United States Tritium Rainout and Its Hydrologic Implications

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Abstract. Tritium concentrations of precipitation, total rainout, and rainfall amounts for 1964 and 1965 are listed for 15 stations in the conterminous United States, Alaska, and Puerto Rico. These data show that the major increase in tritium rainout observed in 1963 was followed by a decline of about 27% in 1964 compared with 1963, and an additional decline of about 51% in 1965 compared with 1964. Rainout patterns are characterized by increases in tritium rainout with northern latitudes and with distance from the oceans. The total tritium rainout, being a function of both concentration and amount of precipitation, is more random than average tritium concentration. Seasonal, annual, and even ten-year tritium pulses have provided a valuable tag for tracing water in many kinds of hydrological and meteorological investigations. The tritium data now available make it possible to estimate the tritium input to the hydrologic environment at any part of the United States. (Key words: Radioactivity; precipitation; quality of water; tracers)

INTRODUCTION

The Water Resources Division of the Geological Survey, charged with appraising the water resources of the nation, has continually searched for new methods for tracing water through the hydrologic cycle to provide a better basis for efficient and effective water use. Water can be traced through complex natural processes by labeling it with a suitable tag. Dyes and other easily detectable chemicals such as salts have provided the hydrologist with a tool useful in some kinds of investigations but of limited use in others. In recent times radioactive isotopes have been found superior to nonradioactive isotopes as water tracers for many investigations, because relatively small amounts are easily detected, and a more accurate indication of hydrologic parameters can be obtained.

One important water tracer is tritiated water (HTO). Tritium, a radioactive isotope of hydrogen, incorporates in the water molecule in much the same way as other hydrogen isotopes and, therefore, provides an excellent label for water. It decays by emitting low energy beta radiation, and it has a half-life of 12.26 years. Tritium concentrations are generally measured and recorded in tritium units (TU), where one tritium unit is defined as equal to one tritium atom in 10^{18} protium atoms and is approximately equal to 3.2 picocuries per liter. Being radioactive, tritium introduces a time factor that makes it useful in determining the age of some waters.

The most significant natural source of tritium is the interaction of cosmic rays with the atmosphere. The production rate is considered to be constant, and the tritium thus produced oxidizes rapidly to HTO and comes to the Earth's surface in precipitation. Precipitation water before 1952 has been estimated to contain a tritium concentration of 2 to 10 TU, depending on geographical location and weather phenomena [*Kaufman and Libby*, 1954, p. 1337; *Libby*, 1961]. This value assumes a constant production rate before 1952, and it is fundamental in dating ground and other waters that have been isolated from recent tritium sources.

Shortly after tritium was found in natural water, testing of nuclear devices placed enough artificially produced tritium in the atmosphere to mask natural levels completely. This has complicated the process of dating water using natural levels of tritium. However, high modern tritium levels are useful in many studies where a pulse of tritium can be followed through the system under investigation. In the last few years, a large pulse of tritium, which will be useful in future water dating and tracing investigations, has been added to the hydrologic environment.

To document tritium input to surface and ground waters, the U. S. Geological Survey established a network in 1958 for collecting and testing rainwater samples for tritium activity. Since about January 1963, the network has included 15 stations, collecting bi-weekly samples for tritium analysis. U. S. Geological Survey tritium data from 1958–1963 are published in reports by *Thatcher* [1962], *Thatcher and Hoffman* [1963], and *Stewart and Hoffman* [1966]. This report covers 1964–1965 tritium rainout data with some reference to earlier data for comparison purposes. The primary purpose of this report is to document tritium rainout data, to discuss general observations, and to point out important hydrologic implications. Subsequent reports will list tritium data for 20 United States rivers and will give more detail on the meteorological factors causing observed rainout patterns as well as trends less general than those included here.

THE NETWORK

To provide bases for natural tritium input to the hydrologic systems of the Nation and yet hold the sample testing volume to a manageable level, stations were selected where they could be representative of a large segment of the surrounding country. Where possible, the stations were located in cities where U. S. Geological Survey personnel could collect the samples. In some cases, however, it was advantageous to locate the stations at regular U. S. Weather Bureau stations. The Washington, D. C., and Boston, Massachusetts, stations are operated by U. S. Weather Bureau personnel. Other stations, operated by the Geological Survey, include: Albuquerque, N. Mexico; Bismarck, North Dakota; Denver, Colorado; Lincoln, Nebraska; Madison, Wisconsin; Menlo Park, California; Ocala, Florida; Palmer, Alaska; Portland, Oregon; St. Louis, Missouri; Salt Lake City, Utah; and San Juan, Puerto Rico. The station at Baton Rouge, Louisiana, was discontinued in 1965.

SAMPLING AND ANALYTICAL METHODS

Samples were collected in standard 8-inch U. S. Weather Bureau rain gages. In most cases the samples represent bi-weekly composites; however, some samples from Boston and San Juan are composited over a longer period of time. The usual procedure was to collect all the precipitation falling in the rain gage during the two-week period. At the close of the two-week period, with the exception of periods in which no precipitation occurred, about 200 ml of sample was poured into polyethylene containers, labeled with pertinent information, and sent to the tritium laboratory in Washington, D. C., for analysis. Stations collecting composites for a longer period of time poured all of the precipitation from each rain into a large bottle from which a representative composite sample was taken for tritium analysis. Generally, the amount of precipitation was measured in the rain gage at the end of the two-week period. Occasionally it was not measured, so that precipitation amounts were estimated from records for the nearest U. S. Weather Bureau station. Occasionally samples were lost in shipping or were not collected, and tritium concentrations were estimated using available tritium data for the station and trends observed at other stations. Samples or time periods for which precipitation amounts or tritium concentrations were estimated are marked in the tables. The errors introduced into annual weighted average concentrations and total rainout by these estimates are negligible.

Specific analytical procedures used to measure tritium radioactivity, except for a few refinements, are outlined by *Hoffman and Stewart* [1966]. High activity samples (generally greater than 500 TU) were counted directly, using a liquid scintillation spectrometer and/or a gas counting system employing Geiger-Müller or proportional detectors.

Before counting by one of the two counting methods, low activity samples were enriched in tritium activity by employing electrolytic procedures.

TRITIUM RAINOUT DATA

The tritium rainout data for 1964 and 1965 are listed in Tables 1 and 2. The location of the sampling station, the collection period, the amount of precipitation, the tritium concentration, and the total tritium rainout are given for each sample collected. The total tritium rainout (TU-cm) is the product of the tritium concentration times the amount of precipitation during the collection period (1 TU-cm $\cong$ 3.2×10^{-3} picocuries per cm^2 of land surface area). Weighted-average tritium concentrations were

