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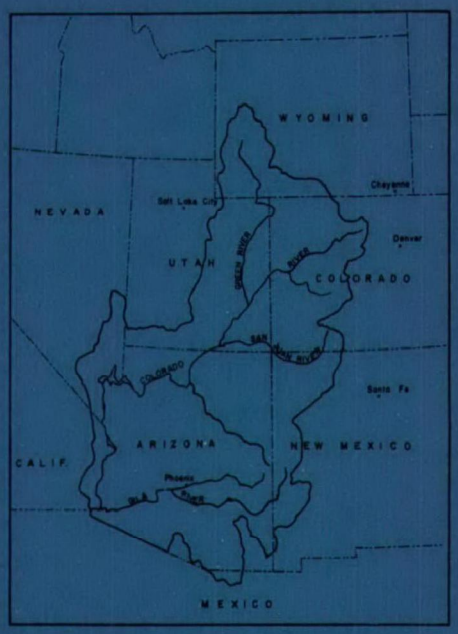
RADIOLOGICAL CONTENT OF COLORADO RIVER BASIN BOTTOM SEDIMENTS AUGUST 1960 - AUGUST 1961



U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service, Region VIII
Denver, Colorado

June 1963

RADIOLOGICAL CONTENT OF

COLORADO RIVER BASIN BOTTOM SEDIMENTS

August 1960 - August 1961

U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Bureau of State Services
Division of Water Supply and Pollution Control
Region VIII

Colorado River Basin Water Quality Control Project
June 1963

ACKNOWLEDGMENT

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U. S. Department of Interior, Bureau of Reclamation, Region 3, Boulder City, Nevada; National Park Service, Lake Mead National Recreation Area, Boulder City, Nevada; Fish and Wildlife Service, Havasu National Wildlife Refuge, Parker, Arizona, and Imperial National Wildlife Refuge, Yuma, Arizona.

The cooperation of the seven Basin states in all Project activities is greatly appreciated.

TABLE I - Uranium Processing Plants - 1961 (1)

Company	Location of Mill	Figure 1 Code No.	Design Capacity (Tons of Ore per Day)
A. COLORADO RIVER BASIN			
U.S.Atomic Energy Commission 1/	Monticello, U.	1	350
Climax Uranium Co.	Grand Junction, Colo.	2	330
Gunnison Mining Co. 1/	Gunnison, Colo.	3	200
Kerr-McGee Oil Industries	Shiprock, N. M.	4	300
Rare Metals Corp. of America 1/	Tuba City, Ariz.	5	300
Texas-Zinc Minerals Corp.	Mexican Hat, Utah	6	1,000
Trace Elements Co.	Maybell, Colo.	7	300
Union Carbide Nuclear Co.	Rifle, Colo.	8	1,000
Union Carbide Nuclear Co.	Uravan, Colo.	9	1,000
Uranium Reduction Co.	Moab, Utah	10	1,500
Vanadium Corp. of America	Durango, Colo.	11	750
		TOTAL	7,230
Union Carbide Nuclear Co. 1,3/	Green River, Utah	12	
Union Carbide Nuclear Co. 1,3/	Slick Rock, Colo.	13	
Vanadium Corp. of America 3/	Monument Valley, Utah	14	
Vanadium Corp. of America 3/	Naturita, Colo.	15	
B. OTHERS			
Cotter Corp.	Canon City, Colo.		200
Anaconda Co.	Grants, N.M.		3,000
Homestake-N.M. Partners 1/	Grants, N. M.		750
Homestake-Sapin Partners	Grants, N. M.		1,500
Kermac Nuclear Fuels Corp.	Grants, N. M.		3,300
Phillips Petroleum Co.	Grants, N. M.		1,725
Lakeview Mining Co. 1/	Lakeview, Ore.		210
Mines Development, Inc.	Edgemont, South Dakota		400
Susquehanna-Western, Inc.	Fall City, Texas		200
Vitro Chemical Co.	Salt Lake City, U.		600
Dawn Mining Co.	Ford, Washington		400
Federal-Radorock-Gas Hills Partners	Fremont Co., Wyoming		520
Globe Mining Co.	Natrona Co., Wyoming		490
Petrotomics Co. 2/	Carbon Co., Wyoming		200
Susquehanna-Western, Inc.	Riverton, Wyoming		500
Utah Construction and Mining Co.	Fremont Co., Wyoming		930
Western Nuclear, Inc.	Jeffrey City, Wyoming		345
Wyo. Mining & Milling Corp. 2,3/	Natrona Co., Wyoming		
		TOTAL	15,620

1/ Inactive

2/ Under construction

3/ Upgrading plants

RADIOLOGICAL CONTENT OF COLORADO RIVER BASIN BOTTOM SEDIMENTS

August 1960 - August 1961

INTRODUCTION AND BACKGROUND

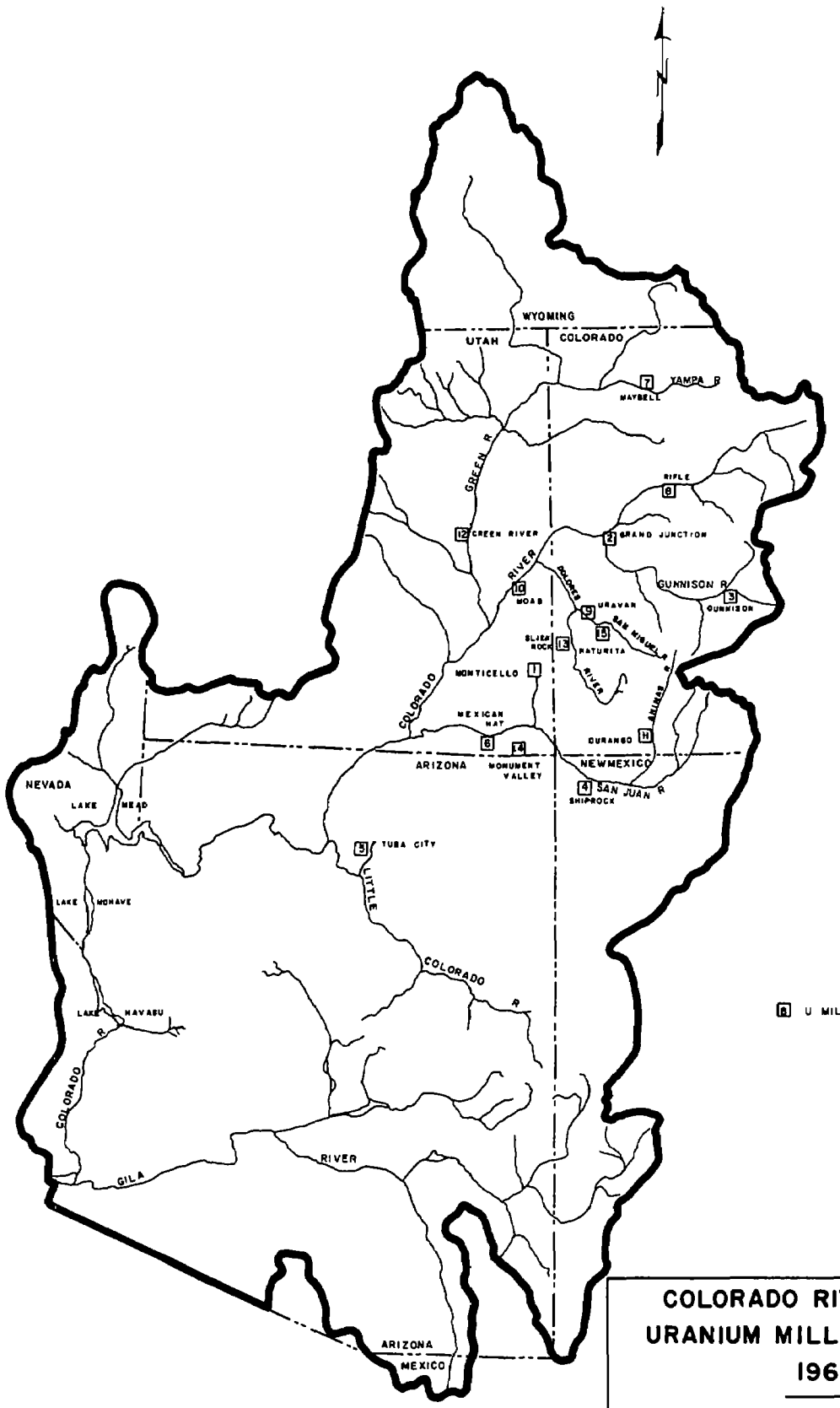
Studies which concern the disposal of and subsequent fate of radioactive materials in the water environment must consider all phases of this environment. This includes the water itself, suspended and bottom sediment material, fish, algae and other aquatic biota. Many investigators have demonstrated that sediments and aquatic life can accumulate significant amounts of radioactivity from overlying waters. The radioactivity contained in these sediments and possibly that from decaying aquatic life can be leached back to the water phase.

In the United States vast deposits of uranium ores are located in the Colorado Plateau area, central Wyoming, and the Grants-Ambrosia Lake areas of New Mexico, with lesser deposits in the western Dakotas, southern Oregon, and northeastern Washington. There were in 1961 twenty-six operating uranium mills and four upgrading plants in the western United States. Table I presents a listing of these facilities and their design capacities. From this table it is seen that, on the basis of design capacity, about 30 percent of the total national uranium ore production is milled in the Colorado River Basin. With respect to the waters of the Colorado River Basin, major sources of radioactive contamination have been those associated with the mining and milling of these uranium-bearing ores. Figure 1 shows the location of uranium mills and upgrading plants in the Colorado River Basin.

Uranium-bearing ores generally average about 0.25 percent uranium as U_3O_8 (2). The milling processes are designed principally to extract uranium from the ore. The bulk of the ore processed becomes a waste product containing large amounts of radioactive constituents other than the uranium originally present in the raw ore. Detailed descriptions of processing and waste disposal operations at various uranium mills are given in recent Public Health Service reports. (1)(3)

Radioactive waste products associated with discharges from uranium milling operations include uranium, radium, thorium, and all of their decay products in varying amounts. By far the most important of these radionuclides is Ra-226 because of its extremely low Maximum Permissible Concentration (MPC) in water (4)(5), its bone-seeking characteristics, and its long half-life of 1622 years.

Studies of the effects of waste discharges from uranium mills on the waters of the Colorado River Basin have been carried out by the Public Health Service since 1950. In 1950 samples of river water were collected at locations above and below several uranium mills. These data showed that the dissolved radium content of river water below uranium mills was increased considerably by waste discharges from the



COLORADO RIVER BASIN URANIUM MILL LOCATIONS 1961

COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

REGION VIII DENVER, COLORADO

JMA

FIGURE 1

milling operations. In the fall of 1955 a second short-term survey was performed on streams in the vicinity of eight uranium mills, seven of which were in the Colorado River Basin (6). At this time, in addition to river water, bottom muds and biota (algae and insects) were collected. Although radium analyses were not performed on the river muds, gross alpha and beta analyses showed accumulation factors of 100 times background or more in the muds. A detailed survey was conducted in 1956 (7) on two of the most seriously polluted streams in the Colorado River Basin. The latter study showed that radium content of river muds immediately below the uranium mills was 1,000 to 2,000 times natural background concentrations.

The Animas River surveys (8)(9) were the first studies which provided detailed information concerning the effect of radium-bearing bottom sediments upon the stream environment. These studies clearly demonstrated that considerable radium was leached out of the sediments with the result that the dissolved radium content of the river water was above the Maximum Permissible Concentration value for radium-226.

One of the questions raised in the Animas River studies was that of the leachability of radium from uranium mill waste solids and river sediments, and the factors which influenced such leaching. Accordingly, detailed laboratory investigations were undertaken along these lines (10). These studies showed that the major factor controlling leachability of radium was the liquid-to-solid ratio (volume of liquid per unit weight of solids). A more detailed discussion of these findings is presented in Appendix A.

The objectives of the three Basinwide sediment surveys conducted by the Colorado River Basin Project during August 1960 to August 1961 were to determine: (a) the radioactivity burden of Basin sediments; (b) distribution of this radioactivity throughout the Basin; (c) the difference between natural background concentrations of radioactivity, and radioactivity resulting from waste disposal operations; and (d) effects of river hydrology on sediment deposition and transport.

GENERAL HYDROLOGY OF BASIN

Within the Colorado River Basin, particularly the upper portions, most of the annual surface runoff is the result of snow-melt. The first melts usually begin each year in early or mid-April, with peak streamflow around the early part of June. Flows subside through the month of July and reach base-levels in the early part of summer. During late summer and early fall local intense rainfalls may be frequent and produce brief periods of somewhat higher flows. From late September until the beginning of snow-melt the following April, streamflows are fairly constant and maintained at minimum levels. Figures 2, 3, and 4 present hydrographs of three typical USGS gaging stations in the Upper Basin.

Flow patterns are distinctly different in the Lower Basin below Hoover Dam. In the area from Hoover Dam to the Arizona-Mexico Border,

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streamflows are highly regulated by releases and diversions from large impoundments on the main stem and major tributaries. A typical hydrograph is given in Figure 5 for the USGS gaging station immediately below Parker Dam in the Lower Colorado River Basin.

CONDUCT OF SURVEY

Three Basinwide stream sediment surveys have been carried out to date and are reported on here. The dates of the three field surveys were as follows:

First survey - August 8-24, 1960
Second survey - March 6-23, 1961
Third survey - August 1-15, 1961

The above sampling periods were selected to coincide with certain hydrologic conditions in the Upper Basin. By reference to Figures 2, 3, and 4, it is seen that the first survey was conducted soon after the spring snow-melts. These snow-melts produced high flows which resulted in scouring of the river bottom and transport of large quantities of sediment to the Lower Basin.

This survey period was representative of relatively clean river beds. The second survey of March 1961 followed an extended period of low flow with resulting accumulation of bottom sediment material. River conditions during the third survey of August 1961 approximated those of the August 1960 study.

Several factors were considered in selecting the various stream sampling stations. The major criteria were the need to obtain data on background radioactivity levels of sediments upstream from uranium mining and milling activity and the deposition of radioactive sediments below such activity. Figures 6, 7, 8, and 9 show locations of all sediment stations with the exception of the Lake Mead samples. Results of Lake Mead sampling are given later in this report. The large majority of stations were situated below uranium milling and mining areas. A complete description of all stations is provided in Appendix B.

Several methods were employed in collection of stream sediments. Samples were obtained either by an Ekman dredge, Petersen dredge, or by hand. The majority of the samples represented a composite of sediment at quarter-points across the width of the stream, and were collected by hand when wading was feasible. When this was not possible samples were taken by means of a dredge lowered from a bridge or boat. When it was not possible to obtain a composite sample across the stream, sediments were gathered along the accessible shores. Both riffle and pool samples were collected at some locations in order to observe any variation in radioactivity content of these two types of sediment. Approximately one pint of sample was obtained at all locations.

