STREAM SURVEYS IN VICINITY OF URANIUM MILLS

IV. AREA OF SHIPROCK, NEW MEXICO - NOVEMBER 1960

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INTRODUCTION AND BACKGROUND

This report contains the findings of an eight-day field survey of stream conditions in the San Juan River below Shiprock, New Mexico, undertaken during November 15-23, 1960. The field study was conducted by the Colorado River Basin Water Quality Control Project in cooperation with the Division of Water Supply and Pollution Control, US PHS, Region VII, and the New Mexico Department of Public Health. This survey followed a brief investigation in August-September 1960 in connection with the accidental release of a relatively large volume of highly toxic acid waste from the Kerr-McGee Oil Industries uranium mill at Shiprock on August 22-23, 1960 (1). A request was made by the New Mexico Department of Public Health on October 14, 1960 to the Public Health Service to undertake a detailed investigation of the quality of river water downstream of the Shiprock uranium mill. The purpose of this investigation was two-fold: to ascertain the residual effects of the August 1960 spill and to evaluate the long-term conditions resulting from seepage to the river in the vicinity of the uranium mill. High river stages during October 1960 necessitated postponement of the survey until November, when the river was low enough to permit the collection of sediment and biological samples.

GENERAL FEATURES OF MILL PROCESS AND AREA

The town of Shiprock, as illustrated in Figure 1, is located within the Navajo Indian Reservation in the northwest corner of New Mexico, approximately 30 miles west of the city of Farmington. The Kerr-McGee uranium mill is situated on a low bluff on the south bank of the San Juan River a short distance upstream and across the river from the town of Shiprock.

Operation of the Kerr-McGee uranium mill began in 1954. The plant was processing from 400 to 500 tons of ore per day at the time of the survey. The mill process, in brief, consists of acid leaching, solvent extraction, stripping from the solvent, precipitation, and filtration of the uranium. The final product is U_3O_8, known as "yellow cake." A complete description of the process is given in Appendix A.

Another significant industrial activity at Shiprock is the U. S. Bureau of Mines Navajo Helium Plant, which began operations in 1944. The Helium Plant is located approximately one-half mile below the uranium mill and on the same side of the river.

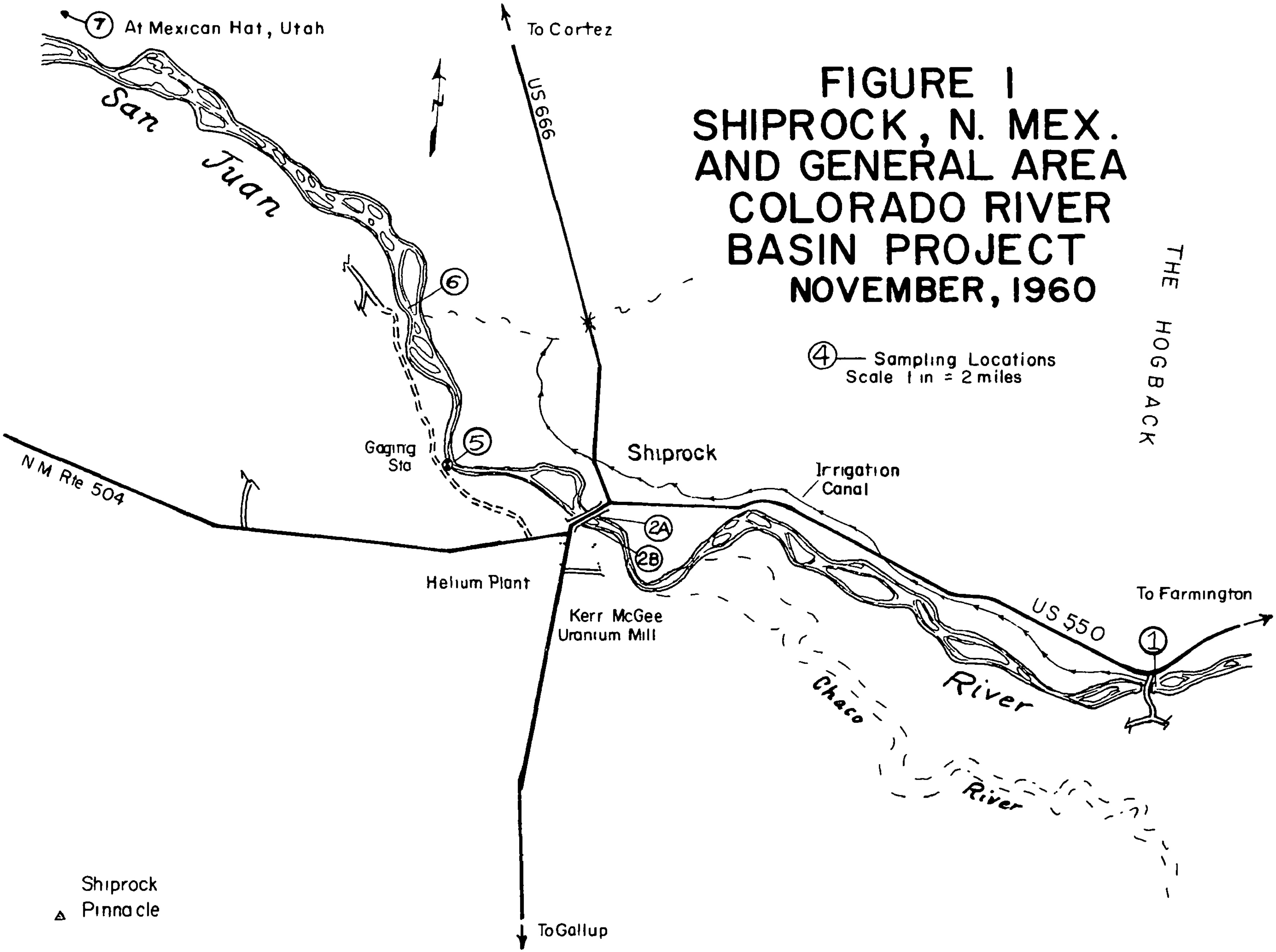


FIGURE 1
SHIPROCK, N. MEX. AND GENERAL AREA COLORADO RIVER BASIN PROJECT
NOVEMBER, 1960

Other activities in the area include extensive oil and gas exploration and some agricultural interests, mostly upstream from Shiprock.

WATER USES

The Kerr-McGee uranium mill draws water directly from the San Juan River for use in its process and as cooling water. This water is then treated by coagulation and settling.

Although Shiprock has considerable potential as a center for oil, gas, and mineral development, tourist activity, and Indian affairs, the greatest single item retarding its growth has been the lack of a satisfactory potable water supply. The town of Shiprock uses the San Juan River as its source of municipal water supply. River water is obtained principally from infiltration galleries located in the river bed approximately one-half mile below and on the opposite side of the river from the uranium mill. This supply is supplemented by surface water drawn directly from the river and, during the summer, by water from a nearby irrigation canal diverted from the San Juan River nine miles above the town. The percentages of surface and infiltration gallery water being used at the time of the November 1960 survey are unknown. The Shiprock water treatment plant, constructed and operated by the U. S. Bureau of Indian Affairs, provides for filtration and chlorination of the raw supply. This system is relied upon to supply an average demand of 0.45 MGD for approximately 2800 persons in the Shiprock area.

The Bureau of Mines Helium Plant also obtains water for domestic and industrial use through infiltration galleries in the river bed located approximately 100 yards below the Shiprock intake but on the same side of the river as the uranium mill with its attendant waste discharges. During the survey, water was being obtained from two of three galleries, the furthest upstream being closed. This supply is filtered, softened by zeolite units, and chlorinated. Average use, including water served to 56 families, is estimated at 60,000 gpd, with a maximum of 160,000 gpd.

The locations of infiltration galleries for both of the above supplies are shown in Figure 2 and specific information on construction and size is given in Appendix B.

The only substantial and fixed demand of San Juan River water below Shiprock for domestic use occurs at Mexican Hat, Utah, 140 miles downstream. There the river is utilized for water supply to a community of approximately 400 people. An average of 1.34 MGD of river water is utilized by the Texas-Zinc Mineral Corporation uranium mill at Mexican Hat, from which is provided full domestic water services to the community. The domestic supply receives complete treatment by flocculation, settling filtration, ion-exchange and chlorination.

Small amounts of water are withdrawn from the river for domestic purposes at scattered points downstream from Shiprock by Indians, but the quantity of use and number of persons using river water directly is quite variable and difficult to determine.