Table 1.—*Tritium rainout data for 1964*

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Albuquerque, New Mex.							
Jan. 1–15	0.13	1,110	140	July 16–30	0.71	1,230	870
Jan. 16–29	.08	855	65	Aug. 1–15	2.13	790	1,680
Feb. 1–15	.28	2,560	660	Aug. 19–26	.46	760	350
Mar. 1–15	.41	3,520	1,405	Sept. 1–15	2.44	920	2,245
Mar. 16–31	.03	1,880	45	Sept. 16–30	1.27	610	775
Apr. 1–15	.94	3,640	3,430	Nov. 1–15	.38	230	90
Apr. 16–30	1.12	5,040	5,645	Dec. 1–15	1.45	420	610
May 16–31	.46	2,900	1,335				
July 1–15	2.66	1,830	4,870	Total	14.95		24,200
Baton Rouge, La.							
Jan. 1–Feb. 2	18.24	390	7,110	Apr. 20–26	11.48	195	2,240
Feb. 3–9	2.46	290	715	Mar 18–24	3.56	334	1,190
Feb. 10–16	1.27	260	330	Sept. 3–Oct. 7	15.88	135	2,140
Feb. 17–Mar. 1	14.02	600	8,410	Oct. 8–17	*1.20	80	95
Mar. 2–8	5.89	220	1,300	Oct. 18–Dec. 5	10.54	115	1,210
Mar. 9–22	9.24	350	3,230	Dec. 6–18	*7.41	120	890
Mar. 23–Apr. 12	7.14	500	3,570				
Apr. 13–19	2.62	280	735	Total	110.94		33,165
Bismarck, N. Dak.							
Jan. 9–24	1.78	1,740	3,100	July 6–19	4.70	2,990	14,050
Jan. 27–Feb. 3	.51	1,830	935	July 20–Aug. 30	4.06	2,850	11,570
Feb. 24–Mar. 22	.51	3,020	1,540	Aug. 31–Sept. 27	2.66	1,220	3,250
Mar. 24–Apr. 5	1.27	2,760	3,500	Sept. 28–Nov. 1	.30	980	295
Apr. 16–19	.38	3,730	1,420	Nov. 2–15	.08	965	75
Apr. 20–May 3	9.27	2,980	27,630	Nov. 16–29	1.02	1,000	1,020
May 4–17	2.16	4,060	8,770	Nov. 30–Dec. 27	1.02	1,110	1,130
May 18–June 7	1.78	5,180	9,220				
June 8–21	1.30	3,500	4,550	Total	38.13		107,405
June 22–July 5	5.33	2,880	15,350				
Boston, Mass.							
Jan. 1–Feb. 20	21.16	1,440	30,500	Oct. 20–21	1.75	340	595
Feb. 21–Apr. 7	11.43	1,800	20,570	Oct. 22–Dec. 31	1.75	205	360
Apr. 8–May 18	8.56	1,120	9,590				
May 19–June 30	5.13	1,750	8,980	Total	68.98		112,985
July 1–Sept. 30	19.18	2,210	42,390				
Denver, Colo.							
Jan. 1–12	0.62	2,280	1,410	July 2–15	0.94	3,270	3,070
Feb. 1–2	.43	2,820	1,210	July 16–Aug. 3	.91	1,530	1,390
Feb. 12–14	.99	2,950	2,920	Aug. 4–15	.15	1,200	180
Feb. 15–Mar. 2	2.24	3,040	6,810	Aug. 16–Sept. 1	.48	1,330	640
Mar. 3–15	.51	2,810	1,430	Sept. 2–15	.08	1,120	90
Mar. 17–Apr. 3	1.80	3,700	6,660	Sept. 16–Oct. 1	.96	1,060	1,020
Apr. 4–15	.46	4,620	2,150	Oct. 2–15	.46	1,280	590
Apr. 16–May 15	.64	9,570	6,120	Nov. 1–15	1.32	920	1,210
May 16–June 1	6.86	4,780	32,790				
June 2–15	1.02	5,150	5,250	Total	21.25		76,370
June 16–July 1	.38	3,810	1,450				
Lincoln, Nebr.							
Jan. 1–15	0.53	2,330	1,230	July 19–31	1.44	1,450	2,080
Feb. 1–15	1.80	2,550	4,590	Aug. 8–14	1.68	1,100	1,850
Feb. 18–Mar. 3	.13	3,740	470	Aug. 17–Sept. 1	8.15	1,090	8,880
Mar. 8–20	2.84	2,180	6,190	Sept. 5–17	2.31	840	1,940
Mar. 25	.43	2,290	980	Sept. 18–30	4.52	905	4,090
Apr. 4–20	3.71	1,980	7,350	Oct. 1–15	.96	890	850
Apr. 22–28	2.74	4,040	11,040	Oct. 21–Nov. 6	.05	935	50
May 1–11	5.16	2,110	10,890	Nov. 12–15	.68	520	350
May 16–30	1.75	1,600	2,800	Nov. 16–30	.08	960	70
June 1–14	15.11	1,880	28,410	Dec. 1–16	1.24	415	515
June 15–30	6.62	1,710	11,320				
July 2–17	7.95	2,090	16,610	Total	69.88		122,555

*Precipitation amount estimated from Weather Bureau records.

Table 1.—*Tritium rainout data for 1964*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Madison, Wis.							
Jan. 1–15	0.10	2,310	230	July 16–31	8.38	1,490	12,490
Jan. 16–31	1.68	655	1,100	Aug. 1–31	8.51	960	8,170
Feb. 1–15	.48	3,150	1,510	Sept. 1–15	2.51	1,050	2,640
Mar. 1–15	3.71	3,460	12,840	Sept. 16–30	3.10	775	2,400
Mar. 16–31	1.68	2,100	3,530	Oct. 1–31	.53	1,200	635
Apr. 1–15	4.04	1,750	7,070	Nov. 1–15	2.76	200	550
Apr. 16–30	3.96	2,680	10,610	Nov. 16–30	.53	480	255
May 1–15	11.84	3,750	44,400	Dec. 1–31	.64	285	180
May 16–31	4.16	2,460	10,230				
June 1–30	5.94	1,840	10,930	Total	66.76		136,090
July 1–15	2.21	2,860	6,320				
Menlo Park, Calif.							
Jan. 6–20	1.16	410	475	June 9–22	1.27	395	500
Jan. 21–Feb. 3	6.58	320	2,110	Aug. 17–31	.38	755	290
Feb. 4–17	.46	365	170	Oct. 26–Nov. 9	4.90	485	2,380
Feb. 18–Mar. 2	.33	370	120	Nov. 10–23	4.42	255	1,130
Mar. 3–16	.64	630	460	Nov. 24–Dec. 2	.51	235	120
Mar. 17–31	1.75	655	1,150	Dec. 7–21	1.62	410	660
Apr. 1–13	.43	1,270	545	Dec. 22–31	14.00	145	2,030
Apr. 27–May 11	.58	485	280				
May 25–June 8	.53	640	340	Total	39.56		12,695
Ocala, Fla.							
Jan. 2–15	10.87	75	815	July 30–Aug. 12	12.26	580	7,110
Jan. 16–29	9.80	190	1,860	Aug. 13–26	8.64	230	1,990
Jan. 30–Feb. 12	8.26	230	1,900	Aug. 27–Sept. 9	.53	190	100
Feb. 13–26	2.64	315	830	Sept. 10–23	28.91	180	5,200
Feb. 27–Mar. 9	3.56	245	870	Sept. 24–Oct. 17	2.82	180	510
Mar. 10–25	5.11	340	1,740	Oct. 18–21	2.24	150	335
Mar. 26–Apr. 8	4.92	575	2,830	Oct. 22–Nov. 4	.81	135	110
Apr. 9–May 6	13.11	275	3,620	Nov. 19–Dec. 2	1.16	50	60
May 7–June 17	3.40	360	1,220	Dec. 3–16	8.20	115	940
June 18–July 1	9.58	780	7,470	Dec. 17–30	5.82	95	550
July 2–15	14.58	530	7,730				
July 16–29	19.68	350	6,890	Total	176.90		54,680
Palmer, Alaska							
Jan. 1–5	1.22	1,290	1,570	June 29	4.39	3,050	13,390
Feb. 10–17	1.02	1,190	1,210	June 30–July 13	4.06	2,890	11,730
Feb. 18–Mar. 9	1.02	1,870	1,910	July 14–Aug. 3	3.30	3,460	11,420
Mar. 10–23	1.54	2,150	3,310	Aug. 4–31	2.28	1,180	2,690
Mar. 27–Apr. 6	.71	4,780	3,390	Sept. 1–10	3.40	980	3,330
Apr. 7–20	1.27	1,895	2,410	Oct. 7–30	4.39	630	2,770
Apr. 21–May 4	.53	3,440	1,820	Dec. 1–31	1.52	1,180	1,790
May 19	1.30	3,580	4,650				
May 20–26	1.14	4,130	4,710	Total	31.44		76,520
June 1–15	1.65	2,680	4,420				
Portland, Oreg.							
Jan. 1–6	2.79	590	1,650	June 24–July 7	0.20	1,040	210
Jan. 7–22	13.56	470	6,370	July 21	1.27	1,080	1,370
Jan. 23–Feb. 4	10.18	470	4,780	July 22–Aug. 4	.81	790	640
Feb. 5–18	1.19	550	655	Aug. 5–18	.58	700	405
Feb. 19–Mar. 3	2.31	440	1,020	Aug. 19–Sept. 1	.71	660	470
Mar. 4–17	4.47	970	4,340	Sept. 2–15	.51	670	340
Mar. 18–31	.94	860	810	Sept. 16–Oct. 13	3.56	375	1,340
Apr. 1–7	1.47	800	1,180	Oct. 14–21	.84	225	190
Apr. 28	2.18	850	1,850	Oct. 22–Nov. 10	5.76	270	1,560
Apr. 29–May 2	2.28	1,100	2,510	Nov. 11–Dec. 8	9.90	330	3,270
May 12–26	1.14	1,150	1,310	Dec. 9–22	16.78	210	3,520
May 27–June 9	2.84	1,010	2,870				
June 10–23	2.28	1,510	3,440	Total	88.55		46,100

