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L. D. POTTER
N. B. PATTISON

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LAKE POWELL RESEARCH PROJECT BULLETIN

BULLETIN EDITORS

Jeni M. Varady and Orson L. Anderson

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SHORELINE SURFACE MATERIALS AND GEOLOGICAL STRATA, LAKE POWELL

Loren D. Potter
and
Natalie B. Pattison

Department of Biology
University of New Mexico
Albuquerque, New Mexico 87131

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LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (formally known as Collaborative Research on Assessment of Man's Activities in the Lake Powell Region) is a consortium of university groups funded by the Division of Advanced Environmental Research and Technology in RANN (Research Applied to National Needs) in the National Science Foundation.

Researchers in the consortium bring a wide range of expertise in natural and social sciences to bear on the general problem of the effects and ramifications of water resource management in the Lake Powell region. The region currently is experiencing converging demands for water and energy resource development, preservation of nationally unique scenic features, expansion of recreation facilities, and economic growth and modernization in previously isolated rural areas.

The Project comprises interdisciplinary studies centered on the following topics: (1) level and distribution of income and wealth generated by resources development; (2) institutional framework for environmental assessment and planning; (3) institutional decision-making and resource allocation; (4) implications for federal Indian policies of accelerated economic development of the Navajo Indian Reservation; (5) impact of development on demographic structure; (6) consumptive water use in the Upper Colorado River Basin; (7) prediction of future significant changes in the Lake Powell ecosystem; (8) recreational carrying capacity and utilization of the Glen Canyon National Recreation Area; (9) impact of energy development around Lake Powell; and (10) consequences of variability in the lake level of Lake Powell.

One of the major missions of RANN projects is to communicate research results directly to user groups of the region, which include government agencies, Native American Tribes, legislative bodies, and interested civic groups. The Lake Powell Research Project Bulletins are intended to make timely research results readily accessible to user groups. The Bulletins supplement technical articles published by Project members in scholarly journals.

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ABSTRACT

In this study, surface materials along the shoreline of Lake Powell were divided into seven major types and the entire 1800 miles of shoreline were mapped at four contours on field maps at a scale of 13.6 inches per mile (1:4,650). These data were condensed with as little loss of detail as possible into maps published herein at a scale of 1:100,170.

The general geological features of Lake Powell are summarized as background for the stratification along the shoreline of the lake. At various water levels from 3620 to 3700 feet there are shifts in the importance of several shoreline materials in some tributaries. However, because of several major upwarps and the general dip to the west of sedimentary layers, there is no consistent shift throughout the reservoir. The 74 percent of the shoreline composed of cliff, talus, and rockslide (54, 19, and 1 percent, respectively) provides much of the scenic aspect of the shoreline, but from the viewpoint of recreational shoreline use is of little significance. Those shoreline materials receiving principal use are the 21 percent of domed terrace, a portion of which is low enough in gradient to be used for shoreline recreation, and especially the 2 percent sand and 1 percent alluvium.

The surface shoreline materials are correlated with availability of shoreline campsites and are presented for the main channel and the named canyons, excluding the large bays near the marinas and the arm up the San Juan River.

INTRODUCTION

The Lake Powell region of the Colorado Plateau is an environment often referred to for its starkness of beauty. The dramatic features of its colored sandstones, bold relief, and dissected erosion are exemplary of the predominant influences of climate and geology of the area. As in much of the arid West, geological strata and physiography are dominant features in controlling vegetational development. And, the underlying geology is not cloaked by a concealing mantle of vegetation. Some of the geological:vegetational correlations have been reported elsewhere (Potter and Pattison, 1976). Although much of the area has been mapped for its geological stratigraphy, the Lake Powell Research Project recognized the need for information on the extent and distribution of the various surface materials which would comprise the shoreline of the lake as the water level rose to full pool at the 3700-foot elevation.

This information relates in several directions. The sedimentation in the lake is derived not only from the silt load of the Colorado River but also from slumping of talus slopes and rockslides from the lake shoreline. It is also determined by the nature of sand deposits and alluvial terraces. In all cases there is an influence of the rock strata involved. There is a close correlation of the nature of the rock substrate and its physiography to the vegetation. The vegetation is greatly influenced by shale, and differences may occur even between types of sandstone.

The nature of the surface material and its contour is a principal determining factor in the vegetational succession which occurs in the drawdown zone resulting from fluctuating water levels of the reservoir. Additionally, the Glen Canyon National Recreation Area, which surrounds Lake Powell, is used by a high percentage of people who camp along the shores of the reservoir. Suitable places for shoreline use, involving safe landing for a boat, offshore swimming, shoreline recreation, and a suitable campsite, are limited to a low percentage of the shoreline consisting of a portion of the domed terrace area and the relatively level shorelines of sand and alluvium. Shoreline use of the latter sites can be expected to have a major impact. These sites also are the ones most readily invaded by the exotic tamarisk which is generally considered to be not in the best interest of a good campsite or for a swimming area, when the plant is submerged under water. As the use of the reservoir increases, the knowledge of the shoreline surface materials will be valuable as a management aid.

GEOLOGIC SETTING

A brief discussion of the geology of the Colorado Plateau and the area of Glen Canyon is essential as a basis for understanding the shoreline surface materials of Lake Powell, which now occupies the lower part of a deeply cut river system.

The deposits of sedimentary material, both in inland seas and by winds, during the Late Paleozoic, Mesozoic, and Early Cenozoic (Appendix A, Geologic Column), were uplifted and deformed during much of the Tertiary. With the faulting, folding, and uplifting, mountains, cliffs, and plateaus were formed from coastal plains and the bed of inland seas. A drainage pattern developed, which by the Middle Miocene had established the general course of the Colorado River and its principal tributaries. The Early Miocene channel is represented today by the broad upper gorge with its own steep cliffs in the upper sediments, its talus slopes, and its frequently extensive flat terraces.

Into this channel a second cutting cycle took place in the Pliocene and Pleistocene and carved an inner gorge throughout much of the region into the Glen Canyon Group--Navajo, Kayenta, and Wingate sandstones. The overlying, marine-deposited Carmel formation was left to form a broad irregular platform between the inner and outer gorges. On several levels of terraces were left alluvial mantles of cobble and gravel of the

Pleistocene stream activity. Above the terraces rise the massive walls of mesas, buttes, and monuments of, for example, Entrada, Summerville, and Morrison formations to the plateau of Cummings Mesa to the south. To the north, talus slopes and vertical cliffs of Upper Cretaceous sediments rise even higher to the Kaiparowits Plateau. These formations comprise the maze of buttressed and recessed cliffs of the outer gorge of the southern part of Glen Canyon. The physiography of the Glen Canyon area and earlier geological studies have been summarized by Cooley (1958, 1959a, 1959b).

Cataract Canyon is the area of the Colorado River from the junction of the Green River to the mouth of the Dirty Devil River. The gradient of the Colorado River bed changes from 1 foot per mile above Cataract Canyon to an average of 8 feet per mile in Cataract Canyon and then to 2 feet per mile in Glen Canyon (the area between the Dirty Devil River and Lee's Ferry). The waters of Lake Powell at the 3700-foot level will inundate the lower part of Cataract Canyon to river-mile 201.8, thus covering principal rapids near Dark Canyon, Gypsum Canyon, and Waterhole Canyon. The largest rapids occur just above the maximum water level: Big Drop at mile 202.2, Upper Big Drop at 202.4, and Calf Canyon at 202.8. In the 2 miles between 201.5 and 203.5 the river drops an average of 38 feet per mile (Baars, 1971a). According to Baars, 31--or all but 21--of 52 rapids of Cataract Canyon will be inundated. The rapids do not occur over ledges of hard rock, but rather where alluvial fans with associated deltas and boulder bars form at mouths of short, steep, tributary canyons during flash floods. The Cataract Canyon rapids are unique because of the large boulder obstacles formed from talus and rockslides of canyon walls.

Below Cataract Canyon, Glen Canyon is the longest continuous canyon along the Colorado River. While Cataract Canyon lies across major anticlinal features, Glen Canyon is aligned with a depression formed by the flanks of the Henry and

Kaiparowits basins, and between the Circle Cliffs uplift to the northwest and the western flank of the Monument upwarp and the laccolithic Navajo Mountain to the southeast. This has resulted in the low average gradient of the Colorado River bed. However, the major structural features are the cause for uplift and dip of strata with the resulting appearance and disappearance as seen along the shoreline. However, because of an overall dip of strata to the west, the river bed which started on Pennsylvanian limestone in Cataract Canyon is on Permian Cedar Mesa sandstone at the Dirty Devil River and at the present dam site is on younger Jurassic Navajo sandstone. Thus, from the upper reaches of Lake Powell in Cataract Canyon and up the San Juan River to the top of the Kaiparowits Plateau there is exposed a cross-section of 200 to 300 million years of sedimentation and erosion history.

The strata will be discussed starting from the oldest formation of the shoreline in Cataract Canyon to the younger shoreline formations of the lower end of the lake and to the top of the adjacent high plateaus.

