Recent Vegetation Changes Along the Colorado River Between Glen Canyon Dam and Lake Mead, Arizona

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agave	*Agave* spp.
Apache plume	*Fallugia paradoxa* (D.Don) Endl.
arrowweed	*Pluchea sericea* (Nutt.) Coville
barrel cactus	*Ferocactus acanthodes* (Lemaire) Britt. & Rose
beavertail cactus	*Opuntia basilaris* Engelm. & Bigel.
bebbia	*Bebbia juncea* (Benth.) Greene
Bermuda grass	*Cynodon dactylon* (L.) Pers.
brittle bush	*Encelia farinosa* Gray
camelthorn	*Alhagi camelorum* Fisch.
carrizo (see reed)	*Phragmites communis* Trin.
catclaw	*Acacia greggii* Gray
cattail	*Typha* spp.
coldenia	*Coldenia* spp.
creosote bush	*Larrea tridentata* (DC.) Coville
desert broom	*Baccharis sarothroides* Gray
desert isocoma	*Haplopappus acradenius* (Greene) Blake
desert plume	*Stanleya pinnata* (Pursh) Britton
desert trumpet	*Eriogonum inflatum* Torr. & Frem.
dicoria	*Dicoria* spp.
dogbane	*Apocynum* spp.
dropseed	*Sporobolus* spp.
dyssodia	*Dyssodia* spp.
elm	*Ulmus minor* Mill.
Emory seep willow	*Baccharis emoryi* Gray
evening primrose	*Oenothera pallida* Lindl.
four-wing saltbush	*Atriplex canescens* (Pursh) Nutt.
Fremont cottonwood	*Populus fremontii* Wats.
globemallow	*Sphaeralcea* spp.
Goodding willow	*Salix gooddingii* Ball
great bulrush	*Scirpus validus* Vahl.
hackberry	*Celtis reticulata* Torr.
horsetail	*Equisetum* spp.
horseweed	*Conyza canadensis* Cronquist
jointfir	*Ephedra torreyana* Wats.
longleaf brickellia	*Brickellia longifolia* Wats.
mistletoe	*Phoradendron californicum* Nutt.
monkey flower	*Mimulus cardinalis* Dougl.
Mormon tea	*Ephedra trifurca* Torr.
netleaf hackberry	*Celtis reticulata* Torr.
ocotillo	*Fouquieria splendens* Engelm.
peppergrass	*Lepidium montanum* Nutt.
poison ivy	*Rhus radicans* L.
rabbitbrush	*Chysothamnus* spp.
range ratany	*Krameria parvifolia* Benth.
red brome	*Bromus rubens* L.
redbud	*Cercis occidentalis* Torr.
red willow	*Salix laevigata* Bebb.
reed (see carrizo)	*Phragmites communis* Trin.
Russian olive	*Elaeagnus angustifolia* L.
Russian thistle	*Salsola kali* L. var. *tenuifolia* Tausch
saltcedar	*Tamarix chinensis* Lour.
sandbar willow	*Salix exigua* Nutt.
sand verbena	*Abronia elliptica* A. Nels.
scouring rush	*Equisetum hiemale* L.
seepweed	*Suaeda torreyana* Wats.
seep willow	*Baccharis glutinosa* Pers.
shrub liveoak	*Quercus turbinella* Greene
slender poreleaf	*Porophyllum gracile* Benth.
smooth horsetail	*Equisetum laevigatum* A. Braun
spiny aster	*Aster spinosus* Benth.
watercress	*Rorippa nasturtium-aquaticum* (L.) Schinz & Thell
waterweed	*Baccharis sergiloides* Gray
western honey mesquite	*Prosopis glandulosa* var. *torreyana* (Benson) Johnston
white bursage	*Ambrosia dumosa* (A. Gray) Payne
willow	*Salix* spp.
wolfberry	*Lycium* spp.
wire lettuce	*Stephanomeria pauciflora* (Torr.) A. Nels.

RECENT VEGETATION CHANGES ALONG THE COLORADO RIVER BETWEEN GLEN CANYON DAM AND LAKE MEAD, ARIZONA

By RAYMOND M. TURNER and MARTIN M. KARPISCAK

ABSTRACT

Vegetation changes in the canyon of the Colorado River between Glen Canyon Dam and Lake Mead were studied by comparing photographs taken prior to the completion of the Glen Canyon Dam in 1963 with those taken afterwards at the same sites. The old photographs, taken by J. K. Hillers, T. H. O'Sullivan, William Bell, F. A. Nims, R. B. Stanton, N. W. Carkhuff, N. H. Darton, L. R. Freeman, E. C. LaRue, and others, document conditions as they were between 1872 and 1963. In general, the older pictures show an absence of riparian plants along the banks of the river. The new photographs of each pair were taken in 1972 through 1976. The most obvious vegetation change revealed by the photograph comparison is the increased density of many species. Exotic species, such as saltcedar and camelthorn, and native riparian plants, such as sandbar willow, arrowweed, desert broom, and cattail, now form a new riparian community along much of the channel of the Colorado River between Glen Canyon Dam and the Grand Wash Cliffs.

The matched photographs also reveal that changes have occurred in the amount of sand and silt deposited along the banks. The photographs show that in some areas erosion has been significant since the time of the earlier photograph while at other locations sediment has accumulated on river bars and terraces.

Detailed maps are presented showing distribution of 25 plant species. Some of these, such as Russian olive and elm, were unknown along the Grand Canyon reach of the Colorado River before 1976.

Relevant data are presented to show changes in the hydrologic regime since completion of Glen Canyon Dam. Flooding, as expressed by annual maximum stage, has decreased in amplitude, and its season of occurrence has changed from spring (May-June) to a longer period from April through October. Dam construction has had a moderating influence on several other hydrologic variables. Compared to the predam era, discharge through the year now varies within narrow limits, changing little from month to month or season to season; annual maximum discharges are now strikingly uniform, and sediment load has materially decreased. Increases have occurred in some characteristics, however, such as daily variation in river stage and median discharge.

The interaction of decreased flooding, decreased sediment load, and increased riparian plant coverage makes the future of existing river fans, bars, and terraces uncertain. The establishment of a new ecological equilibrium at the bottom of the Grand Canyon may require many decades.

INTRODUCTION

When viewed as a water conveyance system, the Colorado River is unspectacular. Its long-term average annual discharge is 16,600 hm^3 (Stockton and Jacoby, 1976), only about one-thirtieth the flow of the Mississippi—less than the flow of such well-known rivers as the Snake, the Missouri, and the Potomac, and less even than such little-known rivers as the Atchafalaya (Louisiana), the Skagit (Washington), or the Apalachicola (Florida). Yet, if measured in terms of its impact on regional and national requirements for recreation, energy, and water, it is, for its size, of disproportionate importance. Many of our national parks and monuments lie within its scenic basin and the Colorado River is the erosional force that shaped the Grand Canyon, one of the great scenic wonders of the world and the main attraction in one of the more heavily visited National Parks. The Colorado River serves as a major power source for the region's cities and industries, and as a major water source for its domestic and agricultural users. When measured in terms of the impact it has upon the daily lives of the many human occupants of the arid southwestern United States and northwestern Mexico, the Colorado River's presence must be accorded far more importance than would be ascribed to it on the basis of discharge alone.

Until recently man was not a major factor affecting the vegetational and fluvial features along the Colorado River within the Grand Canyon. But during the last few decades the river has become one of the most-used rivers in America—both in terms of recreational use and in terms of water consumption. To provide a perspective for viewing the changes along the river, some examples are cited. During the first 86 years of river travel through the Grand Canyon (1869–1955), only 185 persons traversed the canyon by boat (Wallace, 1972); in the 1970's roughly 15,000 persons travel through the canyon by boat each year (Larson, 1974). Coupled with the heavy recreational use has been an increasingly heavy use of the river's water. By the construction of the four units of the Colorado River Storage Project (Flaming Gorge Dam [1962], Navajo Dam [1962], Curecanti Unit dams [1965–66], and Glen Canyon Dam [1963]) in the Upper Colorado River Basin, man has been able to control the flow in the river, curbing the spring floods and distributing throughout the year the water normally carried during these annual events of high flow. The modifications in flow regime have disrupted the equilibrium which formerly existed within the Grand Canyon, the reach of the river of primary concern in this report. But even before major dams appeared in the Upper Colorado River Basin, the Lower Colorado River was impounded by a series of dams beginning with Hoover Dam (1935). By far the greatest diversions from the river occur from these impoundments lying below the Grand Canyon. Before the first diversions were made, approximately 16,600 hm^3 (Stockton and Jacoby, 1976) of water reached the Sea of Cortez (Gulf of California) annually. Today, less than 1 percent of its virgin flow ever reaches the mouth of the Colorado River.

Glen Canyon Dam probably has had greater impact on the riparian habitat within the Grand Canyon than the combined effects of all other river system modifications in the Upper Basin. It is difficult to conceive of a change in regional climate of sufficient magnitude to reduce average annual maximum flows from 2,486 m^3/s to 803m^3/s, to increase the median discharge from 210 m^3/s, to increase the average diurnal fluctuation in stage from a few centimeters to several meters, to reduce the average annual water temperature from a range of 0.2° to 28°C during the predam period (1949–1962) to a range of 5.5° to 18°C during the postdam period (1962–1976), and to simultaneously reduce the median sediment concentration from 1,500 to 7 parts per million (ppm). Yet the foregoing changes have all been recorded at Lees Ferry, 26 kilometers downstream from Glen Canyon Dam. Each of these changes, and others, has had an effect upon the riparian ecosystem since the completion of Glen Canyon Dam, and inevitably, adjustments in the biota and the physical setting have occurred. Although establishment of a new ecological balance requires many years in response to the new fluvial regime, sufficient time has elapsed since the dam's completion in 1963 to reveal many vegetational and riverine shifts.

The study was undertaken to determine the nature of these transformations and to provide a basis for predicting future trends. Conditions existing prior to the regulation of flow in the Colorado River were established by examining photographs and hydrologic records made between 1872 and 1963. Postdam conditions were documented by referring to recent hydrologic records, by photographically matching scenes shown in the predam pictures, and by recording in detail the distribution of riparian plant species.

In the following material, frequent reference will be made to localities along the Colorado River. In keeping with common practice, "mileage" designations downstream from Lees Ferry will follow those established by the U.S. Geological Survey in 1923 (Birdseye and Burchard, 1924). Lees Ferry, at the stream gaging station, is taken as kilometer 0. All distances are based upon this datum. Distances upstream are taken from Glen Canyon National Recreation Area map (National Park Service, no date). The metric system is given preference in this report; accordingly, distances are given in kilometers. Convention and long usage has firmly established proper names along the river such as Seventyfive Mile Rapid and Two Hundred and Ninemile Canyon. Where these place names appear they are used alone without metric equivalents. For the few localities lying upstream from kilometer 0, distance will be shown as kilometers above Lees Ferry. The long-established convention of referring to riverbanks as left or right when viewed downstream is followed here. The altitude given in the captions refers to altitude at river level, regardless of the camera's position.

Before examining the changes, certain features of the Colorado River and the canyon through which it flows should be reviewed. The reach of the Colorado that we examine in this report lies between Glen Canyon Dam, 26 km above Lees Ferry, Ariz., and Pearce Ferry, Ariz., at kilometer 450 below Lees Ferry (pl. 1). This segment of the river is only a small reach of the 2,700-km-long river, yet because it traverses the Grand Canyon, it is the best known and most famous portion. Strictly speaking, the Grand Canyon extends from the mouth of the Paria River near Lees Ferry downstream to the Grand Wash Cliffs; the reach above the Paria is part of Glen Canyon. The Grand Canyon is 21 km across at its widest point, with a depth of as much as 1,800 meters. Various divisions of the Grand Canyon have long been recognized: These include such reaches as Marble Canyon, Conquistador Aisle, and Upper, Middle, and Lower Granite Gorges.

In its course through the Grand Canyon, the Colorado River moves through a narrow valley and is confined by steep, high walls of mostly hard and resistant rock. There is no flood plain along much of the Colorado's course through the Grand Canyon, and the absence of a flood plain broad enough to reduce the force of annual floods produced a predam valley devoid of the dense riparian community typical of other streams of the region. If one ignores the alternating pools and rapids, the river profile is smooth and nearly straight (Leopold, 1969). The river gradient is under dominant control of the tributary fans. The river's tendency to move laterally is greatly reduced compared to rivers in unconfined channels (Leopold, 1969), and the river's poorly understood proclivity for vertical entrenchment rather than lateral movement has served to maintain through millions of years the narrow gorge that today is viewed annually by nearly 3 million people.

Although no river width and depth data exist for the entire reach described in this report, data are available for selected shorter segments (Leopold, 1969). The available depth measurements made in 1963 represent predam conditions with a flow of 1,375 m^3/s. Through the first 223.7 km below Lees Ferry, maximum river depth was 33.5 m (kilometer 183.9). Roughly 20 percent of the depth measurements, taken at 0.16-km intervals, equaled or exceeded 15.5 m, and 50 percent equaled or exceeded 11.0 m. Width measurements have been taken at 0.16-km intervals from 1965 aerial photographs for the reach between kilometer 45.1 and kilometer 177.0 (Leopold, 1969). Although only generalized width values were given, these provide a broad picture of river conditions. For example, of the approximately 800 measurements, fewer than 5 percent were less than 61.0 m, 50 percent of the observations equaled or exceeded 97.5 m, and 20 percent equaled or exceeded 125.0 m. In general terms this is the river examined here. In following chapters specific characteristics of the river will be discussed with particular emphasis on the impact of Glen Canyon Dam.

ACKNOWLEDGMENTS

Completion of this study required the assistance of many people. We owe a major debt of gratitude to the staff of the Museum of Northern Arizona, who provided transportation and support of many kinds during the course of the study. Support by the Museum included financial support for the junior author during the early months of his work on the study. Dr. Steven Carothers' knowledge of the Grand Canyon ecosystem and his skill as a boatman were substantial contributions during several trips through the canyon. Others from the Museum to whom we are especially indebted include Dr. A. M. Phillips III, Dr. B. G. Phillips, Mr. George Ruffner, Mr. S. H. Aitchison, and Mr. D. S. Tomko. To the Phillips' we owe a special debt of gratitude for their assistance in augmenting our plant distribution data. We also wish to express our appreciation for the skill and assistance of Mr. R. A. Heinz and Ms. Carroll Bennett in obtaining some of the photographic matches.

Librarians at the New York Public Library, Manuscript and Archives Division; the U.S. Geological Survey Photographic Library, Denver; and Grand Canyon National Park were important contributors aiding us in the search for old photographs. The National Park Service has been a major collaborator, providing assistance in many ways, including the opportunity to accompany a Park Service crew on a boat trip through the canyon, as well as providing boat transportation between Lees Ferry and Glen Canyon Dam. To Messrs. M. A. Turner, M. S. Pierce, and Thomas Workman we owe thanks for assistance while in the canyon. Dr. P.S. Martin was an early observer of postdam vegetation changes, and his shared insight and knowledge of the area is gratefully acknowledged. Finally, the patience of our companions on each of six photograph-matching trips, as they waited while we tried to find the exact camera position of some early-day photographer, is acknowledged, with appreciation

CHANGES IN COLORADO RIVER STREAMFLOW REGIME

Construction of a dam across a river produces many changes in the hydrologic regime of the river system both above and below the structure. The changes immediately upstream from the dam, such as water impoundment and silt accumulation are often the most striking. The more subtle downstream hydrologic modifications include smoothing the flow duration curve, lowering maximum stages, and increasing base flow (Leopold and others, 1964). The downstream alterations in the discharge regime may directly affect riparian biotic communities. In the present chapter, pertinent streamflow records for the periods before and after construction of Glen Canyon Dam are presented as a basis for interpreting the vegetation changes that will be noted in later sections. In the chapter following this, we have also examined channel changes and some of the causes for the altered channel geometry.

FLOODS

Before the construction of dams along the Colorado River, flooding was commonplace. One of the better known floods occurred in November 1905, when the Colorado River left its old channel via a manmade canal and flowed into the Salton Sink, thus forming the Salton Sea (Sykes, 1937). The river was not returned to its original channel until February 1907 (Grunsky, 1907; LaRue, 1916). With completion of a series of dams along the lower Colorado River, a recurrence of this event is unlikely. Similarly, floods through the Grand Canyon have been curtailed by the construction of Glen Canyon Dam.

A river characteristic that is closely associated with flooding is annual maximum stage (fig. 1*A*). Stage records for the Colorado River at Lees Ferry and near Grand Canyon, Ariz., have been used to illustrate general changes in maximum stage throughout the reach of the Colorado River examined in this report. (The stream gage "near Grand Canyon" is 0.4 km upstream from Bright Angel Creek and 7.5 km northeast of Grand Canyon, Ariz.) Because of variations in channel and valley geometry, the values provide only a relative measure of the height to which banks might be inundated by flood waters.

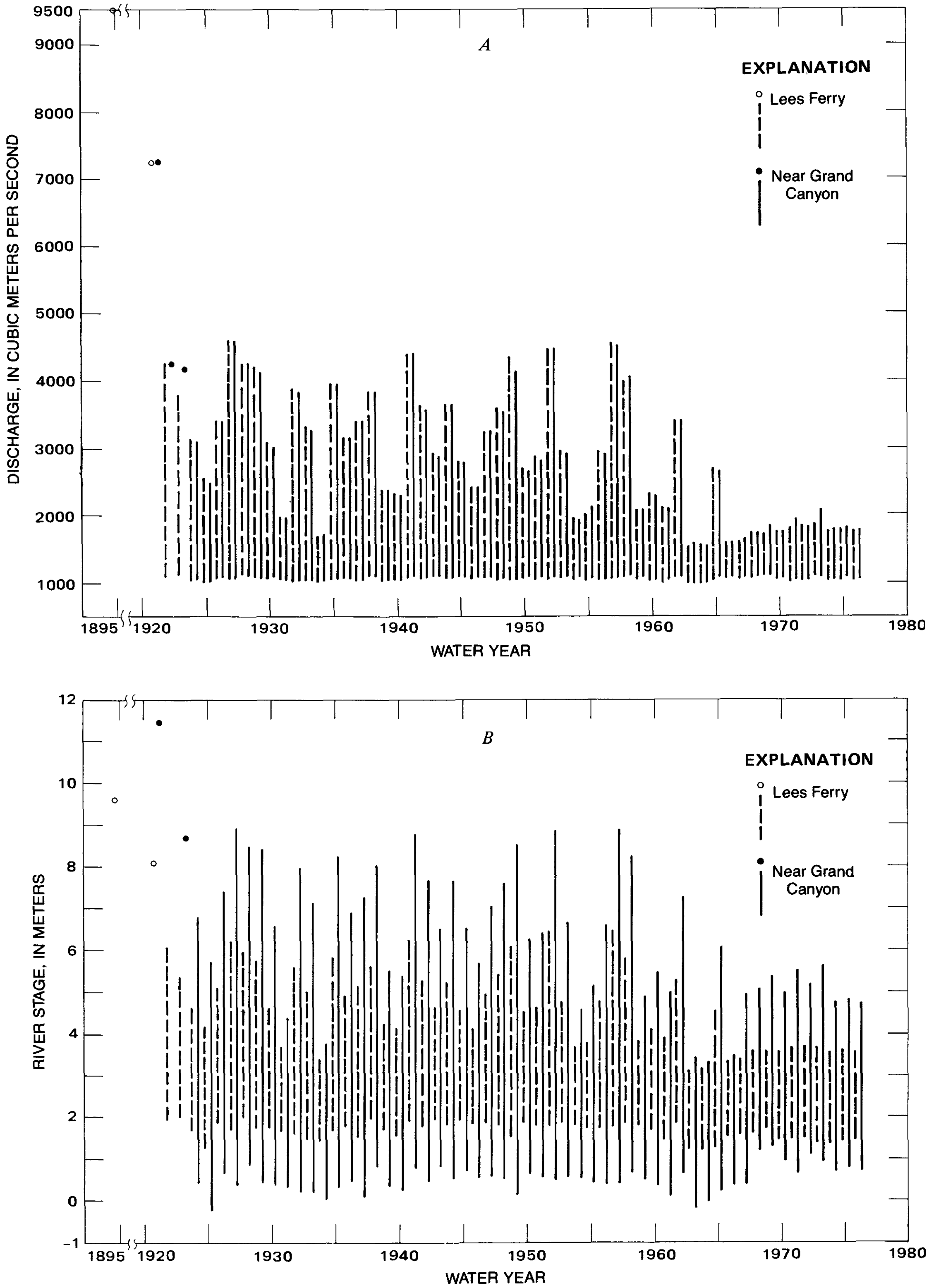

FIGURE 1.—Yearly range between minimum daily and maximum discharge (*A*) and yearly range between minimum and maximum stage (*B*) of Colorado River at Lees Ferry and near Grand Canyon.

Excluding 1965, an anomalous year, the yearly maximum stage (fig. 1*A*; table 1) has varied little at Lees Ferry since Glen Canyon Dam was completed (mean = 3.48 m; std. dev. = 0.19 m). (The high discharge in 1965 resulted from the release of water through a diversion tunnel and hollow jets as a means

TABLE 1.—*Mean, standard deviation, and coefficient of variation of yearly maximum stage for the Colorado River at Lees Ferry and near Grand Canyon*

[Data, based on water years, are values for the total period of record, the predam period, and the postdam period]

	Period of record	Predam	Postdam	
	(1921–76)	(1921–62)	(1963–76)	(1963–76, excl. 1965)[1]
Lees Ferry				
Number of years	56	42	14	13
Mean (meters)	4.67	5.04	3.56	3.48
Standard deviation (meters)	1.06	.96	.35	.19
Coefficient of variation	.23	.19	.10	.06
Near Grand Canyon				
	(1923–76)	(1923–62)	(1963–76)	(1963–76, excl. 1965)[1]
Number of years	54	40	14	13
Mean (meters)	6.35	6.89	4.79	4.69
Standard deviation (meters)	1.57	1.40	.85	.79
Coefficient of variation	.25	.20	.18	.17

[1]The year 1965 was anomalous. See text.

TABLE 2.—*Mean, standard deviation, and coefficient of variation of yearly minimum stage for the Colorado River at Lees Ferry and near Grand Canyon*

[Data, based on water years, are values for the total period of record, the predam period, and the postdam period]

	Period of record	Predam	Postdam	
	(1922–76)	(1922–62)	(1963–76)	(1963–76, excl. 1965)[1]
Lees Ferry				
Number of years	55	41	14	13
Mean (meters)	1.68	1.76	1.46	1.47
Standard deviation (meters)	.21	.17	.15	.15
Coefficient of variation	.12	.09	.10	.10
Near Grand Canyon				
	(1924–76)	(1924–62)	(1963–76)	(1963–76, excl. 1965)[1]
Number of years	53	39	14	13
Mean (meters)	.52	.46	.67	.70
Standard deviation (meters)	.31	.23	.45	.45
Coefficient of variation	.61	.50	.68	.65

[1]The year 1965 was anomalous. See text.

of fulfilling downstream commitments before all the generators were in operation. Since 1965, with all generators operating, flow has been sufficient to meet downstream requirements (A.O. Dewey, U.S. Bureau of Reclamation, oral commun., 1975).) A similar but less marked stability is apparent in the record from near Grand Canyon (mean = 4.69 m; std. dev. = 0.79 m). Annual minimum stage (fig. 1*A;* table 2) appears little changed at Lees Ferry (mean = 1.47 m; std. dev. = 0.15 m) although the record from near Grand Canyon (mean = 0.70 m; std. dev. = 0.45 m) shows a slight increase in these minimal values.[1] (This increase is the result of a December 1966 flood on Bright Angel Creek which deposited new bouldery debris in the Colorado River channel, altering the control for the Colorado River gaging station (Cooley and others, 1977).) At both gaging stations the range between annual maxima and annual minima has been narrowed, especially because of reduced maxima. Thus, the effect of flowing water upon shore-zone plants is now characteristically confined to a rather narrow band at these stations and presumably elsewhere in the canyon.

The maximum stages in figure 1*A* clearly show the reduction in the streamflow amplitude after completion of Glen Canyon Dam. The stage, which had reached 11.43 m near Grand Canyon in 1921, has not exceeded 6.07 m since 1963. Proportional changes in the maximum stage have also been recorded at Lees Ferry.

Means based on the predam and postdam records are shown in table 1. The mean maximum stage at Lees Ferry for the postdam period is 3.48 m, excluding the anomalous values for 1965; the mean for the period prior to the dam is 5.04 m. The mean value for the postdam period is slightly greater than the smallest maximum value (3.37 m), recorded in 1934, for any predam year (fig. 1*A*). Mean values for the Colorado River near Grand Canyon are also given in table 1 and show that as a result of dam construction, mean stage has fallen more than at Lees Ferry. This difference largely results from differences in valley and channel configuration at the two sites.

The coefficients of variation (*CV*) of yearly maximum stages (table 1) during these two periods emphasize further the postdam stability of streamflow. This statistic is a measure of the magnitude of the standard deviation relative to its mean. At Lees Ferry, for the 42-year period before 1963, the *CV* is 0.19; for the 13-year postdam period, it is 0.06 (table 1). Near Grand Canyon the *CV*'s for the predam and postdam periods were 0.20 and 0.17, respectively. The decrease in *CV* is far less near Grand Canyon than at Lees Ferry, a fact largely attributable to flow from the Little Colorado River which enters the Colorado River between the two gaging stations. Flow in the Little Colorado is erratic, there being no large dams along the river, and the unregulated streamflow during flood stage is great enough to affect the flow of the Colorado mainstem.

Prior to 1963, maximum discharges (fig. 1*B*) were almost always greater at Lees Ferry than farther downstream near Grand Canyon. This downstream decrease in maximum discharge probably occurred because of channel storage along the 140.8-km channel from Lees Ferry to the gage near Grand Canyon. In almost all cases, the peaks at Lees Ferry and near Grand Canyon occurred during the same runoff event. Since completion of Glen Canyon Dam, annual peak flows at these stations have not been temporally correlated, and annual peak flows near Grand Canyon have usually been greater than those at Lees Ferry. Before 1963, annual peak flows near Grand Canyon exceeded

[1]These values have been obtained, in part, from unpublished data, including recording charts. When no stage was recorded, estimates were made from available data.

those at Lees Ferry by more than 10 percent during only two years out of 40 (1923 and 1955). In contrast, during the relatively short period 1963–76, peak flows at Grand Canyon have exceeded those at Lees Ferry by more than 10 percent in 1969, 1971, and 1973 (fig. 1*B*). The major reason for the greater peak discharges each time was the flow contributed by the Little Colorado River. In this connection LaRue (1925, p. 116) noted that the large increase in flow at the gage near Grand Canyon in 1923 was produced by a flood on the Little Colorado River.

The reduced flooding along the Colorado River has provided stability in a habitat that was previously highly unstable. Sites along the riverbanks below Glen Canyon Dam are likely to experience approximately the same maximum water depth each year. Before 1963, most newly established plants were subject to possible inundation and uprooting by floodwaters that reached levels considerably higher than those of the postdam period. The dam effectively diminishes the ability of the river to maintain a bank that is periodically stripped of its vegetation.

