LITTLE COLORADO RIVER BASIN
ARIZONA

PART 1 - WATER RESOURCES & POTENTIAL DEVELOPMENTS
BLUE SPRING AREA

PART 2 - GROUND-WATER RESOURCES
WINSLOW-HOLBROOK AREA

MEMORANDUM REPORT

SEPTEMBER 1971

UNITED STATES DEPARTMENT OF THE INTERIOR
ROGERS C. B. MORTON, SECRETARY
Bureau of Reclamation
Ellis L. Armstrong, Commissioner

LITTLE COLORADO RIVER BASIN
Arizona

PART I

WATER RESOURCES AND POTENTIAL DEVELOPMENTS
Blue Spring Area

PART II

GROUND-WATER RESOURCES
Winslow-Holbrook Area

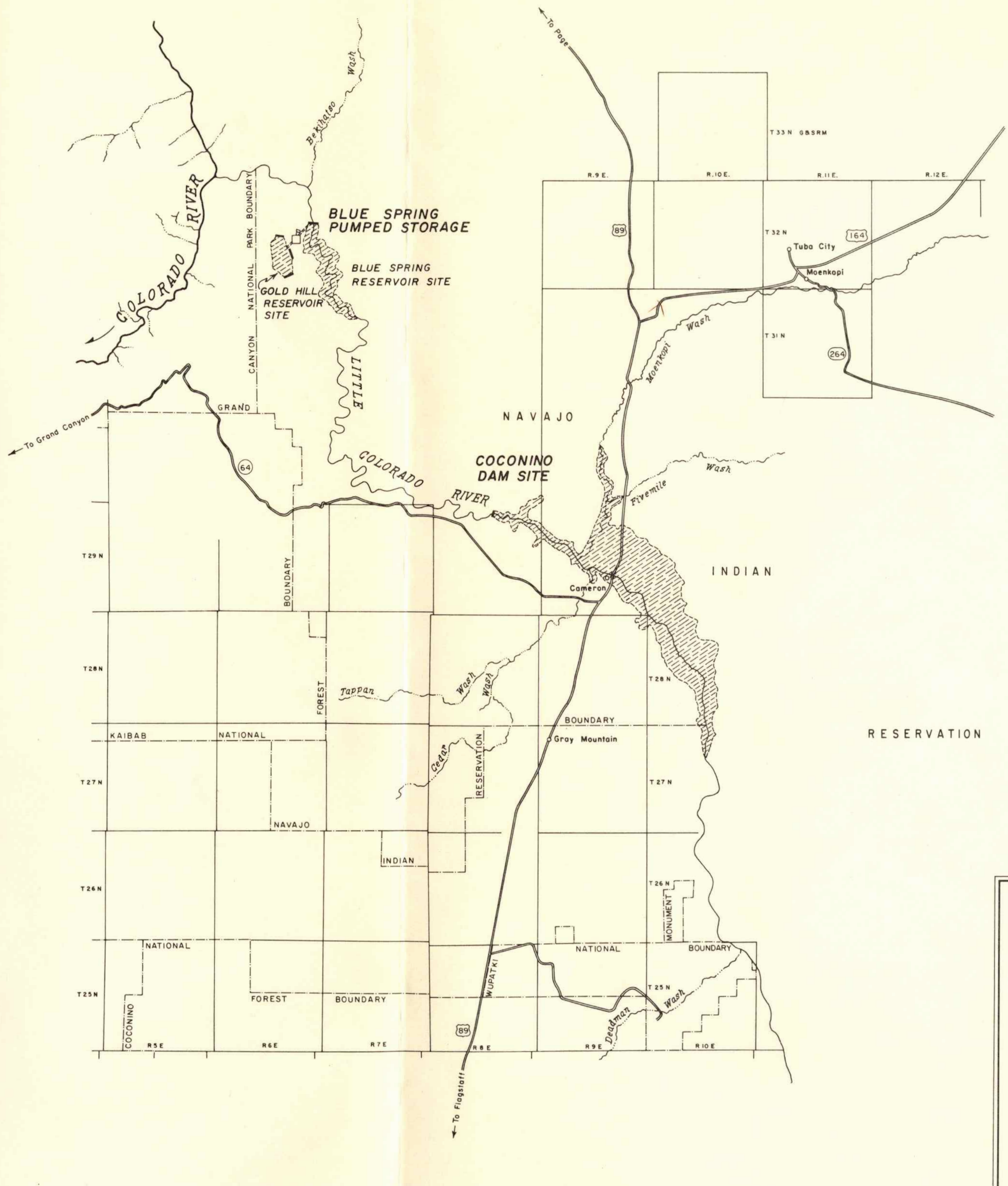
MEMORANDUM REPORT
September 1971

Prepared for Arizona Water Commission

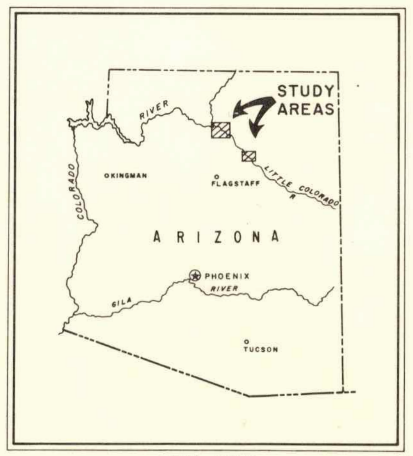
Ellis L. Armstrong, Commissioner
Edward A. Lundberg, Regional Director, Region 3

Bureau of Reclamation

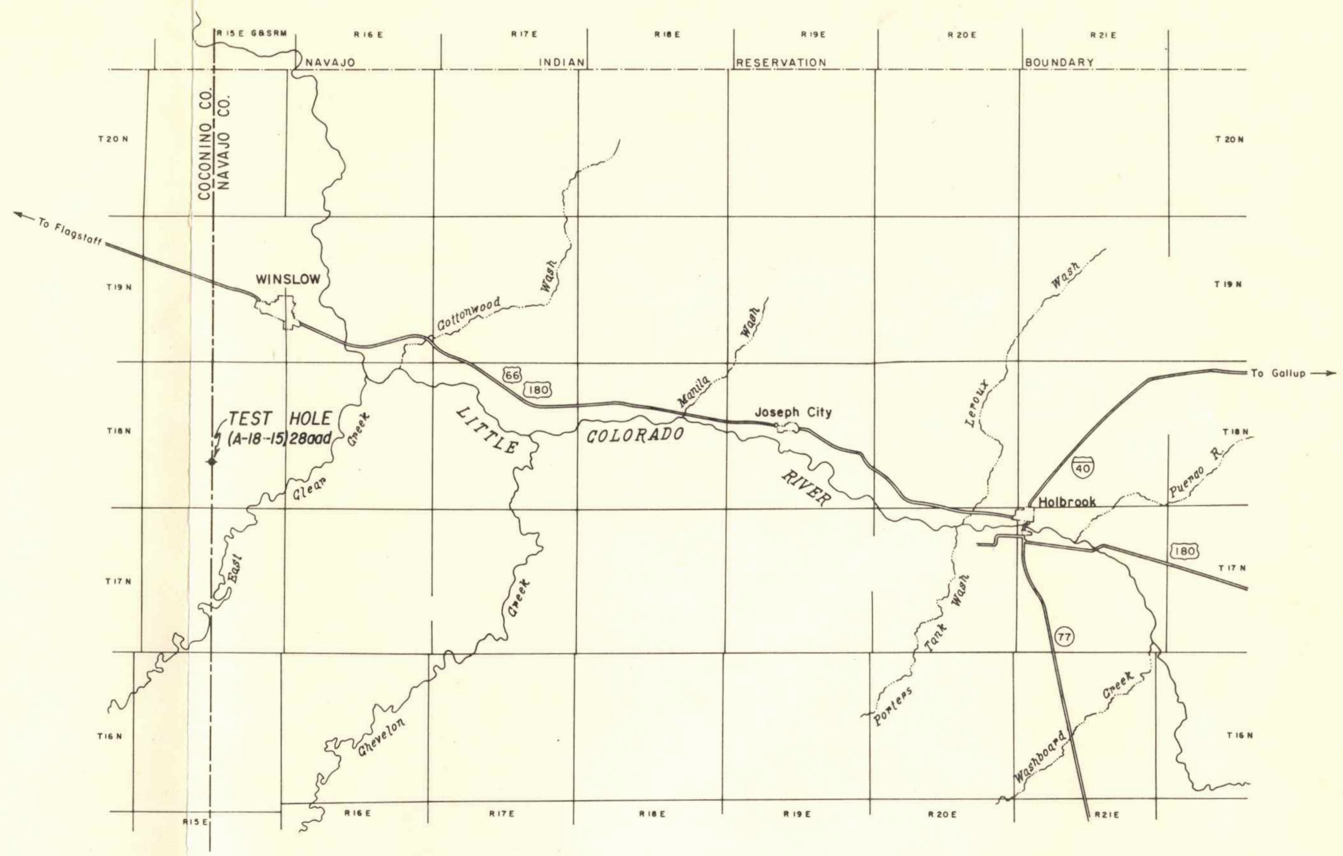
Interior-Reclamation, B.C., Nev.



BLUE SPRING STUDY AREA



KEY MAP



WINSLOW-HOLBROOK STUDY AREA

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LITTLE COLORADO RIVER BASIN

GENERAL MAP

BLUE SPRING STUDY AREA
WINSLOW-HOLBROOK STUDY AREA

MAP NO. 1224-300-1

5 0 5 10 15 20
SCALE OF MILES

MAY 1971

INTERIOR—RECLAMATION, B.C., NEVADA — 9-71

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CHAPTER I

SUMMARY

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CHAPTER 1. SUMMARY

A. Introduction

This memorandum report was prepared for the State of Arizona under Contract No. 14-06-300-2077, dated December 11, 1968. It consists of two parts. The first part presents an independent evaluation of the Little Colorado River, Blue Spring water resources, and summarizes potentials for its ultimate development and use. The second part presents a preliminary evaluation of the ground-water resources in the Winslow-Holbrook area of the potential Mogollon Mesa Project, Arizona.

B. Location

1. Blue Spring Area. This area is located on the Navajo Indian Reservation, Coconino County, Arizona, about 25 miles northwest of Cameron and about 65 miles north of Flagstaff. Blue Spring, the largest of a group of springs, is located in the nearly inaccessible gorge of the Little Colorado River about 13 river miles from the confluence of the Little Colorado River and the Colorado River.

In the Blue Spring area, the Little Colorado River flows through a half-mile-deep, mile-wide meandering gorge carved in sandstone, limestone, and shale. Typically, the canyon walls are a series of near-vertical cliffs in massive limestone and sandstone separated by steep slopes or benches in shale, siltstone, or thin-bedded sandstone. A narrow inner gorge occurs where the Redwall limestone forms the lower canyon walls. The canyon rim above Blue Spring can be reached by vehicle over trails from Cameron and State Highway 64. The canyon bottom can be reached by rugged foot trail from the rim, or by helicopter. Gold Hill, a prominent landmark, is about 2½ miles west of the gorge rim above Blue Spring. The Gold Hill Reservoir site is located on this hill.