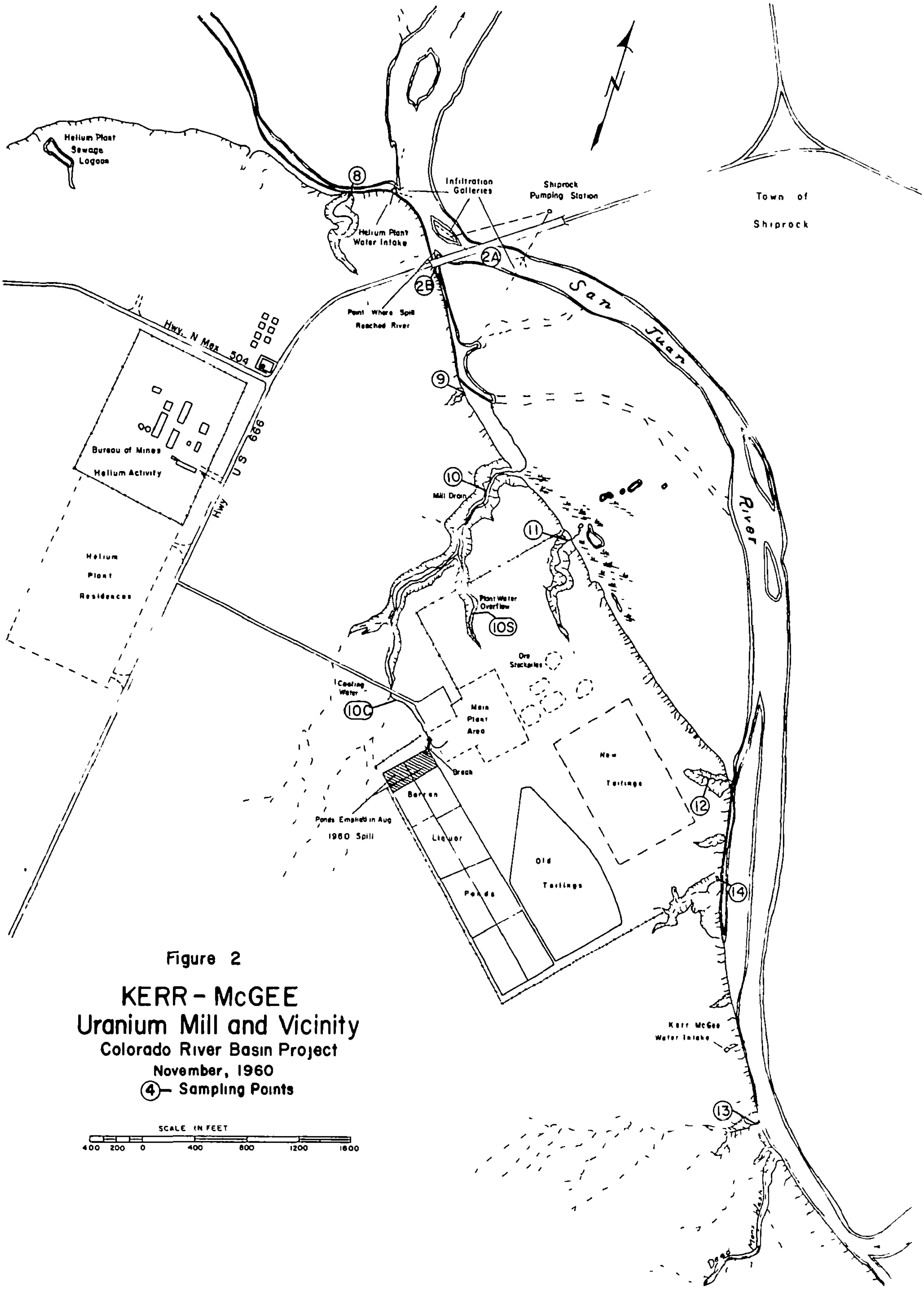


Figure 2

KERR - McGEE
Uranium Mill and Vicinity
Colorado River Basin Project
November, 1960
(4)— Sampling Points

WASTE DISPOSAL

All process wastes at the Kerr-McGee uranium mill at Shiprock are ponded. A layout of the plant site area is given in detail by Figure 2. The spent ore slurry is pumped to a tailings pond located between the mill and the river, herein referred to as new tailings area. Waste liquor, or raffinate, from the solvent extraction circuit and the yellow cake filtrate is pumped to ponds on the south side of the mill. The portions of the ponded liquids which do not evaporate, normally percolate into a 10 to 20 foot thick terrace gravel deposit which is underlain by Mancos Shale. These liquids then flow laterally over the shale to the edge of the bluff, where the shale outcrops from 10 to 20 feet above the narrow flood plain of the river. The major portion of the seepage appears in various gullies and washes where the alluvium has been eroded from the bluff.

Cooling water from the uranium mill fusion furnace and intermittent overflow from the process water storage tank are discharged to separate ditches which drain directly to the large wash as shown in Figure 2 and thence to the river. This wash is herein referred to as the mill drain. Domestic sewage from the uranium mill is treated in a septic tank and the overflow is discharged to a tile drain field. However, during the survey it was found that the septic tank effluent was entering the ditch carrying the overflow process water. This was apparently due to a broken pipe leading to the tile drain field.

Waste disposal facilities at the Helium Plant consist of a septic tank followed by a waste stabilization pond. Sanitary sewage from the town of Shiprock is received by two separate collection systems each having a waste stabilization pond for treatment of wastes. A small complex of homes, house trailers and a service station are also located about 0.3 miles south of the town of Shiprock at the intersection of Highways U.S. 666 and New Mexico 504. The latter development utilizes individual septic tanks for the disposal of domestic sewage and that from the gas station.

CONDUCT OF THE SURVEY

Samples were collected from five river locations; the untreated water supplies for the town of Shiprock and the Helium Plant; six seeps along the south bank of the river in the immediate vicinity of the uranium mill; the mill drain, and spent plant cooling water and process water overflow; and the drainage channel below the bluff and uranium mill which intercepts most of the surface discharge from the adjacent land area. The sampling period consisted essentially of two 4-day compositing cycles, November 15-18 and November 19-22, 1960, with variations in the sampling dates for each station as noted below.

Descriptions of Sampling Stations

Figures 1 and 2 show the location of sampling stations. The river bottom in the sampled reach of the San Juan River consists of fine, shifting sand and scattered gravel bars. Descriptions of the stations are as follows:

Station Code	Description	Sampling Dates
1	San Juan River 9 miles above Shiprock. Water samples were obtained from the irrigation diversion structure.	Nov.15-18, 19-22
2A	San Juan River at Shiprock. A composite sample was taken at three locations across the main channel from U.S. Highway 666 bridge.	Nov.19-22
2B	Drainage channel at Shiprock. Samples taken from highway 666 bridge. Flow in this channel at south bank of river consisted entirely of seepage and mill drain water.	Nov.19-22
3	Untreated water - Town of Shiprock. Samples were obtained from the raw water tap in the pumphouse near the river.	Nov.15-18
4	Untreated water - Helium Plant. Samples were obtained upon discharge to the chlorination tank within the plant grounds.	Nov.15-18 19-22
5	San Juan River 3 miles below Shiprock. Samples were taken at quarter-points from the cable at the U.S.G.S. gaging station.	Nov.16-18 19-22
6	San Juan River 6 miles below Shiprock. Samples were obtained by hand at quarter points across the stream by wading.	Nov.15-18 19-22
7	San Juan River at Mexican Hat, Utah, 140 river miles below Shiprock. Samples were taken by wading at midstream above the mouth of Gypsum Creek, thus avoiding any possible contamination from discharges from the Texas-Zinc uranium mill.	Nov.15-18 19-22
8	Seepage 100 yards downstream from Helium Plant water intake. Samples taken at mouth of gully.	Nov.16-18 19-21, 23
9	Seepage 300 yards upstream from highway bridge. Samples taken below mouth of gully. A large amount of trash had been thrown into this gully.	Nov.16-18
10	Mill drain. Samples taken approximately 100 yards above mouth of wash, 500 yards upstream from bridge. There was no natural flow in this wash during the Nov. 1960 survey. The August 1960 spill followed this route to river.	Nov.16-18 19-21, 23

Station Code	Description	Sampling Dates
10C	Mill cooling water ditch. Sediment sample taken near raffinate ponds.	Nov. 18
10S	Mill process water overflow ditch. Sediment sample taken 5 yards below end of discharge pipe on mill grounds.	Nov. 18
11	Seepage 800 yards upstream from highway bridge. Samples taken near mouth of gully just inside mill grounds.	Nov.16-18 19-21, 23
12	Seepage 1500 yards above highway bridge. Samples taken in gully adjacent to new tailings pond.	Nov.16-18 19-21, 23
13	Seepage 200 yards above uranium mill water intake. Samples taken at mouth of wash. (The next upstream wash, Dead Man's Wash, although draining a much larger area, was dry.)	Nov.16-18 19-21, 23
14	Seepage 350 yards below uranium mill water intake. Samples taken at mouth of gully.	Nov.19-21,23

Samples of bottom organisms were obtained from the river at points 2 miles above the mill and 0.5, 3, 6 and 10 miles below the mill. The 3- and 6-mile biological sampling points correspond to Stations 5 and 6, respectively, given above.