The conduct of the three Basinwide sediment surveys included collection of bottom muds from Lake Mead. In addition, a special mud sampling study was conducted during October 24-28, 1960, of Lake Mead in conjunction

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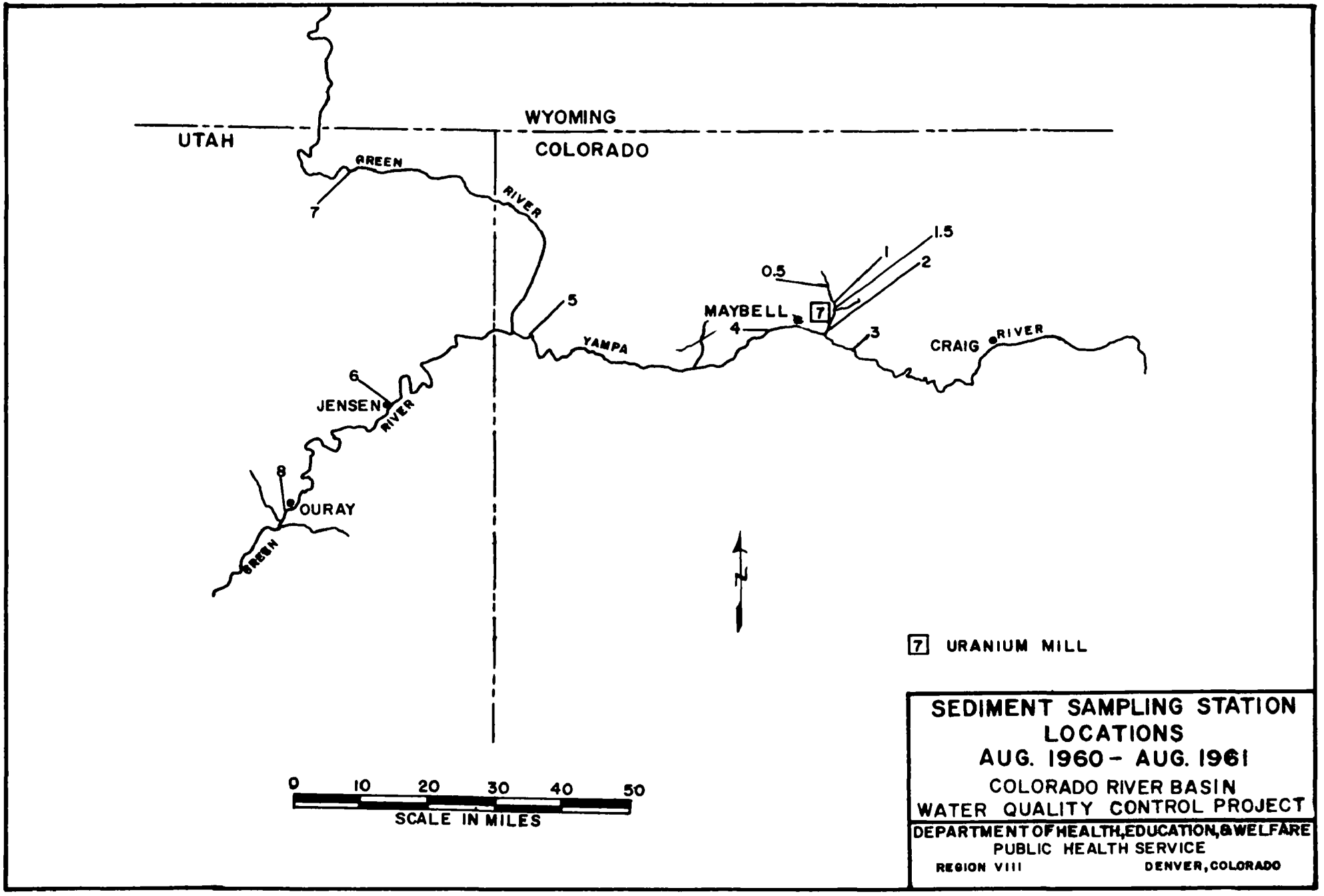

SEDIMENT SAMPLING STATION LOCATIONS AUG. 1960 – AUG. 1961

COLORADO RIVER BASIN
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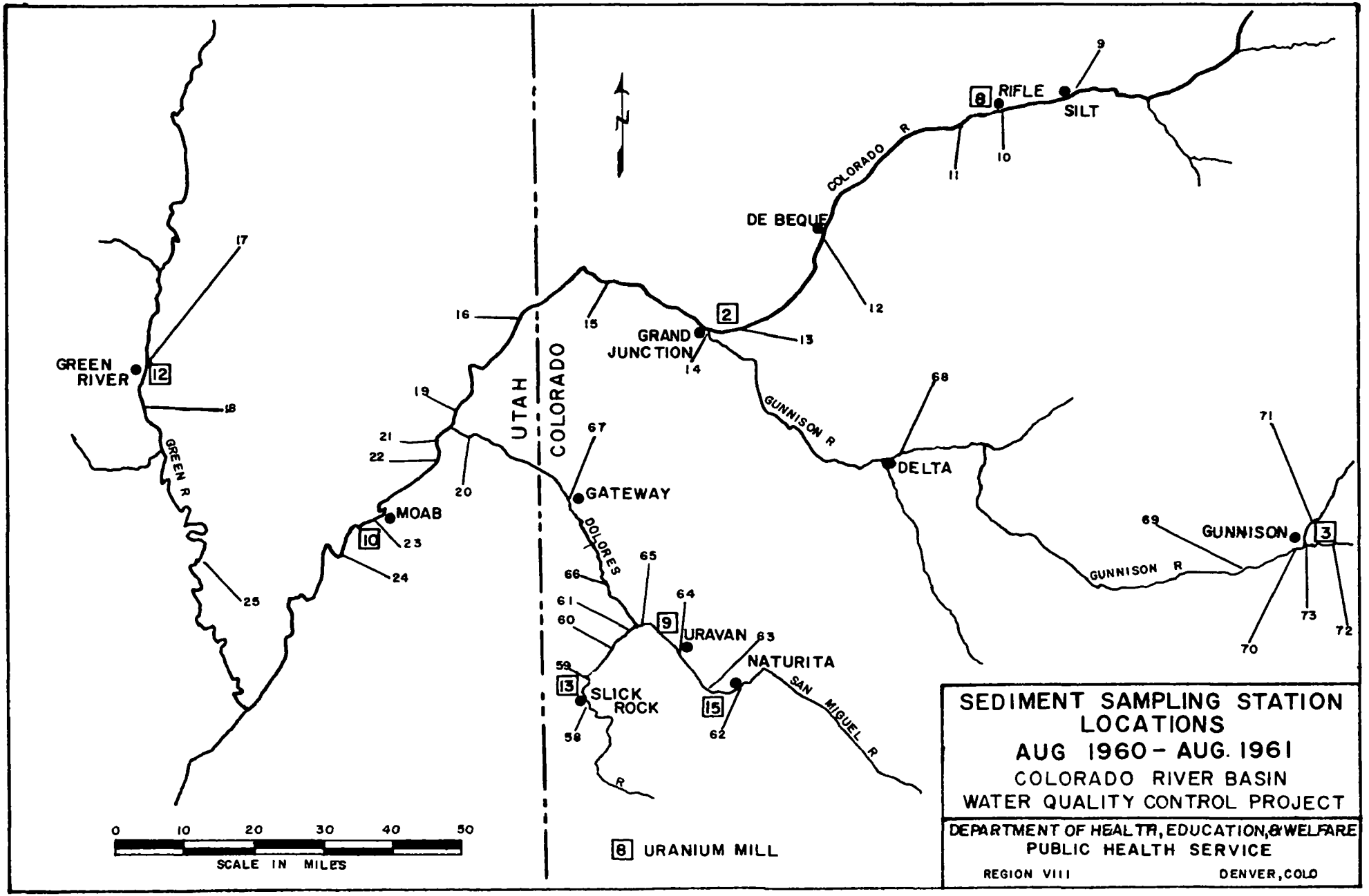
FIGURE 6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GREEN RIVER
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MOAB
10
GRAND JUNCTION
2
DE BEQUE
RIFLE
8
SILT
GATEWAY
DELTA
GUNNISON
3
URAVAN
9
NATURITA
SLICK ROCK
13
15
UTAH
COLORADO
GREEN R
COLORADO R
GUNNISON R
DOLORES
SAN MIGUEL R
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SCALE IN MILES
8 URANIUM MILL
SEDIMENT SAMPLING STATION LOCATIONS
AUG 1960 - AUG. 1961
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
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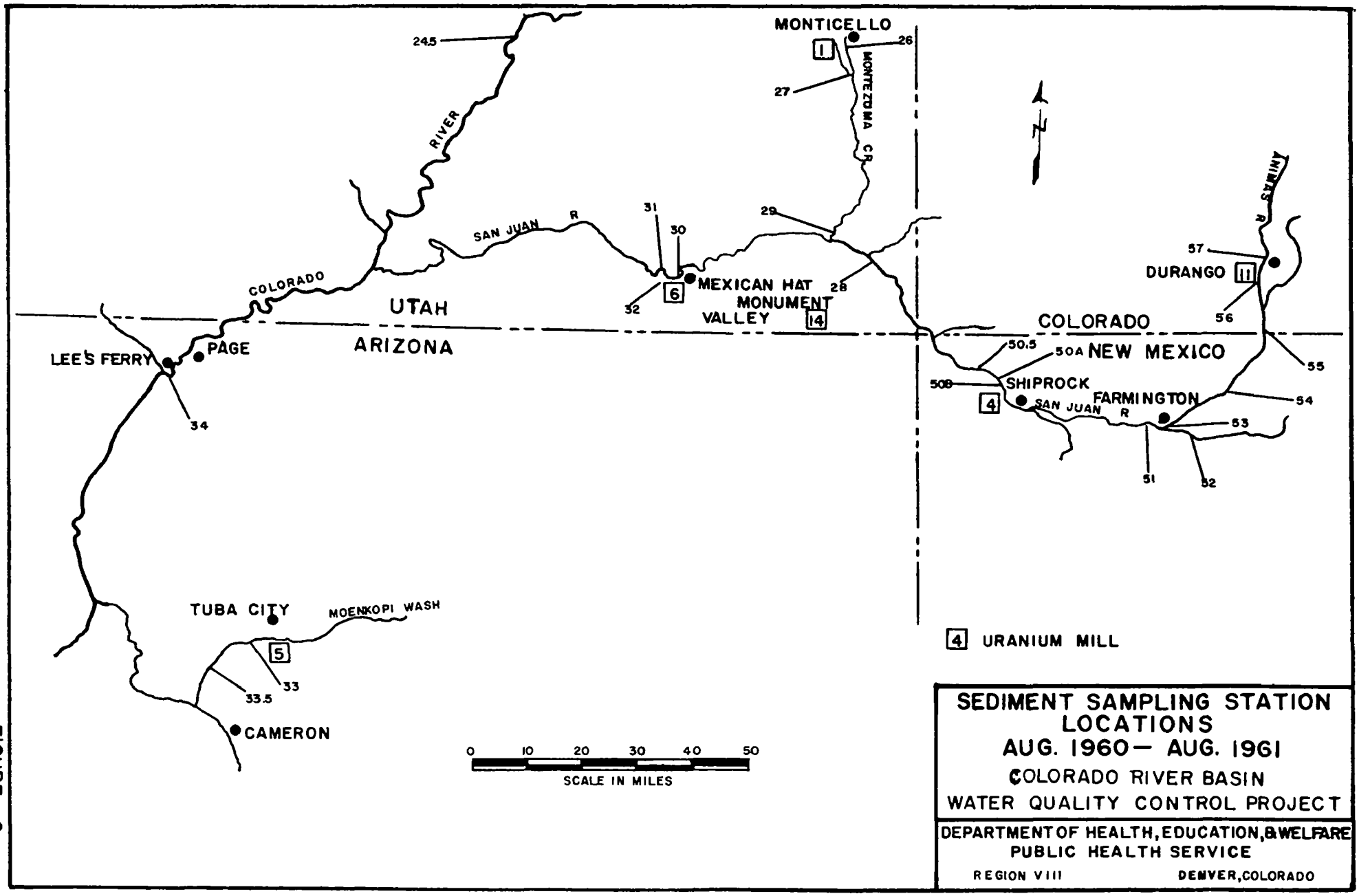
PUBLIC HEALTH SERVICE
REGION VIII
DENVER, COLO

FIGURE 7


MONTICELLO
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27
MONTEZUMA CR.
24.5
RIVER
SAN JUAN R
31
30
29
28
6
MEXICAN HAT
MONUMENT VALLEY
14
32
COLORADO
UTAH
ARIZONA
LEE'S FERRY
PAGE
34
50.5
50A
NEW MEXICO
50B
SHIPROCK
4
SAN JUAN R
FARMINGTON
54
53
51
52
55
57
DURANGO
11
56
ANIMAS R
TUBA CITY
MOENKOPI WASH
5
33
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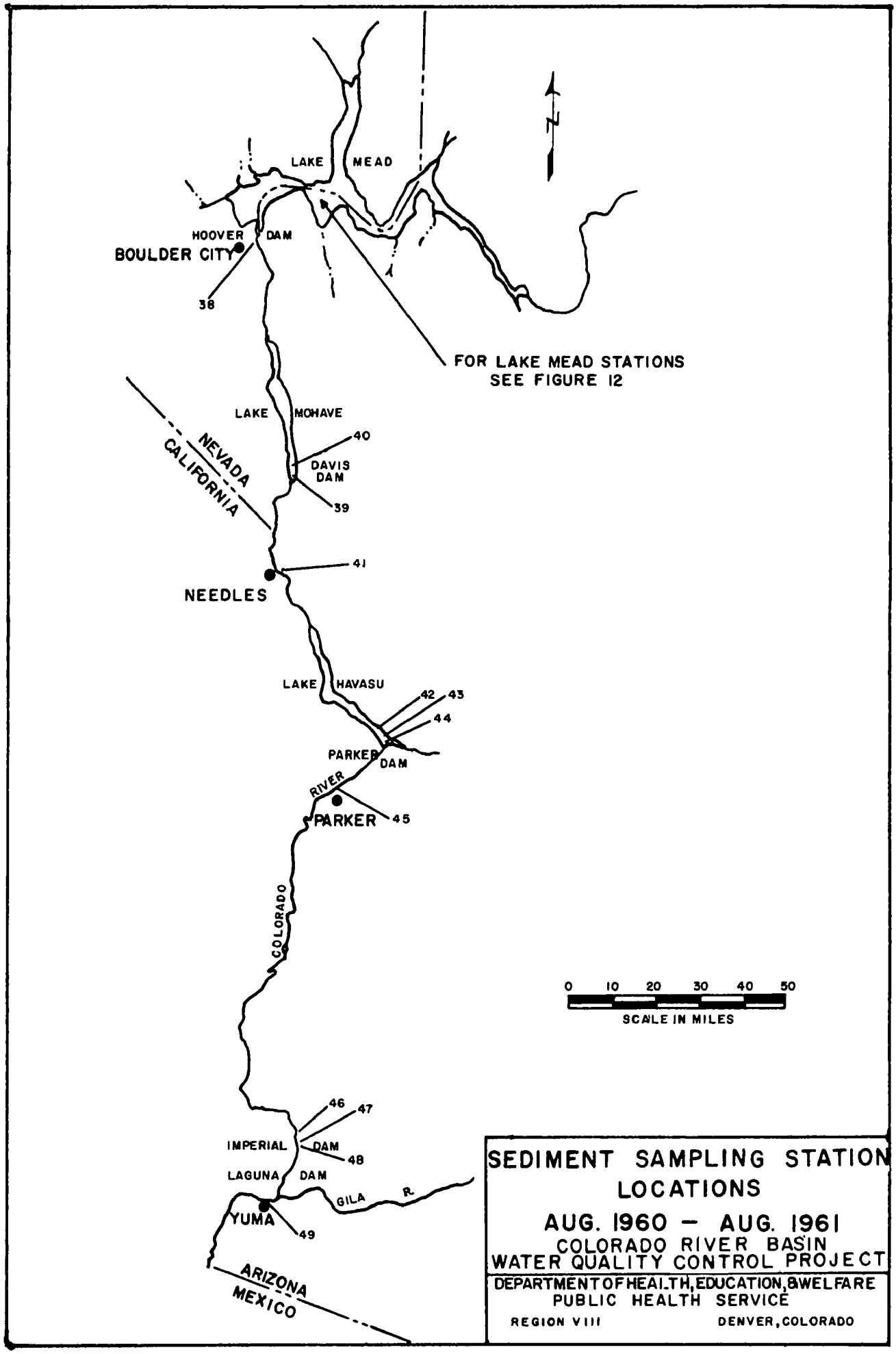
CAMERON
0 10 20 30 40 50
SCALE IN MILES
4 URANIUM MILL
SEDIMENT SAMPLING STATION LOCATIONS
AUG. 1960 — AUG. 1961
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII
DENVER, COLORADO