Near Gypsum Canyon are exposed gypsum beds of the Paradox formation of the Hermosa group (Baars, 1971b). Here also are Hermosa limestones forming vertically eroded cliffs. These Permian beds are marine deposits of Pennsylvanian age and are about 1000 feet thick. Herman and Sharps (1956) have reported on the Pennsylvanian and Permian stratigraphy of the general area.

Above these Permian beds is a stratum referred to as Rico, which is a transitional lithology with affinities to both Hermosa below and Cutler above. This transitional marine to nonmarine sediment is gray to grayish-purple sandstone, siltstone, and limestone. In the San Juan Goosenecks area it forms a plateau cap.

In some areas of Lake Powell's shoreline there is a layer of Halgaito shale as a lowermost member of the Permian Cutler formation. Above it is the massive Cedar Mesa member with thickness up to 1200 feet (Rigby et al., 1971). This stratum is alcoves to develop along vertical cliff faces. These sometimes result in deep cave recesses and, if joined from the opposite side, in a passageway covered by a natural bridge or arch.

The upper part of the Navajo sandstone characteristically is thinly cross-bedded and develops into tilted, shelfy terraces.

For a considerable distance above Warm Creek Bay and at other areas to the east there are extensive level terraces capped by the reddish, marine-deposited Carmel sandstone. This caprock is composed of marine limestone, shale, calcareous sandstone, and gypsum. It frequently contains ripple marks. The sandstone may weather locally into concretions of irregular shapes or spherical balls. Because of the flatness of the Carmel platform, its mantle of weathered material, and its relatively favorable fertility, these areas are usually well vegetated. These terraces at one time served as transportation routes allowing easy passage once a way was found to get up and down the relatively steep, and often inaccessible, Navajo sandstone exposed between the platform and the Colorado River. Many of the chipped steps and trails, both prehistoric and historic, lead from the river up to this platform. Grazing was available principally here or on top of the higher mesas, such as Cummings Mesa.

The overlying Entrada sandstone is light-buff to light reddish brown and very fine- to fine-grained. It may be a combination of eolian and shallow marine deposits. It weathers to form slightly rounded, "slick rim" cliffs often characterized by "swallow holes" which weather out along horizontal layers.

Overlying the light-colored Entrada is the contrasting deep-red Summerville formation, a slope-forming unit of even-bedded sandy mudstone, and fine-grained sandstone and shale with scattered large spherical or elongated masses of gray-white to red chert.

Above the shorelines of Lake Powell but visible from many areas of the lake are multi-strata cliffs rising to plateaus, such as Cummings Mesa and the Kaiparowits Plateau. Above the Summerville is the complex many-layered Morrison formation of

Upper Jurassic with mainly fluvial and lacustrine mudstone, siltstone, and sandstone. The overlying Cretaceous deposits include the light-colored, coal-bearing Dakota sandstone; the gray fossiliferous marine Tropic shale; and the coal-bearing Straight Cliffs sandstone. The last formation provides the cap of much of the southern part of the Kaiparowits Plateau, but farther north it is overlain by buff-colored Wahweap sandstone. Smaller areas are capped by the drab sandstone of the Kaiparowits formation; above it locally is a cover of Eocene Wasatch limestone (Gregory and Moore, 1931).

SHORELINE SURFACE TYPES

Mapping

The shoreline surface types were divided into seven basic categories: cliff face, domed terrace, shelfy terrace, talus, alluvium, sand, and rockslide, each indicated by a type symbol when mapping. A variation was added if a thin mantle of talus, alluvium, or sand was found over a basic type, usually over domed terrace. After mapping portions of the reservoir at several different scales, the entire shoreline of about 1800 miles was mapped in detail on 10-foot contour maps at a scale of 1:4,650 or 13.626 inches per mile. Type differences as small as 200 feet were mapped. Mapping was done to represent the shoreline types at 20-foot intervals from 3620 to 3700 feet.

The transfer of data from the 291 detailed contour maps to the four maps in Appendix B, which are at a scale of 1:100,170, resulted in some loss of detail. Each designated type was enclosed between lines perpendicular to the 3700-foot contour line outlining the maximum pool level of Lake Powell. The shoreline types were designated as follows: A--alluvium, C--cliff, D--domed terrace, R--rockslide, S--sand, ST--shelfy terrace, and T--talus. A single symbol indicates that the entire shoreline from 3620 to 3700 feet in elevation is of that type. A designation such as C/T indicates cliff at 3700- and 3680-foot levels and talus at 3660- and 3620-foot levels. For purposes of map publication the data were reduced to no more than a two-tiered representation. Also, all areas of domed terrace, whether barren or covered by a thin mantle of talus, sand, or alluvium were designated as domed terrace on the map. However, the subtypes are provided in the data of Table 1 (pages 13 to 21).

Description of Types

Alluvium (A)

Throughout the terraces above Lake Powell are areas designated as Pleistocene alluvium and consisting of coarse gravel and boulder mantles. In some areas the mantle has developed its own erosional contours. Recent alluvium is located toward the heads of tributary creeks and canyons which are relatively wide. These areas provide for a relatively rich vegetation, often groves of trees. In a few areas, e.g., Lake Canyon, lacustrine deposits were laid down behind sediment dams produced by flash floods.

Cliff (C)

The cliff face is the shoreline type for which the Glen Canyon area is most famous. The classification was used for both sheer vertical cliffs and for those too steep on which to easily land a boat and get ashore. These cliffs are most common in areas of Navajo, Wingate, and Cedar Mesa sandstones. Alcove development commonly occurs when an underlying layer of impermeable limestone serves as a stratum of horizontal water movement and the solution of the calcium carbonate cementing material weakens its supportive capacity. At the surface of a cliff face the overlying sandstone caves in, producing an arch whose height and depth constantly are increasing to form a recessed cavate alcove. Navajo sandstone most commonly demonstrates this feature, producing great alcoves, arches, and natural bridges. Many of the largest of these recessed alcoves, hundreds of feet wide, high, and deep, have been submerged with the rising water level. The deeply incised glens, for which the area was named, were cut by rapidly descending tributaries starting in fractures or faults. There are a variety of erosional patterns on cliff walls, many of which were formed during the cutting periods thousands and millions of years ago, and upon which is superimposed the continuing deposition and chemical action of highly charged mineral waters which have flowed down over the face of cliffs, frequently evaporating before reaching the base. Various patterns and shadings of patinas or desert varnish result. Alternate wetting and drying and wide temperature ranges may result in exfoliation of the rock surface.

The cliff faces and alcoves are the sites of seeps. Some seeps have a perennial flow, others are sporadic, depending upon the irregular precipitation of the surrounding area which supplies the water to recharge the porous overlying sandstone aquifers. Where a vertical series of seeps occurs in a steeply descending tributary, the multi-tiered alcoves and ledges may form the headwall of a box canyon.

Domed Terrace (D)

This classification refers to the smooth undulating contours that result in domes with sloping sides and gently carved-out depressions between. Navajo sandstone with its particular particle size and cross-bedding is apt to be eroded into this form. The type frequently fulfills the criteria necessary for rock campsites. By selecting the gently sloping areas between domes, a boat can be safely beached and moored, especially with the aid of pitons. The rock bottom is usually smooth, unjagged, and minimally encumbered with boulders. Finding a level place on which to sleep is the principal problem. This type is often mantled by one of a variety of other materials.

Rockslide (R)

This type is of minor extent and was distinguished from coarse talus slopes by the inclusion of large blocky masses of rock which had slid downslope from their stratigraphic position. Such slides are most common in areas of exposure of the soft, crumbling, Chinle formation underlying the blocky Wingate sandstone which fractures and tumbles down over the eroded slopes of the Chinle.

Sand (S)

Where windblown sand had accumulated to several feet or more in depth and had developed any characteristics of dunes, the area was classified in this type. These shoreline areas are the most popular for many vacationers because of the lack of rocks, the ease of mooring a boat and pitching a tent, the generally level topography, the sandy playground for children, and the fulfillment of the "traditional" concept of a sandy beach at the lake. To others, the disadvantage of windblown sand mixed with bedroll and food makes these sites least desirable.

Shelfy Terrace (ST)

This is a shoreline type of limited extent and is most common to the lower end of the reservoir where the upper levels of Navajo sandstone, just below the thin layer of marine-deposited Carmel sandstone, may occur at lakeshore level. It is finely cross-bedded with alternate hard and soft layers which are frequently tilted and erode into projecting shelves. Beaching and mooring a boat here require selection of locations where the bedding plane parallels the beach, or, in well-eroded areas, where they are sometimes filled with a thin layer of sand.

Talus (T)

This classification was used for the weathered rubble of varying size which had eroded and slid downslope, but did not include the large, blocky landslides classified as rockslides. It was also used for some talus slopes which were composed principally of dune sand which commonly blows off the plateaus and down over a cliff face to form a typically shaped talus slope, which in itself does not develop the morphologies of sand dunes. These are sometimes called "falling dunes." In the areas of Navajo and Kayenta sandstones, talus slopes may be several hundred feet high. The variations in texture depend largely on the nature of the sandstone origin and the process of weathering.

