to this point on the Colorado River is at Lees Ferry, which is above the mouth of the Paria River. Lee Ferry, a few miles below the Arizona-Utah boundary, is a natural point of demarcation.

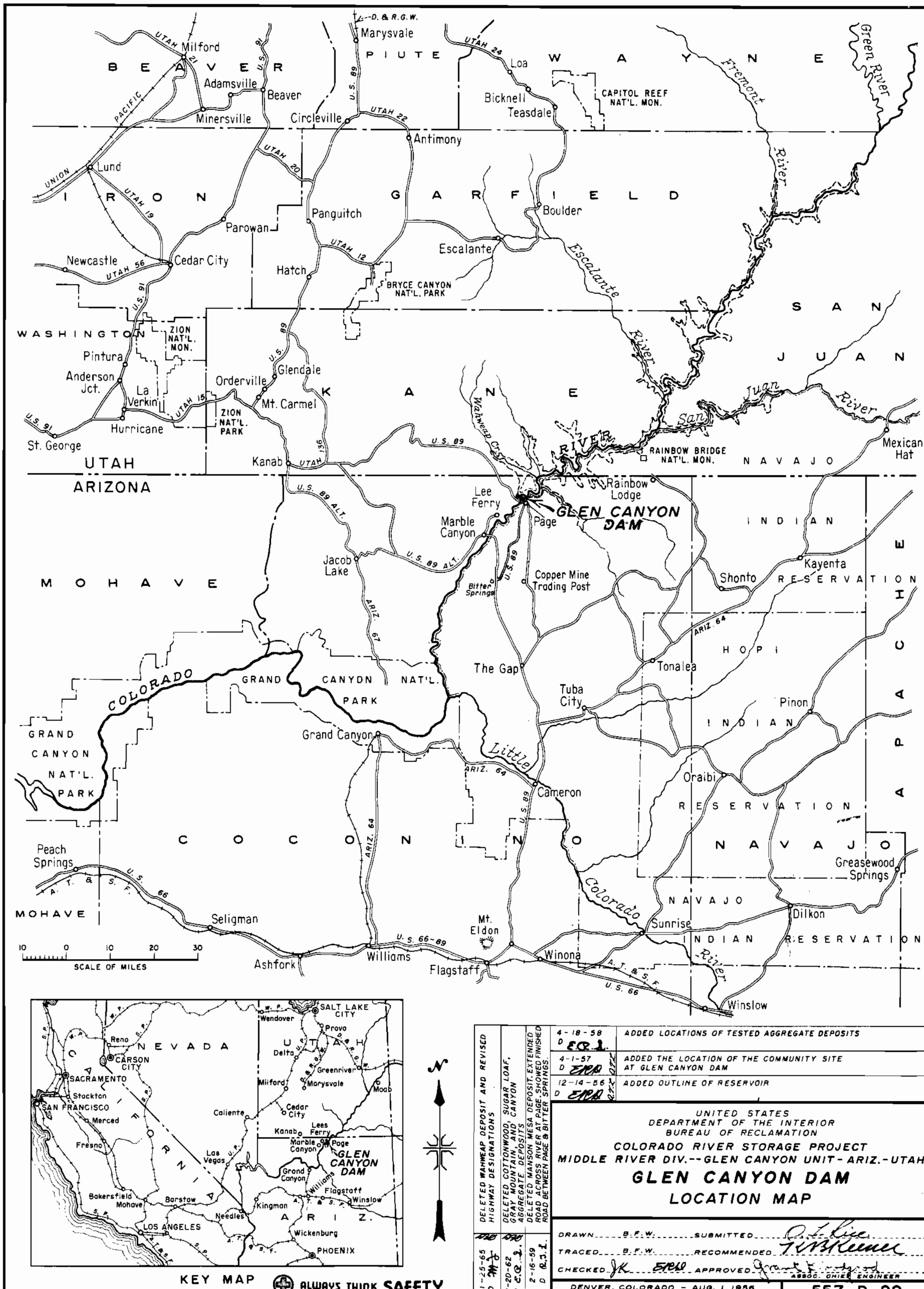

Figure 2.—Glen Canyon Dam location map.

powerplant is shown on figures 150 through 155 and figure 158.

