EDWARDS UNDERGROUND WATER DISTRICT
2603 TOWER LIFE BUILDING
SAN ANTONIO, TEXAS 78205

Environmental Tritium in the Edwards Aquifier Central Texas 1963-71

U.S. GEOLOGICAL SURVEY
OPEN FILE REPORT

JANUARY 1975

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

ENVIRONMENTAL TRITIUM IN THE EDWARDS AQUIFER, CENTRAL TEXAS, 1963-71

By F. J. Pearson, Jr., P. L. Rettman, and T. A. Wyerman

Open-File Report 74-362

Reston, Virginia
January, 1975

CONTENTS

ILLUSTRATIONS

TABLES

CONVERSION FACTORS

Factors for converting English units to metric units are shown to four significant figures. However, in the text the metric equivalents are shown only to the number of significant figures consistent with the values for the English units.

English	Multiply by	Metric
acre-ft (acre-feet)	1.233×10^{-3}	hm^3 (cubic hectometres)
ft^3/s (cubic feet per second)	2.832×10^{-2}	m^3/s (cubic metres per second)
ft (feet)	3.048×10^{-1}	m (metres)
gal (gallons)	3.785	l (litres)
mi (miles)	1.609	km (kilometres)
mi^2 (square miles)	2.590	km^2 (square kilometres)

ENVIRONMENTAL TRITIUM IN THE EDWARDS AQUIFER
CENTRAL TEXAS, 1963-71

F. J. Pearson, Jr., P. L. Rettman, and T. A. Wyerman

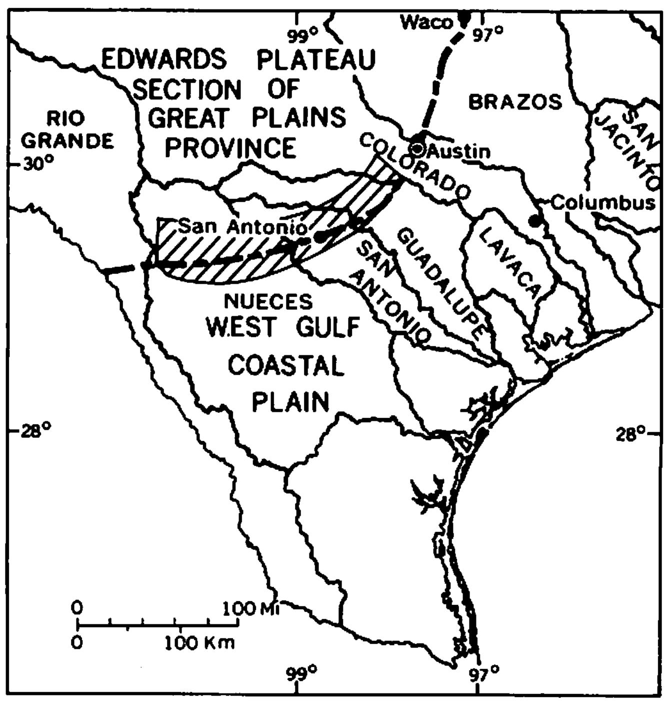
ABSTRACT

Tritium concentrations of samples from 50 wells and springs in the Edwards aquifer in the San Antonio area of Texas have been analysed. Tritium now in the aquifer is partly natural cosmic ray produced tritium, but most is tritium produced by atmospheric thermonuclear tests in the 1950's and early 1960's. The tritium levels in atmospheric precipitation and streams recharging the Edwards are presented for comparison with the ground-water data.

In general, tritium distribution within the Edwards confirms the accepted pattern of water flow within the aquifer. Concentrations of greater than 20 tritium units occur in the recharge areas, while less than 1 tritium unit is present along the aquifer's southern and southeastern boundary.

INTRODUCTION

The Edwards and associated limestones of Cretaceous age form the aquifer that is the chief source of water to San Antonio and vicinity, Texas (figure 1). The aquifer in the San Antonio area lies within two physiographic sections, the Edwards Plateau of the Great Plains province on the north and northwest and the West Gulf Coastal Plain of the Coastal Plain province on the south and east, the two sections being



EXPLANATION

Area of Edwards aquifer

Physiographic province boundary (from Fenneman, 1931)

River basin boundary

Figure 1.--Map of South-central Texas showing location of Edwards aquifer and selected physiographic features.

separated by a series of east- and northeast-trending normal faults and grabens called the Balcones fault zone. The base flow of the streams that drain the Edwards Plateau is springflow from the water-table aquifer in the Plateau. This base flow and a part of the flood flow are lost by seepage in the outcrop of the Edwards aquifer at the Balcones fault zone. Recharge to the aquifer is partly by this seepage and partly by direct infiltration of precipitation on the outcrop. The general flow path in this part of the Edwards aquifer is to the east and northeast, with natural discharge at large springs at New Braunfels and San Marcos (figure 5). The western boundary of the study area is a ground-water divide several miles west of the western boundary of Uvalde County. The eastern boundary is a ground-water divide just northeast of the Blanco River. The section of the Edwards just to the south of the Balcones fault zone where it is at or near the surface supplies potable water. The lower, southern, limit of potable water supply is shown on figure 5 as the sulfide boundary. Downgradient from this boundary the water contains, in addition to sulfide, high dissolved solids and is primarily a calcium sulfate-type water. The geology and hydrology of the Edwards have been described by Garza (1966) and by Pettit and George (1956) and its petrology and depositional environment by Rose (1972).

Since 1963 the U.S. Geological Survey has been regularly analyzing the tritium concentration of samples from a number of wells, springs, and streams which are part of the Edwards aquifer system. The purpose of this report is to present these data and point out some of the conclusions which can be drawn from them regarding flow rates and mixing processes within the Edwards. A mathematical analysis of the implications of these data is not presented here, but is in process.

Yearly water balances in the study area have been made since 1934. Recharge to the Edwards system is calculated from the measured loss of flow of streams crossing the outcrop plus estimates of infiltration of direct precipitation on the outcrop itself. Discharge is determined from the flow of the large springs and from records of pumpage from wells throughout the area where the Edwards is tapped for water supply. From these, the amount of water entering in each stream basin and crossing each of the county lines is calculated (Garza, 1962). Table 1 shows the average annual water balance for the Edwards system for 1934-70.

TRITIUM DATA

Tritium is a radioactive isotope of hydrogen with an atomic mass of 3 and a half life of 12.3 years. It occurs in the environment as a result of both natural and man-made processes. It is produced naturally by interaction of cosmic radiation with nitrogen and oxygen of the upper atmosphere and enters the hydrologic cycle as part of the water molecules in precipitation. Large amounts of man-made tritium were released to the atmosphere by thermonuclear test explosions from 1953 through 1962, and lesser amounts are released by industrial nuclear activities. The tritium concentration of natural waters is expressed in tritium units (TU). One tritium unit corresponds to a concentration of 1 tritium atom per 10^{18} hydrogen atoms and equals 3.2 picocuries per litre.

Table 1.--Average annual (1934-70) recharge and discharge of Edwards aquifer, in thousands of acre-feet

Area	Recharge to Edwards	Discharge by wells and springs	Difference	Cumulative difference
Uvalde Co.				
Nueces and West Nueces Rivers	96.4			
Frio and Dry Frio Rivers	87.9	34.0	182.5	182.5
Sabinal River	32.2			
Medina Co.				
Seco and Hondo Creeks	73.1	5.8	118.7	301.2
Medina River	51.4			
Bexar Co.				
San Geronimo, Leon, and Salado Creeks	57.0	193.0	-136.0	165.2
Comal Co.				
Cibolo and Dry Comal Creeks	90.7	201.6	-110.9	54.3
Hays Co.				
Blanco River and Plum Creek	32.5	104.0	-71.5	-17.2

Tritium is analyzed by measuring the rate of disintegration of tritium per volume of sample. The specific decay rate of 1 TU is 0.0071 disintegration per minute per millilitre of water. Because of this very low disintegration rate and the low energy of tritium decay, very sensitive counting apparatus must be used at all tritium levels. For tritium concentrations below about 50 TU it is necessary to enrich the sample by electrolysis in order to have a disintegration rate high enough to give a significant number of counts above the background of the counting apparatus.