Sampling Procedures

All liquid samples were grab samples taken once daily at all stations and composited for each sampling cycle. The composites amounted to one gallon for uranium and radium-226 analyses, one gallon for chemical analyses, and one quart for gross radioactivity determinations. In addition, one-gallon sample was composited over the total survey period from each of the seeps and the mill drain for fish toxicity studies. Liquid samples were collected in polyethylene bottles.

At each river station, sediment samples were collected once during each sampling cycle and then composited over the two cycles. Where possible, sediment samples were obtained at quarter-points across the stream with an Ekman dredge and elsewhere by hand at accessible points. At each seep and mill drain station, mud samples were taken once during the survey. Sediment and mud samples were collected in one-pint glass jars.

Discharge Measurements

Discharge measurements were made once during the survey at each of the seep and mill drain stations using a V-notch weir at Station 8, 10, and 11 and a volumetric method at Stations 12, 13, and 14. The flow at Station 9 was estimated visually. No flow measurements were undertaken at Station 2B and of the two raw water supplies. There appeared to be little or no variation in discharge from the seeps during the survey. The mill drain discharge was more variable and appeared to be slightly higher at the time of measurement than at other times during the survey. These flow determinations are presented in Table I. San Juan River flows are given in the next section of this report.

TABLE I

Discharge Measurements of Seeps in Shiprock Area
November 1960

Station	Flow (gpm)
8	20
9	1
10	130
11	20
12	0.5
13	1.5
14	4.5

HYDROLOGY

The average flow of the San Juan River at the U. S. Geological Survey gaging station 3 miles below Shiprock for the survey period was 625 c.f.s. This is less than the November mean of 843 c.f.s. for the period of record from 1928 to 1959 but considerably higher than the 1960 summer low of 65 c.f.s. on August 21. The lowest recorded daily flows at Shiprock were 8 c.f.s. in August, 1939 and 12 c.f.s. in July, 1959 (2) (3). Flow frequency studies indicate that a mean daily discharge of 9 c.f.s. or less would occur at Shiprock once approximately every 20 years (4).

Mean daily discharges of the San Juan River at Shiprock and Mexican Hat for the survey period and average values derived from the period of record, as reported by the U. S. Geological Survey are given in Table II. Hydrographs for calendar years 1959 and 1960 are shown in Figure 3 for the Shiprock location to illustrate recently-occurring annual flow patterns in the river. The 1960 flow information shown herein is taken from USGS provisional records whereas the 1959 data is obtained from published records.

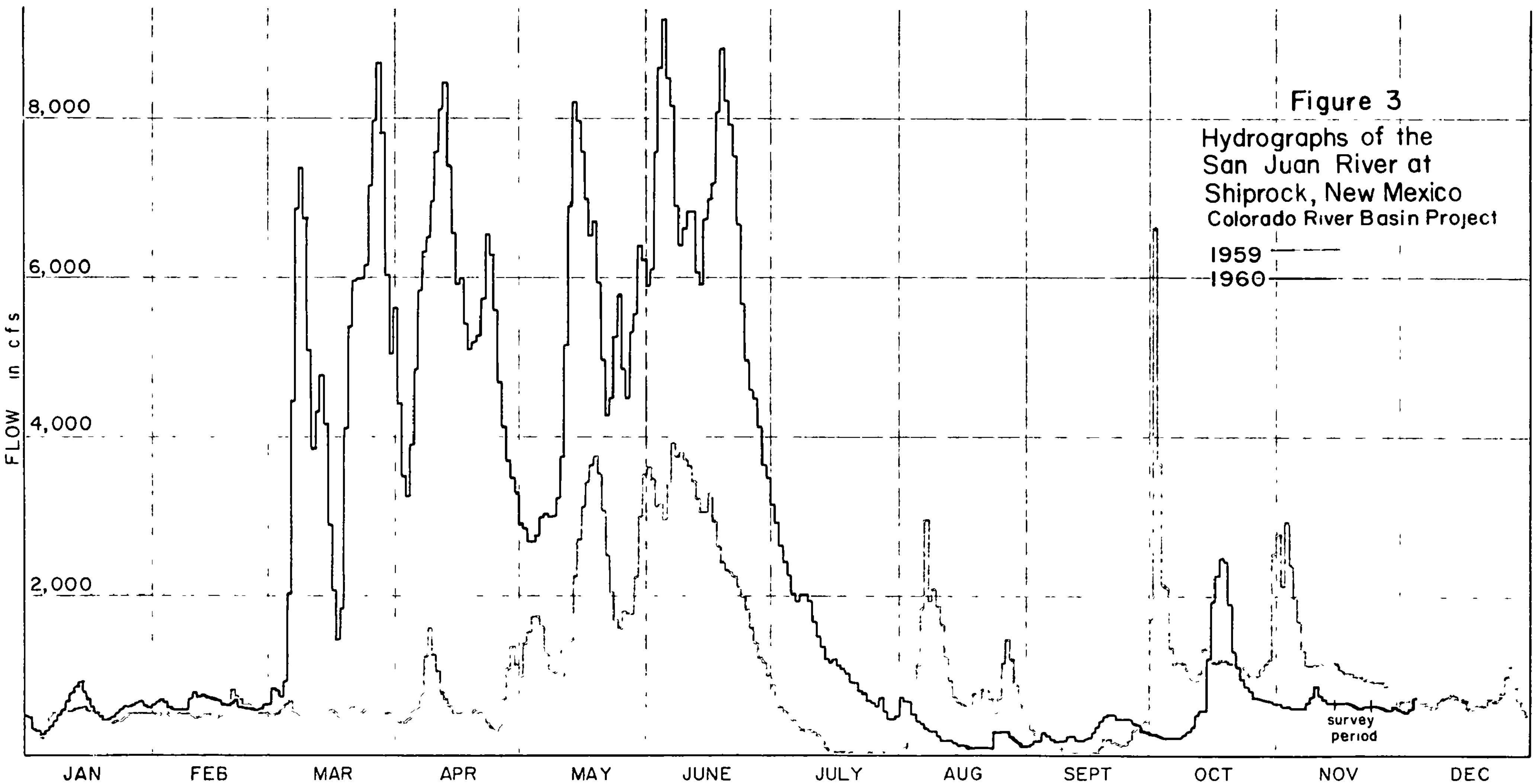


Figure 3
Hydrographs of the
San Juan River at
Shiprock, New Mexico
Colorado River Basin Project
1959
1960
FLOW in cfs
8,000
6,000
4,000
2,000
survey
period
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC

TABLE II

Mean Daily Discharges of the San Juan River
At Shiprock, New Mexico and Mexican Hat, Utah (cfs)

Date	Shiprock, N. M.	Mexican Hat, Utah
November 15, 1960	637	670
16	621	651
17	645	620
18	654	613
19	630	620
20	610	595
21	581	583
22	621	607
23	629	566
Mean period of survey	625	614
November 1960 mean	632	665
November mean, period of record	843 (1928-59)	1,014 (1915-59)
Annual mean, period of record	2,450	2,790

PRESENTATION AND DISCUSSION OF ANALYTICAL RESULTS

Radiological

The gross radioactivity assays of all water and sediment samples were performed at the Taft Sanitary Engineering Center in Cincinnati, Ohio. A portion of the radium-226 determinations and all of the uranium analyses were performed by Colorado River Basin Project Laboratory personnel temporarily located at the Occupational Health Field Station in Salt Lake City. The remainder of the radium-226 determinations were performed by a private laboratory.

Results of radiological analyses of seep and mill drain liquid and mud samples are presented in Table III. Radioactivity levels of river water and river sediment and raw water supplies are presented in Table IV.