The study area is shown on Map 1224-300-1 (Frontispiece). Photograph P57-300-9847 shows Blue Spring at River Mile 13.

2. Winslow-Holbrook Area. This study area is located in Navajo County, Arizona. It lies along the Little Colorado River at the base of the Mogollon slope, a physiographic feature of the Colorado Plateau, in the vicinity of Winslow and Holbrook, Arizona. The study area is shown on Map 1224-300-1 (Frontispiece).

C. Authority for the Report

This report was prepared under the provisions of Federal Reclamation Laws (Act of June 17, 1902, 32 Stat. 388, and acts amendatory thereof or supplementary thereto), and particularly the Act of March 4, 1921, and under terms of Contract No. 14-06-300-2077 between the United States and the Arizona Interstate Stream Commission, dated December 11, 1968.

D. Purpose and Scope

The reconnaissance investigations of Blue Spring study area were conducted to evaluate the possible development of the Blue Spring water resource for the production of hydroelectric power by a pumped-storage project. Consideration was also given to the use of the

Bureau of Reclamation Photo

Photograph P57-300-9847

LITTLE COLORADO RIVER - BLUE SPRING (Mile 13) water from Blue Spring as a source of cooling water for fossil fuel thermal powerplants.

The purpose of the Winslow-Holbrook area investigations was to obtain data on the quality of the ground-water aquifer that underlies the Mogollon slope. A deep ground-water test hole was drilled south of Winslow. This test hole was the first of several planned to expand the Mogollon Mesa investigations to include an evaluation of local and regional aquifers in the Winslow-Holbrook area. Data obtained from this hole and others will be used to determine the long-range potential for ground-water development for municipal and industrial use in the area and if such use would have a discernible effect upon Blue Spring.

CHAPTER II

WATER RESOURCE APPRAISAL

Blue Springs Area

CHAPTER II. WATER RESOURCE APPRAISAL
Blue Spring Area

A. <u>General</u>

The Little Colorado River discharges into the Colorado River (River Mile 61.4) at the northeastern boundary of the Grand Canyon National Park, and is the major source of inflow into the river within Arizona. The historic flow of the Little Colorado River at its mouth is estimated to average about 310,000 acre-feet per year (period of record 1947-1967). Of this total, springflow originating from an 11.6-mile reach of river between Miles 3.0 and 14.6 produces consistently between 155,000 and 170,000 acre-feet per year, or about half the average annual outflow of the Little Colorado River Basin. Discharge from springs in the lower section of the river supports a nearly constant base flow at the mouth that averages about 223 cubic feet per second, or 160,000 acre-feet per year.

Collectively, the above springflow activity, consisting of several large springs and numerous groups of smaller springs and seeps, is referred to as "Blue Spring" (River Mile 13).

In evaluating possible development of the Blue Spring water resource, about 12 man-days were spent in the field to delineate more precisely the respective locations and the hydrogeologic correlation of the major springflow areas. In addition, horizontal and vertical control surveys were established on the rim of the canyon and elsewhere in the study area for use in topographic mapping of reservoir sites and to establish the elevation and coordinate location of several major springs on the canyon floor.

The Blue Spring flows, averaging about 160,000 acre-feet per year, represent the single largest firm source of water remaining unappropriated within the State of Arizona. These flows presently contribute to the Colorado River main stream water supply which is stored in Lake Mead and becomes available for diversion and use by Lower Basin water users in California, Nevada, Arizona, and Mexico.

Because the quality of Blue Spring water is poor, the overall quality of Colorado River main stream water would be slightly improved by appropriation and direct diversion of these waters. If the flows and salts from these springs were removed from the river system, the salinity below Hoover Dam would be reduced by about 28 parts per million. The main disadvantage of such direct diversion would be the quantitative effect on the water supply available for other present and proposed Lower Basin water users, particularly the Central Arizona Project. During low water years prior to Colorado River augmentation, the direct diversion and use of Blue Spring water would, in effect, decrease Central Arizona Project diversions.

B. Hydrogeology

Blue Spring and other springs along the south side of the Colorado River are the principal outlets for ground water moving from the east and south. From the primary recharge areas along the periphery of the Black Mesa Basin and the Mogollon Rim, the water gradually moves downward through structural discontinuities in the sedimentary and volcanic rocks and accumulates in the interconnected joints, fault zones, and solution caverns within the Redwall and Muav limestones. The water emerges under pressure where canyons penetrate the water-bearing zones.

The springflow emerges from numerous openings in two relatively well-defined zones. The principal zone, which includes the main spring at Mile 13, occurs in the Mile 11.5 to Mile 15.0 interval. A secondary zone that occurs between Mile 3 and Mile 7, near the mouths of Big Canyon and Salt Trail Canyon, produces a small portion of the total flow. Measurements near the mouth of the Little Colorado River between 1952 and 1967, as reported by the Geological Survey, indicate the base flows are consistently in the 217 to 230 cubic feet per second range.

In the upper spring zone, seeps and springs occur in the top 200 feet of the Redwall limestone. The canyon first penetrates the Redwall at about Mile 15 and seeps first appear along the canyon floor in that vicinity. Some seeps and large springs occur along a large fault through the canyon, but others, including the main spring, are from joints or fractured zones with no visible relationship to faults. The large springs are all on the canyon floor or at the base of the limestone walls. Some of the smaller springs and seeps occur higher on the limestone walls where they commonly have formed travertine deposits. Relic spring activity is indicated throughout the area by solution channels and dry travertine deposits on the canyon walls near the top of the Redwall limestone. It is probable that these relic springs became inactive as the canyon was cut deeper into the limestone, draining the upper part of the formation and gradually causing the spring zone to move upstream.

The lower spring zone (Mile 3 to Mile 7) comprises the bottom of the Muav limestone and the top of the Bright Angel shale. Some water flows from the mouth of Big Canyon and may originate in the Redwall limestone.

C. Water Quality

The quality of the Blue Spring water is of great significance to economic development of this water resource. As it emerges from the springs, it is clear, salty, slightly acidic 1/, and 65 degrees to 70 degrees Fahrenheit. It is typically sodium chloride water, with secondary concentrations of calcium and bicarbonate. Loss of pressure and rise in temperature in the stream channel apparently cause the escape of carbon dioxide and the precipitation of calcium carbonate and an increase in the pH to slightly alkaline. Precipitation is first indicated by clouding and increasing blueness of the water within a mile downstream from Blue Spring. The typical blue color is apparently not due to chemical pigmentation, because the water appears milky under some light conditions. The color

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1/ From United States Department of the Interior, Geological Survey published records.

change may be due to refraction of light from the fine particles of white precipitate in suspension. Below Mile 11, precipitation is so heavy that the stream bottom is covered by a fine white mud, and hard travertine covers every object long exposed to the water. Between Mile 11 and Mile 5, all rapids are travertine dams or a maze of crescent-shaped reefs arranged in stairstep fashion across the channel. Locally, remnants of old breached travertine dams and travertine ledges on the canyon walls stand as high as 30 feet above the channel floor. Below Mile 3 or 4, precipitation has diminished sufficiently so that little hard travertine has been deposited and boulder-caused rapids again appear. Some white precipitate in suspension, however, is carried on downstream into the Colorado River. From observations made during the June 1969 trip, the quantity of precipitate in much of the stream channel downstream from Mile 11 was covered by one to two inches of white calcareous mud overlying red mud which was probably transported by the last snowmelt runoff in March or April. Chemical analyses on surface flow show a downstream decrease in calcium and bicarbonate. Calculations based on the limited data available indicate that about 50,000 tons per year of $CaCO_3$ precipitate out between River Miles 12.2 and 1.9 of the Little Colorado River. Much of this settles as fine mud and is probably removed periodically by floods. The figure does not include the precipitate that is carried in suspension out into the Colorado River during normal flow. The possibility of deleterious effects of this precipitate on pumping equipment and reservoirs should be thoroughly evaluated.

It is interesting to note that in this section there is an increase in the sodium and chloride ions that is equal to the decrease in the calcium and bicarbonate ions.

Tables 1 and 2 show the summary of chemical analyses of samples taken by the Bureau of Reclamation in the Blue Spring area on June 19, 1965, and on May 22, 1969, respectively. The Geological Survey has also taken periodic samples in the Blue Spring area.

Table 1
CHEMICAL ANALYSES 1/
ALONG THE COLORADO RIVER BETWEEN LEES FERRY AND THE MOUTH OF SPENCER CANYON
Blue Spring Area, Arizona

Station name or number							
U.S. Salinity Laboratory water sample number			29031	29032	29033	29034	29035
Collector's number			10	11	12	13	14
Date collected: 6-19-65							
Analysis Schedule Number 1							
Conductivity, $EC \times 10^6 @ 25^\circ C$.			3320	5810	6770	6820	32,900
Sodium-adsorption ratio (SAR)			11	18	21	20	70
Soluble sodium percentage (SSP)			71	77	80	78	84
Boron	B	ppm	.34	.21	.15	.16	28.0
Dissolved Solids		taf	2.56	4.69	5.53	5.64	33.0
Dissolved Solids		ppm	1882	3446	4068	4150	24,260
pH			8.0	7.8	7.9	7.8	7.4
Silica	SiO_2	ppm	13	10	9	10	12
Calcium+Magnesium	Ca+Mg	meq/l					
Calcium	Ca	meq/l	3.54	7.36	7.86	9.43	24.55
Magnesium	Mg	meq/l	5.60	5.70	5.50	5.70	21.21
Sodium	Na	meq/l	23.12	44.80	55.34	54.86	334.2
Potassium	K	meq/l	.20	.12	.16	.16	19.04
Sum of Cations		meq/l	32.46	57.98	68.86	70.15	399.0
Carbonate	CO_3	meq/l	trace	0	0	0	0
Bicarbonate	HCO_3	meq/l	6.30	7.75	7.45	8.95	31.20
Sulfate	SO_4	meq/l	2.86	4.54	5.24	5.18	62.41
Chloride	Cl	meq/l	23.50	45.75	55.95	56.00	307.2
Fluoride*	F	meq/l	trace	trace	.01	trace	.03
Nitrate	NO_3	meq/l	.01	trace	trace	trace	trace
Sum of Anions		meq/l	32.67	58.04	68.65	70.13	400.8

1/ Water samples were collected by the Bureau of Reclamation on June 19, 1965. The water samples were analyzed by the United States Department of Agriculture, Agriculture Research Division, United States Salinity Laboratory, Riverside, California, on August 30, 1965.