(f) *Switchyard.*—The switchyard is located within a fenced area 1,190 by 473 feet, approximately 850 feet southwest of the right abutment of the dam. The elevation of the switchyard ranges from 3886.00 to 3883.62 feet for drainage purposes. The switchyard is designed to serve loads at 345, 230, and 25 kilovolts initially. The initial equipment includes a 345- to 230- to 25-kilovolt, 300,000-kv.-a. bank of three single-phase autotransformers; a 25-kilovolt regulator; a 25-kilovolt series reactor; a 25-kilovolt grounding transformer; three bays of 345-kilovolt breaker-and-one-half bus; three bays of 230-kilovolt breaker-and-one-half bus; and five bays of 25-kilovolt main and transfer bus. The general arrangement of the switchyard is shown on figure 216.

(g) *Glen Canyon Bridge.*—The bridge across the Colorado River at Glen Canyon Dam is the subject of a prior technical record of design and construction and is available as indicated on the inside of the back cover of this technical record. As an aid to the reader, a portion of that publication has been reproduced and is presented as appendix E.

(h) *Access Roads.*—Owing to the isolation of the Glen Canyon damsite it was necessary to construct an access highway from U.S. Highway No. 89 in the vicinity of Echo Cliffs (Bitter Springs on fig. 2) to the damsite. The nearest railhead was at Flagstaff, Ariz., on U.S. Highway No. 89. The construction of Page, Ariz., as a construction camp and permanent community necessitated building connecting roads to the access highway and to the dam. Access to the dam crest and both spillways was provided by service roads on each abutment which interconnected with the dam access highway. The service road to the powerplant was constructed on the left abutment from a point on the access highway downstream from the Glen Canyon Bridge to the powerplant at the toe of the dam. Owing to the sheer canyon walls, the last approximately 2 miles of service road was constructed in tunnel section. The State of Arizona constructed a road from the vicinity of the west abutment of the Glen Canyon Bridge to the Arizona-Utah State line to provide access from Utah. This road was later reshaped and surfaced by the Bureau and connected to the access highway at Glen Canyon Bridge, providing an all weather road to communities in Utah. A detailed description of each road is given in Chapter X.

5. CLIMATE. The climate at Glen Canyon Dam is typical of the arid plateaus in the western deserts. Summers are hot and dry, with occasional thunderstorms. Winters are dry, with frost at night the general rule. The percentage of sunshine is very high, averaging about 80 percent of the total possible. The relative dryness of the air modifies the effect of the summer heat and winter cold so that the temperature extremes are not too noticeable. High winds and sandstorms occasionally occur during the spring and summer months.

Prior to the construction of the dam, the nearest U.S. Weather Bureau station was at Lee Ferry, Ariz., about 15 miles downstream from Glen Canyon Dam. At Lee Ferry, the rainfall over the 1916-1952 period ranged from 3 to 10 inches per year, with an average of about 6 inches per year. A large part of this rainfall occurred in thunderstorms during the months of July, August, and September. A total annual snowfall of between 3 and 5 inches normally occurs in the area in December and January, although spring snows in March are not uncommon.

The mean annual air temperature at Lee Ferry for the period 1931-1952 was 62.5° F. This compares with the 6-year record at the dam of 61.6° F. at the canyon rim and 64.6° F. at the bottom of the canyon. During the hottest part of the year (usually July), daily temperatures normally range from 73° F. at night to 101° F. during the day at the canyon rim, and from 76° to 105° F. in the bottom of the canyon. During the coldest part of the year (December and January), the daily temperatures normally range from 26° F. at night to 46° F. during the day at the canyon rim, and from 28° to 47° F. in the bottom of the canyon. The average date for the first killing frost is October 29 and for the last killing frost is April 11, making the length of the average growing season 201 days.