DAILY STAGE

Figure 2 illustrates daily variations in river stage at Lees Ferry for two randomly selected years: one (fig. 2*A*) prior to the construction of Glen Canyon Dam and the other (fig. 2*B*) after dam construction. In the predam period, depicted by water year 1939, daily variation in stage was usually only a fraction of a decimeter except for periods of flooding when changes of several decimeters might occur. (Freeman (1930, p. 363) mentioned that when the U.S. Geological Survey party was on the river at Lava Falls in September 1923, the river rose 4.27 m during one night.) In the postdam period, as depicted by water year 1973, daily variations of

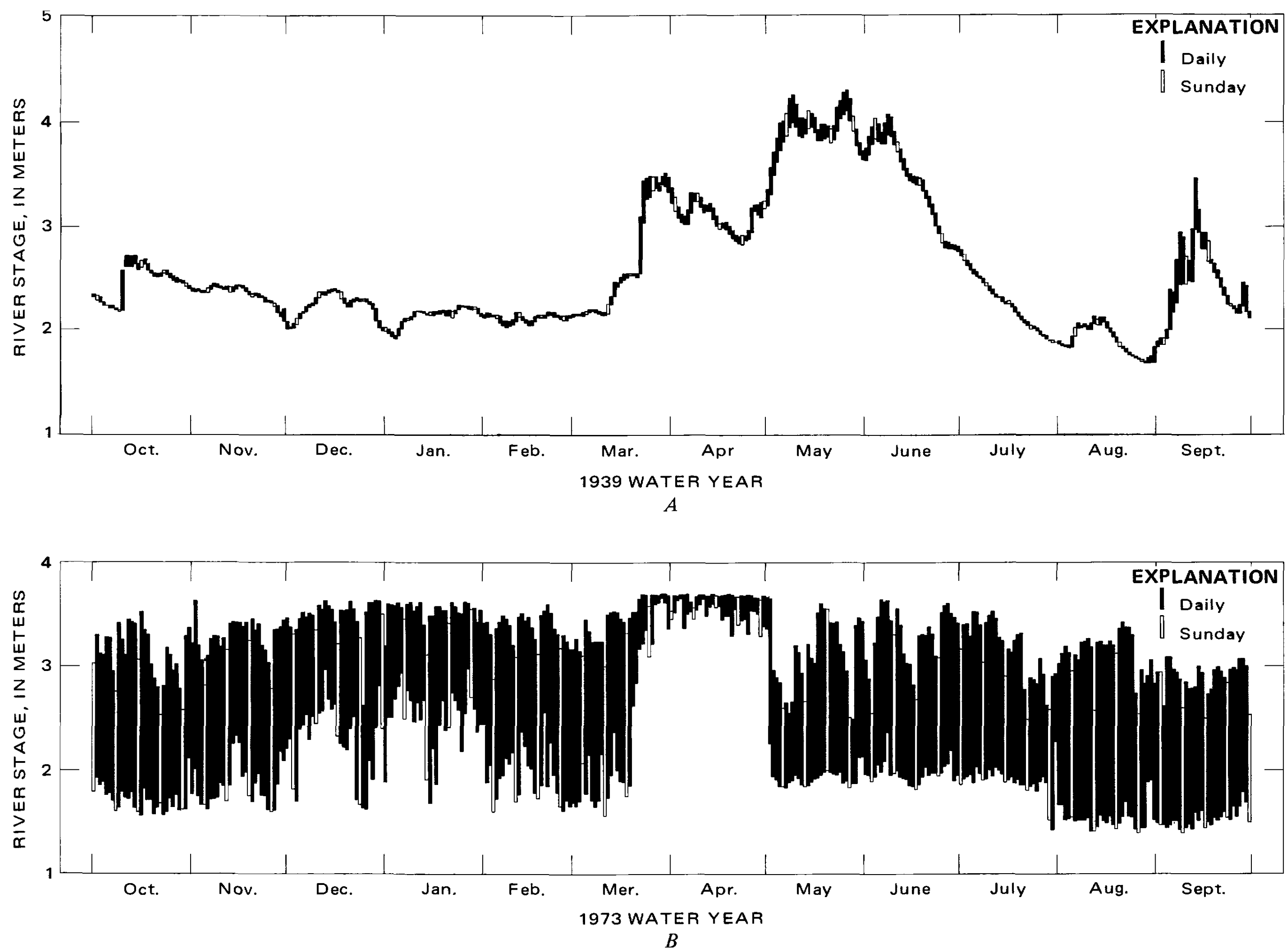

FIGURE 2.—Daily variation in river stage during two selected years, Colorado River at Lees Ferry: (*A*) water year 1939, before Glen Canyon Dam was built; (*B*) water year 1973, after Glen Canyon Dam was completed. Bars connect the daily maximum and daily minimum stage.

more than 1.5 m became typical, and daily variations of less than 0.3 m are almost nonexistent. In 1973, the abnormal releases during March and April resulted from a court decision preventing water of Lake Powell from rising to the base of Rainbow Bridge (Mann, 1976). The predam water year, 1939, shows no difference between stages on any periodic basis. However, the post dam water year, 1973, shows a significant 7-day periodic drop in stage on most Sundays with some striking drops seen on holidays such as Christmas, New Year's, Memorial Day, and Labor Day, as a consequence of decreased power demands on Glen Canyon Dam generators. One additional note that should be made is that 1939 was a year with below normal runoff at Lees Ferry (less than 11,714 hm^3) and with a relatively small maximum discharge (less than 1,416 m^3/s).

ANNUAL DISCHARGE

Within the Grand Canyon vast differences in annual streamflow occurred prior to the construction of Glen Canyon Dam (fig. 3). Discharge, as recorded at the gage near Grand Canyon located 141 km below Lees Ferry, ranged from a low of 5,200 hm^3/calendar year in 1934 to 24,500 hm^3/calendar year in 1929. Since 1962, however, annual flow has ranged from a low of 2,000 hm^3/calendar year, when Lake Powell was filling, to 14,500 hm^3/calendar year in 1965. Postdam streamflow generally falls within the range of 9,900–12,300 hm^3/calendar year. The greater flow at the Grand Canyon compared with that at Lees Ferry, averaging approximately 493 hm^3 annually, results from the contribution of the Little Colorado River (Thomas and others, 1960).

MONTHLY DISCHARGE

Prior to construction of Glen Canyon Dam, the maximum monthly mean discharges generally occurred during the month of June as a result of spring snowmelt in the high mountains at the headwaters of the Colorado River. During postdam years the maximum monthly means have occurred in May and are primarily the result of power and irrigation demands.

During the predam period the maximum monthly mean discharge, 4,300 hm^3, was more than ten times greater than the lowest monthly mean discharge. During the postdam period, the ratio of maximum to minimum is only 1.8 : 1.

The seasonal variability was strongly unimodal during the predam period with a maximum during May and June and a minimum during December, January, and February (fig. 4). Much of the old pattern is now lost. The timing of the annual peak is little changed,

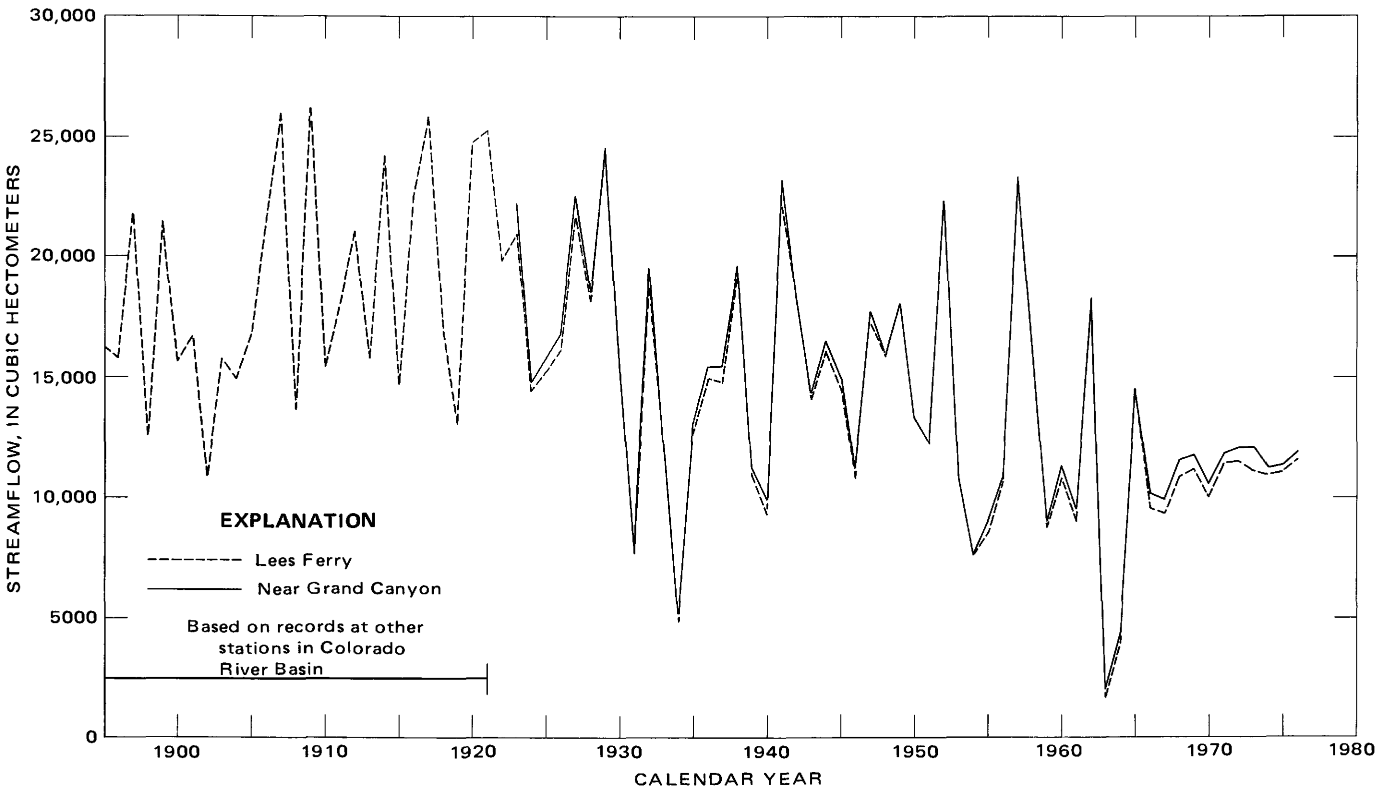

FIGURE 3.—Annual streamflow (by calendar year) of Colorado River at Lees Ferry and near Grand Canyon.

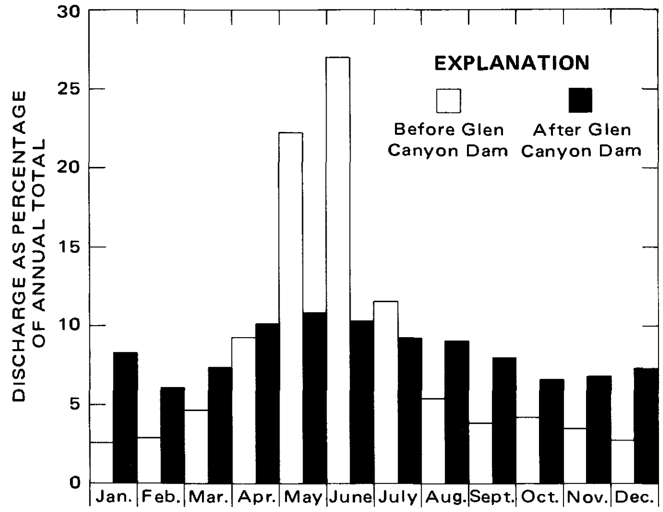

FIGURE 4.—Monthly mean discharge as a percentage of total annual discharge, Colorado River, Lees Ferry: open bars, period before Glen Canyon Dam (calendar year 1901 through calendar year 1962); solid bars, period after Glen Canyon Dam (April 1963 through March 1977).

but the relative magnitude of the monthly values now shows little variation.

CHANGES IN CHANNEL AND ALLUVIAL DEPOSITS IN THE COLORADO RIVER BELOW GLEN CANYON DAM

Except through the Marble Gorges where the canyon is narrow and its walls descend steeply to the river, there are few reaches of the Colorado through the Grand Canyon in which recent alluvium is not a conspicuous feature of the fluvial environment. In some reaches, such as those between Glen Canyon Dam and Lees Ferry, from Lava Canyon to Unkar Creek, and the segment above and below Granite Park, the canyon floor is fairly broad and alluvial flats are well developed (figs. 27, 30, 33, 47, and 64).[2] In most other places, however, deposits of fine alluvium are discontinuous, commonly appearing at the tributary mouths, in eddy zones upstream from rockfalls and boulder deposits, or as scattered flood deposits on lower talus slopes.

The characteristics of alluvial deposits are determined by the interplay among channel features and recent discharges of water and sediment. The extent of deposits and their textural composition are controlled by the nature of recent streamflow events. The predam sediment deposits along the Colorado River probably underwent seasonal variations due to the strongly seasonal character of streamflow events. Because the postdam hydrologic regime shows little seasonal variability, the deposits have had to adjust to the new fluvial environment. Marked changes in riparian plant cover would also affect these deposits through the stabilizing influence of the plants.

The amount of silt carried by rivers has long been known to depend largely on the characteristics of the precipitation producing the runoff. These precipitation characteristics include intensity, duration, frequency, distribution, and season of occurrence (Daines, 1949; Thomas and others, 1960). Nevertheless, there is a close relationship between discharge alone and the amount of suspended sediment recorded at Grand Canyon (Daines, 1949; Thomas and others, 1960; Kister, 1964). Interestingly, the relationship between these two streamflow variables shifted markedly in the early 1940's. Figure 5 shows that prior to 1943 a given annual discharge in cubic hectometers (hm^3) at Lees Ferry was related to sediment yield in megagrams (Mg) by a regression line slope of 16.46. From 1943 to 1963, the slope of the regression line was 5.74. During the postdam period the near absence of sediment at any discharge has resulted in a regression line with a slope of approximately 0. Similar shifts in the sediment-discharge relationship for the station near Grand Canyon occurred at the same times. The 1943 shifts in the sediment-discharge relationships have been discussed by Daines (1949), Thomas and others (1960), and Kister (1964) and may be the result of changes in measurement techniques or of the regional drought in arid watersheds.

That Glen Canyon Dam has a dominant effect on the entire reach to Lake Mead is shown by comparing the predam and postdam sediment yield at the station near Grand Canyon with that at Lees Ferry (fig. 5). In spite of contributions from the Paria and the Little Colorado Rivers below Lees Ferry, sediment yield near Grand Canyon is greatly reduced in the postdam period and is little more than the Lees Ferry values.

In a predam analysis of monthly sediment data, Thomas and others (1960) observed a consistent seasonal trend in sediment load. A spring period, usually May and June, was characterized by high sediment load which correlated with high discharge values. These high values coincided with the period of snowmelt in the river's headwaters. A secondary maximum in runoff and sediment load coincided with the period of summer rains and usually came in August or September. During this late summer and fall period the concentrations of sediment were usually higher than during the spring period.

With the closure of the Colorado River by Glen Canyon Dam, sediment carried by the Colorado River is being trapped in Lake Powell at an estimated annual rate of 128×10^6 m^3 (Gessel, 1963). Releases from the

[2]Figures 26–73 are matched photographs found at end of report.

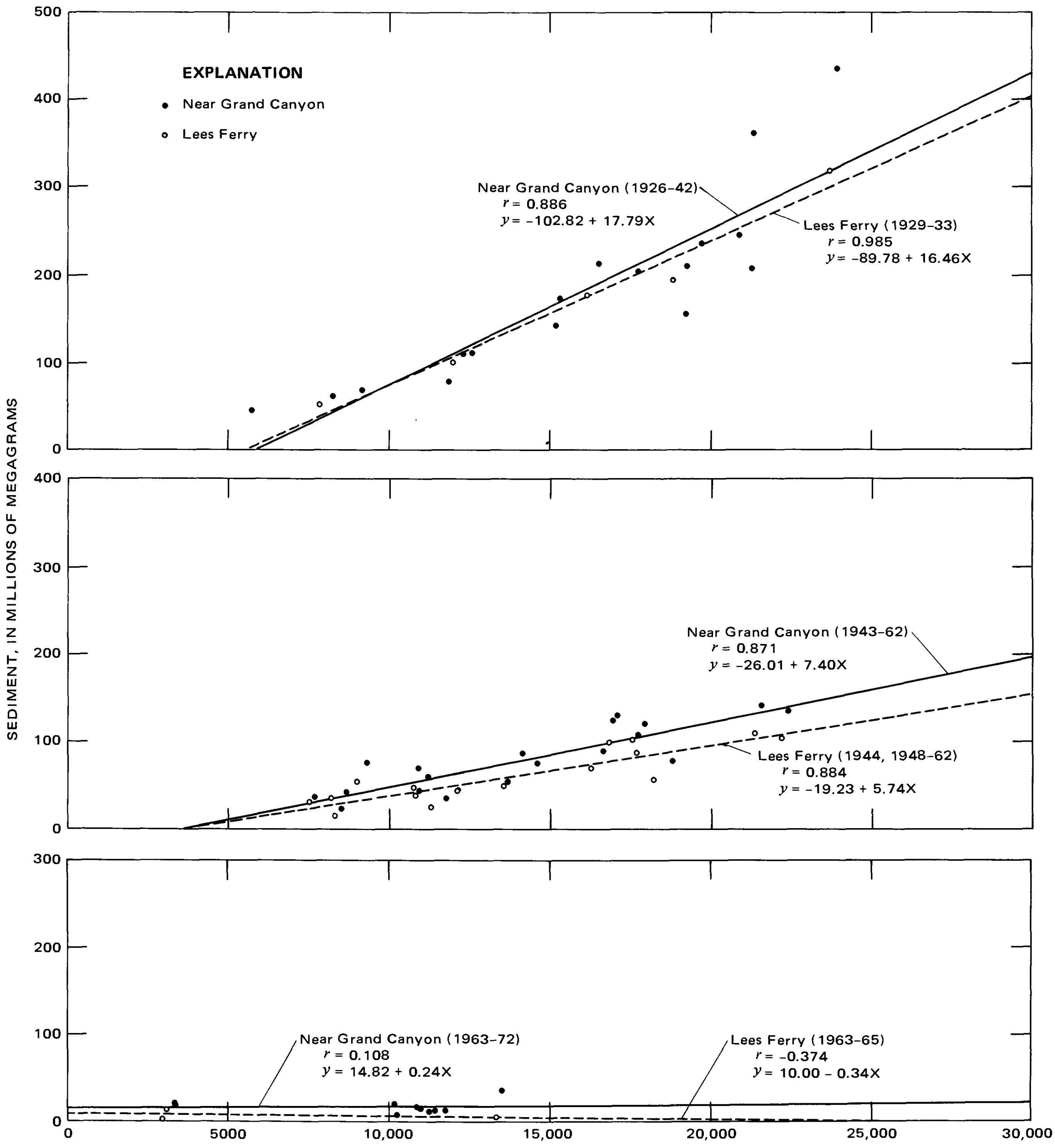

FIGURE 5.—Regression analyses of annual (water year) discharge versus sediment yield as recorded at Lees Ferry and near Grand Canyon.

dam are therefore of clear water and the river's capacity to transport sediment has sharply increased. Because closure has lowered the peak stages, the river's competence to rework tributary debris has diminished and the nature of transported sediment has changed. The changes in fluvial regime have brought about channel changes, many of which were anticipated before dam construction began.

Twenty channel cross sections were surveyed by the Bureau of Reclamation in the reach of river between Glen Canyon damsite and Lees Ferry during 1956, the year dam construction started. These measurements provide base-line data for later observations. The same twenty sections were resurveyed in 1959, 1965, and 1975 (Pemberton, 1976). Erosion occurred at an accelerated rate immediately below the damsite during the construction period from 1956 to 1959 (fig. 6). The degradation that first occurred just below the dam progressed downstream during the next measurement period between 1959 and 1965. By 1975, within the 26-km reach between the dam and the mouth of the Paria River at Lees Ferry, resurveys showed that about 9.87×10^6 m^3 of bottom sediment had been removed from the channel. As this sediment has been removed coarser material has been exposed, resulting in considerable channel armouring by gravel. Approximately 10 gravel-cobble control bars occur through the 26-km reach above the Paria, effectively stabilizing the channel. Comparison of 1975 profiles with those from 1965 indicate that the channel has been quite stable during the past decade with only 12×10^4 m^3 of sediment being scoured from the river bottom during this period. As another indication of stability, Pemberton (1976) noted that some sandbanks were being held in check by increasing plant cover.

In a study of postdam sediment transport through the Grand Canyon, Laursen and others (1976) found considerable evidence of bank erosion between Glen Canyon Dam and Lees Ferry. They found that most talus slopes and beaches either had vertical slump faces or they were protected by exposed rock. The beaches that remain, they found, were in the lee of obstructions or other bank configurations that produce lee eddys. They noted: "On the few sizable beaches left the 'campsite' sign has had to be moved back several times as the beachline retreated." They concluded that

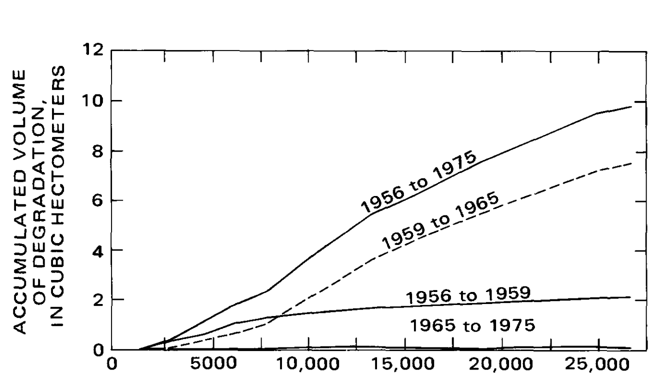

FIGURE 6.—Accumulated volume of degradation below Glen Canyon Dam for various periods between 1956 and 1975 (modified from Pemberton, 1976).

since completion of Glen Canyon Dam, channel degradation had progressed to the vicinity of Lees Ferry and that continuing degradation could be expected downstream through the Grand Canyon. Extrapolating from the known rate of degradation above Lees Ferry, they concluded that somewhat more than 200 years will pass before most of the beaches vanish from the reach below Lees Ferry.

In view of the anticipated changes noted in the foregoing, we have looked in the photographs presented in a later section for evidence of geomorphic changes related to dam construction.

A HISTORY OF PHOTOGRAPHY ON THE COLORADO RIVER

A brief chronological history of photography on the Colorado River will be presented here. Several centuries of exploration preceded the development of the photographic process; it was not until 1871, at the time of Powell's second trip and the Wheeler Survey, that photographs were taken along the Colorado River within the Grand Canyon. There are several sources giving the history of earlier explorations. Notable among these is Dellenbaugh (1903).

The first trip by boat through the Grand Canyon was made by Major J. W. Powell and his men. Powell left Green River, Wyoming, on May 24, 1869, with a crew of nine. Although photography had been developed to a crude but dependable stage by this date, no photographer accompanied this first historic trip. By the time the expedition reached the mouth of the Virgin River on August 30, 1869, four men had quit the group. Powell and two others left the canyon at the Virgin River, leaving four to continue toward the Gulf of California (Smithsonian Institution, 1875; Powell, 1895; Kolb, 1914).

Because of the numerous problems encountered on the first trip, including the loss of much equipment, the results were not as desired and Powell later arranged to make a second trip. The second trip was made in two parts. Powell and a group of 10 men left Green River, Wyoming, on May 22, 1871, and arrived at the mouth of the Paria River on October 23, 1871 (Dellenbaugh, 1908; Thompson, 1939; Bartlett, 1962). After a lapse of several months, Powell's second passage down the Colorado River was resumed at Lees Ferry on August 17, 1872, and ended on September 7, 1872, at Kanab Canyon (Dellenbaugh, 1903; Kolb, 1914; Thompson, 1939; Bartlett, 1962; Fowler, 1972).

Among the members of this second expedition, as it left Green River, was a professional photographer, E. O. Beaman, who made approximately 350 photographs during the next few months, both on and off the river (Darrah, 1948). Beaman did not continue past Lees

Ferry, and his duties were taken over for a brief period by Clem Powell, who was later replaced by James Fennemore, a professional photographer (Thompson, 1939). Fennemore photographed the river from Fremont Creek (Dirty Devil River) down to Lees Ferry. Because of ill health, however, he was forced to quit after having taken some 70 photos (not all on the river). His replacement was J. K. Hillers, who, although initially hired as a boatman, was quick to grasp the photographer's art with the aid of Fennemore. Hillers later became chief photographer for the U.S. Geological Survey. He took some 3,000 photographs between 1872 and 1878 on Powell's expeditions in the Colorado River region (Darrah, 1948). Hillers had a keen eye for composition, and many of his photographs are regarded as masterpieces.

While Powell and his party were making their second trip down the Colorado River, the Wheeler expedition started out on September 16, 1871, from Camp Mohave to go up the Colorado some 322 km to Diamond Creek. On October 19, 1871, after 33 days of very difficult travel, they arrived at their destination (Wheeler, 1872; Dellenbaugh, 1903; Horan, 1966). T. H. O'Sullivan, who took his photographic apprenticeship with M. B. Brady and became the first photographer of the U.S. Geological Survey, was a member of the Wheeler expedition (Horan, 1966). He took some 300 photographs while with Wheeler, a few of which were taken in the Grand Canyon (Wheeler, 1889; Horan, 1966).

The following year (1872) William Bell, an English physician, took O'Sullivan's place as photographer, accompanying the Wheeler Survey into the canyon (Wheeler, 1874; Horan, 1966; Watkins, 1969) both along Kanab Creek and at Lees Ferry. Bell was apparently the first Grand Canyon photographer to experiment with dry-plate photography but with little success (Watkins, 1969).

In 1873, O'Sullivan again joined the Wheeler Survey as photographer. He visited and photographed the river at Lees Ferry during that year.

By the time the Powell and Wheeler Surveys had ended, approximately 3,500 photographs had been taken of the Grand Canyon region. That so many photographs were taken during this early period of Colorado River exploration is all the more surprising when one realizes that the most advanced photographic process at the time was the wet-plate technique which required that the photographer make his own negative by applying wet chemicals to a glass plate just prior to its use. He then had to develop the negative without delay following exposure. The operation required a portable darkroom with many chemicals, jars, bottles, and glass plates. This fragile, bulky cargo, including a large box camera, accompanied the first photographers of the river and often must have been an unappreciated extra burden. After about 1874 this method was replaced by other processes requiring less bulky equipment.

In 1889, two decades after Powell's first historic trip, a railroad survey for the proposed Denver, Colorado Canyon, and Pacific Railway was organized by F. M. Brown, with R. B. Stanton as chief engineer and F. A. Nims as photographer. The expedition started out on May 22, 1889, from Green River, Utah, and ended about 51.5 km below Lees Ferry. By the time the party had reached this point, three men, including Brown, had drowned—needlessly, it seems, for Brown had rejected recommendations to take life jackets for the men. The surviving members of the party climbed out of the canyon near Vaseys Paradise (Stanton, 1965).

A second expedition, with Stanton now in full charge and with all hands supplied with specially designed life jackets, resumed the survey on December 10, 1889. The new boats were hauled overland from Green River, Utah, to the mouth of Crescent Creek in Glen Canyon (Stanton, 1965; Smith, 1967). The party entered Marble Canyon below Lees Ferry on December 28, 1889 (Stanton, 1965). Four days later on January 1, 1890, Nims was seriously injured in an accident. He was lifted and carried out of the canyon, and the expedition continued without him. At this time Stanton decided to assume Nims' duties as photographer, never before having taken a photograph. He was to take some 2,200 photographs during the entire trip but did not know until after the first 1,200 were taken whether any of the photographs were properly exposed. The cameras on this trip used roll film and were far easier to employ than those used earlier on the Powell and Wheeler expeditions. The photographs taken by Nims and Stanton are a particularly rich source of data because the camera was used—as an adjunct to the surveyor's transit—to show an almost unbroken panoramic view of the river from its headwaters to its mouth (Stanton, 1965).

Several years elapsed before other photographers entered the canyon. G. W. James and his companion, Nathan Galloway, started from Lees Ferry in about 1898 and travelled up the river through Glen Canyon, then down river past Lees Ferry a few kilometers to Soap Creek Rapids (James, 1907). James took many photographs of the river. H. G. Peabody made numerous photographs of the canyon around 1900 using dry-plate negatives (Watkins, 1969). In 1901–02 photographs were taken along the lower Colorado River from Gregg's Ferry (Walapai damsite) to Yuma on two trips led by J. B. Lippincott (Lippincott, 1903; Lippincott and Ahern, 1903). F. S. Dellenbaugh also took pictures of the Colorado River in 1907 (Dellenbaugh, 1908). Many others including F. H. Maude, A. F. Messinger, and Oliver Lippincott were to capture the Colorado and its canyons on film (James, 1907).

Other photographs were taken by a group including C. S. Russell, E. R. Monett, and Albert Loper who started downriver from Green River, Utah, on September 20, 1908. Four days later below the junction of the Green and Colorado Rivers, Loper's boat was damaged along with his camera and plates thus ending the photographic coverage for that trip. Loper remained behind for boat repairs at Hite while Russell and Monett proceeded to Lees Ferry to wait. They got tired of waiting for Loper and continued on to Needles. When Loper finally arrived at the Paria and found that the others had continued on without him, he left the river (James, 1910; 1914).

In 1909 a trip was organized by J. F. Stone and Nathan Galloway to go down the Colorado River for the specific purpose of taking photographs. They were accompanied by a photographer, R. A. Coggswell, and by S. S. Deubendorff and C. C. Sharp (Kolb, 1914). The party left Green River, Wyo., on September 12, 1909, and arrived at Needles on November 19, 1909 (James, 1910; Kolb, 1914; Stone, 1932).

The first motion pictures of the canyon were made by the Kolb brothers, E. L. and E. C., using a Pathé camera. They began their trip at Green River, Wyo., on September 8, 1911, and arrived at Needles on January 18, 1912 (Kolb, 1914).

The U.S. Geological Survey made studies of potential damsites along the Colorado River in the early 1920's (LaRue, 1925). In the fall of 1921, Cataract Canyon was surveyed by W. R. Chenoweth, E. C. LaRue, Sidney Paige, Frank Stoudt, E. L. Kolb, and, as photographer, E. C. Kolb (Freeman, 1923, p. 360). L. R. Freeman and several others went up the Colorado River from Lees Ferry to Halls Crossing and then down again with LaRue and others to Lees Ferry in 1922, surveying Glen Canyon for a damsite and also taking photographs (Freeman, 1930, p. 76–77).

Another U.S. Geological Survey team left from Lees Ferry on August 1, 1923, arriving at Needles on October 19, 1923, some 734 km downstream (LaRue, 1925, p. 126). Lt. Col. C. H. Birdseye, Chief Topographic Engineer of the Geological Survey, was the leader. Some other members of the expedition were R. W. Burchard, R. C. Moore, E. C. LaRue, and L. R. Freeman (Freeman, 1937). E. C. LaRue, L. R. Freeman, and E. C. Kolb were responsible for taking still and moving pictures on the trip (Freeman, 1930).

After the studies by the U.S. Geological Survey were completed in 1923, the exploratory phase of the Colorado River travel ended. Detailed maps of the river and its canyon from Lees Ferry to the Virgin River were published in 1924. Trips by boat through the Grand Canyon continued, but until large inflatable boats became available in the 1950's the trip was too dangerous to appeal to most people.

In 1968 a U.S. Geological Survey expedition was orgnized by E. M. Shoemaker with H. G. Stephens serving as photographer. The party followed the route of the second Powell expediton and successfully secured new comparison photographs of 95 percent of the Powell photographs that are preserved in the National Archives. Ten photographs from this 1968 expedition have been published with their earlier Powell expedition counterparts, but these are all from the reach upstream from Lake Powell (Shoemaker and Stephens, 1975).

