ENVIRONMENTAL TRITIUM AS A HYDROMETEOROLOGIC TOOL IN THE ROSWELL BASIN, NEW MEXICO

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ABSTRACT

Tritium analysis of precipitation and ground water samples taken over 13 years, together with geohydrologic and meteorologic data, has led to the construction of a tritium input function for the Roswell artesian basin. This recharge function, rather than tritium concentrations in precipitation, was correlated with tritium-time profiles of seven wells. The profiles of these wells also were correlated among each other. Correlation was greatly facilitated by the slug-flow characteristics of the recharge and the sharp periodicity of precipitation in the recharge area of this semi-arid basin. It was found that recharge is not a linear function of precipitation but proportional to an annual fraction of the mean.

Two distinct subregions, characterized by different circulation patterns, were recognized in the basin. The residence time of water in the northern subregion (Roswell) is about four years. It is larger than seven years in the central region (Artesia). Tritium input characteristics vary from north to south along the western flank of the basin. In the recharge area of the northern subregion, percolation from surface to water table takes between 4-12 months.

Hydrological parameters computed on the basis of tritium data were correlated with lithologic and structural features in the basin. In the northern part of the basin average ground water velocity, porosity, effective thickness of the aquifer, and the dispersion constant were found to be of the order of 70 ft/day, 1%, 2 ft, and 70 ft, respectively. A one-dimensional dispersion model was successfully used to test the precipitation/recharge relation using tritium as a tracer.

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Finally I wish to thank Dr. Charles Holmes and the many students who spent endless hours measuring tritium during the past twelve years. My own endurance during this study would have not been possible without the encouragement and companionship of my wife, Adina.

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1. INTRODUCTION

1.1 Description of the Problem

Tritium concentrations in precipitation in central New Mexico have been monitored by the Tritium Laboratory of the New Mexico Institute of Mining and Technology since 1956. Tritium concentrations in ground waters of the Roswell artesian basin have been measured since 1959. This work is concerned with the application of environmental tritium to the study of interaction between precipitation, ground water recharge, and flow in a confined limestone aquifer in the Roswell basin. The hydrologic system will be tested by its dynamic response to the observed fluctuations of tritium content in precipitation. The investigation is a single tracer problem in the sense that water samples have been analyzed for their tritium content only. This constraint is severe, especially when a quantitative interpretation of large-scale ground water movement is sought. In a study of this type, interpretation of observations has to rely on meteorologic, geologic, and hydrologic observations as well as tracer measurements.

1.2 Environmental Tritium as a Ground Water Tracer

1.2.1 General. Since the detection of natural radioactive hydrogen (tritium) in rain water and the realization by hydrologists of its usefulness, new ways and techniques to evaluate its potential as a tracer in the hydrologic cycle have been continuously sought. In recent years the application of isotopes to surface and subsurface hydrology has become more widespread. The establishment of the International Atomic Energy Agency (IAEA) created the forum for the exchange of ideas and combination of efforts. The program has expanded to include stable isotopes as well as numerous radioactive isotopes. To date, three major symposiums on the applications of isotopes to hydrology have taken place (IAEA, 1963, 1967, 1970a). In addition, IAEA has provided a world survey of tritium, deuterium, and oxygen-18 for meteorological and hydrological purposes (IAEA, 1969, 1970b, 1971).

1.2.2 Tritium Production. Tritium (${}_1H^3$ or T) has a half-life of 12.26 years and emits a beta particle with a principal energy of 0.018 Mev. The reaction is

$$T \rightarrow {}_2He^3 + {}_{-1}\beta^0 + 0.018 \text{ Mev}$$

Natural tritium is produced by cosmic rays and by solar flare accelerated particles in the upper atmosphere. One reaction is due to the flux of secondary neutrons and is given by (Libby, 1946)

$${}_7N^{14} + {}_0n^1 \rightarrow {}_6C^{12} + T + \text{energy}$$

Within two years of the detection of natural tritium in rain water (Grosse et al. 1951), experiments with thermonuclear devices had completely upset the inventory of natural tritium by injecting large quantities of artificial tritium into the upper atmosphere and stratosphere. As far as can be determined, the steady state equilibrium concentration of tritium before 1953 was about 10 T. U.(1) Thermonuclear reactions each involving the fusion of nuclei are as follows:

$$ {}_1H^2 + {}_1H^2 \begin{cases} \rightarrow {}_2He^3 + n^1 + 3.3 \text{ Mev} \\ \rightarrow T + {}_1p^1 + 4.0 \text{ Mev} \end{cases} $$

and

$$ {}_3Li^6 + {}_0n^1 \longrightarrow T + {}_2He^4 + 4.7 \text{ Mev} $$

The relatively large amount of tritium produced by fusion reaction is about 10^{23} to 10^{24} atoms/kt of fusion (7×10^3 to 5×10^4 Ci/kt), depending on the efficiency and kind of thermonuclear fuel (Teller et al.,1968). Although man-made, the tritium produced by nuclear reaction will oxidize or exchange to become part of a water molecule (HTO).

1.2.3 Tritium Circluation and Tracing. The artificial tritium produced by nuclear testing is distributed throughout the hydrologic cycle by natural processes. Therefore, it is considered a natural or an environmental tracer even though tritium levels have on the average risen three orders of magnitude as compared with cosmically produced tritium. The higher

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(1) All units and symbols are compiled and defined in Appendix A.

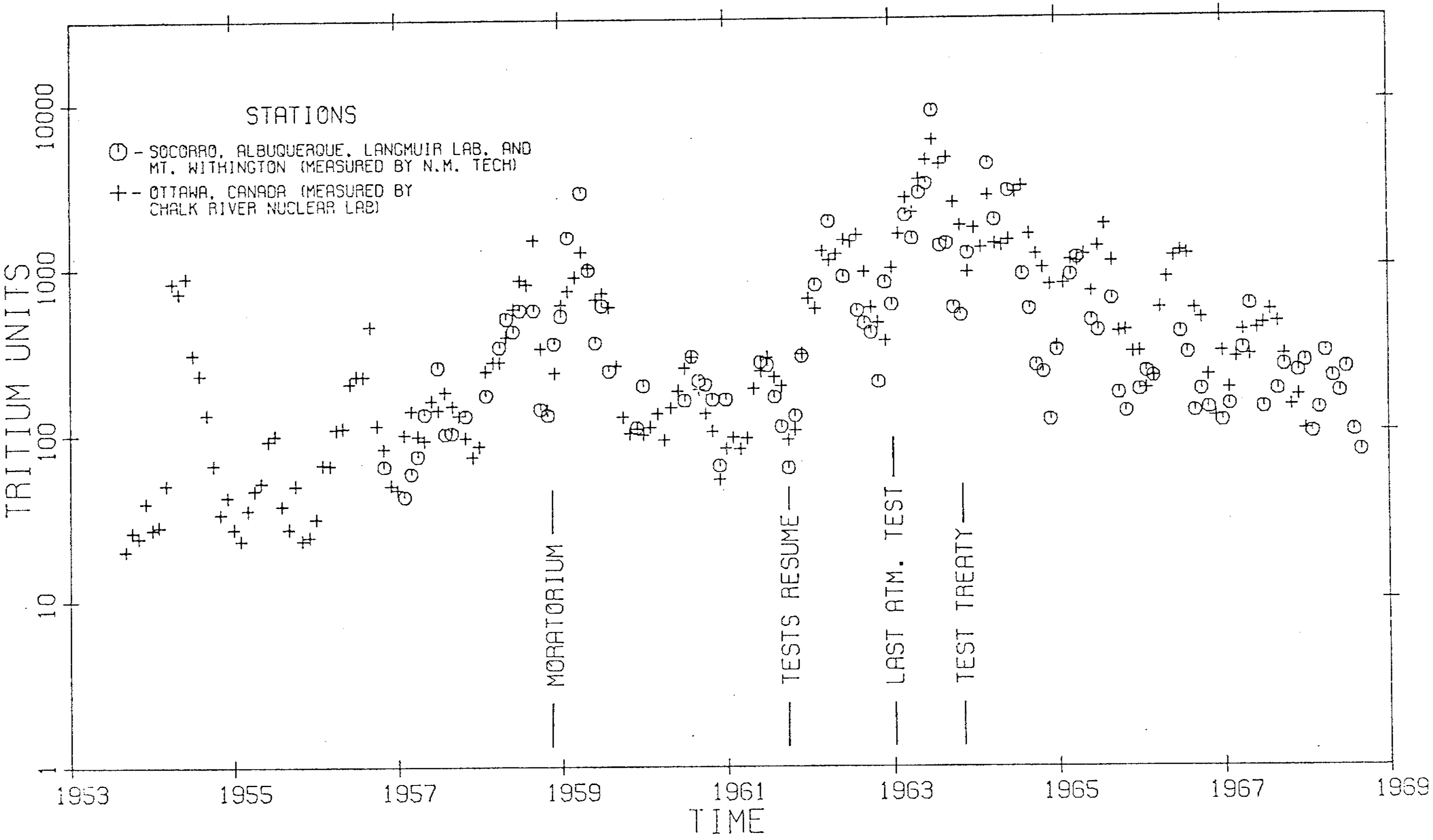
tritium levels are more easily measured, but the weak β-radiation excludes the possibility of in situ measurements.

The increase of tritium concentrations in precipitation as a result of nuclear testing in the atmosphere was detected in the form of "tritium peaks". These pulses, when reaching a ground water reservoir, can be used to trace the flow. The distinction should be made between pre-bomb tritium which was primarily an age indicator and the bomb-produced tritium that can also be used for tracing. Because of its 12.26 year half-life, the time span of tritium dating is limited to about 50 years. For some hydrologic systems, this is sufficient time and another isotope such as Carbon-14 ($T_{\frac{1}{2}}$=5600 years) would have to be used for dating purposes.

The application of tritium pulse tracing and dating requires the knowledge of tritium concentration distribution in precipitation. Figure 1.1 is such a presentation. The two sets of data for Ottawa, Canada (IAEA, 1969, 1970b, 1971) and for central New Mexico are plotted together with the history of nuclear testing in the atmosphere. As will be shown in Chapter 5, such data from different locations can be used to fill gaps in the immediate region of measurement. The nuclear testing period between September 1961 and December 1963 produced large tritium yields. This is shown by the high tritium levels following 1962 (Fig. 1.1). The general contention among many investigators was or is that the high tritium pulses of 1963/1964 caused sufficient signal in many aquifers to provide a reference for years

Figure 1.1

Mean monthly tritium concentration in precipitation, Ottawa, Canada, and central New Mexico.


STATIONS
⊙ - SOCORRO, ALBUQUERQUE, LANGMUIR LAB. AND MT. WITHINGTON (MEASURED BY N.M. TECH)
+ - OTTAWA, CANADA (MEASURED BY CHALK RIVER NUCLEAR LAB)
MORATORIUM
TESTS RESUME
LAST ATM. TEST
TEST TREATY
TRITIUM UNITS
10000
1000
100
10
1
TIME
1953
1955
1957
1959
1961
1963
1965
1967
1969

to come. The study will show that meteorological conditions prevailing at the time have almost eliminated the 1963/1964 peaks in parts of the Roswell basin.

One of the more serious drawbacks of the tritium tracing method is the length of time required for its application which is dictated primarily by the rate of ground water movement. The semi-arid climate of southeastern New Mexico, with summer rains and relatively fast movement of ground water in a cavernous limestone aquifer provides favorable conditions for the application of environmental tritium tracing.

1.3 The Roswell Basin

1.3.1 General. The Roswell artesian basin is located in western Chaves and Eddy counties, New Mexico. The basin is within the Pecos River drainage basin. The eastern edge of the basin is east of the Pecos River and its western boundary is the Sacramento Mountains. The northern and southern limits of the basin are considered to be Arroyo Macho (north of Roswell) and Major Johnson Springs (north of Carlsbad), respectively. The northern and western boundaries, although not defined accurately, are important to any hydrologic study. The basin is characterized by mountains on the west (9,000 feet), a bedrock surface that dips eastward from the crest of these mountains, and flat alluvial plain near the Pecos River on the east (3,400 feet). Relief is low beginning about 15 miles west of the river. The Roswell basin has a semi-arid, continental climate. It is characterized by abundant sunshine, low relative humidity, and large temperature contrasts. Winters are short and mild, and summers are long and hot. Annual mean temperature is 59 °F. Nearly 70% of total precipitation falls from May to September, mostly by intense, but brief, thundershowers. The Roswell basin is one of the most important areas of artesian water production in the United States (Bean, 1949). In addition to the agricultural industry, oil is produced from the San Andres Limestone in the vicinity of Roswell and other locations in the basin.

The hydrologic complex of the artesian basin near the Pecos Valley covers in excess of 3000 square miles (Havenor, 1968). The irrigated lands are mainly located in the eastern half of the basin covered with the Quaternary Alluvium deposits (Fig. 1.2). Most of the irrigation waters are pumped from the San Andres limestone aquifer. Heavy pumpage has produced a continuous decline in water levels since about 1942. Salt water encroachment west of the Pecos River, especially near Roswell, presents a real threat to the management of adequate water quality for irrigation.

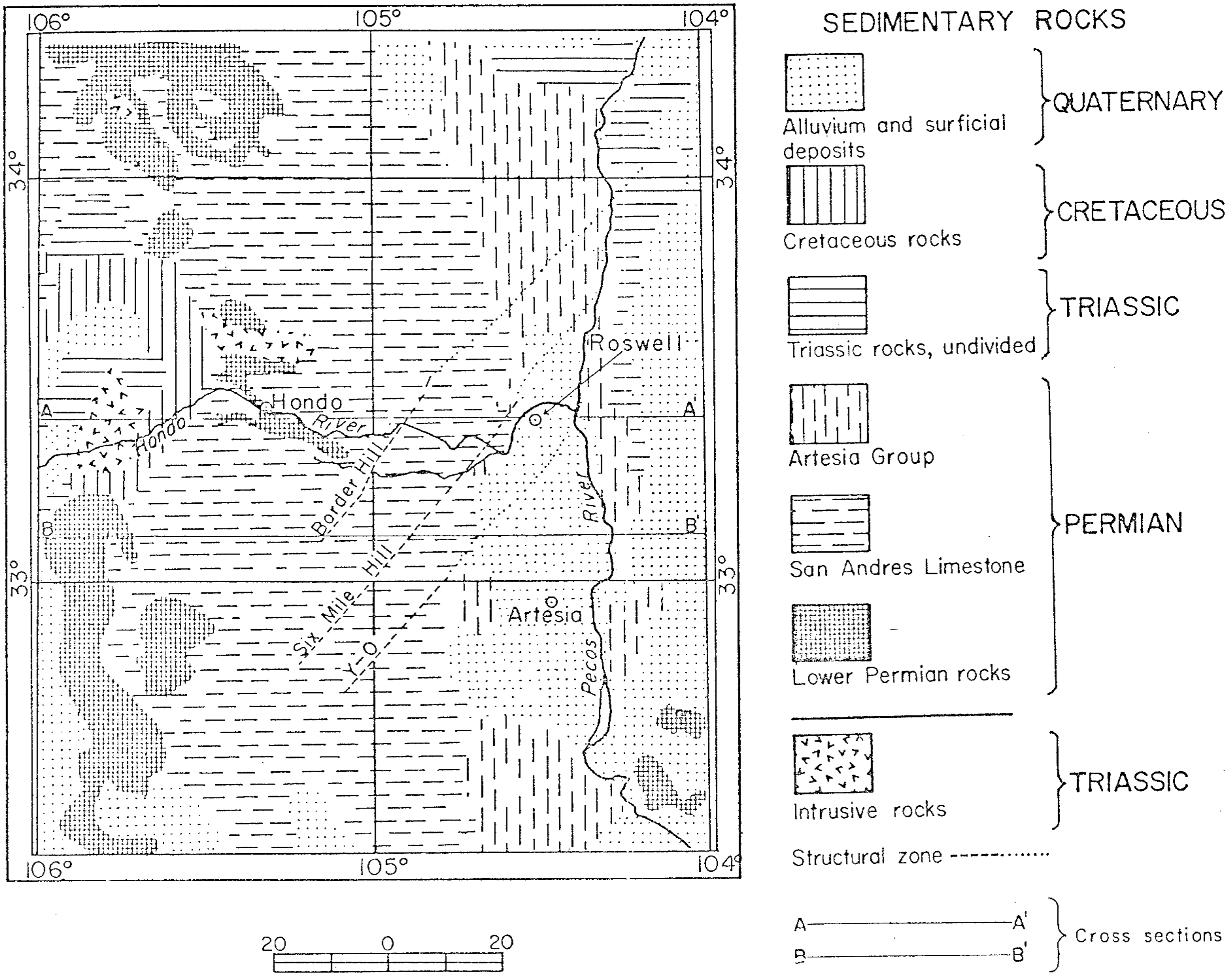
1.3.2 Previous Work Related to the Study. Two bibliographical publications are available which contain background information on the Roswell basin and on tritium tracing. The first publication is: A Bibliography Pertaining to the Pecos River Basin in New Mexico, compiled by Hernandez and Eaton (1968). The bibliographic listing includes some 400 publications which are related to the study area. The second is a U.S. Geological Survey publication entitled: Bibliography of Tritium Studies Related to Hydrology Through 1966, by Rhodehamel et al. (1971). It contains about 1420 references which include tritium tracing of ground water and surface water, atmospheric and biological studies with the aid of tritium, and references to analytical methods used in the actual measurement of tritium activities in liquid and solid samples.

Geologic and hydrologic investigations of the Roswell basin have been conducted since the turn of the century. The first comprehensive investigation to cover both geology and ground water resources of the basin was reported by Fiedler and Nye (1933). Their field work covered three years (1925-1928) and most of their observations and conclusions are valid to the present.

Bean (1949) and Theis (1951) studied the effect on artesian recharge by floodwater stored in the Hondo Reservoir, located on the Rio Hondo 10 miles west of Roswell. Bean investigated the intake capacity of the San Andres limestone in the vicinity of the Reservoir and of the limestone outcrop in general. Theis' contribution was the first quantitative application of the transmissibility coefficient (viz. transmissivity) to the study of the basin. From the gradient of the piezometric surface in the San Andres aquifer and estimated quantity of recharge, Theis calculated the transmissivity of the aquifer.

Figure 1.2

Generalized geologic map of the Roswell basin, New Mexico.


106°
105°
104°
34°
33°
Roswell
Hondo
Hondo River
Border Hill
Six Mile Hill
Y-O
Artesia
Pecos River
A
A'
B
B'
20
0
20
SEDIMENTARY ROCKS
Alluvium and surficial deposits
QUATERNARY
Cretaceous rocks
CRETACEOUS
Triassic rocks, undivided
TRIASSIC
Artesia Group
San Andres Limestone
Lower Permian rocks
PERMIAN
Intrusive rocks
TRIASSIC
Structural zone
Cross sections

Hantush (1955) investigated the hydrology of the basin by treating the three hydrologic units (Shallow, Shallow Confined, and Principal Confined aquifers) individually and then by investigating the mutual interaction of the Shallow and Principal aquifers through the leaky Shallow Confined layer. Hantush's results are based on pumping tests from which formation constants were determined. His attempt to arrive at a quantitative estimation of natural replenishment to the basin was a major contribution.

Hood (1963) was concerned with salt water encroachment in the San Andres limestone. Although the study was hydrochemical in nature the additional information given about well construction and completion proved to be very useful for data interpretation in the present study. Hood's observations include the relation between increased precipitation and the cessation of salt water encroachment in the artesian aquifer.

Motts and Cushman (1964) studied the possibilities of artificial recharge to the basin in order to halt the westward encroachment of saline water and to restore the balance between recharge and discharge. The main emphasis of the study was on recharge characteristics of the exposed rocks, distribution and properties of sinkholes, and the pattern and rate of ground water movement in the area.

Havenor (1968) and Maddox (1969) have utilized data available from oil exploration as well as data obtained by the Pecos Valley Artesian Conservancy District (PVACD). A more accurate evaluation of vertical distribution of porosity and permeability was presented by these investigators. Havenor's report is particularly useful with the presentation of a complete core analysis from the San Andres limestone (to 1100 feet below the surface), possibly the only one in the available literature on the Roswell basin.

Recent work on the stratigraphy and structure of the area, which includes the Roswell basin, was reported by Kelley (1971). The investigation concentrated on aspects of regional structures with special emphasis on Permian age rocks which include the San Andres formation. Some of the structure zones may have strong bearing on the mechanism of recharge to the San Andres aquifer.

The summary to follow on the geohydrology of the studied area was compiled from the above sources.

1.3.3 Geohydrology. The ground water flow system can be generalized as a three-layer system: the Quaternary Alluvium aquifer, a semi-confined aquifer (Artesia Group), and the main deep aquifer (San Andres limestone). In previous work (Saleem and Jacob, 1971), these have been called Shallow Aquifer, Shallow Confined, and Principal Confined Aquifer, respectively. In the present work the Shallow Confined Aquifer did not behave as an independent hydrologic unit. For this reason in the present work only two aquifers are differentiated: Alluvium aquifer and Bedrock aquifer; the latter including both the Artesia Group and the San Andres Limestone.

All three aquifers are present in the region between Roswell and Artesia. The aquifer which is continuous throughout the basin is the San Andres Limestone (Fig. 1. 2). The San Andres aquifer has highly developed solution cavities. The limestone is exposed west of the western boundary of the alluvium and is about 650 feet below the surface near the Pecos River east of Roswell. This same unit is hydrologically continuous south and southeast of Chaves and Eddy Counties. It dips to the east-southeast.

There are two distinct ground water boundaries in the San Andres limestone. One is where the limestone becomes an aquifer in the western part of the basin and the second is at the transition from unconfined to confined condition. Kelley (1971) subdivides the San Andres limestone into three members: the upper member (Fourmile Draw), the middle member (Bonney Canyon), and the lower member (Rio Bonito). Kelley (1971, pages 12-14, and Fig. 4) had recognized a change in facies in the Fourmile Draw member of the San Andres Limestone along a north-south traverse. To the south of T. 16 S. the evaporite facies of the Fourmile Draw changes to a carbonate facies which contains no gypsum. As will be shown in the present work, these facies changes in the central part of the basin have a profound effect on the movement of ground water.

According to Maddox (1969), uplift and erosion have brought the San Andres formation into the zone of aeration. Fracturing has allowed percolating ground water to leach gypsum and anhydrite resulting in secondary porosity. Water movement has continued the leaching process and enlarged the secondary pore spaces, in some instances into caverns. The upper 300 feet of the San Andres limestone are very porous; this zone is the principal aquifer of the Roswell artesian basin (Havenor, 1968; Maddox, 1969). Fiedler and Nye (1933) suggested permeability boundaries within the limestone aquifer. Their observations were based on well yield. Some of their observations were contradicted by a pumping test performed by Hantush (1957) near Dexter. The transmissivity in that region was found to be only 10,000 ft^2/day as compared with over 200,000 ft^2/day near Roswell. These regions will be discussed further in Chapters 4 and 5. Motts and Cushman (1964) have shown that the limestone aquifer combines zones of different permeability. A region of low permeability was indicated between Artesia and the Village of Hope. This region is east and southeast of the location where Kelley (1971) observed the absence of gypsum in the Fourmile Draw member of the San Andres limestone.

The fracturing of the formation along the structural zones (Fig. 1.2) and the extension of the recharge area were discussed by Fiedler and Nye (1933), Morgan (1942), Bean (1949), and Motts and Cushman (1964). The total area that could contribute to recharge is about 7000 to 8000 square miles. The recharge area extends from 10 miles west of Roswell to the ridge of the Sacramento Mountains on the west, standard hydrological and geological techniques which have been employed in the study of the Roswell artesian basin for many years. The present study proposes to investigate the following major areas:

(a) Does the interpretation of the tritium data confirm existing hydrological parameters?

(b) Can the analysis of the tritium data give rise to new information about the hydrology of the Roswell basin previously not obtainable.

(c) Based on the results obtained, the benefit of future use of the tritium tracing technique in the region is to be evaluated.

Any new contribution to the knowledge of the region's hydrology depends on the ability correctly to correlate the tritium input with the observed tritium-time profile at any observation point in the basin. The problem is approached primarily from the experimental viewpoint. A large number of tritium measurements of precipitation and ground water is analyzed and interpreted. In addition, some known analytical models are tested. The one-dimensional (time-dependent) dispersion equation is solved using values obtained from the tritium data and some known hydrologic parameters, to compare predicted tritium concentrations in the basin with the observed concentrations. These equations were solved using the IBM-360 Model 44 computer.