6. HISTORY AND SETTLEMENT OF THE AREA. The first white man known to have visited the Colorado River was the Spanish explorer, Hernando de Alarcon. In 1540, while exploring the Gulf of California, he found the mouth of the then unknown river, and ventured up the reddish-brown stream some 150 miles. Two years later the Grand Canyon of the Colorado was discovered by Cardenas. Cardenas never succeeded in descending the sheer walls of the canyon, and other explorers and missionaries who followed him were also discouraged by the seemingly hopeless task of penetrating this section of the canyon. Two centuries passed before a passage was discovered permitting a crossing.

By the treaty concluding the Mexican War in 1848, and by the Gadsden Purchase of 1853, the United States acquired the territories of New Mexico, Arizona, and California. Discovery of gold in California in 1849

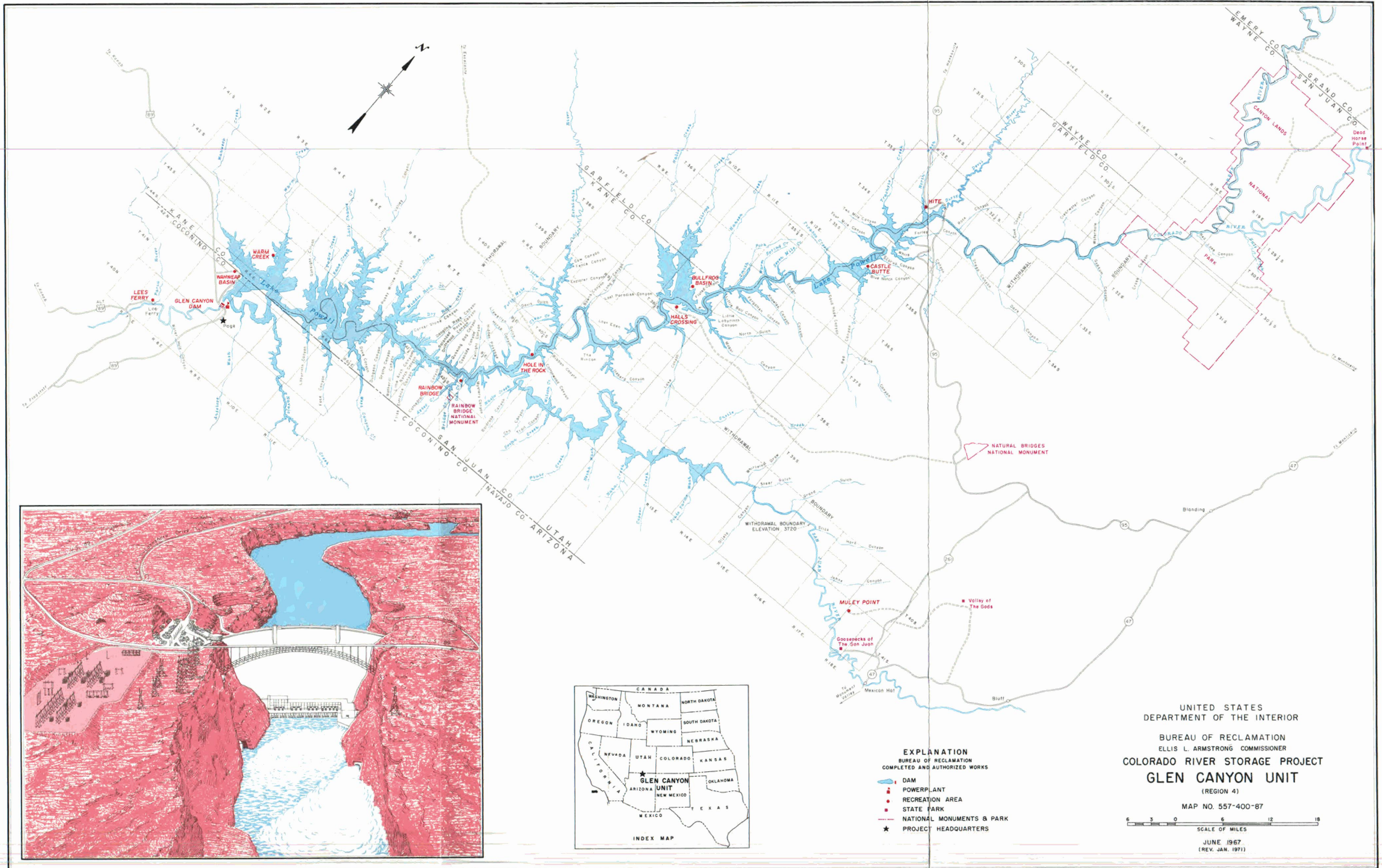

Figure 3.–Glen Canyon Unit location map.