FIGURE 8


LAKE MEAD
HOOVER DAM
BOULDER CITY
38
FOR LAKE MEAD STATIONS
SEE FIGURE 12
LAKE MOHAVE
40
DAVIS DAM
39
NEVADA
CALIFORNIA
41
NEEDLES
LAKE HAVASU
42
43
44
PARKER DAM
RIVER
PARKER
45
COLORADO
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SCALE IN MILES
46
47
IMPERIAL DAM
48
LAGUNA DAM
GILA R.
YUMA
49
ARIZONA
MEXICO
SEDIMENT SAMPLING STATION LOCATIONS
AUG. 1960 – AUG. 1961
COLORADO RIVER BASIN
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FIGURE 9

with the annual Lake survey by the Bureau of Reclamation. For clarity in report presentation, the data from Lake Mead are considered separately from the other results.

All samples from the surveys were analyzed for radium-226 content. All samples from the first Basinwide sediment survey were also analyzed for gross alpha and gross beta radioactivity.

PRESENTATION OF DATA

The data obtained from the three Basinwide sediment surveys have been subdivided into several groups in order to provide clarity and in order to obtain better interpretation. Median values, as well as range and average, are shown since it was noted that a small number of very high results in a data group significantly affected the average.

Gross radioactivity data have been omitted from the detailed tables because gross radioactivity determinations were performed only on the samples collected in August 1960. Averages and ranges of gross alpha and gross beta determinations have, however, been included in summary tables.

The detailed tables include individual results for riffle and pool samples collected at various sampling locations.

A. Background Sediments

Bottom sediment samples were collected at 20 locations unaffected by uranium mining and milling activities. The radioactivity levels of these sediments are indicative of natural background levels. Individual data for this group of stations are presented in Table II whereas average and median values are given in Table III.

The data in Table II show that with the exception of five values, the Ra-226 content of Basin sediments representing natural background conditions is 1.5 μμc/g or less. Table III shows that the average Ra-226 level is 1.1 μμc/g for the 45 samples obtained. The values in Tables II and III confirm earlier survey results on natural background levels of radium in river sediments (8,9).

TABLE II
Radioactivity - Natural Background Sediments
August 1960 - August 1961

Station	Location	Radium-226 (μμc/g) Aug. 1960	March 1961	Aug. 1961
0.5	Lay Creek	--	1.6	1.8
3	Yampa River	≤ 1.0**	--	--
7R***	Green River	≤ 1.0**	1.0	1.0
7P***	Green River	0.8	--	--
9R	Colorado River	1.4	1.4	1.0
9P	Colorado River	2.1	1.8	1.2
17	Green River	0.9	0.6	0.9
33	Moenkopi Wash	1.3	0.9	1.1
52R	San Juan River	0.8	1.2	0.8
52P	San Juan River	≤ 1.0**	0.7	1.1
57	Animas River	1.3	1.4	1.1
62R	San Miguel River	≤ 1.0**	1.1	1.0
62P	San Miguel River	1.0	0.9	0.9
71	Gunnison River	1.6	1.1	0.9
72	Tomichi Creek	1.2	1.2	1.1
74*	Eagle River			1.3
75	Colorado River			1.5
76	Roaring Fork River			1.2
78	Gunnison River			0.8
79	Tomichi Creek			0.9
80	Uncompahgre River			1.2
81	San Miguel River			0.8
82	Little Snake River			1.2
83	White River			0.9

*Stations 74-83 collected December 1961
**Not used in average
*** R=Riffle; P=Pool

TABLE III
Summary Table on Radioactivity of Natural Background Sediments

	Radioactivity - μμc/g Gross Alpha*	Gross Beta*	Radium-226
Average	7.9	44	1.1
Median	8.4	44	1.1
Range	3.1 - 13	19 - 84	0.6 - 2.1
Number of Samples	14	14	45

*Gross activity only determined for August 1960 Survey

TABLE IV

Radioactivity - Main-Stem Colorado River Bottom Sediment

August 1960 - August 1961

Station	Location	Radium-226 (μμc/g) Aug. 1960	March 1961	Aug. 1961
75**	Above Glenwood Springs, Colo.	--	--	1.5
9R	At Silt, Colo.	1.4	1.4	1.4
9P	At Silt, Colo.	2.1	1.8	1.2
10R	Above new UCNC Uranium Mill at Rifle, Colo.	1.5	1.9	1.1
10P	Above new UCNC Uranium Mill at Rifle, Colo.	2.4	1.9	--
11R	Below Rifle, Colo.	2.8	1.2	1.0
11P	Below Rifle, Colo.	2.2	--	25*
12	At Debeque, Colo.	1.9	2.7	1.9
13R	Above Grand Junction, Colo.	2.2	1.9	2.1
13P	Above Grand Junction, Colo.	1.5	--	--
15	At Loma, Colo.	1.0	2.2	1.5
16R	At Westwater, Utah	1.7	1.8	1.0
16P	At Westwater, Utah	1.2	--	--
19	Above Dolores River	2.1	1.5	1.2
21	Below Dolores River	4.3	3.2	2.0
22	3 miles below Station 21	1.5	2.0	2.2
23	Above Moab, Utah	3.1	3.1	1.9
24	Below Moab, Utah	3.0	2.8	1.9
24.5	At Hite, Utah	--	1.3	1.1
34	At Lee's Ferry, Ariz.	1.3	1.3	1.7
38	Below Hoover Dam	0.9	0.9	1.1
39	Immediately above Davis Dam	1.5	2.3	2.0
40	3 miles above Davis Dam	0.6	0.9	0.8
41	At Needles, Calif.	1.0	0.4	0.4
42	0.5 mi. above Parker Dam	2.6	2.2	1.6
43	Lake Havasu, 1 mi. above Parker Dam	3.3	2.3	2.2
44	4 mi. above Parker Dam	2.3	1.8	3.1
45	At Parker, Ariz.	1.3	--	1.1
46	4 mi. above Imperial Dam	0.8	0.4	1.1
47	0.5 mi. above Imperial Dam	1.1	0.8	0.8
48	1 mi. above Imperial Dam	0.9	0.5	0.9
49	At Yuma, Ariz.	$\leq$ 1.0*	0.8	0.5

*Not used in average

**Sediment sample collected December 1961

B. Main-Stem Colorado River Sediments

Individual data are presented in Table IV on the radioactivity content of bottom sediments collected from the main-stem Colorado River. Excluding Lake Mead stations, a total of 27 locations were sampled. These stations cover the Colorado River from 10 miles above Glenwood Springs, Colorado to Yuma, Arizona. Four stations are within the confines of Lakes Havasu and Mohave.

Table V presents a summary of radioactivity results for all sediments collected from the main-stem Colorado River.

TABLE V
Summary Table on Radioactivity of Main-Stem Colorado River Sediments

	Radioactivity - μμc/g		
	Gross Alpha*	Gross Beta*	Radium-226
Average	10	40	1.7
Median	10	34	1.5
Range	1.2 - 27	14 - 84	0.4 - 25
Number of Samples	30	30	84

*Gross activity determined for August 1960 Survey only

The data in Table IV show a sizeable variation in radium content of main-stem river bottom sediments. The 84 individual sampling results have an average of 1.7 μμc/g radium with a range of 0.4 - 25 μμc/g. The twelve samples collected from four stations in Lake Havasu and Mohave (Stas. 39, 42, 43, and 44) below Lake Mead have an average radium content of 2.3 μμc/g with a range of 1.5-3.3 μμc/g. Also the three stations below Lake Mead and Lake Havasu (Stas. 38, 40, 41) and all river stations downstream of Lake Havasu (Stas. 45-49; see Figure 9) show a composite average Ra-226 content of 0.8 μμc/g with a range of 0.4-1.3 μμc/g for 22 samples.

All sediments collected from the eight river stations below Lake Mead show radioactivity results in the range of natural background. By reference to radioactivity values for Lakes Havasu and Mohave given above and those for Lake Mead to be presented later in this report, these data demonstrate that these three Lakes are collectively the final resting place for radioactive sediments discharged above Lake Mead. This observation will subsequently be discussed in greater detail.

C. Locations Immediately Downstream from Uranium Mills

In order to illustrate the effect of uranium mill wastes upon downstream river sediments, it is desirable to group the data from stations located immediately below uranium milling activities. Table VI presents these stations arranged in downstream order from the Upper Basin to the Lower Basin. Table VII offers a summary of the data information in Table VI.

TABLE VI
Radioactivity - River Bottom Sediments Immediately Below Uranium Mills

Station	Location	Radium-226 (μμc/g) Aug. 1960	March 1961	Aug. 1961
1	Lay Creek	76	34	0.9
1.5	Lay Creek	--	15	2.1
10R	Colorado River	1.5	1.9	1.1
10P	Colorado River	2.4	1.9	--
11R	Colorado River	2.8	1.2	1.0
11P	Colorado River	2.2	--	24
73	Tomichi Creek	1.3	--	--
70	Gunnison River	1.4	0.8	0.7
59R	Dolores River	2.9	5.9	1.4
59P	Dolores River	1.9	2.4	2.1
61R	Dolores River	1.6	--	1.0
61P	Dolores River	5.8	3.4	1.9
63R	San Miguel River	4.7	1.4	1.9
63P	San Miguel River	11	1.5	1.3
65	San Miguel River	7.5	9.9	11
24	Colorado River	3.0	2.8	1.9
18R	Green River	2.3	1.2	1.2
18P	Green River	1.5	1.8	1.7
56R	Animas River	8.6	46	2.6
56P	Animas River	19	38	6.2
50R	San Juan River	1.2	0.8	0.9
50P	San Juan River	1.9	--	--
27	South Creek	275*	--	7.6
31R	San Juan River	1.7	1.7	0.4
31P	San Juan River	1.8	2.9	0.8

*Not used in average

TABLE VII

Summary Table of Radioactivity of Sediments Immediately Below Uranium Mills

	Radioactivity - (uuc/g)		
	Gross Alpha*	Gross Beta*	Radium-226
Average	46	97	6.6
Median	21	55	1.9
Range	1.9 - 1255	1.5 - 1310	0.4 - 275
Number of Samples	23	23	65

*Gross activity determined for August 1960 Survey only

Comparison of the above data with that of Tables III and V is of interest. It may be seen that the average radium content of sediments obtained immediately below uranium mill locations is about six times that of background sediments and four times those collected from the main-stem Colorado River.

D. Major Sub-basins

In order to observe the radioactive sediment distribution within major sub-basins of the Colorado River Basin all sampling stations have been grouped according to the following sub-basins: (a) Green River; (b) Upper Main-Stem; (c) San Juan, and (d) Lower Main-Stem. Figure 10 shows all of the major sub-basins of the Colorado Basin.

No samples were taken from the Little Colorado and Gila Sub-Basins, because uranium activity is minimal or absent in these areas.

Table VIII presents the radioactivity data for each of the major sub-basins of the Colorado Basin. The Upper Main-Stem Sub-Basin has been further broken down into the Gunnison River system and the San Miguel-Dolores River system in order to better evaluate the contribution of radioactive sediment from these two systems.

Table IX presents a summary of the data given in Table VIII. Several interesting observations are apparent from this table. Of the four major sub-basins it is seen that the average radium-226 is least in the Lower Main-Stem (1.3 for 39 samples) while the San Juan Sub-Basin has the highest average radium-226 (4.2 for 60 samples). The breakdown of the Upper Main Stem shows the average radium-226 in the San Miguel-Dolores system (3.3 for 66 samples) to be twice as high as in the Gunnison system (1.7 for 55 samples). It is also interesting to note that the average radium-226 concentration in sediments in the Lower Main Stem is essentially identical to the average presented in Table III for natural background sediments, and that the average radium content of all sediments in Colorado River Basin (excluding those in Lake Mead) is slightly more than twice that found in natural background sediments.