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2. SAMPLING AND DATA COLLECTION

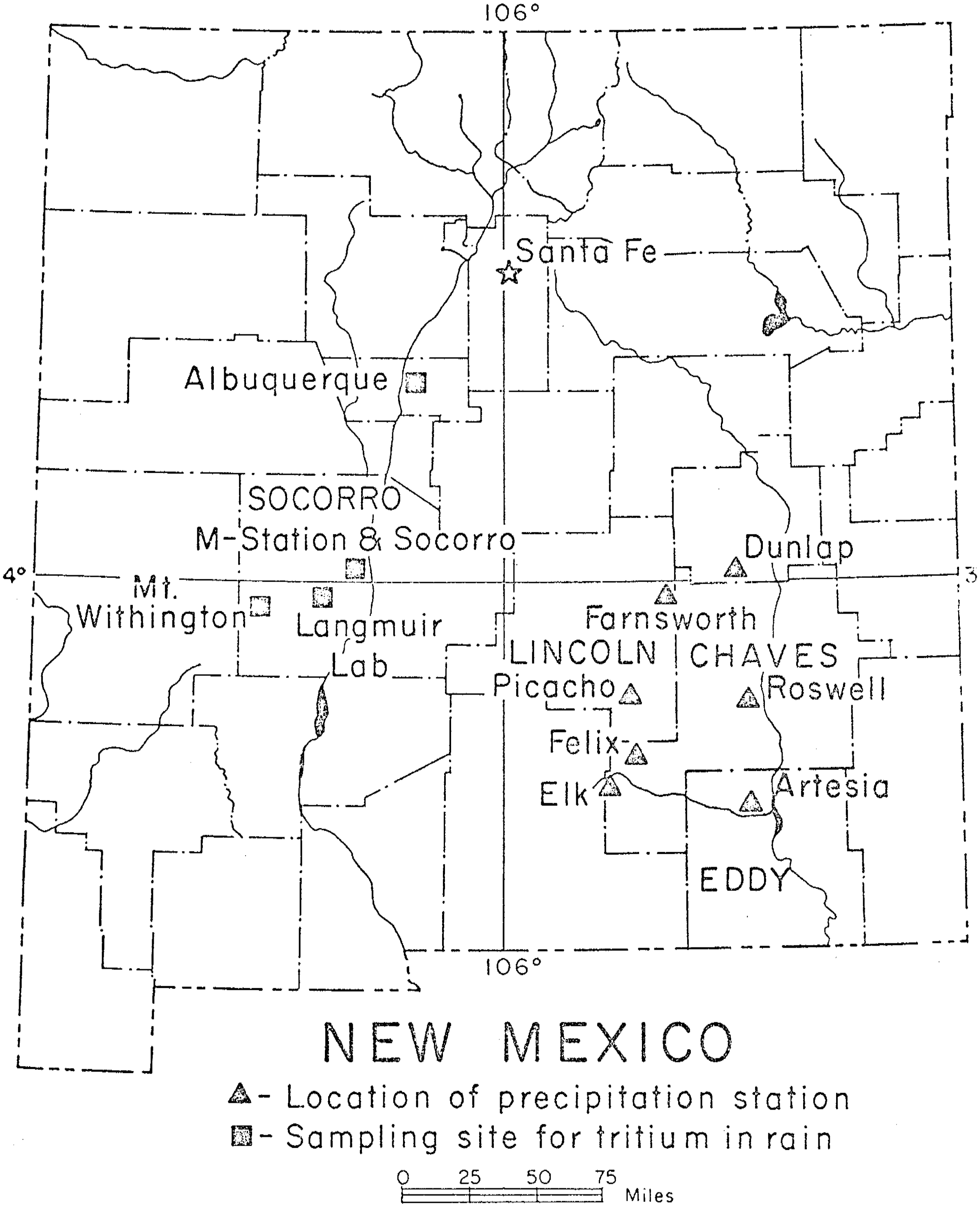
As stated above, the purpose of this study is to bring forth a quantitative interpretation of tritium measurements. This is possible only by using hydrologic, geologic, and meteorologic data obtained by previous investigations. The inherent disadvantage of an investigation of this nature is that data taken at some distance away have to applied to the study area. Although a long record of meteorologic data is not needed for this study, the knowledge of tritium concentrations in recharge water to the aquifer a few years before the beginning of the study is essential. Such data are available from measurements of rain and snow samples collected near Socorro since 1956. Such data are applied in conjunction with the known precipitation distribution measured near Roswell. Tritium data of precipitation near Socorro missing due to dry weather or insufficient sample volume were replaced by data from Ottawa, Canada.

2.1 Water Sampling, Locations and Procedure

Figure 2.1 is a map of New Mexico showing the location of precipitation collection stations and precipitation recording stations used in this study. Tritium concentrations of precipitation are available for the vicinity of Socorro only. The ground water sampling sites are not shown

Figure 2.1

Map of New Mexico with precipitation measuring stations and tritium monitoring stations.


106°
Santa Fe
Albuquerque
SOCORRO
M-Station & Socorro
Dunlap
34°
34°
Mt. Withington
Langmuir Lab
Farnsworth
LINCOLN
CHAVES
Picacho
Roswell
Felix
Elk
Artesia
EDDY
106°
NEW MEXICO
▲ - Location of precipitation station
▨ - Sampling site for tritium in rain
0 25 50 75
Miles

on this map. Most of the wells and springs sampled in this study are located within the area on which the precipitation recording stations are located.

2.1.1 Precipitation Stations. Precipitation samples were collected in the vicinity of Socorro for the purpose of measuring their tritium activities. Their relative location and elevation are shown on the cross section of Figure 2.2. The collection stations are as follows:

(a) Socorro - rain collector on roof of Workman Center, New Mexico Tech campus, elevation 4635 feet. Snow samples were collected by allowing snow melt to drop through the rain collector.

(b) Albuquerque - 75 miles north of Socorro, roof of Geology building, University of New Mexico, elevation 5280 feet (not shown on Figure 2.2).

(c) Langmuir Laboratory - 18 miles southwest of Socorro, elevation 10,500 feet. Large-surface rain collector which can feed ten one gallon bottles in series.

(d) Mount Withington - 35 miles west of Socorro, elevation 10,115 feet. Most of the samples at this station were composite samples of no more than one week.

Langmuir Laboratory and Mount Withington are not accessible during some of the winter months.

2.1.2 Condensed Water. Atmospheric moisture samples were collected 3 miles west of Socorro next to Merritt Mine, elevation 5110 feet (M-station,

Figure 2. 2

Diagrammatic topographic cross section through the tritium monitoring stations, Socorro County, N. M.

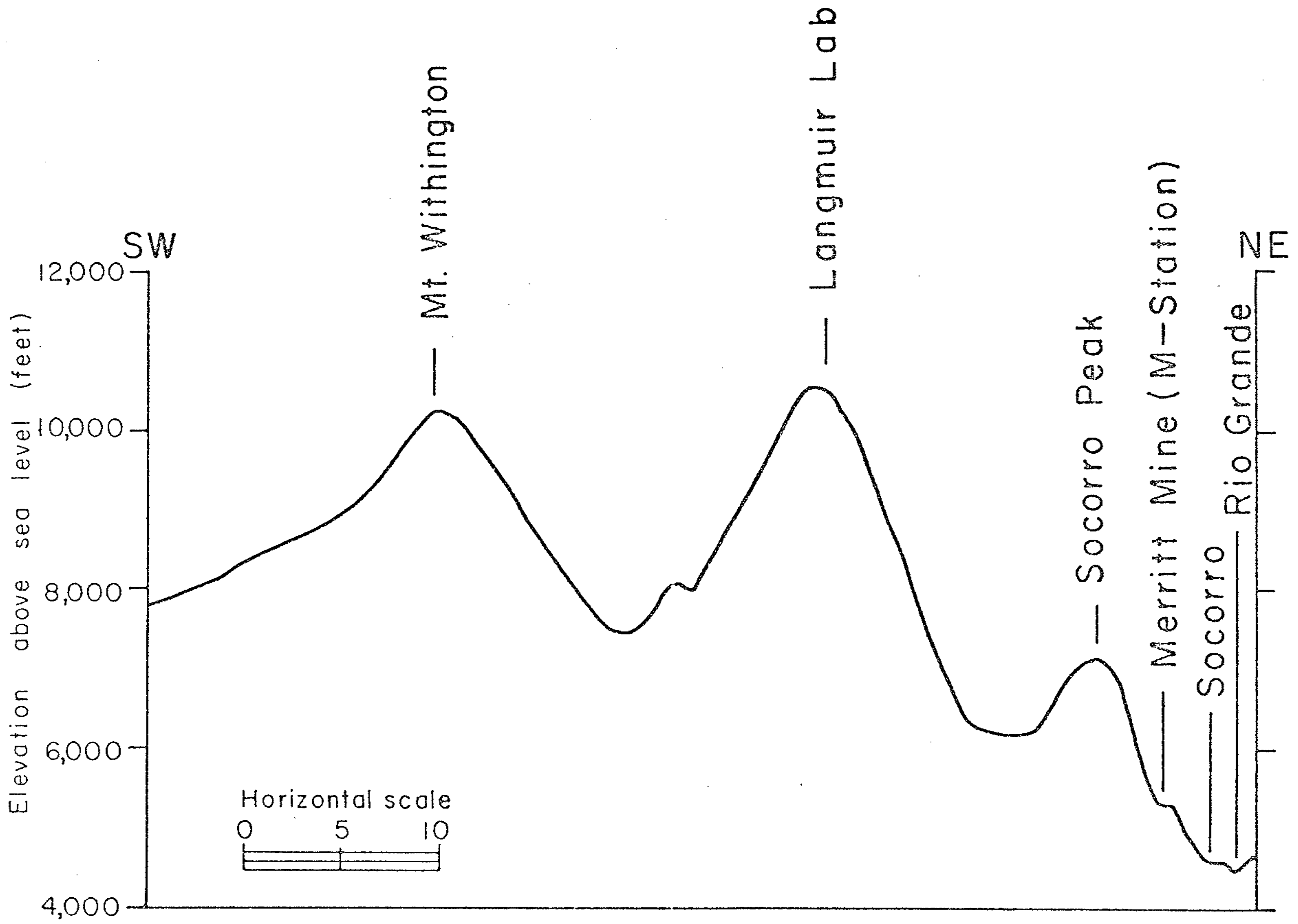

SW
NE
Mt. Withington
Langmuir Lab
Socorro Peak
Merritt Mine (M-Station)
Socorro
Rio Grande
12,000
10,000
8,000
6,000
4,000
Elevation above sea level (feet)
Horizontal scale
0
5
10

Fig. 2.2). Water was condensed with a portable dehumidifier unit (Navy type CAJH-10306 built by General Electric Co.) at preset times. Depending on the relative humidity, 500 to 1000 ml were collected in 2 hours of operation.

2.1.3 Ground Water Samples. Sampling locations for tritium analysis of ground water were selected according to the recommendations of the New Mexico State Engineer in cooperation with the Ground-Water Hydrology Dept. of this Institute. The project was initiated in order to gain information on the response of the aquifer system to post-bomb tritium fallout.

Each water sample consisted initially of 5 gallons, this was later reduced to 2 gallons. If possible, wells were sampled during the irrigation season. This procedure assured samples which would represent the formation water. During shut-off, samples were taken, if possible, after flushing each well with an amount of water equal to a few volumes of its casing (the casing volume of a well 800' deep is about 1500 gallons). Some irregularity in sampling intervals resulted from no flow conditions.

Sample collection between 1959 and 1962 was done in cooperation with other investigators (Hood, 1963; Reeder, 1963). George E. Maddox, USGS field office in Roswell, was responsible for sample collection from 1962 to 1966 (See App. E, F, and G for sample lists).

A description of each individual well is given in Appendix E (wells sampled 1 to 10 times) and Appendix G (wells with 20 to 60 samples) together with the tabulation of tritium concentrations of each well.

2.2 Data Collection

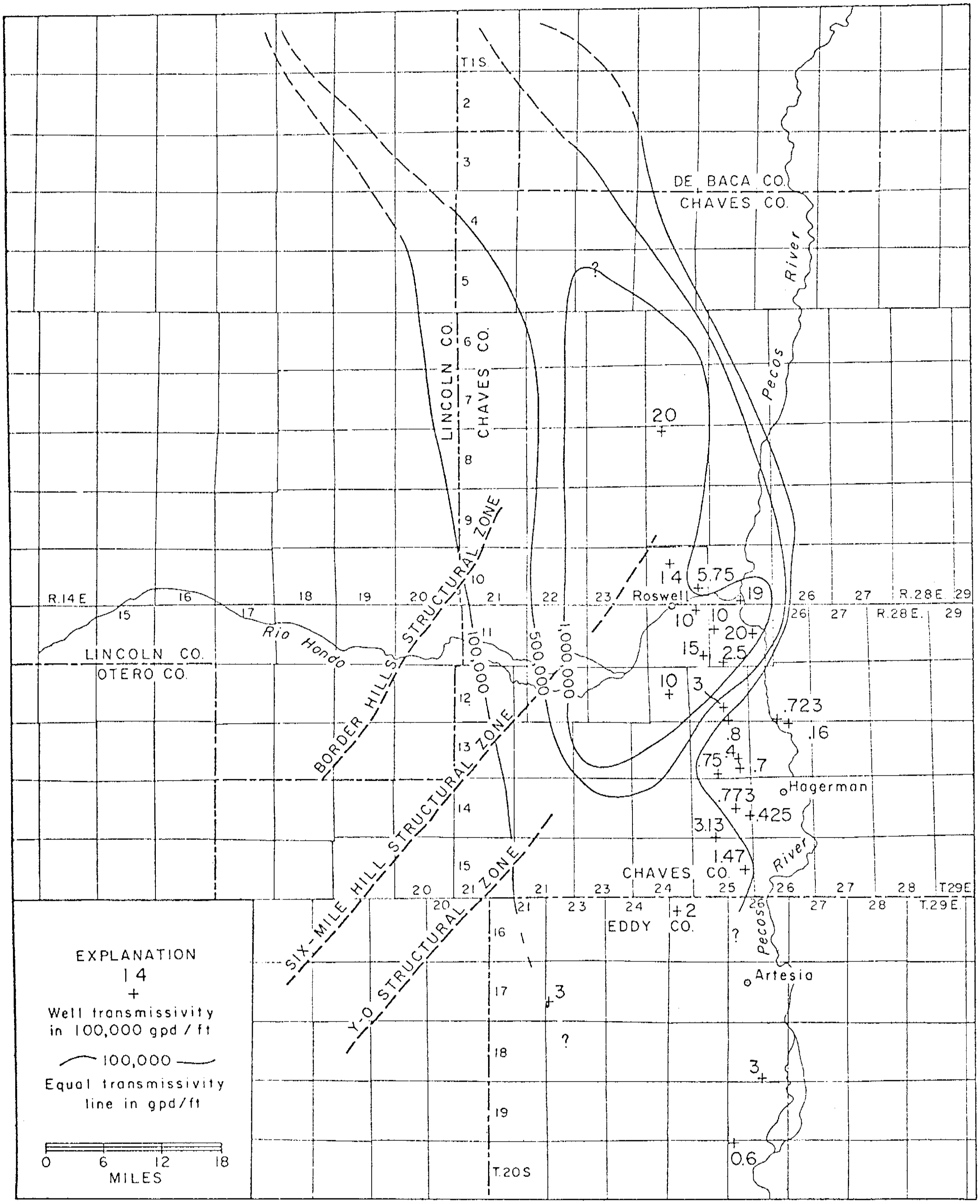
In order to evaluate the hydrologic significance of the tritium data, hydrologic, geologic, and meteorologic findings of other studies are used. The information is needed for the understanding of the position of each well relative to its neighboring wells, the type of hydrologic unit in which it is completed, and the overall position of the wells with respect to the recharge area. Meteorologic data are essential for the construction of tritium fallout patterns over the study area.

The sources for the hydrologic and geologic data were reviewed in Chapter 1.

2.2.1 Hydrological Data. Hydrologic data pertinent to the present investigation are presented in an equal transmissivity map (Fig. 2.3). The map was constructed using results of pumping tests conducted by the Ground Water Hydrology Department (now Department of Geoscience) of New Mexico Institute of Mining and Technology (1956, 1966-1967) and various state and federal agencies (W. K. Summers, personal communication, 1972). Two sources of data frequently used are Hantush (1957), and Saleem and Jacob (1971), especially in conjunction with ground water velocity calculations, water budget, and recharge estimations.

Figure 2. 3

Equal transmissivity map of the Roswell artesian basin (information provided by W. K. Summers, 1972).



EXPLANATION
14
+
Well transmissivity in 100,000 gpd / ft
100,000
Equal transmissivity line in gpd/ft
0
6
12
18
MILES
DE BACA CO.
CHAVES CO.
LINCOLN CO.
CHAVES CO.
LINCOLN CO.
OTERO CO.
EDDY CO.
CHAVES CO.
Pecos River
Rio Hondo
Roswell
Hagerman
Artesia
BORDER HILLS STRUCTURAL ZONE
SIX-MILE HILL STRUCTURAL ZONE
Y-O STRUCTURAL ZONE
100,000
500,000
1,000,000
T1S
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
T.20S
R.14E
15
16
17
18
19
20
21
22
23
24
25
26
27
R.28E
29
T.29E
28
20
14
5.75
19
10
10
20
15
2.5
10
3
.723
.16
.8
.4
.75
.7
.773
.425
3.13
1.47
2
3
3
0.6
?

2.2.2 Geologic Data. The geologic data are presented in a generalized geologic map of the Roswell artesian basin (Fig. 1.2) and two geologic cross sections. The cross sections are in east-west direction with some of the sampled wells projected on their plane. Figure 2.4 is cross section AA' through the Oasis well (W. T. Clardy) just south of Roswell. Figure 2.5 is a cross section BB' through the city of Hagerman. Most of the sampled wells are located in an area between the cross sections or just north or south of them.

2.2.3 Meteorologic Data. The monthly precipitation records were assembled from the New Mexico section of the Climatography Tables published by the U. S. Department of Commerce (1953-1968). The data for 7 stations in the Roswell basin and for Socorro are presented in Appendix D (also see Fig. 2.1 for their locations). The data cover the period from 1953 to 1968. In hydrometeorologic studies a long record is desired for statistical evaluation of data; this investigation, however, is concerned with short duration details which may have influenced local conditions of ground water recharge. The density of the precipitation recording network is about one gauge per 700 sq. miles.

Daily weather maps were used to evaluate sources of moisture during particular times of high tritium concentration in precipitation.

Figure 2.4

Geologic cross section AA', through Roswell with sampled wells (after Summers, 1972).

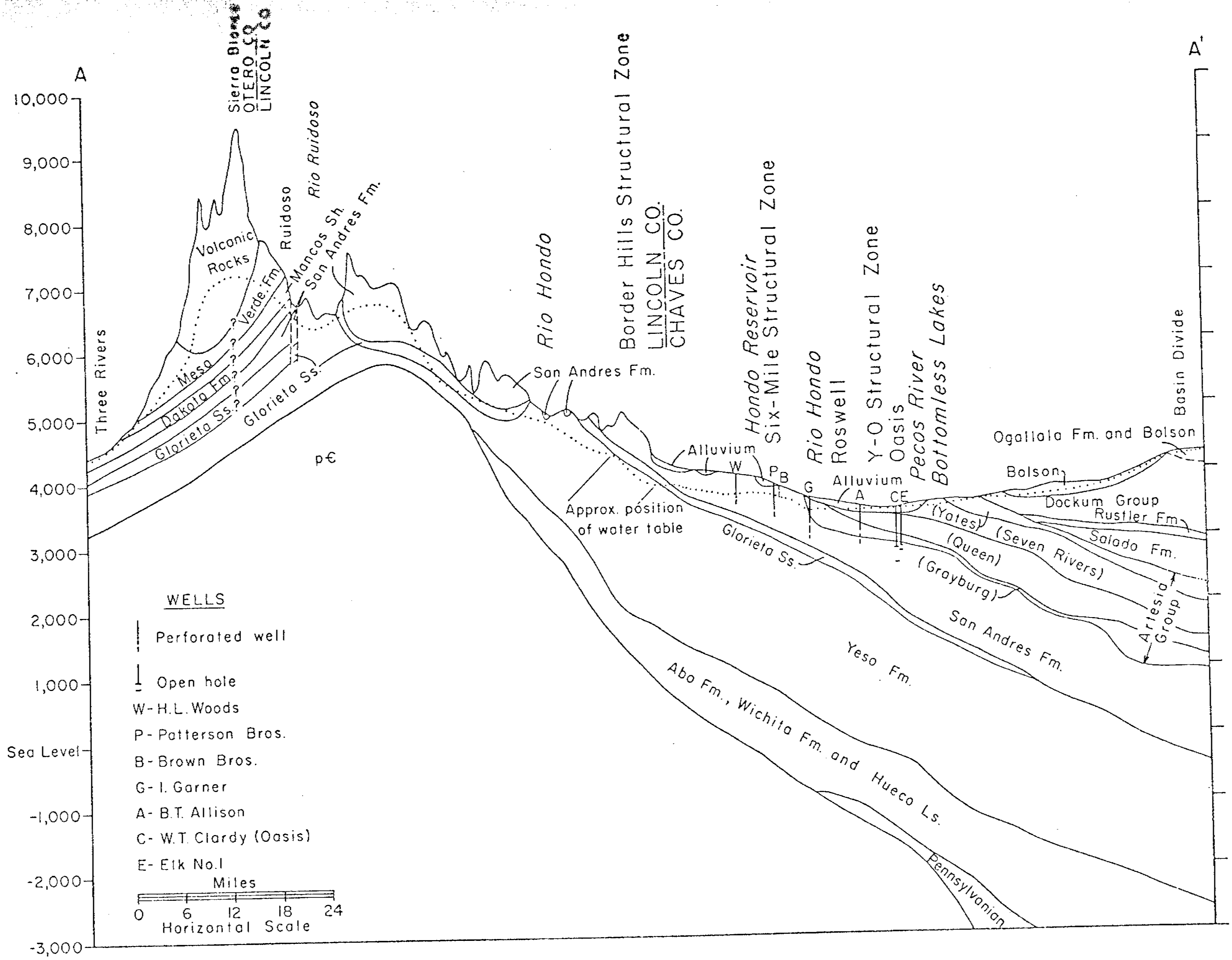
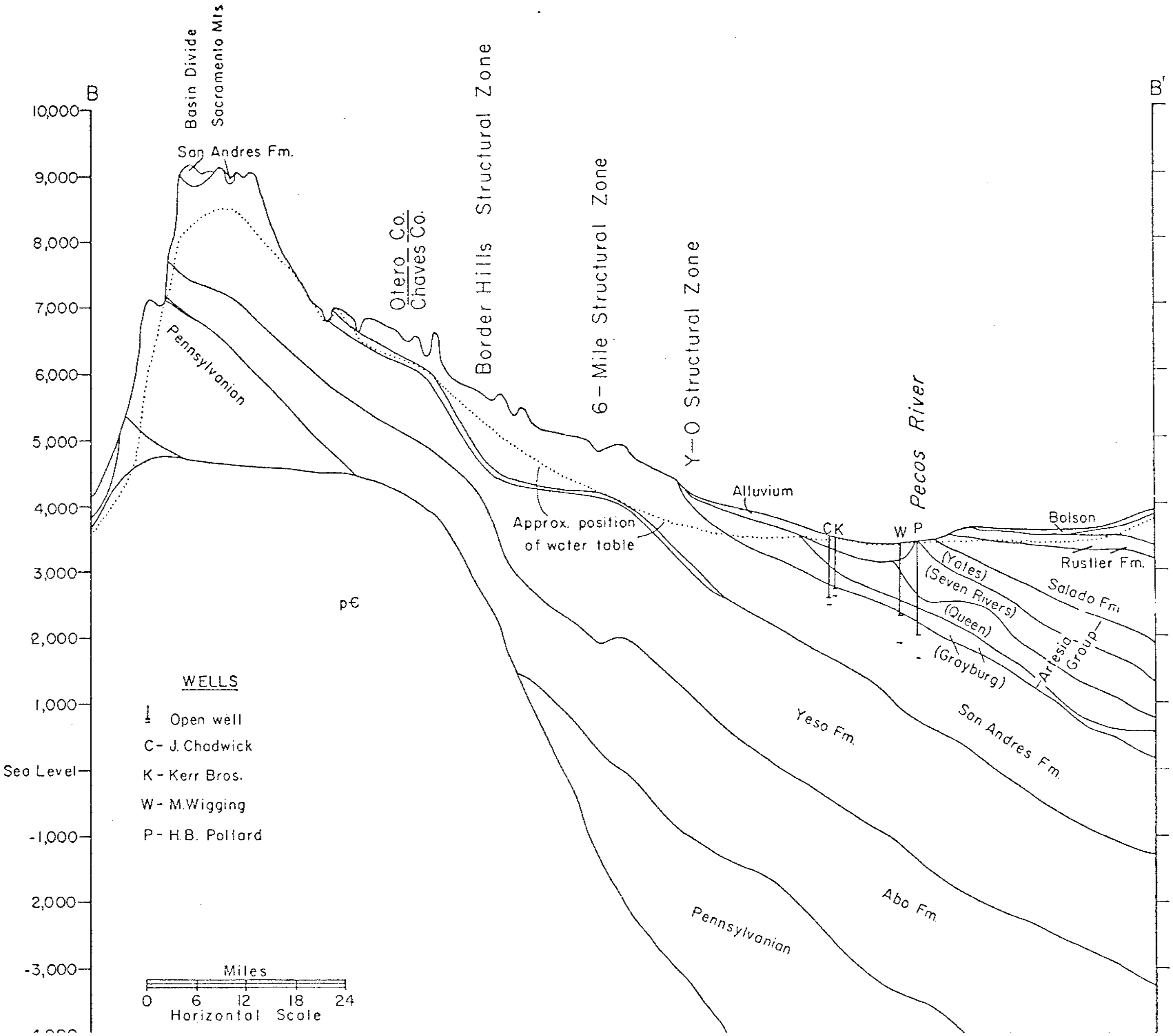

A
A'
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
Sea Level
-1,000
-2,000
-3,000
Three Rivers
Sierra Blanca
OTERO CO
LINCOLN CO
Volcanic Rocks
Ruidoso
Rio Ruidoso
Mancos Sh.
San Andres Fm.
Verde Fm.
Mesa
Dakota Fm.
Glorieta Ss.
Glorieta Ss.
p€
Rio Hondo
San Andres Fm.
Border Hills Structural Zone
LINCOLN CO.
CHAVES CO.
Approx. position of water table
Alluvium
W
Hondo Reservoir
Six-Mile Structural Zone
P B
G
Rio Hondo
Roswell
Alluvium
A
Y-O Structural Zone
Oasis
C E
Pecos River
Bottomless Lakes
Glorieta Ss.
(Yates)
(Queen)
(Grayburg)
(Seven Rivers)
San Andres Fm.
Yeso Fm.
Abo Fm., Wichita Fm. and Hueco Ls.
Pennsylvanian
Ogallala Fm. and Bolson
Bolson
Dockum Group
Rustler Fm.
Salado Fm.
Artesia Group
Basin Divide
WELLS
Perforated well
Open hole
W- H.L. Woods
P- Patterson Bros.
B- Brown Bros.
G- I. Garner
A- B.T. Allison
C- W.T. Clardy (Oasis)
E- Elk No.1
Miles
0 6 12 18 24
Horizontal Scale

Figure 2.5

Geologic cross section BB', through Hagerman, with sampled wells (after Summers, 1972).


B
B'
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
Sea Level
-1,000
2,000
-3,000
Basin Divide
Sacramento Mts.
San Andres Fm.
Otero Co.
Chaves Co.
Border Hills Structural Zone
6-Mile Structural Zone
Y-O Structural Zone
Pecos River
Alluvium
Approx. position of water table
C K
W P
Bolson
Rustler Fm.
Salado Fm.
(Yates)
(Seven Rivers)
(Queen)
(Grayburg)
Artesia Group
San Andres Fm.
Yeso Fm.
Abo Fm.
Pennsylvanian
Pennsylvanian
p€
WELLS
Open well
C - J. Chadwick
K - Kerr Bros.
W - M.Wigging
P - H.B. Pollard
Miles
0
6
12
18
24
Horizontal Scale

2.3 Well-Numbering System

Wells and springs referred to in this report are identified by the location number system used in New Mexico by the U.S. Geological Survey and the New Mexico State Engineer. The system is based on the common subdivision of lands into townships, ranges and sections (Fig. 2.6).