The National Park Service, in 1974, began an ecological survey of the reach of the Colorado River we study here. Using photographs assembled for the present study, a number of camera stations were found and duplicate views recorded on film (Karpiscak, 1976).

VEGETATION

The difference in altitude from the plateaus flanking the Grand Canyon to the Colorado River at the canyon bottom locally exceeds 1,520 m. This great range fosters a varied vegetation pattern within the vertical 1.5 km above the river. Dense coniferous forests at the rim may overlook open desertscrub far below on the valley floor, and several vegetation zones occupy the intervening slopes. Much less variety in vegetation occurs on the arid slopes along the floor of the canyon through the 474.7 km reach from Glen Canyon Dam to Pearce Ferry. At the lower end of this reach, the vegetation is predominantly an extension of Mojave Desertscrub; at the upper end, Great Basin Desertscrub (Brown and Lowe, 1974a; b). Through this reach there is a fall of 571.5 m, an associated rise in temperature, and an apparent increase in desert plant biomass. The gradual increase in temperature is correlated with changes in species distributions along the river valley; none of the floral changes affects the basic open shrubby appearance of the arid-slope communities.

The Colorado River, in its passage through the arid environment along the bottom of the canyon, creates a moist riparian habitat along its banks. Sand and silt deposits, gravel bars, rock piles, and cliff faces all provide more or less suitable substrates for plants at the water's edge. These varied habitats contribute greatly to the variety of plant life along the river.

Several early travelers through the Grand Canyon made brief notes of vegetation. Powell (1875) noted the high waterline marked by scattered hackberry trees.

Stanton made few references to vegetation, although he did record the presence of mesquite groves from Point Hansbrough to a point 22.5 km below the mouth of the Little Colorado (Stanton, 1965).

Several botanical observations were made along the Colorado River at locations accessible from the canyon rims and below the Grand Wash Cliffs. The reach of the Colorado River from the mouth of the Bill Williams River to a point 96.5 km upstream was traversed by J. M. Bigelow, a member of the Whipple expedition of 1853–54. The most common species along the river noted were cottonwood, mesquite, and willow (Bigelow, 1856). J. S. Newberry and a Mr. Mollhousen, who were members of the Lt. J. C. Ives expedition of 1857–58, made some plant collections along the lower sections of the Colorado River including the mouth of Diamond Creek. They commented on the common presence of arrowweed along the banks of the Colorado for the first 805 km above the mouth of the river. In addition, mesquite and catclaw were found to be common below Black Canyon (Ives, 1861). Cannon (1906) noted that a species of *Baccharis* was one of the primary plants growing along the river at the foot of Bright Angel Trail.

Aside from these brief observations, there was no general description available of the vegetation in the canyon until the detailed floristic study of Clover and Jotter (1944), who were with the party led by N. D. Nevilles. Their route followed the course of the Green River from Green River, Utah, to the river's confluence with the Colorado River and then along the Colorado River to Hoover Dam. The trip by boat through the canyon was made in 1938. Additional observations and collections were made in 1939 at a few localities that could be reached by foot or vehicle. Although their purpose was mainly to collect and identify plants and record plant distributions, they gave brief descriptions of the plant habitats and dominants of these sites. They described five habitats found along the canyon bottom: a margin of moist sand next to the river; above that, dry sandy shores; rubble and boulder areas; talus slopes; and areas about springs and waterfalls. One of their general observations of the vegetation is noteworthy: "Owing to constantly changing conditions of the talus by landslides, and of the river's edge in consequence of periodic floods, there is little climax vegetation in the Canyon of the Colorado. However, vegetation may remain undisturbed for years, chiefly at springs and on stabilized portions of the lower talus" (Clover and Jotter, 1944, p. 620).

Several lists of plant species have been published for the Grand Canyon or for adjoining areas (McDougall, 1947; Deaver and Haskell, 1955; Gaines, 1960; Phillips and Phillips, 1974; and Phillips, 1975).

In a description of postdam riparian conditions in the Grand Canyon, three zones were recognized by Dolan and others (1974). According to their scheme, the lowest zone is at the river's edge and consists of postdam fluvial sediments. The dominant plants here are arrowweed, saltcedar, coyote willow, and Bermuda grass. The second zone is of predam fluvial sediments, reworked by eolian processes, and may lie as much as 5.5 m above the present highwater. The common species here are arrowweed, red brome, camelthorn, and Russian thistle. The third zone, of predam flood terraces and eolian deposits, forms the highest beach zone described and may lie as high as 9 m above present highwater. The important species in this area are Apache plume, catclaw, western honey mesquite, and desert broom.

DISTRIBUTION Of MAJOR PLANT SPECIES

In September 1976, we made virtually continuous observations of the occurrence of the dominant plant species growing along the valley of the Colorado River from Lees Ferry to Diamond Creek. These data are based largely upon observations made from the river while aboard boats. A few collections were made during the same trip. Low plants such as Bermuda grass were difficult to sight from the raft and are probably underrepresented in our data. These detailed sightings were supplemented by more casual observations between Lees Ferry and Glen Canyon Dam during the same period and from Lees Ferry to Lake Mead in 1972. In addition, unpublished records of sightings and collections by scientists from the Museum of Northern Arizona and from P. S. Martin, University of Arizona, (written commun., 1970 and 1971) have added significantly to the record. Sightings and collections based on the 1938 trip of Clover and Jotter have also been included as have Jotter's 1939 records from localities accessible by foot (Clover and Jotter, 1944). Data from all these sources are presented in a series of distribution maps (pls. 2, 3, figs. 7–25) showing the occurrence of 24 species at 1-mile intervals along the river beginning at Glen Canyon Dam.

The use of miles instead of kilometers for plotting distributions was mainly for convenience. Because no map with distances marked off in kilometers was available for field use, we used as a base for recording distributions a map with river distances in miles (Belknap, 1969). When referring to the maps, the differences in data reliability should be kept in mind: Casual observations were made for the Glen Canyon Dam-Lees Ferry reach and the Diamond Creek-Pearce Ferry reach, and virtually continuous observations were made for the Lees Ferry-Diamond Creek reach.

The distribution records are based on occurrences near the floor of the main canyon; thus, plants growing nearby in tributary canyons have been intentionally excluded. Observations were confined to the area extending from the present water level to the band of vegetation immediately above the predam flood line. The habitats in which most of the plants occur are postdam fluvial sediments, predam fluvial sediments, and predominantly fine-grained stabilized talus slopes.

The communities in which these species occur are narrow with sharply defined boundaries. The communities on the stabilized talus slopes are apparently limited on the upper side, now as in the past, by unstable conditions or by too little soil. The lower edge of this community was generally sharply defined by the scouring action of major predam floods. Because large floods of predam magnitude no longer occur, this boundary may become less sharp with time.

The written descriptions of distributions that follow indicate which species are apparently undergoing broad changes in distribution and which are merely becoming more abundant within their preexisting range. The set of maps will be useful to future observers for detecting trends in plant range variations.

Five of the 25 plant species for which we present distribution data are introduced to this area. Those five are discussed first.

BERMUDA GRASS

A native of Eurasia, Bermuda grass is almost ubiquitous in warmer parts of the world and was growing along irrigation ditches in Tucson, Arizona, as early as 1891 (specimen, University of Arizona Herbarium). Clover and Jotter (1944) cite occurrences of the species at a few places on or near the Colorado River in 1938, and the grass was probably well established at that time. They found it as far upstream as Bright Angel Creek (kilometer 143.2) but not in the main canyon (fig. 50). Our records (pl. 2, fig. 7) for the Colorado River valley show its first occurrence 144.8 km farther downstream (kilometer 228). Clover and Jotter (1944) also noted that it was apparently a recent colonist rapidly becoming established along the shores of Lake Mead. This plant probably occurs throughout the reach of river we studied, although our records do not show this.

RUSSIAN OLIVE

Russian olive is a common naturalized species in Arizona and adjacent states. It is found along the Rio Grande as far south as El Paso but is better adapted to more northerly environments along that river above Elephant Butte Dam (Campbell and Dick-Peddie, 1964). Christensen (1963) reports the plant established in nature by 1925 in Nevada, by 1942 in Arizona, by 1948 in Utah, and by 1954 in Colorado. Its ability to spread rapidly into a new area is shown by Harlan and Dennis (1976) who noted that the species was planted in Canyon de Chelly National Monument, Arizona, in 1964; by 1974, it was one of the dominant trees of the canyon bottoms.

The tree was first noted in the Grand Canyon at the mouth of Kanab Creek in 1973 (R. R. Johnson, U.S. National Park Service, written commun., 1978), and it is known from the Paria River near Lees Ferry (M. G. Simons, written commun., 1978).

Four of the recent sightings of this tree along the Colorado River have been within 16 km of Lees Ferry (pl. 2, fig. 8). Two collections by the Museum of Northern Arizona at kilometers 231 and 232 (shown as one locality in figure 8) are just below the mouth of Kanab Creek. The tree may have entered the valley of the Colorado River via the Paria River and Kanab Creek and will likely spread from the present localities near these tributaries.

SALTCEDAR

Saltcedar was probably brought to Arizona before 1900 and was found in the wild state along the Salt River in 1901 (Robinson, 1965). It was reported along the Colorado River near the mouth of the San Juan River during the period between 1933 and 1938 (Woodbury and Russell, 1945). Tidestrom (1925) lists *Tamarix gallica*, a species often confused with *T. chinensis*,[3] as an escaped plant along the Virgin River near St. Thomas, Nevada. Thus, by the late 1920's and 1930's, saltcedar was probably a common plant throughout the Colorado River drainage basin, although as Christensen (1962) noted, the fastest rate of invasion may have occurred during the 20-year period from 1935 to 1955. Clover and Jotter (1944) noted that saltcedar was found in 1938 in the entire length of the area we later mapped, except for "a considerable stretch in Marble Canyon." In 1936 it was noted from Nankoweap Creek to the base of Tanner Trail (Patraw, 1936) and at the mouth of Bright Angel Creek (Dodge, 1936). McDougall (1947) did not mention it in his checklist of Grand Canyon plants. Robinson (1965) mapped the occurrence of saltcedar in the western states and showed it along the Colorado River both above and below our area. On his map it was conspicuously absent from the entire Grand Canyon. The absence of this species in all but one of the early photographs (fig. 36*A*) indicates that it occurred during the predam period merely as widespread isolated plants.

[3]The taxonomic status of the introduced and naturalized saltcedar is unsettled. If several species of this difficult group occur in Arizona, as claimed by Baum (1967), then it is possible that our observations along the Colorado River include more than one species. Until the confusion over the identity of the introduced saltcedar is cleared, we prefer to regard all the saltcedars recorded along the Colorado River through the Grand Canyon as one species, *Tamarix chinensis* Lour.

We believe that its nearly continuous presence today (pl. 2, fig. 9) postdates Glen Canyon Dam. This plant reproduces vigorously from seed that remains viable for only a few weeks (Horton and others, 1960). The seedlings require high levels of soil moisture for a prolonged period before establishment occurs. The daily flooding of river bars provides a reliable source of water during the critical period of seed production (approximately April to October). The plants are prolific seed producers; the soil surface may receive as many as 17 viable seeds per square centimeter per season (Warren and Turner, 1975). Saltcedars grow densely along the Colorado River today because of the uniform, dependable moisture supply on the river bars, because of the stable habitat, and the abundant seed source that is available through most of the warm season.

ELM

In 1976, A. M. Phillips III, Museum of Northern Arizona, (oral commun., 1976) found elm at several places near Glen Canyon Dam (pl. 2, fig. 7). It presumably reached the Colorado River from plantings almost directly above at the Page, Ariz., golf course. We know of no other wildland occurrences of the plant. A related species, Siberian elm (*Ulmus pumila* L.), has been rapidly increasing in lowland areas of Utah since its establishment in about 1935 (Christensen, 1964).

CAMELTHORN

The spiny shrub camelthorn was introduced from Asia. The plant entered California via shipments of alfalfa seed prior to the 1930's (Robbins and others, 1941) and has been known in Arizona since the 1930's when it was collected (specimens at the University of Arizona Herbarium) along the Little Colorado River west of Leupp in 1934 and on the Gila River at Gillespie Dam in 1937. Camelthorn was first reported along the Colorado River in 1970 (P. S. Martin, University of Arizona, written commun., 1970) at kilometer 269.5 and at Cardenas Creek, 114.2 km below Lees Ferry, where it had only recently become established. We found it (1976) 1 km below the mouth of the Little Colorado River, and A. M. Phillips III, Museum of Northern Arizona, collected it just below the mouth of the Little Colorado River (written commun., 1978). It occurs at many sites downstream from there, but we do not know of its occurrence above this locality (pl. 2, fig. 10). The shrub probably reached the Colorado River valley via the Little Colorado drainage. It spreads rapidly by means of underground rootstocks and thus is not dependent upon special surface-moisture conditions for seedling establishment. This may explain why it commonly occurs above the zone of daily inundation.

CATCLAW

The shrub catclaw occurs in warm, arid areas of Arizona and adjacent states (Little, 1976) at altitudes up to 1,830 m. The plant was first seen at kilometer 63.4 on the left bank (pl. 2, fig. 11). Downstream from this locality it is an almost constant component of the predam flood-line community which commonly occurs on stable talus and predam alluvial deposits. Predam scouring action of floodwaters produced a sharply defined lower limit to this community (figs. 43A, 44A, 45A, 47A, 64A, and others). Today, many catclaw seedlings occur below the old community boundary and foretell future conditions. For example, in an area below the old flood line on the debris fan at the mouth of Horn Creek, we counted 22 catclaw seedlings growing in an area of 100 m^2. This is equivalent to 4.5 m^2 per plant, a value not unlike that for dense catclaw thickets. These data suggest, assuming that no plants die and that the plants reach a size typical of nearby areas, enough seedlings have already become established here to produce a dense thicket.comparable to the predam flood-line community.

WESTERN HONEY MESQUITE

The western honey mesquite, a shrub or small tree, is widespread in southwestern North America where it and the other varieties of mesquite are among a number of shrubs and trees that have increased in prominence within their ranges in the last 100 years, especially in grassland areas bordering the desert. It is first encountered on the right bank at kilometer 63.4 across the river and slightly upstream from the first occurrence of catclaw. Mesquite was noted by Powell (1875) at approximately the same location, indicating that its range in the Grand Canyon has not expanded during the past century. Stanton also recorded having seen mesquite but farther downstream, between the mouth of the Little Colorado River (kilometer 98.8) and kilometer 120.7 (Stanton, 1965).

Western honey mesquite is part of the predam flood-line community growing on stabilized talus and on dunes, occuring almost continuously from its first appearance until kilometer 120.7, after which its presence becomes discontinuous and sporadic for the next 148 km (pl. 2, fig. 12). It reappears near National Canyon (kilometer 267.9) and from that point downstream shares dominance in the flood-line community with catclaw. Scattered young individuals of western honey mesquite can be seen growing with saltcedar, sandbar willow, and other members of the postdam riparian strip vegetation. Few of these new entrants have yet grown to tree size, but indications are that this species will become a minor but significant member of the riparian community. It is also expected to occupy the niche between the river and the predam flood line that was devoid of woody plants during predam times.

Infestation of western honey mesquites by mistletoe begins abruptly at kilometer 282.9 approximately 25.7 km downstream from the parasite's first occurrence on catclaw (P. S. Martin, University of Arizona, written commun., 1971).

FREMONT COTTONWOOD

Fremont cottonwood is found along the entire Colorado River mainstem from the river's mouth to its headwaters (Little, 1971), at least to an altitude of 1,515 m (Benson and Darrow, 1954). Along the lower Colorado River it was a common occupant of silt flats (MacDougal, 1904; Sykes, 1937), but its position there has now been taken over by saltcedar. Except for figure 60*A*, we found no evidence of Fremont cottonwood occurring along the banks of the Colorado River through the Grand Canyon until after the completion of Glen Canyon Dam. The seedlings typically become established in the open on newly deposited moist sediment. Through most of the Grand Canyon these deposits were among the more unstable habitats, and the trees were probably repeatedly uprooted by floods.

The tree was noted by Clover and Jotter (1944) within the Grand Canyon at two locations but only within tributary canyons. P. S. Martin, University of Arizona (written commun., 1971) noted several occurrences of the tree that seemed to predate Glen Canyon Dam. It is still seen only infrequently along the river (pl. 2, fig. 13). Apparently its establishment is less successful on the postdam sediments than that of the other riparian species, such as saltcedar and sandbar willow, and once the sediment is occupied by the other species, Fremont cottonwood seedlings are effectively excluded. Fremont cottonwood is a preferred food of the beaver, and most trees observed showed signs of having been cut. Perhaps the plant's limited occurrence is related to the heavy use it receives from these animals.

ARROWWEED

Arrowweed is often seen in pure stands in alluvial soils along streams in Arizona and adjacent states up to an altitude of about 915 m (Vines, 1960). The riparian habitat with which it is usually associated is also ideal for saltcedar, and the area formerly occupied by arrowweed has decreased in some regions (Turner, 1974) since the spread of saltcedar along many watercourses in southwestern North America. This willow-like shrub was recorded in 1938 at several locations on the Green River by Clover and Jotter (1944). It is first seen within our area at Lees Ferry (pl. 2, fig. 14). It is common along the Lower Colorado River near Yuma (McDonald and Hughes, 1968).

Apparently unable to withstand the scouring action of floodwaters, this plant occurred only sporadically through the Grand Canyon before Glen Canyon Dam was built. It sprouts readily from roots and most stems in a thicket may be connected by a common root system (Gary, 1963). Its ability to reproduce vegetatively enables the plant to rapidly colonize open alluvial deposits. Arrowweed has become one of the more prominent members of the riparian community throughout the reach of the Grand Canyon we studied.

LONGLEAF BRICKELLIA

This shrub occurs in northern Arizona, Utah, and California at altitudes from 535 m to 1,830 m or higher. It is commonly seen as a subdominant of the arid communities on the slopes above the flood-line community. It is notable in the postdam ecosystem (pl. 2, fig. 15) as one of the species to first dominate the coarse debris fans and talus slopes lying below the predam high flood line (fig. 54 *B*). Whether it will retain this dominant role as these habitats approach an equilibrium with the present flood-free regime is unknown.

RABBITBRUSH

This species barely enters the study area, occurring along the Colorado River only upstream from Lees Ferry. There are several sites at which it forms dense thickets in the 1970's within that short reach; other areas that were dominated by this plant in the late 19th century now support other species, mainly saltcedar (pl. 3, fig. 16; figs. 26, 27, 28, 30, 32, and 33).

DESERT BROOM

Desert broom is a common shrub in Arizona and adjacent states at altitudes below 1,675 m. This ruderal species is a common early occupant of disturbed areas such as roadsides, streambanks, and abandoned fields and is uncommon in more stable habitats. Clover and Jotter (1944) recorded it from only two localities—Lava Falls (kilometer 288.3) and Two Hundred and Fivemile Canyon (kilometer 330.5). P. S. Martin, University of Arizona (written commun., 1971), noted its abundant occurrence at kilometer 265.5 and its common occurrence at Lava Falls and downstream from there. Our records show it at a few localities upstream from kilometer 265.5 (pl. 2, fig. 8), but it is nowhere abundant until that section of the river is reached. Where found, desert broom may be seen next to the river or in the formerly bare strip above the beach but below the predam flood level. It was present in the predam flood-line community, but these older plants are now dying in many places. Perhaps its early establishment on the formerly flooded canyon slopes represents an early stage in a series of stages leading to a permanent, more complex, community.

WATERWEED

Waterweed and desert broom are morphologically and ecologically similar. The two are difficult to distinguish in the vegetative condition, but during the fall when both are in flower they may be distinguished by floral differences. The two occur together near the river and as ruderal species on the canyon sides below the predam high flood line. Waterweed is not known upstream from kilometer 46.7; it is found at Stanton Cave (kilometer 51.5) and sporadically downstream from there; and it is missing, according to our records, between kilometer 281.6 and kilometer 493.3 (pl. 2, fig. 16). It is much less abundant than desert broom throughout the region of their range overlap.

SEEP WILLOW

Seep willow is a common willow-like plant along water courses in Arizona and adjacent states at altitudes below about 1,525 m. It occurs near permanent or semipermanent bodies of water where the water table is near the surface. This tall shrub was the dominant species on recent alluvium throughout much of its range until the introduction of saltcedar. Judging from the early photographs of the Colorado River through the Grand Canyon, this plant was not commonly seen before the construction of Glen Canyon Dam. Today seep willow occurs through the Grand Canyon at short intervals especially at Buck Farm Canyon (kilometer 66) and downstream from there (pl. 3, fig. 17). It is found at Lees Ferry but apparently is not a common plant above this locality. Gaines (1960) collected it on the Colorado River in predam Glen Canyon during 1957 at a locality 8.8 km below Klondike Bar, San Juan County, Utah. Clover and Jotter (1944) recorded it at Lees Ferry in 1939 but not on the river above that location. Today the plant is generally subordinate to saltcedar and sandbar willow in the narrow riparian community at the edge of the river. As the riparian habitat reaches stability in the postdam period, seep willow will probably remain a conspicuous but minor element along the banks of the Colorado River.

EMORY SEEP WILLOW

The shrub emory seep willow is strikingly similar, ecologically and morphologically, to seep willow and is difficult to distinguish from it except during late summer and fall at which time both species are in flower and differences in the position of inflorescences may be used to distinguish the two, even at a distance. Emory seep willow occupies the same habitat as seep willow but according to our records is slightly less common than the latter (pl. 3, fig. 18). The shrub was common near Green River, Utah, in 1939 (Clover and Jotter, 1944), and it has been recorded 12.9 km above Lees Ferry.

APACHE PLUME

Apache plume is an evergreen shrub found from western Texas to southeastern California and south into Mexico. It is normally found at altitudes from 1,065 m to 2,285 m. It reaches its lower elevational limit in the Grand Canyon and distinctly marks the old flood line from Glen Canyon downstream to about kilometer 93.3; it is rare below that locality (pl. 2, fig. 10). Its position of dominance in the old flood-line community has not changed during the postdam period (fig. 35).

NETLEAF HACKBERRY

The netleaf hackberry, a widespread deciduous tree, is usually found in valleys from Oklahoma and Colorado to northern Mexico. In the Grand Canyon it is characteristic of steep slopes at or above the old flood line and occurs discontinuously over the full length of the canyon (pl. 3, fig. 19). It has recently become established below the predam flood line at kilometer 12.6 (P. S. Martin, University of Arizona, written commun., 1971) and can be expected to appear in this newly available habitat at other localities.

REDBUD

The redbud is a small tree inhabiting mesic situations such as alcoves on north-facing slopes, seeps, and the old predam flood line. It is commonly seen from Glen Canyon Dam to the vicinity of Nankoweap (kilometer 85.3). It has recently become established below the old flood line at Vaseys Paradise (kilometer 51.5) (P. S. Martin, University of Arizona, written commun., 1971). Redbud is more abundant than our map (pl. 3, fig. 20) indicates; it is commonly seen from the river in habitats above the predam flood line for which we do not show data.

CATTAIL

Two similar species of cattail, *Typha latifolia* and *T. domingensis*, occur in the Grand Canyon; in the field close examination is required to separate them. Our sightings were made mostly from a raft on the river, and we could not see the plants on the shore clearly enough for identification. The two are ecologically similar and are not separated in our records (pl. 3, fig. 21). These plants are practically limited to aquatic situations with quiet water; the rhizome requires complete and permanent immersion (Ridley, 1930). These plants are important food for beavers and muskrats, the seeds are eaten by some waterfowl, and the dense cover produced by these plants provides shelter and nesting cover for marsh birds, waterfowl, and songbirds. Stands of these plants were probably rare or absent in the predam period but are common today (figs. 37*B*, 65*B*, and 68*B*) and contribute importantly to the new postdam ecosystem along the Colorado River.

REED

The large grass called reed is a cosmopolitan species found in most of the temperate and tropical parts of the world. It characteristically occurs in marshes, at seeps, and along rivers and streams in our region. Clover and Jotter (1944) observed the grass in 1938 at three locations in the Grand Canyon: at the mouth of Bright Angel Creek, near Deer Creek Falls, and downstream from Upset Rapids at kilometer 244.6. The plant was probably well established in the main canyon at seeps above the predam flood level and within tributary canyons. It now occurs as a common member of the new riparian community (pl. 3, fig. 22).

SPINY ASTER

The spiny aster is a green, broom-like herbaceous perennial with poorly developed leaves and sparse thorns. It is a widespread plant in moist habitats up to altitudes of about 1,200 m from Texas to California and south to Costa Rica. In 1938–39 Clover and Jotter (1944) found it at Lees Ferry and downstream from there at several places. It is present along the Colorado River from Glen Canyon Dam to the Sea of Cortez (Gulf of California) in moist alluvial deposits where conditions are stable enough to permit establishment. Spiny aster spreads by rhizomes; it quickly colonizes open areas and can be expected to become common throughout the Grand Canyon (pl. 3, fig. 23).

SANDBAR WILLOW

Sandbar willow is a shrub that attains heights of 2 to 4 m (rarely 5 m). It is one of the more abundant shrubs along the Colorado River today (pl. 3, fig. 24) and is found throughout the Colorado River basin and along most of its tributaries to an altitude of about 2,100 m. In 1970 Martin found it spreading very rapidly along the river below the flood line (P. S. Martin, University of Arizona, written commun., 1970). The shrub is restricted to substrate near river level except at seeps, such as those at Vaseys Paradise, Deer Creek Falls, and Lava Falls. In 1938, Clover and Jotter (1944) reported it at localities from Lees Ferry to kilometer 308.9. Sandbar willow spreads rapidly from roots and is an important beach stabilizer (R. R. Johnson, U.S. National Park Service, written commun., 1978). This plant and saltcedar are the dominant species of the riparian community. Because of its short stature, this shrub may be partially replaced as equilibrium is reached in those areas where it grows with taller plants such as saltcedar (Campbell and Dick-Peddie, 1964). In recent years, its rapid establishment on bare, unstable mud bars below saltcedar has been observed (A. M. Phillips III, Museum of Northern Arizona, written commun., 1978).

GOODDING WILLOW

The only large willow growing along the Colorado River below Glen Canyon Dam is Goodding willow (pl. 3, fig. 25). Clover and Jotter (1944, p. 602) observed that willows in the lower part of the Grand Canyon "became so well established in some locations as to attain a height of thirty or forty feet." The few places that tree willows appear in predam photographs are from the lower part of the Grand Canyon (figs. 62*A*, 63*A*, and 66*A*).

DESERT ISOCOMA

The species desert isocoma is normally less than 1 m tall and is typically found as scattered individuals in the riparian community. It was found at Lees Ferry in 1938–39 (Clover and Jotter, 1944) but has not been reported upstream from this locality. Our records show it (pl. 3, fig. 20) at scattered locations along the Colorado River to the vicinity of Rampart Cave (kilometer 442); it probably occurs downstream from there. Desert isocoma is nowhere important in the habitats below the predam flood line, but in old alluvial deposits above this level it may be the dominant plant.

PHOTOGRAPHIC DOCUMENTATION OF CHANGES

The use of photographs for recording changes in landscapes has many advantages over other methods because the camera records in great detail many features that would otherwise be overlooked. The camera faithfully records such subtle features as highwater stains on streamside outcrops, the intricate details of hexagonal soil cracks on alluvial silt beds, vertical banks formed by recent floods, the presence or absence of plants on flood plains, and numerous details that would easily be overlooked or could be described well only by making painstaking drawings, measurements, and verbal descriptions. Photographs provide an unbiased and unusually complete record of conditions existing at a specific time (Malde, 1973). And when a new photograph is exactly matched against an old, any difference between the two can be readily discerned and taken as evidence for change.

In this section are 48 sets of long-interval, time-lapse photographs. In most instances, the photographs are paired, oblique, terrestrial views—one taken in 1963 or earlier, the other dating from 1972 through 1976. The exceptions are (1) the single aerial photograph series in which the oldest view was taken in September 1952, repeated in May 1965(about 2 years after the dam was completed) and again in June 1973, and (2) in one instance where three matched photographs in one set were used instead of two.

The photographs are arranged, for the most part, in an orderly sequence beginning with the station farthest upstream. The photographs in this report represent approximately one-third of those acquired during the study. The unpublished photographs may prove useful to future students of the Grand Canyon. Negatives for all the recent photographs have been retained in Tucson, Ariz., by the U.S. Geological Survey, Water Resources Division, or by the Museum of Northern Arizona, Flagstaff, Ariz. Most of the predam photographs are from the files of the U.S. Geological Survey Library, the New York Public Library, or from the National Park Service Library at Grand Canyon. The source of all photographs used in this publication is given, with appropriate credit, in table 3. The location is shown on plate 1 of all sites at which published matching photographs were taken.

SUMMARY OF CHANGES

In the preceding section we have attempted to document changes occurring along the Colorado River from the period prior to 1963, the year water impoundment in Lake Powell began, and the early 1970's when our field work was accomplished. Changes can be considered within three separate communities: the community of postdam fluvial sediments lying nearest the river, the zone of predam fluvial sediments found next above, and, the highest of the three zones, communities of predam flood terraces, eolian deposits, and stabilized talus slopes.

ZONE OF POSTDAM FLUVIAL SEDIMENTS

Because all predam photographs show the near absence of plants in this situation, we believe that in the short period of 13 years the zone of postdam fluvial deposits has been transformed from a barren skirt on both sides of the river to a dynamic double strip of vegetation. Here conditions for plant establishment and growth are excellent, and under the new hydrologic regime many plants now grow densely. Foremost among these are saltcedar and sandbar willow. In addition, there occur desert broom, Bermuda grass, carrizo, seep willow, Emory seep willow, and cottonwood. Cattails grow on submerged deposits, as do horsetail and great bulrush.