The analyses reported here were done in the Geological Survey's laboratory, Washington, D. C. Samples containing more than a few hundred tritium units (precipitation and some stream samples) were counted by liquid scintillation spectroscopy. Samples containing from a few tens to a few hundreds of tritium units were counted as hydrogen gas in a proportional counter equipped with anti-coincidence shielding. Samples a few tens to less than 1 tritium unit were enriched by electrolysis and counted in the gas counter. The precision of the results of the higher level samples, if not given in the tables, is approximately ± 10 percent. The analytical errors reported with the lower level results include the statistical counting errors and known process errors and are one-standard deviation errors. That is, the probability that the true tritium concentration in the sample is within the range given is approximately two out of three. All values reported are the tritium concentrations as of the date of collection.

Tritium in Recharge

The physiographic province boundary on figure 1 is located along the Balcones fault zone. Recharge to the Edwards aquifer is from direct precipitation on the outcrop in the area of the Balcones fault zone and from the seepage loss of streams which originate in the Edwards Plateau and cross the recharge area of the aquifer in the Balcones fault zone. In order to arrive at estimates of the total tritium entering the Edwards aquifer a number of analyses of streams draining the Edwards Plateau and of tritium in precipitation have been made.

Precipitation: Cosmic radiation produces tritium in the upper atmosphere. The contribution of cosmic-ray tritium to the total tritium now present in precipitation is uncertain, but from analyses of a limited number of pre-1953 samples, the cosmic-ray tritium concentration of precipitation in the San Antonio area has been estimated at 6-8 TU (Thatcher, 1962). After 1953, the tritium concentration in precipitation increased as a result of thermonuclear testing. The tritium concentration of monthly composite samples of precipitation taken at Waco, Texas 170 mi (273 km) northeast of San Antonio (figure 1) has been measured since late 1961. To estimate pre-1961 tritium levels at Waco, a correlation between available Waco data and analyses of precipitation at Ottawa, Canada, the station with the longest record in North America was used. The relation, derived by the International Atomic Energy Agency (B. Payne, written commun., 1970) from 72 monthly pairs is:

$$\log (\text{TU at Waco}) = 0.8556 \log (\text{TU at Ottawa}) - 0.1042.$$

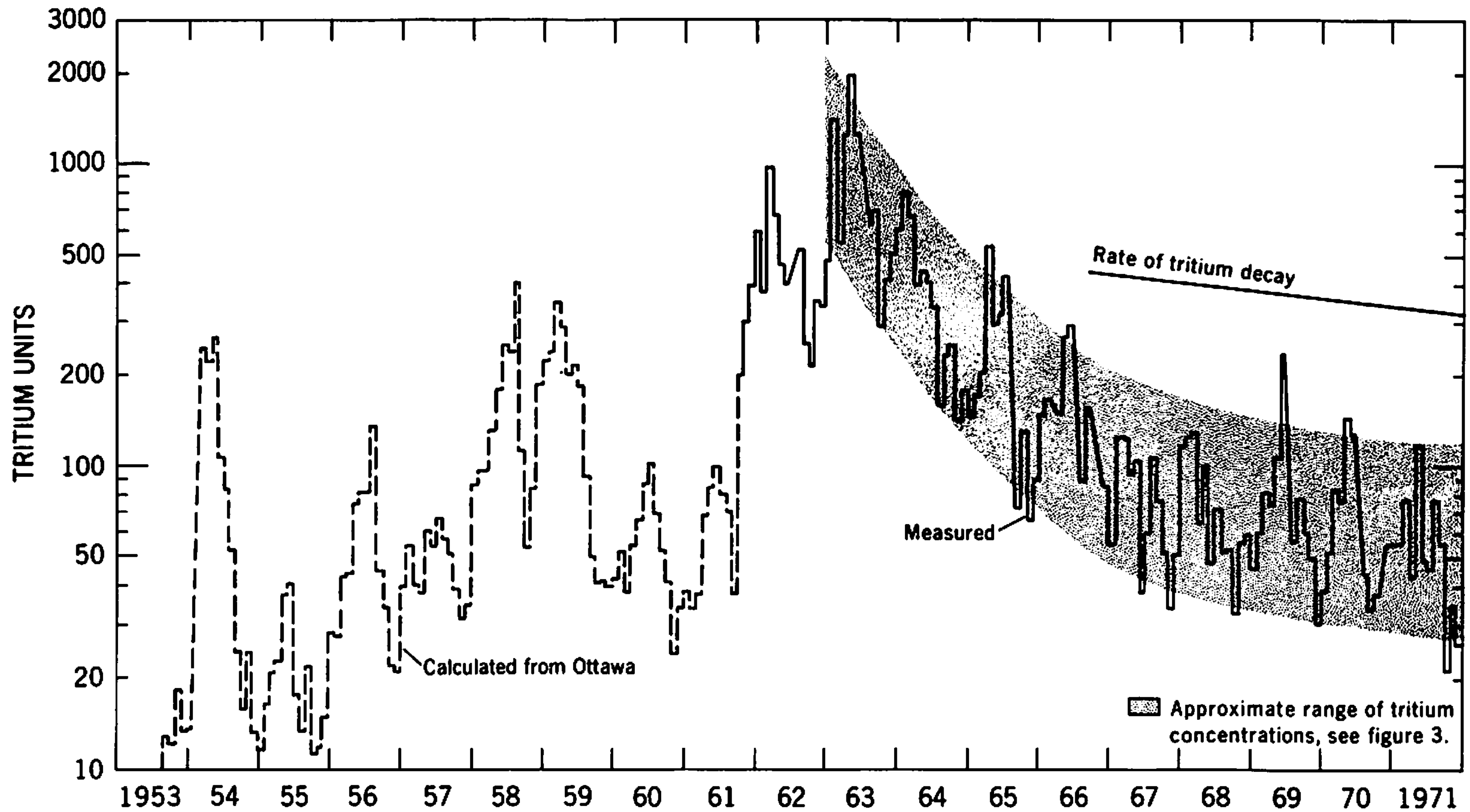


Figure 2.--Graph showing tritium concentration in precipitation at Waco, Texas. Values before October, 1961, calculated from Ottawa, Canada, records.

From it, pre-1961 levels of tritium in precipitation at Waco were calculated. The monthly data themselves are published by the International Atomic Energy Agency (1969, 1970, 1971).

Figure 2 is a graph showing the tritium concentration in precipitation at Waco from 1953 through 1971. The tritium peaks from 1954 to 1959 reflect various thermonuclear tests carried out during that period. The relatively low tritium levels in 1960 and 1961 are a result of a short-lived moratorium on testing, and the decline in tritium since 1963 reflects a longer moratorium, as a result of the Test Ban Treaty. The pattern on figure 2 approximates the range of tritium values found since 1962 and is useful in discussing the tritium concentration of streams.

Streams: If recharge to the Edwards were entirely from precipitation on the outcrop, the tritium input to the Edwards through time could easily be calculated using tritium concentrations in figure 2 and the volume of recharge from the yearly water balances which are available. However, about half of the total recharge is the low flow of streams crossing the outcrop. Because this low flow is seepage from the water-table aquifer in the Edwards Plateau, there is likely to be a certain amount of delay between high tritium concentrations in precipitation and tritium concentrations in the stream base flow.