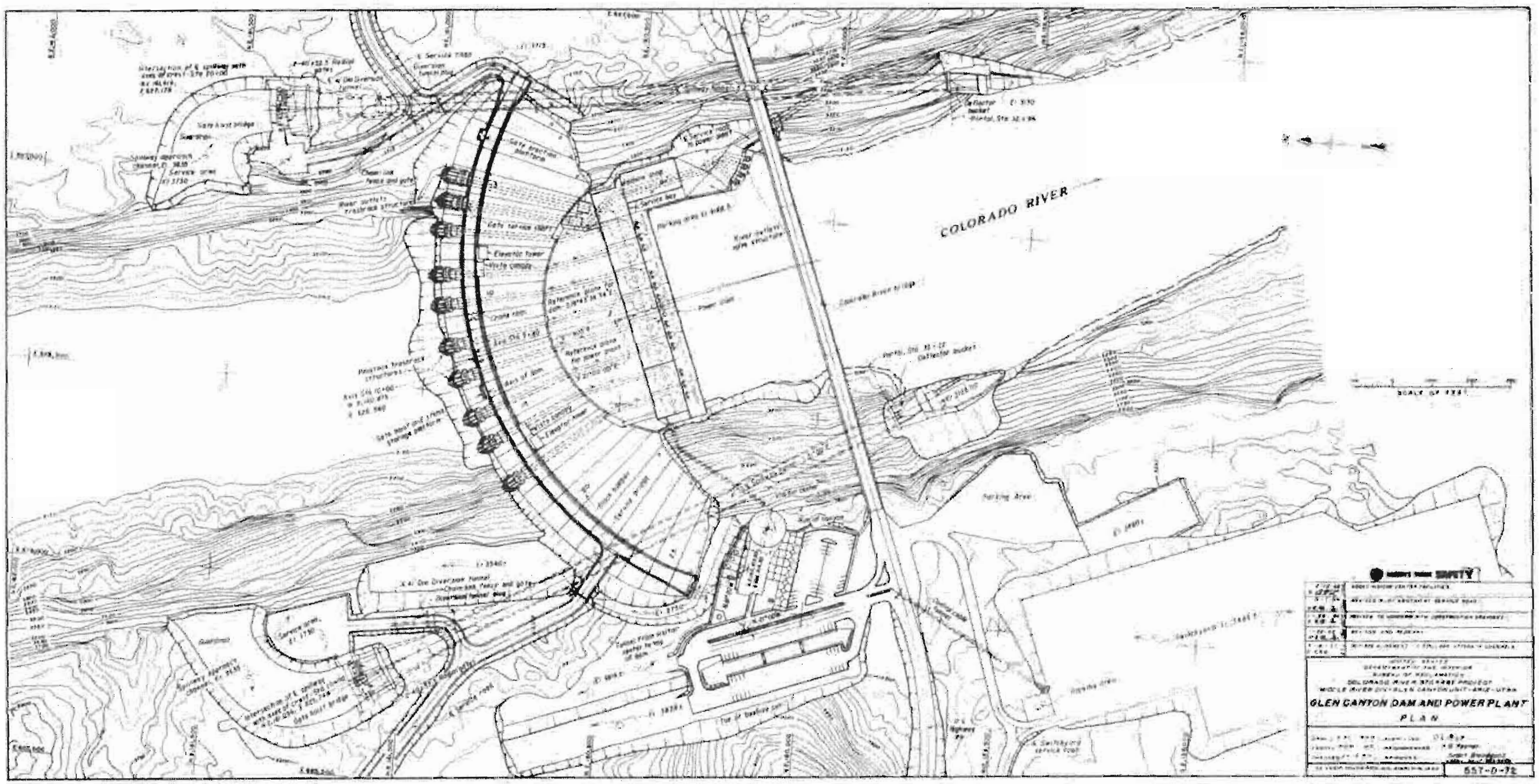

Figure 4.–Glen Canyon Dam and Powerplant–Plan.