The photographs show that this community accounts for most of the striking changes observed. It is doubtful that equilibrium has been reached, and the community is probably still undergoing change, both in compostion and density. From our observations of the rapid spread of camelthorn since 1970 and the recent appearance of Russian olive and elm along the river, we feel that these species, at least, will continue to expand in importance within this zone causing some changes in riparian community composition. Moreover, many of the new plants have not reached full size; as they do, increased community coverage will result.

The increase in plant biomass in this zone has doubtless had effects on the fauna of this habitat. Recent work (Carothers and Johnson, 1975; Carothers, Aitchison, and Johnson, 1976; Ruffner and Carothers, 1975; Tomko, 1975) has shown profound responses to the new habitat by insects, reptiles, small and large mammals, and birds. Beavers are becoming common as a ready source of food has developed. They will obviously influence the composition and density of the zone of postdam fluvial sediments because of their preferential harvesting of cottonwoods and willows. Numerous large cottonwoods as well as willows were observed to have been downed by beaver, but no beaver sign was observed on saltcedar. The increasing population of beaver would appear to be a factor favoring plants other than cottonwoods and certain willows within the postdam fluvial zone.

ZONE OF PREDAM FLUVIAL SEDIMENTS

Prior to construction of Glen Canyon Dam, this predam zone and the previous zone were indistinguishable. Both were under control of frequent floods, and few plants became established. In situations where the floor of the canyon is broad, the scouring action of floods is reduced. If the fluvial deposits are thick and ground water is shallow, the zone of predam fluvial deposits supports plants like arrowweed and desert broom. Thick predam eolian deposits with even greater depth to ground water support dropseed (fig. 40*B*). Free now from flooding, this zone possesses the stability for new community development but lacks the water to

TABLE 3.—*Camera station descriptions, including dates, location, altitude, and photograph credits*

Figure No.	Location [km (mi)/ riverbank left, right, center]	Direction of view	Altitude at river level (m)	Original photography: Date	Original photography: Photographer	Original photography: Credit	Original photography: Collection designation	Repeat photography: Date	Repeat photography: Location of negative	Repeat photography: Negative number	Remarks
26	+24.1 (15.0)/L	Upstream	957	1889	F. A. Nims	NYPL[1]	R. B. Stanton #237	11 June 1975	USGS[2]	757	Stanton, 1932, facing p. 25.
27	+20.6 (12.8)/L	do	956	1889	do	NYPL	R. B. Stanton #239	11 June 1975	USGS	754	
28	+11.3 (7.0)/R	Downstream	954	1889	do	NYPL	R. B. Stanton #244	11 June 1975	USGS	752	
29	+6.4 (4.0)/L	Upstream	953	1889	do	NYPL	R. B. Stanton #245	11 June 1975	USGS	750	
30	+4.8 (3.0)/L	do	953	1872	William Bell	USGSD[3]	Wheeler photo album #68	11 June 1975	USGS	756	
31	+0.5 (0.3)/L	Downstream	951	1923	L. R. Freeman	USGSD	Topo. Div. #6	22 August 1972	USGS	710	
32	0 (0)/L	Across	949	1873	T. H. O'Sullivan	USGSD	Wheeler photo album #70	22 August 1972	USGS	706	Bartlett, 1972, facing p. 361; Horan, 1966, p. 270.
33	0 (0)/R	Downstream	949	ca. 1873	do	USGSD	Wheeler photo album #47	27 June 1972	USGS	671	
34	1.0 (0.6)	Aerial	947	24 Sept. 1952		USGSA[4]	Box #10 Photo #20–54	16 June 1973	USGS	003 WRD 6–16–73	
				14 May 1965		USGS[2]	Roll #1 Photo #1				
35	6.9 (4.3)/C	Upstream	942	21 Oct. 1952	R. S. Leding	NPS[5]	NPS #2354	21 August 1972	USGS	704	
36	12.6 (7.8)/L	Downstream	939	19 June 1952	do	NPS	NPS #2297	21 August 1972	USGS	705	
37	17.7 (11.0)/L	do	933	2 August 1923	E. C. LaRue	USGSD	E. C. LaRue #338	22 August 1972	USGS	672	
38	34.6 (21.5)/R	Across	907	6 August 1923	do	USGSD	E. C. LaRue #353	23 August 1972	USGS	714	
39	39.4 (24.5)/L	Upstream	893	6 August 1923	do	USGSD	E. C. LaRue #355	16 Sept. 1976	USGS	797	Karpiscak, 1976, p. 8.
40	45.5 (28.3)/L	do	884	20 August 1872	J. K. Hillers	USGSD	J. K. Hillers #445	23 August 1972	USGS	673	Darrah, 1947, facing p. 9; Darrah, 1951, Illus. #12; Stegner, 1954, following p. 238; LaRue, 1916, plate 9A; Dellenbaugh, 1903, p. 321; James, 1910, facing p. 248; Rusho, 1969, p. 3.
41	51.3 (31.9)/C	Across	875	8 August 1923	L. R. Freeman	USGSD	Topo. Div. #27	17 March 1974	MNA[6]	2	Karpiscak, 1976, p. 10.
42	53.3 (33.1)/L	Downstream	873	(August?) 1923	do	USGSD	Grand Canyon #173	17 March 1974	MNA	3	Karpiscak, 1976, p. 12.
43	74.8 (46.5)/R	do	858	11 August 1923	E. C. LaRue	USGSD	E. C. LaRue #390	18 March 1974	MNA	5	
44	84.6 (52.6)/R	do	847	(August?) 1923	E.C. Kolb	USGSD	Grand Canyon #45	19 March 1974	MNA	9	Karpiscak, 1976, p. 14.
45	98.8 (61.4)/C	Upstream	826	1872	J. K. Hillers	USGSD	J. K. Hillers #885	23 August 1972	USGS	685	James, 1910, facing p. 159.
46	98.8 (61.4)/L	do	826	13 July 1963	J. Blaisdell	NPS	NPS #4288	2 Sept. 1973	USGS	730	
47	105.4 (65.5)/R	Downstream	817	1872	J. K. Hillers	USGSD	J. K. Hillers #858	26 July 1974	MNA	46	
48	123.1 (76.5)/L	do	780	(August?) 1923	L. R. Freeman	USGSD	Topo. Div. #36	23 August 1972	USGS	715	
49	126.3 (78.5)/R	do	770	1872	J. K. Hillers	USGSD	J. K. Hillers #449	20 March 1974	MNA	11	Darrah, 1951, Illus. #9; LaRue, 1916, plate 2A; Dellenbaugh, 1903, p. 219; James, 1907, p. III.
50	140.6 (87.4)/L	do	741	October 1952	R. S. Leding	NPS	NPS #2349	23 August 1972	USGS	716	
				19 June 1963	J. Blaisdell & A. Wolfe	NPS	NPS #4251				
51	143.1 (88.9)/L	Upstream	732	February 1903	D. T. MacDougal	ARHS[7]	A1–41	20 Sept. 1976	USGS	801	
52	174.7 (108.6)/L	Across	666	1901	N. W. Carkhuff	USGSD	N. W. Carkhuff #A62	23 August 1972	USGS	688	
53	185.8 (115.5)/L	Upstream	645	February 1890	R. B. Stanton	NYPL	R. B. Stanton #542	22 Sept. 1976	USGS	802	
54	200.8 (124.8)/R	Downstream	623	6 Sept. 1923	E. C. LaRue	USGSD	E. C. LaRue #514	22 Sept. 1976	USGS	691	
55	202.7 (126)/L	Upstream	619	1872	J. K. Hillers	USGSD	J. K. Hillers #879B	31 July 1974	MNA	54	Darrah, 1951, Illus. 11; Dellenbaugh, 1908, p. 218.
56	219.1 (136.2)/L	Across	588	10 Sept. 1923	E. C. LaRue	USGSD	E. C. LaRue #546	24 August 1972	USGS	717A	
57	231.2 (143.7)/L	Upstream	572	10 Sept. 1923	do	USGSD	E. C. LaRue #553	24 August 1972	USGS	718	
58	287.4 (178.6)/L	Downstream	511	18 Sept. 1923	do	USGSD	E. C. LaRue #601	3 July 1972	USGS	697	
59	288.5 (179.3)/R	Across	511	19 June 1950	William Belknap, Jr.	NPS	C–57	26 Sept. 1976	USGS	803	
60	313.6 (194.9)/L	Downstream	471	25 Sept. 1923	E. C. LaRue	USGSD	E. C. LaRue #628	25 August 1972	USGS	720	
61	328.9 (204.4)/R	Upstream	454	27 Sept. 1923	do	USGSD	E. C. LaRue #633	3 August 1974	MNA	60	
62	336.0 (208.8)/L	Across	442	28 Sept. 1923	do	USGSD	E. C. LaRue #643 (left half)	30 March 1972	MNA	30	
63	336.0 (208.8)/L	do	442	28 Sept. 1923	do	USGSD	E. C. LaRue #646 (right half)	30 March 1974	MNA	30	Karpiscak, 1976, p. 28.
64	336.6 (209.2)/L	Upstream	439	28 Sept. 1923	do	USGSD	E. C. LaRue #643	27 March 1974	MNA	21	
65	350.3 (217.7)/L	Downstream	424	30 Sept. 1923	do	USGSD	E. C. LaRue #653	4 July 1972	USGS	703	
66	358.1 (222.5)/L	do	413	1 Oct. 1923	do	USGSD	E. C. LaRue #664	25 August 1972	USGS	722	
67	360.7 (224.2)/L	do	408	2 Oct. 1923	do	USGSD	E. C. LaRue #665	29 Sept. 1976	USGS	804	

See footnotes at end of table.

TABLE 3.—*Camera station descriptions, including dates, location, altitude, and photograph credits*—Continued

Figure No.	Location [km (mi)/ riverbank left, right, center]	Direction of view	Altitude at river level (m)	Original photography: Date	Original photography: Photographer	Original photography: Credit	Original photography: Collection designation	Repeat photography: Date	Repeat photography: Location of negative	Repeat photography: Negative number	Remarks
68	363.0 (225.6)/L	Upstream	408	1902	N. H. Darton	USGSD	N. H. Darton #911	25 August 1972	USGS	723B	
69	363.2 (225.7)/L	do	407	22 Sept. 1922	E. C. LaRue	USGSD	E. C. LaRue #675	29 Sept. 1976	USGS	805	LaRue, 1925, plate 45–A; Karpiscak, 1976, p. 34.
70	368.0 (228.7)/R	Downstream	395	7 Oct. 1923	do	USGSD	E. C. LaRue #690	26 August 1972	USGS	724	
71	406.0 (252.3)/L	Upstream	322[8]	13 Oct. 1923	do	USGSD	E. C. LaRue #747	26 August 1972	USGS	725	
72	437.6 (272.0)/R	Downstream	282[8]	15 Oct. 1923	do	USGSD	E. C. LaRue #759	6 August 1974	MNA	72	
73	441.3 (274.3)/L	do	280[8]	15 Oct. 1923	do	USGSD	E. C. LaRue #761	6 August 1974	MNA	73	

[1]New York Public Library, New York, N.Y.
[2]U.S. Geological Survey, Project Office, Tucson, Ariz.
[3]U.S Geological Survey, Photographic Library, Denver, Colo.
[4]U.S. Geological Survey, Arizona District Office, Tucson, Ariz.
[5]National Park Service, Grand Canyon, Ariz.
[6]Museum of Northern Arizona, Flagstaff, Ariz.
[7]Arizona Historical Society, Tucson, Ariz.
[8]River level prior to filling of Lake Mead.

rapidly produce dense plant growth. Changes here are slow, and although underway by the time of our study, few signs of change were detected photographically. The new community, judging from recent plant establishments, will comprise species commonly found upslope. These include catclaw, Apache plume, western honey mesquite, dropseed, brittle bush, and rabbitbrush. Camelthorn, an exotic species, is also rapidly becoming an important member of the community.

Man's influence on the vegetational changes along the Colorado is not limited to his control of river flow. He has become an important element for change by his presence on the river. The annual passage of approximately 15,000 people through the Grand Canyon facilitates the downstream movement of plant disseminules from one beach to another. Species that inhabit the zone of predam fluvial sediments are likely to be affected. The zone below may be similarly affected, but most of the migrant disseminules there are probably carried and deposited by water.

ZONE OF PREDAM FLOOD TERRACES, EOLIAN DEPOSITS, AND STABILIZED TALUS SLOPES

Predam terraces, eolian deposits, and stable talus slopes were situated above the zone of annual inundation and in many places even above the zone reached by extreme flooding. This habitat was marked by general stability and by little competition from plants along its lower margin. As a consequence, the plants composing this community grew to large size and were mostly closely spaced. The effect of dam construction on this community will probably be a decrease in its density, especially on level flood terraces that no longer are periodically inundated. The change is conspicuous at several sites above Lees Ferry and is illustrated in figures 33*A* and *B*. In this same zone on stabilized talus slopes, there are signs in some areas of a decline in the size and number of the woody plants comprised in this community. This is not a widespread phenomenon and was recorded in only one photograph pair (fig. 34*A* and *B*) of the several herein, showing the dense fringe of predam flood-line vegetation. The dominant plants here are rabbitbrush, Apache plume, western honey mesquite, catclaw, and canyon hackberry. These species provide the seed source for the plants newly occupying the predam fluvial deposits on the zone next below.

On talus slopes clearly above the influence of predam flooding, the vegetation is remarkably stable. The photographs in this series do not support earlier conclusions (Clover and Jotter, 1944) that landslides made the talus slopes so unstable that a climax vegetation did not develop. From field observations and from the photographs, we judge that most talus is stable as is the vegetation it supports. Unstable talus is seen in figure 48 and a recent rock fall in figure 57*B*. In the many other views of talus, unstable surfaces are not evident.

Man is directly influencing the stability of this zone above annual inundation by his destruction of plants at camping areas and elsewhere. Trampling of vegetation and trail cutting are especially evident at prime attractions such as the ruins at Nankoweap or at Deer Creek Falls in the area above the old high water line community. These heavily disturbed areas are inhabited predominantly by ephemeral species which thrive on disturbed ground, and many complete their life cycle before the river runners start their season.

GENERAL CONCLUSION

Any serious attempt to predict future changes must await passage of additional time. The vegetation has probably not reached an equilibrium with the new environment, and the final stage cannot be foreseen.

The problem of assessing equilibrium lies only partly in the lack of data for determining rate of vegetation change. It lies partly in our inability to predict changes in river flow, for even though relatively stable, stream discharge still has the potential for causing great change.

The flow in the Colorado River through the Grand Canyon is determined by power-generation needs, by water-supply needs, and by water availability. The last variable in this complex relationship is dependent on regional weather and is unpredictable. The other variables are under man's control yet their effects are hardly more predictable and there is still a large element of uncertainty. As an example, diversion of the dependable allocated water supply relies upon completion of long range programs such as the Central Arizona Project. Completion of this program is behind schedule, and as a result Colorado River flow may be affected. As was noted by the Bureau of Reclamation (1976), "the dependable water supply [of the Colorado River] has been allocated but some of the facilities for its use have not yet been constructed. Since 1962, the resulting temporary excess of supply over demand has been stored in new facilities [such as Lake Powell]. In the near future, storage facilities will be filled to their operating limits requiring the frequent release of excess water. This condition will then continue until the allocated water supply is fully used or a period of deficient water supply occurs." Thus, for the foreseeable future, flow through the Grand Canyon was expected to be greater than during the earlier postdam period, although this prediction was tempered by the acknowledged effect that regional precipitation deficiency would have on any surplus.

The spring of 1977 provided a timely example of the unpredictable effect of drought on the flow of water through the canyon. Instead of the predicted excess water, the river below Glen Canyon Dam actually carried flows far below average. The discharge rate was so low that in one instance river parties were stranded in the canyon and a special release of water from Glen Canyon Dam was required to flush them out.

Should release of excess water become necessary then effects on the riparian vegetation are likely to occur. To the extent that the greater flows inundate established vegetation for longer periods or to greater depths than before, there may be a change in the zones of plants within the newly established riparian strips. If, as occurred during April 1973 (fig. 1), increased flow from Lake Powell is accomplished by maintaining near constant daily flow, some plant species may be eliminated from positions they now occupy because of inability to withstand inundation for long periods. If release of excess water is accomplished by increasing the daily maximum values while maintaining the old minima, then plants now established would probably remain intact and new plants would become established at higher positions on the banks. This release pattern would presumably increase the breadth of the riparian strips, unless, of course, the increased daily maxima result in scouring and uprooting of plants. The exact form of the future plant communities along the Colorado River will in the final analysis depend on the interplay between the whims of man and the vagaries of weather and is therefore probably unpredictable. Yet it is apparent that the future relatively stable riparian vegetation will be dense and will probably include the species that are there now plus new introductions that will occasionally reach the valley of the Colorado River.

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FIGURES 26-73

FIGURE 26*A*.—(1889). F. A. Nims, photographer with the Stanton-Brown railroad survey expeditions, took this photograph looking upstream from a point 1.6 kilometers below the present site of Glen Canyon Dam (24.4 kilometers above Lees Ferry). Woody vegetation on the far bank appears as a dense thicket separated from the water at this river stage by a barren sand bar. The thicket appears to be rabbitbrush. The high sandy terrace supporting the dense growth was a common feature above Lees Ferry but uncommon below. Only in years of extremely high floods would there be overbank flow sufficient to scour out these plants. The sharp lower boundary results from the scouring action of floodwaters. At the base of the distant cliffs above the river in center background are clumps of what appear to be netleaf hackberry. (Altitude 957 meters.)

FIGURE 26*B*.—(1975). Glen Canyon Dam lies just out of view around the bend of the river. Construction activity related to the dam has considerably altered the steep slopes of the left bank. The netleaf hackberry seen in the previous view has been covered by rubble piles below tunnels drilled into the cliffs above. The netleaf hackberry has not reoccupied the niche at the cliff bases, although saltcedar relatively quickly became established along the base of the rubble piles. The foreground has also been altered by rubble from above, although many of the rocks carry over from the older view. The thicket on the opposite bank has enlarged, and its composition has changed—saltcedar dominates today and has spread downward over the barren skirt as far as fluctuations in river level wlll permit. The photograph was taken at 1330 hours, a time of peak-load demand, and the river is probably at near maximum stage. Large saltcedars dominate on the left bank also, forming a narrow almost continuous streamside band along the base of the steep slopes below the cliffs. Maximum lowering in mean streambed elevation (1.83 meters) occurred during the 1956–59 period at a point near the far bend in the river. Subsequently the channel has been stabilized by gravel and cobble-size armor, eliminating continued degradation (Pemberton, 1976).

FIGURE 27*A*.—(1889). The Colorado River is deeply entrenched in the Upper Triassic(?) and Jurassic Navajo Sandstone through the lower section of Glen Canyon between Glen Canyon Dam and Lees Ferry, 20.6 kilometers above Lees Ferry. The view is upstream. The camera station is located near the level of maximum river stage. A single netleaf hackberry (arrow) is at the same level a few hundred feet upstream from the camera. The coarse material of the foreground supports little more than a few grasses and forbs. On the far bank is a thicket of what is probably rabbitbrush. (Altitude 956 meters.)

FIGURE 27*B*.—(1975). Although not an exact match, the new camera position is probably within a few feet of the old. Two towers near the brink of the canyon wall support lines that carry power generated at Glen Canyon Dam. Saltcedar has overgrown both banks and in the vicinity of the camera station occupies what is probably the predam highwater level. Several nearby saltcedars at this level have died. Longleaf brickellia is common on the steep slopes of coarse rubble in the foreground. The sandy bar on the opposite bank is covered by plants to lower levels now than in the earlier view. The deposit is partly submerged by the river, which is at higher stage than before, making difficult any estimate of erosion since the earlier photograph.

FIGURE 28*A*.—(1889). This downstream view was taken below the crest of an actively eroding alluvial deposit, 11.3 kilometers above Lees Ferry. Scattered seedlings have become established on the unstable surface marked by horizontal banding. This photograph was taken at a time of low river stage. At the top of the bank can be seen a dense cover of what is probably rabbitbrush. The dense community has been undercut by the river. (Altitude 954 meters.)

FIGURE 28*B*.—(1975). The old camera position cannot be exactly located so dense is the vegetation now growing on the alluvial deposit. Saltcedar, arrowweed, and sandbar willow occur from the river's edge up the steep bank, and on to the flat surface above. Rabbitbrush still occurs on top of the terrace where it is mixed with the other riparian species. The dense growth of vegetation providing stability to the steep bank is undoubtedly new since completion of Glen Canyon Dam.

FIGURE 29*A*.—(1889). Members of the Stanton-Brown railroad survey team are seen in this upstream view, 6.4 kilometers above Lees Ferry. The vegetation on the foreground terrace is Great Basin Desertscrub (Brown and Lowe, 1974a, b). The dense vegetation crossing the picture in the right midground occupies the arroyo leading from Water Holes Canyon. The river is at low stage exposing a sandy bar near the far shore. (Altitude 953 meters.)

FIGURE 29*B*.—(1975). This photograph is not an exact match of the earlier one but is probably off less than 8 meters. The foreground vegetation is much the same as in the 1889 view and comprises jointfir, fourwing saltbush, beavertail cactus, coldenia, and various grasses. The tallest plants along the midground arroyo are shrub liveoak and netleaf hackberry. Shrub liveoak is rare at river level downstream from this site. The netleaf hackberry is common along the canyon for about 80.5 kilometers below Lees Ferry. It is rare below that station although it can be seen near the river 318.6 kilometers below Lees Ferry. The sandy bar of the preceding view persists to the present and is shallowly inundated at this river stage. Saltcedar now occurs as a narrow band on both sides of the river.

FIGURE 30A.—(1872). This upstream view was taken by William Bell, photographer with the Wheeler Survey. The dense riparian vegetation seen in the background on both banks is typical of beach deposits along this section of the river, 4.8 kilometers above Lees Ferry. At the river stage shown in this picture, the riparian community and the river are separated by bare beach.

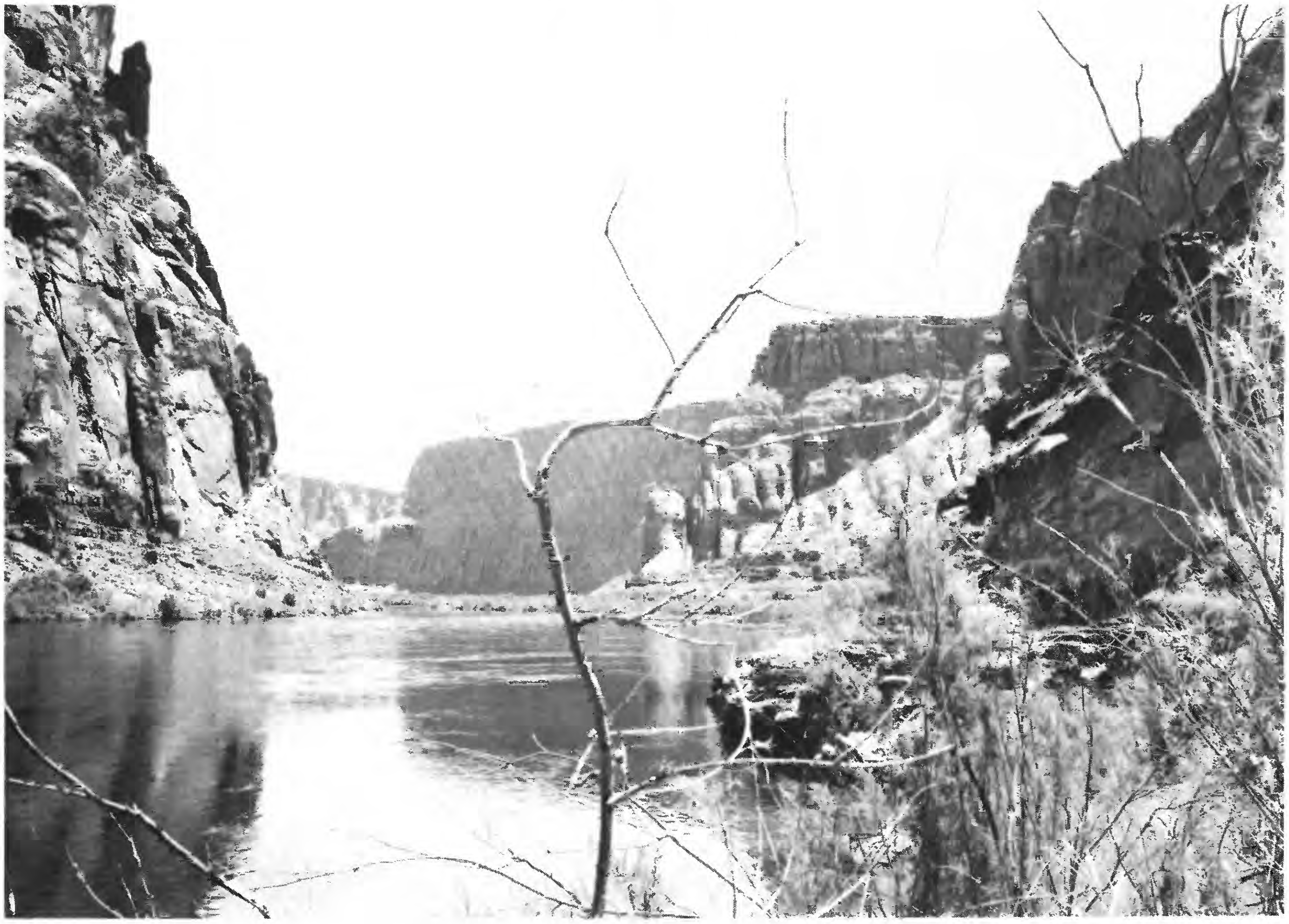

FIGURE 30*B*.—(1975). The old camera location is overgrown with bushes and lies about 3.0 meters upslope to the right. Judging from the position of the water relative to the rocks at the right, the river stage is roughly the same in the two views, and unlike most of the photograph pairs taken along the river, the river level can therefore be used as a datum for judging changes. Saltcedar and sandbar willow (both visible in the right foreground) grow along the section of the beach that was formerly bare. The large trees at the upper edge of the riparian zone are saltcedars. Cattails grow in a few areas at the river's edge.

FIGURE 31*A*.—(1923). The building in left foreground is a boathouse. The cluster of buildings across the river on the right is Lees Ferry. The U.S. Geological Survey river-stage recorder is housed in the cylindric structure standing near the river at the left. This gage marks "Mile 0" in the system used for assigning mileages along the reach of the Colorado River from Lees Ferry to Lake Mead. The Upper Triassic Shinarump Member of the Chinle Formation near the gage and on the opposite side of the Colorado River dips below the level of the river at an inclination of 15° to the east. The plants in the dense thicket near the river cannot be positively identified but included are probably arrowweed, rabbitbrush, and sandbar willow. Saltcedar may be established here, although no record exists of its presence at Lees Ferry until 1938 (Clover and Jotter, 1944). At any rate, no plants on the near shore have reached heights typical of mature saltcedar. (Altitude 951 meters.)

FIGURE 31*B*.—(1972). Lees Ferry has grown. The large inflated rafts (center) are evidence of the town's main industry as a launching facility for boat and raft trips. Saltcedar is the main plant along the near shore, and because of its height, much of the river is screened from view. The cable from which measurements of streamflow are made by the U.S. Geological Survey has been moved from the abandoned tower in the foreground and is now located upstream from the camera station.

FIGURE 32*A*.—(1873). The mouth of the Paria River is seen on the left in this northwesterly view looking across the Colorado River and up the valley of the Paria. The main ferry crossing, still little used by the date of this photograph, lies about 2 kilometers upstream from the Paria. This photograph was taken by T. H. O'Sullivan, photographer with the Wheeler Survey (Bartlett, 1962). In 1872, J. D. Lee, his seventeenth wife, Emma, and their children built a house (arrow) and began farming on the broad, flat floor of the Paria River valley, becoming the first permanent residents of the area (Rusho and Crampton, 1975). In 1776 the Spanish padres Dominguez and Escalante camped at the base of the cliff of the Upper Triassic Shinarump Member of the Chinle Formation on the right (Rusho and Crampton, 1975). The large trees lining the Paria are probably willows (A) and Fremont cottonwoods (B). The dense shrub community (C) extending up the Paria on the right is probably mainly rabbitbrush (see fig. 33*A*). A bare sandy bank slopes from the thicket (of sandbar willow?) to the Colorado River. (Altitude 949 meters.)