The tritium concentration of streams draining the Edwards Plateau and recharging the Edwards is not as well known as is the tritium in precipitation. Tritium data are available for two rivers in South Texas, the Nueces River at Laguna Crossing (figure 5) and the Colorado River at Columbus (figure 1). The Nueces River has a drainage area of 764 mi^2

Table 2.--Tritium concentration of selected streams recharging the Edwards aquifer

Date sampled	Daily discharge (cubic feet per second)	Tritium units ± 1 standard deviation
Nueces River at Laguna Crossing (Station no. 08-1900)		
Aug. 8, 1963	21	201 ± 7
Sept. 11, 1963	16	161 ± 9
Oct. 10, 1963	21	181 ± 14
Nov. 11, 1963	24	200 ± 7
Dec. 10, 1963	34	195 ± 13
Jan. 9, 1964	39	198 ± 8
Feb. 13, 1964	56	186 ± 5
Apr. 10, 1964	65	200 ± 7
May 11, 1964	75	185 ± 7
June 16, 1964	37	168 ± 8
July 10, 1964	22	179 ± 8
Aug. 13, 1964	15	167 ± 8
Sept. 10, 1964	13	141 ± 9
Oct. 12, 1964	342	104 ± 4
Nov. 19, 1964	133	124 ± 5
May 10, 1967	40	60 ± 4
Mar. 26, 1969	72	116 ± 10
June 25, 1969	69	41 ± 2
Aug. 18, 1969	27	91 ± 17
Oct. 22, 1969	333	36 ± 4
Jan. 17, 1970	102	117 ± 6
Mar. 12, 1970	215	31 ± 4
May 27, 1970	150	36 ± 2
Sept. 2, 1970	39	39 ± 2
Dec. 1, 1970	104	35 ± 2
Mar. 16, 1971	44	35 ± 2
July 27, 1971	59	30 ± 2
Frio River at Concan (Station no. 08-1950)		
July 27, 1971	29	28 ± 2

($1,979\ km^2$) and recharges the far western part of the Edwards in Uvalde County. Monthly samples taken in 1963 and 1964 were analyzed for tritium. One sample was taken in 1967, and from 1969 to the present an average of four samples per year is available. The tritium concentration of these Nueces River samples are given in table 2. Monthly Colorado River samples have been analyzed since 1965 and are reported by Wyerman, Farnsworth, and Stewart, (1970). Although the Colorado River does not recharge the Edwards, and at Columbus drains $41,070\ mi^2$ ($106,371\ km^2$), its range of tritium concentration overlaps that of the Nueces during those periods when both were analyzed.

A graph of the tritium concentration of these streams with time is given in figure 3. No attempt is made to relate in detail individual tritium measurements to the tritium concentration of precipitation. The envelope drawn on figure 3, however, is the same envelope shown on figure 2, enclosing the extreme precipitation tritium values. Although most of the Nueces River values are in the lower part of the envelope, several are near its upper limit. Thus from the present data it is possible only to state that in general the rivers do reflect tritium in precipitation, suggesting no lengthy residence time in the Edwards Plateau.

Variation of stream tritium with discharge: The tritium concentration of a stream, like the concentration of a dissolved constituent such as chloride, depends upon the concentration in the source water of the stream. At times of base flow, the concentration in the stream will be the same as that of the ground water feeding the stream; while at times

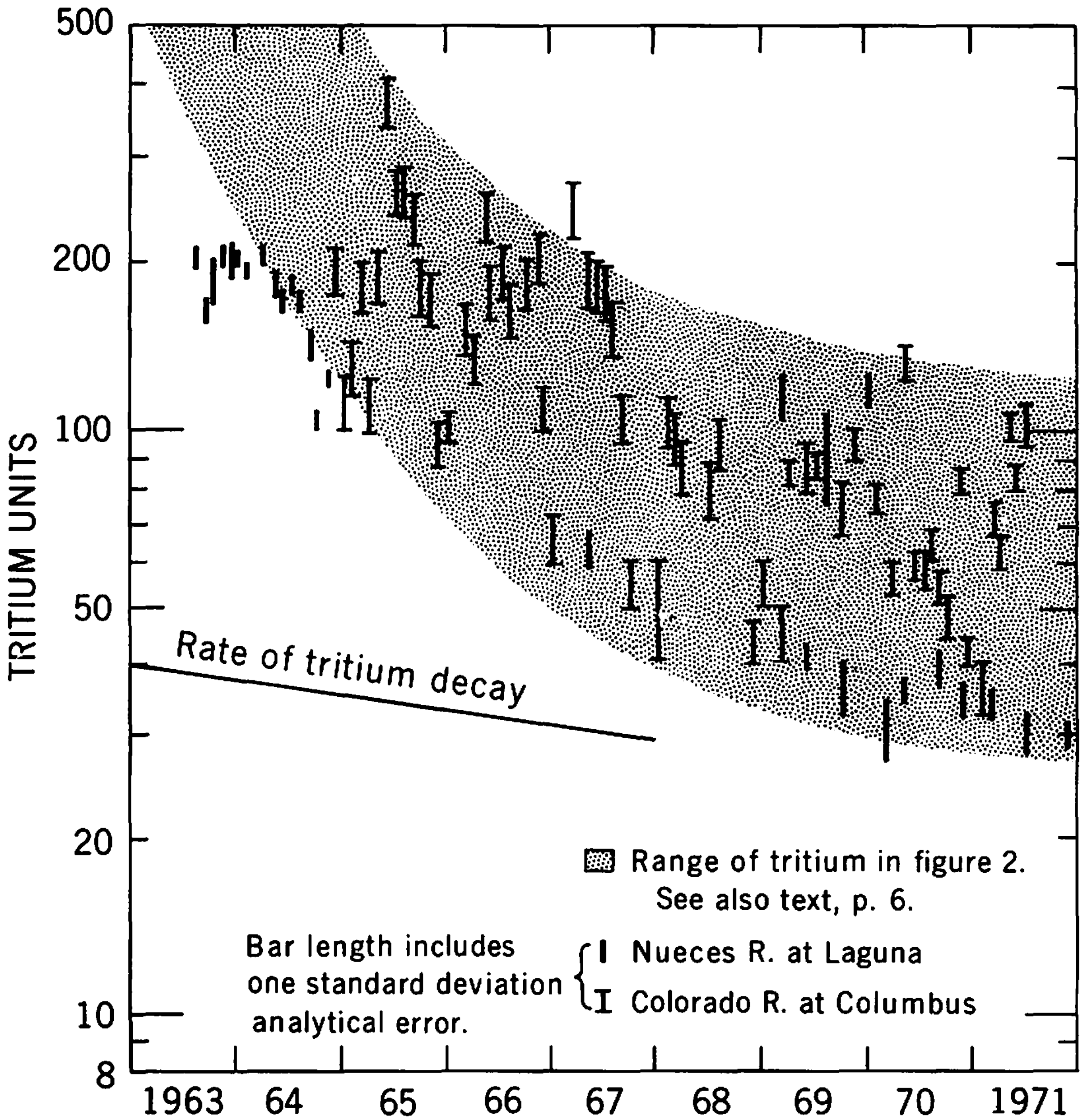


Figure 3.--Graph of tritium concentration of Nueces and Colorado Rivers.

of flood flow, the concentration of the constituent will be equivalent to that in the overland runoff, if overland runoff is an important source of water to the stream at times of high flow. To try to estimate the tritium sources to streams draining the Edwards Plateau, a series of samples were taken at the Nueces River at Laguna during a flood in August 1971. The results of this sampling are shown in figure 4. At this period, the difference in tritium concentration between base flow, which can be taken as equal to the tritium concentration of a sample collected on July 27, 30 days after a previous stream rise, and that of rainfall collected during the storm causing the flood was not great. Some conclusions still can be drawn about the relationship of streamflow and tritium. There is, indeed, a change in the tritium in the stream up to a value approaching that of the rainfall. However, the rise in the tritium in the stream occurs approximately 7 days after the flood peak has passed; the highest tritium was recorded on August 18 while the peak streamflow occurred on August 11. A residence of such a short time would not effect the agreement between monthly precipitation and river samples discussed in the preceeding section.