Table 1.—*Tritium rainout data for 1964*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
St. Louis, Mo.							
Jan. 9–13	2.06	1,460	3,010	June 16–July 1	1.88	1,750	3,290
Jan. 19–31	2.26	1,480	3,340	July 2–10	1.02	2,510	2,560
Feb. 5–15	4.88	1,830	8,930	July 11–31	9.24	2,000	18,480
Feb. 18–26	.96	3,070	2,950	Aug. 16–31	6.07	400	2,430
Mar. 1–15	7.10	1,620	11,500	Sept. 16–31	3.70	525	1,940
Mar. 16–31	2.64	1,610	4,250	Oct. 1–31	1.85	570	1,060
Apr. 1–15	6.58	990	6,510	Nov. 15–30	9.75	190	1,850
Apr. 16–30	6.10	1,220	7,440	Dec. 2–12	1.88	360	675
May 1–15	.76	3,360	2,550	Dec. 16–31	1.27	430	545
May 16–24	6.04	1,876	11,295				
June 1–15	5.60	3,040	17,020	Total	81.64		111,620
Salt Lake City, Utah							
Jan. 1–12	0.33	1,430	470	Aug. 17–30	0.20	1,210	240
Jan. 13–19	.74	1,750	1,290	Sept. 8	.13	1,040	135
Jan. 20–26	1.04	2,130	2,220	Sept. 14–20	.51	1,130	580
Jan. 27–Feb. 17	.71	3,140	2,230	Sept. 21–27	.28	1,610	450
Feb. 23–Mar. 1	.38	3,820	1,450	Oct. 26–Nov. 1	1.22	960	1,100
Mar. 2–15	3.81	2,370	9,030	Nov. 2–8	.66	1,020	670
Mar. 16–29	2.38	2,480	5,900	Nov. 9	2.92	775	2,260
Mar. 30–Apr. 12	2.79	4,130	11,520	Nov. 16	.25	1,030	260
Apr. 13–19	1.65	3,540	5,840	Nov. 23–28	.20	900	180
Apr. 20–25	5.08	4,300	21,840	Dec. 13	1.27	305	390
Apr. 26–May 3	5.13	4,560	23,390	Dec. 15	3.00	665	2,000
May 4–10	3.20	5,580	17,860	Dec. 27	8.10	390	3,160
May 18–31	1.47	6,400	9,410	Dec. 28–31	1.10	640	705
June 1–7	3.12	2,020	6,300				
June 8–28	5.31	3,010	15,980	Total	58.40		148,330
Aug. 3–16	1.42	1,030	1,460				
San Juan, P. R.							
Feb. 1–15	1.34	145	190	Aug. 12–31	8.50	150	1,280
Mar. 1–15	2.87	120	345	Sept. 9–28	17.81	150	2,670
Apr. 1–30	4.60	205	945	Sept. 29–Oct. 13	9.10	90	820
May 1–28	3.25	190	620	Oct. 14–Nov. 23	4.00	160	640
May 29–June 18	3.90	150	585	Nov. 24–Dec. 11	4.00	80	320
June 19–30	8.30	290	2,410	Dec. 12–22	3.66	70	255
July 2–13	9.80	150	1,470	Dec. 23–31	3.45	70	240
July 14–27	5.68	180	1,020				
July 28–Aug. 11	9.02	150	1,350	Total	99.28		15,160
Washington, D. C.							
Jan. 1–15	1.78	960	1,710	July 1–Aug. 18	6.60	1,155	7,620
Jan. 16–Feb. 1	1.65	680	1,120	Aug. 19–Sept. 1	.76	195	150
Feb. 2–16	4.70	1,130	5,310	Sept. 2–27	2.28	675	1,540
Feb. 17–29	9.02	1,220	11,000	Sept. 28–Nov. 20	11.56	1,415	16,360
Mar 1–31	5.84	1,000	5,840	Nov. 21–Dec. 30	4.19	290	1,215
Apr. 1–30	7.11	1,340	9,530				
May 1–31	5.33	1,980	10,550	Total	68.56		82,625
June 1–30	7.74	1,380	10,680				

computed by dividing the total tritium rainout for the year by the total amount of precipitation.

Time and geographical distribution patterns of tritium rainout vary from station to station because of oceanic influences and other meteorological factors. The data reported herein and earlier data [*Stewart and Hoffman*, 1966; *Thatcher and Hoffman*, 1963; *Thatcher*, 1962] show that stations near the oceans, which get their precipitation from maritime air masses, receive precipitation with low tritium concentrations, because of the dilution effects of the ocean. In comparison, the precipitation at midcontinent stations has high tritium concentrations. Curves comparing maritime tritium rainout at Ocala, Florida, with continental tritium rainout at Salt Lake City, Utah, are shown in Figure 1.

Table 2.—*Tritium rainout data for 1965*

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Albuquerque, N. Mex.							
Jan. 1–15	1.45	800	1,160	Aug. 1–15	2.33	660	1,540
Jan. 16–31	1.35	700	945	Aug. 16–31	.56	555	310
Feb. 1–15	1.47	960	1,410	Sept. 1–15	3.96	205	810
Feb. 16–28	.64	1,240	795	Sept. 16–30	.41	195	80
Mar. 1–15	1.57	750	1,180	Oct. 1–15	2.61	140	365
Apr. 3–15	1.65	780	1,290	Oct. 16–30	2.67	140	375
Apr. 16–30	.69	1,860	1,280	Nov. 28–Dec. 15	2.74	180	490
May 1–31	.69	590	405	Dec. 16–31	1.32	305	400
June 1–15	.99	410	410				
June 16–30	1.55	690	1,080	Total	31.49		15,595
July 15–31	2.84	450	1,270				
Bismarck, N.D.							
Jan. 1–23	0.64	1,050	670	July 11–24	5.97	1,960	11,720
Jan. 24–Feb. 20	1.14	1,130	1,290	July 25–Aug. 7	5.97	1,620	9,705
Feb. 21–Mar. 20	1.02	1 620	1,655	Aug. 8–Sept. 3	2.16	1,115	2,410
Mar. 21–Apr. 17	4.32	2,320	10,020	Sept. 4–18	5.97	950	5,680
Apr. 18–May 1	2.67	1,420	3,790	Sept. 19–Oct. 2	3.56	630	2,240
May 2–15	7.87	1,640	12,910	Oct. 3–30	1.14	340	390
May 16–28	4.52	1,330	6,010	Nov. 1–27	.46	490	225
June 1–12	1.52	1,800	2,740	Nov. 28–Dec. 25	.20	350	70
June 13–26	8.64	1,295	11,190				
June 27–July 10	4.83	1,220	5,900	Total	62.60		88,610
Boston, Mass.							
Jan. 1–Mar. 18	16.10	260	4,190	Sept. 30–Dec. 31	13.71	165	2,260
Mar. 19–June 22	18.01	1,150	20,710				
June 23–Sept. 29	10.40	730	7,590	Total	58.22		34,750
Denver, Colo.							
Jan. 29	1.30	750	975	June 1–14	7.57	2,070	15,670
Jan. 31	1.19	1,110	1,320	June 15–30	.56	960	540
Feb. 2–15	1.93	980	1,890	July 1–15	2.64	350	925
Feb. 16–Mar. 1	.91	2,290	2,080	July 16–31	15.06	900	13,550
Mar. 2–15	1.63	2,000	3,260	Sept. 1–15	.91	580	530
Mar. 16–31	1.60	2,640	4,220	Sept. 16–Oct. 1	3.73	550	2,050
Apr. 1–19	1.93	1,540	2,970	Oct. 15–Nov. 1	.84	380	320
Apr. 20–30	4.62	1,645	7,600	Nov. 15–Dec. 1	.91	270	250
May 1–15	1.07	2,130	2,280				
May 16–31	3.78	2,360	8,920	Total	52.18		69,350
Lincoln, Nebr.							
Jan. 1	0.10	280	30	July 16–31	5.26	760	4,000
Jan. 16–31	.74	725	535	Aug. 6	1.68	1,400	2,350
Feb. 7–15	5.71	820	4,680	Aug. 16–31	3.84	690	2,650
Feb. 16–Mar. 1	3.56	1,570	5,590	Sept. 21–30	3.99	300	1,200
Mar. 4–31	2.29	545	1,250	Oct. 18–30	1.04	250	260
Apr. 1–15	7.62	500	3,810	Nov. 1–15	1.67	320	530
Apr. 16–30	1.75	1,105	1,930	Nov. 16–30	.46	360	165
May 1–18	5.92	1,000	5,920	Dec. 1–16	2.18	275	600
May 21–25	10.01	770	7,710	Dec. 17–31	2.39	245	585
June 1–15	14.20	940	13,350				
June 20–July 1	14.76	395	5,830	Total	92.40		67,675
July 2–15	3.73	1,260	4,700				
Madison, Wis.							
Jan. 1–15	0.89	390	350	July 16–30	4.42	1,480	6,540
Jan. 16–31	3.91	525	2,050	Aug. 1–31	12.50	1,040	13,000
Feb. 1–28	1.85	515	950	Sept. 1–16	13.59	250	3,400
Mar. 1–15	4.39	910	3,990	Sept. 17–30	14.83	120	1,780
Mar. 16–31	2.34	1,380	3,230	Oct. 1–15	4.61	500	2,305
Apr. 1–15	5.51	1,095	6,030	Oct. 16–31	4.50	235	1,060
Apr. 16–30	4.39	1,180	5,180	Nov. 1–15	4.88	245	1,200
May 1–15	1.68	890	1,500	Nov. 16–30	2.51	195	490
May 16–31	3.05	890	2,710	Dec. 1–31	5.46	190	1,040
June 1–15	2.97	435	1,290				
June 16–30	1.91	995	1,900	Total	100.89		66,670
July 1–15	4.70	1,420	6,670				