*F (ppm) = F (meq/l) x 19.00
Water Sample 29031. Collector's No. 10 Blue Spring
Water Sample 29032. Collector's No. 11 Little Colorado River above Blue Spring
Water Sample 29033. Collector's No. 12 Little Colorado River right bank, one mile below Blue Spring
Water Sample 29034. Collector's No. 13 Little Colorado River right bank, one mile below Blue Spring
Water Sample 29035. Collector's No. 14 Right bank "Stewpot" "Sipapu"

Table 2
CHEMICAL ANALYSES OF LITTLE COLORADO RIVER 1/
River Mile 1.9 to 15.0
Blue Spring Area, Arizona

Water Sample Number			31858	31859	31860	31861	31862	31863
River Mile			1.9	15.0	14.5	13.2	13.0	12.2
Conductivity, $ECx10^6$@25°C.			4420	1960	6240	4750	4080	4220
Sodium-adsorption ratio (SAR)			16	10	17	15	8.2	10
Soluble sodium percentage (SSP)			79	78	74	77	58	66
Boron	B	ppm	.36	.24	.22	.21	.31	.31
Dissolved Solids	DS	taf	3.35	1.47	4.94	3.62	3.07	3.23
Dissolved Solids	DS	ppm	2464	1084	3635	2663	2260	2378
pH			7.7	8.1	7.4	7.7	7.2	7.3
Silica	SiO_2	ppm	17	12	15	14	18	17
Calcium	Ca	meq/1	3.63	2.96	9.77	6.48	10.89	8.59
Magnesium	Mg	meq/1	5.30	1.07	6.00	3.99	7.26	5.68
Sodium	Na	meq/1	33.24	14.35	46.38	35.12	24.75	27.93
Potassium	K	meq/1	.17	.09	.18	.15	.13	.16
Sum of Cations			42.34	18.47	62.33	45.74	43.03	42.36
Carbonate	CO_3	meq/1	0	trace	0	0	0	0
Bicarbonate	HCO_3	meq/1	5.06	3.60	9.98	6.83	14.49	10.55
Sulfate	SO_4	meq/1	3.49	1.83	4.64	3.69	2.97	3.25
Chloride	Cl	meq/1	33.41	12.77	47.48	35.22	24.99	27.94
Fluoride	F	meq/1	.01	.03	.01	.01	.01	.01
Nitrate	NO_3	meq/1	.01	.01	.01	.01	.01	trace
Sum of Anions			41.98	18.24	62.12	45.76	42.47	41.75

1/ Water samples collected by Bureau of Reclamation on May 22, 1969. Water samples analyzed by the United States Department of Agriculture, Agriculture Research Division, United States Salinity Laboratory, Riverside, California, on June 27, 1969.

Locations and Descriptions

W.S. No. 31858 LITTLE COLORADO RIVER - BLUE SPRING STUDIES No. 1. From right bank, Little Colorado River at Mile 1.9. Water temperature 63.5°F. at 8:30 a.m. Water was milky in appearance, discharge: 250-300 cfs. Sample represents Little Colorado River discharge into Colorado River.

W.S. No. 31859 LITTLE COLORADO RIVER - BLUE SPRING STUDIES No. 2. From right bank, Little Colorado River at Mile 15.0. Water temperature 60°F. at 8:30 a.m. Water very brown and murky, discharge: 6-8 cfs. Sample represents Little Colorado River above all spring activity.

W.S. No. 31860 LITTLE COLORADO RIVER - BLUE SPRING STUDIES No. 3. From springs emitting from above right bank of Little Colorado River at Mile 14.5. Water temperature 65°F. at 9 a.m. Water clear but very salty to taste. Springs emerged as many small seeps from under rocks and in floor of flood plain ranging from 5-10 feet above surface of Little Colorado River. Estimated discharge: 0.5 cfs. Sample represents uppermost spring activity.

W.S. No. 31861 LITTLE COLORADO RIVER - BLUE SPRING STUDIES No. 4. From left bank, Little Colorado River at Mile 13.2. Water temperature 65°F. at 10:05 a.m. Water less brown in appearance than upstream, discharge: 30-40 cfs. Sample represents Little Colorado River just above Blue Spring.

W.S. No. 31862 LITTLE COLORADO RIVER - BLUE SPRING STUDIES No. 5. From large upper spring in series called, collectively, Blue Spring on left bank of Little Colorado River at Mile 13.0. Springs sampled emerge from left canyon wall at junction with canyon floor about river water surface. Water temperature 64.5°F. at 10:15 a.m. Spring water very clear and only slightly salty to taste. Discharge: 5 cfs, approximately. Sample should be representative of Blue Spring proper.

W.S. No. 31863 LITTLE COLORADO RIVER - BLUE SPRING STUDIES No. 6. From right bank of the Little Colorado River near damsite at Mile 12.2. Water temperature 67°F. at 11:45 a.m. Water very blue in appearance but still cloudy. Discharge: 150-175 cfs. Sample represents flow in the Little Colorado River below Blue Spring

ppm - Parts per million
taf - Tons per acre-foot
meq/1 - Milliequivalent per liter

CHAPTER III

POTENTIAL DEVELOPMENTS

Blue Springs Area

CHAPTER III. POTENTIAL DEVELOPMENTS
Blue Spring Area

The best potentials for development of the Blue Spring water supply appear to be related to the production of power. Other industrial uses might be feasible if a major industrial complex were to locate in the Blue Spring area. However, its remoteness from any existing population center or industrial or irrigation development appears to preclude other uses in the foreseeable future. Also, extensive use of this water supply for other purposes is probably precluded because of its poor quality.

Favorable geographic and topographic characteristics of the area indicate that one possible future use of Blue Spring water could be for the production of hydroelectric power by a pumped-storage development. Another possible use could be as a source of cooling water for local fossil fuel thermal powerplants. This report is limited to a discussion of the potentials for development of the Blue Spring water resource for these purposes.

A. Basic Plan of Development

The basic Blue Spring pumped-storage plan would provide for an offstream hydroelectric development to furnish peaking capacity for the Arizona and Southwest power market area. Although its major function would be peaking generation, the Blue Spring development could also provide substantial reserve in case of an emergency. This spinning reserve could be on the line in a matter of minutes to complement and back up fossil fuel thermal powerplants in the market area.

Although not studied as part of this report, the net revenues from the sale of power, either as a State or Federal project, could be incorporated into a "development fund" to assist in the future payment of needed water resource facilities in Arizona.

The basic pumped-storage plan would include an inner gorge dam and reservoir on the Little Colorado River at River Mile 9.8, an underground powerhouse, and an upper storage reservoir located at the foot of Gold Hill. Gravity flow tailrace tunnels would connect the lower inner gorge dam with the underground pumping-generating plant. Connection between the powerhouse and the upper reservoir would be by means of underground pressure penstocks (vertical shafts) and an open concrete-lined canal section. Coconino Dam 1/ at River Mile 48.5 on the Little Colorado River would be required to provide sediment and debris control.

The Blue Spring pumped-storage plan was studied for six different generating capacities ranging from 500 to 4,000 megawatts and as Federal and non-Federal projects. The studies did not consider transmission systems to load centers, and all costs are on an "at-plant" basis.

B. Water Supply

Based on periodic discharge measurements since 1952, the construction of an inner gorge dam at Mile 9.8 would control about

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1/ Coconino Dam was investigated as an integral feature of the Bridge Canyon Project, Arizona, Pacific Southwest Water Plan, January 1964.

90 percent of the present Blue Spring area inflow, or about 145,000 acre-feet per year. In addition, the historic flow of the Little Colorado River near Cameron averages about 152,000 acre-feet per year (1947-1968). Although most of this surface supply comes during the spring runoff period, some could be retained in Coconino and the inner gorge reservoir (Mile 9.8) for blending and for makeup purposes. No hydrologic studies were made to determine an annual yield of the surface runoff by construction of these two reservoirs.

Water losses from reservoir seepage and evaporation and by possible reduction of the Blue Spring flow (see "Site Geology, Inner Gorge Dam and Reservoir") could be made up from the natural flow of the springs and by controlled releases from Coconino Reservoir.

Also, refer to the section on "Water Resource Appraisal" for information relating to water supply.

C. Field Surveys

The Geological Survey third order horizontal control was used to establish eight control points on the Little Colorado River rim in the Blue Spring area. These points were used to establish fourth order horizontal and vertical control of the major spring groups in the study area. The approximate river mile, elevation, and coordinate location of the major springs are as follow:

Spring No.	River Mile	Elevation	Coordinates	
			N	E
SM-1	14.6	3196.76	1,858,421.4	568,006.3
SM-2 (Blue Spring)	13.0	3156.99	1,861,800.6	566,081.5
SM-3	12.8	3150.70	1,862,765.4	566,408.4
SM-4	12.8	3147.79	1,863,072.9	566,826.9

Four additional control points of third order accuracy were also set about one mile west of the Blue Spring area near Gold Hill to control topographic mapping, scale 1" = 400', for the Gold Hill Reservoir area.

D. Regional Geology

The study area is within the Kaibab syncline, which lies to the east of the Kaibab uplift, and to the west of the Echo Cliffs uplift, structural features of the Colorado Plateau of north-central Arizona. The plateau in this area is composed of a thick sequence of relatively flat-lying sedimentary rocks. The strata are locally deformed by folds and high-angle faults trending mostly northeast to northwest. Because of the uplift in the Grand Canyon area to the west, the plateau surface slopes gently to the east, corresponding to the formational dip of a few degrees.

On a regional basis, the faulting in the Blue Spring area is significantly more intense than elsewhere on the plateau. It is assumed that these structural features have influenced the magnitude of flows from Blue Spring.

E. Site Geology

1. Inner Gorge Dam and Reservoir. A dam at Mile 9.8 would be in the narrow inner gorge carved into the Redwall limestone. The walls of the gorge are vertical cliffs rising 300 to 400 feet from the canyon floor. The walls up to a proposed spillway elevation of 3275 feet are massive limestone with no conspicuous weaknesses such as bedding planes, joints, or caverns. The massive limestone probably extends 100 to 200 feet below the canyon floor. Stream deposits and talus, with travertine cementation, cover the valley floor and probably extend to depths of 10 to 20 feet. Superficially, it appears that foundation conditions are adequate for a concrete thin-arch dam with overflow spillway.

The reservoir area would be partly in the cavernous, spring-producing upper part of the Redwall limestone between about Mile 11.5 and Mile 15.0. Above Mile 15, the reservoir would be entirely in the shale and sandstone of the Supai formation. A near-vertical normal fault cuts across the canyon at several places between Mile 11.5 and Mile 16.5. Where exposed in the limestone, the fault is a zone of closely spaced joints and fractures with significant solution features.

This inner gorge reservoir site presents two problems. First, the impoundment of reservoir water over the springs would tend to reduce inflow and force the water to find new outlets downstream of the dam.

The second problem relates to the inherent liabilities of a reservoir in a limestone environment. The relic springs, solution channels, and fault zones that are conspicuous in the area would possibly cause excessive seepage losses.

Extensive investigations would be required to determine the effects of the imposed reservoir on streamflow characteristics and reservoir losses.