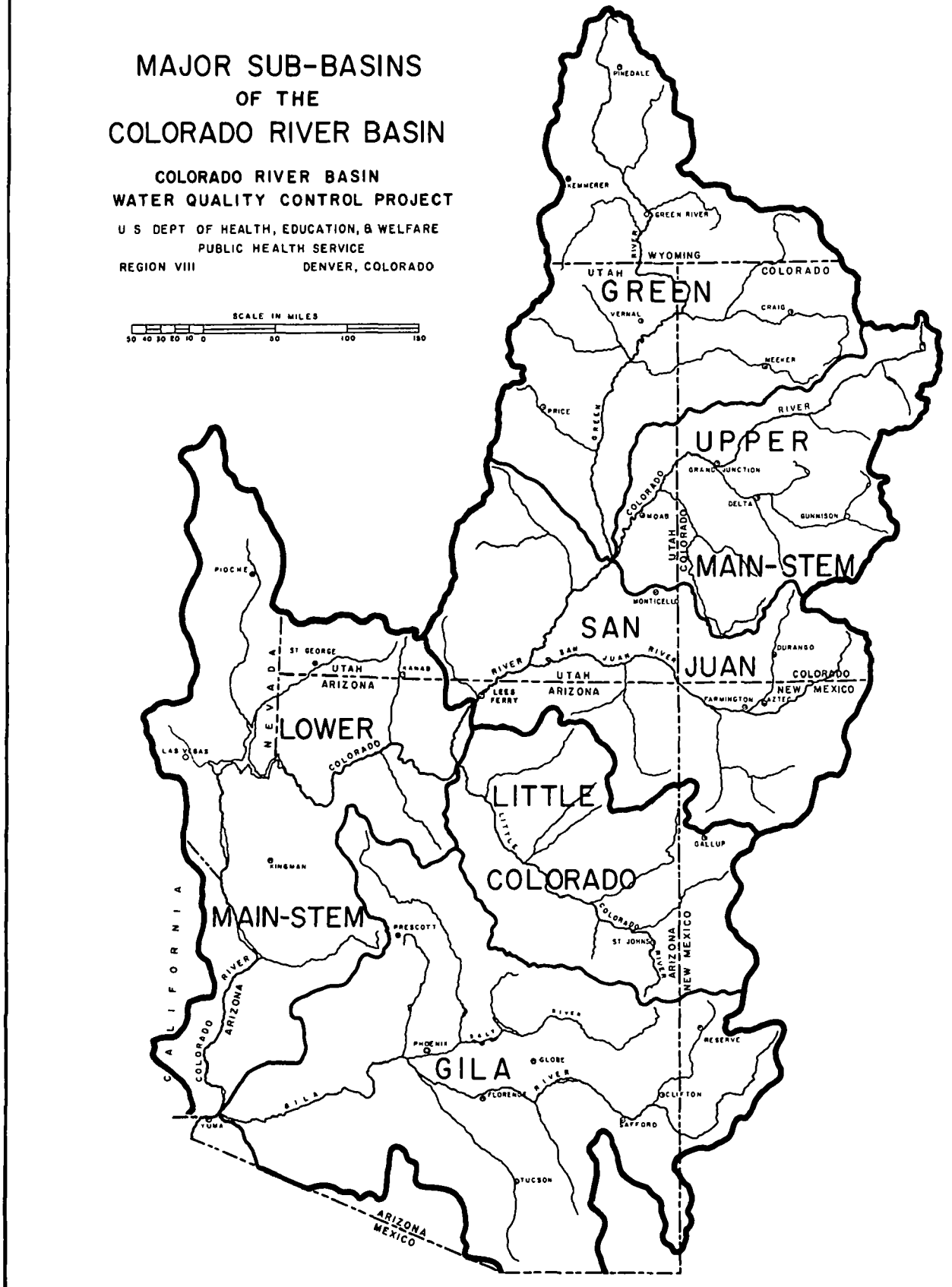

MAJOR SUB-BASINS
OF THE
COLORADO RIVER BASIN
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
U S DEPT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VIII DENVER, COLORADO
SCALE IN MILES
50 40 30 20 10 0 50 100 150
GREEN
UPPER
MAIN-STEM
SAN
JUAN
LOWER
LITTLE
COLORADO
MAIN-STEM
GILA
PINEDALE
KEMMERER
GREEN RIVER
WYOMING
UTAH
COLORADO
VERNAL
CRAIG
MEEKER
PRICE
GREEN RIVER
GRAND JUNCTION
DELTA
GUNNISON
MOAB
COLORADO
UTAH
COLORADO
MONTICELLO
PIOCHE
ST GEORGE
UTAH
ARIZONA
VIRGIN
NEVADA
LEES FERRY
SAN JUAN RIVER
UTAH
ARIZONA
DURANGO
COLORADO
NEW MEXICO
FARMINGTON
AZTEC
LAS VEGAS
COLORADO
GALLUP
KINGMAN
PRESCOTT
ST JOHNS
ARIZONA
NEW MEXICO
CALIFORNIA
COLORADO RIVER
ARIZONA
PHOENIX
SALT RIVER
GLOBE
RESERVE
FLORENCE
GILA RIVER
CLIFTON
SAFFORD
YUMA
GILA
TUCSON
ARIZONA
MEXICO

FIGURE 10

TABLE VIII

Radioactivity - Sediments for Major Sub-Basins of the Colorado River Basin

Station	Location	Radium-226 (μμc/g) Aug. 1960	March 1961	Aug. 1961
1. GREEN RIVER SUB-BASIN				
82 **	Little Snake River	-	-	1.2
83 **	White River	-	-	0.9
0.5	Lay Creek	-	1.6	1.8
1.0	Lay Creek	126*	34*	0.9
1.5	Lay Creek	-	15	2.0
2	Lay Creek	4.0	6.9	3.9
3	Yampa River	≤ 1.0*	-	1.0
4	Yampa River	1.2	1.2	0.8
5R	Yampa River	1.1	-	3.0
5P	Yampa River	0.8	-	-
6	Green River	0.8	.6	0.7
7R	Green River	≤ 1.0*	1.0	0.9
7P	Green River	0.8	-	-
8	Green River	≤ 1.0*	-	0.6
17	Green River	0.99	0.6	0.9
18R	Green River	2.3	1.2	1.7
18P	Green River	1.5	1.8	0.9
25	Green River	1.8	1.2	1.0
2. UPPER MAIN-STEM SUB-BASIN				
A. Gunnison River System				
74 **	Eagle River	-	-	1.3
75 **	Colorado River	-	-	1.5
76 **	Roaring Fork River	-	-	1.2
9R	Colorado River	1.4	1.4	1.0
9P	Colorado River	2.1	1.8	1.2
10R	Colorado River	1.5	1.9	1.2
10P	Colorado River	2.4	1.9	-
11R	Colorado River	2.8	1.2	1.0
11P	Colorado River	2.2	-	17
12	Colorado River	1.9	2.7	1.9
13R	Colorado River	2.2	1.9	2.1
13P	Colorado River	1.5	-	.8
78 **	Gunnison River	-	-	.9
79 **	Tomichi Creek	1.2	1.2	1.1
72	Tomichi Creek	1.6	1.1	0.9
71	Gunnison River	1.4	0.8	0.7

Station	Location	Radium-226 Aug. 1960	March 1961	Aug. 1961
70	Gunnison River	1.0	0.7	0.7
69	Gunnison River	-	-	1.2
80	Uncompahgre River	1.0	1.3	1.6
68R	Gunnison River	1.0	1.0	-
68P	Gunnison River	≤ 1.0*	1.0	0.5
14	Gunnison River	1.0	2.2	1.5
15	Colorado River	1.7	1.8	1.0
16	Colorado River			
B.	San Miguel-Dolores River System			
19	Colorado River	5.5	1.5	1.4
58R	Dolores River	1.9	1.8	1.6
58P	Dolores River	2.5	1.8	1.9
59R	Dolores River	2.9	2.4	1.4
59P	Dolores River	1.9	5.9	2.2
60	Dolores River	1.0	1.4	0.6
61R	Dolores River	1.6	-	1.0
61P	Dolores River	5.8	3.4	1.9
81 **	San Miguel River	-	-	0.8
62R	San Miguel River	≤ 1.0*	0.9	0.7
62P	San Miguel River	1.0	1.1	0.9
63R	San Miguel River	4.7	1.4	1.3
63P	San Miguel River	11	1.5	1.9
64	San Miguel River	2.8	8.7	2.0
65	San Miguel River	7.5	9.9	11
66	Dolores River	4.5	8.4	8.0
67R	Dolores River	1.5	4.3	12
67P	Dolores River	2.7	7.8	-
20	Dolores River	7.6	6.3	4.0
21	Colorado River	4.3	3.2	2.0
22	Colorado River	1.5	2.0	2.2
23	Colorado River	3.1	3.1	1.9
24	Colorado River	3.0	2.8	1.9
24.5	Colorado River	-	1.3	1.1
3.	SAN JUAN SUB-BASIN			
57	Animas River	1.3	1.4	1.1
56R	Animas River	8.6	46	2.6
56P	Animas River	19	38	6.2
55R	Animas River	6.7	22	2.9
55P	Animas River	3.3	5.8	-
54R	Animas River	3.1	3.7	1.8
54P	Animas River	2.9	4.9	0.9
53R	Animas River	2.2	3.6	2.0

Station	Location	Radium-226 Aug. 1960	March 1961	Aug. 1961
53P	Animas River	2.5	3.9	1.3
52R	San Juan River	0.8	3.9	0.7
52P	San Juan River	≤ 1.0*	1.2	1.1
51R	San Juan River	1.4	0.7	0.8
51P	San Juan River	1.0	-	-
50R	San Juan River	1.2	0.8	0.9
50P	San Juan River	1.9	-	-
50.5	San Juan River	-	0.8	0.8
26	South Creek	2.6	7.5	2.0
27	South Creek	253*	-	7.6
28	San Juan River	≤ 1.0*	0.9	1.0
29	Montezuma Creek	≤ 1.0*	0.6	0.7
30	San Juan River	≤ 1.0*	1.3	1.1
31R	San Juan River	1.7	1.7	0.4
31P	San Juan River	1.8	2.9	0.8
34	Colorado River	1.3	1.3	1.7
4. LOWER MAIN-STEM SUB-BASIN				
33	Moenkopi Wash	1.3	0.9	1.1
33.5	Moenkopi Wash	-	0.6	1.2
38	Colorado River	0.9	0.9	1.1
39	Lake Mohave	1.5	2.3	2.0
40	Lake Mohave	1.0	0.9	0.8
41	Colorado River	1.0	0.4	0.4
42	Lake Havasu	2.6	2.1	1.6
43	Lake Havasu	3.3	2.3	2.2
44	Lake Havasu	2.3	1.8	3.1
45	Colorado River	1.3	-	1.1
46	Colorado River	0.8	0.4	1.1
47	Colorado River	1.1	0.8	0.8
48	Colorado River	0.9	0.5	0.9
49	Colorado River	≤ 1.0*	-	0.5

*Not used in average
**Sediment sample collected December 1961

TABLE IX

Summary of Sediment Radioactivity for Major Sub-Basins of the Colorado River Basin

Sub-Basin		Radioactivity - (μμc/gm) Gross Alpha*	Gross Beta*	Radium-226
1. GREEN RIVER				
	Average	11	42	1.9
	Median	10	45	1.0
	Range	4.0-579	19-831	0.6-126
	Number of Samples	13	13	35
2. UPPER MAIN-STEM				
(Total)	Average	16	45	2.5
	Median	12	42	1.8
	Range	2.6-55	18-84	0.5-17
	Number of Samples	41	41	121
A. Upper Main-Stem (Gunnison River System)				
	Average	9.3	42	1.7
	Median	7.8	35	1.0
	Range	3.1-19	18-84	0.5-17
	Number of Samples	19	19	55
B. Upper Main-Stem (San Miguel-Delores System)				
	Average	23	47	3.3
	Median	20	43	2.6
	Range	4.0-55	25-74	0.6-12
	Number of Samples	22	22	66
3. SAN JUAN				
	Average	16	59	4.2
	Median	12	45	1.4
	Range	1.4-1255	19-1310	0.7-253
	Number of Samples	22	21	60
4. LOWER MAIN-STEM (Excluding Lake Mead)				
	Average	7.5	33	1.3
	Median	5.1	29	1.1
	Range	1.2-22	14-68	0.4-3.3
	Number of Samples	13	13	38
Average of all Colorado River Basin Sediments				
	Average	13	44	2.4
	Median	10	43	1.4
	Range	1.2-1255	14-1310	0.4-253
	Number of Samples	89	88	254

* Gross activity determined for August 1960 Survey only

LAKE MEAD SURVEYS

A. INTRODUCTION

The preceding discussion has shown the distribution of radioactivity in sediments of the Colorado River Basin. Such radioactivity has resulted in large part from the discharge over a number of years of waste ore solids from the uranium mills in the Basin.

Lake Mead, impounded by Hoover Dam, has trapped almost all of the transported sediment load of the Colorado River Basin. Therefore it is expected that most of the radioactivity carried by sediments in Colorado River water has been deposited within the confines of Lake Mead and remains there indefinitely. Initially the majority of this load settled in the Upper Lake some 70 to 80 miles above Hoover Dam. In subsequent years the sediments gradually move closer to Hoover Dam.

Lake Mead serves as the domestic water supply for the nearby communities of Las Vegas, Boulder City, and Henderson, Nevada. Downstream from Hoover Dam are large diversions for irrigation and municipal use in southern California, southeastern Arizona and Mexico.

B. HYDROLOGY AND LIMNOLOGY OF LAKE MEAD

Hoover Dam began impounding the waters of the Colorado River to form Lake Mead, on February 1, 1935. The original maximum capacity of Lake Mead was 32,471,000 acre-feet, including dead storage. Accumulation of sediment in the reservoir had reduced the maximum capacity by 1960 to approximately 30 million acre-feet. Sediment is deposited at an average rate of 175,000,000 tons per year which reduces the Lake capacity by more than 100,000 acre-feet annually. Lake Mead may store in excess of two years' equivalent of runoff of the Colorado and Virgin Rivers. The latter have a combined average annual flow reaching Lake Mead of 12.6 million acre-feet per year over the period of record (11,12,13).

At the time of the Colorado River Basin Project survey of Lake Mead in October 1960, the Lake had a water surface elevation of 1,169 feet, a useable content of nearly 20 million acre-feet, a surface area of 195 square miles, and a maximum depth of approximately 420 feet. The profile of the Lake is shown in Figure 11.

Circulation currents found in Lake Mead follow more or less regular season patterns and are caused by differences in water density in the vertical plane. These differences are due directly to variations in temperature, salinity and suspended sediment content of lake water. Turbidity currents, which are actually density currents containing high concentration of suspended sediment,are always present near the upper end of the Lake in the vicinity of Pierce Ferry but these flows rarely are sustained over the entire length of the lake. When these currents reach the dam, a rapid rise in water-sediment interface forms immediately upstream of the dam (12).