The location number is divided into four segments, e.g., 11-23-12-344. The first indicates the township north or south of the New Mexico base line, and the second denotes the range east or west of the New Mexico principal meridian. The third segment is the number of the section within the township, and the fourth segment indicates the 10-acre tract within which the well or spring is located. All wells in the area under study are east and south of the New Mexico principal meridian and base line respectively.

In the discussion to follow some of the more frequently sampled wells will be referred to by their owner's name.

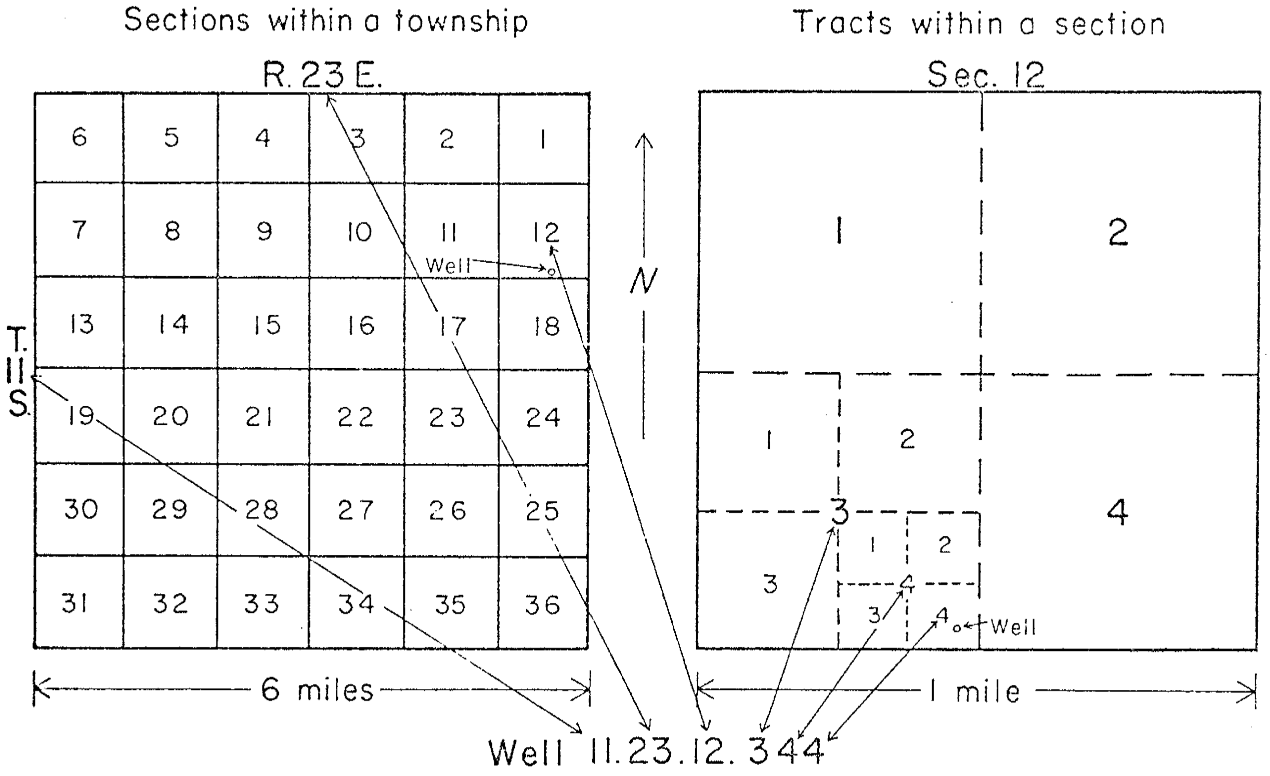
2.4 Distribution and Type of Wells

In the investigated area, there are numerous irrigation, domestic and municipal wells of different depths. Well location and classification according to use is given by Saleem and Jacob (1971, pp. 165-166). About

Figure 2.6

New Mexico system for numbering

wells and springs.


Sections within a township
R.23E.
6
5
4
3
2
1
7
8
9
10
11
12
Well
13
14
15
16
17
18
T.
11
S.
19
20
21
22
23
24
30
29
28
27
26
25
31
32
33
34
35
36
6 miles
N
Tracts within a section
Sec. 12
1
2
1
2
3
4
1
2
3
3
4
4
Well
1 mile
Well 11.23.12.344

60 wells, completed either in the San Andres Limestone, Artesia Group or both; and 14 shallow wells completed in the Alluvial aquifer, were initially sampled for their tritium content. In addition, data for 7 springs are presented together with the shallow wells. The location of each well is shown in Figure 2.7. The number or name next to the well's location refers to data listed in Appendices E-G. A small number of wells in the vicinity of Ruidoso (Lincoln and Otero counties) which are included in the tables are not shown on the map.

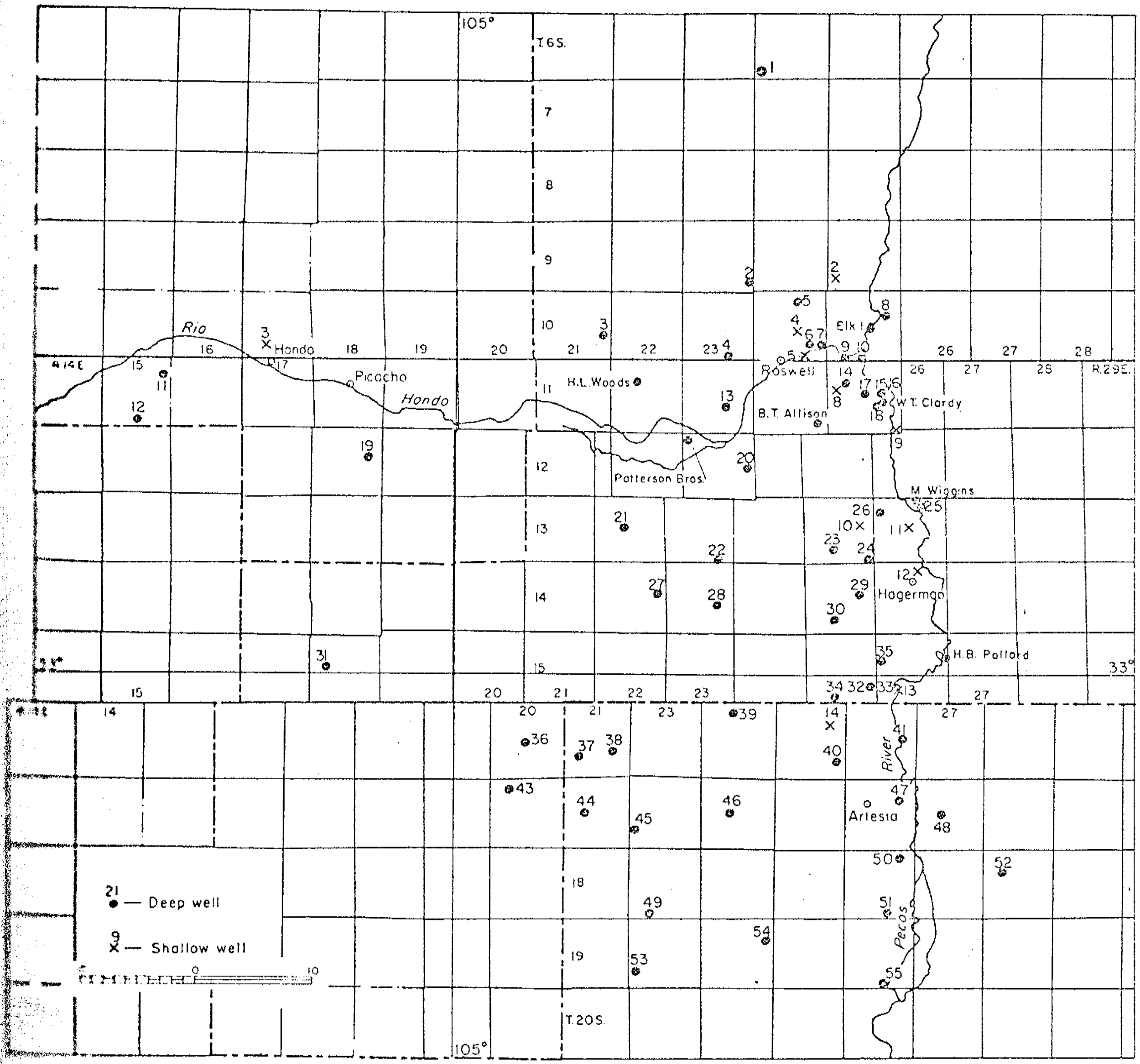
The wells are distributed in three counties: Chaves Co., Eddy Co., and Lincoln Co., and are spread over an area of about 2160 square miles.

Since 1962 the monitoring of tritium in well water has been limited to 6 wells with the addition of Elk 1 (10-25-22-324) in 1964. These 7 wells are designated by name in Figure 2.7.

The criterion employed in the selection of sampling wells requires that each well not tap water of more than one aquifer unit. The wells in the Quaternary deposits ("alluvial" or "shallow" wells) are not deeper than 300 feet, which is the maximum depth of this unit. Most of the deep wells ("bedrock" wells) are in the San Andres Limestone with few exceptions where they are open or perforated through the lower part of the Artesia Group. The shallower of the bedrock wells are either drilled in the exposed San Andres Limestone or close to the boundary between the alluvium

Figure 2.7

Locations and types of wells sampled for tritium (numbers refer to localities listed in App. E and F, and names to App. G).

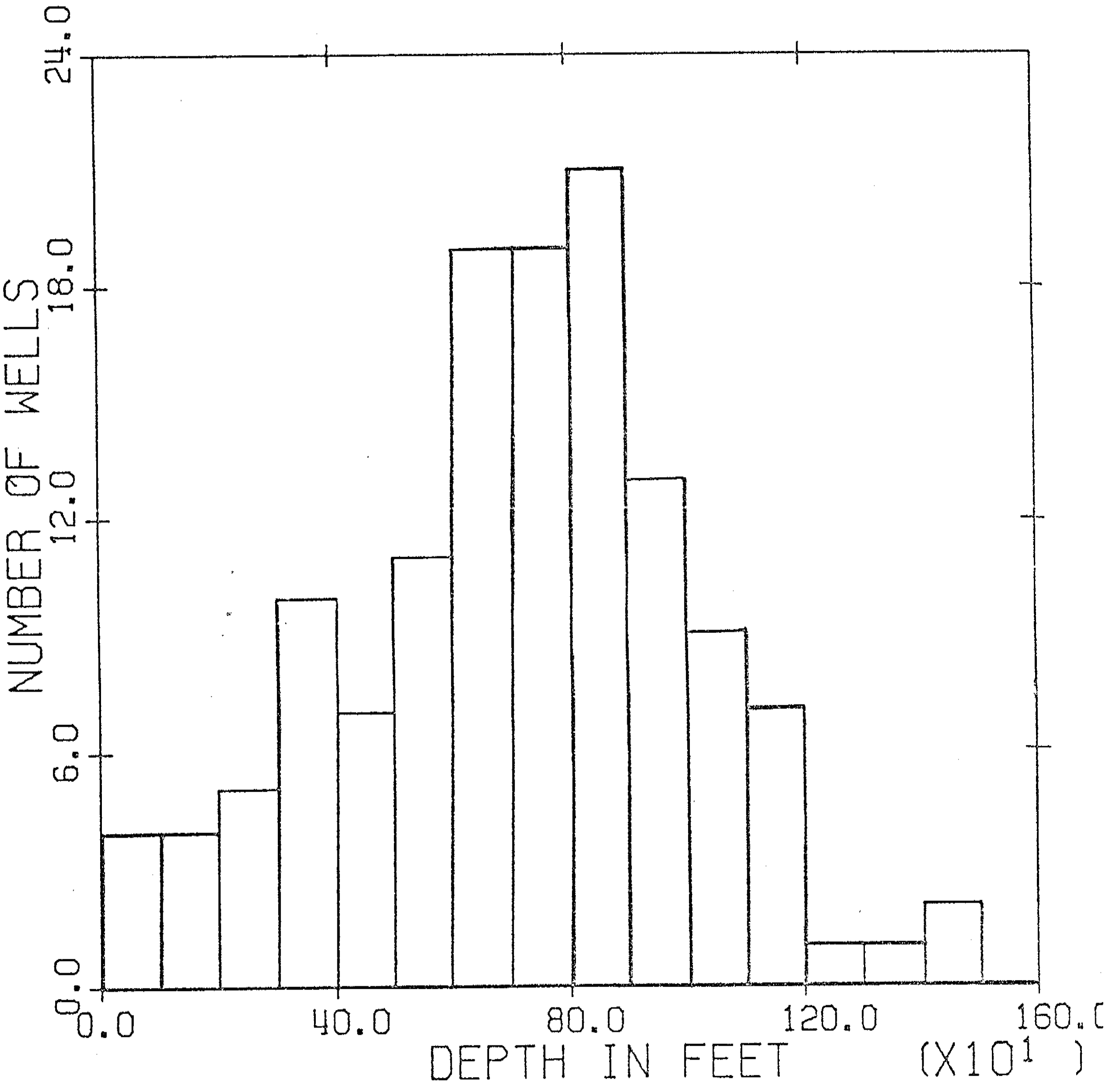


105°
T.6S.
7
8
9
10
11
12
13
14
15
T.20S.
R.14E.
R.29E.
33°
Rio
Hondo
Hondo
Picacho
Roswell
Elk
H.L. Woods
B.T. Allison
W.T. Clardy
Patterson Bros.
M. Wiggins
Hagerman
H.B. Pollard
River
Pecos
Artesia
15
16
17
18
19
20
21
22
23
26
27
28
21 ● — Deep well
9 X — Shallow well
0
10

deposits and the limestone exposure. These are mostly wells west of Range 23. The frequency of depth of production interval for the sampled bedrock wells is given in Figure 2.8.

Figure 2.8

Frequency of depth of production interval for the deep wells.


NUMBER OF WELLS
0.0
6.0
12.0
18.0
24.0
0.0
40.0
80.0
120.0
160.
DEPTH IN FEET
(X10^1)

2.5 References

Hantush, M. S., Preliminary quantitative study of the Roswell ground-water reservoir, New Mexico, N. M. Institute of Mining and Technology, 118 pp., 1957.

Hood, J. W., Saline ground-water in the Roswell basin, Chaves and Eddy counties, New Mexico 1958-59, U. S. Geological Survey Water Supply Paper 1539-M, 46 pp., 1963.

Reeder, H. O., Tritium used as a ground-water tracer between Lake McMillan and Major Johnson springs, Eddy County, New Mexico, U. S. Geological Survey open-file report, 109 pp., 1963.

Saleem, Z. A., and C. E. Jacob, Dynamic programming model and quantitative analysis, Roswell basin, New Mexico, New Mexico Water Resources Research Institute, Report No. 10, 180 pp., 1971.

Summers, W. K., Geology and regional hydrology of the Pecos River basin, New Mexico, Final Report, New Mexico Water Resources Research Institute Project No. 3109-102, 250 pp., 1972.

U. S. Department of Commerce, Environmental Science Services Administration, Climatological Data New Mexico, volumes 57 to 72, 1953-1968.

3. TRITIUM MEASUREMENTS

3.1 General Background

The reliability of the hydrologic interpretation of isotopic data depends on the accuracy of the actual measurements of tritium activities in water. A careful effort was made to check and compare measurements performed with various instruments and techniques during the study. Test solutions of known concentration, obtained from the National Bureau of Standards, were used for calibration and control. The laboratory also participated in a comparison program by IAEA. In general, the method used was the electrolytic enrichment of tritium followed by gas or liquid scintillation counting. Natural deuterium, which is always present in water (between 0.0129 and 0.0150 mole%), was used as the tracer for tritium enrichment by electrolysis. About 80% of the samples were counted with a low level background gas counter.

The various operations that were used for the assay of tritium are outlined below. (See flow diagrams in Figs. 3.1 and 3.2.) Similar methods and comparisons between different laboratories were reported by Kaufman and Libby (1954), Brown and Grummitt (1956), Ostlund and Werner (1962), Ostlund et al. (1964), Bainbridge (1965), and Cameron (1967). The theory of tritium enrichment and the apparatus for determining

Figure 3.1 Flow diagram for the multi-stage procedure.

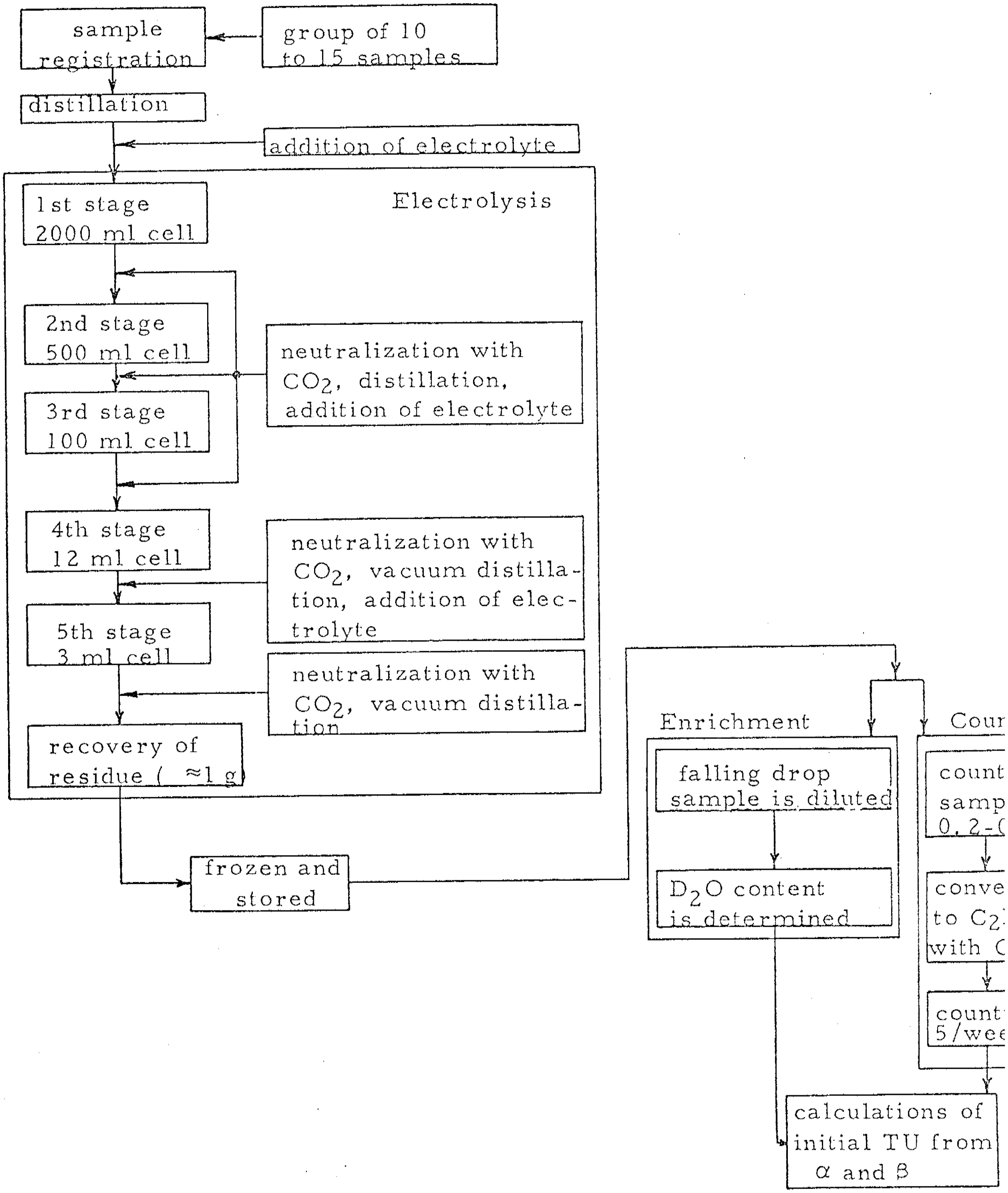
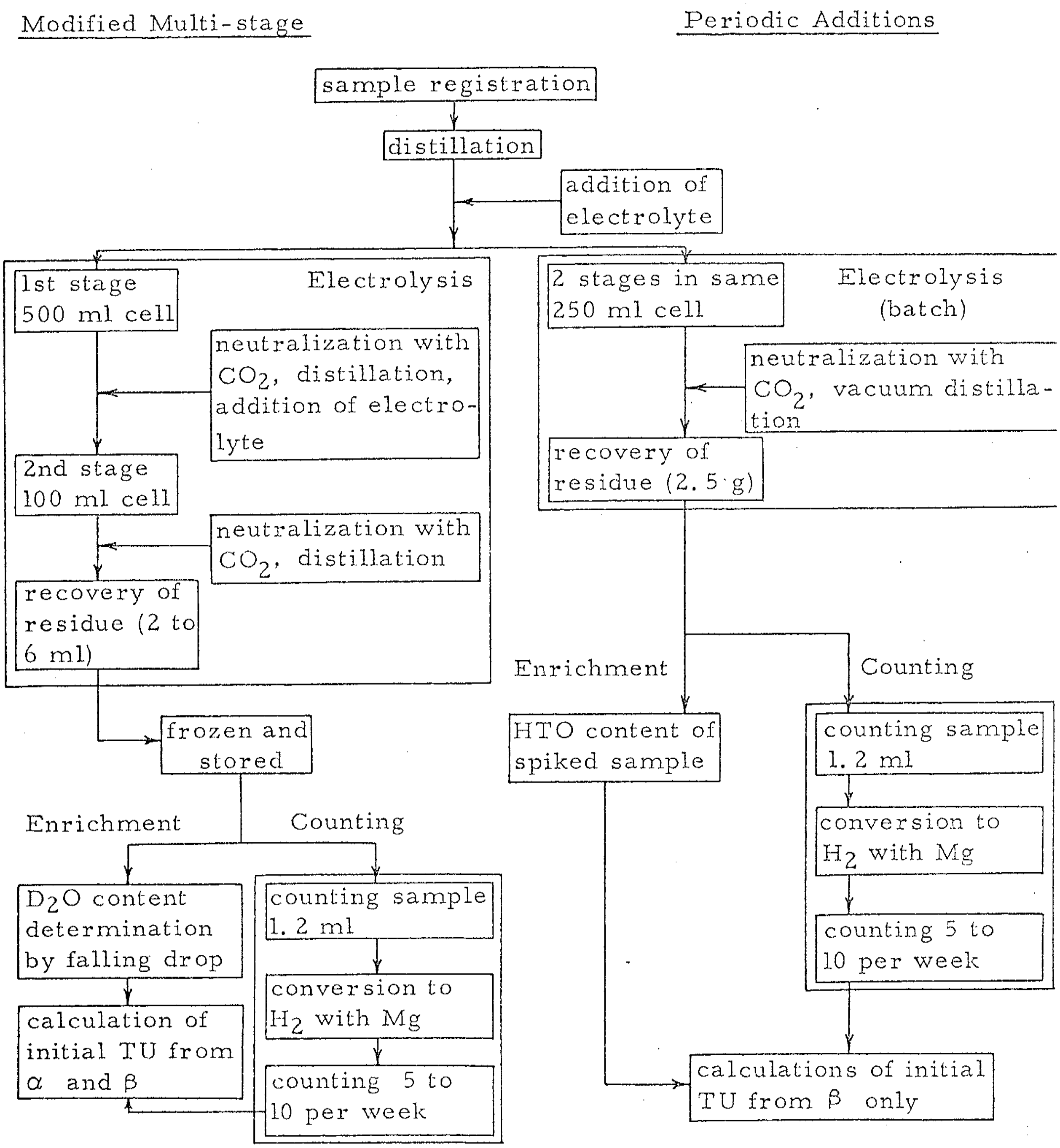


Figure 3.2 Flow diagram for the modified multi-stage and periodic additions.



deuterium enrichment are presented as supplementary material in Appendices B and C.

During the years when the reported data were measured, two gas counters and one liquid scintillation counter were used. Three different tritium enrichment systems and two methods for enrichment determination were also employed. Some of these techniques were in operation concurrently, others were discontinued upon initiation of a new method. Results obtained with different methods have different degrees of accuracy and reliability that must be taken into account in interpretation.

3.2 Enrichment of Tritium by Electrolysis

Tritium is a low energy beta emitter (0.018 Mev maximum). The low concentrations found in natural water require enrichment before measurement. In principle, during a slow rate electrolysis the ratios of deuterium to hydrogen (D/H) and tritium to hydrogen (T/H) increase in the residual volume of water. The heavy isotopes are discharged at the cathode more slowly than ordinary hydrogen (Kaufman and Libby, 1954). Regardless of the electrolysis system used, there are two important factors which affect the efficiency of tritium recovery: temperature and current density. Electrolysis cells should be kept at low temperature to avoid evaporation losses and a decrease in tritium separation factor. At high temperatures the kinetic difference between the hydrogen isotopes (mass ratio T/D/H = 3/2/1) decreases. Current density during electrolysis should not exceed 0.1 amp/cm^2 to avoid overheating of the solution at the electrode surface (Brown and Grummitt, 1956). As the solution in the electrolysis cell diminishes, the electrode surface in contact with the solution becomes smaller and the current density increases. Therefore it is important to adjust the current so as not to exceed the maximum value at any time.

3.2.1 Multi-Stage Electrolysis. This method of enrichment is based on the work by Kaufman and Libby (1954). In the present study their procedure was modified when the original internal gas counter (sensitive volume = 0.14 liters) was replaced by a new counter (sensitive volume = 1.07 liters). With the installation of the new counter, electrolysis was no longer carried out from an extremely large initial volume (2000 to 6000 ml) to a final quantity of less than one gram in 5 or 6 stages. Instead, in the new procedure, the initial sample volume of 500 or 2000 ml was reduced to between 2 and 8 ml in two stages.