2. Upper Dam and Reservoir (Gold Hill). The Gold Hill Reservoir site on the canyon rim is within an elongated valley, flanked on the east and west by rolling hills and ridges about 100 to 200 feet above the valley floor. The valley is drained by three channels to the north, south, and east which empty into the Little Colorado River Gorge.

The site, within the Kaibab limestone, is comprised mostly of thick-bedded sandy limestone, with lesser amounts of calcareous sandstone and chert that dip to the east at about three to five degrees.

Side slopes in the reservoir area are about half rock outcrop and half slopewash or thin residual soil; the valley floor is covered with bouldery, silty sand that is estimated to average at least three feet in thickness. Fault zones are commonly filled with calcite. No sink holes are apparent, and two small existing reservoirs in the area appear to be functional.

Although no potential leakage problems are apparent, the site is suspect because of being in faulted limestone. For this preliminary design, reservoir lining was therefore included in the estimate. No major foundation problems are expected at the site.

3. Water Conveyance Structures. Water would flow between the upper and lower reservoir through a canal-shaft-tunnel system. The canal would extend from the upper reservoir to vertical shafts on the rim of the canyon. The shafts would extend to an underground pumping-generating plant at about stream level. Horizontal tunnels would convey water between the plant and the lower reservoir.

The canal would be entirely in Kaibab limestone, with a maximum cut of about 100 feet. Rock excavation methods would be required. Canal side slopes could stand vertically and benches should be provided at intervals of 20 to 30 feet. Lining should be provided to prevent leakage in jointed zones and to improve flow characteristics.

The vertical shaft system would be in limestone and sandstone, with lesser amounts of shale. It would bottom out in massive limestone. Conventional large-diameter drilling techniques could satisfactorily handle the excavation, and no significant support problems are expected. A liner would be required to prevent leakage and scour.

The tunnel system and underground pumping-generating plant would be in Redwall limestone. The rock is competent and typically intact. Rock excavation methods would be required. High flows of water could be encountered in joints and solution cavities during excavation. No significant support should be necessary, although the system should be lined to prevent excessive seepage losses and intermittent groundwater inflows.

4. Access Roads and Tunnels. Access would consist of a road over the plateau from Cameron to the canyon rim and to the upper reservoir site. The route is over rolling terrain where a large amount of cut and fill would be required. Excavation would be largely in limestone. Cut slopes should stand vertically if presplit.

Access from the canyon rim to the canyon floor would be by tunnel, with a few short open reaches between tunnel segments. The tunnel route would penetrate most of the stratigraphic section from Kaibab limestone through the Supai formation, and the rock types would be largely limestone and sandstone, with lesser amounts of shale.

Tunneling conditions would vary considerably between formations, but no major problems are expected. An estimated 75 percent would require no to light support with rockbolting, and 25 percent would require moderate to heavy support. No significant water or gas should be encountered.

5. Coconino Dam Site 1/. Geological conditions are favorable for the construction of a concrete structure at Coconino Dam site.

The dam would rest on Coconino sandstone and the overlying Kaibab limestone. Compression tests made on cores of both rocks indicate that they exhibit strength far in excess of that required

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1/ Phoenix Office of Project Planning; June 1948; Preliminary Report on Geology of the Coconino Dam site.

for a dam of the size contemplated. No serious structural weaknesses are present in the rock at the damsite. Joints that are weathered and open where exposed become tight generally a few feet back from the surface.

F. Construction Materials

Concrete aggregate and other soil materials are in short supply in the area. The only known natural source of sand and gravel for concrete is about 35 miles away in the vicinity of Cameron. River deposits there have been investigated and found suitable for the potential Coconino Dam. Crushed rock aggregate could be obtained from Redwall or Kaibab limestone at or near the potential project site.

Soil deposits suitable for earthfill and soil cement are few and thin. The Gold Hill Reservoir site and similar valleys to the west, directly north and south of Gold Hill, are floored with silty sand that could probably be used. There are an estimated 5 to 10 million cubic yards available. No other significant soil deposits are known within practical haul distances. Rockfill could be quarried at or near the site. For the dikes at the Gold Hill site, the most practical quarry sites would be in the Kaibab limestone, which could yield limestone and sandstone in a range of sizes up to a few feet in diameter.

G. Physical Features

Map 1224-314-4 shows plan and profile layout of physical features of the Blue Spring pumped-storage unit. Photograph P57-300-9844 shows the Gold Hill Reservoir site (upper reservoir), and the Little Colorado River gorge in the area of the inner gorge damsite and pumping-generating plant site.

1. Inner Gorge Dam (Lower Reservoir). An inner gorge dam would be required at Mile 9.8 on the Little Colorado River about three miles downstream from Blue Spring to contain the lower reservoir. The dam would be a thin-arch concrete design, with an uncontrolled overflow spillway. The height of the dam above streambed would be about 215 feet and the crest length 250 feet. The crest of the spillway would be at elevation 3275, giving an active conservation capacity of 25,000 acre-feet. The lower reservoir would operate with an 80-foot fluctuation.

The dam was designed to pass a maximum flood of 520,000 cfs 1/ plus diversions through the powerplant which could vary from about 3,400 cfs for a 500-megawatt plant to 27,000 cfs for a 4,000-megawatt plant.

2. Gold Hill Dams and Reservoir. This reservoir would be formed by constructing three rock-filled dams, with crest elevation 5405, across the open ends of a natural basin located near the base of Gold Hill. Since the drainage area is small, diversion structures

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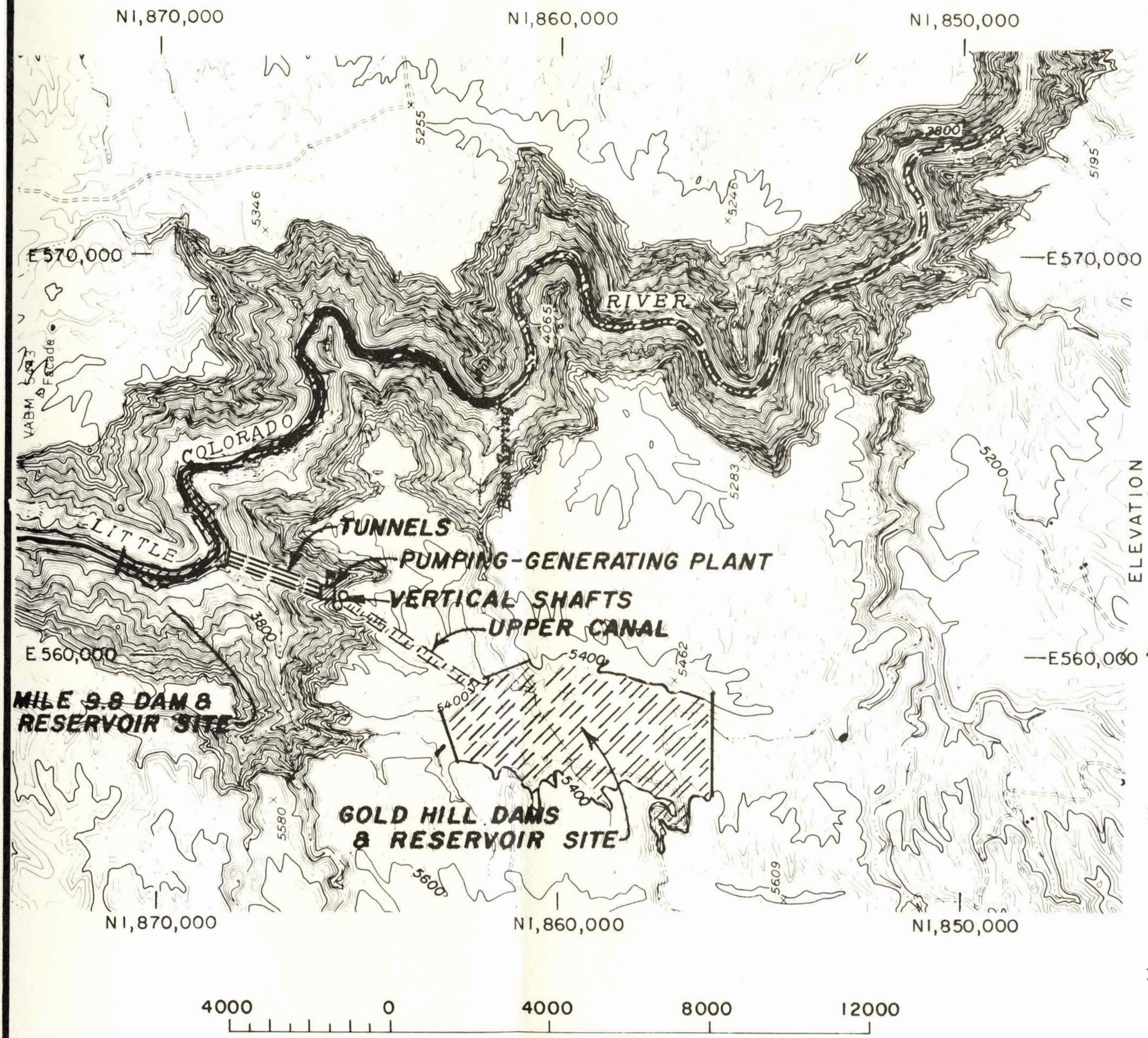
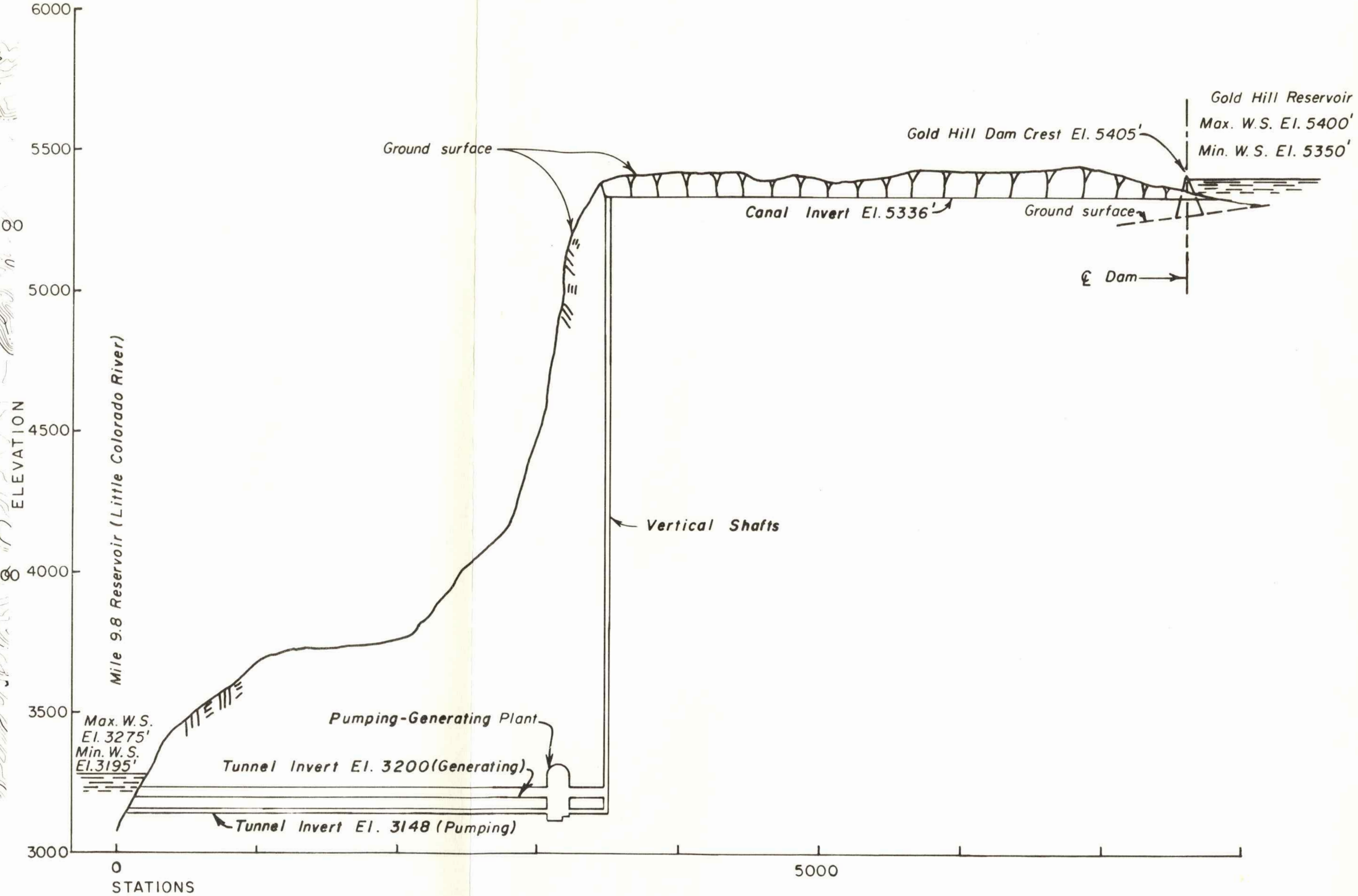
1/ From design flood used for Coconino Dam.