Extent of Types

The linear distances of each of the four contour levels and subtotals of each shoreline type were determined by the use of a map measurer along each contour line for the 291 maps made of the reservoir. Measurements are given in Table 1 (pages 13 to 21) for four contour levels--3620, 3660, 3680, and 3700 feet--and are divided into the main channel, several principal bays, arms of the lake extending up the principal tributaries (San Juan, Escalante, and Dirty Devil rivers), and the named side canyons of the main channel. The total mileage of each shoreline type for the entire lake is also given for each contour level. Respective total shoreline mileages were 1472, 1638, 1733, and 1823.

Table 1: Shoreline surface types in miles at four contour levels and for each major tributary, named canyon, and the main channel of the reservoir

		Shoreline Surface Types (distance in miles)										
			Domed Terrace Mantle of									
Area	Contour (feet)	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Main Channel	3620	241.96	55.45		.37	35.81	24.62	85.98	5.83	1.80	6.57	458.39
	3660	259.06	54.05		.29	29.10	26.86	87.00	6.46	1.39	5.69	469.90
	3680	261.89	46.93		.29	41.10	26.20	99.11	7.12	1.91	3.78	488.33
	3700	263.76	46.82		.26	44.44	26.82	100.91	6.79	1.65	3.89	495.34
Wahweap Bay	3620	15.26	6.94		1.03	11.74	.48		14.60	3.78	.07	53.90
	3660	20.07	7.34		1.10	11.93	.29		13.76	4.55	.07	59.11
	3680	26.86	15.34		1.76	9.25	.88		11.71	.88	.04	66.72
	3700	27.52	14.68		1.32	5.39	.99		11.45	.62	.04	62.01
Antelope C.	3620	3.41										3.41
	3660	4.37										4.37
	3680	3.19					.81					4.00
	3700	3.71					1.39					5.10
Navajo C.	3620	39.67	3.49				.11	.55	.73	.70		45.25
	3660	40.84	3.85				.11	.44	.44	5.03		50.71
	3680	49.46	4.44				.07	.40	.26			54.63
	3700	54.93	5.47				.07	.37	.26			61.10
Warm Creek Bay	3620	4.15	7.16		.88	9.03	2.24	.29	12.07	5.32		41.14
	3660	4.11	6.83		2.97	14.60	1.98	.44	11.74	6.72		49.39
	3680	3.38	2.31		4.66	21.76	1.98		11.38	10.09		55.56
	3700	4.55	1.87		6.02	26.20	1.98		10.93	10.27		61.82
Labyrinth C.	3620	3.89	4.00				.18					8.07
	3660	4.04	3.78				.07					7.89
	3680		7.67				.07					7.74
	3700		8.26				.07					8.33
Gunsight C.	3620	2.61	1.47			6.05		1.36	.51			12.00
	3660	4.92	1.06			6.53		1.36	.48			14.35
	3680	3.93	2.57			4.62		1.10	2.72			14.94
	3700	3.74	2.50			4.40		1.10	3.67			15.41

Table 1 (continued)

Area	Contour (feet)	Shoreline Surface Types (distance in miles): Cliff	Domed Terrace: Barren	Domed Terrace: Mantle of Talus	Domed Terrace: Mantle of Sand	Domed Terrace: Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Padre Bay	3620	21.10	8.40		5.91	8.48	2.72	3.60	4.81	4.04		59.06
	3660	21.98	7.60		5.80	4.29	3.49	3.12	4.00	5.76		56.04
	3680	26.60	10.86		3.85	10.42	3.71	4.62	2.05			62.11
	3700	27.30	11.63		1.83	9.25	3.34	4.48	2.20			60.03
Face C.	3620	13.76	2.13				4.48		.15			20.52
	3660	14.90	1.76				4.66		.29			21.61
	3680	15.04	1.21			2.68	4.07					23.00
	3700	17.32	1.03			2.68	4.22					25.25
Last Chance Bay	3620	44.47	4.00			.84		21.69	.26		1.21	72.47
	3660	46.09	3.08			.59		25.10	.07	1.69	1.14	77.76
	3680	51.19	.84	.66		.73		17.69			1.32	72.43
	3700	52.91	.92	.70		.88		18.60			1.32	75.33
West C.	3620	12.99	9.69	.29	.07	3.41		.70	.04			27.19
	3660	15.26	11.27	.07	.11	2.72		.66	.04			30.13
	3680	19.45	7.63			3.30			.04			30.42
	3700	24.92	7.60			2.79			.04			35.35
Friend-ship Cove	3620	.84			.26			3.23	1.17		.33	5.83
	3660	.70			.59	.88		2.61	1.03		.33	6.14
	3680	3.60			.62			2.39				6.61
	3700	3.67			.51			2.09				6.27
Rock Creek	3620	21.39	1.17		.99	5.98		11.16	.84	.22	.11	41.86
	3660	26.82	1.69		.51	9.43		11.19	.18	.22	.07	50.11
	3680	40.14	2.79		.51	4.70		5.58	.18	.22		54.12
	3700	42.53	2.68		.48	5.28		6.13	.11	.33		57.54
Dungeon Creek	3620	1.06	.55			2.09		.48	.22			4.40
	3660	1.47	.48			3.19		.92	.07			6.13
	3680					.66		4.55	.04			5.25
	3700					.51		5.25	.04			5.80

Table 1 (continued)

Area	Contour (feet)	Shoreline Surface Types (distance in miles)										
			Domed Terrace				Shelfy			Alluv-	Rock	
				Mantle of								
		Cliff	Barren	Talus	Sand	Alluvium	Terrace	Talus	Sand	ium	Slide	Total
Wethe-rill C.	3620	6.57	5.10									11.67
	3660	7.60	4.95									12.55
	3680	10.02	3.23			.07						13.32
	3700	10.24	3.41			.07						13.72
Corner-stone C.	3620	.11					1.03					1.14
	3660	.11					.84					.95
	3680						.81	.15				.96
	3700						.73	.15				.88
Dan-gling Rope C.	3620	7.60	1.76				.37					9.73
	3660	8.62	1.47				.84					10.92
	3680	9.98	1.36				1.21	.07				12.62
	3700	10.05	1.39				1.43	.07				12.94
tain Sheep C.	3620	3.12	6.86									9.98
	3660	4.33	8.04									12.37
	3680	6.05	6.90									12.95
	3700	6.53	6.94									13.47
Cas-cade C.	3620	2.79	.07									2.86
	3660	3.56	.11									3.67
	3680	3.93	.04									3.97
	3700	4.00	.04									4.04
Forbid-ding C.	3620	13.43				.29		.04				13.76
	3660	15.63				.29		.04				15.96
	3680	18.02										18.02
	3700	18.64										18.64
light C. (Nav-ajo V.)	3620	5.65										5.65
	3660	6.90										6.90
	3680	7.63										7.63
	3700	8.22										8.22

Table 1 (continued)

Area	Contour (feet)	Shoreline Surface Types (distance in miles)										
			Domed Terrace Mantle of									
		Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluv-ium	Rock Slide	Total
Secret C.	3620	2.09				.26						2.35
	3660	1.98				.44						2.42
	3680	2.94	.33									3.27
	3700	2.39	.33									2.72
Oak C.	3620	1.17						.04				1.21
	3660	1.17						.73				1.90
	3680	2.79										2.79
	3700	3.45										3.45
Bal-anced Rock C.	3620	.84	.22									1.06
	3660	1.21	.51									1.72
	3680	2.28	.66									2.94
	3700	2.42	.88									3.30
Little Arch C.	3620	.99										.99
	3660	1.10										1.10
	3680	1.39										1.39
	3700	1.47										1.47
Cathe-dral C.	3620	8.22	4.04					.44				12.70
	3660	9.98	4.18					.55				14.71
	3680	10.57	3.38									13.95
	3700	11.60	3.12									14.72
Drift-wood C.	3620	2.28	.73									3.01
	3660	2.72	.62									3.34
	3680	2.97	.40									3.37
	3700	3.01	.40									3.41
Ana-sazi C. (Mystery)	3620	6.83	.18									7.01
	3660	6.90	.22									7.12
	3680	8.15										8.15
	3700	8.15										8.15

Table 1 (continued)