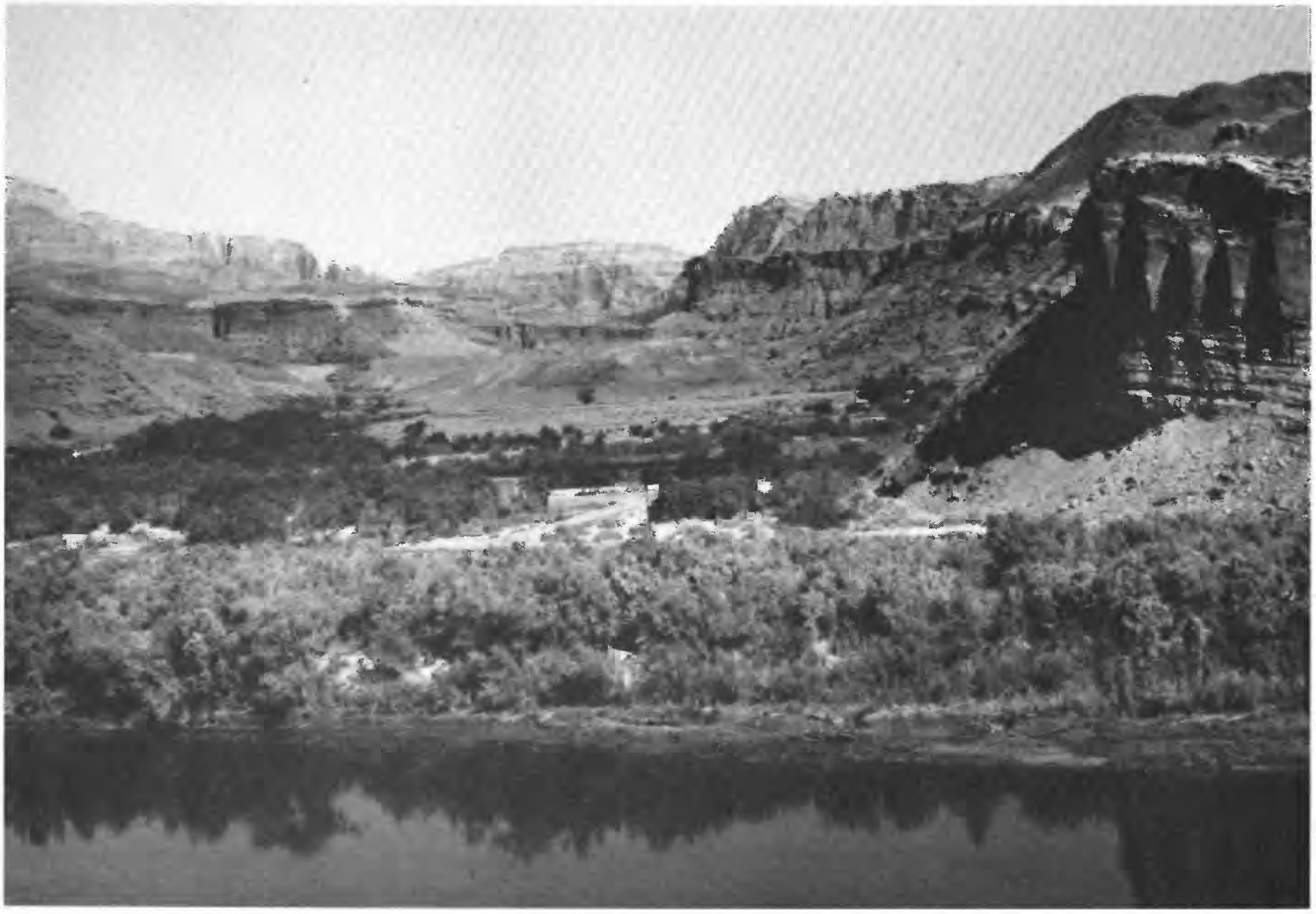

FIGURE 32*B*.—(1972). Almost a century after the preceding view was taken, many of the rocks on the steep slope below the Echo Monocline are still in place. The Paria has shifted its course, accounting for some of the vegetation changes in that valley. The changes along the Colorado River are marked. The thicket of riparian plants has expanded across the bare shore toward the river. Nearest the water's edge is a low community comprising horsetail and a species of bulrush. Plants at this level are probably inundated daily. Shoreward from this low community is a dense forest of saltcedar and a few sandbar willows. This community is out of reach of the diurnal ebb of the river's fluctuating stage.

FIGURE 33*A*.—(1873). In this classic view looking down the Colorado River from a vantage point 0.5 kilometers below Lees Ferry, the Vermillion Cliffs define the distant skyline at right. The low cliffs in the mid-distance are the Chocolate Cliffs, comprising the Upper Triassic Shinarump Member of the Chinle Formation above and the Triassic Moenkopi Formation below. A band of riparian species (probably rabbitbrush) occupies the right bank across the foreground. Evidence of overbank flooding is seen in the piles of debris scattered in the dense thicket. Flow from the mouth of the Paria River, just out of view on the right, crosses at midground along the edge of the fan. This fan, formed by the Paria River, forces the Colorado River toward the left bank. The near shore (left foreground) and the fan are mostly devoid of plants. For scale, note the figure at the bottom, just right of center. (Altitude 949 meters.)

FIGURE 33*B*.—(1972). In this view, taken almost a century after the first, the band of dense riparian vegetation has moved to lower ground, encroaching upon what was formerly a bare shore. The terrace, which was occupied by tall dense vegetation a century earlier, now supports an open growth of arrowweed, Russian thistle, and seepweed. The dense riparian vegetation of today is mainly saltcedar. The fan now supports a continuous broad band of riparian species along its margin. The Paria River has changed its course and now enters the Colorado River below the fan. The dugway road (arrow), seen here crossing the Triassic Moenkopi Formation, was in use for 30 years beginning in 1898 (Rusho and Crampton, 1975).


A
B
N
1952

FIGURE 34.—Three aerial photographs, spanning a 21-year period, record conditions at the mouth of the Paria River near Lees Ferry. The photographs were taken on September 24, 1952; May 14, 1965; and June 16, 1973. Many features shown in figures 31 through 33 can be seen in this series of aerial views. The Echo Monocline forms the cliffs to the right of the Paria River which flows toward the Colorado from the upper right of the photographs. The approximate location of the 1873 channel of the Paria (see fig. 33*A*) is marked with the letter A. The dugway road that was in use until the ferry was abandoned in 1929 can be seen running from point B toward the west above the left bank of the river. The U.S. Geological Survey stream gaging station is located at point B. This is also near the location from which figure 33 was taken.

Lees Ferry, seen at upper left in these photographs, is the embarkation point for boats and rafts that float through the Grand Canyon. In the 1973 photograph, 37 of these craft can be seen tied up either at Lees Ferry or across the river from the town. Two rafts have just departed and appear as the light-colored, elliptical objects in the river toward the right in the 1973 photograph. Lees Ferry has grown in 21 years as has the number of persons embarking here for trips through the Grand Canyon. In 1952, about 50 persons made the trip; in 1965, 547 persons; and in 1973, 15,219 persons (Aitchison, 1976).

The configuration of the debris fan at the mouth of the Paria River changes little from 1952 to 1973, although it appears different as the river level varies. At the time of the September 24, 1952, photograph, the river stage on the gage at B was roughly 2.7 meters; on May 14, 1965, the value was 3.4 meters; and on July 16, 1973, the level was between 1.8 and 2.7 meters.

By 1973, the fringe of saltcedar has become pronounced along some sections of the shoreline. The fan and the plants it supports is shown from another perspective in figure 32 which was taken from point marked C in the 1952 aerial view. Most of the fan surface is probably below the level of maximum flooding, yet some plants have become established there, apparently surviving all but the most severe floods.

FIGURE 34.—Continued.

FIGURE 34.—Continued.

FIGURE 35*A*.—(1952). This upstream view of the river is from the Navajo Bridge on U.S. Highway 89, 6.9 kilometers below Lees Ferry. The bridge was completed in 1928, after which the ferry at Lees Ferry was abandoned. The vertical cliffs expose rocks of the Lower Permian and Toroweap Formation overlying Kaibab Limestone. The interrupted dense thicket is immediately above the infrequently flooded high water level and is composed of netleaf hackberry and Apache plume. Bare beaches of sand appear at this river stage. (Altitude 942 meters.)

FIGURE 35*B*.—(1972). The river is at higher stage here than in the 1952 view, and many of the former sandy areas are covered with water. The new dense riparian community is mainly saltcedar, sandbar willow, and Apache plume with infrequent stands of cattails.

FIGURE 36A.—(1952). Overlooking Badger Creek rapids from a point above the left bank just north of Jackass Creek, 12.6 kilometers below Lees Ferry. Slopewash blankets the Hermit Shale Formation at river level here. The cliffs visible above consist of the Lower Permian Coconino Sandstone and overlying Toroweap Formations. At the time of this photograph (June 19), the discharge for the day at Lees Ferry was 2,799 m^3/s (U.S. Geol. Survey, issued annually). Note the large shrub surrounded by water just off the right bank. This shrub persists in the 1972 photograph. (Altitude 939 meters.)

FIGURE 36B.—(1972). The 24-hour discharge at Lees Ferry on the day of this photograph (August 21) was 529.6 m³/s, approximately one-fifth the volume for the date of the previous photograph (U.S. Geol. Survey, issued annually). Note the raft passing the Badger Creek rapids and several other rafts near the right bank below the rapids. The water through the rapids is obviously more turbulent at this low stage than at the high stage in the 1952 view. The large shrub of the early view is visible and is saltcedar. This plant was present along the river at many places through the Grand Canyon as early as 1938 (Clover and Jotter, 1944), but it probably grew only at scattered localities at or slightly above the contour of maximum river stage. In this view, saltcedar occurs as an interrupted band along both banks of the river.

FIGURE 37*A*.—(1923). This downstream view shows the stretch of quiet water above Soap Creek rapids, 17.7 kilometers below Lees Ferry. The alluvium near the river is devoid of plants. A few outcrops of the Lower Permian Hermit Shale on the slope above the river are exposed through the covering of debris that has fallen from above. (Altitude 933 meters.)

FIGURE 37*B*.—(1972). The large saltcedar shading this spot had a stem diameter (at ground level) of nearly 46 centimeters in 1976. This tree may have become established before the dam during a time of sustained high water. The river no longer reaches this level. Cattails grow in the protected embayment in the foreground. Because the new camera position is too far right for an exact match, judgments concerning erosion of the foreground alluvium cannot be made.

FIGURE 38A.—(1923). The U.S. Geological Survey team camped on the right bank, August 6, 34.6 kilometers below Lees Ferry. A portion of the Pennsylvanian and Lower Permian Supai Group is here exposed at the upper right. The stick in the foreground is a mast for a radio antenna. The conspicuous plants on the sandy knoll behind the four men are probably wire lettuce and spiny aster. On the opposite bank, a discontinuous line of shrubs, probably Apache plume, marks the level of maximum river stage. (Altitude 907 meters.)

FIGURE 38*B*.—(1972). Saltcedar, growing to heights of 6 meters, is the dominant plant on the site. Longleaf brickellia (right foreground), wire lettuce, and spiny aster are also present.

FIGURE 39*A*.—(1923). E. C. LaRue, a member of the 1923 U.S. Geological Survey team, took this upstream view at the lower end of Tanner Wash rapids, 39.4 kilometers below Lees Ferry. These rapids have been difficult to navigate in the past: Powell posted and lined here in 1869; two members of the Brown-Stanton party drowned here in 1889; Bert Loper's boat capsized here in 1939, and he was never seen again (Hamblin and Rigby, 1969; Péwé, 1969). A large pile of driftwood has accumulated on the silt deposit in front of the boats. Pre-Glen Canyon high-water surges probably overflowed the uppermost boulders. Roughly 2 kilometers upstream from this station recent river silts 6–7.5 meters above river level remain as evidence of the height of predam flows in this reach of the canyon (Hamblin and Rigby, 1968). No vegetation can be seen along this section of the river. (Altitude 893 meters.)

FIGURE 39*B*.—(1974). Most of the boulders seen in 1923 are still in place on the debris fan at the mouth of Tanner Wash. The large pile of driftwood seen in the earlier view is gone as is the deposit of fine alluvium beneath it. Saltcedar is growing near the river, and longleaf brickellia is the common shrub at higher levels on the beach. The camera for this photograph is located slightly too far left for an exact match.

FIGURE 40*A*.—(1872). J. W. Powell's boat, the Emma Dean, with Powell's armchair strapped to the deck, is seen in this upstream view at 45.5 kilometers below Lees Ferry. The photograph was taken from a small fan at the mouth of a minor side canyon. The narrow canyon and vertical walls of the Mississippian Redwall Limestone promote high velocities and attendant scouring during times of large streamflow volume. This section of Marble Canyon appears to support no vascular plants. (Altitude 884 meters.)

FIGURE 40*B*.—(1972). The tree on the right is saltcedar. The dominant small shrub on the fan is longleaf brickellia. Shrubs occur at scattered localities on the opposite side of the river. Since Powell's trip, there has developed in this short reach of the canyon an open terrestrial biotic community.

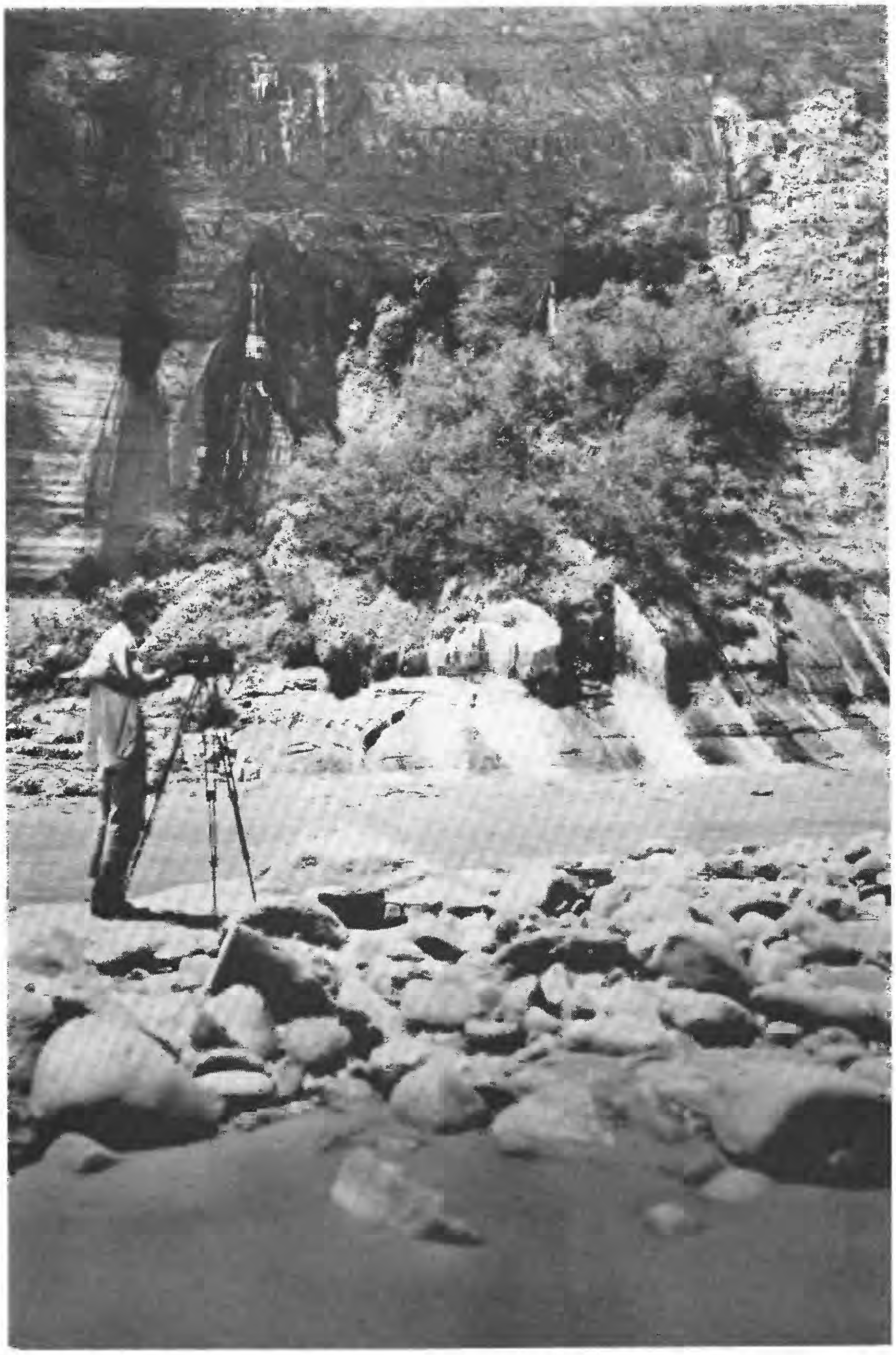

FIGURE 41*A*.—(1923). L.R. Freeman, a member of the 1923 U.S. Geological Survey team, took this picture of E.C. LaRue photographing Vaseys Paradise, 51.5 kilometers below Lees Ferry. This is one of the better known springs along the Colorado River and was named by Powell for Dr. G. W. Vasey, a botanist (Powell, 1961). Stanton Cave, where members of the Brown-Stanton expedition cached their equipment when they abandoned their first trip in 1889, lies only a few hundred meters upstream. Stanton Cave and the cave system from which springs flow at Vaseys Paradise are evidence of the susceptibility of Mississippian Redwall Limestone to solution. The moist area in the scene is generally northeast facing and supports a dense growth of redbud and poison ivy. A bare skirt just above the river marks the strip scoured periodically by heavy flow. (Altitude 875 meters.)

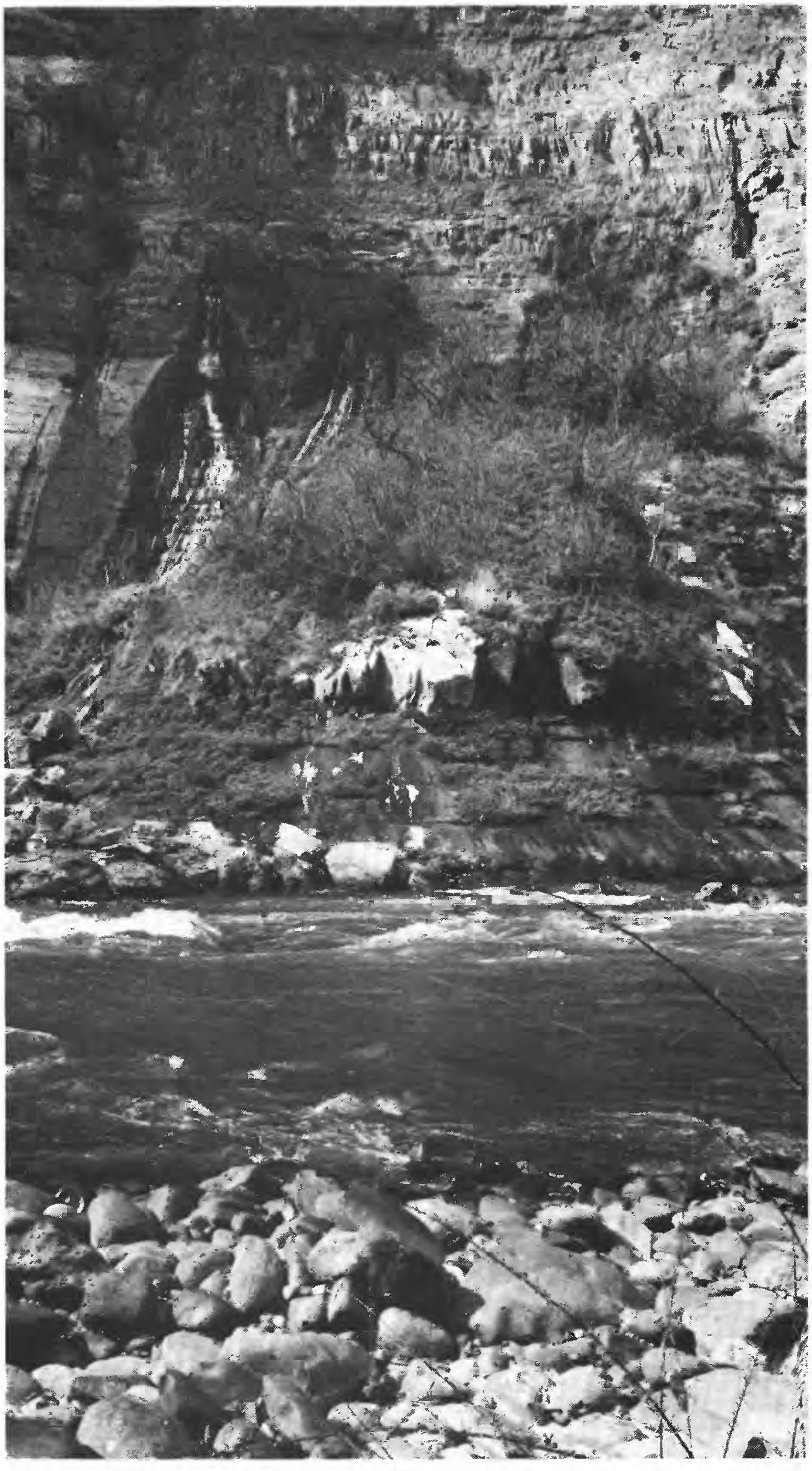

FIGURE 41*B*.—(1974). Many of the redbuds appear dead in this March 17 photograph; however, since this photograph was taken many plants have been periodically observed to have progressively recovered (A.M. Phillips III, oral commun., 1978). Many herbaceous plants now grow within the old scour zone, including scouring rush, watercress, and monkey flower. These plants were reported at Vaseys Paradise by Clover and Jotter (1944) in 1938 and were probably among those plants seen in the 1923 photograph. Saltcedar (right foreground) is now established on the gravel bar near the camera station.

FIGURE 42A.—(1923). This photograph provides a downstream view of the Grand Canyon from within Redwall Cavern, 53.3 kilometers below Lees Ferry. The cavern, formed by solution of the Mississippian Redwall Limestone (Hamblin and Rigby, 1968) is one of the major attractions of the Grand Canyon. Prior to the contruction of Glen Canyon Dam, the river entered the cavern during high flows producing conditions too unstable for plant establishment. Powell camped here during a rainstorm and noted that the floor would be inundated during periods of peak flow by a "raging flood" (Powell, 1875). Waves during an earlier period of high water have produced marks in the sand that are high above the river level in this 1923 view. Erosion of the alluvium is apparent from the vertical bank near the edge of the water. The large blocks on the far side of the cavern and in the foreground have fallen from the roof. The plant in the foreground is dogbane. (Altitude 873 meters.)

FIGURE 42*B*.—(1974). Comparison of this photograph with the earlier one reveals several changes. The impact of wave action is no longer apparent away from the river, but wind ripples are evident in the sand of the foreground. Using the collapse blocks as references, it is apparent that aggradation, perhaps from wind, has occurred on the higher parts of the beach and erosion has reduced the sand deposit toward the base of the sloping beach. The sand bar across the river to the right appears new. The only plants visible are scattered saltcedars. The lack of more vegetation probably results from the low light intensity within the cavern and trampling by the thousands of visitors that stop here each year.

FIGURE 43*A*.—(1923). This view was taken from the top of a talus slope on the right bank a short distance above Triple Alcoves, 74.8 kilometers below Lees Ferry. The vertical outcrops with conspicuous bedding at right foreground are the Middle Cambrian Muav Limestone. The Mississippian Redwall Limestone forms the vertical cliffs above the Muav. The flood-line vegetation is especially well developed on the talus slopes on the right bank. A few logs of driftwood can be seen along the upper part of the boulder-strewn beach; elsewhere on the beach, there are no signs of plants. (Altitude 858 meters.)

FIGURE 43*B*.—(1974). Driftwood is still visible in the same location as before, and many boulders are the same in both views. Much of the sand deposit is still relatively unstable and devoid of plants. In this March view the flood-line community, composed mainly of western honey mesquite in this section of Upper Marble Canyon, is leafless and cannot be easily compared with its counterpart in the August 1923 photograph. Western honey mesquite is first seen in the canyon only 11.5 kilometers upriver from here. Some of the plants (jointfir) on the talus slope at the right seem to be the same as those in the earlier view. The vegetation at the river's edge is predominantly saltcedar and willow, with sparse seep willow, arrowweed, and cattail. Other species found on the beach are peppergrass, desert plume, Russian thistle, red brome, globemallow, brittlebush, dyssodia, longleaf brickellia, and desert trumpet.

FIGURE 44*A*.—(1923). Ancient Indian structures, which were possibly used to store grain, can be seen in a cave within the Mississippian Redwall Limestone in this downstream view near the mouth of Nankoweap Canyon. The photographic station is roughly 259 meters above the Colorado River and 84.6 kilometers below Lees Ferry. A dense stand of catclaw, western honey mesquite, and netleaf hackberry occurs above the level attained by the river during flood stage (Altitude 847 meters.)

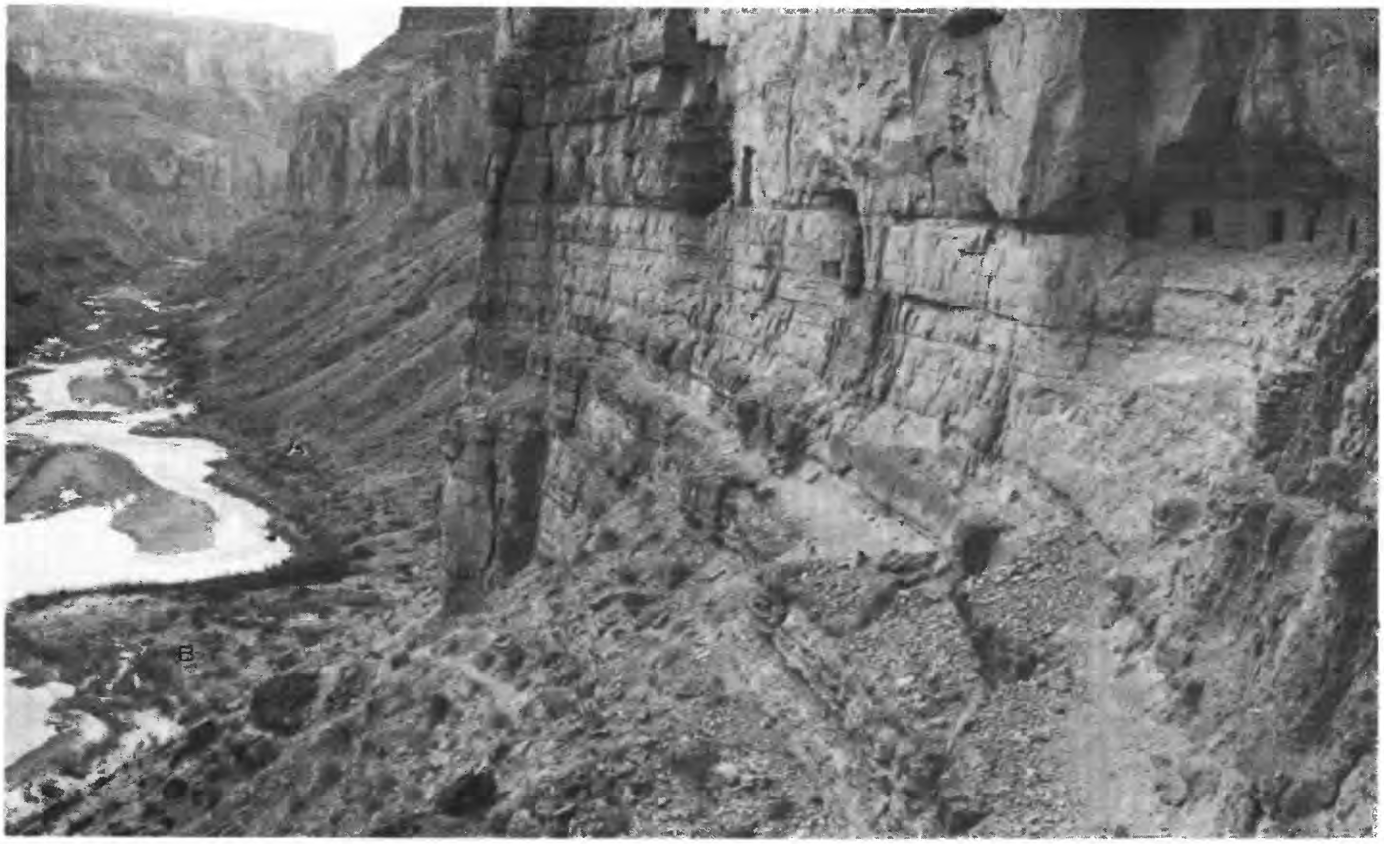

FIGURE 44*B*.—(1974). This matching photograph was taken in March before many of the shrubs and trees in the valley were in full leaf. The preceding photograph was taken in August when foliage was fully developed. Because the decrease in density of the plants at A might be the result of differences in seasonal development, additional photographs, taken by John Richardson, Southern Illinois University, in July 1978, were obtained. These photographs (not shown) were taken at a time of maximum leaf development and reveal the same decline in the predam flood-line community as in this March view. The dense thicket on the terrace above the boats (at B) was thinned by a wildfire that burned through the thicket in May 1970 (P. S. Martin, written commun., 1971). During the 51-year interval between the two photographs, there has been extensive development of the riparian belt near the margins of the river. Saltcedar, arrowweed, sandbar willow, and Emory seep willow are the dominant plants with occasional growths of cattail, smooth horsetail, and great bulrush. Trails have become prominent features of the slope leading to the Indian ruins.