SCALE OF FEET
CONTOUR INTERVAL 40'



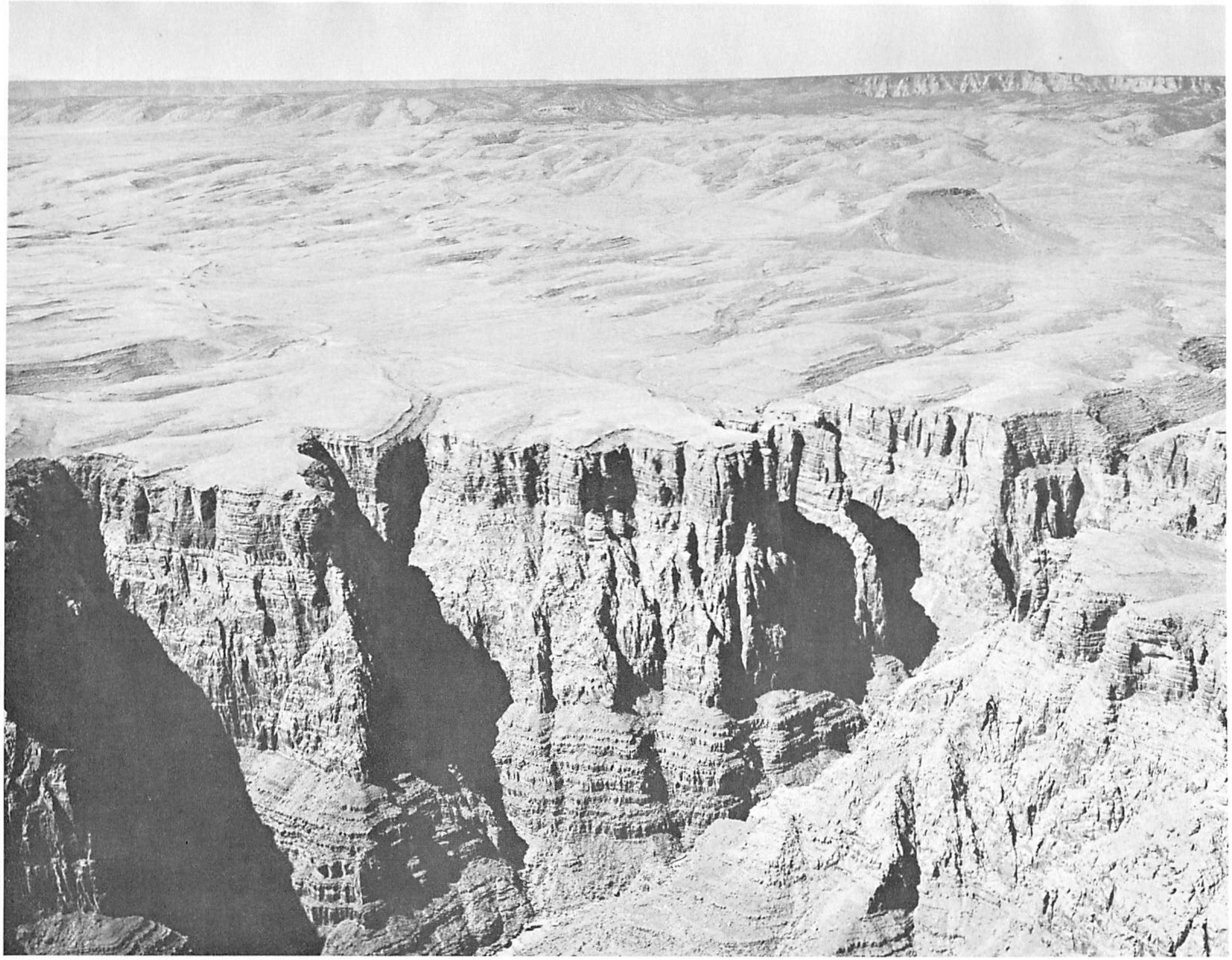
NOTES

Topography from United States Geological Survey 15' Quadrangle sheet, Blue Spring, Arizona.
Arizona state plane coordinates central zone.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
LITTLE COLORADO RIVER BASIN

BLUE SPRING PUMPED STORAGE
PLAN & PROFILE
LITTLE COLORADO RIVER

DRAWN M.D.M. L.H.H. SUBMITTED
TRACED T.K.C. RECOMMENDED
CHECKED APPROVED
PHOENIX, ARIZONA AUG. 28, 69 | 1224-314-4



Bureau of Reclamation Photo

Photograph P57-300-9844.

LITTLE COLORADO RIVER - BLUE SPRING AREA
Gold Hill Reservoir site (upper reservoir). View looking southwest from over Little Colorado River Gorge.

would be used to divert the water away from the reservoir and, therefore, spillway or other protective works would not be necessary.

The three rock-filled dams would be about 1,300, 2,400, and 1,700 feet in length, and would range from 55 to 125 feet in height and contain about 3,400,000 cubic yards of material. All dams would be faced with concrete lining on the reservoir side. Between elevations 5350 and 5405, the reservoir would be shaped and excavated on a $1\frac{1}{2}$:1 slope and lined with concrete. Below elevation 5350, the reservoir would be lined with soil cement.

The Gold Hill reservoir would have a total capacity at the top of the conservation pool, elevation 5400, of 23,000 acre-feet. Of this, 16,000 acre-feet would be active storage between elevations 5400 and 5350. Maximum reservoir fluctuations would be 50 feet.

3. Pumping and Generating Plant. The pumping and generating plant would be underground about 4,000 feet in from the shoreline of the lower reservoir. Installation for the average power head of 2,125 feet would consist of multistage centrifugal pumps, impulse turbines, and motor-generators all on a common shaft. Rotation would be in one direction only. Water would be forced out of the turbine chambers by compressed air during generation to permit operation of the impulse turbines in air. Compressed air would also be used to clear the pump chambers during generation.

Multiple 250-megawatt units would provide total plant capacity, which was studied in a 500- to 4,000-megawatt range.

The main underground powerhouse would be excavated in rock and would house the power units, penstocks, auxiliary equipment, and service and control areas. A separate underground vault would house the unit transformers. Transformer cables would extend through underground galleries and tunnel sections to an aboveground switchyard which would be located on the rim of the canyon in the vicinity of the upper reservoir site. Refer to profile on Drawing 1224-314-4.

4. Water Conveyance System. The upper reservoir would be connected to the pumping and generating plant by a two-way canal which would be excavated along a ridge running northeasterly to the canyon rim, a distance of 4,200 feet. This concrete-lined canal section would be of level grade, with side slope of $1\frac{1}{2}$:1. Bottom grade would be set at elevation 5336 to assure full capacity to the bottom of the active storage reservoir. From the intake at the end of the canal section, pressure conduits would extend vertically downward to connect with the pump-generator units. These conduits would be 9 feet in diameter, 2,188 feet in length, and concrete and steel lined. Surge would be controlled by increasing freeboard on the reversible canal section.

The tailrace system connecting the underground power station with the lower reservoir would consist of separate tailrace and pump intake tunnels 3,150 feet in length, and 27 and 14 feet in diameter, respectively. These tunnels would be lined with reinforced concrete. The invert of the tailrace tunnel was set at 3,200 feet and that of the pumping tunnel at 3,148 feet. These tunnels were included for each 250-megawatt unit to aid in the cost estimating of the various plant sizes.

5. Construction Access. Access to the Blue Spring pumped-storage area would be from Cameron and U.S. Highway 89. A total of 21.5 miles of access road and 27,500 feet of tunnel would be required, of which most would be required before construction could begin within the inner gorge area.

The roadway would be 24 feet wide with a 4-foot shoulder. The tunnel from the canyon rim to the underground powerhouse would also have a 24-foot roadway, with a 25-foot vertical clearance on centerline.

6. Service Facilities. Owing to the remoteness of the Blue Spring area, the estimate includes an allowance for the construction of living quarters for operating and maintenance personnel. These service facilities would probably be located at Cameron.

7. Coconino Dam and Reservoir. The dam would be located about nine miles downstream from Cameron at River Mile 48.5. The structure would be a concrete gravity type, with a crest length of about 480 feet at elevation 4300. Its total height above streambed would be about 250 feet. Coconino Reservoir would be operated

for the single purpose of sediment retention by the placement of stoplogs to maintain a 40,000 to 80,000 acre-foot detention pool. Sufficient reservoir capacity would be available to provide for 100 years of sediment storage.

H. Transmission Arrangements

It was assumed that the transmission system would be constructed by the participating utilities receiving the peaking and/or spinning reserve capacity. Pumping energy and capacity would also be provided by the participating utilities. Also, see writeup in Chapter IV, "Alternative Development Possibilities."