Tritium in Ground Water

From 1963 through 1971, 50 wells and springs in the Edwards aquifer were sampled for tritium. Of these 28 were sampled once and 22 several times. From the large number of wells sampled at least once, the areal distribution of the tritium within the Edwards can be outlined, and by using the wells which have been sampled several times it is possible

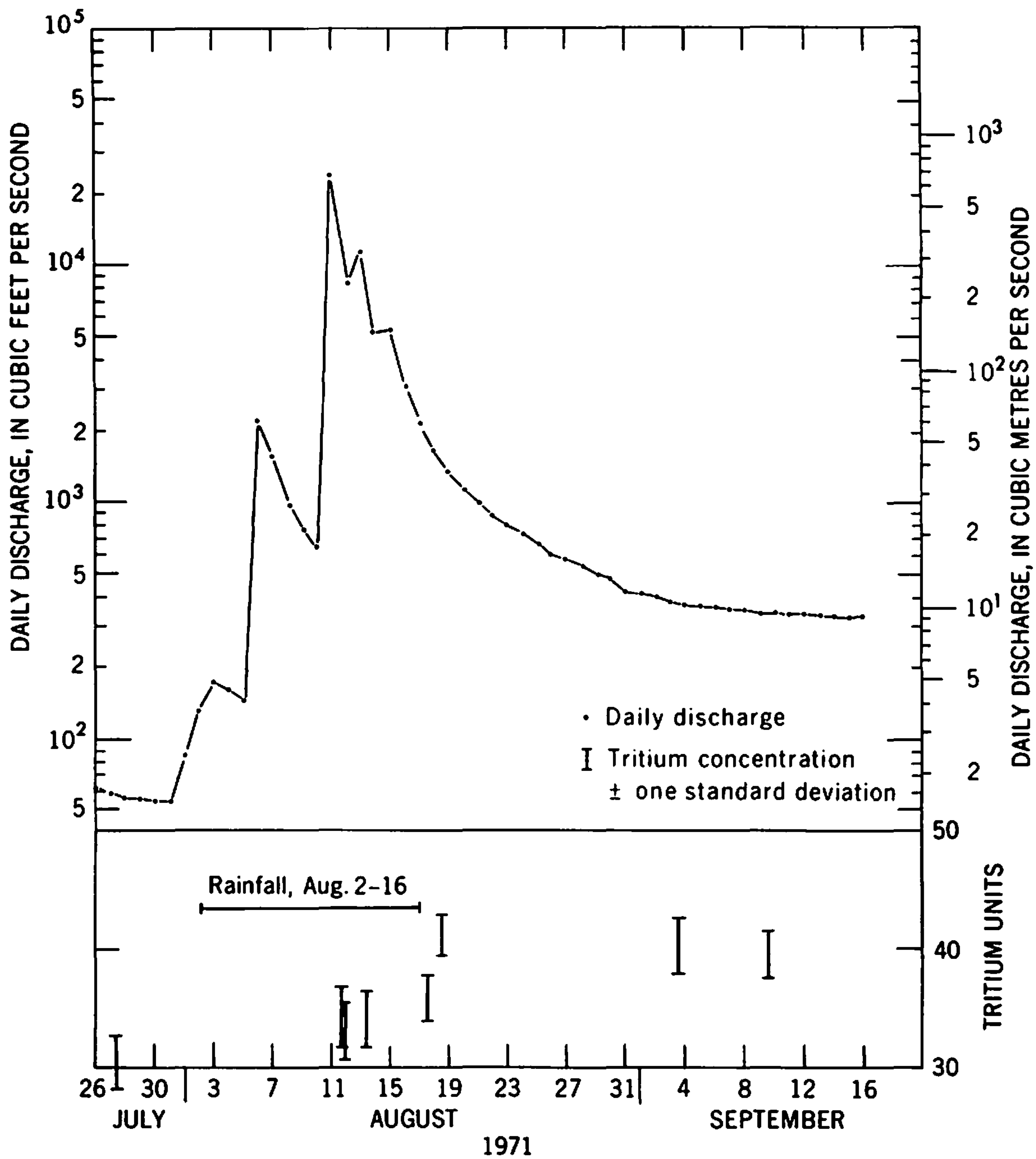


Figure 4.--Graph of discharge and tritium content of Nueces River at Laguna during storm of August, 1971.

also to discern the trend of tritium in the Edwards with time.

Descriptions and locations of the wells sampled are given in table 4 and figure 8. More detailed well descriptions and location maps are given by Rettman (1969). Table 3 lists the tritium concentrations in the wells at various times. This part of the report will discuss only the general patterns described by the data.

Areal variation: The map pattern of tritium distribution in the Edwards is given on figure 5. It is based, for the most part, on samples collected in 1970. Because not all wells were sampled that year, values of samples collected in other years (1967-71) were used to estimate the locations of the lines of equal tritium concentration shown. In most areas where this was necessary, available duplicate samples showed that reasonable estimates of tritium values in 1970 could be made, and that the lines as drawn are virtually correct.

The general pattern of tritium concentration agrees very well with present knowledge of the hydrology of the Edwards. The highest tritium values reported are in the northern part of the system along the lower limit of Edwards outcrop and in the western part of the system in Uvalde County. These are the recharge areas to the system and, therefore, would receive tritium resulting from thermonuclear explosions first. Very low tritium values occur further within the system suggesting that no significant amount of tritium resulting from thermonuclear explosions has yet penetrated into the deeper part of the system.

Variation with time: The variation with time of tritium in wells and springs in the Edwards aquifer which were sampled several times is