Table 2.—*Tritium rainout data for 1965*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Menlo Park, Calif.							
Jan. 1–18	2.21	130	290	Apr. 12–26	1.93	220	425
Jan. 19–Feb. 1	2.72	120	325	Oct. 25–Nov. 8	.90	100	90
Feb. 2–15	1.47	195	290	Dec. 6–20	1.12	120	135
Feb. 16–Mar. 1	.71	220	155	Dec. 21–20	8.86	75	665
Mar. 2–15	.69	510	350				
Mar. 16–28	1.37	275	375	Total	28.08		5,050
Mar. 31–Apr. 11	6.10	320	1,950				
Ocala, Fla.							
Jan. 14–27	5.97	190	1,130	July 29–Aug. 11	14.30	115	1,640
Feb. 2–Mar. 10	2.69	165	445	Aug. 12–25	10.54	120	1,260
Mar. 11–24	2.90	150	435	Aug. 29–Sept. 8	4.04	65	265
Apr. 18–22	4.06	235	955	Sept. 9–22	12.34	100	1,230
Apr. 23–May 6	3.43	175	600	Sept. 27–Oct. 3	5.13	60	310
May 21–June 3	2.59	305	790	Oct. 7–20	7.11	50	355
June 5–17	17.25	225	3,880	Oct. 21–Nov. 3	.86	40	35
June 18–28	4.14	270	1,120	Dec. 13	3.84	65	250
July 1–14	17.37	240	4,170				
July 15–28	10.95	500	5,200	Total	129.51		22,160
Palmer, Alaska							
Jan. 1–Feb. 3	5.08	590	3,000	Aug. 5–18	6.38	875	5,580
Feb. 4–Mar. 4	.10	950	95	Aug. 19–31	*.01	700	10
Mar. 5–Apr. 30	1.57	725	1,140	Sept. 2–22	*11.30	305	3,450
May 30–June 3	1.40	1,180	1,650	Oct. 1–Dec. 31**	*12.04	300	3,610
June 4–July 6	3.73	1,070	3,990				
July 7–Aug. 2	3.18	1,560	4,960	Total	44.79		***27,545
Portland, Oreg.							
Jan. 1–5	11.58	330	3,820	July 21–Aug. 3	0.53	585	310
Jan. 6–19	3.43	410	1,410	Aug. 4–17	.89	425	380
Jan. 20–Feb. 2	5.08	210	1,070	Aug. 18–31	1.02	585	595
Feb. 3–16	2.80	475	1,330	Sept. 28–Oct. 12	1.29	155	275
Feb. 17–Mar. 1	3.43	325	1,110	Oct. 13–26	3.50	115	400
Mar. 2–13	1.40	830	1,160	Oct. 27–Nov. 9	5.02	115	575
Mar. 16–30	3.30	545	1,800	Nov. 10–23	5.18	150	775
Apr. 13–29	5.05	640	3,230	Nov. 24–Dec. 7	3.43	145	495
Apr. 30–May 11	1.70	260	440	Dec. 21–31	5.08	120	610
May 12–25	2.21	545	1,200				
June 8–22	1.80	725	1,300	Total	68.43		22,620
June 23–July 20	.71	470	335				
St. Louis, Mo.							
Jan. 1–15	3.86	500	1,930	July 1–15	4.90	745	3,650
Jan. 16–31	2.51	885	2,220	Aug. 1–15	3.66	640	2,340
Feb. 1–15	2.11	270	570	Aug. 16–31	5.46	320	1,750
Feb. 16–28	.84	325	273	Sept. 1–15	2.90	295	855
Mar. 1–15	3.91	880	3,440	Sept. 16–30	4.72	160	755
Mar. 16–30	2.03	785	1,590	Oct. 1–15	.79	290	230
Apr. 1–13	5.03	370	1,860	Oct. 16–31	.38	320	120
Apr. 14–30	4.29	665	2,850	Nov. 1–15	1.27	200	255
May 1–15	.64	305	195	Dec. 16–31	5.30	530	740
May 16–31	2.87	350	1,000				
June 1–15	3.02	690	2,080	Total	65.16		32,160
June 16–30	4.67	740	3,460				
Salt Lake City, Utah							
Jan. 1–10	1.07	515	550	Apr. 5–11	1.75	1,560	2,730
Jan. 11–17	.76	435	330	Apr. 12–18	.33	1,490	490
Jan. 18–24	2.11	330	700	Apr. 19–25	3.38	1,710	5,780
Jan. 25–31	3.05	390	1,190	May 3–9	3.23	2,830	9,140
Feb. 1–7	.84	580	490	May 10–16	.25	1,570	390
Feb. 8–14	1.40	1,000	1,400	May 17–23	.33	2,550	840
Feb. 22–Mar. 1	.36	1,450	520	May 24–28	1.88	2,220	4,170
Mar. 8–14	.05	1,390	70	June 1–6	.36	1,830	660
Mar. 22–28	1.02	1,270	1,300	June 7–13	.48	2,000	960
Mar. 29–Apr. 4	.66	1,440	950	June 21–26	.89	1,040	925

See footnotes at end of table.

Table 2.—*Tritium rainout data for 1965*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Salt Lake City, Utah—Continued							
June 27	0.36	1,760	635	Oct. 5–14	2.03	230	465
July 5–18	.71	625	445	Nov. 1–14	.25	210	50
July 19–Aug. 1	4.06	635	2,580	Nov. 15–28	3.96	275	1,090
Aug. 2–16	.58	515	300	Nov. 29–Dec. 12	2.06	380	780
Aug. 17–29	4.95	520	2,570	Dec. 13–26	1.40	650	910
Aug. 30–Sept. 12	5.84	255	1,490				
Sept. 13–Oct. 3	2.64	630	1,660	Total	53.04		46,560
San Juan, Puerto Rico							
Jan. 7–Feb. 11	6.40	50	320	Aug. 16–Sept. 13	4.47	45	200
Feb. 12–Mar. 4	2.13	55	115	Sept. 14–Oct. 21	4.72	30	140
Mar. 6–31	4.83	60	290	Oct. 22–Dec. 30	4.86	35	170
Apr. 1–26	6.15	50	310				
June 11–Aug. 2	28.14	95	2,670	Total	61.77		4,215
Washington, D.C.							
Jan. 4–Feb. 2	6.86	305	2,090	June 9–July 20	1.78	990	1,760
Feb. 3–Mar. 5	7.67	295	2,320	Aug. 22–Sept. 9	2.29	495	1,130
Mar. 6–27	5.21	525	2,735	Sept. 10–Dec. 1	8.12	175	1,420
Mar. 31–Apr. 14	1.40	820	1,150	Dec. 15–30	.38	200	75
Apr. 15–May 3	.76	1,030	785				
May 4–20	1.35	770	1,040	Total	36.02		14,505

*Precipitation amount estimated from Weather Bureau records at Anchorage, Alaska.
**No sample collected; tritium concentration estimated to be 300 T. U.
***The weighted average tritium concentration and the total tritium rainout values are based upon above estimates.