Original procedure. Electrolysis was performed in graduated cylinders of glass (2000 ml, 500 ml, and 100 ml) and graduated centrifuge tubes (12 ml, and 3 ml). The electrodes for all stages were made of nickel (anode) and mild steel (cathode). The electrode assemblies were held with rubber stoppers fitting the various cell sizes. To provide sufficient electrolyte for electrolysis of each sample, 2% by weight of sodium peroxide (Na_2O_2) was added at the beginning of each of the first three stages. Na_2O_2 is reduced by the reaction

$$H_2O + Na_2O_2 \rightarrow 2NaOH + \tfrac{1}{2}O_2 \qquad (3\text{-}1)$$

Sodium peroxide was preferred to sodium hydroxide (NaOH) because no additional hydrogen is added to the sample. Samples low in tritium could have been contaminated if the NaOH contained some tritium or exchanged some of its hydrogen with tritium atoms present in the room atmosphere. At the end of each electrolysis stage, the solution in the cell was very basic (pH $\approx$ 14) and it was necessary to lower the pH to enhance the recovery of any tritium which might have been bound as NaOT. This was done by passing CO_2 through the solution

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O \qquad (3\text{-}2)$$

The separation of the salt from the water was done by distillation into the next smaller size electrolysis cell. In the final two stages of electrolysis, i.e., 12 ml → 3 g and 3 g → 0.5 g, the electrolyte added to the sample was 1% by weight and the distillation was done by a vacuum distillation technique.

Modified procedure. The number of stages was reduced to two. Only two types of electrolysis cells were used: 500 ml and 100 ml volume, respectively. The first stage was periodic addition of 2000 ml in portions of 400 ml to the electrolysis cell every time the volume decreased to about 100 ml. After reduction of the whole sample to a residual volume of 100 ml, it was neutralized with CO_2 and distilled into a 100 ml cell. The final reduction was continued to 6 ml. A few (low level) samples were reduced to 2 ml.

Each group of cells (of the same volume) was placed in a constant temperature bath of 5-7 °C, and the electrodes were connected in series to a power supply which provided each cell with 3 volts. With this system, the rate of electrolysis was 40 ml of water per day at a current of 5 amp. During the first stage, 10 days were required to reduce the volume to 100 ml per 500 ml cell. The current was reduced as the electrolysis progressed to smaller volumes. At the final stage of the large volume reduction, only 50-100 ma were used.

The enrichment factor (E), written in terms of volume/volume, is given by

$$E = \frac{\tau}{\tau_o} = \left(\frac{V_o}{V}\right)\left(\frac{D}{0.015} \cdot \frac{V}{V_o}\right)^{\alpha/\beta} \qquad (3\text{-}3)$$

where: τ_o and τ are the initial and final tritium concentrations; V_o and V are the initial and final volumes of a sample; 0.015 and D are the initial and final concentration of deuterium of the sample in mole percent. Appendix B gives a detailed discussion of the enrichment theory.

Originally deuterium measurements were done in order to determine the density of the enriched samples so that the residual weight/volume ratio could be written in terms of volume/volume ratio (Equation 3.3). The ratio β/α was assumed constant and equal to 2.1 ± 0.1 (after Kaufman and Libby, 1954). After a long search through the basic data available in this laboratory, it was concluded that although deuterium recovery by electrolysis was constant for the same batch of samples, conditions changed from one batch to the next. Meanwhile, other investigators had reported that the correlation between the tritium and deuterium enrichment during electrolysis is not in a constant ratio of their separation factors, but rather that the ratio of the logarithms is a constant

$$\log \beta / \log \alpha = 1.41 \pm 0.01 \qquad (3\text{-}4)$$

(Roy, 1962; Bigeleisen, 1962). Since β cannot be measured directly without spiked samples of known initial tritium concentration, it was decided to calculate the separation factor for tritium from the measured α for each sample individually. The deuterium content of each sample was available, so the additional computations were not laborious. The only assumption imposed was that electrolytic loss of tritium and deuterium are linearly related.

Deuterium analysis was by the falling drop method. The apparatus and the procedure for its operation are given in Appendix C.

Table 3.1 is a comparison between different initial and final

Table 3.1 Tritium separation and enrichment factors for different initial and final conditions of electrolysis.

LAB NO	Initial and Final Conds.			Enrichment			
	V_o(ml)	W(g)	V(ml)	V_o/V	β	β/α	E
463A	940	0.60		1253	8.7	1.87	1009
472A	500	0.50		983	8.7	1.87	817
605A	2000		9.2	210	15.2	2.2	148
687I	500		2.5	164	13.7	2.1	114
690A	2000		7.5	205	16.6	2.2	149
901I	500	0.94		502	7.1	1.77	211
902I	500	0.88		515	6.6	1.73	202
905I	500	0.88		515	12.8	2.1	317
906I	500	1.06		339	16.8	2.3	241
933I	2000	1.08		609	8.4	1.86	285
980A	1000		2.72	360	11.6	2.0	217
981	2000	0.91		1762	4.3	1.53	909
982	2000	1.28		1213	3.9	1.49	467
999	2000		2.66	677	10.8	2.1	369
1050	2000		9.0	170	15.0	2.2	121
1064	2000		8.1	188	15.3	2.2	134

conditions of electrolysis and the resulting separation and enrichment factors for tritium. It is clear that those samples which were electrolyzed through 4 or 5 stages to one gram or less ($V_o/V > 500$) actually lost tritium. All of the samples with residual volume larger than 2 ml had consistently higher β-values (>10) and their average $\beta/\alpha = 2.14 \pm 0.07$. Table 3.2, in addition to different initial and final volumes, shows the reproducibility of results when the same sample was processed under different conditions. Samples 913C and 913I, enriched by the modified electrolysis in two stages to 9.5 ml and 3.0 ml respectively, have the highest tritium recovery. Samples 665A and 665I were both reduced to about 0.7 grams. The agreement in the determination of their initial tritium concentration was within 4%. The difference in enrichment procedure was in the initial volume. The first stage reduction from 2000 ml to 500 ml was omitted for sample 665I which initially was 500 ml. This indicates that the largest errors were introduced during the final stages of electrolytic enrichment when the quantity of sample was small. The source of errors could be one or a combination of the following:

(a) Current density was very difficult to control due to the very thin wires used as electrodes in the last stage of electrolysis.

(b) Errors in weighing the small residual sample.

(c) Dilution of the falling drop samples required when V_o/W was large. The dilution was done by weight and involved samples on the order of 0.01 to 0.05 grams.

Table 3.2 Reproducibility of results under different initial and final conditions of electrolysis.

LAB	ENRICHMENT					COUNTING		INITIAL CONC.
NO	VO(ml)	W(g)	V(ml)	β	β/α	CONV.	COUNTER	(TU)
665A	2000.	0.73		3.9	1.5	CaC_2	G-M(1)	2500. ± 25. (2)
665I	500.	0.68		3.6	1.4	CaC_2	G-M	2390. ± 62.
683A	2000.	0.60		5.7	1.7	CaC_2	G-M	29. ± 1.
683B	2000.	0.71		5.2	1.6	CaC_2	G-M	35. ± 2.
683D	2000.	0.54		4.5	1.6	CaC_2	G-M	17. ± 4.
913A	6000.	1.02		3.1	1.4	CaC_2	G-M	24. ± 4.
913B	2000.	1.17		4.3	1.5	Mg	G-M	27. ± 10.
913C	2000.		9.5	8.3	1.8	---	LS(3)	25. ± 5.
913I	500.		3.0	12.7	2.1	CaC_2	G-M	13. ± 10. (4)

---

(1) Geiger-Muller

(2) ± value was determined from variations in background count, counter's effective volume, and total number of counts.

(3) Liquid Scintillation

(4) counted during high background (≥3.0 cpm)

In summary, the multi-stage enrichment was an inefficient and time consuming method for the concentration of tritium in water because of the many steps of transfer and handling involved which also introduced sources of error.

3.2.2 Electrolysis by Periodic Additions (Batch Determination). A batch of 10 electrolysis cells for periodic additions was used during the latter part of the study (1971). The method was first introduced by Ostlund and Werner (1962) and the cells are commercially available. The initial volume of sample required was 250 ml which was reduced to about 2.5 ml in two stages (3 amp and 0.3 amp). The advantages of this method are that the sample remains in the same cell and does not require intermediate treatment until electrolysis is completed. The sample is stored in a 250 ml drop funnel above the cell with only 50 ml of the sample in actual contact with the electrodes. Na_2O_2 served as the electrolyte (1.2% by weight) and the constant temperature bath was maintained at $7.0 \pm 0.5\ ^{o}C$. During the first stage, electrolysis occurred at the rate of 25 ml per day (72 amp-hr), requiring 25 ml to be added on each subsequent day until the volume was reduced to about 15 ml. At this point the second stage began and the current was reduced. The electrolysis continued until the sample had been reduced to about 2.5 ml. As in the multi-stage electrolysis, the sample was neutralized with CO_2 to prevent hydrogen or tritium from being bound as NaOH. Vacuum distillation was done directly from the electrolysis cell into a weighing bottle. From the initial volume and the weight of the residue, the volume/weight enrichment was determined. The enrichment theory and equations for tritium determinations are given in Appendix B.

The tritium enrichment factor for this method is calculated by "spiking" one sample per batch with an initially known tritium concentration. From the known initial volume and final weight of the sample and initial and final tritium concentrations in the sample, the value of β can be computed

$$\beta = \frac{\ln\left(\frac{V}{V_o}\right)}{\ln\left(\frac{\tau}{\tau_o}\,\frac{V}{V_o}\right)} \tag{3-5}$$

The β-value is then applied to the unknown samples in the batch and their initial tritium concentrations are calculated (App. B). The spiked sample was diluted from NBS standard No. 4926. During the first four batches of operation the value of β increased from 8.6 to 16.1, due to "aging" of the electrodes. From time to time a blank sample was put through the enrichment process to check for any sources of contamination.

Only a small number (60) of the total samples measured in this study were enriched by this method. In addition, electrolysis by periodic additions was used for checking the overall accuracy of tritium measurements by multi-stage electrolysis and the validity and accuracy of the falling drop method. The overall system check was done by rerunning samples which had previously been analyzed for tritium. The accuracy of the falling drop method was checked by independently calculating the enrichment factor of each sample by both falling drop and batch methods. The results are compared in Table 3.3 Most of the samples were reduced to about 2.5 gm ($V_o/V = 100$) and the deuterium concentrations were between 0.52 and 0.62 mole%. Two samples, 1370 and 1367, were reduced to about 1.6 gm ($V_o/V = 155$) and their deuterium concentrations were equal to 0.95 mole%. The table also illustrates the degree of uniformity of the ratio β/α if the final weight is kept well above 1 gm.

The final group of samples in Table 3.3 are the standard samples used for the batch determination of β. The initial concentrations were computed from falling drop determinations of β/α and the enriched tritium concentrations. Their measured average value was 1625 ± 25 T.U. as compared to their calculated value of 1625 ± 10 T.U.

3.2.3 Evaluation of the Methods. The efficiency of tritium recovery by electrolysis can be calculated by the relationship

$$E_T = \frac{V\tau}{V_o\tau_o} \tag{3-6}$$

where all quantities are readily available. When the sample residue is recovered by weight, the density of the sample is calculated and $V/V_o = \rho^{-1}(W/V_o)$. τ is the time-corrected concentration of the enriched

Table 3.3 Comparison between falling drop and batch determination of tritium concentrations.

LAB NO	PERIODIC ADDITIONS β	PERIODIC ADDITIONS Initial conc. (TU)	PERIODIC ADDITIONS WITH FALLING DROP β	PERIODIC ADDITIONS WITH FALLING DROP β/α	PERIODIC ADDITIONS WITH FALLING DROP Initial conc. (TU)
Batch One					
Blank	8.6	7.1 ± 0.4	9.2	1.9	6.8 ± 0.4
605	8.6	48.0 ± 4.3	12.3	2.1	41.1 ± 4.3
901	8.6	25.8 ± 2.6	8.6	1.9	26.1 ± 2.6
801	8.6	121.4 ± 3.5	8.0	1.8	125.3 ± 3.5
Batch Two					
1365	10.7	8.4 ± 1.3	9.5	1.9	9.1 ± 1.3
1363	10.7	4.2 ± 0.6	12.1	2.1	4.1 ± 0.6
1369	10.7	17.0 ± 3.9	11.6	2.0	16.6 ± 3.9
1368	10.7	7.5 ± 2.0	9.1	1.9	7.1 ± 2.0
1366	10.7	8.6 ± 1.0	8.7	1.9	10.5 ± 1.0
Batch Three					
1370	12.1	11.4 ± 1.2	12.3	2.1	11.3 ± 1/2
1367	12.1	19.3 ± 1.0	10.6	2.0	20.5 ± 1.0
1364	12.1	15.6 ± 1.6	9.9	1.9	17.0 ± 1.6
1371	12.1	110.8 ± 1.7	11.2	2.0	113.8 ± 1.7
1372	12.1	126.2 ± 1.5	10.5	2.0	133.5 ± 1.5
1373	12.1	23.4 ± 1.6	10.5	2.0	24.7 ± 1.6
1374	12.1	137.6 ± 1.9	12.7	2.1	135.3 ± 1.9
Standard Samples					
Blank	Socorro spring		9.2	1.9	6.8 ± 0.4
Std. 2-1	Spiked sample for		9.2	1.9	1589.9 ± 3.8
Std. 2-1	batch determination		9.2	1.9	1641.3 ± 3.6
Std. 2-2	diluted to initial con-		10.5	2.0	1630.3 ± 4.1
Std. 2-3	centration of 1625.0 ± 10. TU		12.3	2.1	1640.4 ± 1.6

sample. Table 3.4 is a summary of results for selected samples discussed elsewhere in this chapter. The table should be inspected for three groups of data:

(a) Multi-stage enrichment with small final sample of about 37% average tritium recovery. The variations are from 18% to 65%. β-values for these samples are less than 10.

(b) Modified multi-stage enrichment with large final sample. Tritium recovery was more uniform, about 60%. β-values for these samples were calculated to be larger than 10 from the deuterium enrichment.

(c) Enrichment by periodic additions with uniform initial volume and final sample of about 2.5 gm. This group shows the most uniform results in both tritium recovery and β-values. (The β-values in Table 3.4 were determined by the falling drop method.) Tritium recovery was 69% and the average β-value was equal to 11.5.

Modified multi-stage electrolysis and by periodic additions are comparable in efficiency. A spiked sample should be used to determine the tritium enrichment factor for the modified multi-stage electrolysis. The falling drop method is reliable, but is time consuming. It is important to notice from the data presented in the tables that the ratio β/α is not constant as reported by Kaufman and Libby (1954) but varies between 1.4 and 2.2. This observation agrees with Roy (1962) who found variations in

β/α between 1.8 - 2.8, at a constant temperature of 0.5 °C, and Ostlund and Werner (as reported by Roy, 1962) who obtained 1.6 to 2.5.

3.3 Tritium Counting Procedure and Devices

Two types of counters are used in measuring tritium activities: Geiger-Muller low background gas counters, and liquid scintillation counters. For maximum efficiency of counting, the low background gas counter was preferred, although it is very slow. Because of the backlog of enriched samples (stored in a freezer) liquid scintillation counting was later employed. Some 200 enriched samples were counted with the liquid scintillation counter and most of them had a counting rate of about twice the background. After initial discrimination, low count samples were counted longer in order to achieve the same level of statistical confidence as in the high count samples. A large number of samples that had been previously counted by gas counter were recounted by liquid scintillation to assure reproducibility of results (Table 3.7).

Both gas counting and liquid scintillation counting of tritium are well known techniques, reported in the literature. The most comprehensive contributions are by von Buttlar and Stahl (1962), Ostlund (1962), Cameron and Payne (1965), Hoffman and Stewart (1966), Cameron (1967), and Williams and Florkowski (1967). In the following sections only those features of the method that are unique to this study will be discussed.

Table 3.4 Efficiency of tritium recovery by different methods of electrolysis.

LAB NO	% RECOVERY OF TRITIUM				SEPARATION FACTORS	
	$\frac{W}{V_o}$	$\frac{V}{V_o}$	$\frac{\tau}{\tau_o}$	E_T(%)	β	β/α
Multi-stage Electrolysis (original)						
463A	0.60/940		12651/13	64.6	8.7	1.8
665A	0.73/2000		2874978/2506	41.9	3.9	1.5
902I	0.88/500		95087/471	35.5	6.6	1.7
913A	1.02/6000		25667/24	18.2	3.1	1.4
913B	1.17/2000		11152/27	24.2	4.3	1.5
Multi-stage Electrolysis (modified)						
605A		9.2/2000	5060/34	67.5	15.2	2.2
687I		2.5/500	72796/645	56.4	13.7	2.1
1050		9.0/2000	12129/2000	54.4	15.0	2.2
Periodic Additions						
605	3.34/250		2332/41	75.9	12.3	2.1
1367	1.52/250		2169/21	64.1	10.6	2.0
1370	1.72/250		1195/11	72.6	12.3	2.1
1371	2.63/250		7302/114	67.6	11.2	2.0
1372	2.24/250		9552/134	64.0	10.5	2.0

3.3.1 Gas Preparation. During the reported study, two different methods were used in the preparation of the counting gas. The two gas fillings were (a) acetylene and (b) hydrogen. The conversion procedures of a water sample to either acetylene or hydrogen are outlined below:

(a) The acetylene counting gas (C_2H_2) was prepared by calcium carbide (CaC_2) conversion. The conversion of an enriched water sample to acetylene followed the reaction

$$CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2 \qquad (3\text{-}7)$$

From the reaction vessel (made of Pyrex glass) the evolved acetylene was admitted directly into the counting tube. Samples used in this technique were those enriched by multi-stage electrolysis where only a fraction of a milliliter was available for counting. Between 0.2 and 0.3 ml of an enriched sample was used for conversion. This quantity produced about 5 to 6 cm of C_2H_2. Calcium carbide conversion was used with the 0.14 liter counter only. Argon was added to a total pressure of about 50 cm. (At 4600 feet above sea level the average atmospheric pressure is 65 cm.) The calcium carbide was discarded following each conversion and no additional sample was converted until the previous one had been counted. This type of conversion had two major disadvantages: fractionation of tritium during conversion and the introduction of solid particles into the counting tube with the evolving acetylene. Some of the tritium atoms were undoubtedly bound in the solid residue as Ca(OT)(OH). By frequently repeating the conversion of standard samples this effect was compensated for when the activity of a sample was calculated. Cold traps between the counter and the reaction vessel captured some of the solid contaminants, but many hours of pumping were required until the counter evacuated satisfactorily. Table 3.5 is a comparison between tritium concentrations measured after calcium carbide conversion (C_2H_2) and after magnesium conversion (H_2). For those samples that were prepared by both methods, Mg conversions gave consistently higher results. The CaC_2 method of gas preparation was therefore discontinued and the results were corrected.

(b) Water samples were converted into hydrogen gas by reaction with magnesium at 600 °C in an evacuated stainless steel furnace, according to the reaction

$$H_2O + Mg \xrightarrow{600^{\circ}C} MgO + H_2 \qquad (3\text{-}8)$$

Figure 3.3 is a diagrammatic representation of the conversion system. Since it is independent of the counting system, more than one sample can be prepared at a time. The evolved hydrogen gas is trapped by adsorption on activated charcoal at liquid nitrogen temperature. As many as four samples per day were converted with the same filling of magnesium. About 1.2 ml of sample was required for each conversion.

Table 3.5 Comparison between results obtained by CaC_2 and Mg conversions and recounts.

LAB NO	TYPE OF CONVERSION	C_2H_4	H_2	COUNTER (liters)	TRITIUM CONC. (TU)
716	CaC_2	5.4		0.14[(1)]	30. ± 14.
716	CaC_2	4.4		0.14	42. ± 4.
753	CaC_2	5.05		0.14	39. ± 3.
753	Mg		12.5	0.14	45. ± 3.
780	CaC_2	5.1		0.14	32. ± 3.
780	Mg		7.7	0.14	55. ± 3.
804	CaC_2	5.3		0.14	100. ± 6.
804	Mg		12.7	0.14	110. ± 1.
877	CaC_2	5.8			3. ± 3.
877	Mg		16.05		21. ± 1.
985	Mg		19.5	1.0	23. ± 1.
985	Mg		20.3	1.0	22. ± 1.
1037	Mg		20.5	1.0	468. ± 6.
1037	Mg		20.7	1.0	462. ± 4.

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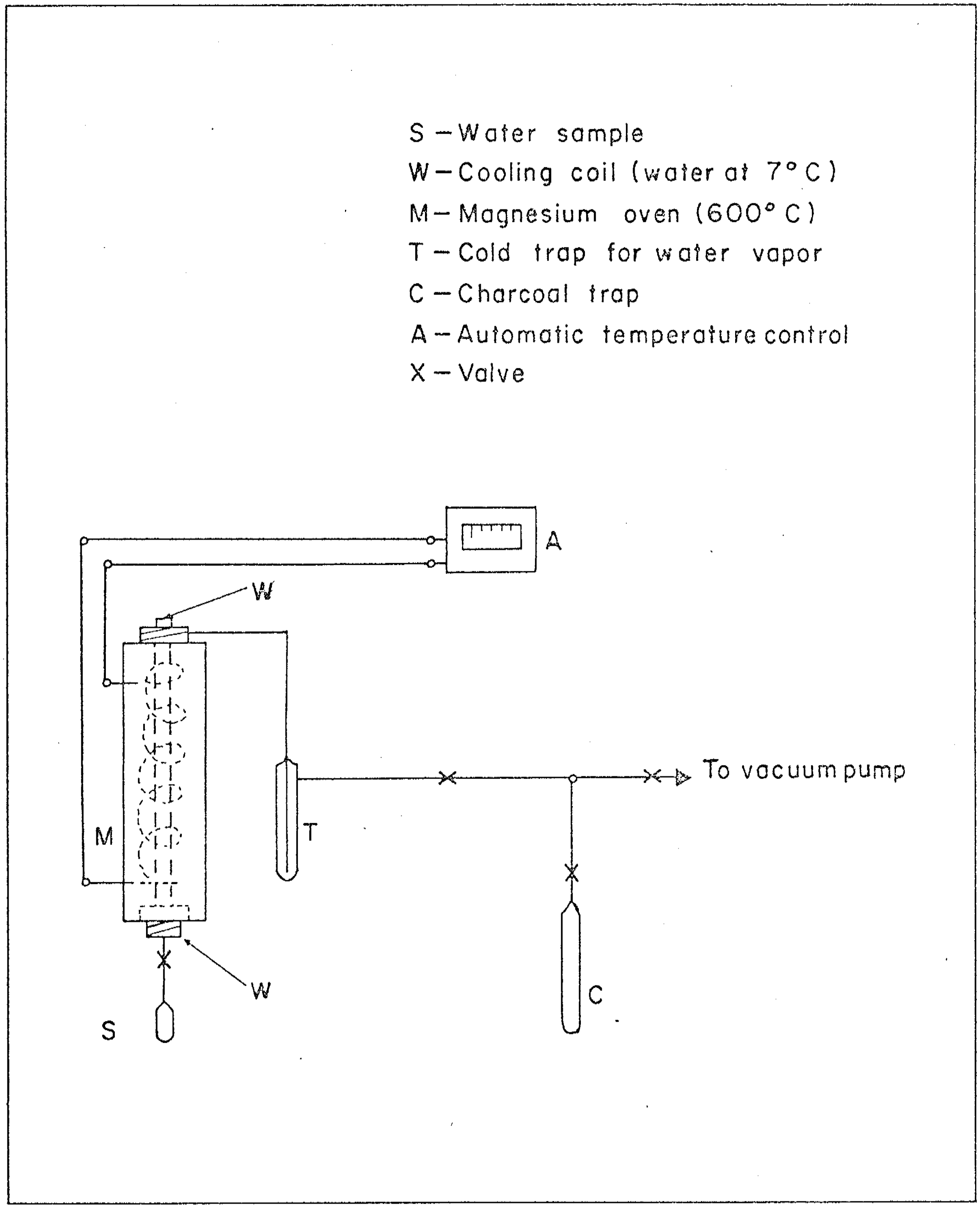
(1) The use of this counter was discontinued after the installation of the larger counter.

Figure 3.3

Diagrammatic representation of the conversion system.


S – Water sample
W – Cooling coil (water at 7° C)
M – Magnesium oven (600° C)
T – Cold trap for water vapor
C – Charcoal trap
A – Automatic temperature control
X – Valve
A
W
M
T
To vacuum pump
W
C
S

Once a conversion was complete, the charcoal trap was removed from the conversion system and transferred to the counting system. The hydrogen gas was then released from the trap into the evacuated counter. Hydrogen pressure inside the counter varied from 20 to 22 cm. Quenching gas (ethylene) and the control gas (argon) were then added successively to a total pressure of about 33 cm. The ratio of ethylene to argon was 2 to 1. The three gases were allowed to mix for about 60 minutes before beginning to count. Blank samples were converted between samples of high tritium concentrations to check for possible contamination in the magnesium. No memory effect was observed. Magnesium conversion gave both higher and more consistent results than calcium carbide conversion (Table 3.5).

3.3.2 Gas Counting. Two internal gas counters were used in the detection of low level tritium. Both counters were operated in the Geiger region and had a ring of anticoincidence wires inside their gas filled volume. The use of the first counter (effective volume = 0.14 liters) was discontinued upon the installation of a larger counter (effective volume = 1.07 liters) in 1966. The stainless steel Geiger counter of the Oeschger type was designed and built by Dr. C. R. Holmes of this Institute. Table 3.6 presents the main features of these counters. The old counter was limited to 5 samples per week whereas the new counter could handle up to 10 low level samples per week.

Table 3.6 Gas counting devices,

structure and performance.