Seep and Drain Liquids.

Seepage liquids exhibited a wide range of dissolved gross radioactivity, average values ranging from 17 to 860 micromicrocuries per liter alpha activity and from 150 to 1600 $\mu\mu c/l$ beta activity. The highest activities were found in seepage in the immediate vicinity of the tailings ponds (Stations 12 and 14), while seeps most distant (Stations 8 and 13)

TABLE III

RADIOACTIVITY OF SEEP AND DRAIN SAMPLES [a/]

Sample No.	Location	Liquids [b/] Gross Alpha μμc/l	Gross Beta μμc/l	Ra-226 μμc/l	Uranium μg/l	Mud Gross Alpha μμc/g	Gross Beta μμc/g	Ra-226 μμc/g
2B [c/]	Drainage channel at bridge	90	220	1.8	340	16	47	---
8	Seep: 100 yds below helium plant intake	21 13	100 200	0.5 0.6	---	16	46	2.2
9 [d/]	Seep: 300 yds above bridge	31	---	0.2	---	---	56	2.6
10	Mill drain	200 140	190 180	2.5 2.9	860 560	650	600	39
10-C	Cooling water ditch					2200	2600	120
10-S	Process water overflow ditch					440	670	120
11	Seep: 800 yds above bridge	94 120	400 420	4.9 5.0	700 530	470	770	115
12	Seep: 1200 yds above bridge	770 760	1400 1800	2.1 1.4	3800 3900	150	200	14
13	Seep: 200 yeds above mill water intake	19 70	260 ---	0.2 0.2	--- ---	7.2	---	1.6
14 [c/]	Seep: 350 yds below mill water intake	860	1600	2.0	4800	30	57	4.2

a/ First and second values correspond to sampling cycles I and II, respectively, for which sampling dates are given in Page 4 of this report.
b/ Dissolved fraction only.
c/ Cycle II only
d/ Cycle I only

TABLE IV

RADIOACTIVITY OF RIVER AND RAW WATER SAMPLES[a/]

Station Number	Location	Water: Gross Alpha μμc/l	Water: Gross Beta μμc/l	Water: Ra-226 μμc/l	Water: Uranium μg/l	Sediment: Gross Alpha μμc/g	Sediment: Gross Beta μμc/g	Sediment: Ra-226 μμc/g
SAN JUAN RIVER								
1	9 mi. above mill	3.1	7.8	0.2	12	9.1	36	1.5
		5.0	8.3	≤1.	20			
2A	Shiprock bridge	5.1	7.4	0.3	20	6.5	58	1.0
5	3 mi. below mill at USGS gage	3.3	15	0.2	13	5.3	25	0.9
		7.3	15	0.2	21			
6	6 mi. below mill	4.5	6.0	≤1	16	4.9	25	1.6
		7.9	6.0	≤1	20			
7	Mexican Hat	6.4	35	0.2	16	4.8	37	1.5
		3.4	15	0.2	13			
RAW WATER SUPPLIES								
3	Town of Shiprock	8.6	28	0.1	44			
		8.8	8.3	0.1	34			
4	Helium Plant	6.9	17	0.0	28			
		2.6	13	0.1	25			

a/ First and second values correspond to sampling cycles I and II, respectively, for which sampling dates are given in Page 4 of this report.
b/ Dissolved fraction only.
c/ Cycle II only.

showed the least activity. A number of factors could be responsible for this variation, including the length of subsurface travel, the precipitation of solids while in transit, ion exchange in the alluvium, and the source of liquid involved.

Average concentrations of Ra-226, an alpha emitter, ranged from 0.2 to 5.0 μμc/l for individual stations and accounted for from 0.1 to 8 percent of the respective gross alpha activities. Uranium contributed most of the remaining gross alpha. The Ra-226 concentrations of all samples were unusually low, considering the source of wastes and the high gross alpha activity and uranium content. Average dissolved uranium concentrations ranged from 340 to 4800 μg/l.

Since the flow in the mill drain of 130 gpm was more than twice the total of all seepage discharged, the latter being equal to 50 gpm, the quality of mill drain effluent was important. Its characteristics vary considerably, since it is directly affected by short-term variations in plant processing. Gross alpha and beta activities and uranium concentrations for the mill drain water were considerably less than those found in seepage nearest the tailings ponds, while gross alpha and Ra-226 activities of the drain water were higher than those found in seeps more distant from the tailings. Uncertainty as to the source of radioactivity was introduced by the presence in this channel of residue from the August 1960 spill. Some of the dissolved radioactivity values found in the mill drain water may have been leached from these deposits.

The U. S. Atomic Energy Commission Standards for Protection against Radiation (5) require that effluents to unrestricted areas from private entities licensed to possess radioactive materials contain a maximum of 10 μμc/l Ra-226 plus one-half of the equilibrium amounts of its daughter products. None of the sampled seepage nor the mill drain exceeded this limit during the November 1960 survey.

The total Ra-226 discharged to the river in all discharges sampled was 2.6 μc per day. This amount could not have produced detectable increases in Ra-226 concentrations in the San Juan River at the time of the survey, considering the dilution provided by a discharge of more than 600 c.f.s. It was previously estimated that a low flow of 9 c.f.s. or less would occur, on the average, once every 20 years. For this discharge the Ra-226 contribution of all the seeps and the mill drain to San Juan River water would be 0.1 μμc/l, still virtually undetectable. The latter findings however do not condone the routine discharge of greater amounts of radioactive material or an accidental release such as occurred on August 22-23, 1960.

Seep and Drain Muds.

The mud samples from the seeps in the immediate vicinity of the tailings, especially Stations 11 and 12, showed considerable gross alpha and beta and Ra-226 activity. The liquid samples from these two seeps in addition had high dissolved gross radioactivity. The mill drain (Station 10) mud samples also indicated deposits of solids having considerable alpha and beta radioactivity. In fact, the 39 μμc/g Ra-226 in the mill drain mud was higher than mud Ra-226 concentrations found in this drain at approximately the same location following the August spill (1).

The highest gross radioactivity and radium counts were obtained from mud collected from the channel carrying the cooling water (Station 10C) as it passed near the raffinate holding ponds. The holding ponds emptied by the August spill remained unfilled during the November survey. From the Ra-226 concentration of 120 μμc/g in mud from the cooling water channel observed during this survey and from samples collected following the August 1960 spill (1), it was observed that the sediment activity of the cooling water channel was comparable to observed levels of radioactivity in sludge samples collected in August 1960 from the nearby holding ponds. Seepage from these lagoons may contaminate the cooling water channel, which is then scoured and the sediment transported throughout the mill drain.

Mud obtained from the channel carrying the process water overflow (Station 10S) to the mill drain also showed high radioactivity. Its Ra-226 concentration of 120 μμc/g was equal to that of the cooling water channel mud. A possible explanation of this level of radioactivity in this channel is contamination by dust from ore trucks and nearby ore stockpiles.

River Water

Samples at stream locations above all sources of radioactive contamination yield important data on natural background radioactivity levels. Such samples (4)(6)(7)(8) contain gross alpha activity up to 10 μμc/l, gross beta up to 50 μμc/l and soluble Ra-226 activity generally less than 0.3 μμc/l. Although industrial sources of radioactive pollution exist upstream of Shiprock, these are of no consequence at Shiprock because of substantial dilution and the minimal amounts initially present. Accordingly, the levels of radioactivity in river water at Station 1 above Shiprock were found to be in the background range. (See Table IV)

All downstream river water samples also showed gross radioactivity, Ra-226 and uranium concentrations approximating background conditions. There were no significant increases over upstream levels, and none would have been expected, considering the small total amounts of radioactivity discharged from the Shiprock uranium mill and the available dilution.

Average gross alpha and beta activities over the entire stretch of river under study varied from 4.1 to 6.2 μμc/l and 6.0 to 25 μμc/l, respectively. Dissolved Ra-226 concentrations were equal to or less than 0.3 μμc/l for all finite results; three results simply indicated levels equal to or less than 1.0 μμc/l. Dissolved uranium values for river water again did not vary from upstream to downstream locations and ranged from 12 to 20 μg/l throughout the study area.

Raw Water Supplies

Radioactivity of raw water from the Shiprock pumping plant and the Helium Plant was comparable to river water samples. Uranium concentrations were slightly higher, while Ra-226 was low (0.1 μμc/l or less). Gross alpha activities in the raw water supplies were not significantly above that of river water.