I. Operations

Several operating patterns are available for utilization of Blue Spring pumped-storage generating capacity. For maximum daily utilization, water could be pumped from the lower inner gorge reservoir during offpeak periods and returned through the turbines to provide peaking capacity during high power demands. Weekly plant factor would vary, depending on the plant size. For the 500-, 750-, 1,000-, and 2,000-megawatt plants, peaking capacity could be available for 50 hours per week, or at a weekly plant factor of about 30 percent. The 3,000- and 4,000-megawatt plants could operate for about 47 and 36 hours a week, respectively, or at weekly plant factors of 28 and 21 percent. This peaking installation could be integrated into the existing EHV transmission system by the construction of the appropriate transmission facilities.

The plant could provide spinning reserve to back up other generating plants on the participating utilities' systems. There would be no scheduled generation and plant use would be limited to emergency conditions. Pumping would be limited to makeup water and to replacement of storage releases resulting from unscheduled daily generation. Storage replacement would be by overnight pumping.

In case of emergency, the 16,000 acre-feet of usable storage in the upper reservoir could provide the following maximum continuous hours of full operation at the various plant sizes studied:

Plant Size (megawatts)	Maximum Hours of Operation
500	57.1
750	38.1
1,000	28.5
2,000	14.3
3,000	9.5
4,000	7.2

Possibly the most practicable plant operation would be a multipurpose mode where both peaking and spinning reserve capacities are dedicated for use. For instance, in a 4,000-megawatt plant, 3,000 megawatts could be dedicated for scheduled peaking capacity, and 1,000 megawatts could be available at all times for spinning reserve. Final multipurpose assignment of plant capacity would be subject to requirement for peaking and reserve capacity.

J. Power Marketing

For the purpose of this report, the power market area for the Blue Spring pumped-storage unit has been defined as encompassing the Lower Colorado River Basin watershed in Arizona, southern Nevada, southern Utah, and western New Mexico.

Projections of future electric power requirements for this area were based on data and estimates prepared by the Federal Power Commission, San Francisco Regional Office. The annual electric power requirements for the years 1980, 2000, and 2020 are shown in Table 3.

Table 3
ANNUAL ELECTRIC POWER REQUIREMENTS
FOR 1980, 2000, AND 2020 CONDITIONS
Blue Spring Area, Arizona

Source	Generation Capacity (Megawatts) 1980	2000	2020
Power Requirements			
Baseload Resources	5,900	25,500	77,300
Existing-Planned Peaking Resources	3,500	3,783	1,077
Other "Future" Peaking Resources	0	10,917	43,623
"Future" Pumped-Storage Resources	1,000	4,500	13,600
Power Requirements	10,400	44,700	135,600
Reserves	-2,100	-8,900	-27,100
At-Plant Power for Marketing	8,300	35,800	108,500

To serve the above-listed loads would require a combination of existing, proposed, and yet to be investigated resources.

The total "future" pumped-storage resources, as shown on Table 3, were based on about 30 percent peak load demand which would be about the operational limit for economic development of the Blue Spring Unit.

Based on the future need for peaking capacity (Table 3), the Blue Spring Unit could provide a part of the 1,000-, 4,500-, and 13,600-megawatt load shown for years 1980, 2000, and 2020, respectively. Also, the Blue Spring Unit could provide a portion of "reserve" generating capacity. Reserve capacity was estimated at 20 percent of the total at-plant power requirement, and would require about 2,000, 8,900, and 27,100 megawatts in years 1980, 2000, and 2020, respectively.

Other "future" peaking resources would generally be based on higher load factors and would be supplied by high efficiency hydro, steam, and gas turbine units.

As Table 3 indicates, the marketing of Blue Springs pumped-storage power would probably not be required or be feasible until around 1990 to 2000. It is obvious, however, that there would be a future need for considerable new peaking capacity of this type to be integrated with the large thermal generation stations now being built and planned in the Arizona power market area.

K. <u>Construction Costs</u>

The total estimated construction cost (at plant) for the Blue Spring pumped-storage facilities, including the Gold Hill and Coconino Reservoirs, is based on preliminary reconnaissance designs and estimates. The unit prices are as of January 1969 and include engineering and other indirect costs. See the following tabulation:

Plant Size (megawatts)	Total Construction (million)	Costs (per kilowatt)
500	$195.7	$390
750	226.9	300
1,000	258.0	260
2,000	359.5	180
3,000	455.9	150
4,000	576.5	140

Designs and estimates were based on Reclamation guidelines for the preparation of pumped-storage facilities. Estimates were based on Bureau of Reclamation topographic maps, scale 1" = 440', for the Gold Hill Dam and Reservoir; and on Geological Survey enlarged quadrangle maps, scale 1" = 4,000', for the inner gorge dam and reservoir.

The above cost estimates do not reflect the possible effects of Blue Spring water on hydraulic components subject to high velocities or temperatures. Preliminary analysis indicated that because of the poor quality of water, stainless steel would be required to resist cavitation and corrosion on most high velocity hydraulic equipment. Also, because of higher temperatures associated with a cooling water system for the generator and bearings, corrosion and scale deposits would be a problem unless Blue Spring water was treated.

Total estimated construction period would be from 6 years for the smaller 500-megawatt plant to 12 years for the 4,000-megawatt plant.

L. Power Costs

The preliminary results presented below show the Federal and non-Federal investment and annual equivalent costs per kilowatt for the six Blue Spring alternative developments. It was assumed that the purchaser of the power output would supply the energy for pumping purposes, and also provide transmission facilities.

The cost of financing the Blue Spring development was based on an interest rate of 5.375 percent for the Federal alternatives and a rate of 7 percent cost for the non-Federal alternatives. The non-Federal alternatives were based on the sale of bonds (7 percent) and reinvestment of funds with a net return of 5 percent on approximately one-third of the total funds used for construction. The results of these two interest rates indicate the influence of the interest charge and the means of financing the cost of power. See Tables 4 and 5.

Following the usual non-Federally financed utility practices, the annual capital costs for the non-Federal projects included interest only as the bond issues would be refinanced at each maturity date. The annual capital costs for the Federal projects include interest and amortization, and are higher than would be experienced if detailed payout studies were prepared. This is true because revenues from power units installed earlier would be available after the 50-year payout period to repay the remaining Federal investment of the other units. In the larger installations, the differential

Table 4
COST OF FEDERAL FINANCING
(Based on an Interest Rate of 5.375 Percent)
Blue Spring Area, Arizona

Federal Development 1/	Sizing of Blue Spring Development 500 mw	750 mw	1,000 mw	2,000 mw	3,000 mw	4,000 mw
Investment, Dollars Per Kilowatt	438	344	292	203	171	162
Annual Cost, Dollars Per Kilowatt						
Capital Charge 2/	25.40	19.95	16.93	11.77	9.91	9.39
Operation, Maintenance, and Replacement	2.47	2.01	1.76	1.38	1.24	1.19
Total	27.87	21.96	18.69	13.15	11.15	10.58

1/ Includes costs for Coconino Dam, inner gorge dam, Gold Hill Dams, power-pumping plant and canals, access roads, and switchyard.

2/ 50 years at 5-3/8 percent.

Table 5
COST OF NON-FEDERAL FINANCING
(Based on an Interest Rate of 7 Percent)
Blue Spring Area, Arizona

Non-Federal Development 1/	Sizing of Blue Spring Development 500 mw	750 mw	1,000 mw	2,000 mw	3,000 mw	4,000 mw
Investment, Dollars Per Kilowatt	482	370	312	213	179	168
Annual Cost, Dollars Per Kilowatt						
Capital Charge	33.74	25.90	21.84	14.91	12.53	11.76
Operation, Maintenance, and Replacement	2.47	2.01	1.76	1.38	1.24	1.19
Total	36.21	27.91	23.60	16.29	13.77	12.95

1/ 50 years at 7 percent.

between the annual charges for the Federal and non-Federal projects would be slightly greater than shown in Table 5.

CHAPTER IV

ALTERNATIVE DEVELOPMENT POSSIBILITIES

Blue Spring Area

CHAPTER IV. ALTERNATIVE DEVELOPMENT POSSIBILITIES
Blue Spring Area

A. Cooling Water

A major alternative for use of Blue Spring and surface waters of the Little Colorado River would be as cooling water for local fossil fuel thermal powerplants. A firm water supply is essential for thermal development, and is scarce in the Black Mesa coal fields on the Navajo and Hopi Indian Reservations in northern Arizona. The Coal Mine Mesa area, about 10 miles southeast of Tuba City, Arizona, is on the western edge of the Black Mesa deposits.

Coconino Reservoir would be about 20 miles southwest of the Coal Mine Mesa area. The east side inner gorge rim above Blue Spring would be about 32 miles west of the Coal Mine Mesa area.

Based on Federal Power Commission data, cooling water requirements for a 1,000-megawatt thermal powerplant under 2000 conditions, would be 5,220 acre-feet per year for cooling pond or 8,200 acre-feet per year for cooling towers. These figures are based on a plant factor of 85 percent.

With minor modifications to the dam, water pumped from Coconino Reservoir could support, on a firm basis, an installed capacity of at least 7,000 megawatts for cooling pond-type installations or 5,000 megawatts for cooling tower-type. Blue Spring water could support an additional 8,000 megawatts for cooling pond-type installations or 6,000 megawatts for cooling tower-type.

The total annual cost, including capital and OM&R, for development of about 40,000 acre-feet of Little Colorado River water from Coconino Reservoir and 49,200 acre-feet from Blue Spring for use in cooling thermal power unit would be about $23 and $95 per acre-foot, respectively. These annual charges would provide water delivery only to the canyon rim area and do not include water conveyance or treatment facilities.

B. Power Facilities for Pumping

Although not considered as a part of the Blue Spring pumped-storage proposal, power for pumping could possibly be supplied by construction of local coal-fired thermal powerplants in the Coal Mine Mesa area. Favorable characteristics exist concerning the local supply of water and fuel with respect to the pumping load center at Blue Spring.

Cooling water from Coconino Reservoir could be conveyed some 15 miles to mine-mouth thermal units near Coal Mine Mesa, or coal slurry could be conveyed to thermal units located near Coconino Reservoir. Studies were not made to determine the most economical arrangement.

During the day when pumping demands are zero, the thermal unit could provide power to meet a portion of the peaking load.

CHAPTER V

GROUND–WATER RESOURCES

Winslow–Holbrook Area

CHAPTER V. GROUND-WATER RESOURCES
Winslow-Holbrook Area

A. Introduction

The Winslow-Holbrook area is an integral part of the Mogollon Mesa Project. This project is under current investigation at feasibility-grade level. Hydrogeologic studies are basic to both the Flagstaff-Williams and the Winslow-Holbrook areas, quantitatively as well as qualitatively, to evaluate local water supplies and to evaluate the effects of potential surface water impoundment of the ground-water resource.