FEATURES	OLD COUNTER	NEW COUNTE
Geometry		
Length of center wire (cm)	26.0	30.8
Total volume (cm^3)	1760.	4410.
Calculated sensitive volume (liters)	0.213	1.070
Gas Filling		
Synthesis	CaC_2	Mg
Counting gas (cm-Hg)	C_2H_2 (4.5-6.0)	H_2(20.0-24.0)
Quenching gas (cm-Hg)		C_2H_4(8.6)
Plateau control (cm-Hg)	Ar(45.0)	Ar(3.5)
Special Features		
Sensitive volume envelope	stainless steel	Electrostatic fie
Electronic quench	-------	Both center and coincidence tube
Counter Performance		
Operating voltage: center count (volts)	1650	2000
anticoincidence (volts)	1750	2250
Plateau: length (volts)	100	175
slope (%)	3	2
Background (cpm) (1)	2.1 ± 0.10 (1)	2.0 ± 0.05 (2)
Measured sensitive volume (liters)	0.144 ± 0.010	1.02 ± 0.04
Efficiency of sensitive volume (%)	69	95
Overall counting sensitivity for unconcentrated samples (TU/cpm)	20100 ± 1600	600 ± 25
Minimum counting sensitivity for concentrated samples (TU/cpm)	20 ± 5	
Stability	Background samples were counted fo 80 hours (total 10,000 net counts) with out decomposition of the counting mix	

(1) Average over 3 years

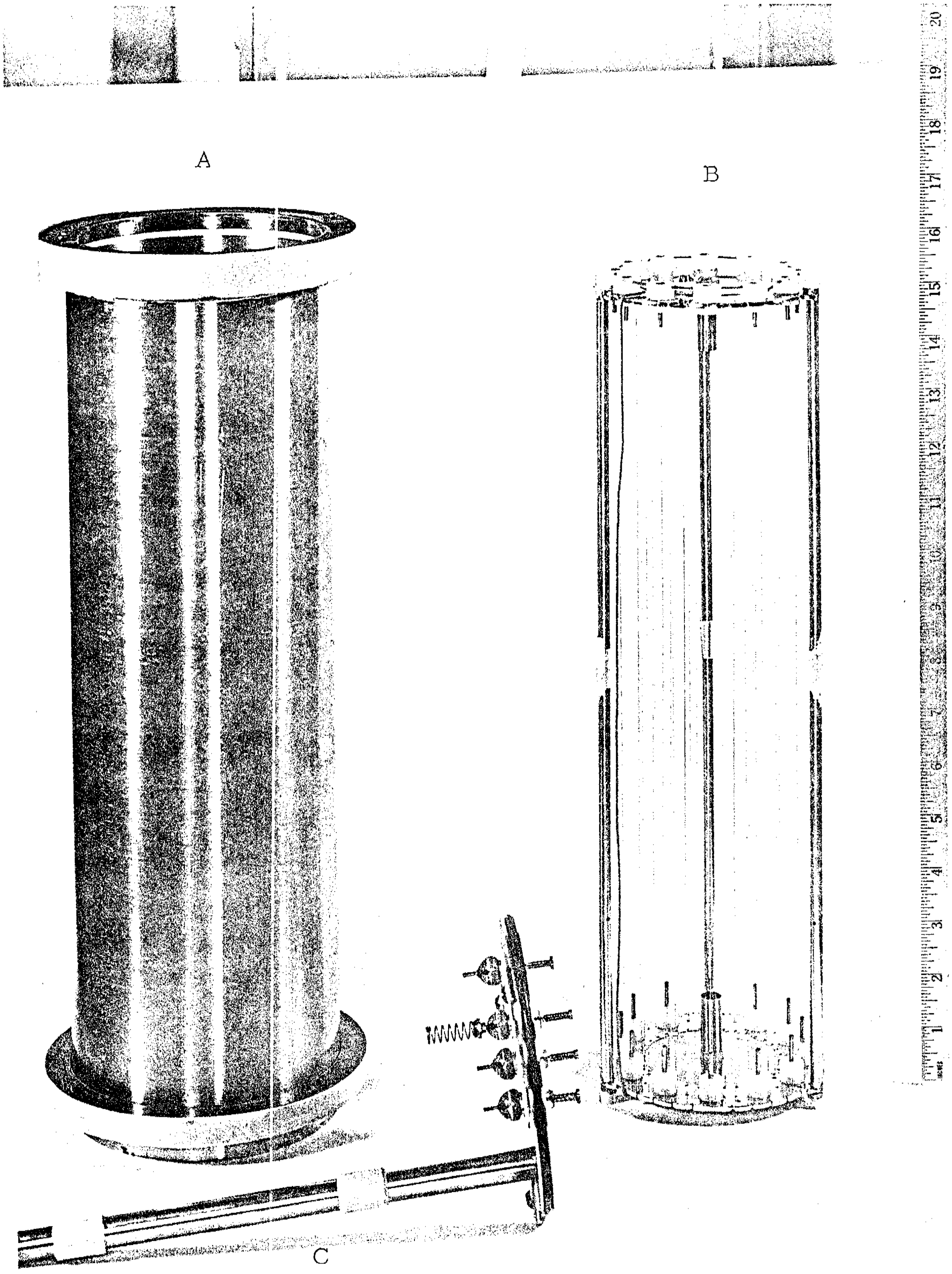
(2) Average over 2 years

Figure 3.4

General view of the major components

of the gas counting tube.

A. Stainless steel canister.
B. Anticoincidence array and counting volume assembly.
C. End plate with gas filling and electrical attachments.


A
B
C
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
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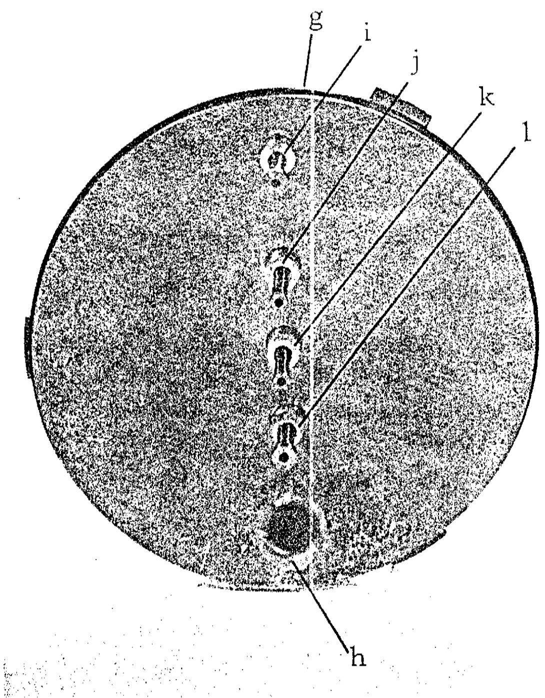
17
18
19
20

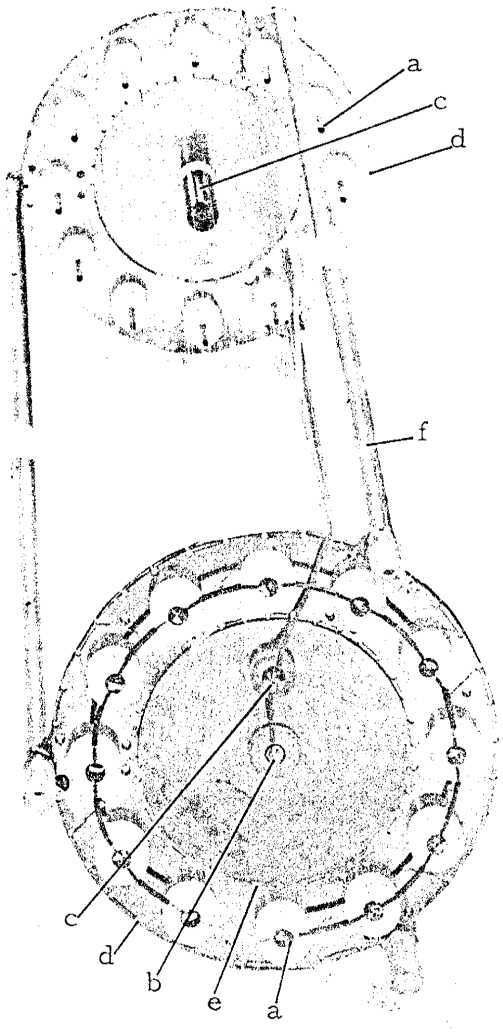
Figure 3.5

Details of the counting assembly

and end plate of the gas counter.

a. Array of 12 anticoincidence counters mounted in Teflon insulators.
b. Anode wire (center counter).
c. Guard electrode to anode wire.
d. Cathode wires, counter's outer wall.
e. Counter wall.
f. Support rod and Teflon insulators.
g. O-ring - end plate.
h. Gas inlet.
i. Anticoincidence spring-plug.
j. Ground spring-plug.
k. Anode (center counter spring-plug.
l. Guard electrode spring-plug.


g
i
j
k
l
h


a
c
d
f
c
d
b
e
a

In general, the operation of the gas counter in the Geiger region is based on the fact that with the proper gas mixture and voltage a single ion pair produces a discharge of a magnitude that depends only on the characteristics of the counter. In the operation of a Geiger counter, there exists a threshold voltage below which ionization is insignificant. By increasing the voltage above threshold, the counting efficiency increases rapidly. Beyond this is a plateau which extends over about 150 volts, depending on the tube's performance. In the plateau region, the counting efficiency does not increase as the voltage is raised. Above this the tube may go to continuous discharge after which the anode and cathode wires have to be replaced.

After the reduction of water to hydrogen gas and the addition of a quenching gas (C_2H_2), and inert gas (Ar) to control the plateau, the appropriate operating voltage is applied. Counting time is determined by the activity of the sample. The counter is shielded from environmental radioactivity and the soft cosmic ray component of the background by $7\frac{1}{2}$ inches of steel. The high energy cosmic rays, although not eliminated by the metal shield, are subtracted from the sample count by an anticoincidence circuit connected to a ring of 12 cosmic ray counters surrounding the sensitive volume.

The anticoincidence array and the sensitive counting volume are enclosed in a single stainless steel canister. Cathode wires take the place of a conventional counter's walls.

Figures 3.4 and 3.5 present a general view and construction details of the counting tube. The main parts are listed on the title page of each figure. The plates on which the anticoincidence anode wires are mounted are also stainless steel with Teflon insulators for each wire. The tube was designed to operate below atmospheric pressure. All of the anticoincidence tubes and the center counter are defined by stainless steel wires. The stainless steel cathode wires are 140 μ in diameter (304 Nilstain, B. Driver Co., Newark, N.J.) and the center Kovar wire is 61 μ in diameter.

Since the radioactive decay process occurs randomly, the successive disintegrations of tritium in the counter are not evenly spaced in time. After each count, an electronic quench circuit makes the counter insensitive to any other ionized particle by dropping the voltage below threshold. This interval is known as the "dead time" of the counter. By calibration of the counter with standard samples of known activities, correction was made for the loss of counts due to electronic quenching. With this type of equipment, minimum background and maximum sensitivity was obtained.

3.3.3 Liquid Scintillation Counting. About 200 enriched samples

(LAB NO higher than 1050) were counted with a Packard, Tri-Carb Spectrometer, Model 2111. The measurement technique for low level beta radiation by liquid scintillation counting has been described by many investigators. A summary was given by Rapkin (1963), and Watt and Ramsden (1964).

The most suitable scintillator for water samples was found to be as follows (quantity per batch of 150 samples): 1000 ml toluene; 500 ml Triton X-100; 8.25 g. PPO (2,5-diphenyloxazole); and 0.25 g. dimethyl POPOP. All are available commercially. Scintillator solution was prepared well in advance and was kept in the dark to eliminate chemiluminescence which was observed following the preparation of the scintillator solution. Water to scintillator ratio was 1/10. Samples were counted in vials of glass low in potassium. High and low level standards and background samples were counted alternately with unknowns. The background was about 20 cpm and the overall counting efficiency for tritium was 20%.

A few samples which had previously been measured with the gas counter were counted again by liquid scintillation counting. Table 3.7 is a comparison between gas and liquid scintillation counting. The enrichment factor for each sample is also presented. Most samples are in good agreement. Two low count samples (924 and 925) were measured by gas counting during a period of high background (>3 cpm); this may explain the large discrepancy in the results.

Table 3.7 Comparison between gas and liquid scintillation counting.

LAB NO	ENRICHMENT β	β/α	FACTOR	GAS COUNTING	LIQUID SCINTILLATION COUNTING
924	4.9	1.6	584	21. ± 24. (1)	32. ± 5.
925	3.8	1.5	591	18. ± 23. (1)	33. ± 6.
1050	15.0	2.2	121	100. ± 3.	99. ± 8.
1057	6.2	1.7	67	142. ± 14.	130. ± 5.
1060	7.2	1.8	72	171. ± 5.	172. ± 10.
1062	11.3	2.0	123	108. ± 3.	113. ± 8.
1064	15.3	2.2	134	164. ± 3.	154. ± 8.
1067	26.1	2.6	122	141. ± 3.	151. ± 8.
IAEA Samples (Florkowski et al. 1970) (2)					
1202	13.0	2.1	109	22. ± 2.	5. ± 5.
1203	16.9	2.3	126	50. ± 3.	59. ± 5.
1204	10.8	2.0	113	200. ± 5.	210. ± 7.

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(1) Counted during period when background > 3.0 cpm.

(2) The true values from intercomparison are: 1202 = 9.7; 1203 = 44.; 1204 = 244. T.U.

In low-level counting, the counting time that will yield a certain statistical accuracy must be determined. The standard deviation of a sample is given by (Williams and Florkowski, 1967):

$$\sigma_s = \sqrt{\sigma_G^2 + \sigma_b^2} = \sqrt{\frac{R_s + R_b}{T_G} + \frac{R_o}{T_b}} \qquad (3\text{-}9)$$

where, σ_G is the gross standard deviation (unknown sample plus background), σ_b is the background standard deviation. R_s and R_o are the counting rates of the sample and background, respectively. T_G and T_b are the counting times for the gross count and background, respectively. The percent error in R_s (at the 68% confidence level) is defined as

$$a = \frac{100\,\sigma_s}{R_s} \qquad (3\text{-}10)$$

then by substituting Eq. (3-9) into Eq. (3-10) the required gross counting time can be determined. Most samples were counted for at least 150 minutes to achieve less than 10% counting error.

3.4 Gas Counter. Calibration and Errors

Because of its special construction, the internal gas counter has no solid wall between its sensitive counting volume and the volume occupied by the array of anticoincidence tubes. The effective counter volume is confined by the guard tube ends (Fig. 3.5c) at top and bottom and the array of cathode wires (Fig. 3.5e) that provide an electrostatic wall at the periphery.

For precise absolute determination of the tritium activity of a sample the effective volume of the counter was determined periodically. The determination was done with a sample of known tritium activity (diluted from NBS standard No. 4926) once every two weeks. The determination of the effective volume was always followed by a background count. After one year of operation, the effective volume and the background count stabilized at 1.008 ± 0.046 liters and 2.02 ± 0.06 cpm, respectively. This is about 94% of the geometric configuration of the sensitive volume. These numbers are based on a long time average. Ordinarily an average value of effective volume and background counting rate are assigned to each group of samples measured between consecutive calibrations. These calculations and the computer program used were presented elsewhere (Rabinowitz, 1969).

In determining the uncertainty of each sample two possible errors were considered: (a) counting errors; (b) the error involved in the determination of the effective volume which also includes the variations in background count. The variations in background count affected the error determination the most. In periods of high background samples were not counted. However, two weeks was the minimum time between calibrations; high background was sometimes observed at the end of the counting period.

The accuracy for samples with tritium content below 20 T. U. was, at best, ± 10%. Some high activity samples (> 100 T. U.) are reported with a 25% error of determination as a result of improper handling.

Table 3.7 includes the results of an interlaboratory comparison of analyses of tritium in natural waters. The project was carried out by the International Atomic Energy Agency, Vienna, Austria. The samples were enriched by modified multi-stage electrolysis and were counted by both gas and liquid scintillation counters. The measured tritium concentration of sample LAB NO 1203 was in excellent agreement with the mean value reported by all the 35 participating laboratories. The discrepancy in the low value sample (10 T. U.) was 100% and in the high value sample 20%.

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4. RESULTS

4.1 Introduction

In this chapter the tritium data are presented and interpreted. The measured tritium concentrations are tabulated in Appendices E through I. The data are divided into the following four categories:

(a) Short-record observations of tritium content in well water (1-10 samples per well). Data compiled in Appendix E for deep wells and Appendix F for shallow wells and springs.

(b) Long-record observations of tritium content in well water (20-60 samples per well). Data are compiled in Appendix G, sections G.1 to G.7.

(c) Variations of tritium concentration in precipitation as a function of time and location. Data compiled in Appendix H.

(d) Tritium concentrations of atmospheric moisture. Data compiled in Appendix I.

Data points on each map or graph which will be presented are tabulated in the appendices. In addition to its laboratory registration number (LAB NO), each sample is assigned a sequential number (NO) within its group. The location of each well can be identified on the maps by its NO and type (bedrock or alluvial). The tables also include additional information about well depth, casing, and flow or pump conditions at the time of sampling. For wells with a large number of observation points, a more detailed description of the location, physical parameters of the well, and special remarks are provided at the beginning of each table.

Tritium content of precipitation samples is listed in the daily order in which the samples were collected, regardless of the location. The type of precipitation (rain, snow, or hail) is also given.

The data are presented and discussed separately for each sample category.

4.2 Tritium Concentrations in Ground Water

Short-record observations were used mainly for determining the tritium concentration at the beginning of the study. A single observation of tritium content does not allow a quantitative examination of the tritium-time profile at a point in the region. As previously mentioned, most of the wells in the short-record category were sampled in conjunction with other investigations. The majority of the wells are located between the exposure of the San Andres limestone to the west along R. 18 E., and the Pecos River to the east, and between Salt Creek to the north (T. 9 S.) and Lake McMillan to the south (T. 19 S.). See Figure 2.7.

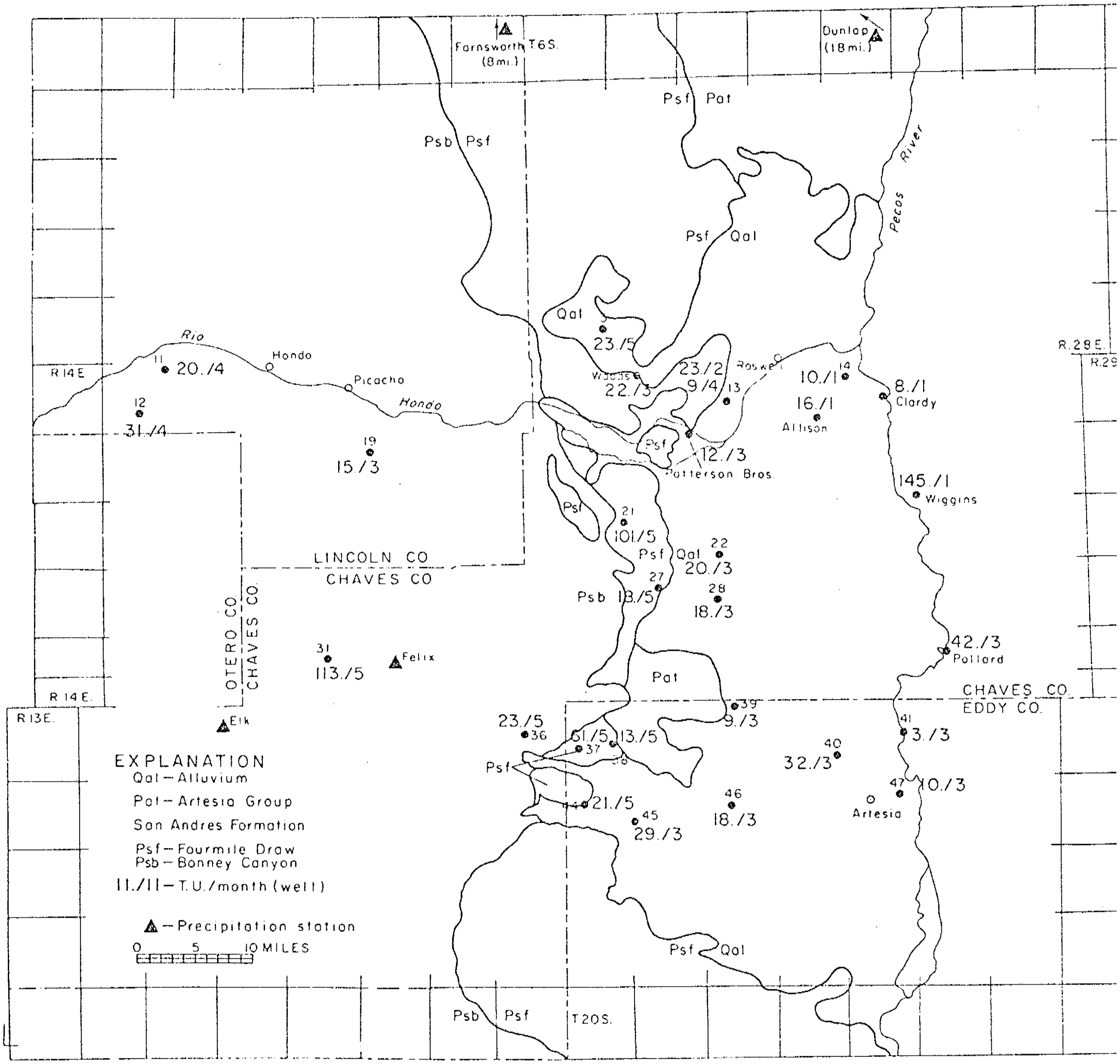
Long-record observations spanned the years 1961-1968 and were limited to seven wells. With one exception, all have their source of water in the San Andres aquifer. These wells are located at different distances with respect to the San Andres-Alluvium boundary. From the available hydrologic data (Fig. 2.3), they are completed in sections of the aquifer of different transmissivities. As used in this study, the term deep or bedrock wells refers to those completed in the San Andres Limestone or the Artesia Group. Shallow or alluvial wells are completed in the Alluvial aquifer.

4.2.1 Short-Record Observations. A large number of wells were sampled for their tritium content in 1959 and 1961. During late 1966 and early 1967 samples were collected during pumping tests which were conducted by New Mexico Institute of Mining and Technology. The data are presented here by maps on which the geologic boundary between the Permian San Andres Limestone and the Quaternary Alluvium is drawn. The precipitation-measuring stations are also shown on these maps. Most of the recharge to the San Andres Limestone takes place by precipitation falling directly over its outcrop. Some of the tritium data were previously reported by Reeder (1964).

Tritium Distribution in Deep Wells - 1959. In Figure 4.1, each sample is labeled by the well NO, next to it the measured T.U., and the month during which the sample was collected.

Figure 4.1

Tritium Distribution in Deep Wells - 1959.


Farnsworth T6S.
(8mi.)
Dunlap
(18 mi.)
Psf Pat
Psb Psf
Psf Qal
Pecos River
Qal
23./5
Rio Hondo
Hondo
Picacho
11 20./4
12 31./4
19 15./3
Woods 22./3
23./2
9./4 13
Roswell
14 10./1
16./1
Allison
8./1
Clardy
Psf
12./3
Patterson Bros.
145./1
Wiggins
Psf
21 101/5
Psf Qal
22 20./3
27
Psb 18./5
28 18./3
LINCOLN CO
CHAVES CO
OTERO CO
CHAVES CO
31 113./5
Felix
42./3
Pollard
Pat
39 9./3
CHAVES CO
EDDY CO
Elk
R 14 E.
R 13E.
R 14E
R.28E.
R.29
23./5
36
61./5 13./5
37
38
Psf
41 3./3
40 32./3
47 10./3
Artesia
21./5
44
45 29./3
46 18./3
Psf Qal
Psb Psf
T20S.
EXPLANATION
Qal – Alluvium
Pat – Artesia Group
San Andres Formation
Psf – Fourmile Draw
Psb – Bonney Canyon
11./11 – T.U./month (well)
– Precipitation station
0 5 10 MILES

There is no information on the levels of tritium in New Mexico precipitation prior to the injection of man-made tritium into the atmosphere. From a few measurements conducted in Chicago, Illinois (Begemann and Libby, 1957) and Ottawa, Canada (Brown, 1961), the average "pre-bomb" level must have been about 10 T. U. When examining the areal distribution of tritium, this number should be kept in mind. Tritium content of ground water decreases by radioactive decay as the water moves down gradient from the recharge area. In addition, mixing and dilution, due to hydrodynamic dispersion, take place between the incoming water and the older water of the aquifer. Theoretically, precipitation with tritium content of 10 T. U., which fell west of R. 22 E., will show up as ground water having a maximum concentration of about 5 T. U. after 12.3 years.

Figure 4.1 reveals the presence in 1959 of "post-bomb" tritium in many of the sampled wells. Since sampling was not restricted to a particular aquifer horizon, the presence of tritium also indicates vertical distribution. (From the geologic cross sections, Figures 2.4 and 2.5 and the information given in Appendix E, the stratigraphic elevation of each sample can be determined.) Well depth varies from 85 feet (well NO 13 in T. 10 S., R. 23 E.), to about 1380 feet (Pollard well T. 15 S., R. 27 E.). Water samples taken in 1959 represent four aquifers in the basin: Yeso Formation, Glorieta Sandstone, San Andres Limestone, and the Artesia Group. Tritium concentrations varied from 3. ± 5. to 145. ± 19. T.U.

Wells NO 11, 12, and 19 produce from the Yeso formation (flow = 3 gpm). These wells vary in depth from 650 feet (NO 12) to 900 feet (NO 19). The surface elevation of NO 11 and 12 is higher than 5500 feet. The wells were sampled within one month and all three exhibited tritium concentrations well above the natural levels. Along the Rio Ruidoso, which eventually becomes the Rio Hondo, the San Andres Limestone is eroded and the Yeso Formation is exposed. The same situation exists between the Village of Hondo and Picacho. The appearance of post-bomb tritium in these deep wells indicates induced recharge to the Yeso Formation along the Rio Ruidoso. Although the tritium-concentration gradient is in the expected direction, the only conclusion with regard to the three wells is the apparent infiltration time of their water. The first series of thermonuclear-bomb testing in the atmosphere took place in the spring of 1954, therefore, the maximum infiltration time of water in the Yeso Formation along the Hondo valley is 5 years.

One other well which is not in the San Andres limestone is NO 3. The well is 603 feet deep and penetrates at least the Glorieta Sandstone. At this location the Glorieta is very thin (cross section Figure 2.4) and the water could very well come from the Yeso Formation below. However, here too, tritium content is at least twice as much as the natural levels.

Woods well, 4 miles to the southeast, which penetrates 435 feet into the San Andres Limestone, was sampled on the same day. Both wells had the same tritium concentration 22. ± 3. T.U. The observed tritium in both wells could have been derived from the same source or from two different tritium peaks.