The National Committee on Radiation Protection (9) has established maximum permissible concentrations (MPC) of radionuclides in water for continuous occupational exposure. In addition, the International Committee on Radiological Protection (10) recommends a conversion factor of 1/30 for members of the population at large. The resulting MPC for Ra-226, a bone-seeker, is 3.3 μμc/l and for natural uranium is 6700 μμc/l, or 9500 μg/l.

The 1961 Public Health Service Drinking Water Standards (11) include radioactivity limits for the first time. Radium-226 concentrations which exceed 3.0 μμc/l, on the average, for a period of one year, shall constitute grounds for rejection of the supply. Concentrations of Ra-226 and uranium in the raw water samples for Shiprock and the Helium Plant were well within the Maximum Permissible Concentrations given above. Also gross radioactivity levels in the raw waters were in the range of background as normally found for river waters.

River Sediments

Information concerning natural background levels of radioactivity in stream sediments are also available. Results of gross alpha, gross beta, and Ra-226 analyses of several samples collected during this Project's first Basinwide sediment survey (12) are given in Table V. As can be seen from Table IV, all San Juan River sediments collected in the Shiprock area in November, 1960 from below the mill, fall within these ranges.

TABLE V

Background Levels of Radioactivity
In Stream Sediments (12)

Location	Gross α μμc/g	Gross β μμc/g	Radium μμc/g
Colorado River at Silt, Colorado	6.5	78	1.7
Yampa River at Juniper Springs, Colo.	4.0	50	$\leq$1.0
Green River near Dutch John, Utah	8.6	45	$\leq$1.0
San Juan River above Farmington, N.M.	5.3	21	0.9
Animas River above Durango, Colorado	11.0	29	1.3
San Miguel River above Naturita, Colo.	9.5	38	1.0
Gunnison River above Gunnison, Colo.	9.0	52	1.6
Tomichi Creek above Gunnison, Colo.	11.0	47	1.2

Chemical

Results of chemical analyses performed on seep and drain samples are presented in Table VI, and chemical analyses on river and raw water supply samples are presented in Table VII. All chemical determinations were performed in accordance with Standard Methods (13).

Seep and Drain Effluents

In considering the various seeps that were sampled, those nearest the tailings ponds contained the highest chemical concentrations. Total dissolved solids, calcium, magnesium, and sodium contents were not reported. However, estimates of total dissolved solid levels based on reported anion concentrations ranged from 9,000 mg/l for Station 8 to 14,000 mg/l for Station 12. The seep liquors were also very hard, containing a large portion of non-carbonate hardness. The latter is shown by the difference between total hardness and alkalinity. High levels of sulfates undoubtedly contributed most of the non-carbonate hardness. Concentrations of chemical constituents in the seep samples varied considerably: hardness from 3,400 to 10,400 mg/l, sulfates from 3800 to 3900 mg/l, alkalinity from 256 to 1660 mg/l, chlorides from 99 to 440 mg/l, and nitrates from 111 to 1640 mg/l (as NO_3).

The high sulfate content of the seeps may have been due to sulfuric acid in the slurry (pH about 2.0) pumped to the tailings pond, or to the leaching of natural sulfates from the ground. The very high nitrate and relatively high chloride concentrations of the seeps were apparently also due to leaching of these salts from the alluvium and/or waste ponds. Ammonia was used in the process and contained in the wastes sent to the barren liquor ponds, where it may be converted to the nitrates form.

The mill drain samples were nearly equal to or somewhat lower than seep samples in all chemical concentrations except vanadium which was higher. This drain was the most important source of chemical pollution because of its greater waste volume. Much of the dissolved solids content of this discharge (estimated t.d.s. 6,000 mg/l) was likely being leached from solids deposited in this channel during the August spill (as was previously suggested for radioactive materials).

The drainage channel at the bridge, Station 2B, was high in sulfates (3900 mg/l), nitrates (806 mg/l), and chlorides (330 mg/l) and was a potential source of chemical pollution to the infiltration galleries immediately downstream.

The mineral contribution to the river of all measured seepage and the mill drain has been determined for various constituents, using average concentrations obtained over the two sampling cycles. For a time-of-survey river discharge of 625 c.f.s., the total seep and drain discharge to the river would increase alkalinity by 0.2 mg/l, sulfates and hardness by 2 mg/l,

TABLE VI

CHEMICAL QUALITY OF SEEP AND DRAIN SAMPLES[a/]

(All Values Reported in mg/liter except pH)

Station	2B[b/]	8	9[c/]	10	11	12	13	14[b/]
Analyses								
pH	---	7.8	7.5	6.7	7.6	7.4	7.5	---
	7.0	7.9	---	7.8	7.6	7.5	7.5	7.5
Total Alkalinity (as $CaCO_3$)	---	256	365	235	1320	1570	905	---
	440	320	---	180	1210	1660	1000	1250
Fluoride	---	0.82	0.90	0.57	0.86	1.2	0.82	---
	0.65	0.84	---	0.57	0.84	1.1	0.74	0.62
Selenium	---	.009	.003	<.001	.004	.008	.009	---
	<.001	.001	---	.002	.005	.007	.002	.002
Iron	---	.04	.09	.09	<.04	1.6	<.04	---
	.28	.05	---	.53	.04	<.04	.05	<.04
Manganese	---	.04	<.04	.17	<.04	4.9	.04	---
	.31	<.04	---	.26	<.04	4.9	<.04	<.04
Sulfate	---	3900	3900	2800	3900	3900	3900	---
	3900	3900	---	2000	3800	3800	3800	3900
Total Hardness (as$CaCO_3$)	---	3400	3870	2170	6800	10800	5850	---
	3400	3400	---	1600	6700	10300	5660	5400
Chloride	---	106	280	142	430	440	390	---
	330	99	---	215	430	428	413	174
Copper	---	<.01	<.01	<.01	<.01	.01	<.01	---
	<.01	<.01	---	<.01	<.01	<.01	<.01	<.01
Vanadium	---	<.003	<.003	.300	<.003	.007	<.003	---
	.111	<.003	---	.442	<.003	.007	<.003	.033
Nitrate (as NO_3)	---	487	111	266	1640	1462	1484	---
	806	478	---	257	1462	1218	1440	310
Phosphate (total)	---	<.5	<.1	<.1	<.1	<.5	<.1	---
	<.1	<.1	---	<.1	<.1	<.5	<.1	<.5
Lead	---	.018	.022	.008	.010	.015	.012	---
	.025	.005	---	.005	.005	<.005	<.005	.010
Arsenic	---	<.01	<.01	<.01	<.01	<.01	<.01	---
	<.01	<.01	---	<.01	<.01	<.01	<.01	<.01

a/ First and second values correspond to sampling Cycles I and II, respectively, for which sampling dates are given in Page 4 of this report.

b/ Cycle II only.

c/ Cycle I only.

TABLE VII CHEMICAL QUALITY OF RIVER AND RAW WATER SAMPLES[a/]
Shiprock, New Mexico Area, November 1960
(All Values Reported in mg/liter, except pH)

Station	1	2A[b/]	3	4	5	6	7
Analyses							
pH	7.5	---	7.5	7.5	7.5	7.5	7.5
	7.5	7.4	7.5	7.5	7.6	7.8	7.5
Total	113	---	177	111	152	152	174
Alkalinity	164	156	180	200	162	170	174
Fluoride	0.45	---	0.53	0.37	0.49	0.45	0.43
	0.49	0.53	0.57	0.37	0.45	0.51	0.53
Selenium	.009	---	.006	.006	.008	.008	<.001
	<.001	<.001	.002	.003	.005	.003	.006
Iron	.57	---	.41	.07	.66	.90	3.9
	.56	.72	.08	.12	.46	.75	1.8
Manganese	<.04	---	.30	<.04	<.04	.05	.18
	.04	<.04	<.04	.05	<.04	.05	.10
Sulfate	320	---	790	510	400	430	540
	295	345	530	480	360	390	510
Total	320	---	680	430	450	450	450
Hardness	360	360	570	470	380	380	450
Chloride	16	---	66	26	18	18	22
	16	19	46	27	20	22	20
Copper	<.01	---	.01	<.01	.01	.01	<.01
	<.01	<.01	<.01	<.01	<.01	<.01	<.01
Vanadium	.010	---	<.003	<.003	<.003	<.003	.026
	.010	.010	.033	<.003	.006	.004	.010
Nitrate	.35	---	.71	.31	.13	.04	2.2
(as NO_3)	.49	1.9	13.3	13.4	2.0	1.6	2.6
Phosphate	<.5	---	<.1	<.5	<.1	<.1	<.1
(Total)	<.1	<.1	<.1	<.1	<.1	<.1	<.1
Lead	<.005	---	.005	.010	.045	<.005	<.005
	.008	.005	.008	<.005	.008	.010	.045
Arsenic	<.01	---	<.01	<.01	<.01	<.01	<.01
	<.01	<.01	<.01	<.01	<.01	<.01	<.01

a/ First and second values correspond to sampling Cycles I and II, respectively.
b/ Cycle II only.

and chlorides and nitrates by 0.1 mg/l. These increases are usually undetectable, considering concentrations generally found in the San Juan River. Observed chemical concentrations in the river water are discussed below.