During winter the inflowing Colorado River water is of greater density than the water in the reservoir, due to lower temperature and greater salinity and hence, flows along the bottom. The spring runoff, due

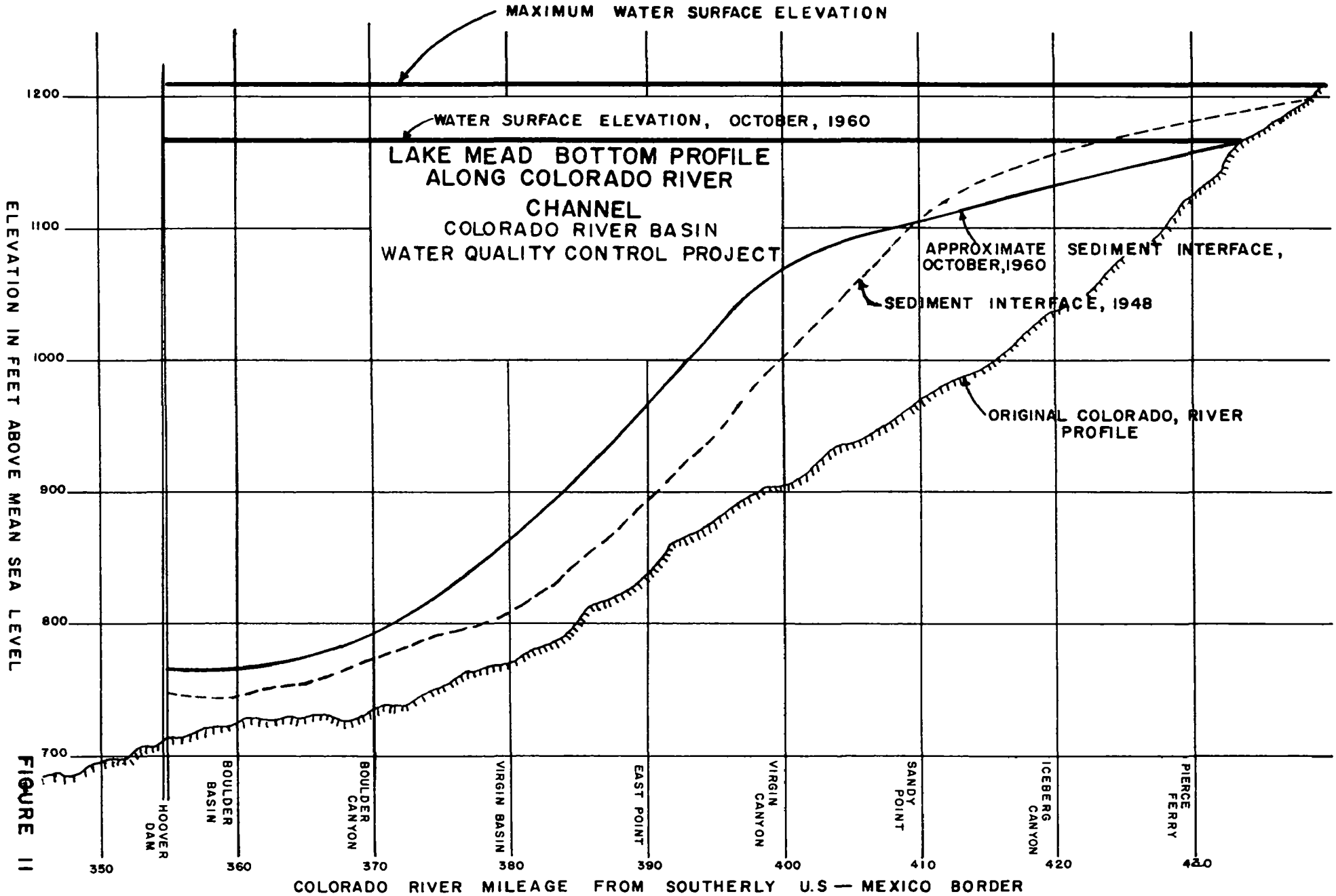

MAXIMUM WATER SURFACE ELEVATION
WATER SURFACE ELEVATION, OCTOBER, 1960
LAKE MEAD BOTTOM PROFILE
ALONG COLORADO RIVER
CHANNEL
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
APPROXIMATE SEDIMENT INTERFACE, OCTOBER, 1960
SEDIMENT INTERFACE, 1948
ORIGINAL COLORADO, RIVER PROFILE
ELEVATION IN FEET ABOVE MEAN SEA LEVEL
1200
1100
1000
900
800
700
HOOVER DAM
BOULDER BASIN
BOULDER CANYON
VIRGIN BASIN
EAST POINT
VIRGIN CANYON
SANDY POINT
ICEBERG CANYON
PIERCE FERRY
350
360
370
380
390
400
410
420
430
COLORADO RIVER MILEAGE FROM SOUTHERLY U.S — MEXICO BORDER

FIGURE 11

to its low salinity, flows out over the lake water. In summer, with increasing salinity of inflow, the downlake spread of river water occurs as an interflow about 80 feet below the surface. In the fall during which season the second sediment survey of Lake Mead was conducted, the decreasing temperature of the inflowing river water causes it to sink to greater depths as the season progresses. At this time, there is downlake flow along the bottom to the vicinity of Iceberg Canyon and Sandy Point. However, as denser lake water is encountered at the greater depths, there is likely a flow spreading horizontally downlake to Virgin Canyon which further slopes gradually toward the surface. Concurrently, two large cellular circulations, one producing uplake movement of surface water and the other producing uplake movement of bottom water, exist in the autumn above the Virgin Basin. (12,13). Thus, during the second Lake survey, bottom sediment down to about Iceberg Canyon was likely in contact with recent inflow, while the interface below this point to near Virgin Basin was in contact with an uplake flow of water, which had been impounded from a previous time.

C. CONDUCT OF LAKE MEAD SURVEYS

Four separate radioactivity surveys have been conducted in Lake Mead. The first, third and fourth surveys on Lake Mead correspond in time to the three Basin-wide studies of August 1960, March 1961, and August 1961, and may be considered as part of these studies. Because of time and equipment limitations, adequate areal coverage of the lake was not obtained by this sampling program.

The second Lake Mead survey was undertaken during the U. S. Bureau of Reclamation's annual survey of the Lake on October 24-28, 1960, and provided more comprehensive data on radioactivity of both sediments and waters. The U. S. Bureau of Reclamation provided Colorado River Project personnel with boat transportation and operator facilities on the October 24-28, 1960 survey when it was necessary to sample in the main part of the lake.

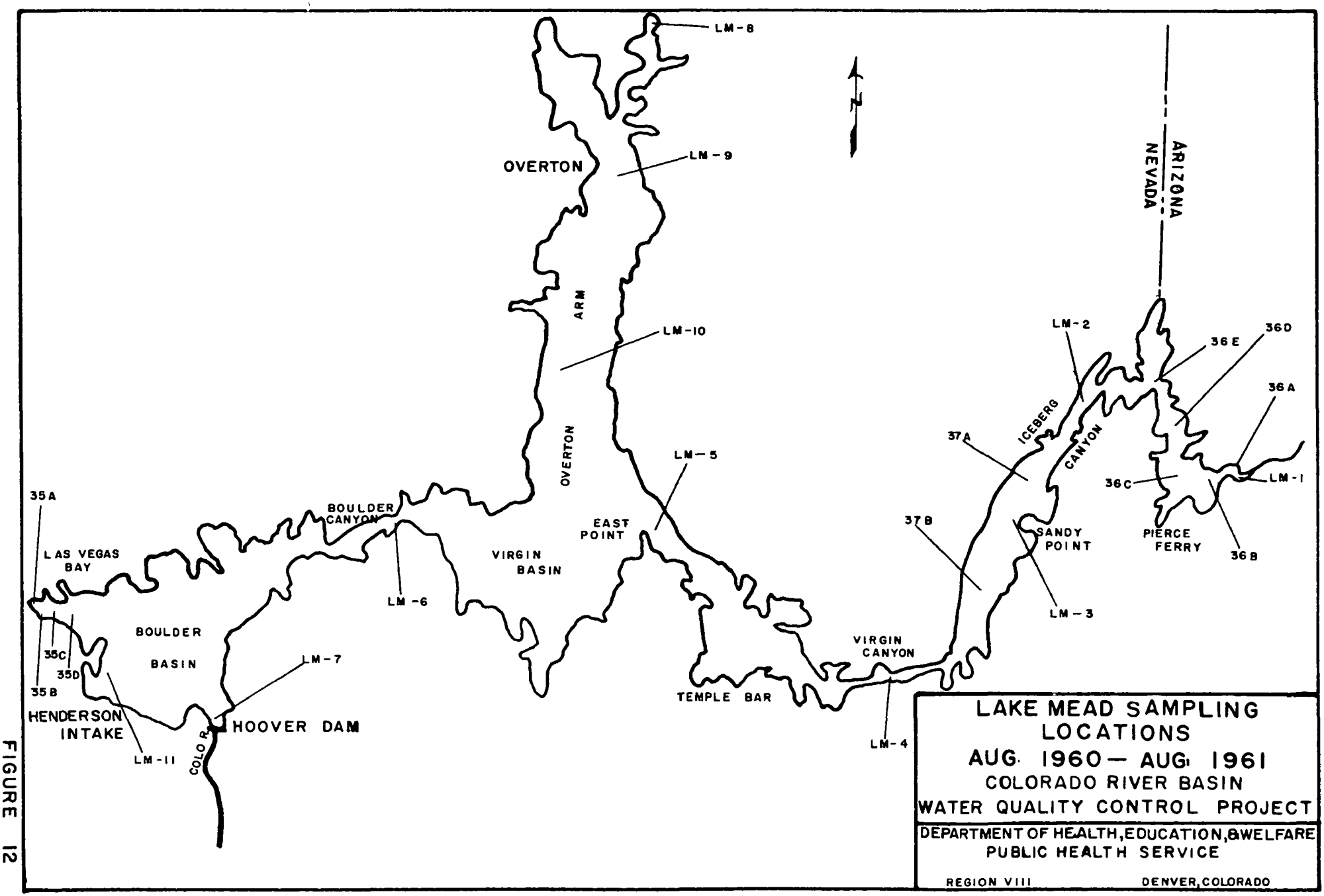
A 1200 to 2000 cc Kemmerer-type sampler was used to obtain all deep-water sediment samples. A skiff, normally towed by the main boat, provided access for sampling in shallow water at the head ends of the reservoir on the Colorado River and also on the Virgin River. At these locations, sediment and, in addition, water samples were collected by hand. All sediments from both deep and shallow waters were obtained from the top layers of water - sediment interface. Sediments were collected in one pint glass jars.

During the October 1960 lake survey, water samples were also collected. These were taken by a Kemmerer-type sampler from the lake surface and the liquid-solid interface to investigate possible leaching of Ra-226 and uranium elements from the bottom sediments to overlying waters. Water samples were collected in one-quart polyethylene bottles.

Table X presents a brief description of all Lake Mead sampling stations and Figure 12 gives a map of the location of each sampling station. In most cases, samples were obtained over the original channel of the river. Additional comments concerning a few of the stations are included as follows:

TABLE X
Lake Mead Sediment Sampling Locations
October 1960

Station No.	Description
1. October, 1960 Survey	
LM-1	Emery Falls
LM-2	Iceberg Canyon
LM-3	Sandy Point
LM-4	Virgin Canyon
LM-5	East Point
LM-6	Boulder Canyon
LM-7	Hoover Dam
LM-8	The Narrows
LM-9	Overton
LM-10	Virgin Narrows
LM-11	Henderson Intake
2. August 1960, March & August 1961 Surveys	
36a	Colorado River at head of Lake Mead
36b	Just above Pierce Ferry
36c	Midlake opposite Pierce Ferry
36d	Midway between Pierce Ferry & Grand Wash
36e	Main Channel opposite Grand Wash
37a	Midway between Sandy Point & Iceburg Reef
37b	Midway between Sandy Point & Virgin Canyon
35a	Near mouth of Las Vegas Wash
35b	Upper end of Las Vegas Boat Harbor
35c	Las Vegas Bay opposite Gypsum Wash
35d	Las Vegas Bay opposite Government Wash



LAKE MEAD SAMPLING LOCATIONS
AUG. 1960 — AUG. 1961
COLORADO RIVER BASIN WATER QUALITY CONTROL PROJECT

DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

REGION VIII DENVER, COLORADO

FIGURE 12

LM-1, Emory Falls: This location was approximately 0.5 miles above the head of the reservoir at the time of the survey. Water was sampled near the center of the stream and sediment was collected near the left bank.

LM-5, East Point: The measured depth at this point was somewhat less than the depth at the next upstream location. Therefore, the sediment sample was apparently not taken over the original channel of the river.

LM-8, the Narrows: Samples were collected near the west shore of the wide, shallow basin at the present mouth of the Virgin River. "The Narrows" is a constriction in the river channel immediately below this basin.

LM-10, Virgin Narrows: This location was downstream of the lower limit of heavy sediment deposits in the Overton Arm. The sampling device intercepted a hard surface or rock deposit at a depth of 275 feet and subsequently a sediment sample was not collected.

LM-7, Hoover Dam and LM-11, Henderson Intake: Mechanical failure of the winch used for lowering and raising the sampling device necessitated postponement of the sample collection at these two locations. Depths to the interface at both locations were not reported. The Henderson Water Intake is located on the east side of Saddle Island in Boulder Basin.

All uranium and a portion of the Ra-226 analyses were performed by the Project Laboratory. Gross radioactivity of the sediment samples was determined at the R. A. Taft Sanitary Engineering Center at Cincinnati, Ohio. The remainder of the radium-226 analyses were performed by a private laboratory.

D. PRESENTATION OF RESULTS

Water-Radium concentrations in the water samples collected during the October 1960 Lake Mead Survey are presented in Appendix C.

Sediment-Table XI presents the data obtained on all sediments collected in Lake Mead. Table XII presents a summary of these data.

It is seen from Table XII that the average radium content of all sediments collected in Lake Mead is slightly more than two and one-half times the natural radium content of unpolluted sediments. The sediments collected during the comprehensive October 1960 survey have an average radium content almost four times natural background concentrations.

From Table XI it is interesting to note that there appears to be a progressive decrease in radium content of sediment from the headwaters of Lake Mead to Hoover Dam (LM-1 through LM-7). Also, Station LM-8 sediment radium is very low indicating natural sediment entering Lake Mead from the Virgin River.

TABLE XI

Radioactivity of Lake Mead Sediments

Station	Radium-226 -(μμ/gm) Aug. 1960	Oct. 1960	Mar. 1961	Aug. 1961
MAIN LAKE				
LM-1	-	4.1	-	-
36a	1.0	-	-	-
b	2.6	-	2.9	-
c	4.6	-	1.8	0.6
d	2.2	-	3.0	3.0
e	5.5	-	2.3	3.1
LM-2	-	4.5	-	-
37a	4.7	-	4.1	4.9
LM-3	-	3.8	-	-
37b	1.8	-	4.6	4.9
LM-4	-	5.0	-	-
5	-	4.0	-	-
6	-	4.2	-	-
7	-	3.9	-	-
OVERTON ARM				
LM-8	-	$\leq$ 1.0*	-	-
9	-	3.6	-	-
LAS VEGAS BAY				
35a	-	-	1.6	1.2
b	2.2	-	2.3	1.8
c	2.1	-	1.8	1.9
d	1.9	-	2.2	0.5
LM-11	-	2.9	-	-

* Not used in average

TABLE XII
Summary of Lake Mead Sediment Radioactivity

	Radioactivity - (μμc/gm)		
	Gross Alpha	Gross Beta	Radium -226
Average	16	55	2.9
Range	7.0 - 32	21 - 70	0.5 - 5.5
Number of Samples	21	10	38

RADIUM-226 TO GROSS ALPHA RATIOS

The determination of radium-226 involves quite lengthy radiochemical and counting procedures in order to obtain the desired result. In contrast, gross radioactivity determinations can be accomplished in a fraction of the time required for a radium analysis. Oftentimes, a gross radioactivity analysis has been regarded as a crude device without any real meaning. Gross alpha determinations however have been found to be sensitive indicators of pollution from uranium mills. In all types of samples a very consistent relationship between radium-226 and gross alpha has been found.

Table XIII presents the radium-to-gross alpha ratios for the sediment samples collected in the Colorado River Basin.

From this table it is seen that there is a relatively narrow range in the average radium-226 to gross alpha ratio for the various types of sediments encountered in the Colorado River Basin. This range is 0.16 to 0.26. The average of all samples for which both gross alpha and radium-226 analyses were performed (176 samples) indicates a radium content of 21% of the gross alpha activity.