The wells which lie along a north south trend, parallel to the boundary between the Limestone and the Alluvium, all produce from the unconfined part of the San Andres Limestone. These wells are clustered in three groups: (a) Woods and NO 21 with depths of 435 and 630 feet, respectively; (b) Patterson Bros. and NO 13, 22, 27, and 28 produce from between 300-665 feet; (c) the southernmost wells NO 36, 37, 38, 44, and 45 vary in depth from 600 to 810 feet below the surface. Well NO 31, although producing from a depth of only 300 to 306 feet,was reported to be flowing at a rate of 1800 gpm. All of these wells had higher than natural tritium content. West of the San Andres/Alluvium boundary, three wells NO 21, 31, and 37, had exceptionally high tritium levels of 101., 113., and 61. T.U., respectively. Each ground water sample is representative of a certain vertical section of the aquifer (e.g. in NO 21 the water column in the well was 90 feet) therefore, 100 T.U. is a high concentration because of the dilution effect. Tritium peaks in precipitation prior to 1959 were less than 1000 T.U. and averaged about 150 - 200 T.U. (Appendix H).

Since the horizontal distance between the wells along the north south line is small, with the assumption that the tritium observed was derived from the same source (i.e. tritium high of April - June, 1958) an equal T. U. line or isochron may be drawn. Thus, the distribution of tritium concentrations along the western boundary of the confined-unconfined conditions in the San Andres aquifer may be interpreted as a tritium peak, with maximum residence time of one year moving eastward.

The wells along the Pecos River all penetrate the San Andres limestone. NO 14, Clardy, Wiggins, and Pollard are 800, 843, 1150, and 1380 feet deep, respectively, and sampling was done under flow conditions. The three wells near Artesia are also deeper than 1000 feet. NO 14 is reported to be in the Grayburg Formation which overlies the San Andres limestone. North of T. 16 S. (Fig. 2.7), the well samples show the presence of recent recharge (1954 or younger) because of their higher tritium content. Based on one observation per well, the high tritium values in Wiggins and Pollard cannot be positively identified whether they belong to the up or down concentration gradient of a tritium peak. However, the relatively low values observed in Clardy and Allison suggest the down gradient of the passing peak. This conclusion agrees with the high transmissivity values in that part of the basin (Fig. 3.3). South of T. 15 S., east of the recharge boundary, the observed levels of tritium are low (NO 40 excluded). These levels are somewhat higher than the

June 1957 measurements reported by von Buttlar (1959). He reported three tritium measurements in wells (located in sec. 14, T. 17 S., R. 26 E.) at different depths: 1050, 240, and 90 feet; which had 1.5, 1.7, and 5.1 T.U. respectively. (From the information about the location and depth, the deepest sample could have been taken from well NO 47.) Thus, in 1959, post-bomb tritium had perhaps reached the deep wells near Artesia but to a lesser extent than in the northern wells.

The 1959 survey shows that the tritium content in the basin was higher than the pre-thermonuclear levels. Precipitation since 1954 had begun to circulate throughout the deep limestone aquifer. Thus, the residence time for ground water in the northern part of the Roswell basin must be of the order of 5 years or less. In the southern part, some of the tritium levels are possibly of pre-bomb (cosmic) origin. The residence time must be of the order of 5 years or more.

Trends in 1959 data. The distribution of the 1959 tritium concentrations in the basin indicates the following:

(a) A tritium high in the western part of the basin.

(b) A tritium high in wells along the Pecos River.

(c) Lack of tritium in the southern low permeability portion of the basin.

Analysis of the data, to be discussed in Chapter 5, correlates the western peak to the atmospheric tritium peak which occurred in 1958, and the eastern peak corresponds to the atmospheric high of 1954. Thus, the dominant direction of ground water flow north of T. 15 S. is west-east. This confirms earlier studies.

Tritium distribution in deep wells - 1960/1961. (Fig. 4.2) Some new wells were added to those sampled in 1959. During October 1960, a sample was taken from well NO 1 T. 6 S., R. 24 E., (production interval 614 - 640 feet). Its tritium content measured 104. ± 5. T.U. In August 1961, it was only 5. ± 2. T.U. Thus, after the passage of the high tritium slug, tritium levels returned to below the natural content of precipitation. This suggests the possibility of older water leaking from the deeper horizons of the aquifer.

Well NO 8 was flowing under artesian pressure, it is located in a region where high salinity water was produced from the San Andres Limestone. In spite of this mixing, the tritium concentration was 47. T.U.

The following discussion is related to tritium observations north of T. 16 S. There are three trends of tritium variations which could imply the presence of at least three tritium pulses. They are as follows:

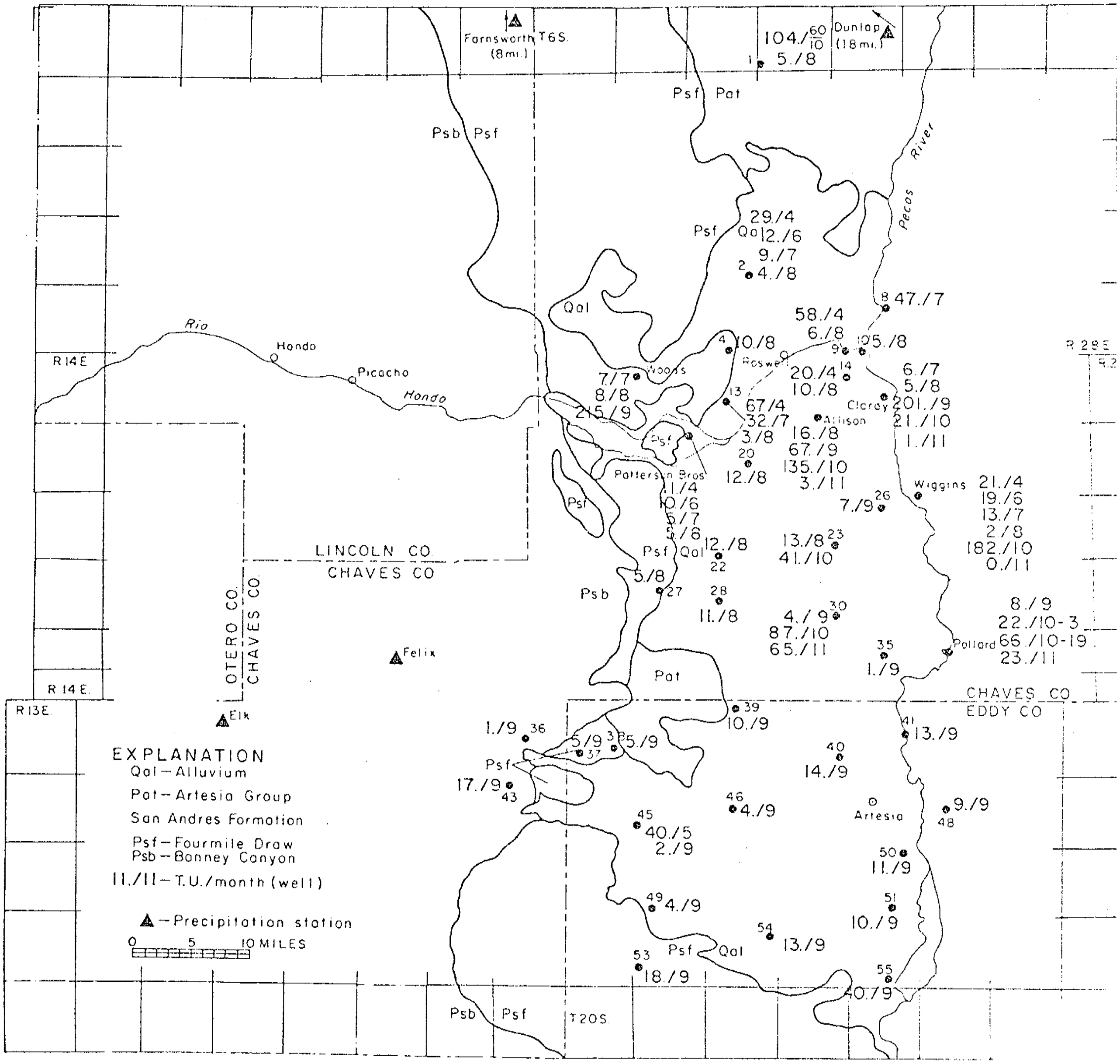
(a) Wells NO 2, 9, 13, and Patterson Bros., north of the Rio Hondo, which were sampled from April to August, show a gradual decrease in tritium concentrations. The levels in tritium content varied between 60. T.U. and 4. T.U.

Figure 4. 2

Tritium distribution in deep wells - 1960/1961.

(Pollard well was sampled on October 3

and October 19).


Farnsworth T6S. (8mi.)
Dunlap (18mi.)
104./60/10
1 5./8
Psf Pat
Psb Psf
Pecos River
Psf Qal
29/4
12./6
9./7
2 4./8
Qal
8 47./7
58./4
6./8
4 10./8
Roswell
9
10 5./8
R 28 E
R14E
Rio Hondo
Hondo
Picacho
Woods
7/7
8/8
215/9
14
20./4
10./8
6./7
5./8
Clardy
201./9
21./10
1./11
13
67/4
32./7
3/8
Allison
16./8
67./9
135./10
3./11
Psf
20
12./8
Patterson Bros.
11/4
10./6
5./7
5./6
Psf
Wiggins
21./4
19./6
13./7
2./8
182./10
0./11
26
7./9
LINCOLN CO.
CHAVES CO.
Psf Qal
12./8
22
23
13./8
41./10
Psb
5./8
27
28
11./8
30
4./9
87./10
65./11
8./9
22./10-3
66./10-19
23./11
Pollard
OTERO CO.
CHAVES CO.
Felix
35
1./9
Pat
R 14 E.
R13E.
Elk
CHAVES CO
EDDY CO
39
10./9
41
13./9
1./9 36
5./9 37
38 5./9
Psf
17./9 43
40
14./9
EXPLANATION
Qal – Alluvium
Pat – Artesia Group
San Andres Formation
Psf – Fourmile Draw
Psb – Bonney Canyon
11./11 – T.U./month (well)
– Precipitation station
0 5 10 MILES
46
4./9
Artesia
9./9
48
45
40./5
2./9
50
11./9
49 4./9
51
10./9
54
13./9
53
18./9
Psf Qal
55
40./9
Psb Psf
T20S.

(b) Clardy, Allison, Wiggins, and Pollard wells, south of the Rio Hondo and along the Pecos River, were sampled between August and November and showed a sharp increase in tritium concentration (>100 T. U.) followed in some cases by an equally sudden decrease even to below pre-bomb levels.

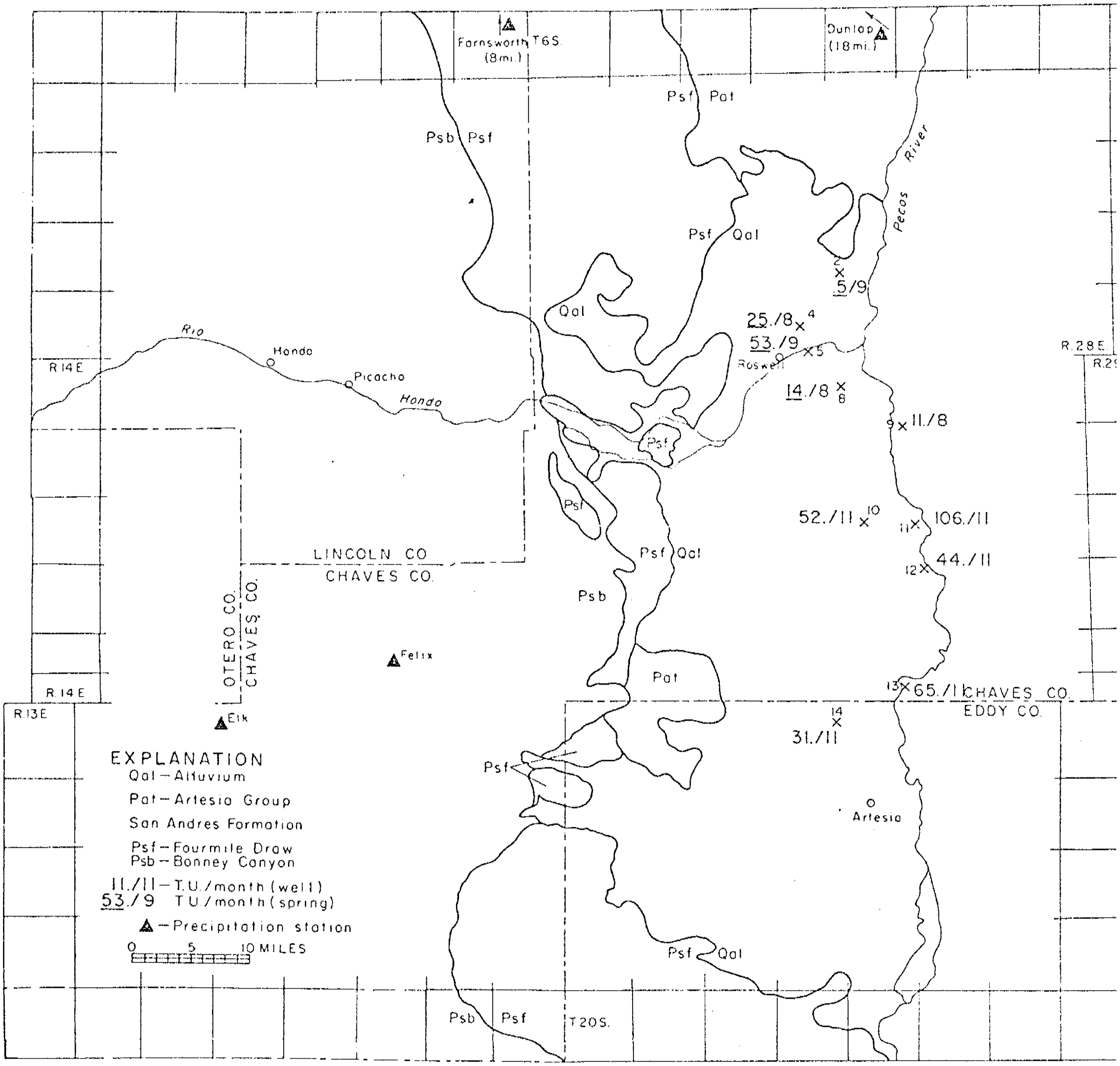
(c) Wells NO 23 and 30, in the center of this northern part of the basin, sampled between August and November, also showed relatively high tritium content during these months. The rise continued into 1962. To clearly understand why these trends are indicative of three tritium pulses between the outcrop of the San Andres limestone and the Pecos River, the direction of flow and distance between the groups of wells should be considered. The ground water flow in the limestone aquifer north of the Rio Hondo has a very strong southeast component (Motts and Cushman (1964)). In the vicinity of Wiggins, NO 23, NO 30, and Pollard, the flow is from west to east (Motts and Cushman, 1964). The assumption of two different tritium pulses, observed at NO 23/30 and Wiggins/Pollard, is substantiated by examining the tritium data of these wells in Appendices E and G. Both NO 23 and 30 had high tritium content (≥200 T. U.) as early as February of 1962 (the corresponding rise of tritium levels in Wiggins and Pollard did not take place until about 8 months later). As will be shown in Section 5. 3. 1 the time delay of tritium arrival and the distance between these two groups of wells are in accordance with the calculated regional ground water velocity. In addition, along north-south lines, the tritium concentrations are uniform; this strongly suggests an eastward direction of tritium migration and hence of ground water movement in the San Andres Limestone.

Tritium concentrations in wells south of T. 15 S. are consistently lower than those measured near Roswell or Hagerman. The sampling dates (1959, 1961) and the areal distribution of these wells (NO 36 through 54) preclude the possibility that a tritium peak passed through this part of the aquifer between these dates and remained undetected. As indicated by Figure 4.2, the tritium content did not rise with respect to 1959, with the exception of well NO 45.

Trends in 1961 data. Compared to 1959 (Fig. 4.1), additional rise of tritium concentration was observed in the northern part of the basin. Three different types of tritium variations were observed. Wells in the basin north of Rio Hondo showed a gentle decrease. Wells located close to the Pecos River showed a sudden rise and equally sharp decrease. The wells further to the west (NO 23 and 30) showed a different magnitude of tritium levels. Thus, the distribution of tritium peaks over the basin matches the two different flow directions suggested by Motts and Cushman (1964). The peak of well group (a) above is younger than the peak observed in group (b). The peak of wells (c) is also younger than the peak in group (b). The relative age of peaks in groups (a) and (c) cannot be ascertained from these data.

Figure 4.3

Tritium distribution in springs and shallow wells - 1961.



Farnsworth (8mi.)
T6S.
Dunlop (18mi.)
Psf Pat
Psb Psf
Psf Qal
Pecos River
Qal
5/9
25./8
53./9
Roswell
14./8
11./8
Rio Hondo
Hondo
Picacho
R14E
R.28E.
R.29
Psf
52./11
106./11
44./11
LINCOLN CO
CHAVES CO
Psf Qal
Psb
OTERO CO.
CHAVES CO.
Felix
Pat
65./11
CHAVES CO.
EDDY CO.
R.14E
R.13E
Elk
31./11
EXPLANATION
Qal – Alluvium
Pat – Artesia Group
San Andres Formation
Psf – Fourmile Draw
Psb – Bonney Canyon
11./11 – T.U./month (well)
53./9 T.U./month (spring)
▲ – Precipitation station
0 5 10 MILES
Artesia
Psf Qal
Psb Psf
T20S.

The sharp tritium peaks in ground water may represent an unmixed flow system (slug type flow through solution channels?). This would seem necessary to explain the observed drop in Wiggins well from 182. to 0. T.U. in one month.

In the southern part no increase in tritium concentrations was observed. The difference of this southern region with respect to the measurements north of T. 16 S. probably is due to a lower permeability in the San Andres aquifer (Motts and Cushman, 1961).

Tritium distribution in springs and alluvial wells - 1961. Four springs and six wells were sampled once during 1961 (Fig. 4.3). The springs (NO 2, 4, 5, and 8) all discharge from the Quaternary Alluvium. NO 4 and 5 are in the thinner part of the alluvium and show 25 and 53 T.U., respectively. The only clear trend of tritium observations in these springs is the decrease in concentration with increasing distance from the Alluvium-San Andres boundary to the west.

The shallow wells, NO 9, 11, 12, and 13, are located along the Pecos River. The recharge to the shallow aquifer is such that the tritium content of a water sample may have its origin in direct precipitation over the area, irrigation water from the San Andres Limestone, or upward leakage from the deep aquifer. For wells close to the Pecos River, the tritium content may even be representative of the river water. The thicker part of the alluvium (about 300 feet) is toward the Pecos River and the sampled wells penetrate different horizons. The only clear trend in these wells is a tritium decrease with depth, as shown in the following tabulation:

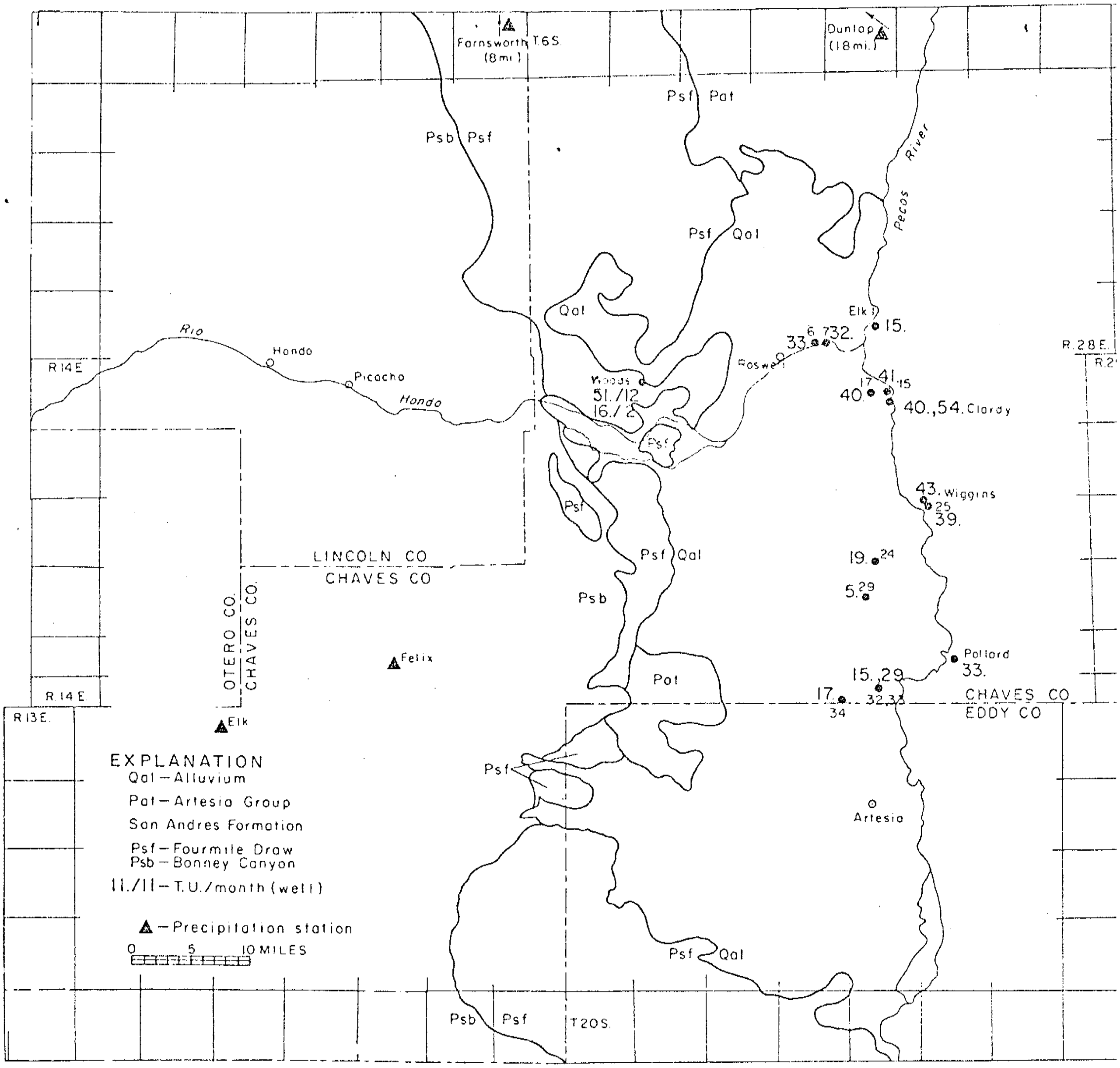
Well	Production interval (feet)	Tritium concentration (T. U.)
NO 11	12 - 135	106. ± 3.
NO 13	water level 25' below surface	65. ± 5.
NO 12	89 - 95	44. ± 4.
NO 14	70 - 200	31. ± 4.
NO 9	235	11. ± 3.
NO 10	262	52. ± 2.

The discrepancy in tritium concentrations between NO 9 and NO 10, which are about the same depth, could be due to location because well NO 9 is east of the Pecos River. Although the water level in well NO 14 was only 70 feet below the surface, its tritium concentration was relatively low. This may reflect the observed low tritium content of deep water in the southern part of the basin.

Tritium distribution in bedrock wells - 1966/1967. (Fig. 4.4) In addition to the regular sampling program, samples were collected following pumping tests between December 1966 and February 1967. Sampling was done at the end of each test after 3 acre-feet had been pumped. Tritium levels in deep wells did not rise during 1967 and in fact returned to those

Figure 4.4

Tritium distribution in deep wells - 1966/1967. (wells without indication of month were sampled during December 66 - January 67, Clardy well two samples January 67, well NO 32 and 33 are represented by a single dot).


Farnsworth T6S.
(8mi.)
Dunlap
(18mi.)
Psf Pat
Psb Psf
Pecos River
Psf Qal
Qal
Rio Hondo
Hondo
Picacho
R14E.
Woods
51./12
16./2
Roswell
Elk
15.
33.
6
7
32.
R.28E.
R.2
41.
17
15
40.
40.,54. Clardy
Psf
Psf
43. Wiggins
25
39.
LINCOLN CO
CHAVES CO
Psf Qal
19.
24
5.
29
Psb
OTERO CO.
CHAVES CO.
Felix
Pollard
33.
Pat
15.,29.
17.
34
32.,33
CHAVES CO
EDDY CO
R 14 E.
R 13 E.
Elk
EXPLANATION
Qal – Alluvium
Pat – Artesia Group
San Andres Formation
Psf – Fourmile Draw
Psb – Bonney Canyon
11./11 – T.U./month (well)
– Precipitation station
0 5 10 MILES
Psf
Artesia
Psf Qal
Psb Psf
T20S.

observed during 1959. A tritium "sweep", from west to east, is indicated in Fig. 4.4. Wells NO 24, 29, 32, 33, and 34 west of the Pecos River already have lower values of tritium than the wells along the Pecos River or around Roswell. The neighboring wells (e.g. NO 32/33, Wiggins/NO 25 etc.) are no more than one mile apart and were used as mutual observation wells in pumping tests. Here too, along north-south lines tritium concentrations are very similar.