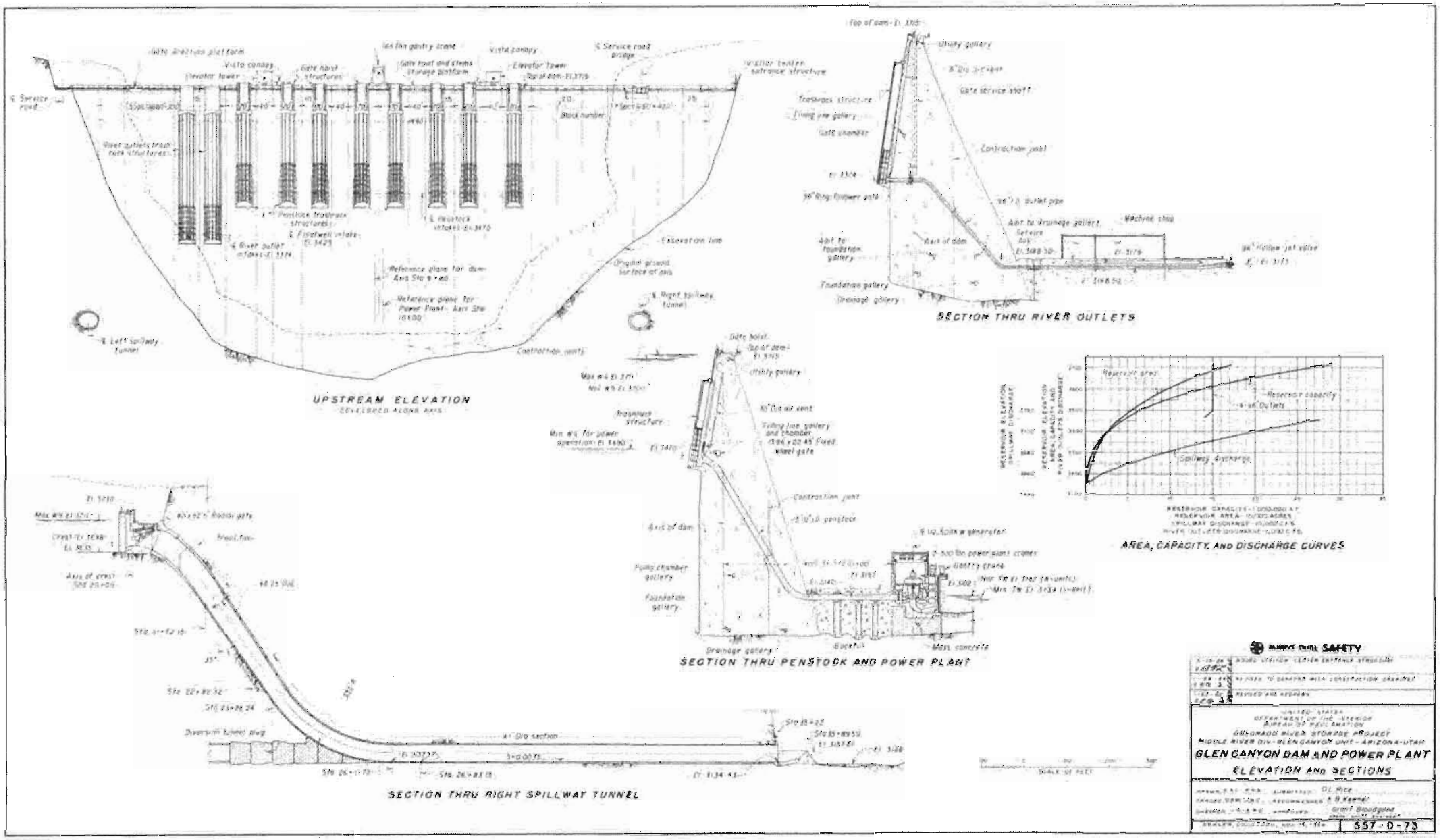

Figure 5.—Glen Canyon Dam and Powerplant—Elevations and sections.

brought hordes of adventurers westward. They poured across the Colorado River at two points. One crossing was near Yuma, Ariz., and the other at Needles, Calif.

With the acquiring of the territory, sentiment grew in the United States that the area should be explored at all costs. In 1857 the War Department dispatched Lieutenant J. C. Ives to the task, instructing him to proceed up the river by boat as far as practicable. He succeeded in going 400 miles up the river to the Black Canyon, present site of Hoover Dam. He reported the region to be valueless.

In 1869 Major J. W. Powell of the Geological Survey succeeded in leading a river expedition down the canyon of the Colorado. His expedition traveled from Green River in Utah to the Virgin River in Nevada, a few miles above where Lieutenant Ives stopped. Powell covered a thousand miles of unknown rapids and treacherous canyons, and became the first white man to gaze up at the sheer walls of the Grand Canyon and live to describe the adventure. Further discussion of Major Powell's investigations is given in section 9.

Following this, efforts were made to investigate methods whereby the river might be used beneficially. The river, annually fed by melting snows in the Rockies, swelled to a raging flood in the spring, then dried to a trickle in the late summer and fall, so that crops were frequently destroyed. Farmers built levees to keep out the river. Even when the levees held, however, crops withered and died during the months when the river ran too low to be diverted into the canals.