These curves also show annual and seasonal variations in tritium rainout.

Large peaks in the late spring-early summer period are attributed to greater vertical mixing of stratospheric synthetic tritium with the troposphere at that time of year. These peaks were very pronounced in 1963 but became less distinct in 1964, and for some stations were barely distinguishable in 1965. The highest measured tritium concentration was 12,950 TU for a precipitation sample collected at Denver, Colorado, during May 5–18, 1963. Salt Lake City and Ocala are by no means unique in their behavior; the data in Tables 1 and 2 show similar trends for the other stations.

Stations in the North generally receive higher tritium concentrations than stations in the South because of greater mixing near the poles between the tritium-rich stratosphere and the weather-producing troposphere, and because the largest thermonuclear detonation occurred in the Northern Hemisphere. Geographical distributions showing differences between stations are easily seen from the maps in Figures 2–6. In addition to showing geographical differences, the general time dependent trend in tritium rainout for individual stations is given for the years 1963–1965.

GENERAL TRENDS

From the 2–10 TU concentrations before 1952, concentrations increased with accelerated thermonuclear tests. The large thermonuclear tests in late 1962 and the nuclear test ban treaty that followed soon thereafter resulted in 1963's being the year for the greatest tritium rainout. The highest peak concentrations occurred in 1963 for all stations except Albuquerque, New Mexico (Figure 7), where peak concentration occurred in 1964. Since reaching a maximum in 1963, tritium rainout has declined each year.

Precipitation-weighted averages for all stations for 1963, 1964, and 1965 show that the 1964 tritium concentration (1220 TU) averaged about 25% less than the 1963 average (1630 TU) and about 52% greater than the 1965 average (580 TU). The 1965 average concentration was about 64% lower than the 1963 average. Tritium rainout data for 1962 are not complete for all stations reported on here [*Stewart and Hoffman*, 1966; *Thatcher and Hoffman*, 1963]; however, for the stations at Lincoln, Nebraska,

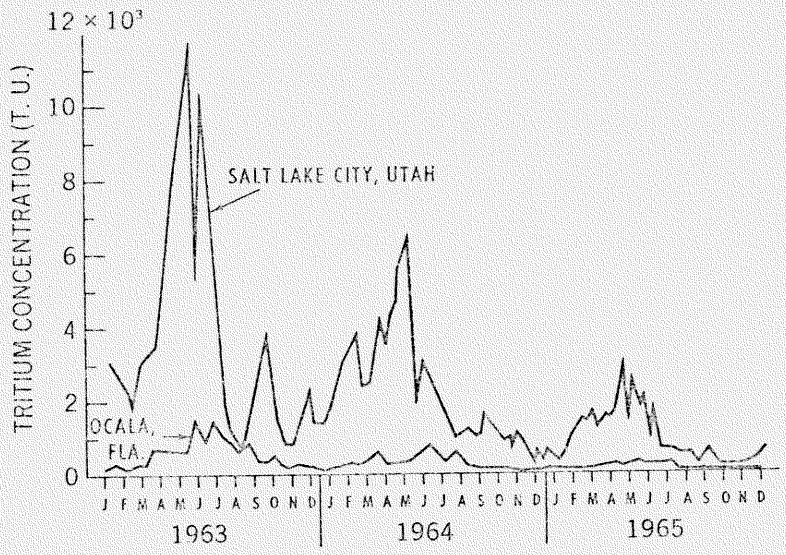

Fig. 1. Tritium concentrations of precipitation in 1963, 1964, and 1965 at Salt Lake City, Utah, and Ocala, Florida.

Menlo Park, California, Ocala, Florida, and Palmer, Alaska, they are almost complete, and comparisons with 1963, 1964, and 1965 data can be made. The 1962 weighted average tritium concentrations for these stations are as follows: Lincoln, 820 TU; Menlo Park, 170 TU; Ocala, 250 TU; and Palmer, 670 TU. The precipitation weighted average for these four stations was slightly greater in 1962 (460 TU) than it was in 1965 (420 TU), and it was about 65% below the 1963 value (1330 TU). It is not intended to imply that the values in parentheses represent an average concentration for U. S. precipitation for the specific year, but they can be compared to show general trends and the magnitude of yearly changes. The 1964 weighted average tritium concentration for Denver, Colorado, Washington, D. C., and Boston, Massa-

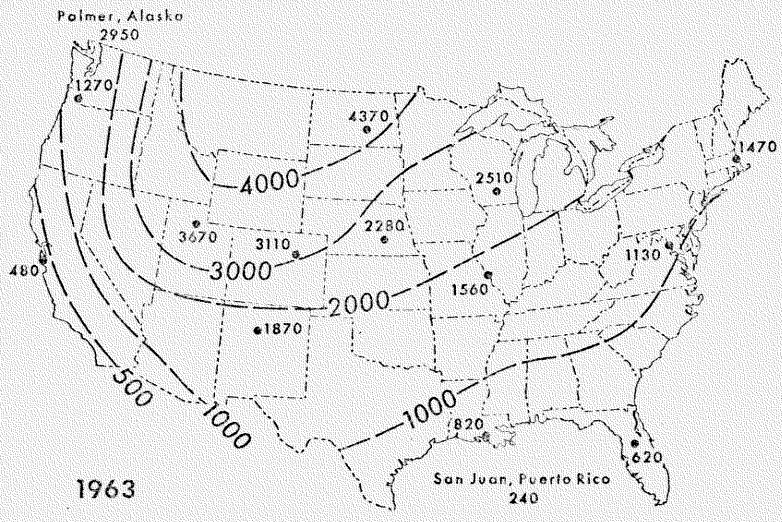

Fig. 2. Geographical distribution of weighted average tritium concentrations (TU) for 1963 precipitation.

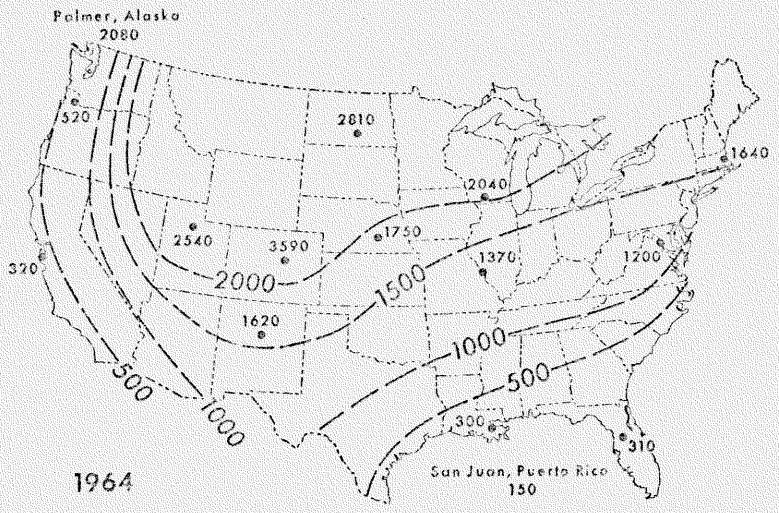

Fig. 3. Geographical distribution of weighted average tritium concentration (TU) for 1964 precipitation.

chusetts, was greater than the 1963 value. However, the total 1963 rainout for these stations was greater than in 1964.

The total tritium rainout follows trends similar to those observed for average concentrations. However, the geographical distribution pattern for total rainout (Figure 6) is not as distinct as it is for weighted average concentrations (Figures 2–5). Considering all stations in this network as being representative of the U. S., the results show that the tritium rainout in 1964 averaged about 27% less than it did in 1963 and about 54% greater than in 1965, and that the total 1965 rainout was about 67% lower than the 1963 rainout. The total 1962 rainout for Lincoln, Menlo Park, Ocala, and Palmer was as follows: 60,640 TU-cm, 6090 TU-cm, 27,390 TU-cm, and 20,170 TU-cm, respectively. Therefore, the total 1962 rainout for these four stations is about the same as the 1965 rainout, and it was about 68% lower than the 1963 rainout. Generally, the relative decrease in rainout between 1963 and 1965 was less for the midcontinent region than for coastal regions.