Use of the ground-water resource in the Winslow-Holbrook area is projected mainly for municipal and industrial demands. Its use for agriculture, as well as for municipal and industrial, is limited by the quality. The occurrence of saline ground water in main aquifers of the Colorado Plateau is well documented, but definitive hydrogeologic data on the saline ground waters and their relationship to fresh ground waters, both vertically and horizontally, are almost nonexistent. The main purpose of the Bureau hydrogeologic studies for the Mogollon Mesa Project is to establish a working knowledge of these saline, fresh water aquifers and their relation to municipal water supplies for Winslow and Holbrook. Other exploratory holes will be drilled as part of the Bureau feasibility study.

B. Regional Hydrogeology

The primary aquifer in the Winslow-Holbrook area is the Coconino sandstone. Lithologically, this aquifer is remarkably consistent over the Colorado Plateau, but its hydrogeologic properties are highly variable, dependent upon structural discontinuities. The quality of the ground water in the Coconino is also highly variable, total dissolved solids range from under 300 ppm to over 100,000 ppm. Recharge to the aquifer is primarily accomplished from snowmelt and streamflow originating on the Mogollon slope.

C. Test Hole (A-18-15) 28 aad

The potential Wilkins Dam on East Clear Creek, a feature of the Mogollon Mesa Project, could provide a municipal water supply to Flagstaff. A water committee in the City of Winslow became concerned about possible harmful effects of this dam upon the City's ground-water supply, primarily related to quality of water. Test hole (A-18-15) 28 aad was located to provide partial data in response to this concern, as well as to provide data for the regional hydrogeologic study.

The hole was cored and drilled to a depth of 1,210 feet. Drilling started in the Moenkopi formation, penetrated the Kaibab limestone at 40 feet, went into the Coconino sandstone at 50 feet, and encountered the Supai formation at 1,020 feet. Drilling was terminated in the Supai. The regional ground water was penetrated at about 265 feet below ground surface. Upon completion of drilling, a water-quality sampling program was conducted utilizing a double-packer drill stem device that isolated 100-foot intervals. The results of this program are contained in Table 6.

While testing an isolated interval of the Supai, a water-level measurement was obtained which indicated that the water level associated with the Supai aquifer occurs 60 feet below the water level associated with the Coconino formation.

After water sampling, geologic logs were run. These logs and well log are appended to this section.

D. Preliminary Conclusions

The ground water from the Supai formation and the lower part of the Coconino sandstone confirms the occurrence of highly saline water on the Mogollon slope comparable to the highly saline water that occurs generally north and east of the Little Colorado River. The salt water body may be continuous throughout the region, with fresh water lenses intermittently overlying that are related to areas of high recharge and geological structural features. Knowledge of the fresh water-salt water interface at depth is basic to any planned development of the ground-water resources in the region. The feasibility report for the Mogollon Mesa Project will more fully evaluate and interpret the data provided by test hole (A-18-15) 28 aad.

Table 6
CHEMICAL ANALYSES OF WATER FROM TEST WELL (A-18-15) 28aad 1/
Winslow-Holbrook Area, Arizona

Collector's Number			1	2	3	4	5	6	7	8	9
Laboratory Number			32104	32105	32106	32107	32108	32109	32110	32111	32112
Collected: 1969			7/31	8/1	8/4	8/5	8/6	8/7	8/8	8/11	8/11
Received: 1969			9/9	9/9	9/9	9/9	9/9	9/9	9/9	9/9	9/9
Conductivity, ECx10^6@25°C.			116,000	27,800	4,380	4,740	4,420	2,880	3,020	18,800	12,400
Sodium-adsorption ratio (SAR)			312	97	25	29	23	16	11	79	58
Soluble sodium percentage (SSP)			96	94	89	91	87	84	74	94	93
Boron	B	ppm	3.29	.51	.12	.13	.21	.09	.02	.48	.24
Dissolved Solids	DS	taf	149	24.1	3.31	3.66	3.42	2.28	2.63	15.5	9.84
Dissolved Solids	DS	ppm	109,500	17,740	2,434	2,690	2,517	1,674	1,932	11,380	7,234
pH			7.4	7.5	7.9	8.2	7.8	7.8	7.7	7.9	8.0
Silica	SiO_2	ppm	4	4	8	10	10	12	14	8	7
Calcium	Ca	meq/l	42.92	10.28	2.21	2.05	2.68	2.50	5.99	4.96	3.86
Magnesium	Mg	meq/l	20.08	6.26	1.99	2.09	2.56	1.81	1.68	5.37	3.89
Sodium	Na	meq/l	1,749	279.0	36.68	41.20	37.20	23.31	22.30	180.1	114.7
Potassium	K	meq/l	2.19	.42	.12	.16	.12	.10	.15	.30	.25
Sum of Cations			1,814	296.0	41.00	45.50	42.56	27.72	30.12	190.7	122.7
Carbonate	CO_3	meq/l	0	0	0	.28	0	0	0	trace	trace
Bicarbonate	HCO_3	meq/l	1.81	3.01	4.88	5.03	4.65	4.71	3.83	5.26	5.51
Sulfate	SO_4	meq/l	50.07	11.94	4.76	6.15	5.83	7.67	12.85	5.83	5.43
Chloride	Cl	meq/l	1,790	284.5	32.06	34.21	32.38	15.39	13.51	182.4	112.3
Fluoride	F	meq/l	.04	trace	.02	.02	.02	.02	.03	trace	.02
Nitrate	NO_3	meq/l	trace	trace	trace	.01	trace	trace	.01	trace	trace
Sum of Anions			1,842	299.4	41.72	45.70	42.88	27.79	30.23	193.5	123.3
Zone Samples (feet below ground surface) 2/			1,210 to 1,076	946 to 846	826 to 726	716 to 616	606 to 506	496 to 396	424 to 265	926 to 826	926 to 826
Intake Valve at (feet below ground surface)			1,176	934	814	704	594	482	410	914	914
Quantity Pumped Before Sampling (gallons) 3/			250	240	720	630	1,350	900	1,100	2,400	1,050
Field Temperature of Sample (°F.)			64	64	64	64	64	64	64	64	64

1/ Water samples collected by U.S. Bureau of Reclamation; analyzed by the U.S. Salinity Laboratory, Riverside, California.

2/ Zone isolated by inflatable packers.

3/ Pumped by airlift.

APPENDED MATERIAL

Form No. PHD-22
July 1963

CONDENSED GRAPHIC LOG OF GROUND WATER TEST HOLE

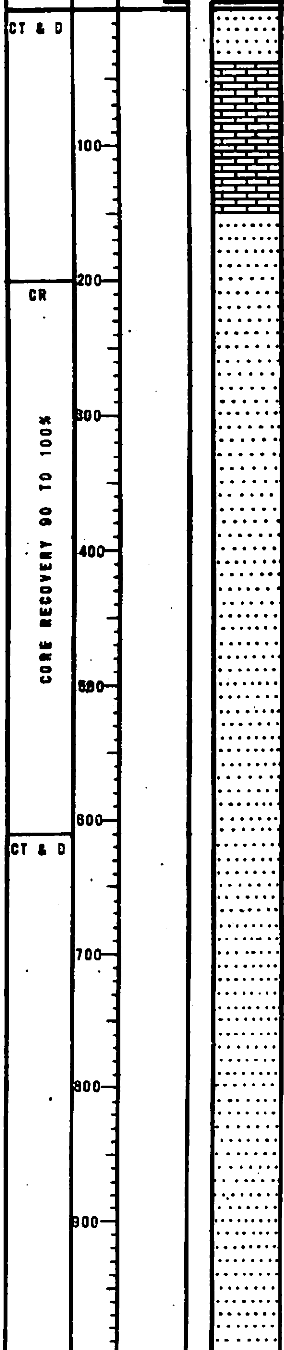
PROJECT: MOGOLLON MESA, WINSLOW-HOLBROOK DIVISION — STATE: ARIZONA

HOLE NO: (A-18-15)28 aad - WINSLOW TEST HOLE — GROUND ELEVATION: 5180±

BEGUN: MAY 5-1969 — FINISHED: JULY 23, 1969 - SEPT. 3, 1969 — TOTAL DEPTH: 1210

DEPTH OR ELEVATION OF WATER TABLE: 285.5'± 7/29/69 — HOLE LOGGED BY: G. D. Ford

TYPE OF SAMPLE	DEPTH	PIEZOMETER DATA	LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION



0'- 40': MOENKOPI FORMATION: reddesh brown to red toward bottom, fine grained sandstone, firmly cemented with siliceous cement, slight reaction to acid.

40'- 150': KAIBAB LIMESTONE: pale gray to pale yellow; yellow colored zone sandy fine grained, cemented with calcareous cement; slight to moderate reaction to acid; cherty and iron stained in bottom 10 feet.

150'-1020': COCONINO SANDSTONE: white to tan, spotted and streaked with orange iron staining, well sorted, fine grained, subangular to rounded quartz with scattered magnetite, moderately to firmly cemented with siliceous or calcareous cement, slight to no reaction to HCl, bedding is often massive or very poorly defined, cross bedding usually dips 2° to 22° to core normal, irregularly spaced joints dip from 60° to vertical to core normal, some are well healed by silica and are tight, others are iron stained indicating open joints while some have no stains and may have been opened during drilling.

Detailed Log of Cored Interval:

200'- 242': Core recovered in lengths from .1 to 1.5 ft. with most between .3 and .8 ft. Core breaks are mostly mechanical along the bedding planes. Open joints are at 203' dipping 60° to core normal with some iron staining and at 210' dipping 70° to core normal with no staining.

242'- 250': Core recovered in broken pieces from .05 to .3 ft. long with only one large length .7 ft. long. Breaking is along planes mostly from horizontal to dipping 4° to core normal. Iron staining is spotty throughout and is present on most of the break planes. The core from 240' to 248' is badly eroded from drilling and some of the break planes are rounded.

250'- 288': Core recovered in lengths from .2 to 2.8 ft. with most between .5 and 1.0 ft.. Most breaks are along the bedding planes dipping 18° to 22°. The breaks along the 2° to 4° dipping planes appear to be mostly mechanical. Open joints at 252' dipping 80° to core normal and a vertical joint from 254.1 to 254.5 ft. show no staining.

288'- 291': Core recovered in lengths from .1 to .3 ft. Breaks are along the bedding planes. This interval is mottled with iron staining with quite heavy staining along some of the break planes.

291'- 441.6': Core recovered in lengths from .2 to 3.0 ft. with most from .3 to .8 ft. Most breaks are along the bedding planes, some are lightly iron stained, others show no staining. Open joints are at 297' dipping 75° to core normal and a vertical joint from 310.8' to 311.2' both with heavy iron staining. A joint at 334' dipping 70° to core normal has no staining and may have broken mechanically. There is a color change at 381' from predominately white to predominately tan.

441.6'- 450.3': Core recovered in lengths from .1 to .5 ft. with most from .3 to .4 ft. Breaks along bedding planes dipping 18° to 22° to core normal are most prominent. Some partings along these bedding planes are poorly healed with heavy iron deposits. Breaks on the planes dipping 2° to 4° to core normal are probably mostly mechanical.