Statistical analysis of these data show that the standard deviation is 0.035. In other words, 95% of all sediment samples in the Colorado River Basin would be expected to have a radium to gross alpha ratio between 0.14 and 0.28.

SUMMARY AND DISCUSSION OF DATA

The preceding portion of this report has presented detailed tables of results of radium-226, gross alpha, and gross beta determinations on sediments collected throughout the Colorado River Basin during August and October 1960, and during March and August of 1961. A final summary of these data is pertinent at this point.

Specifically, 49 samples representing 20 different sampling stations were collected in locations where the sediment was not influenced by uranium mining and milling activity. These locations have been referred to as background locations. All of the samples were analyzed for radium-226, while 14 of them were analyzed for gross alpha and gross beta activity. These data showed an average radium content of 1.1 μμc/gm with a range of 0.6 - 2.1 μμc/gm.

TABLE XIII
Radium-226 - Gross Alpha Ratios
Colorado River Basin Sediments

Table No.	Sediment Type		Ra-226/Gross Alpha
II	Background Locations	Average	0.17
		Range	0.06-0.45
		Number of Samples	17
IV	Main-Stem Colorado River	Average	0.22
		Range	0.05-0.48
		Number	30
VI	Immediately Downstream From Uranium Mills	Average	0.20
		Range	0.07-0.63
		Number of Samples	23
VIII	Major Sub-Basins		
	I. Green River Sub-Basin	Average	0.16
		Range	0.06-0.31
		Number of Samples	13
	2. Upper Main-Stem Sub-Basin		
	a. Gunnison River System		
		Average	0.19
		Range	0.07-0.45
		Number of Samples	18
	b. San Miguel-Dolores River System	Average	0.19
		Range	0.07=0.45
		Number of Samples	21
	3. San Juan Sub-Basin	Average	0.23
		Range	0.05-0.63
		Number of Samples	22
	4. Lower Main Stem Sub-Basin	Average	0.26
		Range	0.11-0.48
		Number of Samples	12
XII	Lake Mead Sediments	Average	0.22
		Range	0.10-0.41
		Number of Samples	20
	ALL COLORADO RIVER BASIN SEDIMENTS	Average	0.21
		Range	0.05-0.63
		Number of Samples	176

For the sediment surveys reported here, 254 samples representing 121 different sampling stations were collected in all parts of the Colorado River Basin. In order to obtain an over-all view of the data, Table XIV presents a general summary table.

TABLE XIV
Radium-226 in Colorado River Basin Sediments

Concentration μμc/gm	Multiples of Background	Number of Samples	Percent of Totals
≤ 1.1	≤ 1	95	38
> 1.1-5	1 to 4.5	132	52
5-10	4.5 to 9	15	6
10	> 9	12	4
		254	100

Average of All Sediments: 2.4 μμc/gm
" " Background
Sediments: 1.1 μμc/gm

From Table XIV it is seen that about 40 percent of all sediments collected in the basin were equal to natural background concentrations of radium, while half of the samples were between 1 and 4.5 times background levels. Ten percent of the samples were greater than 4.5 times background.

The data have shown, among other things, that Lake Mead has been essentially the final resting place for the radium contaminated sediments of the Basin. With the closure of Glen Canyon Dam upstream, Lake Powell will then become the final resting place for future radium contaminated sediments. The data also show that a small fraction of the contaminated sediment has at some time passed through Lake Mead to be trapped by Lakes Mohave and Havasu. The sediments in these two lakes are 1.5 to 2 times natural background radium concentrations. The sediments in the stream stretches between Lake Mead and Lake Mohave and between Lake Mohave and Lake Havasu are all less than the 1.1 μμc/gm of radium found as an average for background stations in the Basin. From Lake Havasu to the Arizona-Mexico border the sediment radium content is essentially no different from natural background concentrations.

With regard to the effects of hydrology on the deposition and accumulation of radium-bearing sediment the data yield some other interesting observations. Daily hydrographs have been presented earlier for three typical locations in the Upper Colorado River Basin. As pointed out, two of the surveys were conducted soon after subsidence of flood flows and one just before the spring snow-melts. Earlier studies on the Animas(8) showed that the radium content of sediments increased considerably during extended periods of low flow, due to accumulation of mill solids, which were picked up and transported further downstream during high flow periods. In order to provide additional information

on the accumulation of radium in sediments the data from the March 1961 Basin-wide survey were averaged and compared to averages of the data from the two August surveys. These are discussed below.

Sediments collected in locations unaffected by uranium mining and milling activity showed an average radium-226 content of 1.21 μμc/gm for the March 1961 survey compared to 1.25 μμc/gm for the two August surveys. This is an interesting comparison and is what would be generally expected; namely, that in natural background locations the radium content of the sediment should remain constant and unaffected by any changes in flow patterns of the river.

Sediments collected immediately downstream from uranium mills showed an average radium-226 content of 8.73 μμc/gm for the March 1961 survey and an average of 3.24 for the two August surveys. These data clearly show the accumulation of radium in sediments during extended low flow periods.

Another interesting comparison is obtained when the data from samples collected only on the main-stem Colorado River are treated in the above manner. These data show an average radium content of 1.71 μμc/gm for the March 1961 survey and an average of 1.66 μμc/gm for the two August surveys. These data tend to indicate that in a very large river such as the Colorado the amount of scour and transport of bottom sediment even during low flow periods in most cases is significant enough to prohibit much accumulation. Also the accumulation of radium-bearing ore solids is probably masked by the tremendous volumes of other sediment material. In a smaller river the accumulation might be more readily apparent.

When all sediments other than natural background sediments are considered, as a whole, the data show an average radium-226 content of 4.19 μμg/gm for the March 1961 survey and an average of 2.22 μμc/gm for the two August surveys.

The values of 8.73 μμc/g and 4.19 μμc/gm are largely influenced by a very few samples taken from dry washes immediately below several uranium mills.

Excluding these, the data show a great reduction of sediment radium content since 1956[7]. This is a result of improved waste disposal practices at the uranium mills in the Basin.

The data also show that the river sediments can be useful indicators of radiological contamination. Such samples accumulate radioactivity and yield information on conditions for an extended period of time subsequent to collection. Water samples on the other hand yield information on instantaneous values at time of collection.

It was mentioned earlier that both riffle and pool samples were collected from various locations to observe if there was significant variation in radium content of these two types of samples. The data have been shown in the various tables which have been presented.

Observation of the riffle and pool data shows that while some of the pool sediment contained more radium than did riffle sediment, the data are generally not significantly different at a given location. In some cases the riffle sediment contained more radium than pool sediment. At two locations the pool sediment contained quite a bit more radium than did riffle sediment (Stations 56, and 63, Table VIII).

RADIUM LEACHABILITY

The quantity of radium-226 which can be leached from uranium mill waste solids and river sediment material by overlying waters is governed by a complex combination of chemical and physical factors. A brief discussion of results of recent laboratory studies on this subject is presented below.(10)

The results showed that -

1. Significant quantities of radium in terms of current maximum permissible concentrations can be leached from uranium mill waste solids and from river sediments.

2. The amount of radium which is leached from uranium waste solids and river sediments is primarily governed by the liquid to solid ratio (ml/gm) as shown by distilled water-leaching tests. The effect is greater for uranium waste solids than for river sediments. In the case of uranium waste solids the amount of radium leached from a given quantity of solids versus the volume of leaching liquid is seen to follow an "S" shaped curve. Such a curve is shown in Appendix A. At low liquid volumes (10 ml - 30 ml) the amount of radium leached is practically independent of the quantity of solids, the amount leached being governed by the amount of barium sulfate precipitation taking place.

3. There appears to be essentially no time dependence after 15 minutes on the amount of radium leached from uranium mill waste solids and river sediments, so far as laboratory experiments are concerned. These effects most probably have a different time relation in a river.

4. The diffusion of radium from the interior to the surface of particles was found to be insignificant and unimportant. This was true whether the solids were stored in a dry condition or in a wet environment. This indicated the radium is only leached from the surface of such particles and is an important finding in terms of "storage" of samples in a reservoir or in a river during low flows.

5. For a given liquid-solid ratio, repetitive leachings of solids with distilled water showed essentially no additional radium being leached after two consecutive leachings.

6. The amount of radium which is leached with distilled water is small compared to that which can be leached with vigorous leaching agents such as 0.01 M barium chloride solutions.

7. Of the cations, H^+, Na^+, K^+, Mg^{++}, Ca^{++}, Sr^{++}, and Ba^{++} at 10^{-2}M, only barium exerts a significant effect on the amount of radium leached from river sediments, with considerable amounts being leached by barium. Barium concentrations in the range which would be expected to be encountered in natural river waters of the West leach no more radium than distilled water.

8. The chemical characteristics of natural river waters from representative locations in the Colorado Plateau have no different effect on the leachability of radium than distilled water. In fact, because of high sulfate concentrations and precipitation of barium sulfate, the amount of radium leached from uranium waste solids by natural waters is significantly less than that leached by distilled water.

9. The effect of temperature in the range 3° to 25° C and degree of agitation, as long as the solids are intimately mixed with the leaching liquid, are not important parameters in the amount of radium leached.

A more detailed discussion of the results of the laboratory research is given in Appendix A.

A brief discussion is given below of the effect of the discharge into the water environment of radium-bearing waste solids and the behavior of radium in this water environment.

Upon discharge into a river of uranium mill waste solids which contain appreciable quantities of radium, there will be an immediate leaching of some radium with an almost immediate co-precipitation of this radium as barium-radium sulfate. This comes about because of the relatively high sulfate content of the river water, the sulfates released from the solids, and the insolubility of barium sulfate ($K_{sp}=1 \times 10^{-10}$). Of the radium left in solution, a large part will be adsorbed onto the river sediment and a portion will also probably be readsorbed back onto the mill solids. The result of these reactions is that only a small amount of the radium originally dissolved remains in solution.

A short distance below the mill discharge the bottom sediment material in the river will consist of a mixture of natural river sediment which contain radium, and waste ore solids also containing radium. Assuming a period of low flow, the bulk of the stream sediment will remain undisturbed on the bottom with only the very fine material being transported in solution. For a low flow associated with nonturbulent velocities, it is reasonable to expect the suspended solids concentration to be very low at the surface and increasing to a maximum at the liquid-solid interface.

The amount of leaching taking place from the bottom sediment during these periods of low flow will vary depending on particular circumstances. It is low relative to other conditions of turbulent flow and scour described below. Because of the small amount of suspended solids transported during low flows, it is likely that an equilibrium will exist between the radium in solution and the radium content of the suspended sediment. A short distance below a mill, however, the relative proportions of fine ore solids versus the true river sediment transported will in large measure determine the amount of radium leached from the mixture of solids.

With the advent of spring snow melts and resulting high river flows, the bottom sediment is thoroughly mixed, picked up and transported further downstream. At this time appreciable amounts of radium are leached from the transported solids. This has been found to be true from the Animas River and other studies. There is also at this time another re-distribution of the radium between mill solids and river sediments. As the high flows subside and low flows again set in, a repeat process on a lesser scale, of the previous low flow conditions occurs.

With each subsequent high flow condition, mixing and transportation of sediments downstream, the amount of radium which is leached becomes progressively less. Eventually a situation is reached in which the maximum amount of radium has been leached, with little further leaching from the transported solids. With discharge of the river into a large reservoir, the amount of leaching which takes place in the reservoir sediments is probably negligible, provided the incoming solids have been transported far enough to have had the maximum amount of radium leached from them.

The above discussion has neglected several factors which may be of significance in the behavior of radium in a river. These factors are (1) the uptake of radium by the aquatic life in the river, algae, insects, fish, water weeds, etc., (2) use of the river for irrigation, (3) number of uranium mills discharging effluents into the river, and (4) other factors depending on local conditions and circumstances.

SUMMARY

The data presented in this report have provided information concerning the radium content of bottom sediment material throughout the Colorado River Basin. The data on sediments from locations unaffected by any uranium mining and milling activity present useful information regarding natural background concentrations of radium in such sediment.

On the basis of these natural background radium-226 determinations any sediments in the Basin which show an average radium content significantly greater than 1.5 μμg/gm can be considered to be contaminated either as a result of waste discharges from uranium mills or from mining operations.

Assuming that significant discharges of waste ore tailings into the waters of the Basin have ceased and that waste ore from existing and abandoned tailings piles is prevented from reaching these waters, it is reasonable to expect that the sediments of the Basin will become stabilized in their radium content at the usual natural level. Once such stabilization is reached sediments showing higher radium content can only result from pollution activities. By routine monitoring in selected locations sudden increases in sediment radium can be noted and the source readily determined.

FUTURE WORK DESIRED

In conjunction with material presented in this report there are several areas in which further information would be desirable. These areas are discussed below.

With regard to the Lake Mead sediments it would be desirable to obtain information regarding the radium content of lake sediments prior to uranium milling activity in the Basin. During the period December 1947 to April 1949 the U. S. Geological Survey collected core samples of Lake Mead sediment deposited between 1935 and 1949. Initial contact has been made with the U.S.G.S. on the possibility of obtaining portions of these early sediments for radium analyses.

As a follow-up it would also seem desirable to obtain core samples of sediment deposited since 1949 in order to determine radium content of these sediments since the advent of intensive uranium mining and milling in the Basin.

Another aspect which deserves special consideration is a study of the distribution of dissolved radium in river water, radium in transported (or suspended) sediment, bottom sediment material and aquatic biota. This could be done at a particular location by observing the radium distribution among these phases over a period of time. Such a study would yield additional information on the fate of radium in the water environment.

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APPENDIX A

LABORATORY STUDIES ON RADIUM LEACHABILITY

The following discussion presents a summary of the salient findings of the leachability studies.

It was shown for uranium waste solids and for river sediments that an equilibrium was reached rapidly with regard to the amount of radium leached from the solids as a function of time. After about fifteen minutes no additional radium was leached up to a period of six days. Figure A-1 shows a typical curve.

It was also shown through several tests that radium is more likely to be leached from uranium waste solids than from natural uranium ore. This is brought about by the processes which take place during extraction of uranium from the ore. In this extraction it is reasonable to expect that, as a result of the sulfuric acid leaching steps, some radium is also solubilized from the ore. Later in the mill process this radium is re-precipitated and ends up in the waste solids and is subject to leaching.

One of the most significant findings of this research was the effect of liquid-to-solid ratio on the leachability of radium. It was found that for a given quantity of solids a plot of the amount of radium leached versus volume of leaching liquid described an "S" shaped curve with three distinct regions. Such a curve is shown in Figure A-2. At low liquid volumes the amount of radium leached remained constant with increase of leaching volume. Beyond a certain volume, small increases in volume resulted in large amounts of radium being leached. A third region existed where large increases in volume resulted in very little additional radium being leached. In this third region, the amount of radium which can be leached is apparently a maximum and is primarily governed by the quantity of solids available or the total radium reservoir. In the lowest liquid volume range, the amount of radium leached was independent of the quantity of solids present.