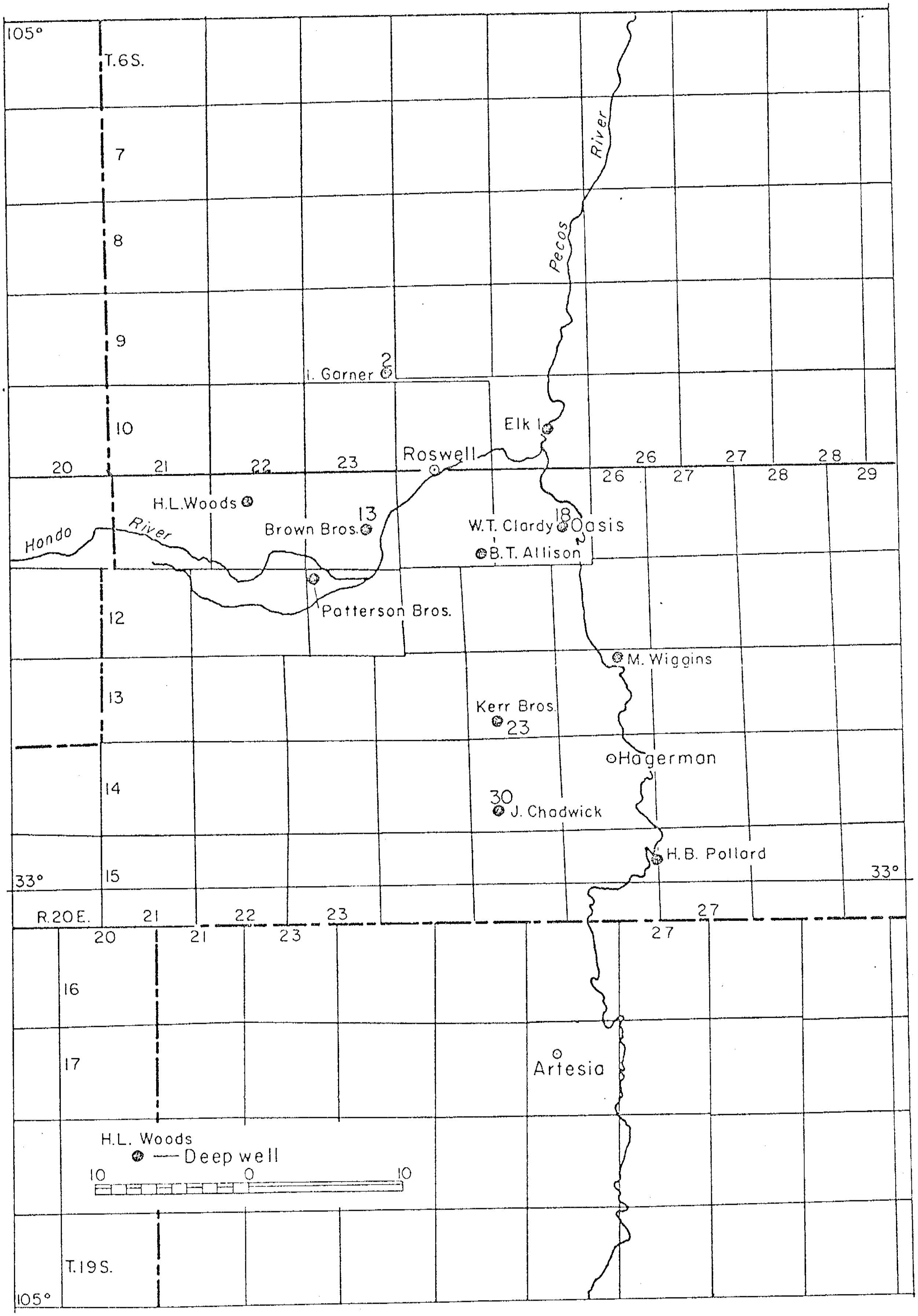
4.2.2 Long-Record Observations. Seven wells were sampled from 1959 to 1971 (Fig. 4.5). Sampling interval was most consistent between 1961 and 1968. The information about each well is given in Appendix G together with the listing of the individual tritium measurements. Also in Fig. 4.5 are four wells (numbered) which were previously discussed and for which the data are given in Appendix E. The additional four wells, although sampled for tritium only five to nine times, are key wells with respect to their location and the period during which samples were collected. These wells are located between the seven wells and the intake area. They were sampled at the end of 1961 or the beginning of 1962 when large tritium pulses were first observed. They are used in tracing these pulses from the recharge area to the Pecos River.

Successive water samples were collected at unequal time intervals and some had to be discarded due to analytical errors. Therefore, the data have been smoothed with a bimonthly moving average where

Figure 4.5

Location of deep wells with a

large number of tritium observations.


105°
T.6S.
7
8
9
10
12
13
14
15
33°
R.20E.
20
21
22
23
26
27
28
29
Pecos River
2
I. Garner
Elk 1
Roswell
H.L.Woods
13
Brown Bros.
Hondo River
W.T. Clardy
18
Oasis
B.T. Allison
Patterson Bros.
M. Wiggins
Kerr Bros.
23
Hagerman
30
J. Chadwick
H.B. Pollard
33°
16
17
Artesia
H.L. Woods
Deep well
10
0
10
T.19S.
105°

gaps between successive samples did not exceed 5 months. Each point in the tritium-time series is replaced by an average value between itself and the following value. Fig. 4.6 is a comparison between the raw and the smoothed data for the Wiggins well. The comparison indicates that this does not distort the peaks nor shift them in time. An effect on the actual magnitude of the data is noticeable only for the very high tritium levels.

The data are presented in Figures 4.7 to 4.13. The scale, T. U. vs. time (in years), is the same for all wells. All seven wells are shown on the geologic cross sections in Figures 2.4 and 2.5.

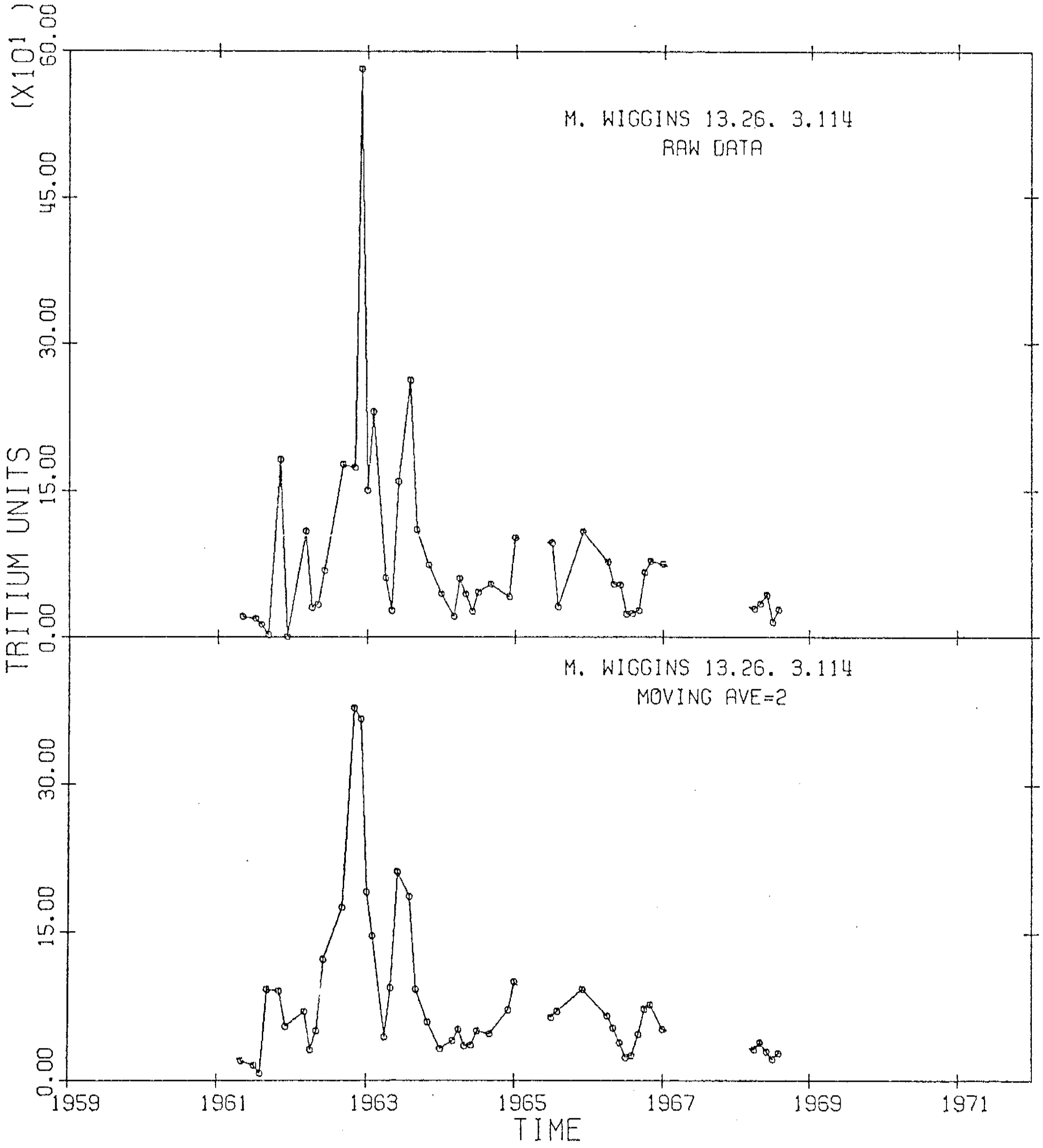
H. L. Woods well. (Fig. 4.7). Combined samples from two wells without overlap. Woods (2) was drilled about 100 feet from the original windmill and was completed October 1964. With the exception of the sample taken during that month no break in trend was observed. Tritium concentrations before and after the change in well were as follows:

Woods (1)	
July	53. ± 3. T. U.
September	87. ± 13. T. U.
Woods (2)	
October	112. ± 18. T. U.
December	42. ± 2. T. U.

Woods (2) was drilled 140 feet deeper and a pump was installed. It will

Figure 4.6

Comparison between presentation of raw data and two-month moving average.


(X10^1)
60.00
45.00
30.00
15.00
0.00
TRITIUM UNITS
M. WIGGINS 13.26. 3.114
RAW DATA
M. WIGGINS 13.26. 3.114
MOVING AVE=2
30.00
15.00
0.00
1959
1961
1963
1965
1967
1969
1971
TIME

be shown later, from comparison in trend between this well and others, that for all practical purposes the change in location and depth could have passed unnoticed.

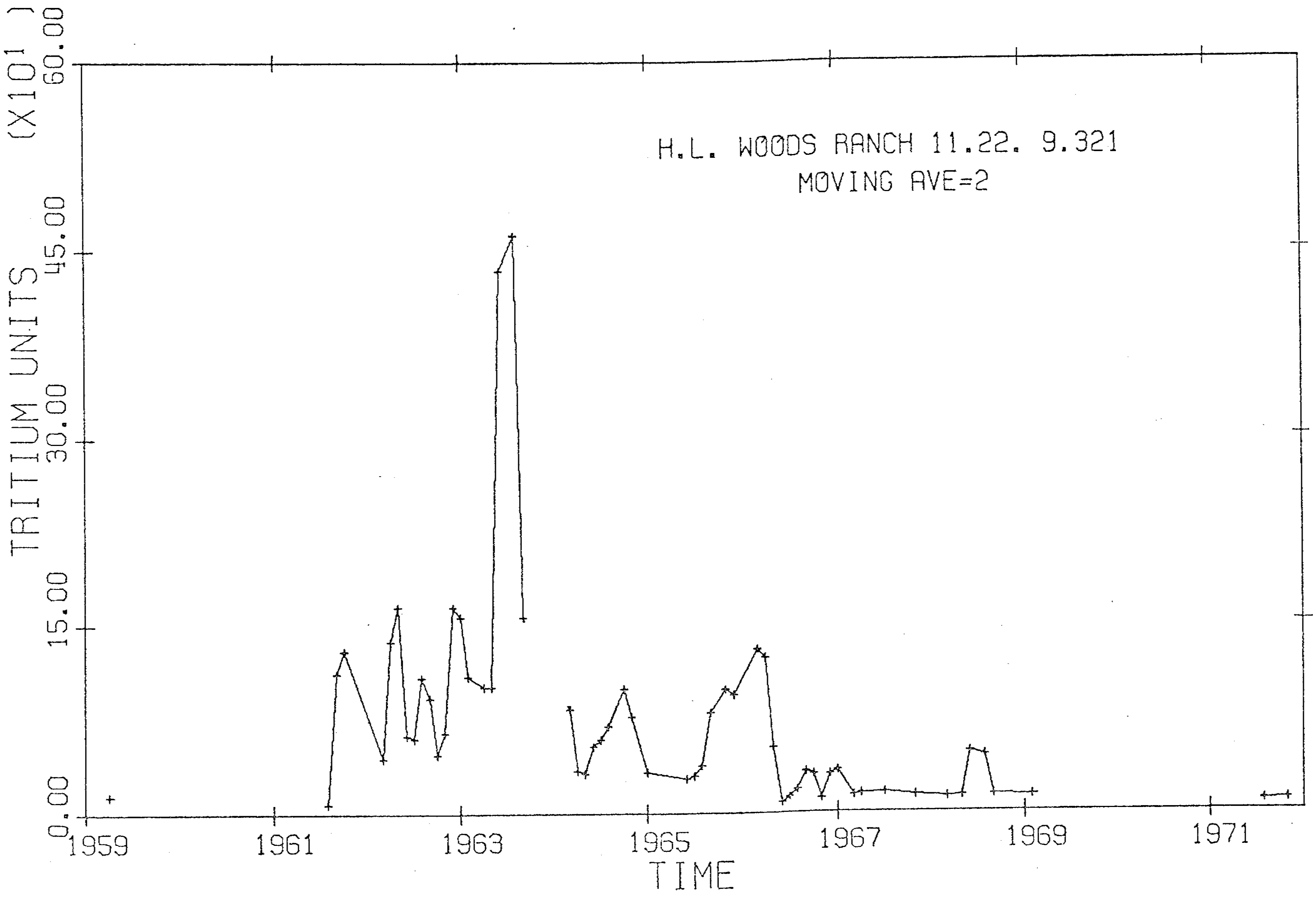
The well is located on a cattle ranch in the outcrop area of the San Andres Limestone where the ground water is unconfined and more than 500 feet below the surface. Since the Artesia Group is missing there is no downward leakage of water derived from another source. Only about 2500 gallons are pumped daily. Possibly the most important use of this well is in the observation of tritium variations in time, undisturbed by seasonal variations of pumping.

By examining Figure 4.7 and the data in Appendix G it is clear that soon after the arrival of the first tritium pulse (early 1962) tritium levels remained well above background. Only after the 1966 peak did the tritium levels drop back to a consistently low level. The highest tritium concentration measured was 730. ± 32. T.U. in July of 1963. A sample taken October 1971, from another windmill 4 miles west of Woods yielded the same concentration as Woods, 10. ± 1. T.U. The three main features of the profile are a strong increase in tritium concentrations lasting about 2½ years, followed by two peaks in 1964 and 1965/1966.

Although tritium levels in this well might be expected to have risen earlier than in wells near the Pecos River, this was not the case. The reason will later be found to reside in different recharge areas for

Figure 4.7

Tritium concentration-time profile
for H. L. Woods well, 11.22.9.321
(two month moving average).


H.L. WOODS RANCH 11.22. 9.321
MOVING AVE=2
TRITIUM UNITS (X10¹)
0.00
15.00
30.00
45.00
60.00
1959
1961
1963
1965
1967
1969
1971
TIME

these two portions of the basin and different transmissivities (Section 5.3.2).

W. T. Clardy well. (Fig. 4.8). Sometimes referred to as the Oasis well, it is the best artesian well in the basin. The well is 280 feet into the San Andres limestone with the bottom 200 feet as an open hole. (This well bottoms about 1000 feet lower than Woods.) Here too, conditions changed due to the installation of a pump in May of 1963.

On two occasions in 1963, the well was sampled twice during the same month. On the 3rd and the 26th of April the values were 119. ± 7. and 48. ± 7. T.U., respectively. On the 31st of May two samples were collected on the same day and their values were 90. ± 13. and 81. ± 12. T.U., respectively. The sharp drop in tritium concentration during April was the natural trend of the concentration pulse.

No samples were collected between June 1963, and February 1964. Well NO 16, Appendix E, which is located one mile from the Clardy well was sampled at three different depths on November 22, 1963. The sampling was done under flow conditions, and the sample from 793 to 853 feet had a concentration of 272. ± 7. T.U. This depth is at the same horizontal elevation as the Clardy production interval. Thus, the sampling gap in the Clardy well hides a strong tritium peak rapidly passing through. Tritium measurements of samples taken during the 1966/1967 series of pumping tests in this area indicated no north-south gradient (Fig. 4.4, wells NO 15, 17, and Clardy).

Figure 4.8

Tritium concentration-time profile

for W. T. Clardy well, 11.25.15.343

(two month moving average).

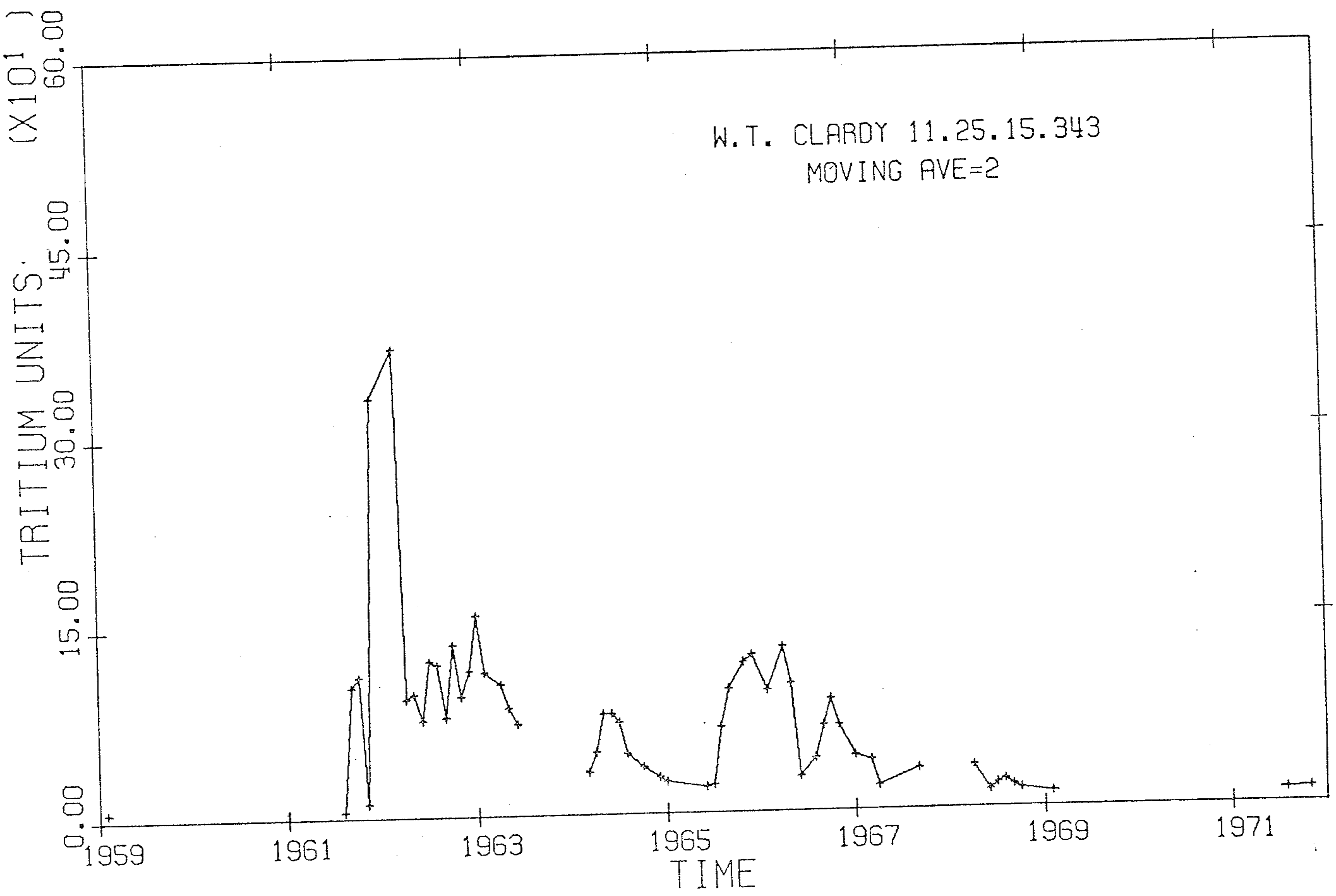
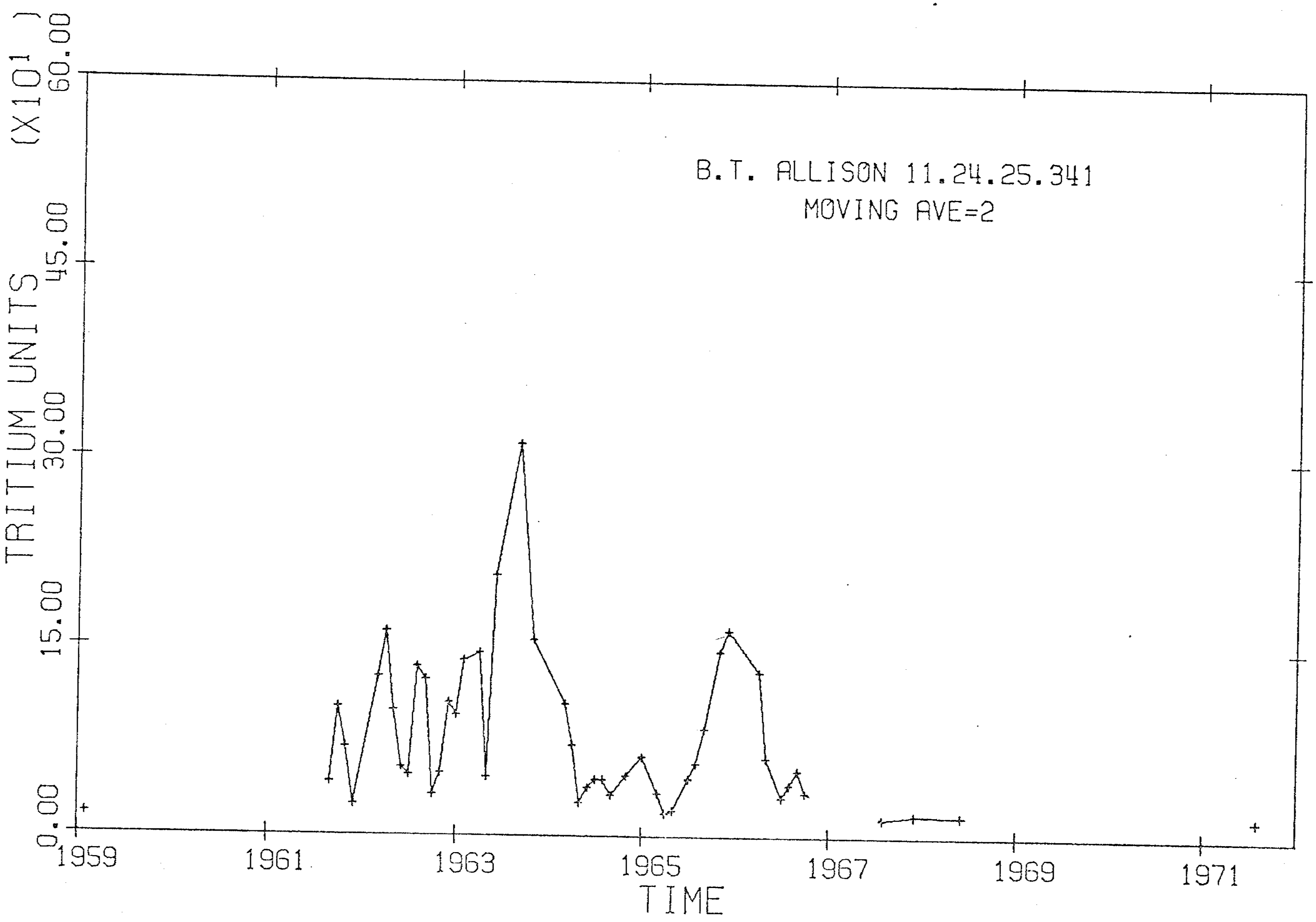

W.T. CLARDY 11.25.15.343
MOVING AVE=2
TRITIUM UNITS
(X10^1)
60.00
45.00
30.00
15.00
0.00
1959
1961
1963
1965
1967
1969
1971
TIME

Figure 4. 9

Tritium concentration-time profile

for B. T. Allison well, 11. 24. 25. 341

(two month moving average).

B.T. ALLISON 11.24.25.341
MOVING AVE=2
TRITIUM UNITS
(X10¹)
0.00
15.00
30.00
45.00
60.00
TIME
1959
1961
1963
1965
1967
1969
1971

B. T. Allison well. (Fig. 4.9). The well is 678 feet deep and mainly produces from the Grayburg-Queen formation of the Artesia Group. It was never reported to be flowing. In general it has the same trend as Clardy which is 6 miles to the east. Its first tritium peak of October 1961 has almost the same characteristics as Clardy's: high concentration followed by a sharp decrease to pre-thermonuclear levels. The broad tritium peak from August 1963 to March 1964, occurred during the gap in sampling at Clardy. Its October 1963 value of 229. ± 14. T.U. is the same as the one observed near Clardy in well NO 16 on November 22, 1963. Thus, the "missing" peak at Clardy can be deduced.

Before continuing with the discussion about Wiggins and Pollard wells, a remark is in order about a well (NO 5 in sec. 4, T. 10 S., R. 24 E.) for which two tritium measurements were done at the end of 1965 and the beginning of 1966. This well is deeper than 833 feet and was sampled as follows (Appendix E): November, 1965, 111. ± 3. T.U. and February, 1966, 176. ± 4. T.U. The well is 10 miles north of Clardy and Allison which during the same months had tritium concentrations of the same values. Once again observations covering large areas point toward uniform north-south distribution of tritium concentrations.

M. Wiggins well. (Fig. 4.10). Located about 9 miles south of Clardy on the east side of the Pecos River. The well was 1135 feet deep, producing from a 500 feet open hole in the limestone. The well was under artesian pressure during the winter months. Since 1966, strong sulfur smell and turbid appearance of the water were reported. Finally, it was abandoned in 1968. The same general trend of change in tritium concentration prevails here that was observed for the preceding long-term wells. It is apparent that, from whatever source, the addition of sulfur and the turbid appearance did not affect the tritium peaks observed in 1966 and 1967. Discussion on the characteristics of tritium peaks in this well will follow the data presentation for the Pollard well.

H. B. Pollard well. (Fig. 4.11). This well is the deepest among the long-record wells, 1381 feet. The production interval is 280 feet and the well was reported to flow during the winter of 1965. The well is 14 miles south of Wiggins and just north of the low permeability region mentioned previously (Section 4.2.1).

Samples taken at two week intervals again indicate rapid change in tritium concentrations, from October 3 to 19, 1961, from 22. ± 22. to 66. ± 7. T.U., and from July 19 to 31, 1962, the increase was from 90. ± 27. to 143. ± 16. T.U.

The two wells, Wiggins and Pollard, exhibit very similar, rapidly changing tritium peaks. In particular, tritium analysis of samples from Pollard, even though taken only once a month or every other month, reveal very sharp peaks.

The similarity between the two wells is such that the 1965 tritium peak at Pollard could fill the gap in sampling at Wiggins.

Figure 4.10

Tritium concentration-time profile

for M. Wiggins well, 13.26.3.114

(two month moving average).