Area	Contour (feet)	Shoreline Surface Types (distance in miles)										
			Domed Terrace Mantle of									
		Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Hidden Passage C.	3620	3.38	.37									3.75
	3660	3.89	.37									4.26
	3680	4.48										4.48
	3700	4.59										4.59
Reflection C.	3620	5.14	.59					1.76		.04	.04	7.57
	3660	5.54	.70					2.24		.66	.04	9.18
	3680	8.66	.44					.95			.07	10.12
	3700	8.92	.37					.95			.07	10.31
San Juan R.	3620	88.73	5.87			21.12		81.44	.38	.38	.57	198.49
	3660	98.86	5.40			33.81		87.31	.38	.38	.57	226.71
	3680	100.28	4.07			27.75		101.23	4.07		.76	238.16
	3700	114.49	3.50			32.48		102.75	3.22		.76	257.20
Llewellyn Gulch	3620	2.72			.15	.37		.37				3.61
	3660	2.64			.22	.51		.33		.07		3.77
	3680	1.98			.22	1.17		1.47				4.84
	3700	2.09			.22	1.65		2.02				5.98
Cottonwood C.	3620	1.47						.70				2.17
	3660	3.01						.88				3.89
	3680	2.05				.84		2.35				5.24
	3700	2.42				.81		2.94				6.17
Ribbon C.	3620	1.69						.51			.04	2.24
	3660	1.76						.70			.04	2.50
	3680	1.50						1.14			.04	2.68
	3700	1.47						1.47			.04	2.98
Escalante R.	3620	65.94	4.44		.11	2.46		10.60	.84	.15	.66	85.20
	3660	76.03	4.44		.11	2.39		12.07	1.25	.44	.70	97.43
	3680	84.40	4.15		.04	.33		9.87	.62		.55	99.96
	3700	90.60	4.07		.04	.26		10.49	.59		.62	106.67

Table 1 (continued)

Area	Contour (feet)	Shoreline Surface Types (distance in miles)										
			Domed Terrace Mantle of									
		Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluv-ium	Rock Slide	Total
Long C. (Navajo Cr.)	3620	2.94										2.94
	3660	3.38										3.38
	3680	3.74										3.74
	3700	3.89										3.89
Iceberg C.	3620	7.93	.29					3.34			.22	11.78
	3660	8.15	.26					5.06		.88	.37	14.72
	3680	11.71						2.83		1.98	.59	17.11
	3700	13.61						3.08		2.94	.51	20.14
Slick Rock C.	3620	.33						2.16			.15	2.64
	3660	.40						3.16			.11	3.67
	3680	.44						3.16			.07	3.67
	3700	.44						3.23			.07	3.74
Annies C.	3620	.15						.07				.22
	3660	.15						.07				.22
	3680	.22										.22
	3700	.22										.22
Lake C.	3620	8.95	1.50					.07		.88		11.40
	3660	8.88	2.61					.04		2.31		13.84
	3680	9.76	6.68					.04				16.48
	3700	11.23	7.63					.04				18.90
Lost Eden C.	3620	3.93										3.93
	3660	4.07										4.07
	3680	4.62										4.62
	3700	4.77										4.77
Halls Creek Bay	3620	3.56	4.22			12.11		.07		1.91		21.87
	3660	3.45	4.40			13.76		.07		7.12		28.80
	3680	5.76	4.15			10.46		9.43				29.80
	3700	4.81	3.93			9.32		13.76				31.82

Table 1 (continued)

Area	Contour (feet)	Shoreline Surface Types (distance in miles)										
			Domed Terrace									
				Mantle of								
		Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Bull-Frog Bay	3620	6.31	2.02		1.28	29.65		2.57		.22		42.05
	3660	9.43	2.24		1.83	41.17		1.91		1.76		58.34
	3680	8.15	3.63		2.20	45.79		1.32				61.09
	3700	9.17	4.62		2.13	42.27		1.32				59.51
and North Gulch	3620	11.30	.07					1.25	1.06	.07		13.75
	3660	12.00	.04					1.39	2.42	.07		15.92
	3680	17.61										17.61
	3700	19.01										19.01
Hansen Creek C.	3620	4.15	2.42			.04		.15	.26	.48		7.50
	3660	4.70	2.83			.26		.07	.29	1.91		10.06
	3680	4.59	3.78			.18		.40	.26	1.43	1.32	11.96
	3700	5.83	4.18			.37		.33	.26	1.39	1.32	13.68
Crystal Spring C.	3620	5.03	.29					.40				5.72
	3660	5.14	.26					.40				5.80
	3680	5.17	.81					.07				6.05
	3700	5.32	.81					.11				6.24
Smith Fork C.	3620	5.72	.51					.15				6.38
	3660	5.87	.95					.37				7.19
	3680	8.22	.15									8.37
	3700	8.73	.29									9.02
For-gotten C.	3620	7.34						1.06				8.40
	3660	8.95						1.06				10.01
	3680	10.79	1.54					.55				12.88
	3700	11.82	2.20					.55				14.57
Knowles C.	3620	1.69					.07	1.47	.11		.81	4.15
	3660	1.87					.15	2.20	.15		.92	5.29
	3680	3.27						1.72			.95	5.94
	3700	3.27						2.39			.95	6.61

Table 1 (continued)

Area	Contour (feet)	Cliff	Domed Terrace: Barren	Domed Terrace, Mantle of: Talus	Domed Terrace, Mantle of: Sand	Domed Terrace, Mantle of: Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
		Shoreline Surface Types (distance in miles)										
Warm Spring C.	3620	2.35						.18				2.53
	3660	2.35						.18				2.53
	3680	2.42										2.42
	3700	2.42										2.42
Cedar C.	3620	3.56	.15					.84			.48	5.03
	3660	4.84	.07					.92			.59	6.42
	3680	5.69	.04					.62			.37	6.72
	3700	6.20	.04					.62			.44	7.30
Seven-Mile C.	3620	2.97						.73				3.70
	3660	3.82						.95				4.77
	3680	5.06						.59				5.65
	3700	5.94						.73				6.67
Ticaboo C.	3620	.92						1.76		.07	.62	3.37
	3660	1.25						1.54		.15	.62	3.56
	3680	1.69						1.91			.40	4.00
	3700	1.87						1.91			.40	4.18
Red C.	3620	4.62	.07			3.30		2.68			.44	11.11
	3660	7.41	.15			3.19		3.05			.44	14.24
	3680	3.96				1.83		9.91				15.70
	3700	6.72				2.20		11.52				20.44
Blue Notch C.	3620	.66						5.14		.04		5.84
	3660	2.13						5.50				7.63
	3680							8.51				8.51
	3700							8.48				8.48
Four-mile C.	3620	.66				.11		1.65		.26	.29	2.97
	3660	.37				.37		2.02		.22	.22	3.20
	3680							3.52			.22	3.74
	3700							4.62			.22	4.84

Table 1 (continued)

Area	Contour (feet)	Shoreline Surface Types (distance in miles)										
			Domed Terrace Mantle of									
		Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluv-ium	Rock Slide	Total
Two-mile C.	3620	.48						1.50				1.98
	3660	.51						1.91				2.42
	3680	1.39						1.21				2.60
	3700	1.47						1.32				2.79
Trachyte C.	3620	2.86				3.85		4.73		.29	.59	12.32
	3660	2.64				2.64		3.63		2.05	.48	11.44
	3680					.07		13.06			.59	13.72
	3700							14.09			.59	14.68
White C.	3620	8.44						3.85		.51	.44	13.24
	3660	9.69						4.07		3.89	.44	18.09
	3680	5.80				2.64		11.34				19.78
	3700	6.46				3.23		13.65				23.34
Farley C.	3620	3.30				1.10		.77				5.17
	3660	4.48				3.38		.81				8.67
	3680	1.25				5.39		1.10				7.74
	3700	1.25				7.85		1.14				10.24
North Wash	3620	2.09				1.72		2.75		.07	.07	6.70
	3660	2.31				1.36		3.34		.07	.11	7.19
	3680	6.27						2.16			.11	8.54
	3700	6.75						2.16			.11	9.02
Dirty Devil R.	3620	14.60	.62			1.61		.07			.55	17.45
	3660	16.26	.48			2.42		.11			.59	19.86
	3680	9.10	5.91			.81		.77			.37	16.96
	3700	9.28	6.35			.81		.84			.44	17.72
Total	3620	774	147	0.3	11	161	36	264	44	21	14	1472
	3660	863	148	0.1	14	188	39	282	43	47	14	1638
	3680	931	154	0.7	14	197	40	327	40	17	12	1733
	3700	992	158	0.7	13	203	41	346	40	17	12	1823

In Table 2 (page 23) are presented the percentages of each shoreline type for the entire lake. In the varying water levels from 3620 to 3700 feet, there are shifts in the importance of shoreline types within some tributaries, especially among cliff, terrace, and talus. However, because of the several major upwarps and the general dip of the sedimentary layers, there is no consistent shift of shoreline types throughout the entire reservoir. While some regions of the upper end of the reservoir, e.g., Bullfrog Bay, seem to exhibit the development of extensive areas of shallow waters with increasing water levels, other regions have terraces which have already been covered and there the shoreline becomes confined by cliffs. There are slight overall increases in the percentages of cliff and talus. The 74 percent of the shoreline composed of cliff, talus, and rockslide (54, 19, and 1 percent, respectively) provides much of the scenic aspect. These areas, however, will not be impacted by recreational use of the shoreline. The greatest impact on the shoreline will occur on the 3 percent which is sand and alluvium. Lesser use and impact will be on the low-gradient areas of the domed terrace type.