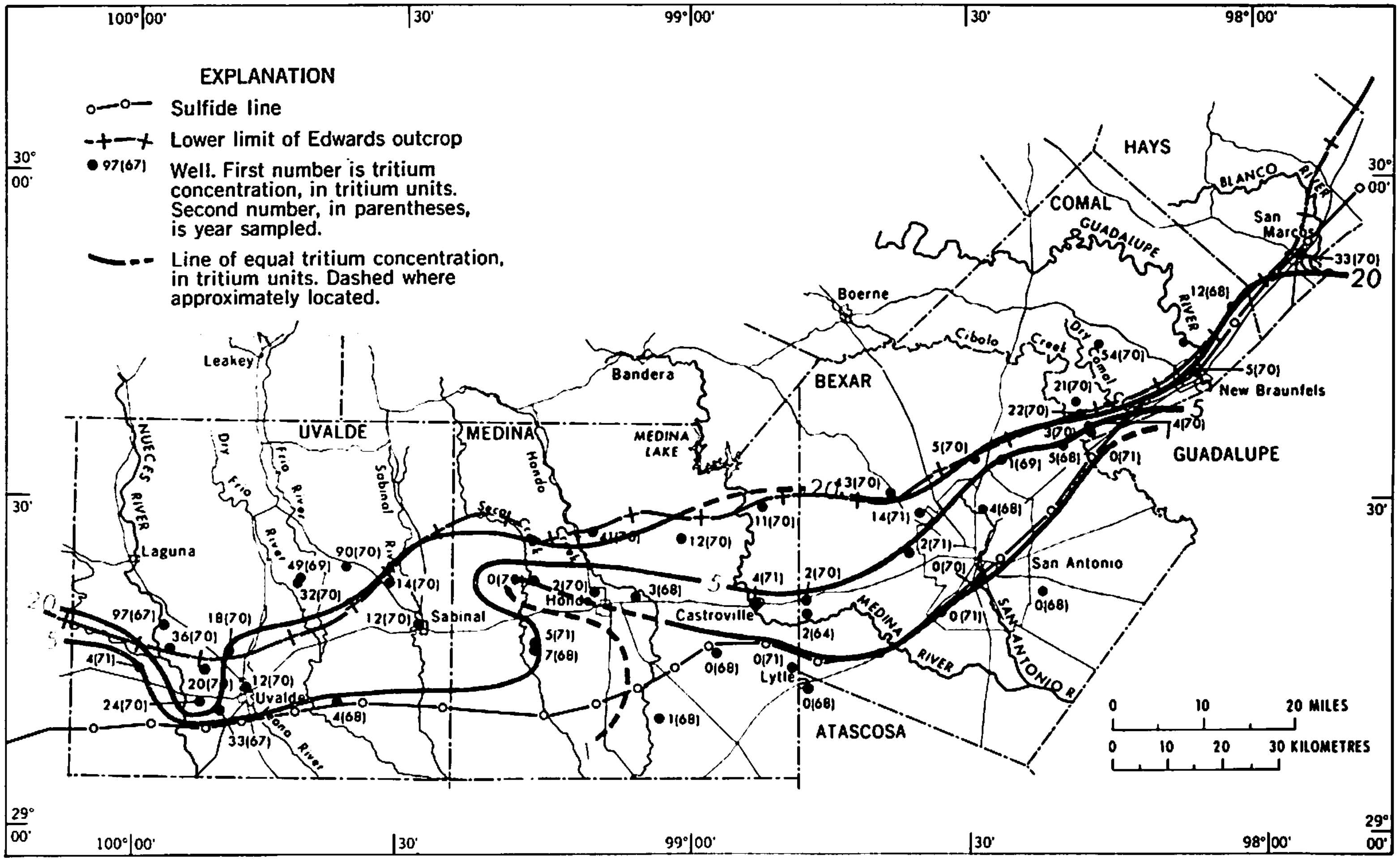


Figure 5.--Map showing limits of Edwards aquifer systems and lines of equal tritium concentration.

shown in figure 6. The location of these and other wells sampled is shown on figure 8. The concentrations and changes in concentration are in keeping with the locations of the sampling points in the ground-water flow system. Before thermonuclear bomb testing began the tritium in precipitation in the San Antonio area was constant at approximately 6-8 TU. Water in the aquifer which entered as recharge during the pre-bomb era therefore should have a tritium concentration of less than 8 TU, which should not vary with time. Because of the radioactive decay of tritium, by which half of the tritium orginally present is lost each 12.3 years, the actual tritium concentration at a point will depend on the mean residence time of the water at that point.

Two of the wells shown on figure 6 have low tritium concentrations suggesting that they might well represent water recharged in the pre-bomb test era. Well (TD-68)- 47-301 has had an average tritium concentration of 1.9 TU since 1961. Well (AY-68)- 42-210 has had an average tritium concentration of 1.6 TU since 1963. No sample from either well departed from this average value by more than the analytical error, and thus there is no evidence for any change in these concentrations with time.

The tritium concentrations of the remaining wells and springs shown on figure 6 have generally increased with time except for San Marcos Springs, (LR-67)- 01-801, and well (YP-69)- 50-308. The 1963 and 1964 samples from well (TD-69)- 40-901 are the same within analytical limits (5.4 TU). Since the autumn of 1964 the tritium concentration of this well has been increasing. The samples from 1963 and 1964 from Comal

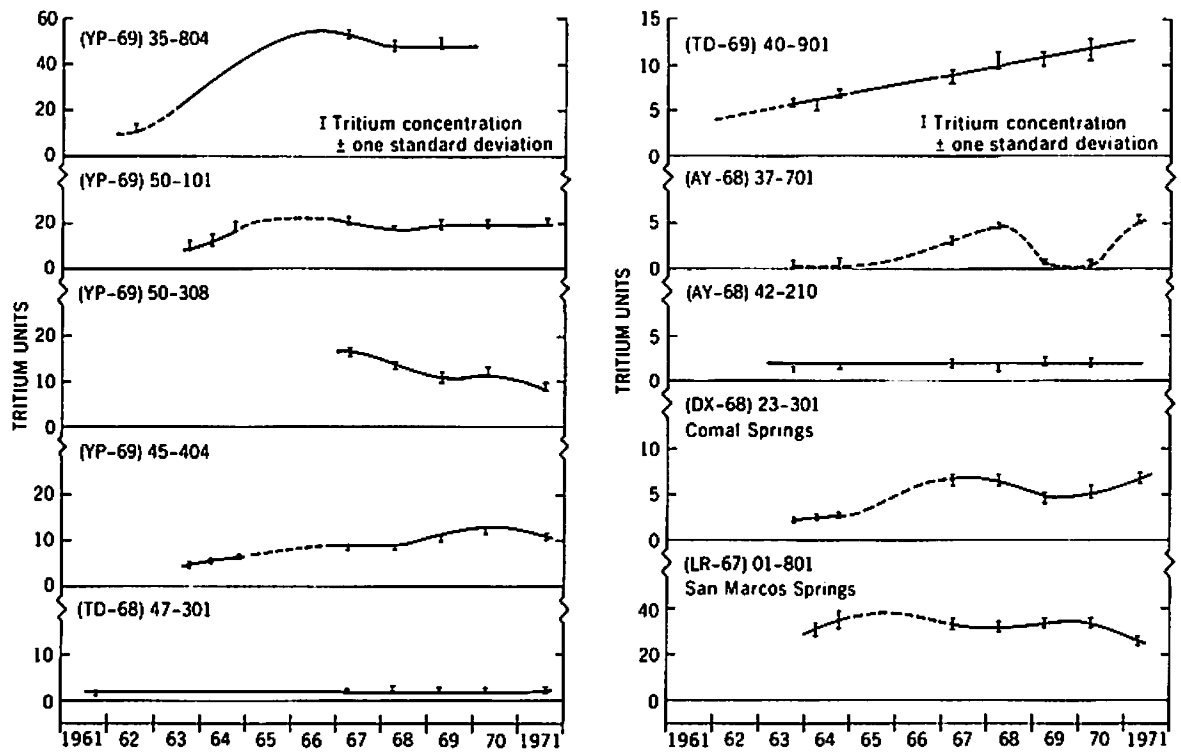


Figure 6.--Graph of tritium variation with time in several wells and springs.

Springs, (DX-68)- 23-301, likewise had tritium concentrations that are the same within the limits of analytical error (2.3 TU). Since then the tritium concentration of Comal Springs has ranged from 4.4 to 6.7 TU. The lack of change in the early tritium concentrations and the low tritium levels themselves suggest that perhaps tritium resulting from thermonuclear explosions did not reach these two sampling points until late 1964 or 1965 at the earliest.

Well (YP-69)- 35-804 has shown the widest fluctuation in tritium concentration in any of the wells sampled - from 12 TU in 1962 to 53 TU in 1967. As this well is located on the Edwards outcrop it is not surprising that it should respond so dramatically to changes in the tritium input to the system.

Well (AY-68)- 37-701 is a public supply well for the city of San Antonio. It had less than 1 TU in 1963, 1964, 1969, and 1970, in keeping with its position deep within the Edwards flow system (figure 5). In 1967 and 1968, and again in 1971, however, the well contained as much as 5 TU. To try to understand this behavior, records of chloride and sulfate concentrations of water from this well and water level elevations in a nearby observation well were examined. There is no correlation between chemistry and tritium concentration in this well; nor is there any apparent correlation between tritium concentration and water levels, nor between change of tritium concentration and change in water levels. Until such time as more information is available about flow in the vicinity of this well its tritium behavior must be left unexplained.

The remaining wells, (YP-69)- 50-101 and (YP-69)- 45-404, have had varying tritium concentrations with time and showed evidence of tritium resutling from thermonuclear explosions even in the earliest samples taken. Thus, they represent a part of the aquifer which has responded rapidly to the input of tritium resulting from thermonuclear explosions.

PRELIMINARY CONCLUSIONS

Interpretations of tritium data are generally most satisfactory when accompanied by mathematical models of whatever complexity is needed to adequately reproduce the data observed. Attempts are now being made to model tritium in the Edwards, but are not included in this report for its purpose is merely to present in detail the data on which later interpretive reports will be based. However, there are several obvious features of the tritium pattern within the Edwards which require comment and these are discussed in this section.

As mentioned above, the pattern of tritium concentrations in the Edwards as shown in figure 5 confirms the previous interpretation of the movement of water within the system. In particular, the tritium shows that recharge to the system occurs along the northern edge and in the western part of the system in Uvalde County, and that flow is to the east and northeast parallel to the fault system. The tritium pattern in Medina County is of interest because it suggests an area of restricted flow in the southeastern quarter of the county. If flows from Uvalde to Bexar County were unrestricted there should be smooth lines of equal tritium concentration at the 5 and 1 TU level across Medina County.