However, for a daily river discharge of 9 c.f.s., the estimated 20-year low flow, dilution would not be adequate (as almost expected) to prevent serious chemical pollution in the San Juan River. Sulfates and hardness would each be increased by 110 mg/l, alkalinity 15 mg/l, chlorides 10 mg/l, nitrates as NO_3 22 mg/l, and vanadium by 0.01 to 0.02 mg/l. Pollution introduced by other chemicals for which results are reported in Table VI, that is fluorides, iron, manganese, copper, phosphates, lead, arsenic and selenium, would be negligible in all cases.

River Waters

As noted above, no observable increases in chemical concentrations would have been expected in the river water at the time of the survey due to the direct waste discharges from the uranium mill area. However, average sulfate levels at downstream locations, as shown by Table VII, did increase in the order of 35 percent from 300 to 400 mg/l and likewise hardness increased 20 percent from 340 to 415 mg/l. Values at Stations 5 and 6 were compared with Station 1 for this purpose. The river water was quite high in sulfates and hardness even upstream of Shiprock, undoubtedly due in large part to natural sources above this point. Nitrates also were higher downstream, increasing from an average of 0.4 mg/l at Station 1 above Shiprock to 2.4 mg/l at Station 7. Iron content was relatively high and showed a large increase from Station 5 to Station 7, both stations located below Shiprock, with maximum levels of 3.9 and 1.8 mg/l at Station 7. As the seep samples were especially high in hardness, sulfates, and nitrates, the possibility of considerable groundwater seepage to the river, both from the Shiprock uranium milling activity and from natural sources, is indicated.

Raw Water Supplies

Some chemical constituents in the raw water supplies are reported to have been present in concentrations higher than the recommended limits presented in the Public Health Service Drinking Water Standards (11). These are discussed individually.

Sulfates averaged 660 mg/l in the Shiprock raw water, nearly twice the concentration in the main channel of the river at the infiltration galleries (Station 2A). In the Helium Plant raw water, sulfates averaged 495 mg/l. The limit recommended in the Drinking Water Standards is 250 mg/l. The infiltration galleries for the Shiprock water supply have reportedly produced a sulfate concentration as high as 2933 mg/l (14). As mentioned previously, river samples both above and below Shiprock also contained sulfate concentrations greater than 250 mg/l.

The Drinking Water Standards recommend a nitrate limit of 45 mg/l as NO_3, since higher concentrations if used are associated with greater incidence of methemoglobonemia in infants. Although this limit was not exceeded during the survey, uncertainty exists in the long-term nitrate levels in the water supply of both water plants.

Samples collected of the Shiprock water supply at various points in the distribution system by the New Mexico Department of Public Health over the period January 1957 to January 1958 indicated levels of 124 to 195 mg/l nitrates (as NO_3). Results from two samples collected from the Helium Plant water system in 1956 and 1957 showed nitrate concentrations of 0.4 and 8.9 mg/l as NO_3. Levels of nitrate in three San Juan River water samples collected in the Shiprock area from April, 1957 to January, 1958, by the New Mexico Department of Public Health, ranged from 1.8 to 4.4 mg/l as NO_3(15).

Some variation of nitrate level in the Shiprock water supply may be explained by an alternation of source from surface water to gallery water and vice versa. All of the Helium Plant supply is however obtained from infiltration galleries. Personnel at the Helium Plant in November of 1960 related that nitrate concentrations increase greatly when river water is pumped from the collector furthest upstream. Because of the very high nitrate levels determined for the Shiprock water supply by the State of New Mexico as given above, and uncertainty of the nitrate content of the Helium Plant supply, further study of factors contributing to this effect is definitely indicated.

During Cycle I, a value of 0.41 mg/l iron was obtained for the Shiprock raw water, which is higher than the Public Health Service recommended limit of 0.3 mg/l for this same material. This limit is based on the tendency of iron to stain laundry and porcelain. The two samples collected of Helium Plant raw water and the second sample taken of Shiprock inflow contained lesser iron concentration, approximating 0.1 mg/l. It is noted that all river samples were shown to have an iron content greater than the 0.41 mg/l found for the Shiprock water supply sample of Cycle I. The recommended limit for manganese is 0.05 mg/l. The Shiprock raw water sample from Cycle I showed a Mn concentration of 0.3 mg/l, well above the desired level. The manganese content of all other raw water and river samples were equal to or less than 0.05 mg/l excepting the waters at the furthest downstream location of Station 7 which contained an average of 0.14 mg/l Mn.

Although there are no drinking water standards for hardness, water containing an excess of 250 mg/l is usually considered undesirable for domestic and industrial use in most sections of the country, without prior softening. Total hardness of the Shiprock raw water averaged 625 mg/l, and at the Helium Plant, 450 mg/l. Hardness levels in river water were also above 250 mg/l as discussed above.

Chloride concentrations in the untreated water supplies were considerably below the maximum permissable level of 250 mg/l, based on tastes in drinking water. However, it is observed that chloride levels were somewhat higher in the water obtained from the infiltration galleries than in the river directly above the galleries.

Raw water determinations other than those already discussed were all within recommended limits for acceptable drinking water.

Biological

Bio-Assay

Fish toxicity studies were undertaken at the Taft Sanitary Engineering Center in Cincinnati, Ohio, with the seep and drain sample collected in the vicinity of the Shiprock uranium mill. Bluegill sunfish one and one-quarter inches to two inches in length were exposed to various dilutions of effluent liquors from sampling Stations 8, 9, 10, 11, 12, 13, and 14. The prepared dilution water had a pH of 7.4 and contained 18 mg/l alkalinity and 20 mg/l hardness.

Initially, one fish was tested in one liter of each effluent at 100 percent concentration. Within 30 minutes, the test fish in the seep effluent from Station 12 was dead. At the same time, two test fish were placed in a 2-liter volumes of 100, 10, and 1 percent concentrations of all effluents except No. 12. All the test fish observed in the various concentrations of samples from Stations 8, 9, 10, 11, and 14 were alive at the end of a 96-hour test. In the various concentrations of the sample collected from Station 13, all fish were alive after this 96-hour period except one fish in a concentration of one percent effluent.

Further information was desired on the characteristics of the drainage liquor from Station 12. Therefore, two fish were placed in 2-liter volumes at waste concentrations of 56, 32, and 1 percent. Additionally two fish were placed in 2-liter volumes, in duplicate, at 18, 10, and 5.6 percent waste concentrations. The results of bio-assay tests with this seep effluent are shown in Table VIII.

TABLE VIII

Bioassay Tests on the Kerr-McGee Seep Sample No. 12

No. of Fish	Volume Liters	Test Concentration	% Survival 24 hrs.	48 hrs.	72 hrs.	96 hrs.
1	1	100%	0	-	-	-
2	2	56	0	-	-	-
2	2	32	0	-	-	-
2	2	18 1/	0	-	-	-
2	2	10 1/	100	0	-	-
2	2	5.6 1/	100	100	100	100
2	2	1.0	100	100	100	100

1/ In duplicate

Since only two fish were used in each test, the results obtained are indicative only of a general range of toxicity, and should be interpreted in this light. The data presented in Table VIII indicate that the 96-hour median tolerance limit (TL_m), or the concentration of waste of Station 12 that will kill half of the test fish in a 96-hour period, is in the range of 5-10 percent. To prevent damage to fish life in the receiving stream the necessary dilution water may be calculated by the formula:

$$\text{Dilution Water} = \frac{100 - TL_m}{TL_m} \times \text{waste flow} \times \text{application factor}$$

The application factor will vary according to the characteristics of the waste and receiving stream. Generally, this factor is not less than 3 and may be 10 or more. The purpose is to provide sufficient water in excess of the TL_m concentration to dilute the wastes to a harmless concentration.