Correlation to Campsites

Early in the development of the Lake Powell Research Project the National Park Service expressed concern about and interest in the number of shoreline campsites available in some of the tributaries. With the tremendous increase in recreational use of the lake, an immediate concern is the overcrowding of parking space and the use of developed campgrounds near the marinas. Some vacationers use these as a base camp from which daily trips are taken. However, many thousands prefer to camp along the shoreline of the lake. During the years of conducting the shoreline research we have observed the camping habits and site selections throughout the entire year, during which we have also

Table 2: The percentage of each shoreline type and the total mileage of shoreline at each of the four contours: 3620, 3660, 3680, and 3700 feet

Total Shoreline Surface Types

Contour	Percent Distance										Mileage
		Domed Terrace Mantle of									
(feet)	Cliff	Barren	Talus	Sand	Allu-vium	Shelfy Terrace	Talus	Sand	Allu-vium	Rock Slide	Total
3620	52.58	9.99	.02	.75	10.94	2.45	17.93	2.99	1.43	.95	1472
3660	52.69	9.04	.01	.85	11.48	2.38	17.22	2.63	2.87	.85	1638
3680	53.72	8.89	.04	.81	11.37	2.31	18.87	2.31	.98	.69	1733
3700	54.42	8.67	.04	.71	11.14	2.25	18.98	2.19	.93	.66	1823

camped in all areas of the lake. In conjunction with the shoreline mapping, we have also designated exact locations of feasible campsites at several contours throughout the entire reservoir.

Any inventory of campsites is fraught with several inherent difficulties. There is a variation of shoreline use with season of the year. For example, most of the recreationists camping along the shore in early spring are adults who are there to fish. Because the water is too cold for recreational swimming and there are few children in the parties, campsite selection does not consider the factor of a favorable swimming beach. From May through the summer, greater emphasis is placed on locating a sandy shore, which is favorable for beach recreation, pitching a tent, and swimming. As the temperature increases, there is an increased tendency to locate in areas providing protection from the sun, especially in late afternoon and evening. During windy days, protection from the wind becomes a selective factor. Selecting a campsite on smooth, relatively level rock surfaces (slickrock) requires a technique different from sand camping. Anchorage of boats and shelters requires the use of pitons or piles of rocks; this task is, of course, simplified by building no shelter at all. The advantages of camping on these slickrock surfaces are the increased cleanliness and the avoidance of blowing sand.

The greatest variable results from personal habits and preferences. Some people require a large expanse on which to spread out a tremendous variety of facilities. Others need only a ledge on which to sleep. Some insist on parties of large numbers and would be fearful of camping alone. Others seek solitude and jealously defend their "territorialism." Some parties eat and sleep on the beach, while others live partly or entirely on a boat.

The ultimate of the latter is the increased use of houseboats for which required shoreline characteristics are completely different. With proper techniques a houseboat can be moored with lines to stakes, pitons, shrubs, or rocks along almost any shoreline.

Our study of campsites considered actual shoreline campsites and not houseboat sites. Designation as a site was based on several criteria: safe place to land and moor a boat, safe place on shore not endangered by falling rocks or flash floods from summer thunderstorms, and a level place on which to camp. Both slickrock and sand sites were studied. Not all sites used by recreationists were counted, for these sometimes included locations in hazardous positions, such as below unstable talus slopes and rockslides.

In Table 3 (pages 26 to 37) is given a summary of the inventory of what we considered to be reasonable campsites at the 3660-foot level. Locations are divided into the main channel and the named canyons, except that the San Juan River arm and the large bays near the marinas, namely Wahweap, Warm Creek, Hall's Creek, and Bullfrog, are not included. All of these latter sites have a great abundance of campsites and are frequently used. For each area, data are given on the linear shoreline distance of each shoreline surface and the total of all types. The number of campsites is a combination of individual sites capable of accommodating one to several boats, and, in some areas--especially sandy and alluvial shores--stretches of beach several hundred feet long which were mapped as compound campsites. The latter have been given a value of four individual sites. Table 3 also includes a summation of total miles, number of campsites for each type, and the average number of campsites per mile of shoreline of each type.

Though it would seem impossible to have a campsite along a shoreline classified as cliff, there are areas too small to map separately which have ledges or alcoves where camping is possible. These account for the average of a minimal number of campsites per mile for the cliff type. The sandy shores have the highest number of campsites, averaging 3.24 per mile, followed by domed terraces with and without a mantle which average

Table 3: The relation of shoreline surface types to abundance of campsites at the 3660-foot contour

	Shoreline Surface Types (Distance in Mi.)/No. of Campsites										
		Domed Terrace									
			Mantle of			Shelfy				Rock	
	Cliff	Barren	Talus	Sand	Alluvium	Terrace	Talus	Sand	Alluvium	Slide	Total
Main Channel											
Mi.	259.06	54.05		.29	29.10	26.86	87.00	6.46	1.39	5.69	469.90
No.	26	110		4	71	42	55	20	8		336
Antelope C.											
Mi.	4.37										4.37
No.	1										1
Navajo C.											
Mi.	40.84	3.85				.11	.44	.44	5.03		50.71
No.	4	2						2	1		9
Labyrinth C.											
Mi.	4.04	3.78				.07					7.89
No.	3	15									18
Gunsight C.											
Mi.	4.92	1.06			6.53		1.36	.48			14.35
No.		3			18		1	2			24

Table 3 (continued)

Shoreline Surface Types (Distance in Mi.)/No. of Campsites

		Domed Terrace	Mantle of								
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Padre Bay											
Mi.	21.98	7.60		5.80	4.29	3.49	3.12	4.00	5.76		56.04
No.	3	11		13	8	8	1	16	13		73
Face C.											
Mi.	14.90	1.76				4.66		.29			21.61
No.	3	1				4		1			9
Last Chance Bay											
Mi.	46.09	3.08			.59		25.10	.07	1.69	1.14	77.76
No.	2	3			3		9	1	5		23
West C.											
Mi.	15.26	11.27	.07	.11	2.72		.66	.04			30.13
No.	1	11			9		1				22
Friendship Cove											
Mi.	.70			.59	.88		2.61	1.03		.33	6.14
No.				2				2			4

Table 3 (continued)

Shoreline Surface Types (Distance in Mi.)/No. of Campsites

	Cliff	Domed Terrace Barren	Domed Terrace Mantle of Talus	Domed Terrace Mantle of Sand	Domed Terrace Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Rock Creek											
Mi.	26.82	1.69		.51	9.43		11.19	.18	.22	.07	50.11
No.	8	3		2	36		4				53
Dungeon C.											
Mi.	1.47	.48			3.19		.92	.07			6.13
No.		2			8		2	1			13
Wetherill C.											
Mi.	7.60	4.95									12.55
No.	2	3									5
Cornerstone C.											
Mi.	.11					.84					.95
No.						9					9
Dangling Rope C.											
Mi.	8.62	1.47				.84					10.92
No.	8	4									12

Table 3 (continued)

Shoreline Surface Types (Distance in Mi.)/No. of Campsites

		Domed Terrace									
			Mantle of								
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Mountain Sheep C.											
Mi.	4.33	8.04									12.37
No.	1	8									9
Balanced Rock C.											
Mi.	1.21	.51									1.72
No.		7									7
Little Arch C.											
Mi.	1.10										1.10
No.											0
Cathedral C.											
Mi.	9.98	4.18					.55				14.71
No.											0
Driftwood C.											
Mi.	2.72	.62									3.34
No.		1									1

Table 3 (continued)

	Shoreline Surface Types (Distance in Mi.)/No. of Campsites										
		Domed Terrace									
			Mantle of								
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Cascade C.											
Mi.	3.56	.11									3.67
No.											0
Forbidding C.											
Mi.	15.63				.29		.04				15.96
No.											0
Twilight C.											
Mi.	6.90										6.90
No.											0
Secret C.											
Mi.	1.98				.44						2.42
No.	2										2
Oak C.											
Mi.	1.17						.73				1.90
No.	1						4				5

Table 3 (continued)

Shoreline Surface Types (Distance in Mi.)/No. of Campsites

	Cliff	Domed Terrace: Barren	Domed Terrace: Mantle of Talus	Domed Terrace: Mantle of Sand	Domed Terrace: Mantle of Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Anasazi C.											
Mi.	6.90	.22									7.12
No.	1	1									2
Hidden Passage C.											
Mi.	3.89	.37									4.26
No.											0
Reflection C.											
Mi.	5.54	.70					2.24		.66	.04	9.18
No.											0
Llewellyn Gulch											
Mi.	2.64			.22	.51		.33		.07		3.77
No.	2			2	1		3		2		10
Cottonwood C.											
Mi.	3.01						.88				3.89
No.	4						12				16

Table 3 (continued)

	Shoreline Surface Types (Distance in Mi.)/No. of Campsites										
		Domed Terrace									
			Mantle of								
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Ribbon C.											
Mi.	1.76						.70			.04	2.50
No.	1										1
Escalante R.											
Mi.	76.03	4.44		.11	2.39		12.07	1.25	.44	.70	97.43
No.	5	3			5		8				21
Long C.											
Mi.	3.38										3.38
No.											0
Iceberg C.											
Mi.	8.15	.26					5.06		.88	.37	14.72
No.	4	1					1		1		7
Slick Rock C.											
Mi.	.40						3.16			.11	3.67
No.							4				4