The fact that the 5 and 1 TU lines bend toward and around the city of Hondo suggests that an area of circulation more restricted than in adjacent parts of Uvalde and Bexar County exists here. It suggests that flow from Uvalde County may move north of Hondo as it enters Bexar County, or that if there are zones of significant water movement south of Hondo, they were not sampled for tritium analysis.

Hydrologic data suggest an area of low permeability in southeastern Medina County. Throughout most of the Edwards the temperatures in the fresh-water part are well below the temperatures which one would expect at the depths of the wells sampled. This suggests circulation of water so rapid that a normal geothermal gradient cannot be established in these areas. In southeastern Medina County, however, the water is considerably warmer at a given depth than it is in corresponding depths in Uvalde and Bexar Counties. Likewise, the presence of hydrogen sulfide in this area as shown by the sulfide line on figure 5 suggests a zone of restricted circulation.

The tritium concentration and its time variation at sampling points at Comal Springs, (DX-68)- 23-301 and San Marcos Springs (LR-67)- 01-801 is of interest for the information it gives about discharge from the Edwards system. The discharge elevation at San Marcos Springs is lower than at Comal Springs and from the water balance (table 1) it appears that much of the discharge from San Marcos Springs has moved through much of the Edwards system. However, San Marcos Springs had tritium levels of 30 TU or more from 1964 to 1970, while Comal Springs had what was probably pre-bomb era tritium only in 1963 and 1964, and since 1967 has had a maximum of only 6.7 TU. This implies that much of San Marcos Springs discharge is locally recharged, while Comal Springs is discharging water of greater residence time.

The area around these major discharge springs is shown in detail on figure 7. There is an area of water of less than 6 TU adjacent to the Comal Springs Fault, defined by wells (DX-68)- 30-215, -30-312, and Comal Springs themselves. To the north is an area of much higher tritium water extending northeastwards to San Marcos Springs.

As Table 1 shows, there is insufficient recharge in the immediate vicinity of San Marcos Springs to account for more than about 35 percent of their discharge, so the remainder must be from further south and west in the system. From 1957 through 1969 the Cibolo and Dry Comal Creeks recharge areas have passed about 1.5 million acre-ft (1.8 billion m^3) of water into the Edwards system. The tritium concentration at Comal Springs does not show an increase in tritium as high as would be expected were this amount of recharge water being discharged through them. Hueco Springs, (DX-68)- 15-901 to the north of Comal Springs has a high tritium concentration as if it were receiving quite recently recharged water. Furthermore, Hueco Springs discharges at a higher elevation than that of water levels in the aquifer immediately south of the Hueco Springs Fault (George, 1952, p. 51). This head loss across the fault suggests, with the tritium pattern, that flow in Comal and Hays Counties is not well mixed. That is, water having passed through the entire Edwards system is in the part of the aquifer adjacent to Comal Springs Fault (figure 7) as it enters Comal County and most of it is discharged at

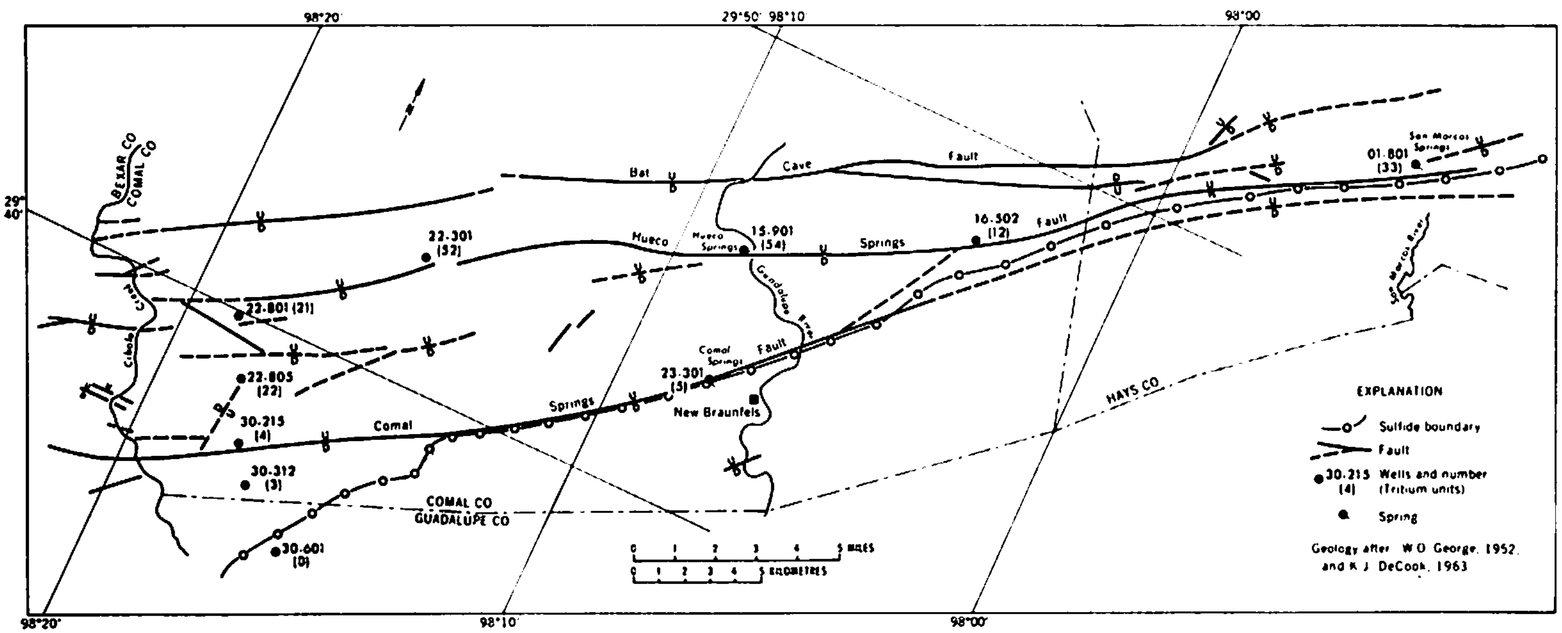


Figure 7.--Map showing faults and tritium concentration of water in the Edwards aquifer in vicinity of Comal and San Marcos Springs.

Comal Springs. Water recharging in northern Bexar and Comal Counties does not mix with water from further west in the Edwards, but rather flows to the east in a subsystem of its own and discharges in part at Hueco Springs, but primarily at San Marco Springs.

It is probable that more quantitative information about flow patterns in the Edwards aquifer can be deduced from further study of the data given here. Simulation modeling is now in progress to aid in formulating quantitative interpretations of these data. Also tritium sampling and analysis continues to provide new data with which to test the models as they develop.