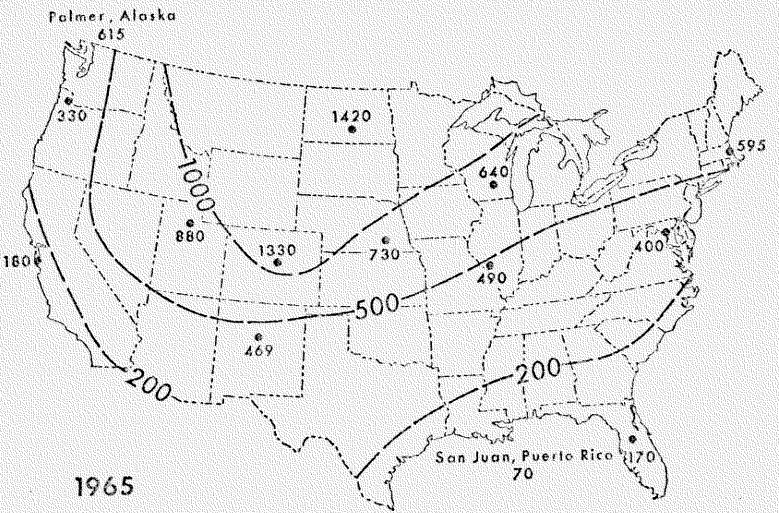

Fig. 4. Map showing weighted average tritium concentrations in 1965 precipitation.

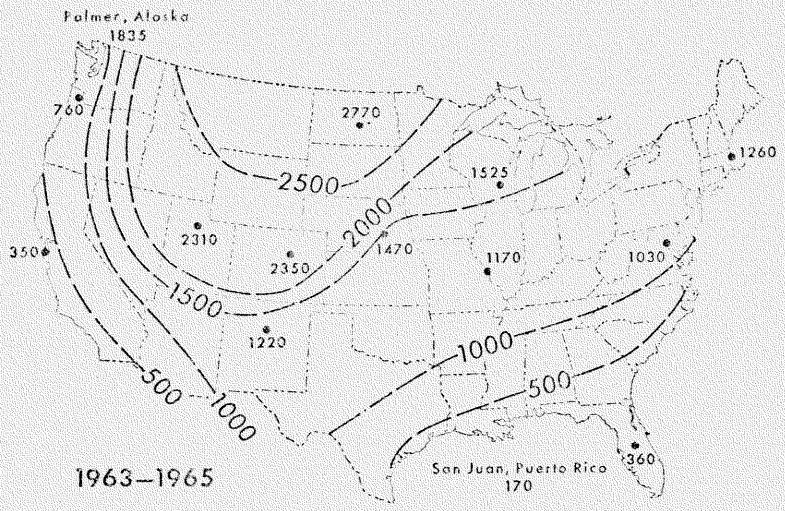

Fig. 5. Geographical distribution of weighted average tritium concentrations (TU) for 1963–1965 precipitation.

Albuquerque, Bismarck, Menlo Park, Ocala, Palmer, Portland, San Juan, and Washington, D. C., all received more tritium rainout in 1963 than they did during all of 1964 and 1965.

HYDROLOGIC IMPLICATIONS

Rainout tritium is adaptable to many kinds of hydrologic investigations, such as the following: (1) to follow water in rapid recharge areas (flow patterns, velocity, direction, regional flow systems, recharge source, interconnection of aquifers or aquifers and springs, detecting fractures and solution channels, etc.); (2) to study the amount and character of hydrodynamic dispersion (aquifer capacity, mixing of waters of various ages, turnover rates, etc.); and (3) to date water by categorizing it as generally post-hydrogen bomb or pre-hydrogen bomb water.

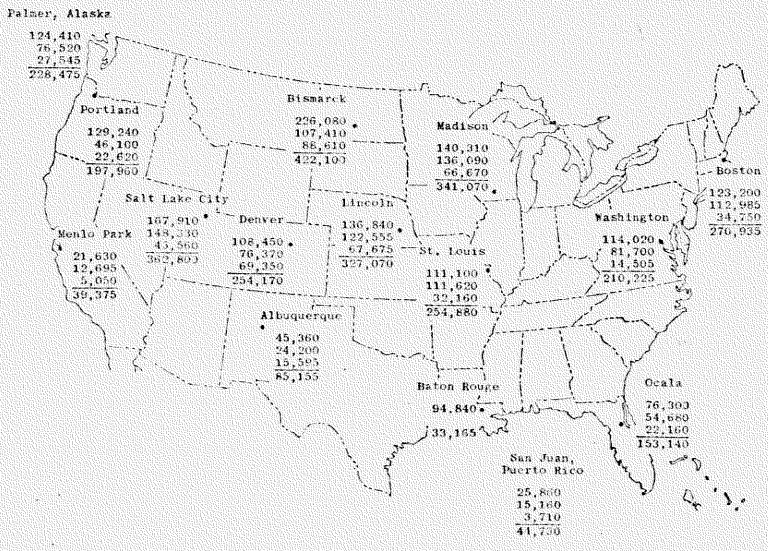

Fig. 6. Geographical distribution of total tritium rainout (TU-cm) in 1963 (top number), 1964 (second number from top), 1965 (third number from top), and the total rainout, 1963–1965 (below line). Data for Baton Rouge are incomplete.

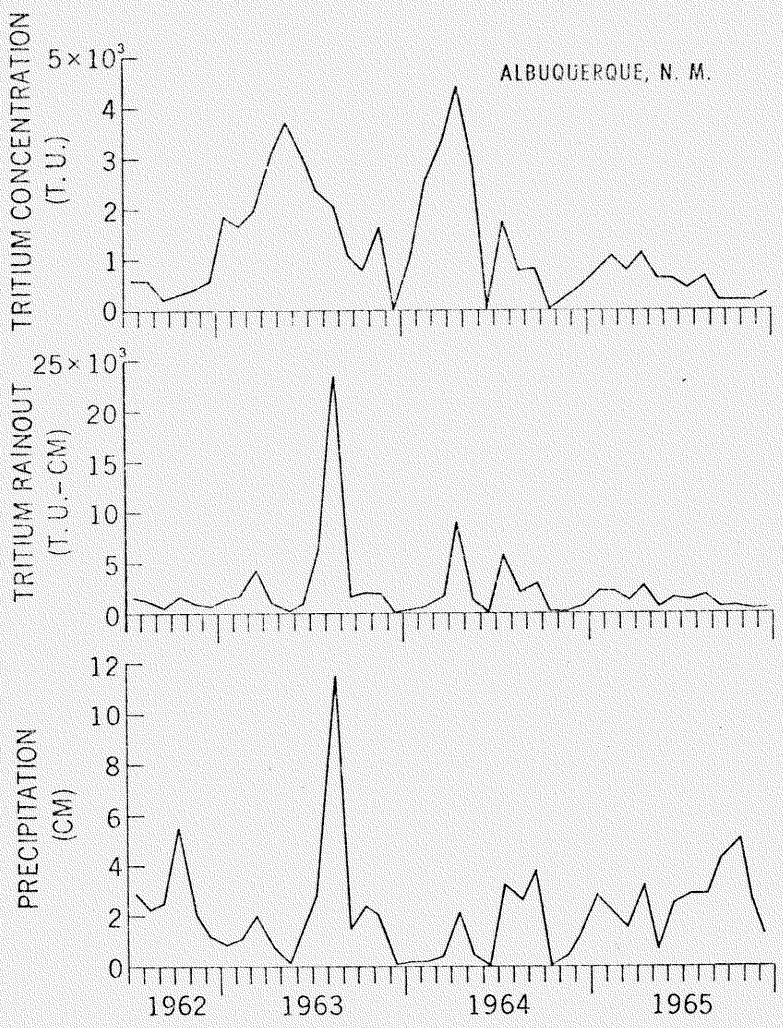

Fig. 7. The relationship between amount of precipitation, tritium concentration, and total tritium rainout for Albuquerque, New Mexico.

The successful use of tritium in any of these kinds of investigations requires that caution be used in interpreting tritium data and that conclusions be based upon sound hydrologic principles. The discussion that follows points out a few of the factors considered important in employing tritium tracer techniques in hydrologic studies and particularly in relating rainout data to field data.