In fact, it was shown by special tests that, for the particular solids studied, the amount of radium which could exist in solution at low leaching volumes was severely limiting and governed almost entirely by the sulfate present in solution. This is brought about by the fact that the waste solids had associated with them, as a result of the mill process, large quantities of sulfate. This sulfate could be easily solubilized by small quantities of liquid and because of the trace amounts of barium present, precipitation of barium sulfate resulted. Along with this radium was co-precipitated with the barium sulfate. This was demonstrated by adding a known amount of standard radium spike to a sample containing waste solids and distilled water and leaching for a period of time. These tests showed that when radium was added prior to leaching and filtration, all of it was lost as a result of co-precipitation with barium sulfate. When the radium was added to a leachate after filtration, all of it was recovered.

Repetitive leaching tests showed a rapid decrease in the amount of radium leached in consecutive leachings following an initial leaching. The decrease was greater in the case of sands-slime waste solids than for river sediments.

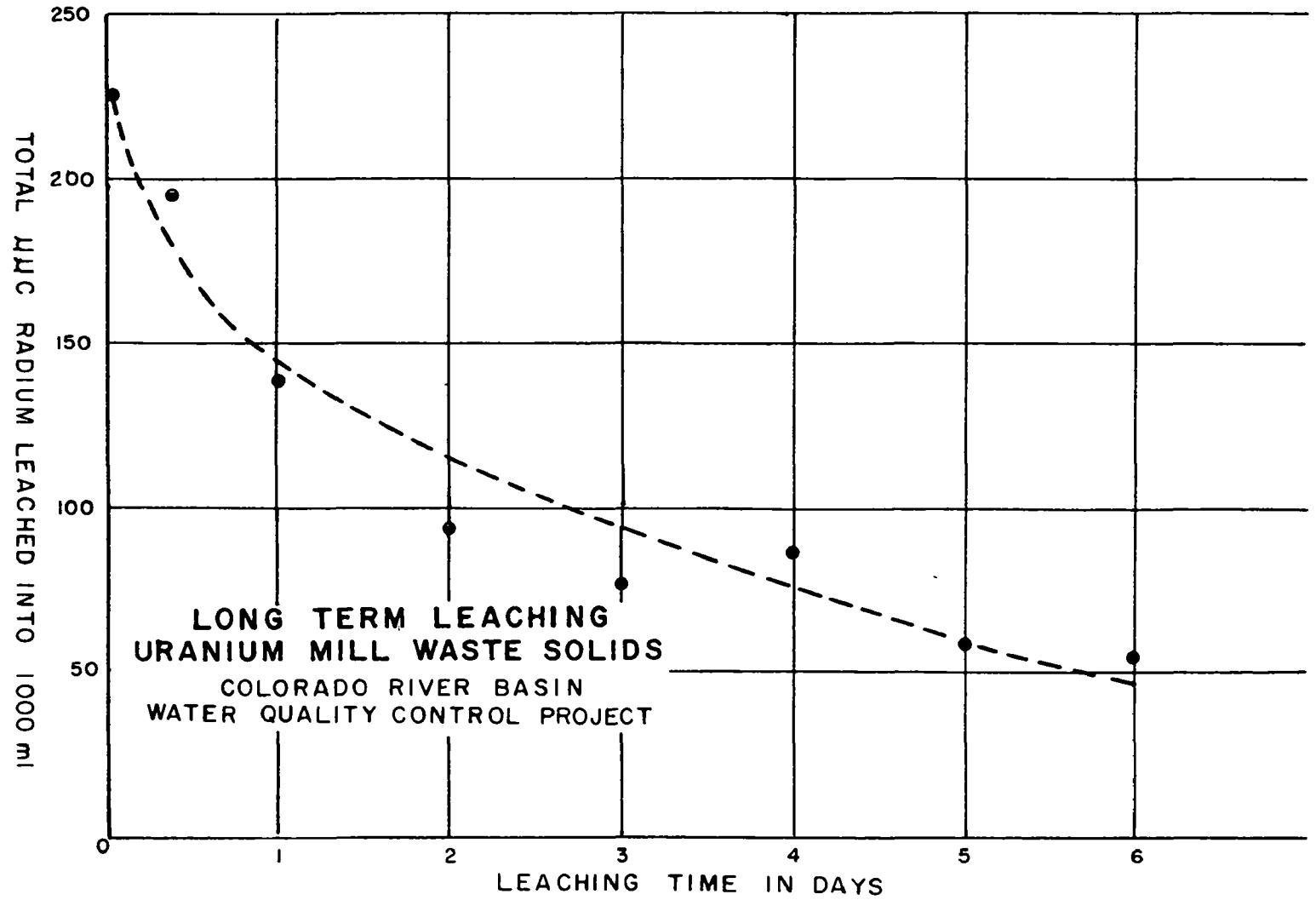

250
200
150
100
50
0
TOTAL μμC RADIUM LEACHED INTO 1000 ml
LONG TERM LEACHING
URANIUM MILL WASTE SOLIDS
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
1
2
3
4
5
6
LEACHING TIME IN DAYS
CALCULATED LINE BASED ON DILUTION AND ASSUMING NO FURTHER LEACING AFTER ONE HOUR.
EXPERIMENTAL POINTS OBTAINED
1 0047 GRAMS 976 μμC RADIUM
1000ML DISTILLED WATER T = 25°-27°C

FIGURE A-1

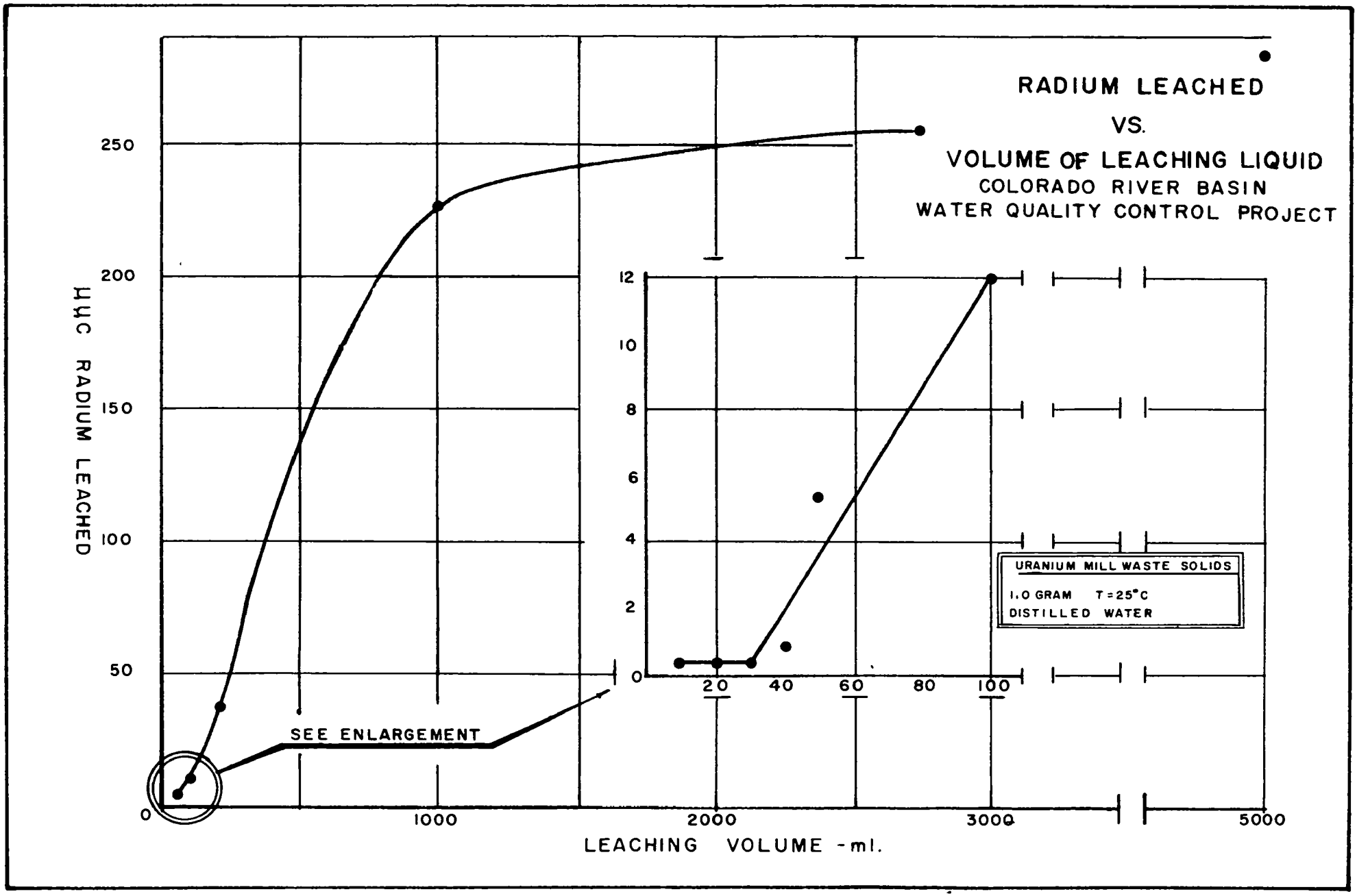

RADIUM LEACHED
VS.
VOLUME OF LEACHING LIQUID
COLORADO RIVER BASIN
WATER QUALITY CONTROL PROJECT
μμc RADIUM LEACHED
250
200
150
100
50
0
1000
2000
3000
5000
LEACHING VOLUME - ml.
SEE ENLARGEMENT
12
10
8
6
4
2
0
20
40
60
80
100
URANIUM MILL WASTE SOLIDS
1.0 GRAM T=25°C
DISTILLED WATER

FIGURE A-2

Another important finding of the research was that the role of diffusion is insignificant in the leachability of radium from uranium waste solids and from river sediments. Prior work reported in the literature has shown that diffusion of radium from the interior of particles to the surface was the major factor in the amount of radium leached from natural ores and from specially prepared salts which contained radium. It was shown in this work that storage of samples, after repetitive leachings, either in a dry or wet environment for a long period of time resulted in no appreciable increase in the amount of radium leached. This was true for uranium waste solids as well as for river sediments. Figure A-3 shows a typical curve of repetitive leaching plus diffusion.

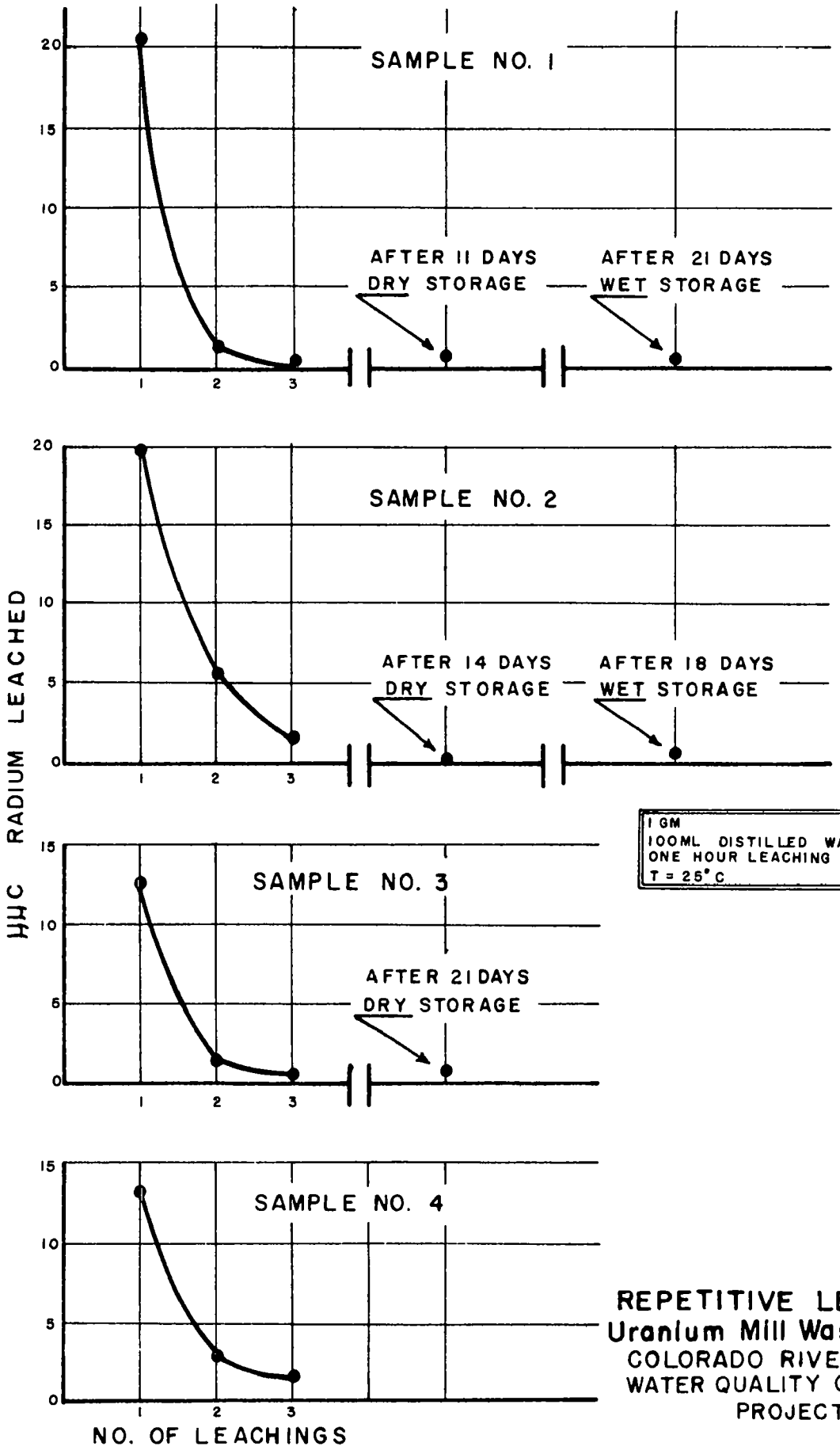
In conjunction with the diffusion studies it was found that if uranium mill waste solids, which had been leached a number of times with distilled water, were subsequently leached with 0.01 M barium chloride, between 30 and 40 per cent of the radium was leached in a one hour leaching. Tests on river sediments indicated that one hour leachings with 0.01 M barium chloride solutions removed about 20 percent of the radium.

Leaching tests conducted on river sediments using 0.01 M solutions of the common inorganic cations found in western river waters showed that barium was the only ion which had any appreciable effect of the amount of radium leached. This effect on the amount of radium leached increased in the order Na^{+} K^{+} for elements in column IA of the Periodic Table and in the order Mg^{++}, Ca^{++}, Sr^{++}, Ba^{++}, for elements in column IIA of the Periodic Table. This is the effect which would be expected based on the exchange properties of these cations with respect to a cation like Ra^{++}.