Table 3 (continued)

	Shoreline Surface Types (Distance in Mi.)/No. of Campsites										
		Domed Terrace									
			Mantle of								
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Annies C.											
Mi.	.15						.07				.22
No.	1										1
Lake C.											
Mi.	8.88	2.61					.04		2.31		13.84
No.	5	13									18
Lost Eden C.											
Mi.	4.07										4.07
No.											0
Moqui C. & North Gulch											
Mi.	12.00	.04					1.39	2.42	.07		15.92
No.							3	10			13
Hansen Creek C.											
Mi.	4.70	2.83			.26		.07	.29	1.91		10.06
No.	1	12							11		24

Table 3 (continued)

	Shoreline Surface Types (Distance in Mi.)/No. of Campsites										
		Domed Terrace Mantle of									
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Crystal Spring C.											
Mi.	5.14	.26					.40				5.80
No.											0
Smith Fork C.											
Mi.	5.87	.95					.37				7.19
No.	1	1									2
Forgotten C.											
Mi.	8.95						1.06				10.01
No.	12										12
Knowles C.											
Mi.	1.87					.15	2.20	.15		.92	5.29
No.							2				2
Warm Spring C.											
Mi.	2.35						.18				2.53
No.											0

Table 3 (continued)

Shoreline Surface Types (Distance in Mi.)/No. of Campsites

	Cliff	Domed Terrace Barren	Domed Terrace Mantle of Talus	Domed Terrace Mantle of Sand	Domed Terrace Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Cedar C.											
Mi.	4.84	.07					.92			.59	6.42
No.	1										1
Sevenmile C.											
Mi.	3.82						.95				4.77
No.	3										3
Ticaboo C.											
Mi.	1.25						1.54		.15	.62	3.56
No.	2										2
Red C.											
Mi.	7.41	.15			3.19		3.05			.44	14.24
No.	10				4		9				23
Blue Notch C.											
Mi.	2.13						5.50				7.63
No.							4				4

Table 3 (continued)

Shoreline Surface Types (Distance in Mi.)/No. of Campsites

		Domed Terrace	Mantle of								
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
Fourmile C.											
Mi.	.37				.37		2.02		.22	.22	3.20
No.					1		3				4
Twomile C.											
Mi.	.51						1.91				2.42
No.											0
Trachyte C.											
Mi.	2.64				2.64		3.63		2.05	.48	11.44
No.	1						9				10
White C.											
Mi.	9.69						4.07		3.89	.44	18.09
No.							15				15
Farley C.											
Mi.	4.48				3.38		.81				8.67
No.					4		1				5

Table 3 (continued)

	Shoreline Surface Types (Distance in Mi.)/No. of Campsites										
		Domed Terrace									
			Mantle of								
	Cliff	Barren	Talus	Sand	Alluvium	Shelfy Terrace	Talus	Sand	Alluvium	Rock Slide	Total
North Wash											
Mi.	2.31				1.36		3.34		.07	.11	7.19
No.	4										4
Dirty Devil R.											
Mi.	16.26	.48			2.42		.11			.59	19.86
No.		5									5
Total											
Miles	727	122	.1	8	73	37	192	17	26	13	1215
Number of Campsites	123	220	0	23	168	63	151	55	41	0	844
Number of Campsites Per mi.	.17	1.8	0	2.88	2.3	1.7	.79	3.24	1.58	0	.69

2.02 per mile, shelfy terraces with 1.70, alluvium with 1.58, talus with 0.79, cliffs with 0.17, and rockslides with none per mile.

Some of the tributary canyons which are favorites for fishing, e.g., Iceberg and Slickrock, have few campsites. Also, in many steep-walled canyons the campsites may be concentrated near the upper part of the canyon, unless it ends as a box canyon. Additionally, it should be pointed out that this survey represents the availability of campsites when the lake level is 3660 feet. Although the percentages for shoreline types for the entire reservoir do not change greatly with a change in water level, because of a dip of strata to the west, the percentage of a type, and thus the available campsites, within a single canyon may change significantly with the rise and fall of water levels. The relative amount of change would be reflected in the data for shoreline types at four water levels as given in Table 1.

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GLOSSARY

alluvium	detrital deposits resulting from operations of recent streams, including sediments of riverbeds, flood plains, lakes, fans of canyon mouths, and estuaries
anticline	a fold that is convex upward or had such an attitude at some stage of development
butte	a conspicuous isolated hill, especially one with steep sides; a mesa
caprock	a comparatively impervious stratum immediately overlying a more porous stratum
cavate	to carve out or cut back into a cliff face to form a cave
Cenozoic	the latest of four eras of geologic time as recorded by the stratified rocks of the earth's crust; it includes the Tertiary and Quaternary periods
concretion	hard, compact, rounded aggregate of minerals precipitated from aqueous solutions in sedimentary or volcanic rock
conglomerate	rounded waterworn fragments of rock or pebbles, cemented together by another mineral substance

Cretaceous — the third and last of the geologic periods of the Mesozoic era

cross-bedding — the arrangement of laminations of strata transverse or oblique to the main planes of stratification

desert varnish — a surface stain or crust of manganese or iron oxide, of brown or black color and usually with a glistening luster

detrital — referring to loose material (as rock fragments or organic particles) that results directly from disintegration

dip — the angle at which a stratum is inclined from the horizontal

drawdown zone — the shoreline area exposed as the water level of the reservoir is lowered

eolian — applied to deposits arranged by the wind

fault — a fracture along which there has been displacement of the sides relative to one another parallel to the fracture

fluvial — of, or pertaining to, rivers; produced by river action, as, a fluvial plain

formation — the primary unit in stratigraphy consisting of a succession of

formation (continued)	related strata, subdivided into members
fracture lines	linear breaks in rocks due to intense folding or faulting
glen	a secluded narrow valley
gradient	degree of inclination, steepness of slope, ratio of vertical to horizontal
group	an association, as of two or more formations, based upon some feature of similarity
gypsum	a common mineral of evaporites, $CaSO_4 \cdot 2H_2O$
interbed	interstratified, occurring between beds
Jurassic	the middle one of three periods of the Mesozoic era
laccolith	a concordant, intrusive body that has domed up the overlying rocks
lacustrine	pertaining to, formed, or growing in lakes
limestone	a bedded sedimentary deposit consisting chiefly of calcium carbonate
lithology	the physical character of a rock, generally as determined megascopically or with the aid of a low-power magnifier

mesa	a tableland; a flat-topped mountain or other elevation with steep side or sides
Mesozoic	an era of geologic time, from the end of the Paleozoic to the beginning of the Cenozoic; also referred to as the Age of Reptiles
Miocene	the fourth of five epochs into which the Tertiary period is divided
Paleozoic	second of four eras of geologic time; it is between late Precambrian and Mesozoic
patina	thin, light-colored outer layer produced by weathering
Permian	the last period of the Paleozoic era
physiography	the study of the origin and evolution of land forms
plateau	a relatively elevated area of comparatively flat land, commonly with at least one side having an abrupt descent
Pleistocene	the earlier of two epochs in the Quaternary period; also called Glacial epoch or Ice Age
Pliocene	the latest of the epochs of the Tertiary period

sandstone	a cemented or compacted detrital sediment of predominantly quartz grains of sand size
shale	laminated sediment in which the particles are predominantly of clay size
siltstone	very fine-grained consolidated elastic rock composed predominantly of silt particles
stratigraphy	the formation, composition, sequence, and correlation of the stratified rocks
stratum; strata	section or sections of a formation that consists throughout of approximately the same kind of rock material
terrace	benches of relatively flat, horizontal surfaces, usually bounded by steeper ascending slopes on one side and descending on the other
Tertiary	earlier of two geologic periods of the Cenozoic era
travertine	calcium carbonate, $CaCO_3$, of light color and usually concretionary and compact, deposited from solution in ground and surface waters
Triassic	the earliest of the three geologic periods of the Mesozoic era

uplift — elevation of any extensive part of the earth's surface relative to some other parts

upwarp — an area that has been uplifted, generally used for broad anticlines

APPENDIX A: GEOLOGIC COLUMN

Subdivisions Derived from Strata				Notable Events in Evolution of Organisms
	Systems	Series	Stages	
CENOZOIC	Quaternary	(Recent) Pleistocene	More than twenty widely recognized	Man appears
	Tertiary	Pliocene		Elephants, horses, large carnivores become dominant
		Miocene		Mammals diversify
		Oligocene		Grasses become abundant; grazing animals spread
		Eocene		Primitive horses appear
		Paleocene		Mammals develop rapidly
MESOZOIC	Cretaceous	Two or more series in each system	About thirty widely recognized	Dinosaurs become extinct; flowering plants appear Dinosaurs reach climax
	Jurassic			Birds appear
	Triassic			Primitive mammals appear; conifers and cycads become abundant Dinosaurs appear
PALEOZOIC	Permian		Many recognized	Reptiles spread; conifers develop
	Pennsylvanian (Upper Carboniferous)			Primitive reptiles appear; insects become abundant Coal-forming forests widespread
	Mississippian (Lower Carboniferous)			Fishes diversify
	Devonian			Amphibians, first known land vertebrates, appear Forests appear
	Silurian			Land plants and animals first recorded
	Ordovician			Primitive fishes, first known vertebrates, appear
	Cambrian			Marine invertebrate faunas become abundant
PRECAMBRIAN Complex assemblages of rocks, largely metamorphosed				Seas characterized by simple marine plants

Source: Longwell, Chester R., Richard Foster Flint, and John E. Sanders, Physical Geology, John Wiley and Sons, Inc., 1969, p. 123 (Table 6-1). Reprinted with permission of the publisher.