Table 3.--Tritium concentration of water from wells and springs in the Edwards aquifer
Explanation: Tritium units ± 1 standard deviation
(date collected)

Well number	1961,62	1963	1964	1964	1967	1968	1969	1970	1971
Uvalde Co. (YP69)									
35-804	11.8 ± 0.7 (7/20/62)	----	----	----	53.2 ± 2.0 (3/31)	48.0 ± 2.7 (4/5)	49.3 ± 2.8 (3/26)	----	----
35-805	----	----	----	----	----	----	----	32.2 ± 1.7 (5/13)	----
36-701	----	----	----	----	----	----	41.4 ± 2.2 (6/24)	89.6 ± 4.8 (5/13)	30.1 ± 1.7 (4/28)
36-901	----	----	----	----	----	----	14.2 ± 0.9 (4/8)	13.9 ± 0.9 (6/19)	11.2 ± 0.7 (6/15)
41-502	----	----	----	----	97.2 ± 5.2 (3/31)	----	----	----	----
41-505	----	----	----	----	67.7 ± 2.7 (5/16)	----	----	36.3 ± 2.1 (5/13)	----
41-701	----	----	----	----	----	----	----	----	4.3 ± 0.5 (6/17)
42-804	----	----	----	----	16.2 ± 0.9 (3/8)	----	----	18.1 ± 1.4 (4/14)	----
45-404	----	4.3 ± 0.6 (8/12)	5.7 ± 0.5 (3/10)	6.5 ± 0.4 (11/19)	8.5 ± 0.5 (5/11)	8.0 ± 0.5 (4/12)	10.3 ± 0.6 (4/1)	12.0 ± 1.1 (4/1)	11.7 ± 0.8 (7/28)
49-601	----	----	----	----	50.5 ± 2.7 (5/16)	----	----	24.3 ± 1.4 (7/9)	----
50-101	----	10.2 ± 2.2 (9/10)	11.0 ± 2.1 (4/10)	18.9 ± 2.2 (11/19)	22.1 ± 1.0 (5/11)	18.0 ± 0.8 (3/11)	19.8 ± 2.4 (4/10)	20.1 ± 1.5 (3/16)	21.0 ± 1.5 (7/26)
50-308	----	----	----	----	16.9 ± 0.9 (5/11)	13.7 ± 0.8 (4/12)	11.1 ± 1.3 (4/10)	12.2 ± 1.1 (3/23)	9.3 ± 0.7 (7/8)
50-410	----	----	----	----	33.1 ± 1.9 (6/13)	----	----	----	----
52-401	----	----	----	----	----	4.0 ± 0.4 (5/29)	----	----	----

Table 3.--continued.

Well number	1961,62	1963	1964	1964	1967	1968	1969	1970	1971
Medina Co. (TD69)									
38-902	----	----	----	----	----	----	1.4 ± 0.4 (6/19)	0.1 ± 0.3 (5/11)	----
39-502	----	----	----	----	----	----	40.4 ± 2.2 (6/16)	40.7 ± 2.2 (5/13)	----
40-901	----	5.6 ± 0.5 (8/12)	5.2 ± 0.5 (3/10)	6.7 ± 0.5 (11/19)	8.5 ± 0.7 (3/8)	10.3 ± 0.9 (4/5)	10.4 ± 0.7 (4/8)	11.5 ± 1.2 (4/14)	----
46-901	----	----	----	----	----	----	----	----	5.1 ± 0.5 (5/22)
46-902	----	----	----	----	----	7.4 ± 0.5 (5/29)	----	----	----
47-301	1.0 ± 0.5 (10/10/61)	----	----	----	1.7 ± 0.5 (3/8)	2.4 ± 0.6 (4/5)	2.0 ± 0.3 (3/26)	1.9 ± 0.4 (2/19)	2.4 ± 0.3 (7/28)
48-102	----	----	----	----	----	3.0 ± 0.3 (5/29)	----	----	----
56-501	----	----	----	----	----	0.9 ± 0.2 (11/5)	----	----	----
Medina Co. (TD68)									
33-301	----	----	----	----	----	----	9.3 ± 0.6 (6/16)	10.8 ± 0.7 (5/13)	----
41-303	----	----	----	----	----	----	----	----	3.5 ± 0.5 (7/29)
41-801	----	----	----	----	----	0.3 ± 0.4 (11/5)	----	----	----
42-806	----	----	----	----	----	----	----	----	0.4 ± 0.4 (7/30)

Table 3.--continued.

Well number	1961,62	1963	1964	1964	1967	1968	1969	1970	1971
Atascosa Co. (AL68)									
50-201	----	----	----	----	----	0.4 ± 0.2 (10/29)	----	----	----
Bexar Co. (AY68)									
27-515	----	----	----	----	45.8 ± 2.5 (4/10)	----	44.4 ± 2.4 (4/8)	42.8 ± 2.4 (4/14)	----
29-109	----	----	----	----	----	----	6.1 ± 0.8 (4/21)	5.4 ± 0.4 (3/25)	----
29-403	----	----	----	----	----	0.5 ± 0.3 (11/4)	1.2 ± 0.3 (5/5)	----	----
30-103	----	----	----	----	----	5.2 ± 0.4 (6/3)	----	----	----
35-904	----	----	----	----	----	----	----	----	1.9 ± 0.7 (7/19)
36-102	----	----	----	----	----	----	----	----	13.9 ± 0.8 (7/30)
37-104	----	----	----	----	----	4.4 ± 0.3 (5/15)	----	----	----
37-701	----	0.6 ± 0.4 (8/12)	----	0.5 ± 0.5 (11/20)	2.9 ± 0.4 (3/10)	4.7 ± 0.3 (4/1)	0.5 ± 0.1 (3/7)	0.6 ± 0.4 (4/2)	5.4 ± 0.4 (4/27)
42-210	----	1.2 ± 0.3 (8/12)	----	1.6 ± 0.3 (8/13)	1.7 ± 0.4 (5/9)	1.3 ± 0.3 (5/22)	2.2 ± 0.3 (5/28)	1.9 ± 0.4 (6/19)	----
42-212	----	----	1.6 ± 0.2 (2/19)	----	----	----	----	----	----
44-210	----	----	----	----	----	----	----	----	0.4 ± 0.6 (7/21)
45-102	----	----	----	----	----	----	----	0.1 ± 0.3 (7/17)	----
45-301	----	----	----	----	----	0.0 ± 0.2 (11/13)	----	----	----

Table 3.--continued.

Well number	1961,62	1963	1964	1964	1967	1968	1969	1970	1971
Guadalupe Co. (KX68)									
30-601	----	----	----	----	----	----	----	----	0.4 ± 0.7 (7/26)
Comal Co. (DX68)									
15-901	----	----	----	----	39.3 ± 3.9 (8/4)	60.0 ± 3.4 (3/13)	----	54.2 ± 2.9 (4/6)	----
16-502	----	----	----	----	----	11.5 ± 0.7 (11/21)	----	----	----
22-301	----	----	----	----	----	----	51.6 ± 3.8 (4/16)	----	----
22-801	----	----	----	----	----	----	----	20.7 ± 4.1 (5/19)	----
22-805	----	----	----	----	----	----	----	22.4 ± 1.2 (6/18)	----
23-301	----	2.0 ± 0.2 (8/12)	2.4 ± 0.2 (3/19)	2.6 ± 0.3 (11/20)	6.2 ± 0.6 (5/19)	6.3 ± 0.5 (4/1)	4.4 ± 0.6 (3/7)	5.3 ± 0.4 (3/3)	6.7 ± 0.4 (4/15)
30-215	----	----	----	----	----	----	----	4.0 ± 0.4 (6/18)	----
30-312	----	----	----	----	----	----	----	3.0 ± 0.4 (6/12)	----
Hays Co. (LR67)									
01-801	----	----	29.9 ± 1.6 (3/19)	34.2 ± 1.9 (11/20)	33.5 ± 1.8 (5/19)	30.7 ± 1.7 (4/1)	32.5 ± 1.9 (3/7)	32.6 ± 1.8 (3/3)	26.1 ± 2.1 (3/16)