Using the flow of 0.5 gpm given previously for Station 12 and the above ranges of TL_m and application factors the required dilution of San Juan River water to completely mitigate fish toxicity for conditions experienced during the survey ranged from 0.03 cfs to 0.21 cfs. There should be no toxicity problem to fish and wildlife attributable to waste discharges from the Kerr-McGee uranium mill under normal operating procedures, since the flow of the San Juan River at Shiprock is always much greater than the minimum required.

Biological Sampling Collection of bottom organisms was undertaken at one station above the Shiprock uranium mill and at four downstream locations. Detailed examination of stream biota was not made. However, some information of interest was obtained. Bottom fauna collected from one square yard at selected river locations is shown in Figure 4.

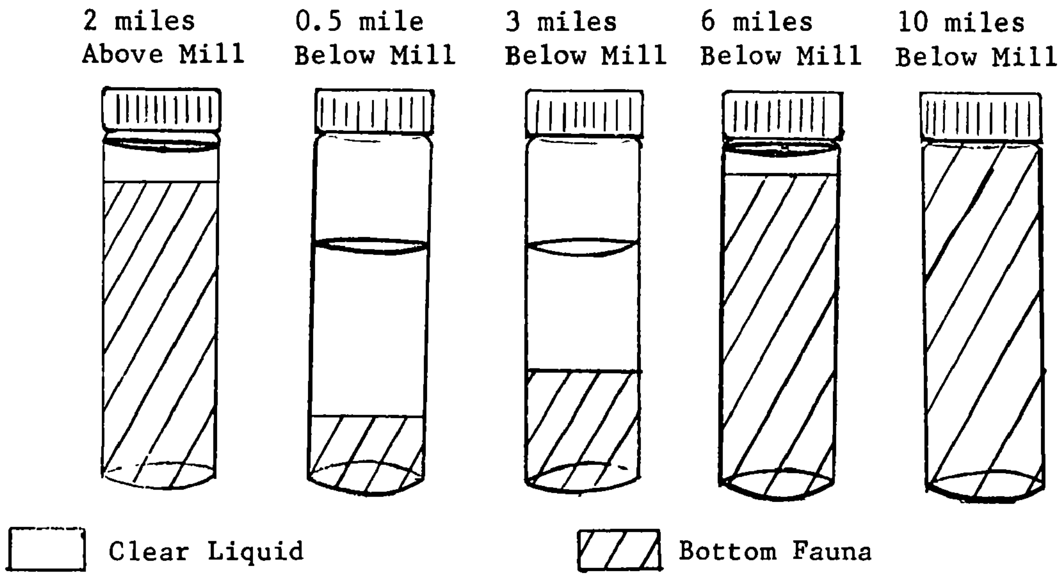
The volume of organisms per square yard was about the same at the station upstream from the mill and at the stations 6 and 10 miles downstream. The collection was composed mainly of caddis, stone, dragon and may flies. At the stations near the Helium Plant water intake (0.5 mile below the mill) and near the USGS gage (3 miles below the mill), the bottom organisms were far less numerous but consisted of a fairly good variety. It is likely that this sparcity of organisms was the residual result of the relatively large amount of toxic wastes released during the accidental uranium mill spill of August 22-23, 1960 rather than an effect of continuous mill discharges under normal operation. The bottom fauna at the stations 6 and 10 miles below the mill apparently were not affected by adverse conditions during the preceeding few months.

Since the flow in the river in August 1960, at the time of the spill, was very low, there is a likelihood that much of the wastes released accidentally at that time traveled in a somewhat confined channel, and marginal areas received little of this effluent. Effort was made, during this survey, to sample what appeared to be the main channel in riffles, and duplicate the area covered by the flowing stream in August of 1960.

There is considerable value in future sampling of biological life in the San Juan River in the vicinity of Shiprock during a period of very low flow. Although such activity will have little value in estimating the past effects of the spillage of mill wastes in August 1960, the effect of continous discharges from the uranium mill area may be evaluated more fully.

Figure 4

Relative Volumes of Bottom Fauna Collected from One Square Yard
San Juan River at Shiprock, New Mexico, November 1960



SUMMARY AND CONCLUSIONS

1. An eight-day field survey was undertaken in the Shiprock, New Mexico area during November 15-23, 1960 to determine the pollutional significance of the many seeps and drainages to the San Juan River from the general area of the Shiprock uranium mill. The quality of river water above and below Shiprock and of the water supplies for the town of Shiprock and the Navajo Helium Plant were also determined. This survey was a follow-up to determine residual effects of an accidental spill of toxic wastes released from the Shiprock uranium mill on August 22-23, 1960. Water quality conditions were evaluated on the basis of radiological, chemical and biological data collected in the study area.

2. The proximity of a number of seeps to the Kerr-McGee uranium milling activity, and the relatively high chemical and radioactivity content of seepage indicate that the source of this seepage very likely is the tailings and/or barren liquor ponds at the mill.

Discharge via the mill drain, consisting of cooling water and wasted process water, is the most important single source of direct mill pollution to the San Juan River because it comprises the majority of total surface waste discharge from the mill. The flow in the mill drain is affected by variations in plant processing but additionally it was found that considerable radiological contamination was present in the form of deposits probably resulting from the accidental mill spill of August 1960.

3. The range in average dissolved radioactivity levels of the various seepages and mill drain effluent were 17 to 860 μμc/l alpha activity, 150 to 1600 μμc/l beta activity, 340 to 4800 μg/l uranium and 0.2 to 5.0 μμc/l radium-226.

Radioactivity in muds collected from seeps soemwhat distant from the mill proper were in the order of 1-3 times background levels. The cooling and process water ditches (Stations 10C and 10S) leading to the main drain, the seep as measured by Station 11 and the main drain at Station 10 contained muds showing very high radioactivity. For these samples, gross alpha activity ranged from 440 to 2200 μμc/g, gross beta from 600 20 2600 μμc/g and radium from 39 to 120 μμc/g.

Seep and drain liquors were relatively high in levels of various chemical constituents. The range in average values were hardness, 1900 - 10,600 mg/l; sulfate 2,400 to 3,900 mg/l; nitrate (asNO_3) 111 to 1550 mg/l; and total dissolved solids (estimated), 9,000 to 14,000 mg/l.

4. Radioactive and chemical pollution of the river by direct surface discharge of the seeps and mill drain were negligible under conditions prevailing at the time of survey. However, chemical pollution from these sources at times of very low river flow would be significant.

5. Efforts should be made to seal or other wise maintain high impermeability of the beds of various storage ponds and lagoons on the mill site. Significant radioactive contamination of the mill drain by the previous spill of August, 1960 illustrates the long-term contamination caused by such incidents which must be prevented by correct waste-ponding practices. The source of radioactive contamination in the cooling water and water overflow ditches need be more precisely determined and measures taken to correct this situation. The radiological and chemical quality of the cooling water before it passes near the barren waste liquor ponds should be evaluated. The routing of this discharge as found in November, 1960 is highly undesirable and should be altered.

6. Radioactivity levels in all water and sediment samples collected from the San Juan River above and below Shiprock were in the range of background.

From chemical analyses of river water samples, it was found that average sulfate and hardness levels in the San Juan above Shiprock were respectively 300 and 340 mg/l. Substantial increase in both of these chemical values in the order of 20 to 35 percent was evident in the stretch of river in the near vicinity of an below Shiprock. Total dissolved solids (although not measured directly) and nitrate levels in river water in this same area showed similar increases. It is noted that sulfate, hardness and total dissolved solids levels in river water above Shiprock were in excess of generally accepted limits if this water were to be used for domestic supply without suitable means of treatment. This water quality is undoubtedly affected by natural influences upstream of Shiprock.

7. Radiological quality of all samples collected of the Shiprock and Helium Plant raw water supplies was in the range of background.

Sulfate, hardness and chloride levels of the Helium Plant raw water were somewhat higher than respective concentrations in the river water immediately upstream of the infiltration galleries. In the case of the Shiprock supply, the relative increases were even greater. Concentrations of nitrate and manganese are apparently higher in both raw water supplies than in river water at the intake locations. The State of New Mexico has collected data in the past which shows that nitrate levels (expressed as NO_3) in the Helium Plant water system has ranged from 0.4 to 8.9 mg/l, and nitrate in the Shiprock water system has ranged from 124 to 195 mg/l. Further studies are necessary to determine levels of iron, manganese and most importantly that of nitrate, over an extended period of time. These should be related to Drinking Water Standards.