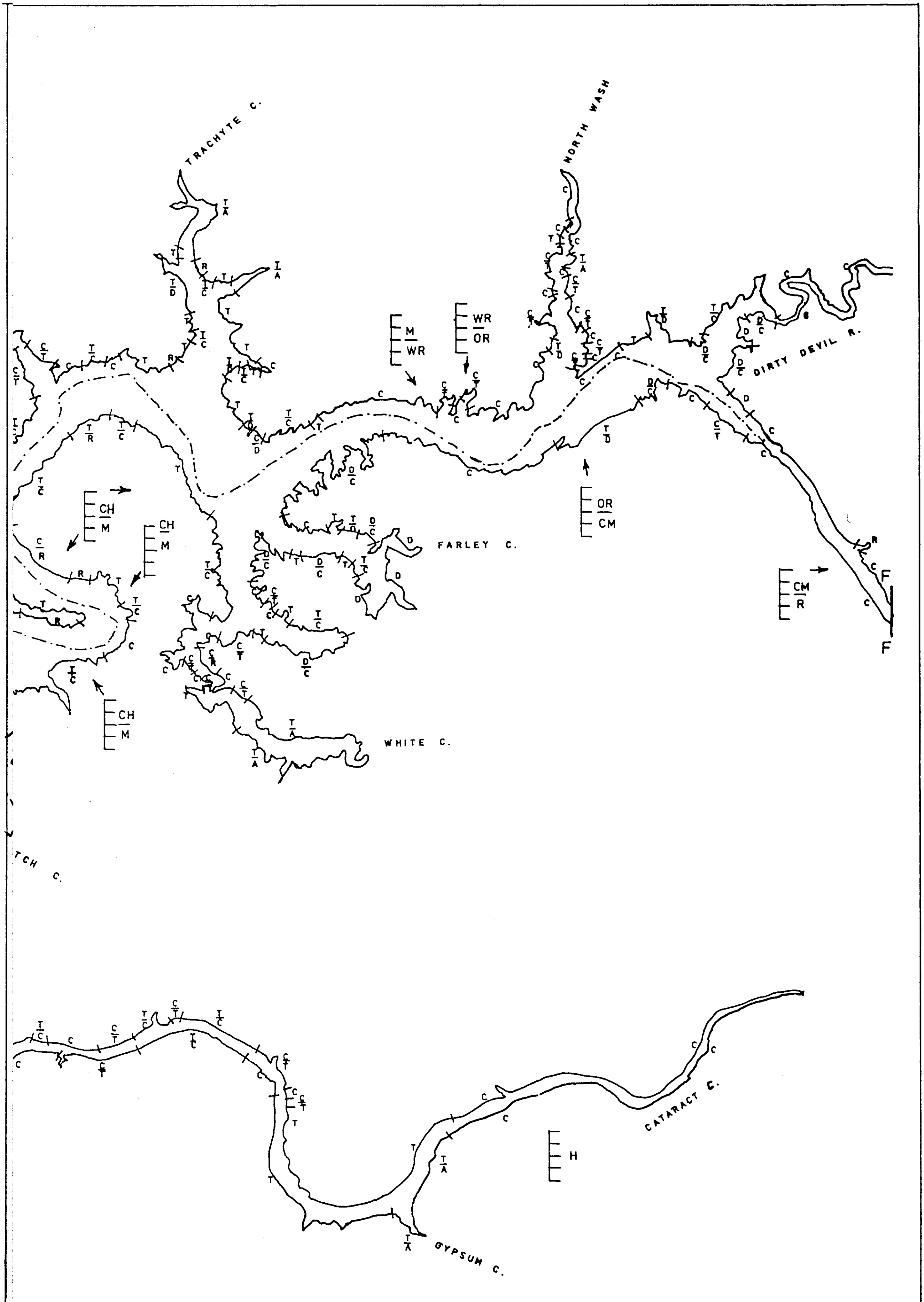
APPENDIX B: FOUR MAPS OF LAKE POWELL SHORELINE TYPES

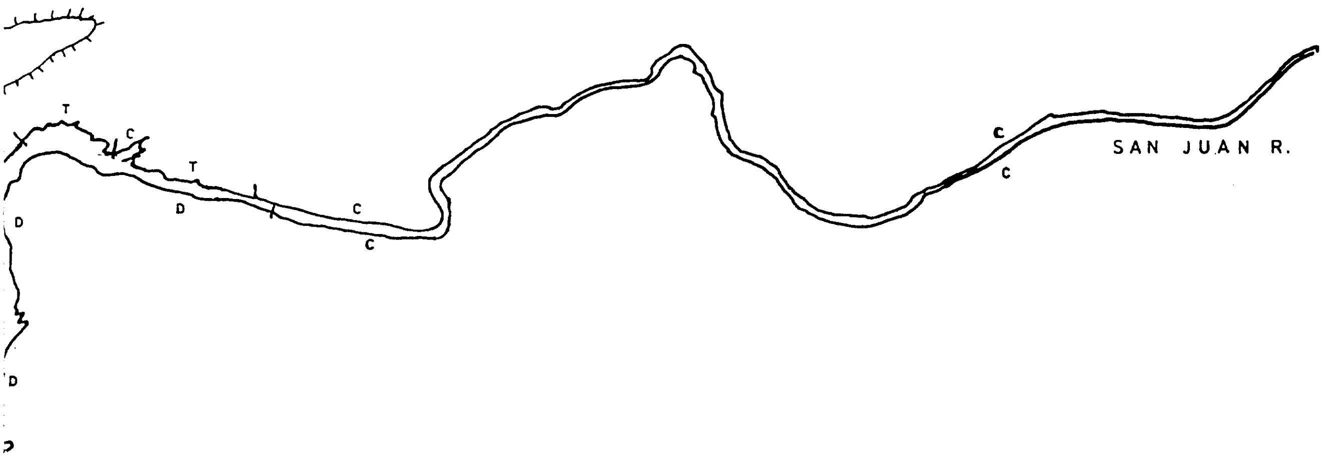
Map 1 Shoreline surface materials and geological strata, Glen Canyon Dam to Forbidding Canyon

Map 2 Shoreline surface materials and geological strata, Forbidding Canyon to Bullfrog Bay

Map 2a Shoreline surface materials and geological strata, San Juan

Map 3 Shoreline surface materials and geological strata, Bullfrog Bay to Cataract Canyon