Because of the high thermonuclear production of tritium, its use as a dating tool has been greatly curtailed, and its greatest potential today is not as a pure dating tool but rather in pulse tracing. As a pulse tracer, rainout tritium is best suited to areas of rapid recharge where ground water shows signs of containing tritium produced by thermonuclear devices. Because of its short half-life compared with the travel times of some ground water, not all hydrologic systems are suitable to tritium tracer investigations.

In planning a study where natural rainout tritium is to be used as a tag for water, these questions must be answered: (1) what are the tritium input levels from precipitation and what have they been? (2) what are the present tritium levels in the ground water under study? and (3) what have the natural ground-water levels been?

The answer to the questions 'what are natural ground-water levels and what have they been' is, in effect, to determine the tritium background against which the presence or absence of labeled water can be determined.

The complete absence of tritium in a ground-water sample is a sign of water age and does have hydrologic significance that should be considered as correlating evidence. Samples having a small amount of tritium can be used to estimate water age, but various factors involving hydrodynamic principles that may influence the tritium level must be considered. If on the basis of good hydrologic principles the water can be assumed to have entered the ground before 1952 and if the background before 1952 is known, then an estimate of age may be obtained by use of the decay constant. One of the main factors to consider in trying to date waters having pre-1952 tritium levels is the uncertainty as to whether a little modern precipitation containing high tritium has mixed with a lot of old water containing little or no tritium. If a sample contains higher tritium than the 1952 background, then it is certain that at least some of the water is post-1952, but again, mixing of water of various ages may be a significant factor to consider in interpretation of the tritium data.

The tritium concentration of ground water at an observation point may be affected by many factors, three of which will be considered here: (1) tritium input levels are affected by the time, intensity, and tritium concentration of precipitation and the distance this precipitation moves in surface water to the recharge area; (2) evapotranspiration of precipitation water; and (3) diffusion rates and hydrodynamic dispersion.

The effects of factors 1 and 2 are somewhat uniform throughout regions, and an attempt will be made to show that network stations are representative of other locations within the region. These two factors are related to conditions that affect the tritium input to ground water, whereas the third factor involves mechanisms that affect the tritium concentration of moving ground water.

Heavy precipitation resulting in high total tritium rainout, rather than high concentration alone, is of the greatest hydrologic importance. For some areas the highest tritium concentrations occur during periods of low amounts of precipitation, and, therefore, little tritium is added to surface and ground waters. For other locations, greater amounts of precipitation fall during the late spring or early summer when meteorological conditions favor greatest tritium concentrations in precipitation. Extreme West Coast areas, for example, receive very little precipitation in the middle of the year. Menlo Park, California, received very little precipitation in 1962, 1963, 1964, and 1965 during the period from May through September (Figure 8). As a result, during this 5-month period only about 10% or less of the total yearly tritium was rained out. In 1962 and in 1965, only a negligible amount of precipitation fell during this 5-month period, and no significant amount of tritium was rained out. In 1963, the tritium concentration peak occurred in July, but only 0.08 cm of precipitation fell. In 1964, the peak concentration occurred in April, but, with only 0.43 cm of precipitation, the total rainout during that sampling time was small compared with the sample collected for March 17–31, 1964.

The Northern Great Plains and a region extending as far south as northern Texas receive their greatest precipitation in the late spring and early summer. This condition holds for Bismarck, North Dakota, where the precipitation during the months of April, May, June, and July contained about 90% of the total 1963 tritium rainout, about 78% of the 1964 total, and about 69% of the 1965 total. More tritium was rained out at Bismarck during these four months in 1963 than was rained out during all of 1964 and 1965. The time distribution curves in Figure 9 show that the total rainout curve corresponds closely with the concentration curve, because generally the heavy rains occurred in the spring when the tritium concentration was high.

The data in Figures 7, 8, and 9 illustrate the time dependent relationship between tritium concentration, amount of precipitation, and total rainout. Of all stations in the network, Bismarck had the highest average tritium concentration (2770 TU) and the greatest total rainout (422,100 TU-cm) for the 3-year period, mainly because of its geographical location, but in part due to its precipitation distribution pattern. Whereas San Juan, Puerto Rico, had the lowest average concentration (170 TU), Menlo Park (average concentration 350 TU) had the lowest total rainout (39,375 TU-cm,

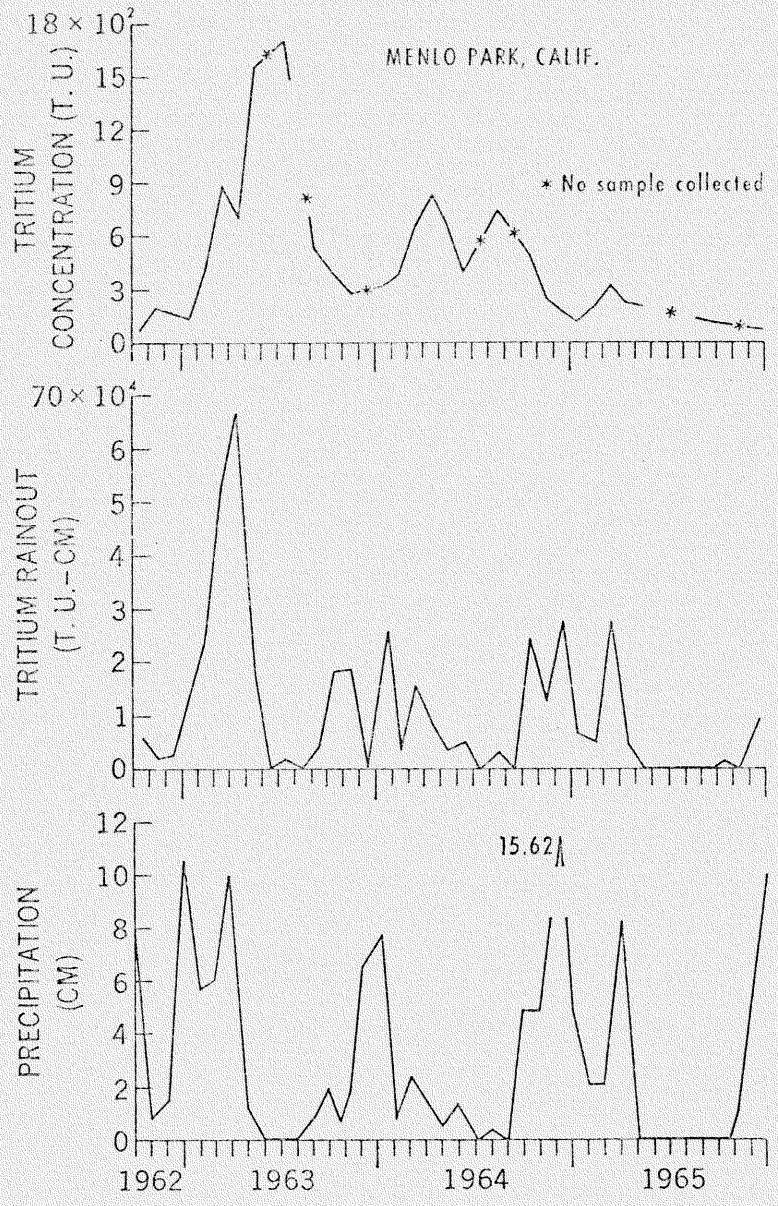

Fig. 8. Graph comparing Menlo Park, California, tritium concentration of precipitation and total rainout with the amount of precipitation. Asterisks indicate that no samples were collected during the period, since no rain fell, but that lines are drawn connecting concentration points before and after this period.

San Juan 44,730 TU-cm) of all stations for the 3-year period, because of its low rainfall during May–September. Albuquerque's total rainout is also lower than expected for its geographical location because of low total precipitation during the year. Its weighted average concentration was higher than expected when compared with some of the other stations because of the high relative amounts of precipitation during times of high tritium concentration in the atmosphere.

The second contributing factor, evapotranspiration, may cause the tritium input to ground water to differ from the input expected when

only the tritium concentration of precipitation from the principal recharge area is considered. Regions in the West and southwest United States receive very little precipitation throughout the year, and other areas such as the Pacific Coast receive little precipitation during the late spring-summer period when tritium concentrations in the atmosphere are high. The effect of precipitation on the tritium concentration of ground waters in these areas depends on the amount of precipitation that remains in the ground and the amount that is evapotranspired. Furthermore, the tritium entering the atmosphere as re-evapotranspired tritium undoubtedly influences the tritium level of subsequent storms. Although evapotranspiration effects are not well understood, they should be considered at least qualitatively when rainout data are used to make estimates of tritium input.