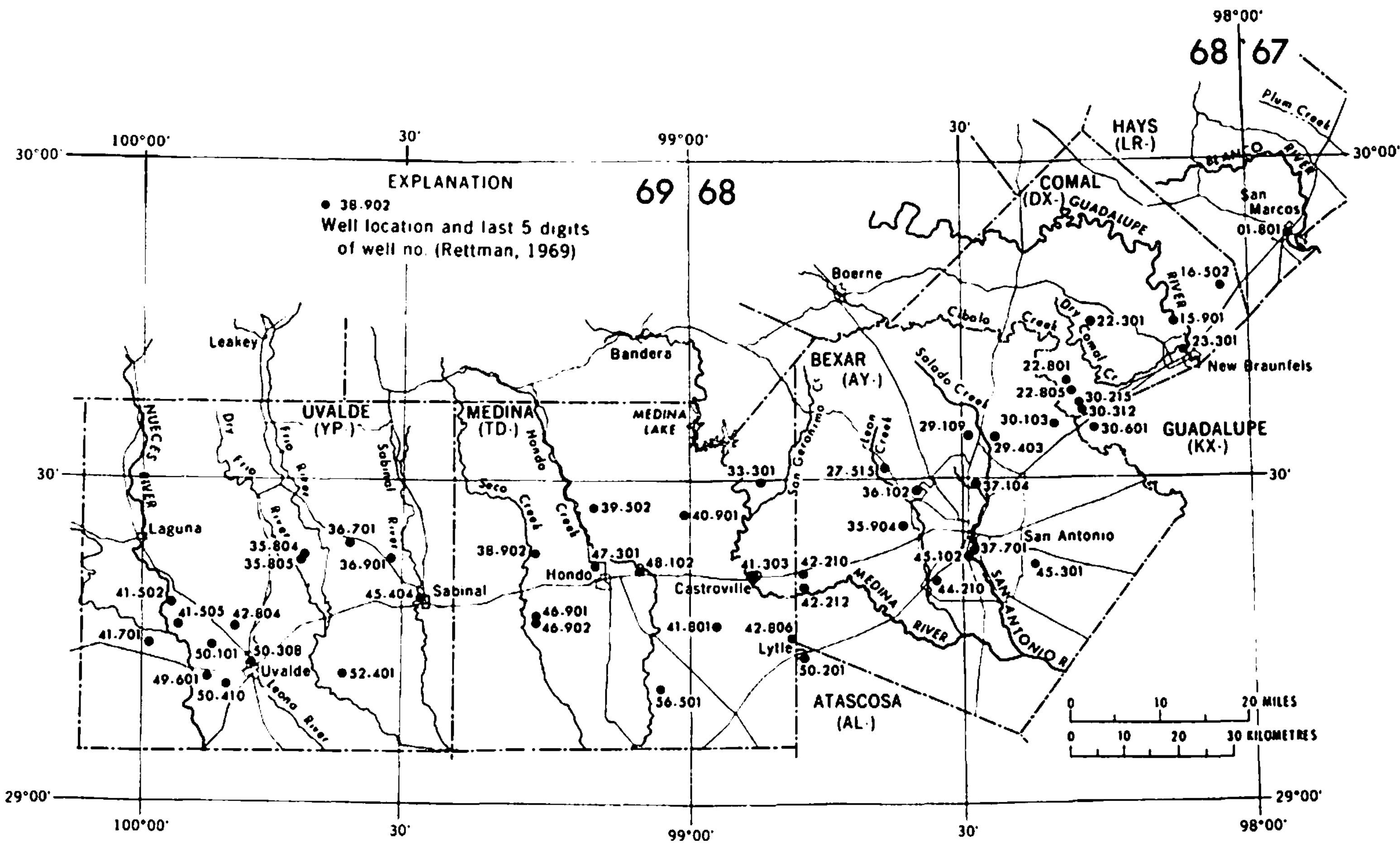


Figure 8.--Map showing locations of wells and springs sampled for tritium analyses.

Table 4.--Description of sampling points

Well or spring number	Date constructed	Well depth (feet)	Casing depth c-(cemented) (feet)	Located on or near Edwards outcrop
Uvalde County				
(YP69) 35-804	1894			X
(YP69) 35-805	1966	600	100	X
(YP69) 36-701	1966	500	45	X
(YP69) 36-901	1968	1246	c-890	
(YP69) 41-502	1963	403	120	X
(YP69) 41-505	1960	260	81	X
(YP69) 41-701	1929	593		
(YP69) 42-804	1951	350		X
(YP69) 45-404	1953	1211	c-930	
(YP69) 49-601				
(YP69) 50-101		100		
(YP69) 50-308	1953	602	c-80	
(YP69) 50-410	1951	1200	80	
(YP69) 52-401	1952	1200	300	
Medina County				
(TD68) 33-301	1963	805	740	X
(TD68) 41-303	1955	717	c-631	
(TD68) 41-801	1954	1609	c-1433	
(TD68) 42-806	1971	2044	c-1990	
(TD69) 38-902	1954	1000		
(TD69) 39-502	1968	530	c-240	X
(TD69) 40-901	1951	1216	c-1160	
(TD69) 46-901	1963	1444	c-1040	
(TD69) 46-902	1955	1313	c-1100	
(TD69) 47-301	1942	1510	c-1285	
(TD69) 48-102	1957	1654	c-1320	
(TD69) 56-501	1967	2646	c-2122	
Bexar and Atascosa Counties				
(AY68) 27-515		360		X
(AY68) 29-109	1945	600	c-190	X
(AY68) 29-403	1964	340	248	X
(AY68) 30-103	1960	841	c-435	
(AY68) 35-904	1958	675	c-612	
(AY68) 36-102	1963	786	c-338	
(AY68) 37-104	1963	995	c-570	
(AY68) 37-701	1951	1582	c-1275	
(AY68) 42-210	1955	1200	c-882	
(AY68) 42-212	1952	985	c-876	
(AY68) 44-210	1955	1672	c-1422	
(AY68) 45-102	1910	2103	1200	
(AY68) 45-301	1956	2172	c-1750	
(AL68) 50-201	1955	2379	c-2304	

Table 4.--Description of sampling points - continued.

Well or spring number	Date constructed	Well depth (feet)	Casing depth c-(cemented) (feet)	Located on or near Edwards outcrop
Hays, Comal, and Guadalupe Counties				
(LR67)01-801	---------San Marcos Springs--------			X
(DX68)15-901	-----------Hueco Springs-----------			X
(DX68)16-502	1965	230	c-160	X
(DX68)22-301	1934	375		X
(DX68)22-801	1964	400	c-198	X
(DX68)22-305	1926	340		X
(DX68)23-301	-----------Comal Springs-----------			X
(DX68)30-215	1968	660	c-185	
(DX68)30-312	1962	645	598	
(KX68)30-601	1896	565		

REFERENCES

DeCook, K. J., 1963, Geology and water resources of Hays County, Texas: U.S. Geol. Survey Water-Supply Paper 1612, 72 p.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw-Hill, 534 p.

Garza, Sergio, 1966, Ground-Water resources of the San Antonio area, Texas: A progress report on studies, 1960-64: Texas Water Development Board Report 34, 31 p.

_______ 1962, Recharge discharge, and changes in ground-water storage in the Edwards and associated limestones, San Antonio area, Texas: A progress report on studies, 1955-59: Texas Board of Water Engineers Bull. 6201, 41 p.

George, W. O., 1952, Geology and ground-water resources of Comal County, Texas: U.S. Geol. Survey Water-Supply Paper 1138.

International Atomic Energy Agency, 1969, Environmental isotope data no. 1, World survey of isotope concentration in precipitation (1953-1963): Tech. Reports Series No. 96, IAEA, Vienna, 421 p.

_______ 1970, Environmental isotope data no. 2, World survey of isotope concentration in precipitation (1964-1965): Tech. Report Series No. 117, IAEA, Vienna, 402 p.

_______ 1971, Environmental isotope data no. 3, World survey of isotope concentration in precipitation (1966-1967): Tech Report Series No. 129, IAEA, Vienna, 402 p.

Pettit, B. M., Jr., and George, W. O., 1956, Ground-water resources of the San Antonio area, Texas: Texas Board of Water Engineers, Bull. 5608, Pt. 1 and 2.

Rettman, Paul, 1969, Records of wells and springs, San Antonio Area, Texas: Edwards Underground Water District, San Antonio, 29 p.

Rose, P. R., 1972, Edwards Group, surface and subsurface, Central Texas: Bur. Econ. Geol., The Univ. of Texas at Austin, Rept. of Investigations 74, 198 p.

Thatcher, L. L., 1962, The distribution of tritium fallout in precipitation over North America: Internat. Assoc. Sci. Hydrol. Bull., V. 7, p. 48-58.

Wyerman, T. A., Farnsworth, R. K., and Stewart, G. L., 1970, Tritium in streams in the United States, 1961-1968: Radiological Health and Data Reports, V. 11, p. 421-439.