The effect of various concentrations of barium chloride on the leachability of radium was studied using river sediments as a test material. The results showed a linear relationship in the range 1.5×10^{-2} M to 10^{-3} M. Below 10^{-3} the amount of radium leached was drastically reduced. At a concentration of 10^{-4} M the amount of radium leached was not significantly greater than that leached with distilled water. A concentration of 10^{-4} M barium chloride would be equivalent to 14 mg/l of Ba^{++}, a concentration not very likely to exist in western river waters because of high sulfates.

Repetitive leaching of a contaminated river sediment with 0.01 M barium chloride solutions showed a rapid decrease in the amount of radium leached with a total of 21 percent being leached in four successive hours.

Another significant finding of the research showed that natural river waters had essentially no different effect on the leaching of radium than would be observed with distilled water. This is especially true for river sediments. For uranium mill waste solids, however, the amount of radium leached with the river waters was considerably less than was found with distilled water leaching. This was due to the high sulfate present in the river waters which caused additional precipitation of barium-radium sulfate.



REPETITIVE LEACHING
Uranium Mill Waste Solids
COLORADO RIVER BASIN
WATER QUALITY CONTROL
PROJECT

FIGURE A-3

It was shown that grinding of solids to a particle size of minus 140 mesh resulted in a slight but detectable increase in the amount of radium leached in the case of uranium waste solids but essentially no increase in the case of river sediments.

Finally it was shown that by reducing the temperature of leaching from 25° to 3° C, and by reducing the shaking rate to half, no appreciable difference in the quantity of radium leached was observed for the uranium waste solids.

APPENDIX B

The location and description of the various sampling stations established for the sediment sampling surveys were as follows:

Station Number

0.5 Lay Creek 50 yards above Maybell, Colo., uranium mill effluent wash.

1 Mill effluent wash below Maybell, Colo., uranium mill. Sample taken above Lay Creek, 200' below Highway U. S. 40 culvert 6.4 miles east of Maybell, about 4 miles below the mill.

1.5 Lay Creek 500' below Maybell, Colo., uranium mill effluent wash.

2. Lay Creek above confluence with Yampa River. Sample taken at bridge on county road about 1/4 mile above confluence with Yampa River.

3. Yampa River above Lay Creek. Sample taken near Juniper Springs, Colorado. 4.0 miles from county road junction with U. S. 40, 4.0 miles east of Maybell.

4. Yampa River below Maybell, Colorado. Sample taken at bridge on Colorado Route 318 (at Sunbeam) 6.2 miles northeast of junction with U. S. 40 at Maybell, Colorado.

5. Yampa River near mouth. Sample taken at Mantle Ranch at Castle Park in Dinosaur National Monument; about 43 miles from junction of U. S. 40 and Colorado 45.

6. Green River at Jensen, Utah. Sample taken from U. S. 40 highway bridge with a Petersen dredge from mid-river.

7. Green River near Dutch John, Utah. Sample taken just above the wooden suspension bridge on temporary Utah 44, about 1 mile above Flaming Gorge damsite along the north bank of the river.

3. Green River at Ouray, Utah. Sample taken at quarter points from Utah 38 highway bridge.

9. Colorado River at Silt, Colo. Sample taken approximately 7 miles upstream of the old Union Carbide Nuclear uranium mill; taken from two bridges which span two separate channels of the river. A pool sample was collected from the south channel bridge; a riffle sample was taken from the north channel bridge.

10. Colorado River at Rifle, Colorado. Sample taken between the old and the new Union Carbide Nuclear mills from the bridge on Colorado 13.

Station Number	
11	Colorado River below Rifle, Colorado. Sample taken 3.3 miles downstream from the new Union Carbide Nuclear mill and 10 miles west of Rifle at Rulison, Colorado; collected from the bridge on a side road 1/4 mile from Highway 6.
12	Colorado River at DeBeque, Colorado. Sample taken at the DeBeque raw water intake at the bridge on the old highway through DeBeque.
13	Colorado River above Grand Junction, Colorado. Sample taken at the bridge on the county road near Clifton, Colorado; 6 river miles above the U. S. 50 bridge.
14	Gunnison River near mouth at Grand Junction, Colorado. Sample taken 0.5 miles above the mouth from the bridge near the AEC Operations Office.
15	Colorado River below Grand Junction. Sample taken at the PHS Basic Data Station at Loma, Colorado; 2.3 miles south from the crossroads at Loma.
16	Colorado River at Westwater, Utah. Sample taken at the end of the road which parallels the D&RGW RR.
17	Green River near Green River, Utah. Sample taken from the U. S. 6-50 bridge just east of Green River, Utah.
18	Green River below Green River, Utah. Sample taken just upstream of Crystal Geyser; 4 miles east of Green River, Utah on U. S. 6-50, turn right on dirt road, proceed 6 miles to river. The pool sample was collected just upstream of Crystal Geyser; the riffle was taken about 1/2 mile below the geyser.
19	Colorado River above Dolores River. Sample taken 3.1 miles upstream from Dewey bridge on Utah 128.
20	Dolores River near mouth. Sample taken at the termination of the road from Dewey bridge to the river, approximately 0.3 miles from the bridge.
21	Colorado River below Dolores River. Sample taken from Dewey bridge on Utah 128 by dredge.
22	Colorado River below Dolores River. Sample taken 2-1/2 miles downstream from Dewey bridge from the east bank.
23	Colorado River at Moab, Utah. Sample taken from U. S. 160 highway bridge 2 miles west of Moab.

Station Number

24 Colorado River below Moab, Utah. Sample taken along the east bank at the entrance to the canyon (The Portal), about 2 miles below the URECO uranium mill.

24.5 Colorado River at Hite, Utah.

25 Green River at Mineral Canyon. Sample taken about 30 miles below Green River, Utah. Proceed Dead Horse Point turnoff 9 miles north of Moab on US 160, go 14 miles and turn right to Mineral Canyon; go 15 miles and take right fork 0.6 miles to the river bank. Sample collected along the east bank.

26 South Creek above Monticello, Utah, AEC uranium mill. Sample taken just above municipal sewage treatment plant discharge.

27 South Creek below Monticello, Utah AEC uranium mill. Sample taken about 1.0 mile below the discharge from the mill on T. M. Sorenson property.

28 San Juan River above Montezuma Creek near Aneth, Utah. Proceed Utah 262, 21 miles to end of pavement. Continue 4.0 miles through oil fields to the bridge over the San Juan River. Sample taken by dredge from the bridge.

29 Montezuma Creek near confluence with San Juan River; Utah 262 crosses Montezuma Creek 0.8 miles before the end of the pavement, 20.0 miles from junction with Utah 47. Sample collected about 1000' upstream from the bridge. The stream was dry at the time of the August 1960 survey.

30 San Juan River above Mexican Hat, Utah. Sample taken near the USGS weather station.

31 San Juan River below Mexican Hat, Utah. Sample taken about 1/2 mile downstream from the uranium mill effluent discharge to the river.

32 Uranium mill effluent wash at Mexican Hat, Utah. Sample taken from the effluent wash which enters the San Juan River below the mill.

33 Moenkopi Wash at Moenkopi, Arizona. Sample taken at the bridge on Indian Route 3 just below the Tuba City uranium mill. The wash was dry at the time of the August 1960 survey.

33.5 Moenkopi Wash below Tuba City, Arizona at U. S. 89 Highway bridge.

Station
Number

34 Colorado River at Lee's Ferry, Arizona. Sample taken 5 miles north of U. S. 89 at the end of Lee's Ferry road along the west bank of the river.

35a. Las Vegas Bay area of Lake Mead. Sample collected near the mouth of Las Vegas Wash.

b. Temple Bar-Pierce Ferry area of Lake Mead. Sample taken at the western entrance to Grand Canyon.

c. Sample taken in Las Vegas Bay opposite Gypsum Wash.

d. Sample taken in Las Vegas Bay opposite Government Wash.

36a. Colorado River at head of Lake Mead. Sample taken at the western entrance to Grand Canyon.

b. Temple Bar-Pierce Ferry area of Lake Mead. Sample taken at the narrowing of the channel above Pierce Ferry.

c. Lake Mead. Sample taken at mid-lake opposite Pierce Ferry.

d. Lake Mead. Sample taken midway between Pierce Ferry and Grand Wash. Depth at this point was about 25'.

e. Lake Mead. Sample taken in the Lake Mead main channel opposite Grand Wash. Depth was about 40'.

37a. Lake Mead. Sample taken midway between Sandy Point and Iceberg Reef. Depth about 200'.

b. Lake Mead. Sample taken midway between Sandy Point and Virgin Canyon toward the south shore of the lake. Depth about 200'.

38 Colorado River below Hoover Dam. Sample taken at Willow Beach along the east bank between the concession and the fish hatchery.

39 Lake Mohave. Sample taken at mid-lake above Davis Dam just above Bullshead Rock.

40 Lake Mohave. Sample taken about 3 miles above Davis Dam opposite the cabins on the east shore.

41 Colorado River at Needles, California. Sample taken from the Government bridge by dredge.

Station Number	
40	Lake Havasu. Sample taken about 4 miles above Parker Dam opposite Bluegill Island.
43	Lake Havasu. Sample taken opposite the Metropolitan Water District of Southern California intake, about 600' from the west shore.
44	Lake Havasu. Sample taken about 1/2 mile above Parker Dam under the power lines.
45	Colorado River at Parker, Arizona. Sample taken along the west bank under the Arizona 72 Highway bridge.
46	Colorado River above Imperial Dam. Sample taken in the reservoir main channel about 4 miles above Imperial Dam.
47	Colorado River above Imperial Dam. Sample taken in the center of Squaw Lake off the reservoir main channel.
48	Colorado River above Imperial Dam. Sample taken in the main channel about 1 mile above the dam.
49	Colorado River at Yuma, Arizona. Sample taken from the U. S. 95 Highway bridge.
50a	San Juan River at Shiprock, New Mexico. Sample taken from the U. S. 660 Highway bridge.
b	San Juan River at Shiprock, New Mexico, uranium mill effluent seepage channel.
50.5	San Juan River 6 miles below Shiprock, New Mexico.
51	San Juan River below Farmington,New Mexico. Sample taken near Kirtland, New Mexico, below confluence of the Animas River, approximately 1 mile east of Kirtland.
52	San Juan River above Farmington,New Mexico. Sample taken above the Animas River confluence, approximately 4 miles east of Farmington just off New Mexico 17.
53	Animas River at Farmington, New Mexico. Sample taken at the bridge on New Mexico 17.
54	Animas River at Aztec, New Mexico. Sample taken 1/4 mile upstream from highway bridge on U. S. 550.
55	Animas River at Colorado-New Mexico state line. Sample taken at the Riverside PHS Basic Data Station just off U. S. 550.

Station Number	
56	Animas River below Durango, Colorado. Sample taken 2 miles below the Vanadium Corporation of America uranium mill.
57	Animas River above the Durango uranium mill. Sample taken at the Fish Hatchery on U. S. 550.
58	Dolores River above Slick Rock, Colorado. Sample taken from highway bridge on Colorado 30, about 2.5 miles above the Slick Rock mill.
59	Dolores River below Slick Rock, Colorado. Sample taken about 1/2 mile below the Slick Rock uranium mill. There was no stream flow at the time of the August 1960 survey.
60	Dolores River at Bedrock, Colorado. Sample taken from the highway bridge on the main road through Bedrock.
61	Dolores River above confluence of San Miguel River. Sample taken 0.7 miles above the mouth of the San Miguel River.
62	San Miguel River above Naturita, Colorado. Sample taken from the farm property adjacent to the river, approximately 1 1/2 miles above Naturita.
63	San Miguel River below Vancorum, Colorado. Sample taken at the bridge on a side road 1.2 miles below the mill.
64	San Miguel River above Uravan, Colorado. Sample taken at highway bridge on Colorado 141, 1.3 miles above the main intersection at Uravan.
65	San Miguel River below Uravan, Colorado. Sample taken about 1/2 mile above the mouth of the San Miguel River.
66	Dolores River below San Miguel River. Sample taken from the bridge approximately 3 miles below the mouth of the San Miguel River.
67	Dolores River at Gateway, Colorado. Sample taken immediately below the Colorado 141 highway bridge.
68	Gunnison River at Delta, Colorado. Sample taken from Colorado 65 highway bridge 6 miles east of Delta.
69	Gunnison River below Gunnison, Colorado. Sample taken along U. S. 50 about 3 miles west of Gunnison.
70	Gunnison River below the Gunnison uranium mill. Sample taken below the U. S. 50 highway bridge 1 mile southwest of Gunnison.

Station Number	
71	Gunnison River above Gunnison, Colorado. Sample taken at the Colorado 135 highway bridge about 3 miles north of Gunnison.
72	Tomichi Creek above the Gunnison Mining Co. uranium mill. Sample taken 100' above the bridge on the mill road.
73	Tomichi Creek below the Gunnison mill. Sample taken about 1 1/2 miles below the bridge on the mill road.
74	Eagle River above Colorado River confluence.
75	Colorado River 10 miles east of Glenwood Springs, Colorado.
76	Roaring Fork River at Glenwood Springs, Colorado.
78	Gunnison River 2 miles north of Gunnison, Colorado.
79	Tomichi Creek above Gunnison, Colorado.
30	Uncompahgre River, 5 miles south of Montrose, Colorado.
31	San Miguel River above Naturita, Colorado.
32	Little Snake River 17 miles northwest of Maybell, Colorado.
33	White River at Meeker, Colorado.

APPENDIX C

RADIOACTIVITY OF LAKE MEAD WATERS

In conjunction with the comprehensive October 1960 sediment survey in Lake Mead, water samples were taken for analysis of radium and uranium. Samples of surface water, as well as water at the liquid-sediment interface were collected in order to observe if leaching of radium and uranium was taking place from the bottom sediment. Table C-1 presents the data obtained.

From this table it is seen that with the exception of one anomalous result, all radium concentrations are well below the current MPC of 3.0 μμc/l. Also no significant difference was observed between surface and bottom water.

TABLE C-1
Radioactivity of Lake Mead Waters
October 1960

Station	Description	Depth of Water, Ft.	Depth of Sample, Ft.	Radioactivity Radium-226 μμc/l.	Radioactivity Uranium μc/l.
LM-1	Emery Falls	5	0-1	≤ 1.0	16
LM-2	Iceterg Canyon	120	5	1.1	7.3
		-	120	≤ 1.0	-
LM-3	Sandy Point	208	5	3.4	8.0
		-	207	≤ 1.0	10
LM-4	Virgin Canyon	307	5	1.3	6.3
		-	307	≤ 1.0	6.6
LM-5	East Point	275	0-1	≤ 1.0	5.5
		-	275	≤ 1.0	-
LM-6	Boulder Canyon	404	5	≤ 1.0	-
		-	403	1.2	-
LM-7	Hoover Dam	420	5'	≤ 1.0	8.1
		-	420	≤ 1.0	8.0
LM-8	The Narrows	3	0-1	≤ 1.0	-
LM-9	Overton	170	0-1	0.4	-
		-	170	0.5	-
LM-10	Virgin Narrows	275	5	0.4	5.8
		-	275	0.4	-
LM-11	Henderson Intake	-	5'	≤ 1.0	7.9
		-	Bottom	0.9	8.1