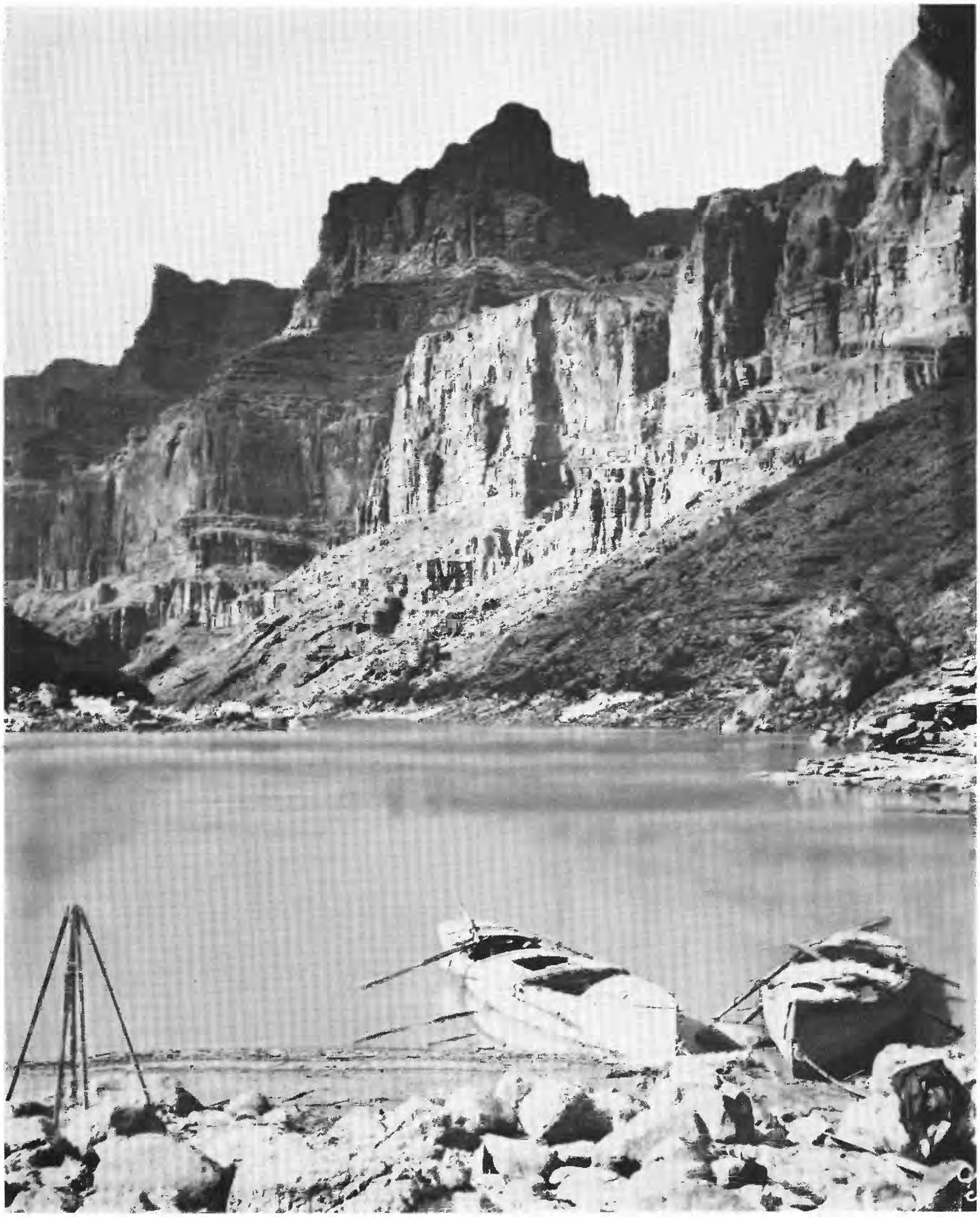

FIGURE 45A.—(1872). Two of Powell's boats are shown tied up at a small island at the mouth of the Little Colorado River 98.8 kilometers below Lees Ferry. The mouth of the Little Colorado is just out of view on the right. This upstream view of the Colorado River valley shows a well established zone of dense vegetation above the level of maximum river stage and at the approximate base of the Middle Cambrian Bright Angel Shale. Several light-colored deposits of sand appear on both banks; these accumulations are deposited during spring high flows. (Altitude 826 meters.)

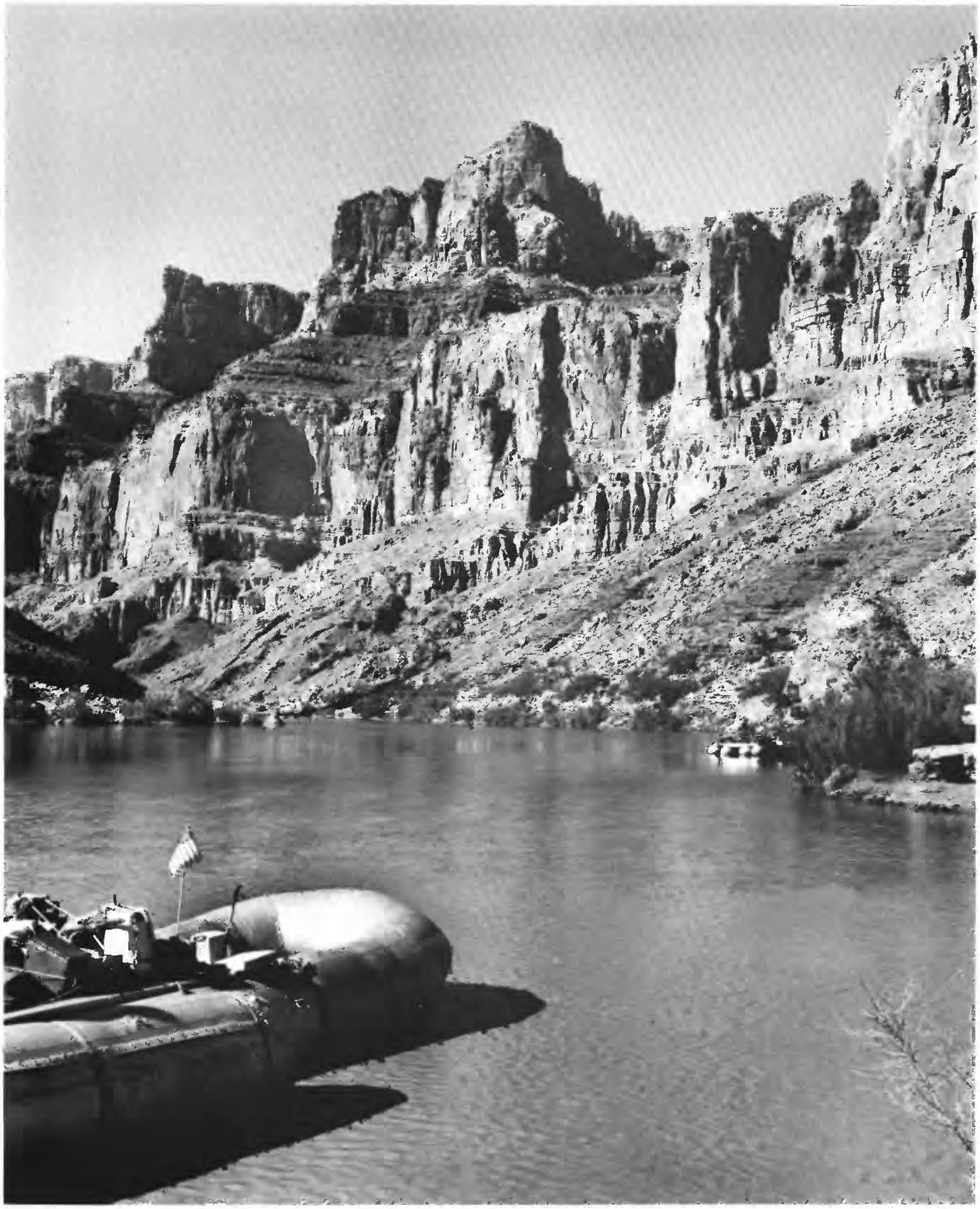

FIGURE 45*B*.—(1972). Two boats representative of styles commonly in use today appear in this view. Saltcedar now occupies the habitat nearest the river. The zone of dense vegetation above the old high water line is little changed in 100 years and is mainly catclaw. The river stage is several feet higher in the 1972 view than at the time of Powell's visit. A silt deposit now covers formerly bare surfaces on the rocky promontory in the Lower and Middle Cambrian Tapeats Sandstone at right.

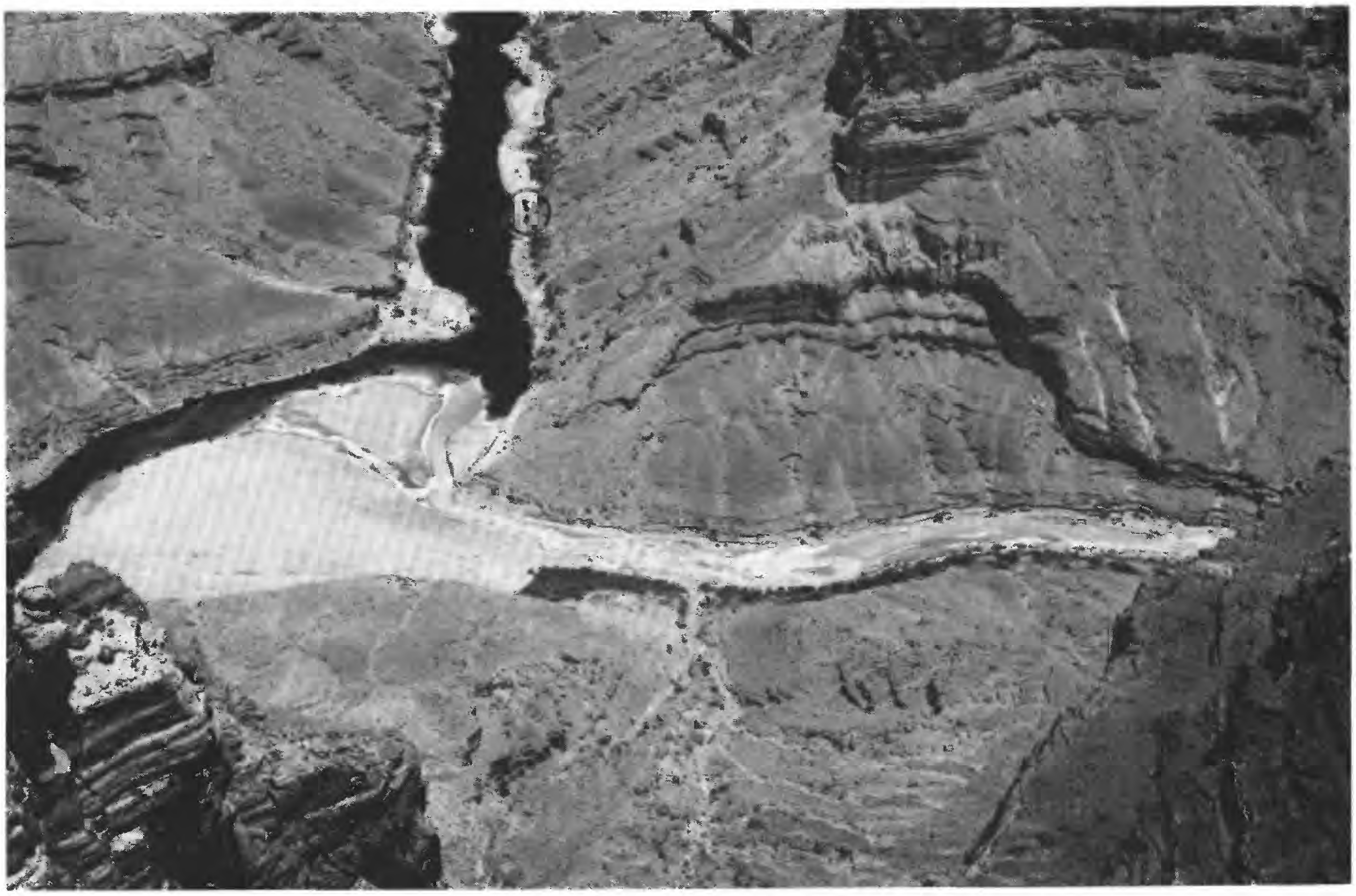

FIGURE 46A.—(1963). The mouth of the Little Colorado River as seen from Cape Solitude, 1,167 meters above river level. This upstream view of the Colorado River was taken after completion of Glen Canyon Dam and during a period of low flow when Lake Powell was filling. From this vantage point, the interrupted line of dense vegetation marking the flood level is visible, especially on the left bank. A few shrubs (circle) have become established below the upper fringe of plants. The Little Colorado River enters from the right, and its waters appear turbid in this July view. A dense stand of riparian vegetation lines its left bank. (Altitude 826 meters.)

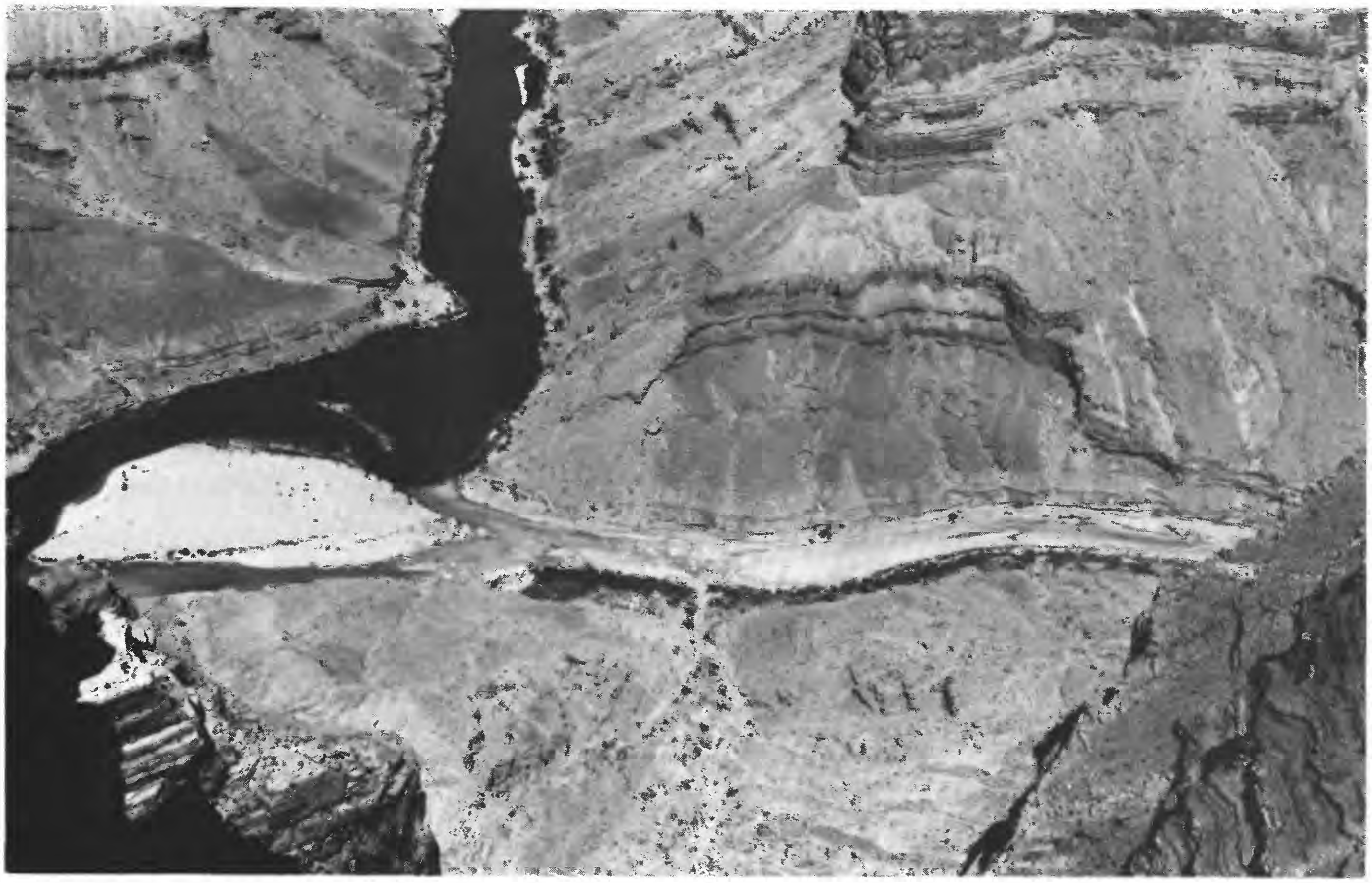

FIGURE 46*B*.—(1973). In the 10-year period between the dates of the two photographs the dense stand of saltcedar remains approximately the same along the lowest reach of the Little Colorado River. Vegetation changes along the Colorado River mainstem show three trends, depending upon location: Changes are slight or nonexistent within the dense stand of catclaw marking the former high water line; changes are conspicuous near the edge of the water where a dense growth of saltcedar has recently appeared; the few shrubs that had become established below the upper fringe by 1963 have increased in size but not in number.

FIGURE 47*A*.—(1872). This photograph was taken by J. K. Hillers from near the mouth of Lava Canyon 105.4 kilometers below Lees Ferry. The vegetation on the opposite bank grows on a fan at the mouth of Palisades Creek. The dominant plants appear to be western honey mesquite and catclaw. Note the ripple marks on the block at the right. (Altitude 817 meters.)

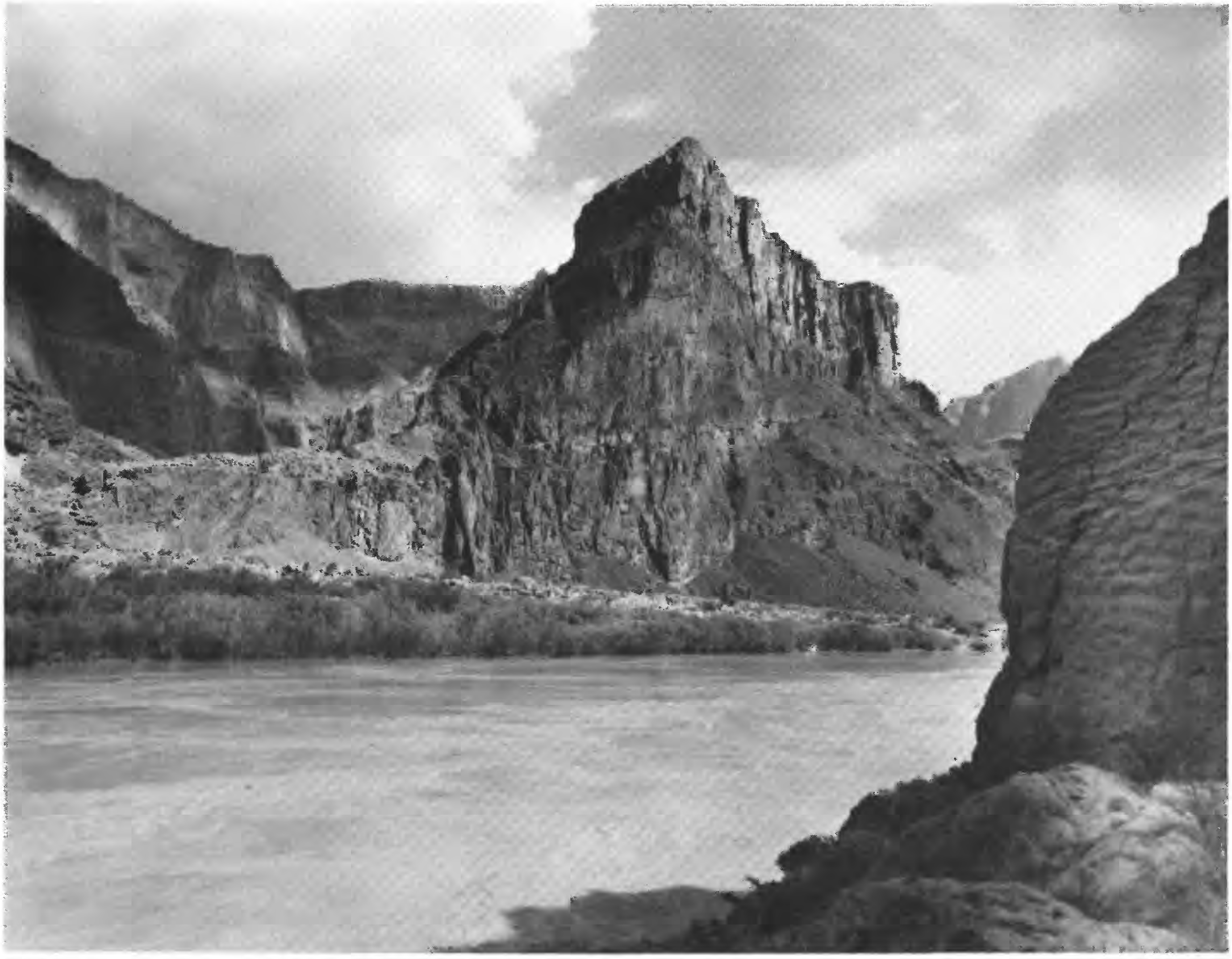

FIGURE 47*B*.—(1974). The foreground rocks show little change in the 102 years since the first photograph of this pair was taken. On the opposite shore, the bare sandy beach of the previous century is now covered by sandbar willow and saltcedar with minor inclusions of seep willow and arrowweed. The zone with western honey mesquite and catclaw is little changed and, although not discernible in this view, is separated from the riparian vegetation bordering the river by an open zone of mainly ephemeral plants.

FIGURE 48A.—(1923). The U.S. Geological Survey team is shown packing up for portage at the head of Hance Rapids, 123.1 kilometers below Lees Ferry. The pack animals were able to reach the river from the South Rim by descending the Hance Trail. The base of the vertical exposure of Precambrian Shinumo Quartzite (upper left) is well defined by differential weathering of the underlying Hakatai Shale. A thicket of desert shrubs can be seen on the left above the zone scoured by floods. (Altitude 780 meters.)

FIGURE 48*B*.—(1972). The depth of the sand deposit has increased and saltcedar grows densely along the edge of the river. The sand dune is new on the sloping area at left midground. The thicket of desert shrubs at left, comprising western honey mesquite, catclaw, and four-wing saltbush, is rearranged but may have changed little in biomass. The Hance Trail is no longer maintained and is not usable by pack animals. The remains of a campfire and the many human tracks attest to the heavy use the area receives as a campground by parties floating down the river. In 1974 this campsite was given a subjective human impact rating of 20.0 on a scale from 10.0 (no impact) to a maximum impact value of 22.6 (Aitchison, 1976). In spite of the heavy use, saltcedar has become established in abundance.

FIGURE 49*A*.—(1872). This downstream view, taken by J. K. Hillers on Powell's second expedition, shows the head of the rapids named Sockdolager by Powell in 1869. In boxing parlance this name means a heavy or finishing blow. The rapids are 126.3 kilometers below Lees Ferry and are the first in the Upper Granite Gorge, which begins about 2.4 kilometers upstream from here. Because the lower Precambrian rocks through the Upper Granite Gorge are resistant to erosion, steep walls and a narrow V-shaped canyon are produced. The great length of the rapids and the thunder produced by the sound of the waves reverberating from the walls as the water tumbles through the gorge, gives the rapids a frightening aspect. There is little substrate for terrestrial plants near the river or above on the cliff faces. (Altitude 770 meters.)

FIGURE 49*B*.—(1974). Except for one clump of saltcedar, leafless in the March view, little has changed in 102 years. Because of the narrow canyon and the near vertical walls, fluctuations in water level are exaggerated through this reach. The reaches of the river with the least vegetation change are the "Inner Gorges" represented by this view.

FIGURE 50*A*.—(1952). This photograph is the first in a set of three that spans 20 years. The photograph is taken from the Kaibab Trail just above the Kaibab Suspension Bridge, 140.6 kilometers below Lees Ferry, and shows the mouth of Bright Angel Creek. The debris fan at the mouth of Bright Angel Canyon is devoid of plants except on higher ground where western honey mesquite is the dominant large plant. The large trees around the base of the hill near midground are Fremont cottonwoods. Phantom Ranch is out of view upstream on Bright Angel Creek. The area near the mouth of Bright Angel Creek is the most heavily visited location in the bottom of the Grand Canyon and is served by two trails from the south rim and one from the north. (Altitude 741 meters.)

FIGURE 50*B*.—(1963). On the date of this photograph, Glen Canyon Dam had been completed and the water was being impounded in the reservoir area above it. No plants occur at the river's edge. Most of the boulders on the beach are the same in this and the earlier photograph.

FIGURE 50*C*.—(1972). In the 9 years since the previous photograph was taken many new features are apparent. In December 1966, record flooding occurred in the Bright Angel watershed and the creek left the old channel, flowing across the debris fan toward the camera point. Boulders in the path of the flood were removed from the fan (or covered?) and finer material was deposited in their place. In the absence of subsequent flooding along the Colorado River, this area has remained free of boulders. The bridge across the Colorado River on the left was built in 1967 and is used as a foot bridge. The bridge also supports a pipeline carrying water from the upper reaches of Bright Angel Creek to the south rim. The cottonwoods at midview have declined as have the mesquites on the right (between the bare fan and the trail above). Plants now occupying the debris fan near the edge of the water include sandbar willow, saltcedar, and several Fremont cottonwood saplings. The fan was visited in May 1978. Beavers had cut the sapling cottonwoods, but the trees had produced multiple basal spouts.

FIGURE 51*A*.—(1903). Bright Angel Trail reaches the Colorado River at the mouth of Pipe Creek (kilometer 143.1), the point from which this upstream view was taken. The floor of the canyon is devoid of plants. In the vicinity of the camera station, the only apparent features near the river are sand, cobbles, and consolidated rocks. (Altitude 732 meters.)

FIGURE 51*B*.—(1976). The sand deposits seen in the earlier view are largely gone and a few plants have become established along the river banks. The route of a trail cut through the Precambrian Vishnu Schist in 1936 (Hughes, 1967) can be seen above to the right. A large rock block, present in the earlier picture near the river at right, has fallen. It may have been displaced by falling rubble at the time of trail construction. Although not seen in this view, high water levels of predam time are expressed as sand and coarse gravel plastered against the canyon walls 12 to 18 meters above the river (Hamblin and Rigby, 1969).

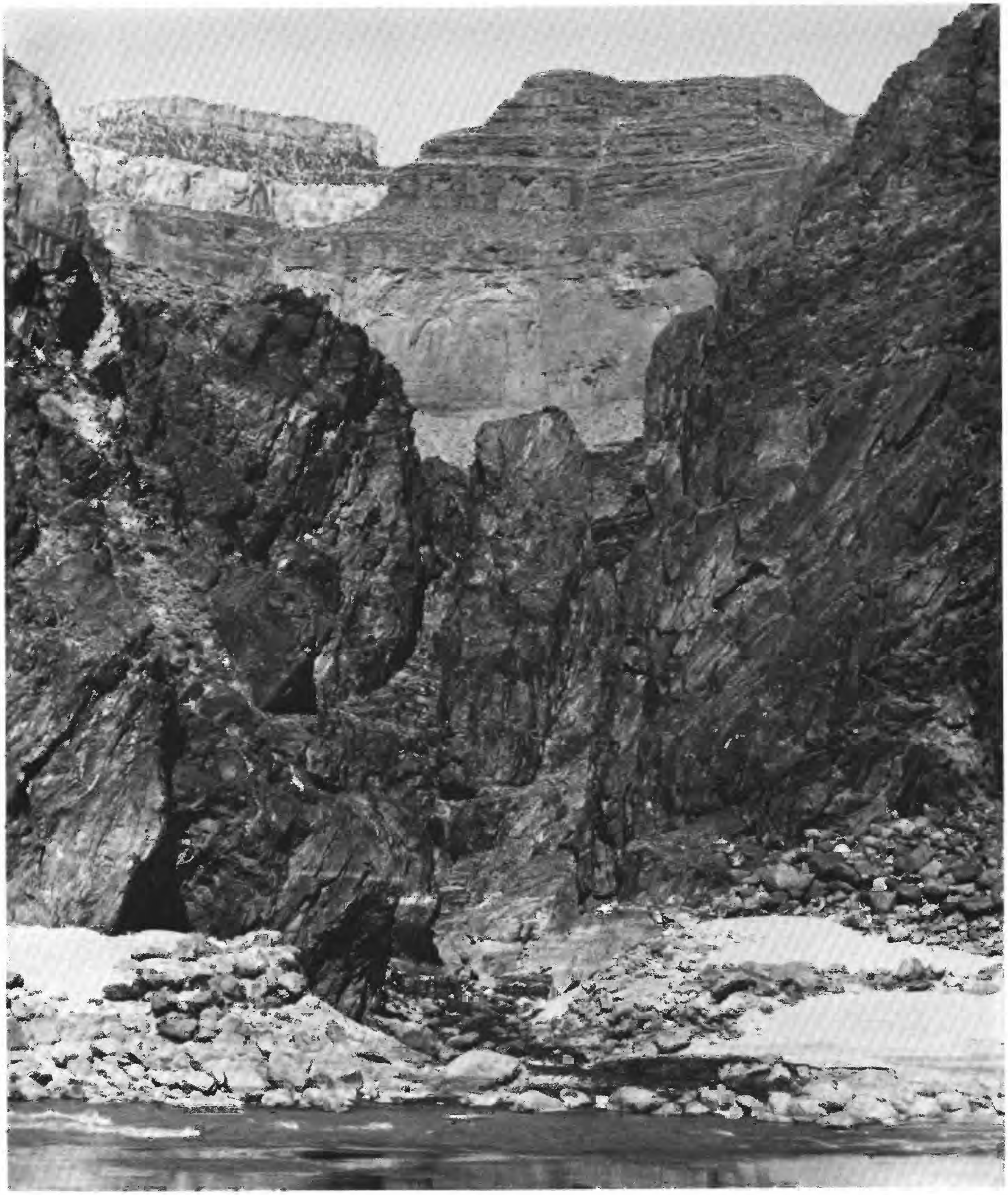

FIGURE 52A.—(1901). The Colorado River flows from right to left in this view up Shinumo Creek, 174.7 kilometers below Lees Ferry. The photograph was taken from the opposite bank and shows horizontal water stains on cliffs to the left of the canyon mouth. The deposit of sand and boulders at the mouth of Shinumo Creek is not occupied by plants. (Altitude 666 meters.)