8. Sizeable increases in sulfates and hardness of San Juan River water in the vicinity of Shiprock indicate probable ground water contribution of these constituents. Higher concentrations of certain chemical values in the Shiprock and Helium Plant raw water supplies over and above that found in the river and the high chemical concentrations of the seep liquors further indicates chemical pollution of ground water particularly from the immediate area of the uranium mill. Also some correlation exists between the chemical makeup of seep liquors as compared to the mill drain effluent and to the makeup of ponded liquors on the mill site. A detailed geological investigation is recommended to determine the configuration of the ground water table, the sources and extent of, and the path of travel of ground water contamination in this area.

9. The bottom fauna population in the San Juan River immediately below Shiprock apparently was in a state of recovery from the August 1960 uranium mill spill. The bottom fauna further downstream (6 miles or greater) apparently were not affected by these adverse conditions. There is much value in sampling biological life during period of low flow to evaluate the effect of continuous waste discharges from the Shiprock uranium mill on this environment.

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APPENDIX A

MILL PROCESS AND WASTE DISPOSAL PRACTICES (at the time of the November, 1960 Study)

The Kerr-McGee Oil Industries began operations at its Shiprock, New Mexico uranium mill in 1954. Nominal capacity of the mill when completed was 400 tons per day of ore. At the time of the November, 1960 Survey, the plant was processing between 400 and 500 tons of ore per day.

Ore is crushed, sampled, and ground to 18 mesh in a rod mill. Fine ore is fed to the first of six agitators in series where water and sulfuric acid are added. At a pH of 1.0 in the agitators the uranium is leached from the ore pulp.

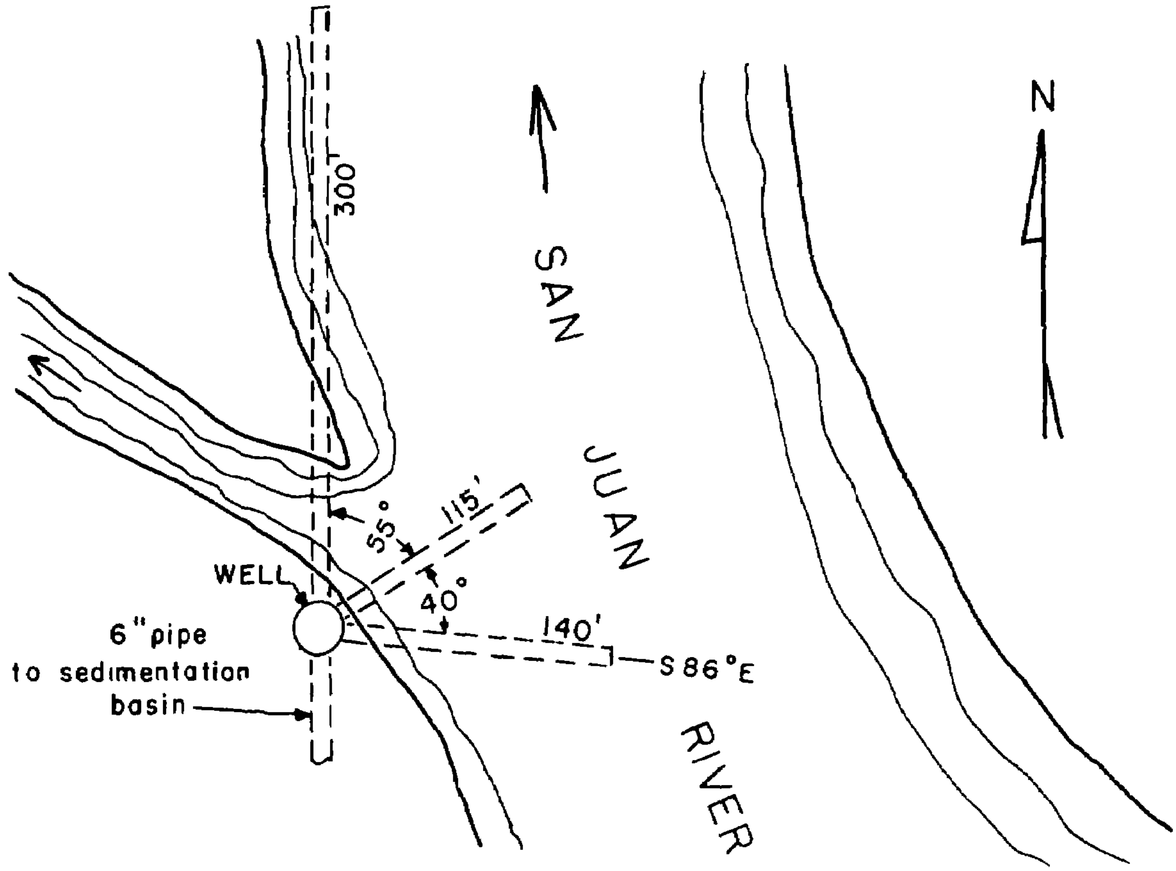
A sand-slime separation is made on the ore pulp in cyclone separators with the sands being sent through four spiral classifiers and the slimes through four thickeners. Fresh water is added to the No. 4 thickener and also to the No. 4 classifier, and solids are washed as the liquid flows counter-current to the solids through the four stages. The pregnant overflow liquor from the No. 1 thickener is sent to the uranium recovery section. Underflow from the No. 4 thickener and the sands from the No. 4 classifier are mixed and pumped to the tailings pond. The pH of this slurry is about 2.0.

Uranium in the pregnant liquor is extracted in a 4-stage mixer-settler solvent extraction circuit. The solvent used consists of 95 percent kerosene and approximately equi-molar concentrations of tributyl phosphate and di-2-ethylehexyl phosphoric acid to make up the remaining 5 percent. Raffinate from the extraction flows to the barren waste ponds. This waste liquor also has a pH of 2.0 and an approximate flow of 130 gallons per minute. Solvent losses from the system amount to 1/2 gallon per 1,000 gallons of aqueous solution. This is reduced to 0.1 gallon of solvent per 1,000 gallons aqueous by de-entrainment.

The uranium is stripped from the solvent with a 10 percent sodium carbonate solution and the solvent is recycled. Pregnant carbonate liquor is acidified to a pH of 3.0 and ammonia is added to precipitate the uranium. This slurry is filtered and the "yellow cake" product is dried and drummed for shipment. The filtrate is pumped to the barren waste ponds.

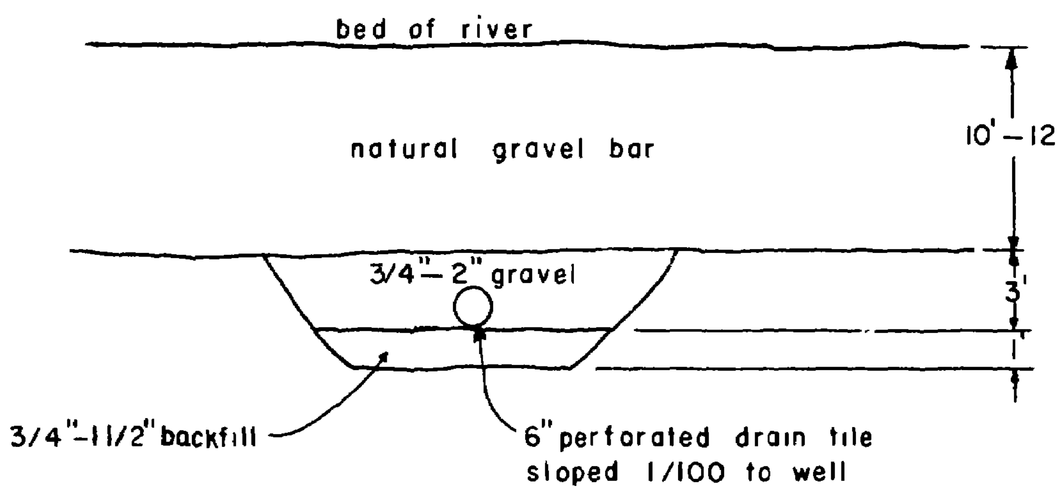
HELIUM PLANT SHIPROCK, NEW MEXICO

INFILTRATION GALLERIES



PLAN

Scale: 1" ≅ 100'



CROSS – SECTION

TOWN OF SHIPROCK, N. MEX. INFILTRATION GALLERIES