Studies by *Starr et al.* [1965] have shown that in some arid areas there is a net outflow of water in the atmosphere. To satisfy this con-

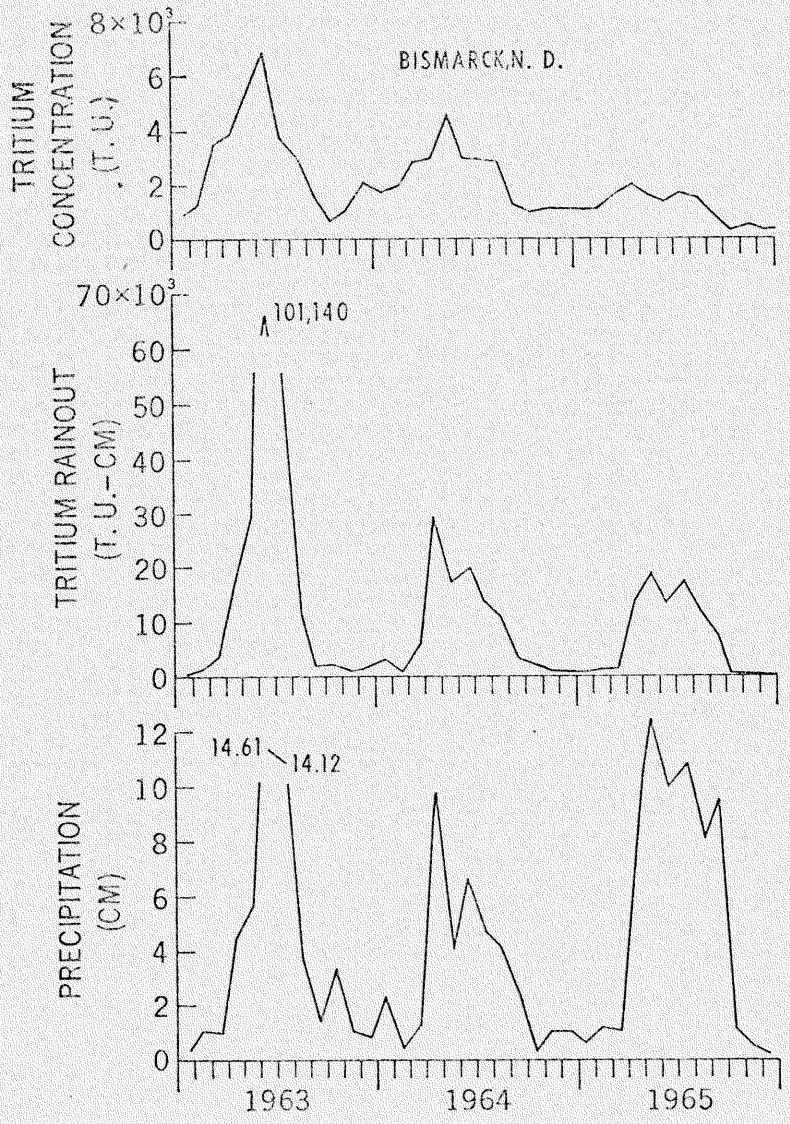

Fig. 9. The relationship between amount of precipitation, tritium concentration, and total tritium rainout for Bismarck, North Dakota.

dition requires that atmospheric outflow be balanced by an inflow of surface or shallow ground water. Under these conditions it is possible that there would be a net loss of moisture from the ground, and that the effect of precipitation on the tritium concentration of ground water would be small.

The third factor affecting the tritium concentration of ground water is associated with mixing and dispersion. Hydrodynamic dispersion, caused by heterogeneous permeabilities and flow patterns, and the removal of tracer from tracer solution by physical and chemical interactions with the porous medium are factors that affect the travel times of tracers and determine whether pulses will be identifiable. Mathematical models to describe hydrodynamic dispersion in homogeneous porous mediums are available and apparently work quite well. In the field case, however, where the system is nonhomogeneous and complex, it is difficult to define flow, and dispersion may be several orders of magnitude greater than in the more simple case of uniform mediums. Under these conditions, mathematical models are complex and may be of limited value in interpreting data.

It is beyond the scope of this report to give a quantitative and authoritative evaluation of these factors, but it is important to recognize their possible effects when relating tritium data from an observation well to tritium rainout data.

In ground-water hydrology, the systems dealt with are complex, and water movement is through nonhomogeneous materials sometimes having cracks, caverns, etc., whose presence and location are matters of speculation. It is under these types of conditions that tracers may have their greatest potential, and they may provide the best tool available to the hydrologist. If a sampling field can be set up so that pulses can be recognized from the time they enter the ground until they cross the sampling field, then the effects of hydrodynamic dispersion will not be strictly a liability but with careful study may provide bonus information about dispersion and water movement through the field.

A single measured tritium value from an observation well gives limited hydrologic information about the water from which it came, and caution must be exercised in relating data from this sample or from a single suite of samples to specific rainout events of the past. It is not intended to infer that a suite of samples, collected at the same time and down a piezometric gradient or as a function of distance from a major recharge area, does not have hydrologic significance, but its value is largely determined by the proper selection of observation points, the hydrologist's interpretation of the data, and his understanding of the system he is working with. By resampling and observing changes in tritium of ground water as a function of time, it becomes more likely that the tritium data can be related to special rainout events of the last few years. This generally requires a well planned sampling field with periodic collection combined with background knowledge of suspected major recharge areas.

For studies to be started now, the big 1962–1966 pulse and the annual pulses for this same time period are already in the ground; however, with proper sampling, it may be possible to recognize this tremendous pulse (or pulses). To undertake such a study requires that estimates of tritium inputs for the last few years be made. Fortunately, most practical applications using natural rainout tritium require only approximate estimates, since mixing, dispersion, and other factors completely mask the errors associated in making estimates of tritium inputs. From the data listed in this and previous reports, although they are limited to only a few locations in the United States, both current input and past input can be estimated with an accuracy sufficient for most hydrologic investigations. For investigations requiring more accurate knowledge about tritium input levels, factors such as storm time and intensity, evapotranspiration, topography, geography, etc., must be considered. Also, estimates can be improved by employing tritium data from other laboratories, from the U. S. Geological Survey's monitoring network for rivers, and by correlation with other fallout isotopes. (The International Atomic Energy Agency, Vienna, Austria, publishes a report of consolidated tritium rainout and stream data from laboratories throughout the world.)

The maps in Figures 2, 3, 4, and 5 are helpful in estimating tritium rainout at specific locations. Weighted average tritium concentrations for the monitoring stations, data from other sources, and meteorological considerations were used in plotting the isopleths shown on

the maps. The maps can be used to estimate average tritium concentration, and total tritium rainout can then be estimated by using precipitation records for the nearest U. S. Weather Bureau station.

SUMMARY

The data reported herein and those found in earlier reports show that recent precipitation has been labeled with tremendous tritium pulses and suggests that, if wise procedures and techniques are developed to trace these pulses, a wealth of information about many aspects of the hydrologic cycle can be obtained. A major increase in tritium rainout occurred in 1963; this was followed by a decline of about 27% in 1964 compared with 1963, and an additional decline of about 54% in 1965 compared with 1964 levels. The total tritium rainout, being a function of both concentration and amount of precipitation, is more random than average tritium concentrations. In general, rainout is greater for midcontinent regions than for coastal areas, even though the coastal areas receive greater amounts of precipitation. Both average concentration and total rainout were found to increase with increasing northern latitude. Average concentrations were greater for midcontinent stations than for coastal stations.

With tritium data now available, it is possible to estimate present and past tritium input levels at any location in the United States with an accuracy sufficient for most practical hydrologic applications.

Seasonal, annual, and even ten-year tritium pulses have provided a valuable tag for tracing water in many kinds of meteorological and hydrologic investigations. The hydrologic importance of these pulses, and particularly this one large tritium input for this era of time, for investigations several decades in the future depends upon obtaining a better understanding of mechanisms involving water flow, dispersion, mixing, and isotopic effects related to chemical and physical processes involving water, and upon interferences that may be caused by future nuclear events.

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