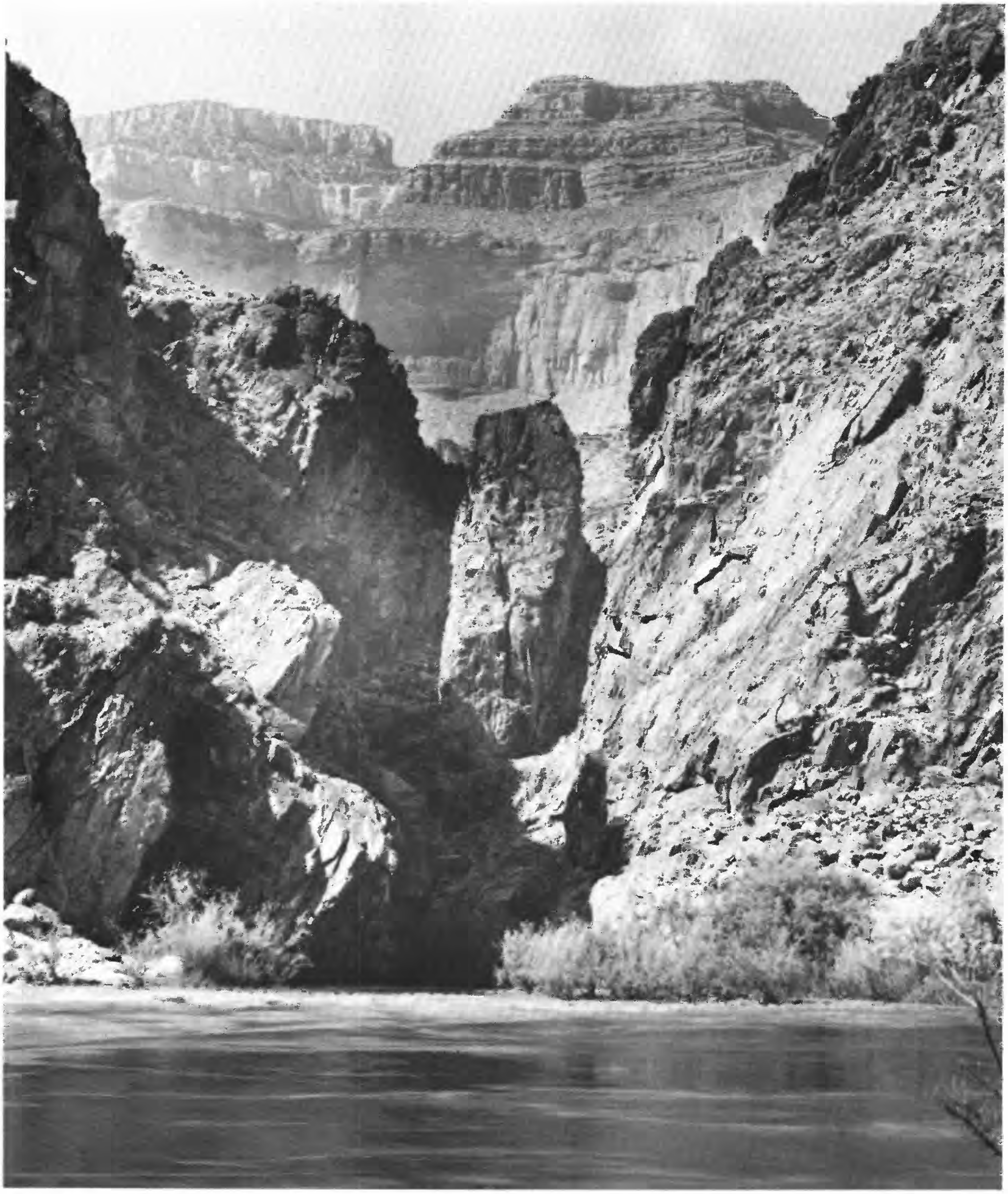

FIGURE 52*B*.—(1972). The river is at higher stage than in the previous view, but several changes are apparent: the sand deposit at left is gone, and saltcedar now flanks the mouth of Shinumo Creek and also occupies the camera location. The pile of rounded boulders has changed little since 1901.

FIGURE 53*A*.—(1890). The three boats of the Stanton Survey party are tied up at a small sandy beach 185.8 kilometers below Lees Ferry. This upstream view shows the well-bedded Lower and Middle Cambrian Tapeats Sandstone at river level again, having been at varying elevations above the river since roughly the mouth of the Little Colorado River (fig. 45). Sand deposits near the camera station and upstream on the opposite bank have been left by high flows. No plants are established below the upper edge of these deposits. (Altitude 645 meters.)

FIGURE 53*B*.—(1976). The river is at higher stage now than in the earlier view but loss of much of the higher sand deposits is evident. A few plants of dicoria occur on the sand. Saltcedar is perhaps 3–4 meters tall where it grows in scattered pockets near the edge of the river.

FIGURE 54*A*.—(1923). This downstream view shows the debris fan at the mouth of Fossil Canyon (out of view on left), 200.8 kilometers below Lees Ferry. The Middle Cambrian Bright Angel Shale is exposed near river level through this reach of the canyon, although it is mostly covered by slope wash. A line of scattered shrubs marks the high water line above the barren beach of rocks and patches of sand. (Altitude 623 meters.)

FIGURE 54*B*.—(1976). The line of shrubs seen in the previous view is composed of catclaw and appears to be little changed. Both views were taken in September, a month when the shrubs are in full leaf. The camera is too far back for an exact match. The catclaw right of center has grown in size. The herbaceous plants of the foreground slope are approximately as dense now as in 1923. This camera station is on a well-travelled burro trail. Saltcedar grows densely along sandy stretches on the opposite bank and long-leaf brickellia grows in an open stand on the rocky areas. The sand deposits on the opposite bank are less thick than in 1923.

FIGURE 55A.—(1872). A. H. Thompson, who was in charge of topographical work on Powell's second expedition (Dellenbaugh, 1908; Bartlett, 1962), was photographed looking upstream from the left bank a short distance below Fossil Canyon at the head of the Middle Granite Gorge, 202.7 kilometers below Lees Ferry. The Lower and Middle Cambrian Tapeats Sandstone forms a shallow inner gorge here. There is no observable vegetation on the pile of boulders in the foreground. (Altitude 619 meters.)

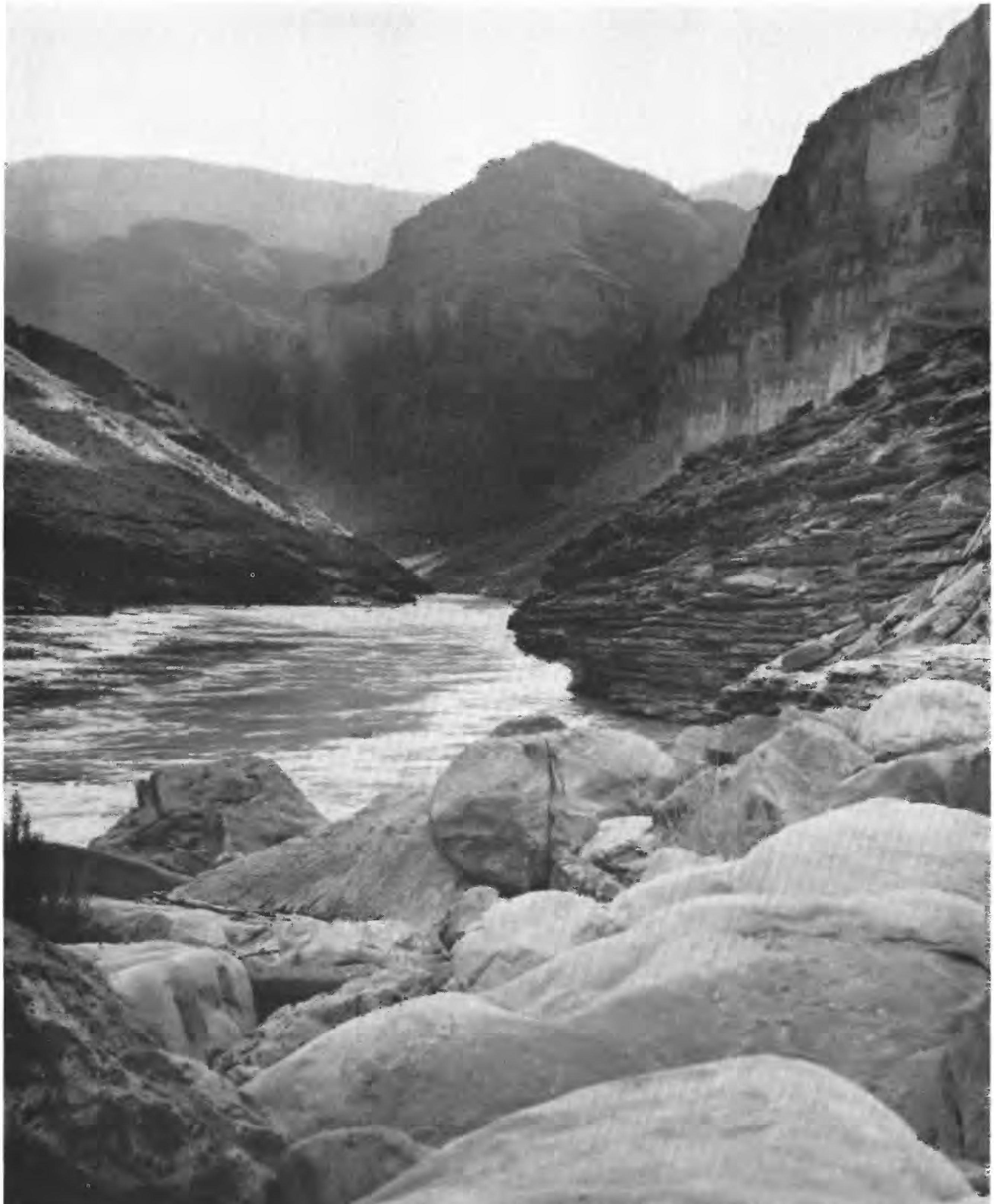

FIGURE 55*B*.—(1974). Although the photograph is not an exact match, one can easily see that the configuration of the pile of boulders has changed little, if at all. After 102 years, such plants as dropseed, seep willow, and saltcedar have become established among the large rocks. The light colored sand deposits appear smaller now than before.

FIGURE 56*A*.—(1923). The water in Deer Creek plunges more than 30 meters through a slot cut in the Lower and Middle Cambrian Tapeats Sandstone just before entering the Colorado River, 219.1 kilometers below Lees Ferry. Angular blocks from the cliff face above lie on the banks of the river. The Colorado River flows from right to left in this picture. (Altitude 588 meters.)

FIGURE 56*B*.—(1972). Few raft parties pass here without stopping: between 1963, when Glen Canyon Dam was completed, and August 1972, when this photograph was taken, an estimated 50,000 people had visited this site. Saltcedar, sandbar willow, and seep willow grow densely at the mouth of Deer Creek in spite of the heavy human impact. The large blocks and boulders have not changed noticeably but changes involving some of the smaller rocks along the beach are evident. The large sand deposit on the left in the old photograph is gone.

FIGURE 57*A*.—(1923). Kanab Creek (left foreground) enters the Colorado River 231.2 kilometers below Lees Ferry and is seen here from a camera station approximately 100 meters above the river. Powell ended his second trip here in 1872, leaving the Grand Canyon via Kanab Canyon. The Middle Cambrian Muav Limestone is exposed at the entrance to Kanab Canyon, with Mississippian Redwall Limestone and Devonian Temple Butte Limestone forming the vertical walls above. The development of a well-defined row of shrubs above the position of maximum flood stage is the most conspicuous feature of the vegetation in this view. (Altitude 572 meters.)

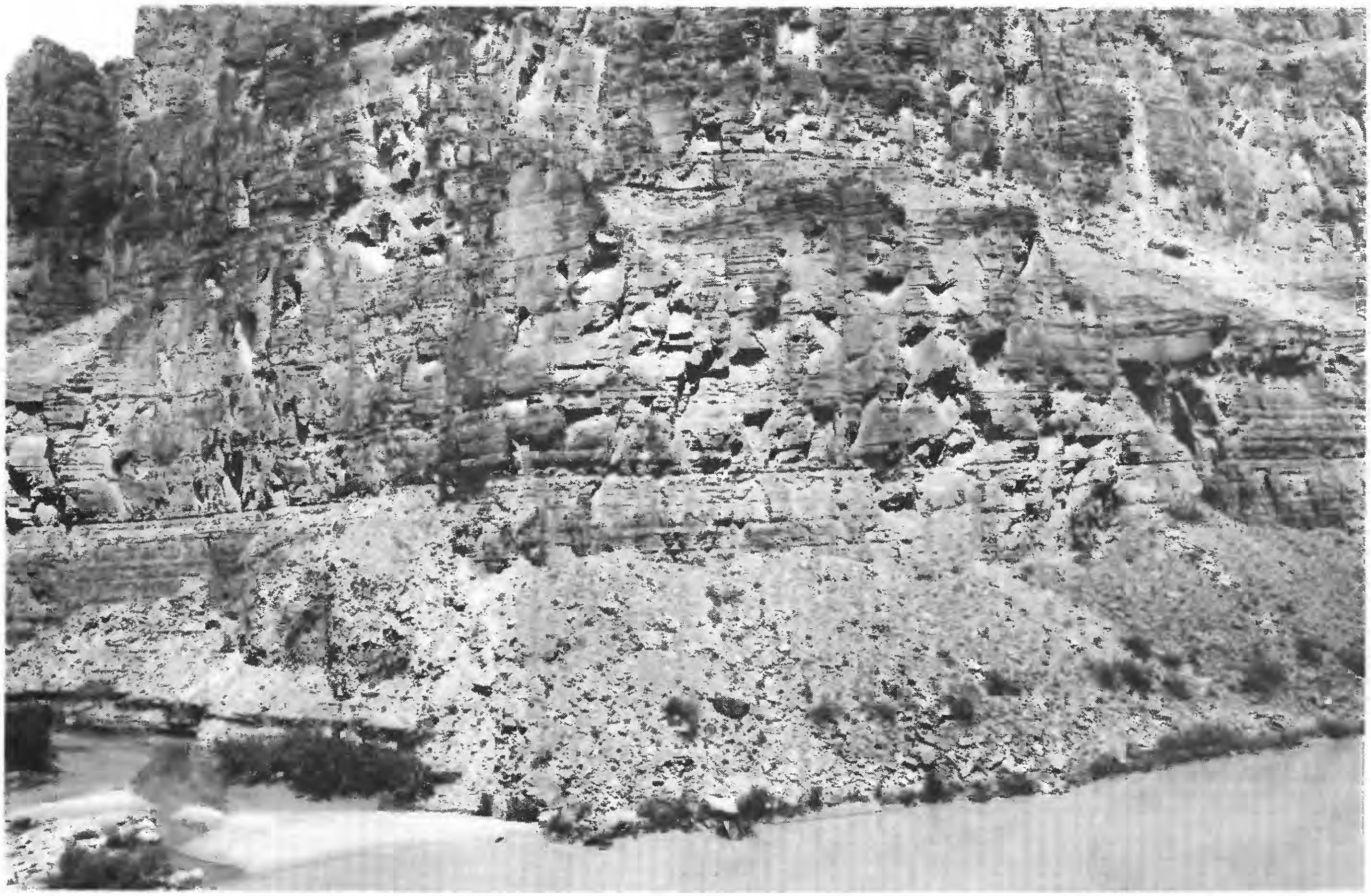

FIGURE 57*B*.—(1972). The row of shrubs marking the predam high flood stage is catclaw and has persisted with little change through almost half a century. The new riparian community comprises several species, including saltcedar, seep willow, waterweed, Emory seep willow, cattail, and desert isocoma. A rock avalanche at upper right is new since 1923.

FIGURE 58*A*.—(1923). A bare skirt, several times wider than the length of the U. S. Geological Survey boat at left, is seen in this view of the right bank a short distance above Lava Falls, 287.4 kilometers below Lees Ferry. A dense shrub community occurs above the reach of flood water. (Altitude 511 meters.)

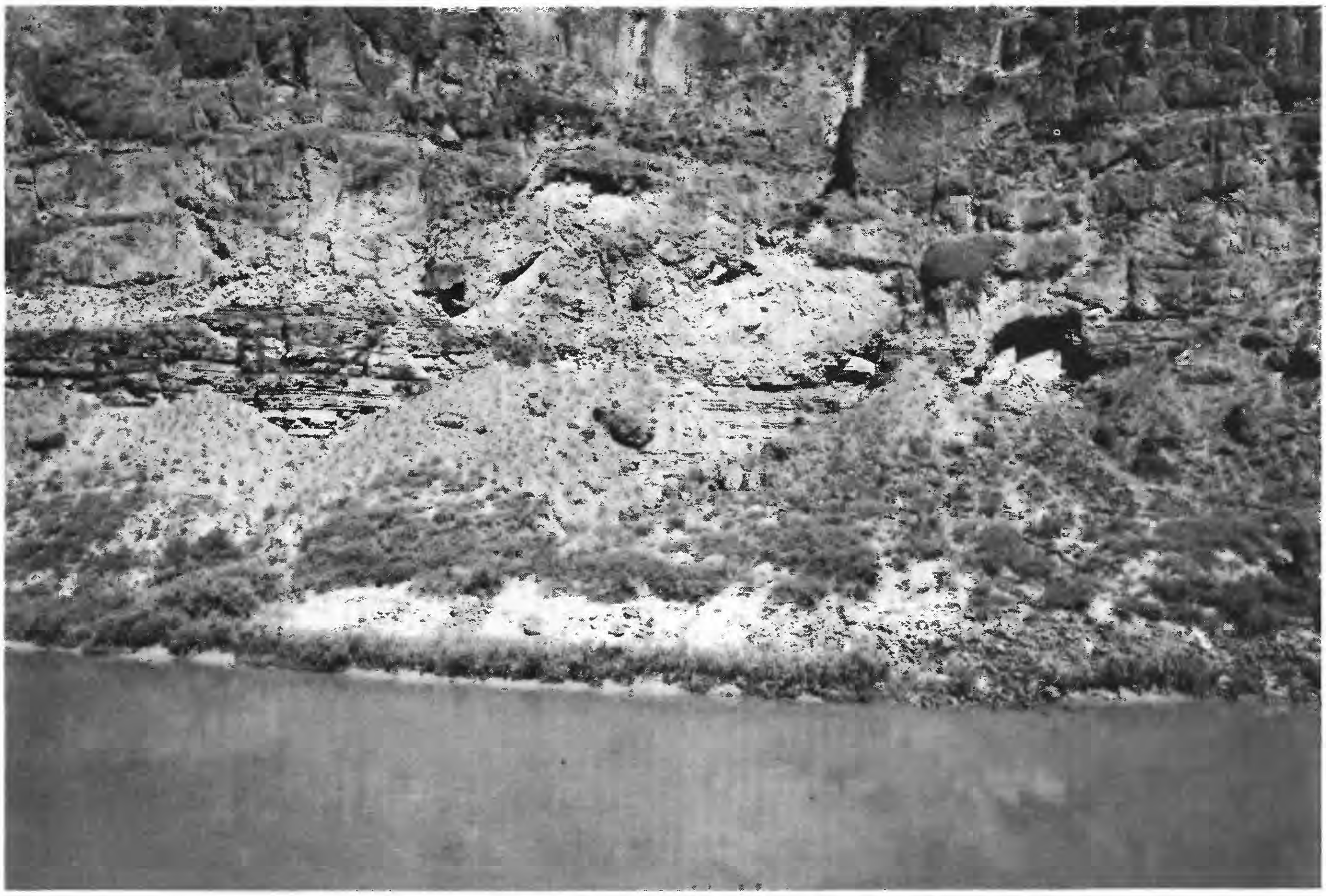

FIGURE 58*B*.—(1972). Slight thinning may have occurred along the upper fringe of the dense plant community present in 1923. (The 1923 and 1972 photographs were taken in September and July, respectively, and the degree of foliation should be approximately the same in both.) The community is dominated by western honey mesquite and catclaw. The open desert community on the upper parts of the talus slopes beneath the cliffs is composed mainly of creosote bush which reaches its range limit 15 kilometers upstream from this point (P. S. Martin, written commun., 1971). The riparian community is dominated by saltcedar with lesser amounts of arrowweed and desert broom. The latter species became an important member of this community beginning about 24 kilometers upstream from this station. Sandbar willow and cattail grow along the lower edge of the riparian community in the strip subjected to diurnal flooding. Cambrian strata, mostly covered by slope wash, lie just above river level. Upper Cenozoic basalt flows overlie the sedimentary rocks. Layers of river gravels, laid down during periods between successive flows, are exposed on the cliff face.

FIGURE 59*A*.—(1950). Most boatmen agree that Lava Falls Rapids, which lies 288.5 kilometers below Lees Ferry, represent the greatest hazard to navigation on the Colorado River. This remarkable photograph was taken of the rapids from the right bank looking toward the mouth of Prospect Canyon. Flow in the river was approximately 1,473 m^3/s. The great turbulence created when the water encounters erosional debris from Prospect Canyon is clearly seen in this photograph. The large dark shrubs in this view were still present in 1976 (fig. 59*B*) and are catclaw. Some of the shrubs on the opposite bank are desert broom. (Altitude 511 meters.)

FIGURE 59*B*.—(1976). This photograph was taken from a slightly different position and at a time when the Colorado River was carrying only 102 m^3/s. There has been a notable biomass increase in the riparian community during the 26 years since the original photograph was taken. The erect, coarse grass at the mouth of Prospect Creek is carrizo. Other plants growing near the river include arrowweed, desert broom, cattail, saltcedar, and horseweed. On the dissected fan at the mouth of the canyon is creosote bush, catclaw, ocotillo, and barrel cactus. The last seems to have declined in number since 1950.

FIGURE 60A.—(1923). This photograph was taken from the left bank 313.6 kilometers below Lees Ferry. A Quaternary basalt flow is seen at river level on the right. The canyon of the Colorado River is broad enough here so that the scouring action of flood waters is dampened and some perennial plants became established in the alluvium near the river. A flood, 6 days earlier, overtook the U.S. Geological Survey crew at Lava Falls, 25.1 kilometers upstream from here and the river stage increased by 6.7 meters (Freeman, 1930). The signs of recent wave action high on the beach in this photograph probably stem from the same flood. Several plants such as the tree (Fremont cottonwood or willow) at right midground, desert broom (left foreground), and what is probably saltbush (near the men), withstood these floodwaters. (Altitude 471 meters.)

FIGURE 60*B*.—(1972). At the time of this photograph a Goodding willow was growing at the same location as the tree in the previous view. The present tree is smaller than the one in the earlier photograph. Either the original tree was broken and then resprouted or there is now a different tree growing in the same location. Desert broom is the dominant woody plant of the foreground beach. The grasses, which have increased notably over the beach area, will serve to stabilize the sandy soil of the beach. The new camera location closely matches the old, although the lack of stable foreground features precludes exactly matching the two views. An increase in sand deposition on the beach is obvious. The giant grass, carrizo, grows at the edge of the river with saltcedar.

FIGURE 61*A*.—(1923). This upstream view was taken from a point just above Spring Canyon, 328.9 kilometers below Lees Ferry. The Middle Cambrian Bright Angel Shale, mostly covered by slope wash, is at river level. A well-developed community occurs above the flood line on both sides of the river. At the present river stage, a large bar, unoccupied by plants, is exposed. (Altitude 454 meters.)

FIGURE 61*B*.—(1974). The camera station is too far forward and too far to the right for an exact match. The plants that now densely occupy the higher ground of the old bar include saltcedar, seep willow, desert broom, catclaw, arrowweed, and some large western honey mesquites. The present exposed bar is probably low enough to be inundated by the regular daily high flows. Because of the slightly darker tones of western honey mesquite and catclaw foliage compared to the color of the riparian plants, the contact between the old highwater community and the new riparian community is apparent. Across the river where the talus slopes have a northerly aspect, the highwater community is mostly western honey mesquite and catclaw. This elongate community appears slightly more open in 1974 (August) than in 1923 (September). The same highwater community below the camera station has a southerly aspect, and four species share dominance: western honey mesquite, wolfberry, creosote bush, and catclaw. On the slope in the foreground is Mohave Desertscrub vegetation comprising ocotillo, brittlebush, creosote bush, Morman tea, and barrel cactus.

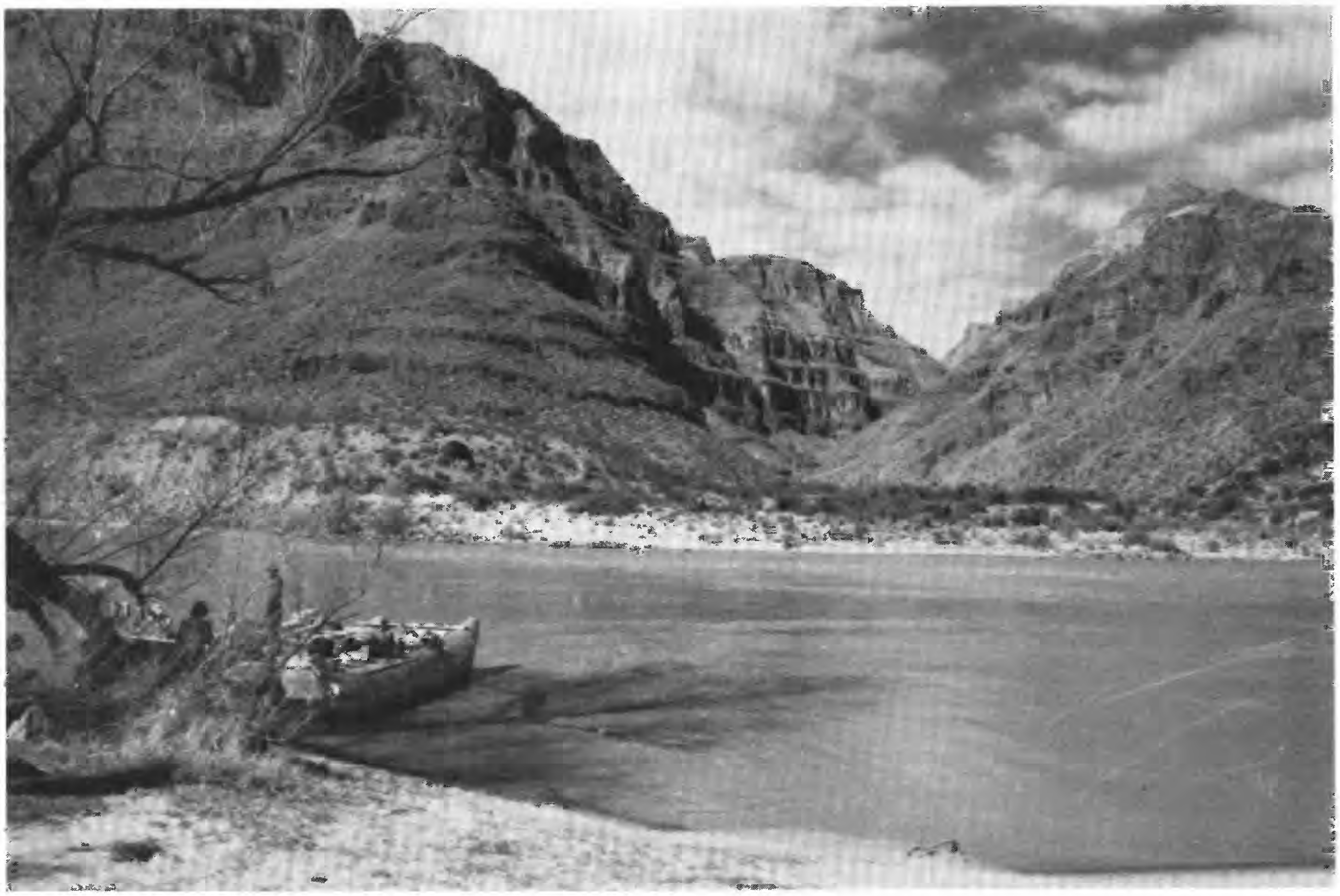

FIGURE 62*A*.—(1923). The mouth of Two Hundred and Ninemile Canyon is seen across the river from this camera station in a small cove at Granite Park, 336 kilometers below Lees Ferry. The first cliffs above the river to the right of the canyon mouth are remnants of a basalt flow and are preserved here, as elsewhere along this reach of the Grand Canyon on the inside of a meander bend. The willow at left is one of those seen from a distant hill in figure 64*A*. Once these plants have developed a large enough root system, they withstand considerable buffeting by floods in the broad valley at Granite Park. A well-developed flood-line community can be seen across the river at the mouth of Two Hundred and Ninemile Canyon. (Altitude 442 meters.)

FIGURE 62*B*.—(1974). Because the old camera station is now overgrown by saltcedar and desert broom, this photograph was taken from a slightly different location than in 1923. The tree at left is Goodding willow and is the same plant as in the earlier view. Bermuda grass now grows on the beach near the tree. The flood-line community at the mouth of Two Hundred and Ninemile Canyon comprises western honey mesquite and catclaw. Although not evident in the photograph, close field inspection revealed that both species, trimmed through grazing by burros, are infested by mistletoe.