TRACHYTE C.
NORTH WASH
DIRTY DEVIL R.
FARLEY C.
WHITE C.
CATARACT C.
GYPSUM C.
WR
OR
M
WR
CH
M
OR
CM
CM
R
H



SHORELINE TYPES

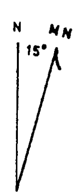
- A ALLUVIUM
- C CLIFF
- D DOMED TERRACE
- S SAND
- ST SHELFY TERRACE
- T TALUS

CONTOURS

- — 3700 FEET
- — 3680
- — 3660
- — 3640
- — 3620

STRATA

	NAVAJO	N
	KAYENTA	K
	WINGATE	W
TRIASSIC	CHINLE	CH
	SHINARUMP	SH
	MOENKOPI	M
PERMIAN	WHITE RIM	WR



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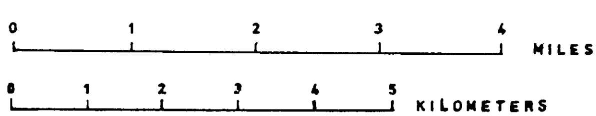
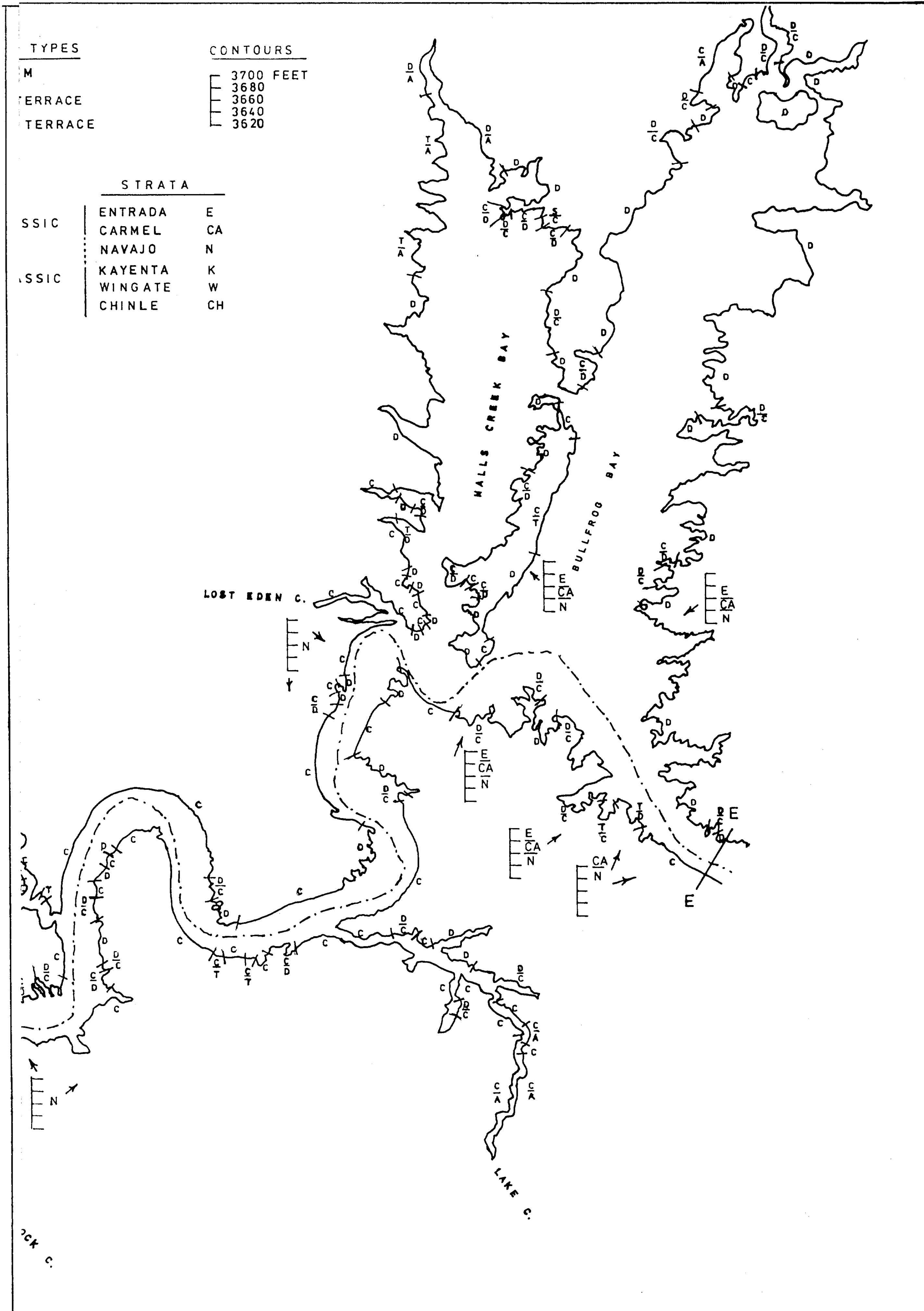
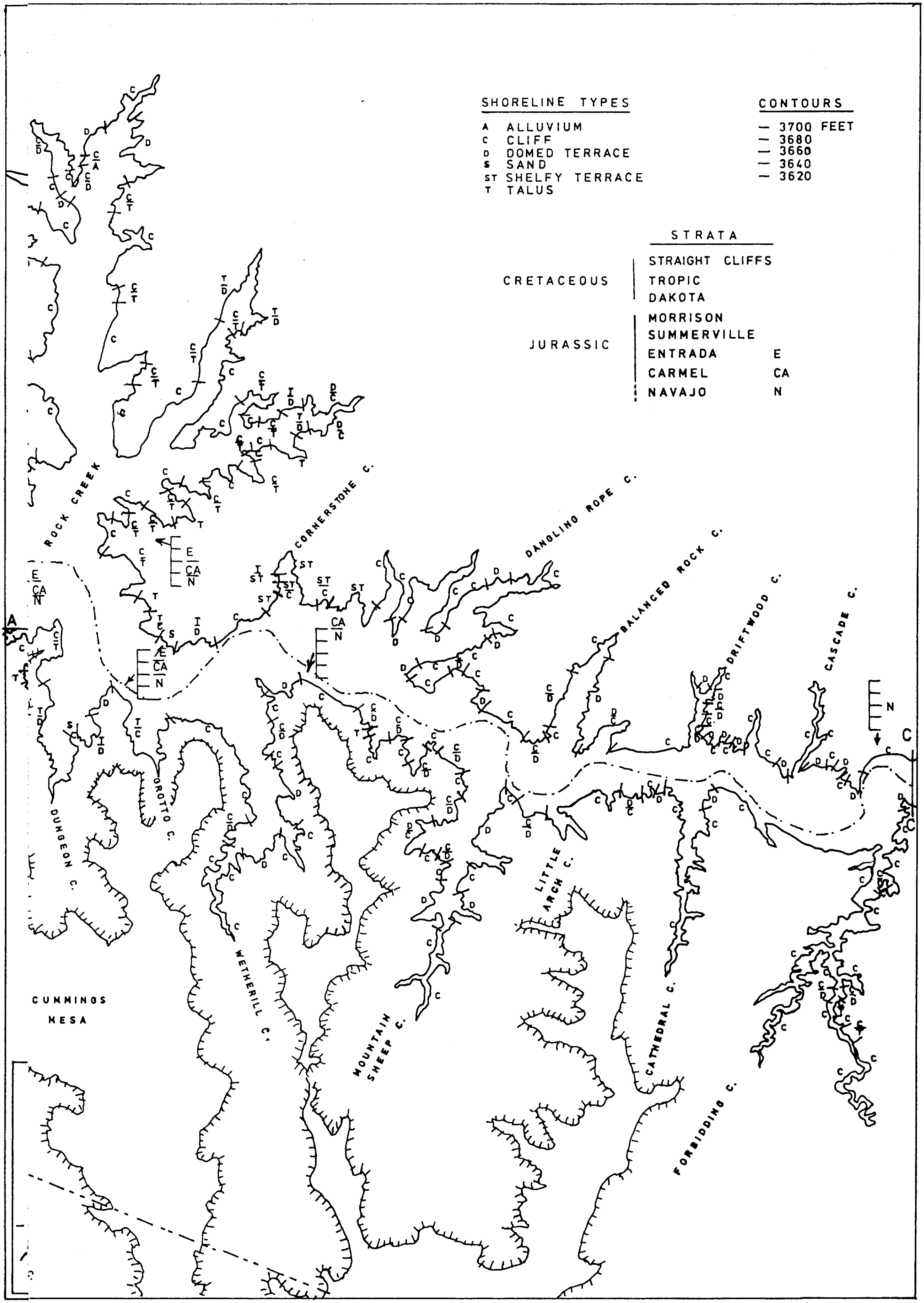




TYPES
M
ERRACE
TERRACE
CONTOURS
3700 FEET
3680
3660
3640
3620
STRATA
SSIC
ENTRADA E
CARMEL CA
NAVAJO N
SSIC
KAYENTA K
WINGATE W
CHINLE CH
HALLS CREEK BAY
BULLFROG BAY
LOST EDEN C.
LAKE C.


SHORELINE TYPES
A ALLUVIUM
C CLIFF
D DOMED TERRACE
S SAND
ST SHELFY TERRACE
T TALUS
CONTOURS
3700 FEET
3680
3660
3640
3620
STRATA
CRETACEOUS
STRAIGHT CLIFFS
TROPIC
DAKOTA
JURASSIC
MORRISON
SUMMERVILLE
ENTRADA E
CARMEL CA
NAVAJO N
ROCK CREEK
CORNERSTONE C.
DANGLING ROPE C.
BALANCED ROCK C.
DRIFTWOOD C.
CASCADE C.
DUNGEON C.
GROTTO C.
WETHERILL C.
MOUNTAIN SHEEP C.
LITTLE ARCH C.
CATHEDRAL C.
FORBIDDING C.
CUMMINGS MESA

THE AUTHORS

Loren D. Potter is Professor of Plant Ecology in the Biology Department, University of New Mexico. From 1958 to 1972 he was chairman of that department. He was one of the founders of the Lake Powell Research Project. His plant ecology research has included studies in the arctic, ponderosa pine, rangelands, and ecology-archeology. Current research is with the National Park Service at Chaco Canyon and Bandelier, and he is directing research for the U.S. Forest Service and ERDA on land stabilization and revegetation. He is presently Principal Investigator of the Shoreline Ecology Subproject and Co-Principal Investigator of the Heavy Metals Subproject of the Lake Powell Research Project.

Natalie B. Pattison has been involved in the Lake Powell Research Project beginning in 1970 as a recipient of a John Muir Institute grant, and since 1971 as a part-time researcher with the Shoreline Ecology Subproject. In addition, she is a part-time employee of the National Park Service--University of New Mexico Chaco Center.

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