450.3'- 567.5': Core recovered in lengths from .2 to 2.0 ft. with most from .3 to .6 ft. Breaks along bedding planes. The bedding is accentuated by iron staining below 520'. At 550' there is a break which has been badly rounded by drilling action.

CR = CORE
CT = CUTTINGS
D = DRILLERS LOG

CLAY & CEMENT PACKER

BOTTOM OF PIEZOMETER TUBE & SUFFIX NUMBER (2)

D DENSITY SAMPLE
P PERMEABILITY SAMPLE
M MOISTURE SAMPLE

Sandstone
Limestone
Siltstone

HOLE NO. (A-18-15)28 aad

Form No. PHD-22
July 1963

CONDENSED GRAPHIC LOG OF GROUND WATER TEST HOLE

PROJECT MOGOLLON MESA, WINSLOW - HOLBROOK DIVISION STATE ARIZONA

HOLE NO. (A-18-15)28 aad - WINSLOW TEST HOLE GROUND ELEVATION 5180 ±

BEGUN MAY 5, 1969 FINISHED JULY 23, 1969 - SEPT. 3, 1969 TOTAL DEPTH 1210

DEPTH OR ELEVATION OF WATER TABLE 285.5'± 7/29/69 HOLE LOGGED BY G.D. Ford

TYPE OF SAMPLE	DEPTH	PIEZO-METER DATA	LOG (SAMPLES FOR TESTING)	CLASSIFICATION AND PHYSICAL CONDITION
CT & D	1100 1200 1300		T.D.	587.5' - 594.5': Core recovered in lengths from .08 to .8 ft. with most from .15 to .3 ft. Breaks along bedding planes with a predominance of breaks dipping 2° to 4° to core normal. 594.5' - 610': Core recovered in lengths from .1 to 1.3 ft. with most from .4 to .8 ft. Breaks along iron stained bedding planes dipping predominately from 2° to 4° from core normal. Surface of core has grain sized, iron stained pits. 1020' - 1210': SUPAI FORMATION: light brown to orange and red, uniform fine grained sandstone and siltstone very weakly cemented, lower portion predominately red siltstone, slight to no reaction to acid.

REMARKS: Drilling equipment:
Failing 1500

Drilling:
- Drilled 8" rock bit to 200'
- Set 200' of 8" casing, cemented
- Cored (NC) 200' to 610'
- Reamed to 4 3/4" - 200' to 610'
- Rock bit 4 3/4" 610' to 1210'
- Tested water quality and took sample for analysis
- Reamed to 5 5/8" from 610' to 1120'
- Ran " E " logs to 1120
- Backfilled with gravel from 1210' to 900'
- Cemented from 900' to 500' with type 5 cement

Casing:
- 0' to 200' 8" casing
- 200' to 500' open hole

Development:
Drilling mud washed from hole 310' to 500' by jetting and airlift pump

Water level:
M.P. to W.S. = 285.5 (7-29-69)
285.8 (8-4-69)

Water samples:
Used packers to isolate intervals sampled

Interval tested (ft.)	Depth of intake valve (ft.)
1,078 to 1,210	1,176
848 to 948	934
828 to 926	914
728 to 826	814
618 to 718	704
508 to 606	594
388 to 486	462
265 to 424	410

CR = CORE	CLAY & CEMENT PACKER	D DENSITY SAMPLE	Sandstone
CT = CUTTINGS	BOTTOM OF PIEZOMETER TUBE & SUFFIX NUMBER (2)	P PERMEABILITY SAMPLE	Limestone
D = DRILLERS LOG		M MOISTURE SAMPLE	Siltstone

SCHLUMBERGER

DUAL INDUCTION - LATEROLOG

COUNTY NAVAJO, ARIZONA
FIELD or LOCATION TEST WELL
WELL
COMPANY BUREAU OF RECLAM.

COMPANY BUREAU OF RECLAMATION

WELL (A-18-15) 28aad

FIELD TEST WELL

COUNTY NAVAJO STATE ARIZONA

LOCATION SE NE NE

Sec. 28 Twp. 18N Rge. 15E

Other Services: BHC/GR

Permanent Datum: GL, Elev. 5180
Log Measured From GL, -- Ft. Above Perm. Datum
Drilling Measured From GL

Elev.: K.B. --
D.F. --
G.L. 5180

Date	8/21/69			
Run No.	ONE			
Depth—Driller	1210			
Depth—Logger	1120			
Btm. Log Interval	1116			
Top Log Interval	200			
Casing—Driller	6" @ 200	@	@	@
Casing—Logger	200			
Bit Size	5"			
Type Fluid in Hole	FBM + LCM			
Dens. | Visc.	-- | --			
pH | Fluid Loss	-- | -- ml	ml	ml	ml
Source of Sample	FLOWLINE			
R_m @ Meas. Temp.	2.8 @ 82 °F	@ °F	@ °F	@ °F
R_{mf} @ Meas. Temp.	2.3 @ 82 °F	@ °F	@ °F	@ °F
R_{mc} @ Meas. Temp.	-- @ -- °F	@ °F	@ °F	@ °F
Source: R_{mf} R_{mc}	M | --			
R_m @ BHT	-- @ -- °F	@ °F	@ °F	@ °F
Time Since Circ.	2 HRS.			
Max. Rec. Temp.	94 °F	°F	°F	°F
Equip. | Location	3872 | FARM			
Recorded By	SCHULTZ			
Witnessed By	MR. KOMIE			

SWS—902-G

The well name, location and borehole reference data were furnished by the customer.

FOLD HERE

8-25-69 17839

REMARKS

Scale Changes

Type Log	Depth	Scale Up Hole	Scale Down Hole

Equipment Data

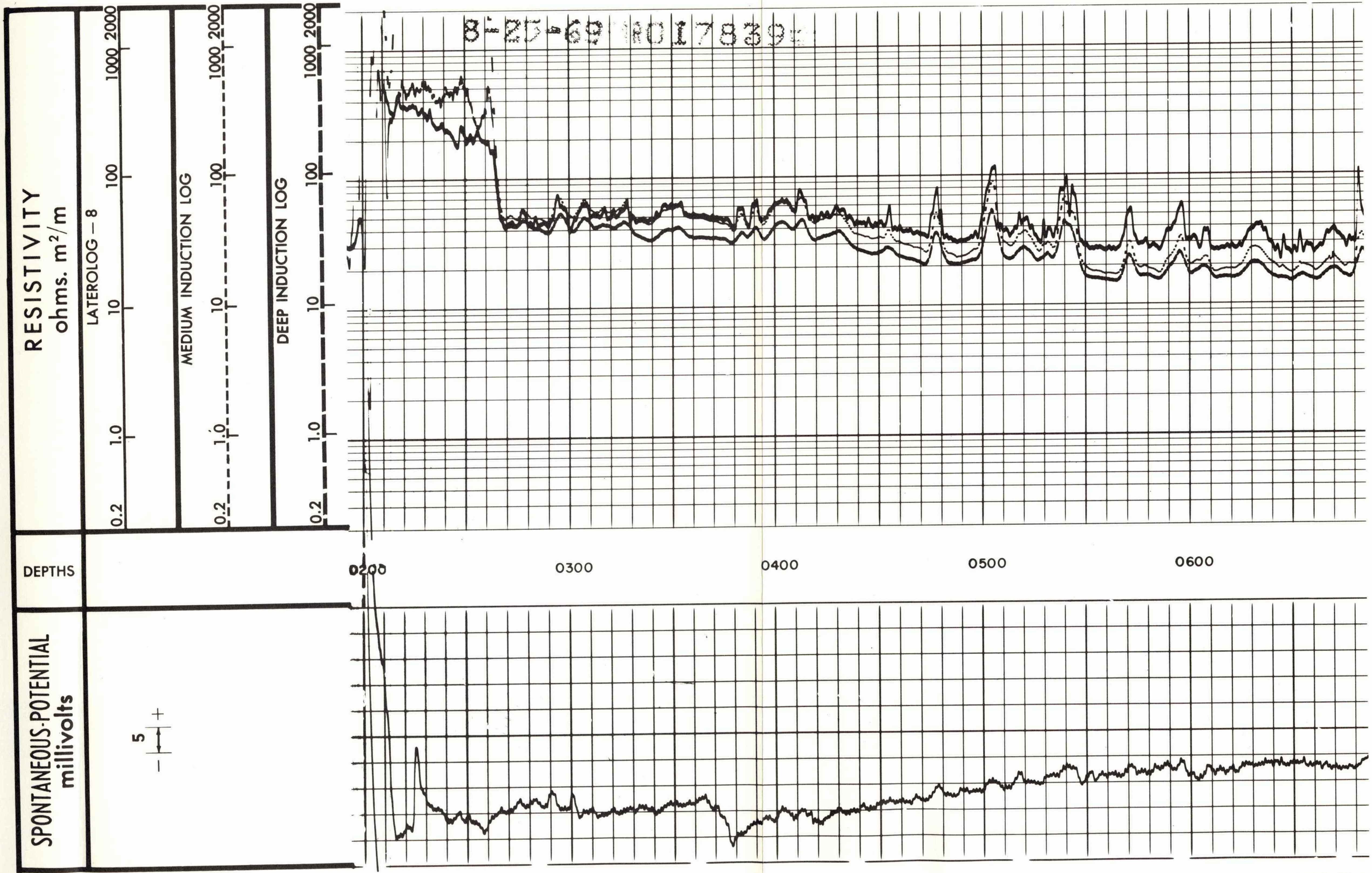
Run No.	Tool Type	Tool Position	Other

Changes in Mud Type or Additional Samples

Date | Sample No.		
Depth—Driller		
Type Fluid in Hole		
Dens. | Visc.		
ph | Fluid Loss	ml	ml
Source of Sample		
R_m @ Meas. Temp.	@ °F	@ °F
R_{mf} @ Meas. Temp.	@ °F	@ °F
R_{mc} @ Meas. Temp.	@ °F	@ °F
Source: R_{mf} R_{mc}		
R_m @ BHT	@ °F	@ °F
R_{mf} @ BHT	@ °F	@ °F
R_{mc} @ BHT	@ °F	@ °F

Run No.:	ONE
C.D.:	--
S.O.:	--
Equip. Used: PANEL No.:	90A
CART. No.:	33B
SONDE No.:	11B
IAP No.:	328B
S.B.R.:	4

Check one, filling in blanks where applicable:
[X] Surface determined sonde errors used for ILM and ILD.
[ ] ILM and ILD sonde errors corrected for inch borehole signal at R_m =
[ ] ILM and ILD zeros set in hole at depth of feet.


RESISTIVITY
ohms. m²/m
LATEROLOG – 8
0.2 1.0 10 100 1000 2000
MEDIUM INDUCTION LOG
0.2 1.0 10 100 1000 2000
DEEP INDUCTION LOG
0.2 1.0 10 100 1000 2000
DEPTHS
0200
0300
0400
0500
0600
SPONTANEOUS-POTENTIAL
millivolts
5
+
–