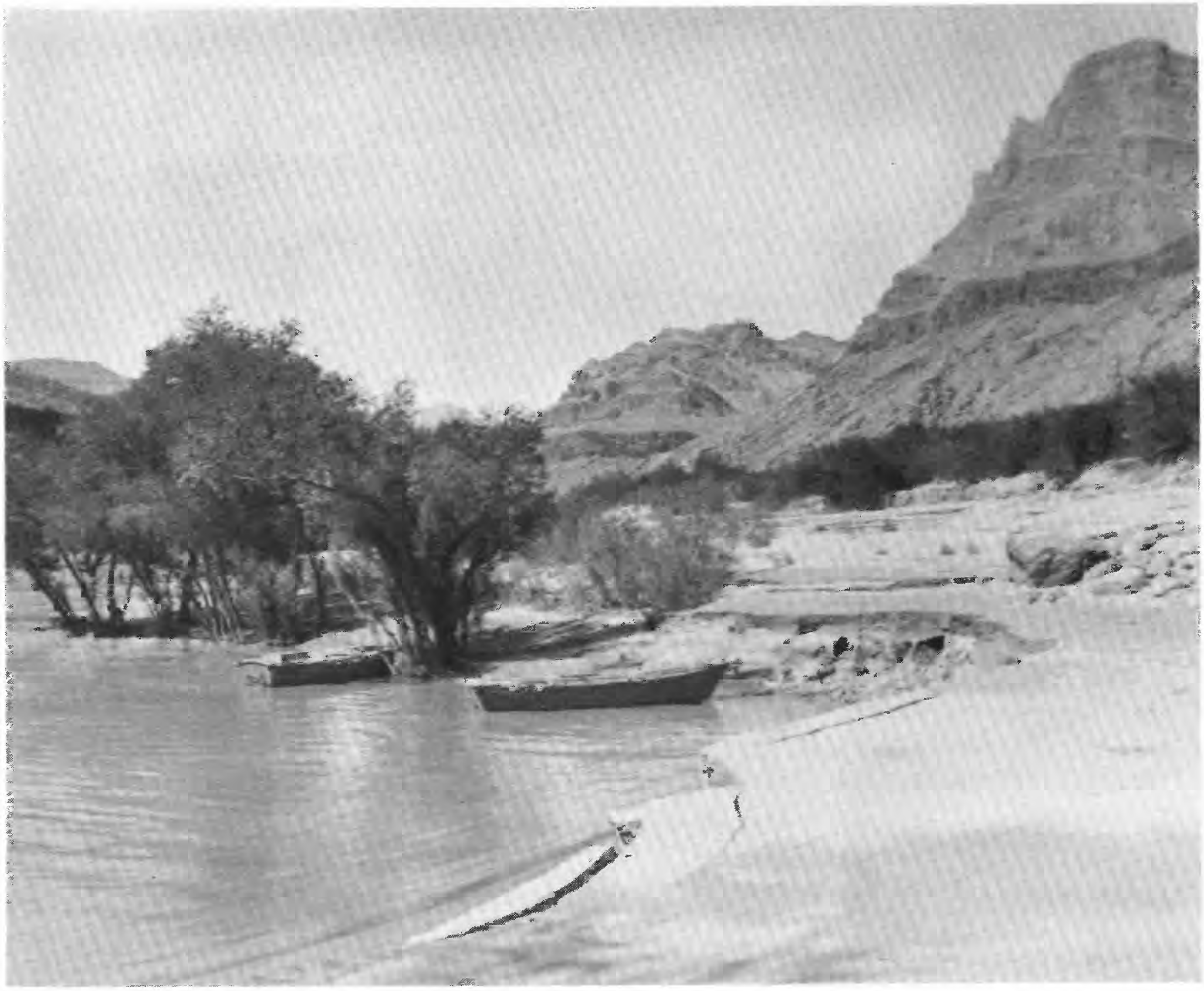

FIGURE 63*A*.—(1923). E. C. LaRue used a panoramic camera that took pictures through a wide angle of view. This photograph was taken with that camera and is a continuation to the right of figure 62*A*.Temple Butte Limestone forms much of the conspicuous butte on the right; thicker bedded limestones form cliffs, thinner bedded limestones form the shallow ledges. The large shrubs near the U.S. Geological Survey boats appear to be willows and the smaller shrubs behind them to the right, arrowweeds. The vertical banks below the flood-line community at right midground and on the beach near the boats suggest that erosional processes are active. (Altitude 442 meters.)

FIGURE 63*B*.—(1974). The clump of large shrubs seen near the boats in the previous view are gone and have been replaced by a few small Goodding willows which are obscured by the more abundant saltcedar. The band of arrowweed has expanded and now occupies, with desert broom, the sandy beach between the saltcedar fringe along the river and the scarp below the first terrace. On the terrace, the dark shrubs of the old flood-line community are mainly western honey mesquite with some catclaw.

FIGURE 64*A*.—(1923). This upstream view was taken from a point 168 meters above the Colorado River and shows Granite Park, 336 kilometers below Lees Ferry. A flood-line community is strongly developed along this section of the canyon. Some trees have become established at the edge of the river, a habitat that is here more stable than usual because of the great width of the valley floor. (Altitude 442 meters.)

FIGURE 64*B*.—(1974). This view, taken in March, shows a greatly diminished flood-line community, but this reduction in plant biomass is more apparent than real—the shrubs comprising the community are leafless at this season, whereas in the 1923 photograph, taken in September, the plants were in full leaf. The streamside plants that were present in 1923 and which persist to the present are willows. Unlike the condition in 1923, the beach at Granite Park now supports a dense growth of plants. The dominant species on the beach are willow, arrowweed, saltcedar, camelthorn, red brome, and Bermuda grass. All but the first two species have been introduced to this continent from other parts of the world. Feral burros, another introduced species, are found only on the right side of the river. On areas of poorly stabilized sand, grow sand verbena, evening primrose, and dropseed. The vegetation of the bajada is typical Mohave Desertscrub with creosote bush, white bursage, brittlebush, ocotillo, range ratany, and various cacti.

Sand deposits on the large formerly barren island are becoming stabilized by such plants as dropseed, sand verbena, evening primrose, bebbia, globemallow, longleaf brickellia, and slender poreleaf. The arm of the river to the right of the island in the photograph now carries little flow and may be an incipient marsh. Along its margin grow such marsh species as cattail, carrizo, and horsetail in addition to saltcedar, seep willow, willow, and arrowweed.

FIGURE 65*A*.—(1923). This downstream view was taken at kilometer 350.3 from a station just below the mouth of Two Hundred and Seventeenmile Canyon and only a short distance into the Lower Granite Gorge. Except where sediment has entered the canyon from tributaries, there are few sand or gravel shores within the Lower Granite Gorge, so steeply have the Precambrian rocks eroded to river level. Even where substrate exists for riparian communities, as on the foreground debris fan, the narrowly defined valley tends to increase the depth of flood waters making these habitats too unstable for plant establishment. The flood-line community is also missing on the steep slopes above the river. (Altitude 424 meters.)

FIGURE 65*B*.—(1972). Seasonal flow maxima are greatly reduced under the present flow regime and formerly inhospitable debris fans now support a varied plant life. Among the species on the foreground alluvium are arrowweed, cattail, carrizo, desert broom, sandbar willow, and saltcedar. The conspicuous shrub below the sloping flat boulder at upper left is catclaw; the plant has changed little in nearly half a century.

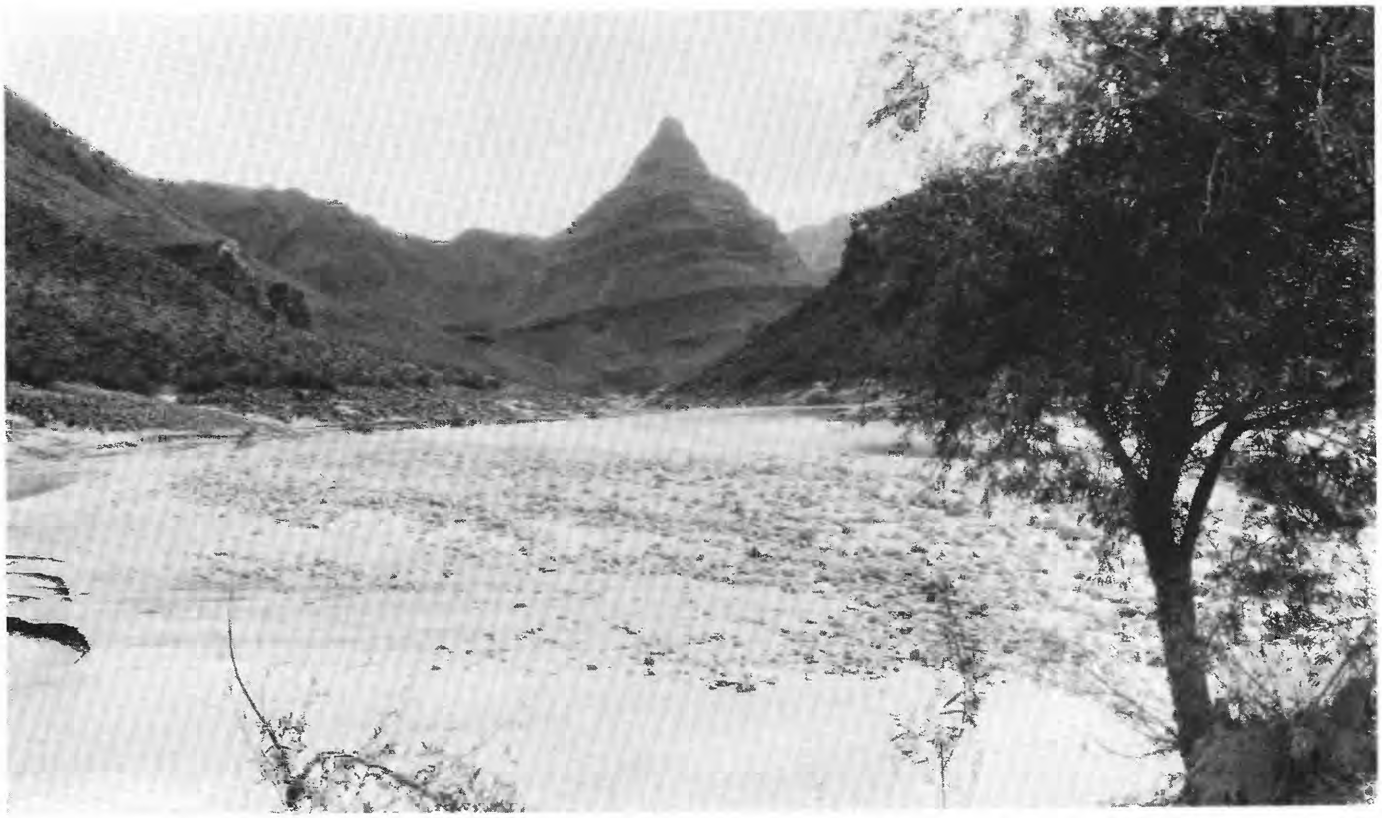

FIGURE 66*A*.—(1923). Members of Powell's second river expedition found quartz crystals on an ant hill near the pyramid-shaped peak at center and the peak became known as Diamond Peak (Dellenbaugh, 1908). The valley is broad through this section of the Lower Granite Gorge, and alluvial deposits are common. There is a single plant at the left on the far side of the gravel bar in this downstream view taken 358.1 kilometers below Lees Ferry. The plant's identity is uncertain, but it appears bent over, perhaps from the same flood of a few days earlier that overtook the U.S. Geological Survey team at Lava Falls. The flood-line community is conspicuous in this photograph taken in early October. In the foreground, a large willow can be seen. (Altitude 413 meters.)

FIGURE 66*B*.—(1972). The camera station is now in a dense stand of arrowweed. Many saltcedar plants grow around the edge of the gravel bar where a half century earlier only one plant was visible. In addition, two western honey mesquites, desert broom, Goodding willow, and desert isocoma grow near the shore. The flood-line community, mainly of catclaw with few western honey mesquites, is still present but seems diminished in this August view. Close inspection of this community shows that there are numerous burro trails and the basal portions of flood-line community shrubs are stripped of foilage where in reach of the animals.

FIGURE 67*A*.—(1923). View down the V-shaped canyon cut through Precambrian metamorphic rocks. The stratified formation capping the Precambrian rocks is the Lower and Middle Cambrian Tapeats Sandstone. The far skyline is defined by a formation of the Pennsylvanian and Permian Supai Group. The sand deposit in the foreground and the one across the river are both at the mouths of minor tributary canyons 360.7 kilometers below Lees Ferry. A flood line is apparent from stains on the rocks of the opposite shore and no plants are visible below that level. (Altitude 408 meters.)

FIGURE 67*B*.—(1976). The boulder with the man standing on it in the previous photograph is now hidden by saltcedars, which form a discontinuous strip along both shores. The depth of sand around the base of the boulders is less now than before. The sand deposit is now partially stabilized by dropseed (the coarse grass), red brome, and Russian thistle. Signs of burros are abundant.

FIGURE 68*A*.—(1902). This photograph was taken from the small promontory of rocks seen beyond the fan in the previous pair of pictures and shows in close view the same large tree near the river as seen in the previous views. For the tree to have reached this size would probably require 10 or more years of growth. Thus, the tree became established in about 1892 or earlier and persisted until at least 1923 (fig. 69*A*). (Altitude 408 meters.)

FIGURE 68*B*.—(1972). Saltcedar, arrowweed, and seep willow grow thickly at the site occupied earlier by the single tree. Slightly to the right of that position can be seen a clump of cattails.

FIGURE 69*A*.—(1923). Diamond Creek enters the Colorado River 363.2 kilometers below Lees Ferry and is the first place in that distance where vehicles can reach the river. The mouth of Diamond Creek was visited by Ives and his party in 1858 (Ives, 1861) and was the terminus of the Wheeler Expedition in 1871 (Wheeler, 1872). The Diamond Creek Hotel was in operation here for sightseers from 1884 to 1889 before scenic areas farther east were developed (Barnes, 1960; Simons and Gaskill, 1969). In this upstream view, the only plant at the river's edge is a large tree visible on the opposite bank in a protected area below a bar. (See also figure 68*A*.) Large plants on the fan at the mouth of Diamond Creek (right midground) are probably mesquites. On the uppermost sandy terrace of the fan a dense growth of small shrubs is evident. (Altitude 407 meters.)

FIGURE 69*B*.—(1976). A dense community of saltcedar, arrowweed, and seep willow has become established along the shore on both sides of the river. The fan at right is more heavily overgrown by plants than before, except for the formerly stabilized high terrace which now seems to be covered by a sand deposit. The large tree on the opposite bank has not persisted to the present. The Colorado River no longer floods the large bare area with boats and people on it; as a result, fine material, deposited by flooding on Diamond Creek, now covers the gravels that were present earlier. Bermuda grass grows in moist soil near the shelters. The lower reach of Diamond Creek (foreground) is lined by a riparian community dominated by saltcedar.

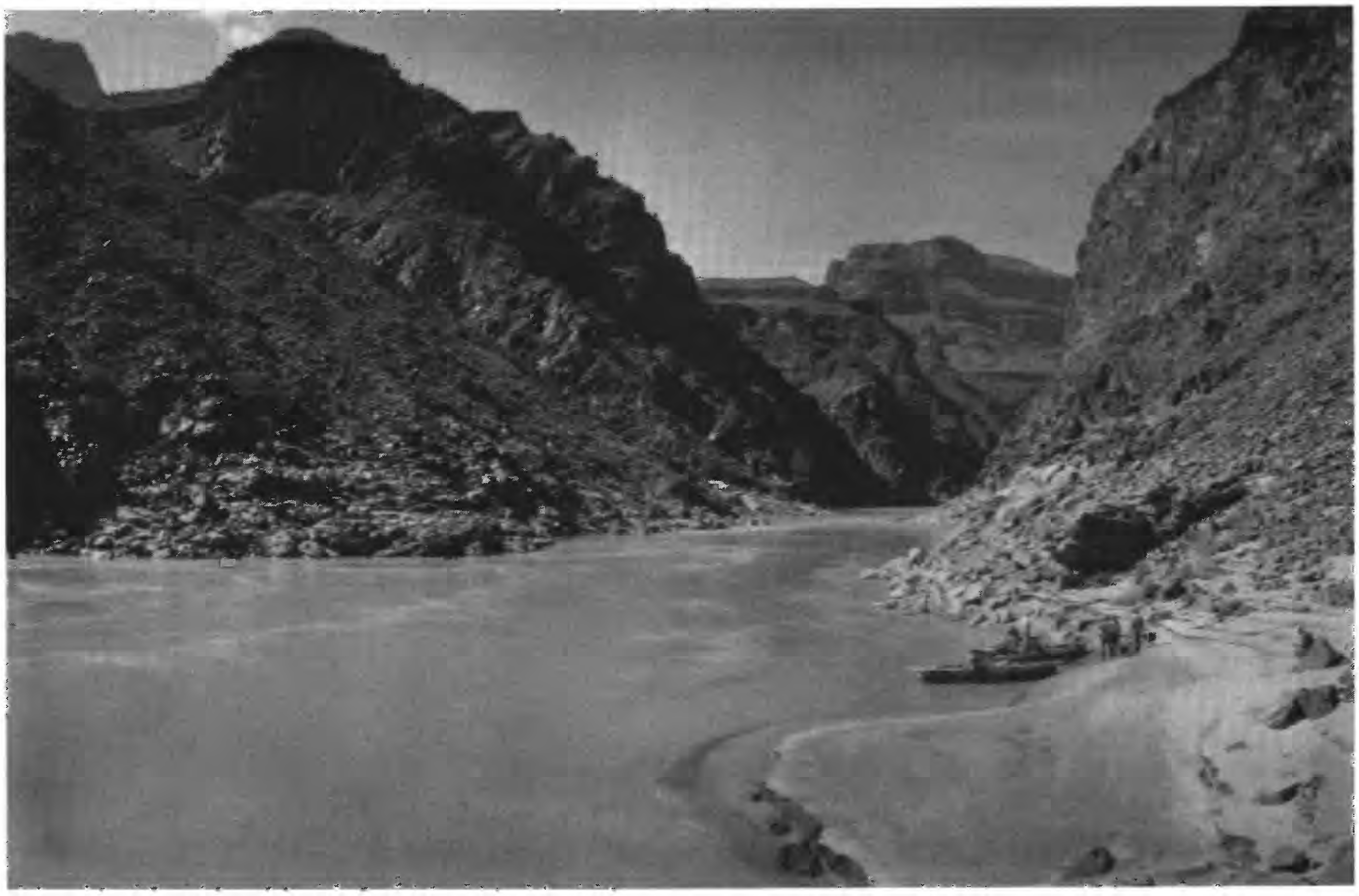

FIGURE 70*A*.—(1923). The U.S. Geological Survey team has moored its boats near a large rock at a sand bar on the right bank, 368.0 kilometers below Lees Ferry. Although no flood-line community is found on the steep walls of the Lower Granite Gorge, the flood line is visible because of stains on the rocks of the talus slope. No plants are found below that line, and above it are seen widely scattered desert shrubs. (Altitude 395 meters.)

FIGURE 70*B*.—(1972). The new flood line now lies below the large rock and several plants of brittlebush grow on the slope between the new and the old flood lines. The bar in the foreground is unusual in that no plants have become established there. The Inner Gorge is narrow here and during times of high flow the bar is flooded, making for an unstable surface for plant establishment.

FIGURE 71*A*.—(1923.) This upstream view of the Colorado River was taken from a hill above the mouth of Maxson or Reference Point Canyon, 406.0 kilometers below Lees Ferry. At the time of the photograph, barren silt accumulations deposited during floods could be seen high on the steep walls of the Inner Gorge. For explanation of the dashed line, see the next figure. (Altitude 322 meters.)

FIGURE 71*B*.—(1972). Silt had accumulated to a depth of over 50 meters in this reach of the Lower Granite Gorge by 1948, approximately 13 years after the completion of Hoover Dam (Pampel, 1960). The old camera station is now within the reservoir area of Hoover Dam and is buried beneath Lake Mead silt. The new station has been moved upslope. Saltcedar is the dominant plant of the foreground. The dashed line in the previous figure marks the approximate location of the surface of the silt deposit seen in this view. The vertical silt bank extends approximately 5.5 meters above the present water surface and has developed since 1963 when the water level in Lake Mead was lowered sharply at the time impoundment of water in Lake Powell began. A secondary riparian community has developed at the base of the bank. At the time of the photograph, the lake level was approximately 352.5 meters above mean sea level (U.S. Geological Survey, issued annually). By the following May, the lake level reached 361.8 meters above mean sea level (U.S. Geological Survey, issued annually), at which time the silt bank was probably inundated resulting in the death of many of the saltcedars.

FIGURE 72*A*.—(1923). The Lower Marble Canyon ends at about kilometer 414.3 and the steep walls of the Inner Gorge give way to less steep talus slopes. In this view, looking down the canyon of the Colorado River 437.6 kilometers below Lees Ferry, the flood-line community is well developed above the conspicuous highwater line. The Middle Cambrian Bright Angel Shale is at river level. Typical Mohave Desertscrub species of the foreground include ocotillo, white bursage, and agave. The floodline community probably includes western honey mesquite and catclaw. (Altitude 282 meters.)

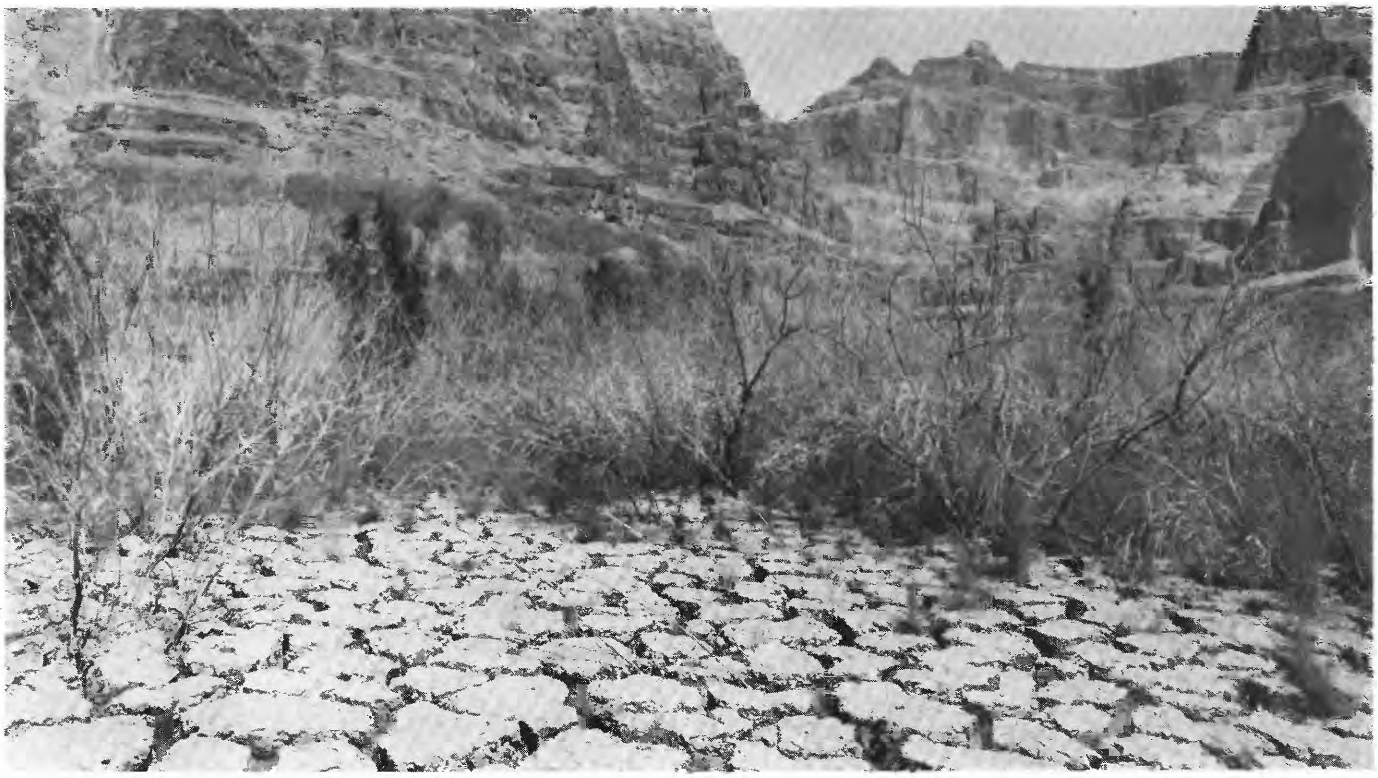

FIGURE 72*B*.—(1974). The old camera station lies beneath Lake Mead silt several meters below and to the right of the new position. Before Hoover Dam was built the thalweg altitude was roughly 275 meters; now the thalweg altitude exceeds 350.5 meters, representing an accumulation of 76.2 meters of sediment (Pampel, 1960). Saltcedar is the only plant seen on the deeply cracked silt deposit. Many of the plants are dead in this August view, presumably from submergence during earlier months when this site was covered by water to a depth of 2.7 to 3.7 meters. Some taller plants survived. Seedlings growing from the deep cracks in the foreground became established after the water receded. This scene illustrates the dynamic nature of the saltcedar community on Lake Mead silt.

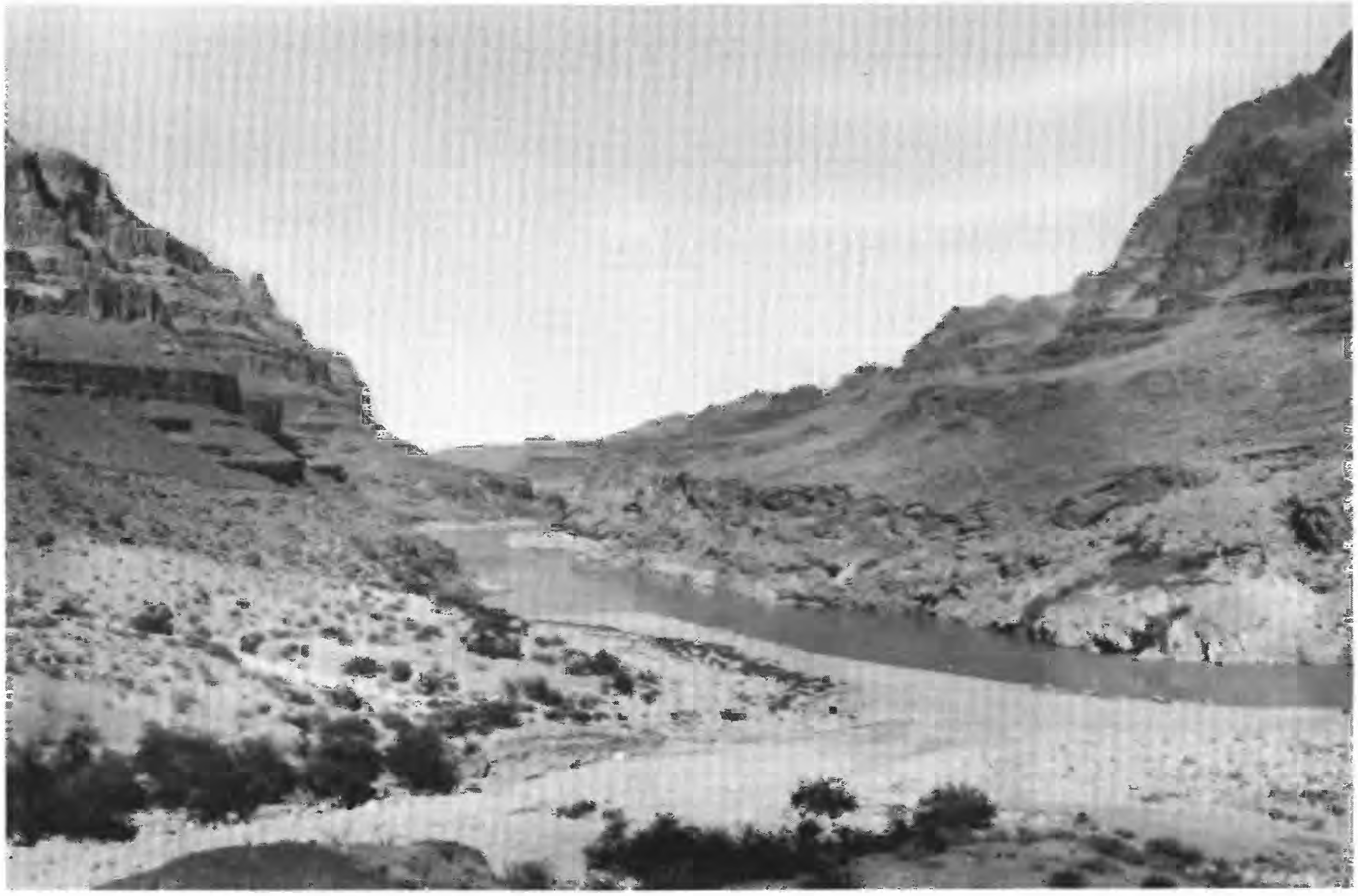

FIGURE 73*A*.—(1923). What appear to be catclaw and western honey mesquite form a dense community lining the channel of Cave Canyon which enters the Grand Canyon from the left bank 441.3 kilometers below Lees Ferry. This community merges with the flood-line community of the Colorado River valley. There is apparently a moist area in a travertine deposit on the bank opposite the mouth of Cave Canyon which supports a low growth of plants that extends to the edge of the river. The slopes near the camera station are dominated by creosote bush and white bursage. (Altitude 280 meters. Estimated from Pampel, 1960; Belknap, 1969.)

FIGURE 73*B*.—(1974). The original camera station is now covered by water and silt and cannot be reoccupied. By 1948–49, silt had filled the valley at this location to depths as great as 73.2 meters (Pampel, 1960). The upper surface of the silt deposit is exposed near the opposite bank and is densely overgrown with saltcedar. Plants of the saltcedar thicket are leafless and dead at the time of this August photograph; death was probably from inundation during 1973. That year the lake reached the highest levels since 1963 when diversion began for filling Glen Canyon Dam.

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