The flow of the Colorado River is extremely erratic, ranging from 4 to 22 million acre-feet annually at Lee Ferry. There is a tendency for the high years or the low years to be grouped, thus accentuating problems of river regulation and use. Faced with constantly recurring cycles of flood and drought, the people of the Southwest appealed to the Federal Government to solve the problem. With the establishment in 1902 of the Reclamation Service, engineers began extensive studies of the river in search of a feasible plan for its control. The completion of Hoover Dam in 1936 undoubtedly did more to regulate the erratic flow pattern of the mighty Colorado than any other single item of construction. However, the upper reaches of this river were still more or less uncontrolled. The Glen Canyon Dam was one of the key structures depended upon for additional regulation of this river system.

7. COST SUMMARY. The following tabulation summarizes the total estimated cost of construction of Glen Canyon Dam and Powerplant and appurtenant structures based on information contained in the Final Construction Report. The costs are as of June 30, 1967. A listing of contracts and purchase orders is contained in appendix A.

COST SUMMARY

Land rights	$ 421,876	
Labor by Government forces	394,904	
Construction facilities	905,768	
Construction by contract	178,087,355	
Materials furnished by Government	35,192,407	
Subtotal		$215,002,310
Investigations, engineering, and other costs:		
Investigations	$ 1,560,384	
Engineering and supervision	8,634,019	
Design and specifications	9,669,859	
General services	7,797,749	
Service facilities	2,348,664	
Subtotal		$ 30,010,675
Total		$245,012,985
Less transfers and credits		142,435
Total estimated cost of Glen Canyon Dam and Powerplant and appurtenant structures		$244,870,550