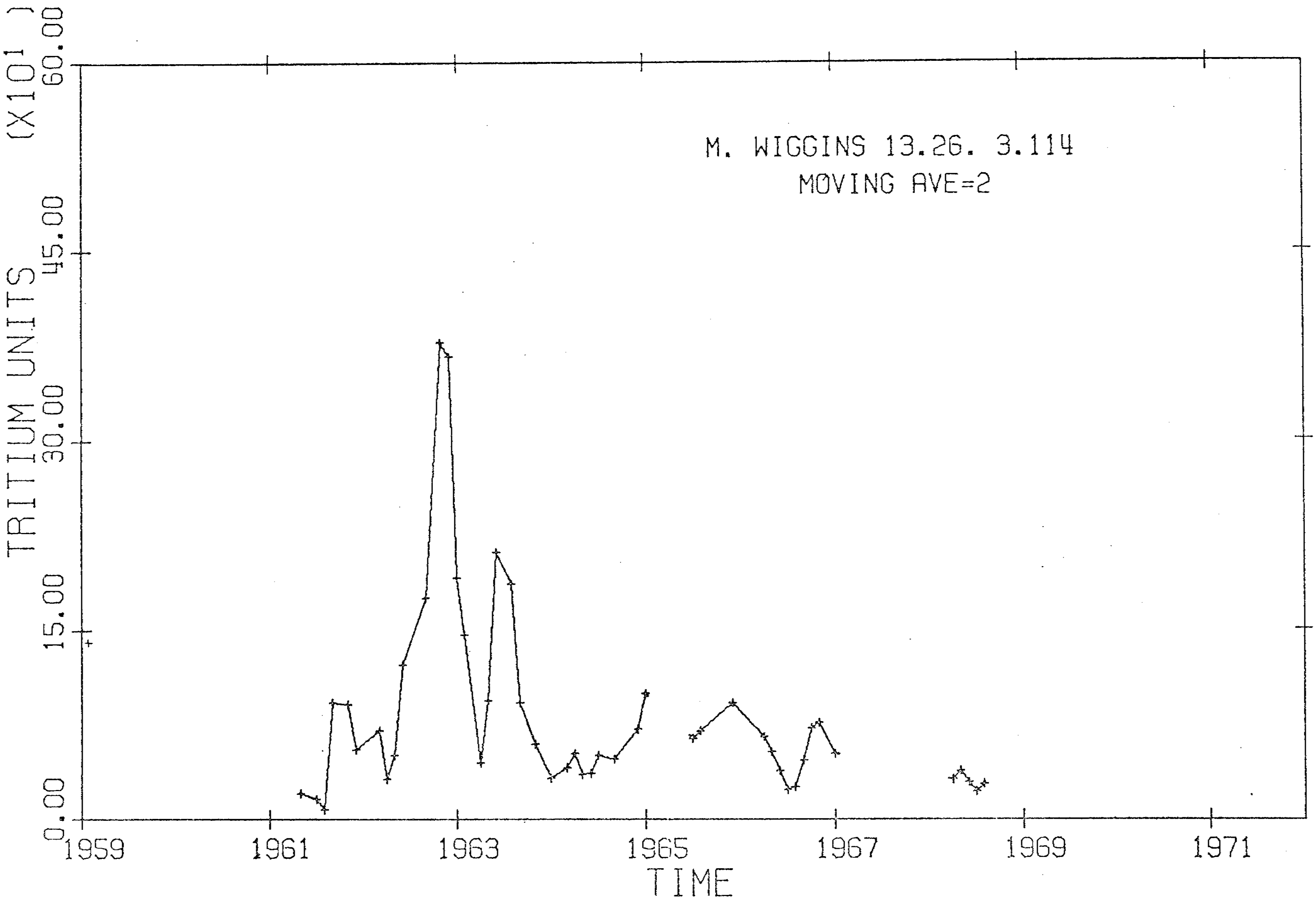
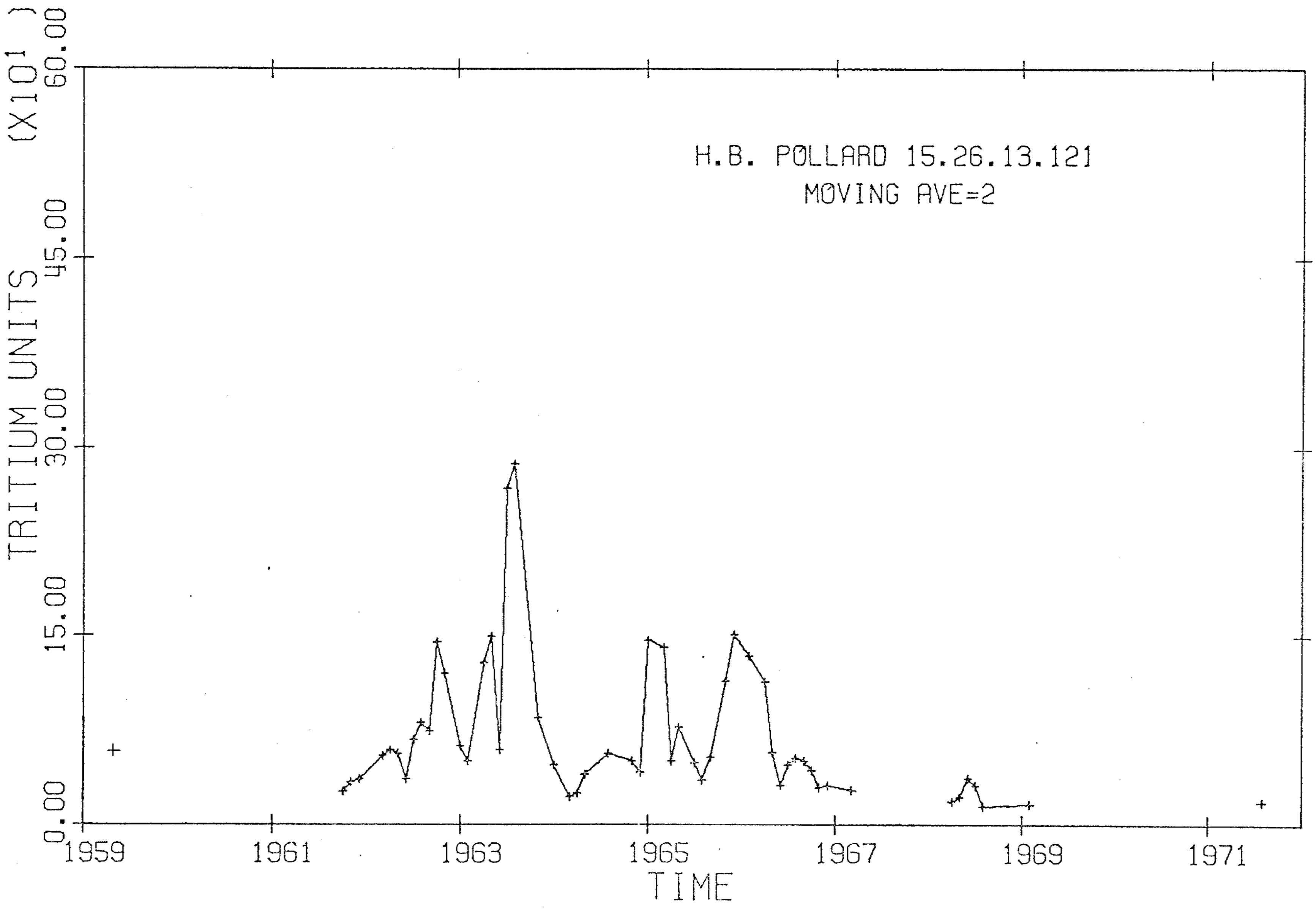

M. WIGGINS 13.26. 3.114
MOVING AVE=2
TRITIUM UNITS (X10¹)
0.00
15.00
30.00
45.00
60.00
TIME
1959
1961
1963
1965
1967
1969
1971

Figure 4.11

Tritium concentration-time profile

for H. B. Pollard well, 15.26.13.121

(two month moving average).


H.B. PØLLARD 15.26.13.121
MØVING AVE=2
TRITIUM UNITS (X10¹)
0.00
15.00
30.00
45.00
60.00
1959
1961
1963
1965
1967
1969
1971
TIME

Elk No. 1 well. (Fig. 4.12). Although only 30 samples in total were collected from this well, it has the most complete set of samples between April 1964 and December 1966. This well is situated 6 miles northeast of Roswell in the brackish (2,600 ppm Cl^-) water zone of the San Andres Limestone aquifer. The profile of this well exactly correlates with Clardy (Fig. 4.8).

Correlation also exists with bedrock well NO 5 during November 1965 and February 1962. This well is 6 miles northwest of Elk No. 1.

The 1965/1966 tritium peak is of interest because of its symmetric shape. This is possibly the result of an orderly monthly sampling program.

Patterson Bros. Wells. (Fig. 4.13). This set of data is again a combination of two wells located within the same section. The wells are located close to the recharge area and to the Rio Hondo. This explains the height of the 1963 peak (300 T.U.). They are relatively shallow (production intervals 275 to 665 feet and 315 to 640 feet, respectively). The Artesia Group is missing in the area. The observed rise in tritium content at the beginning of 1962 was not affected by change of well. The rise in tritium content is comparable to the change observed in Clardy. The most pronounced change in tritium content was observed between October 1962 and April 1963. This is the same period when an increase was also observed at Clardy though not as high. This seems to support a southeasterly flow direction suggested by Cushman and Motts (1964).

Figure 4.12

Tritium concentration-time profile

for Elk Oil Co. Well No. 1, 10.25.22.324

(two month moving average).

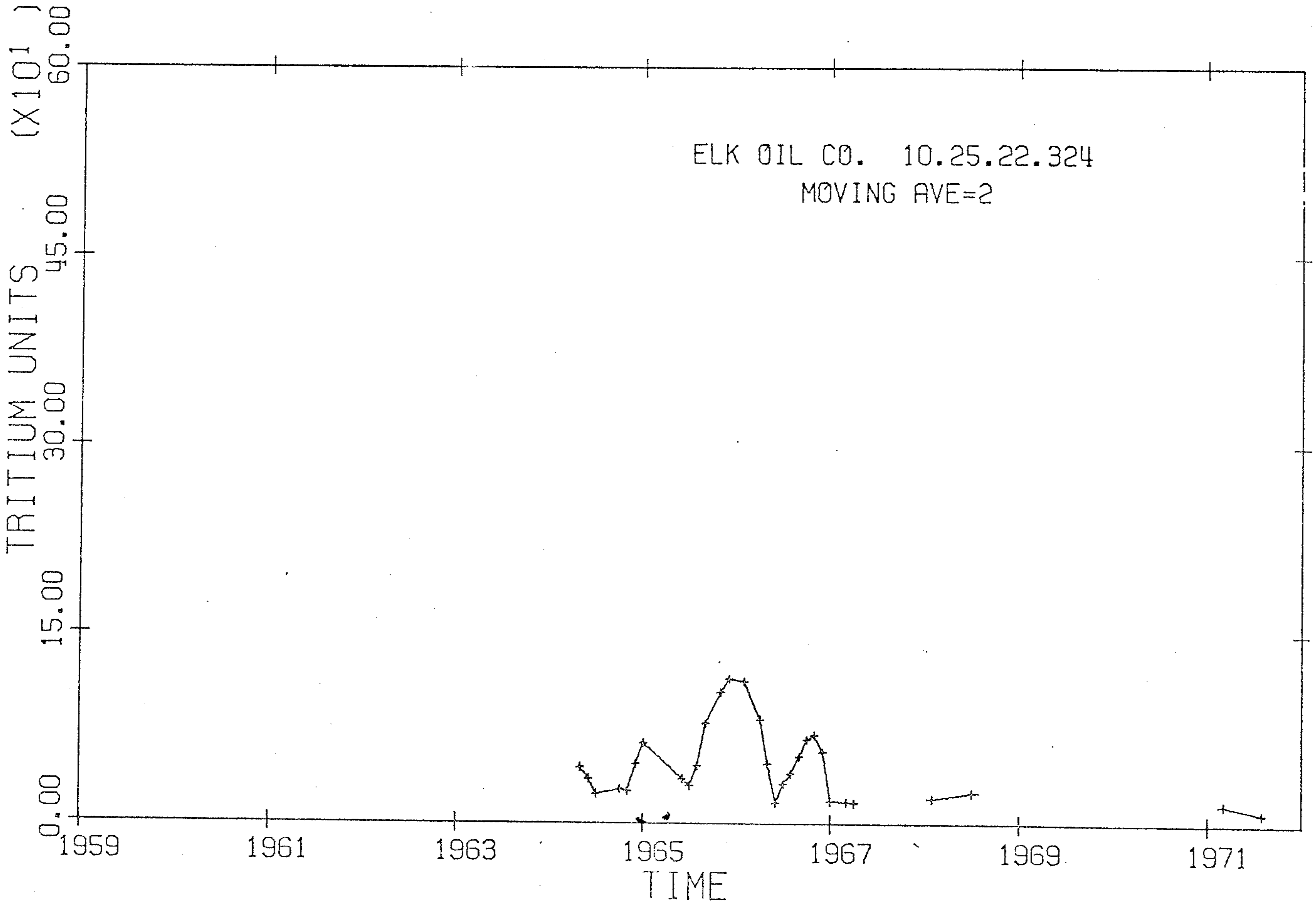
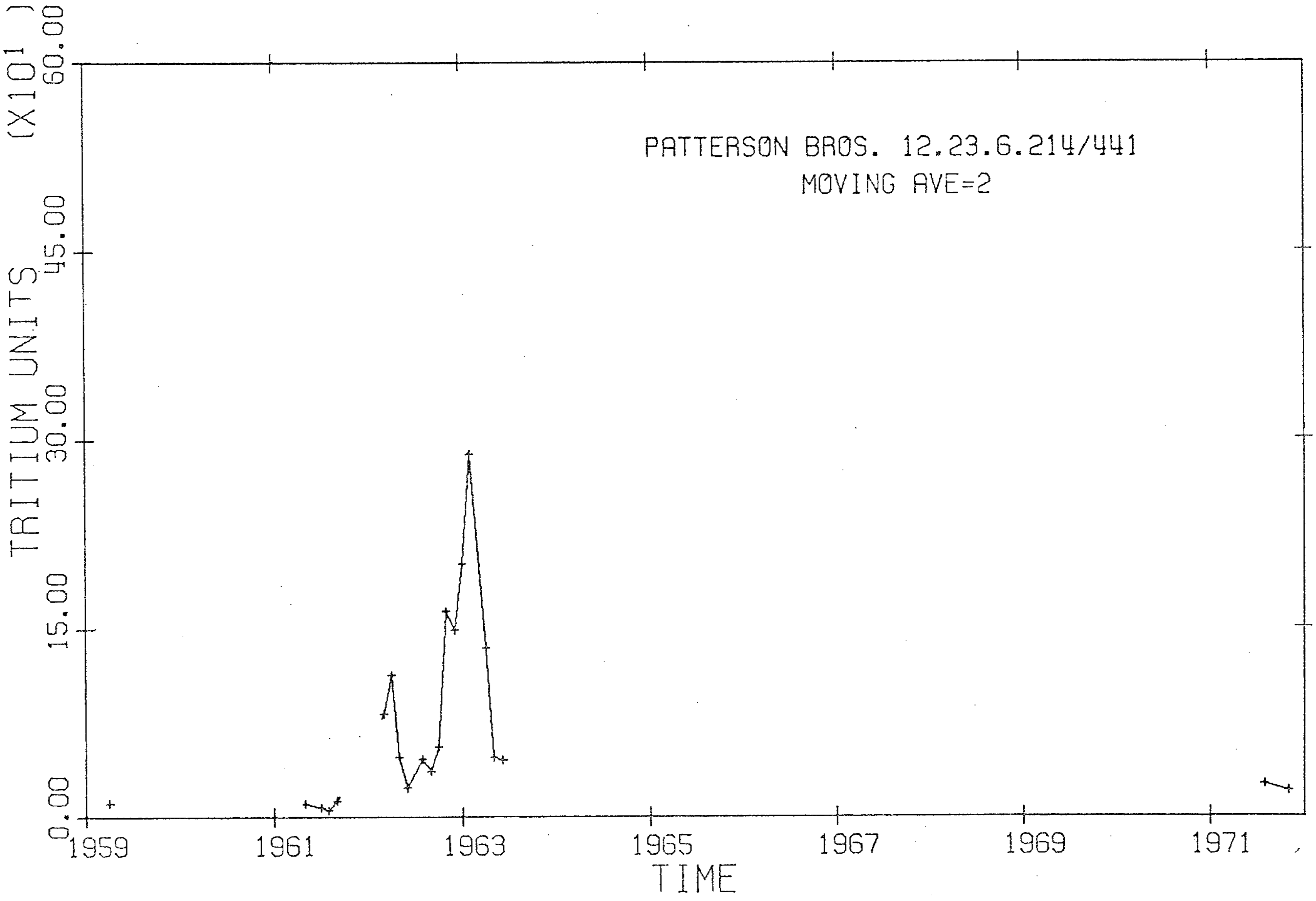
ELK 0IL C0. 10.25.22.324
M0VING AVE=2
TRITIUM UNITS (X10^1)
60.00
45.00
30.00
15.00
0.00
1959
1961
1963
1965
1967
1969
1971
TIME

Figure 4.13

Tritium concentration-time profile

for Patterson Bros. well, 12.23.6.214/441.


PATTERSON BROS. 12.23.6.214/441
MOVING AVE=2
TRITIUM UNITS (X10^1)
0.00
15.00
30.00
45.00
60.00
1959
1961
1963
1965
1967
1969
1971
TIME

Trends in long-record observations. It follows from the discussion of the short-record observations of tritium that trends (such as peaks or lows in different parts of the basin) are more useful than the correlation of specific events (e.g. of a particular peak in one part of the basin to a particular peak in another). The preceding discussion of tritium measurements in well waters shows that an overall similarity in tritium concentration changes across the Roswell basin can be recognized. Allison and Clardy wells in the northern part of the study area and Wiggins and Pollard wells in the center part exhibit similar features: A first group of tritium peaks (magnitude varied between 150 and 450 T. U.) was observed continuously from 1961 to 1964. This group was followed by two broad peaks (up to 150 T. U.) in 1965 and 1966. The 1965/1966 peaks were also observed in the Elk well. The last identifiable peak was observed in Woods, Clardy, Wiggins, and Pollard wells during 1968 (magnitude of about 50 T. U.).

The multiple tritium peaks (1961 - 1964) in the northern wells have a greater number of spikes and have a lower ratio of high/low than in Wiggins and Pollard, which showed only three clear spikes. (The same trend is also seen from the raw, unsmoothed data.)

The 1965/1966 peak in Elk very closely resembles the normal distribution curve. That could be the result of an undisturbed flow in a region of the aquifer where there is no pumpage for irrigation, and an orderly sampling program.

The very fast changes in tritium concentrations (Clardy, April 1963; Pollard, October 1961 and July 1962; NO 23. March 1962) show that tritium peaks could have easily been missed since the average sampling interval was one to two months.

An interpretation of the relationships between tritium/time profiles of those long-record wells requires an investigation of the precipitation/recharge relationships and an examination of the recharge area itself. These topics will therefore be presented next. The tritium/time profiles will be taken up again in Section 5.3.1 (Ground Water Flow Velocity and Direction).

4.3 The Variations of Tritium Content in Precipitation

4.3.1 General. Since most of the atmospheric testing of fusion devices took place in the northern hemisphere and since, furthermore, mixing between the northern and southern hemispheres is restricted, the bulk of bomb-produced tritium has been deposited over the northern hemisphere. The fallout of radioactive debris from atomic weapons is usually classed as follows (Facy, 1962):

(a) Close or local fallout (mainly from low yield devices).

(b) Intermediate or tropospheric fallout (high yield devices at tropospheric level).

(c) World wide or stratospheric fallout (high yield and high altitude devices).

Only surface detonations of very low yield will cause local fallout. The other two classes of fallout are initially injected at the tropospheric level below the tropopause (about 10 kilometers) and into the stratosphere (above 20 kilometers), respectively. In general, rainout and snowout are the processes by which tritiated water molecules are deposited on the surface of the earth. Some work has been done on the tritium content of atmospheric hydrogen (Begemann, 1963, and Martell, 1963).

4.3.2 Variations of Tritium Concentration in New Mexico. Tritium activities in precipitation and atmospheric moisture at Socorro, N. M. and points nearby (Figures 2.1 and 2.2) have been monitored since 1956. These data are tabulated in Appendix H.

Figure 4.14 shows the daily and weekly variations in tritium concentration of precipitation samples. The monthly averaging of the tritium concentrations is represented by the solid line through the individual data points. From Fig. 4.14 and Appendix H it is evident that there is a short time variation in tritium concentrations in samples collected during the same week or even from one day to the next. In addition, some lateral variations are observed in samples from different collection stations, even though in some cases the samples originated from the same storm. A few examples are shown in Table 4.1. In some cases, tritium measurements revealed no change in concentration of samples taken on the same day or on consecutive days.

Figure 4.14

Daily and weekly variations in tritium concentrations in New Mexico precipitation (the solid line is the trend of monthly averaging).

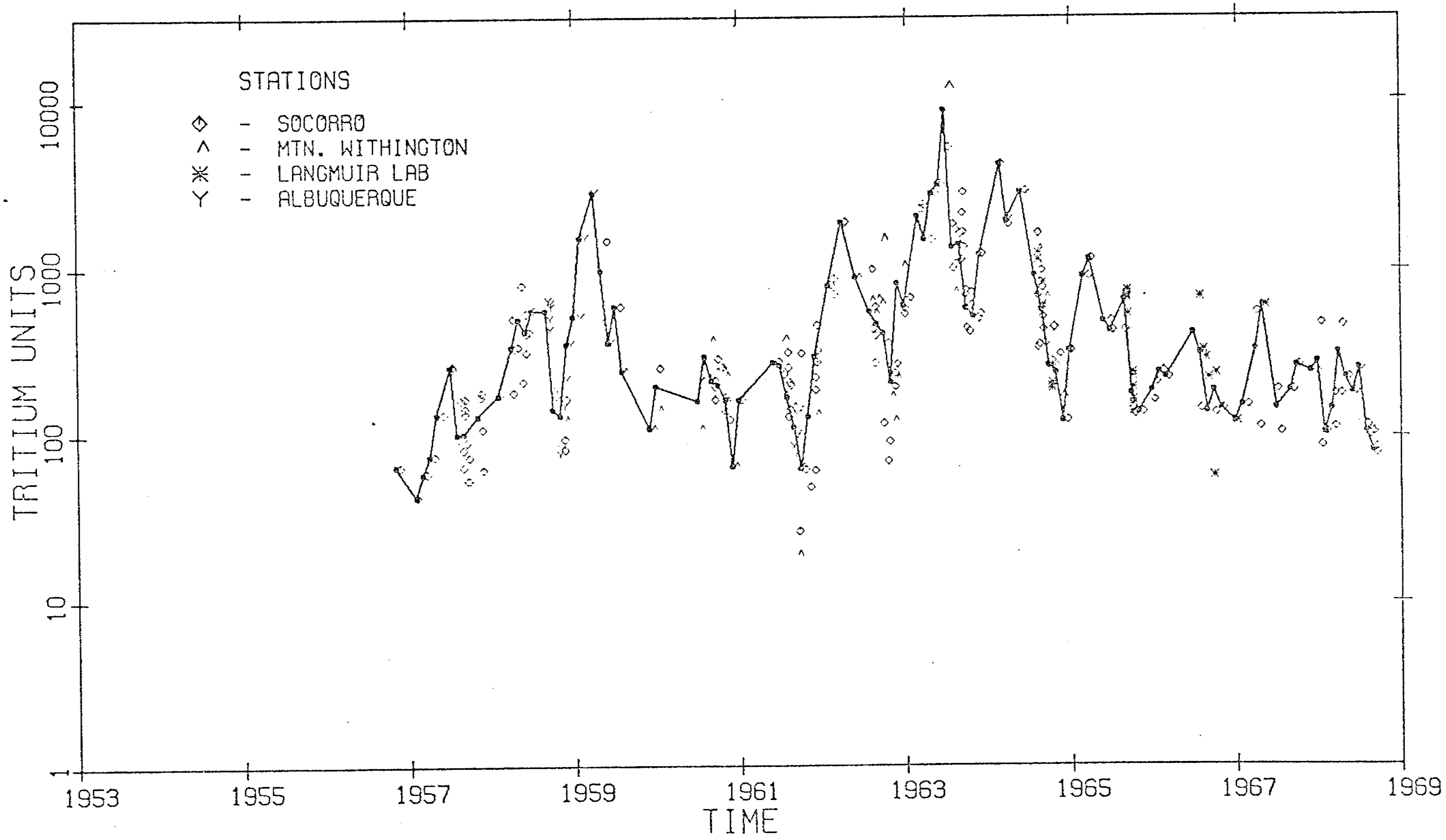

STATIONS
◇ - SOCORRO
^ - MTN. WITHINGTON
⋇ - LANGMUIR LAB
Y - ALBUQUERQUE
TRITIUM UNITS
10000
1000
100
10
1
TIME
1953
1955
1957
1959
1961
1963
1965
1967
1969

Table 4.1

Daily variations in tritium concentration

(compiled from App. H).

LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-[1]	REMARKS
Socorro	Rain	1958	5	2	407.	41.	
Socorro	Rain	1958	5	2	540.	54.	
Socorro	Hail	1960	8	11	211.	2.	Just before rain 1/2 mi. west of Socorro.
Socorro	Rain	1960	8	11	162.	2.	1630-1700 hrs., not same storm as hail.
Socorro	Surface runoff	1960	8	11	192.	1.	Collected west of Socorro rain and hail.
Socorro	Rain	1961	6	15	228.	9.	
M. Withington	Rain	1961	6	15	173.	4.	
Socorro	Rain	1961	11	8	270.	29.	No. 1 (1 gallon)
Socorro	Rain	1961	11	8	451.	3.	No. 2 (1 gallon)
Socorro	Snow	1963	2	22	2248.	20.	Rain and snow - 2 hours
Socorro	Rain	1963	2	22	2385.	20.	End of rain = 1/2"

---

(1) +OR- is the standard deviation of the measured sample.

Table 4.1 continued

LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	REMARKS
Socorro	Rain	1963	8	16	1614.	14.	Collected after 0.1", rain continued all night
Socorro	Rain	1963	8	17	2832.	34.	End of storm
Langmuir	Rain	1964	7	12	1220.	29.	No. 1 (1/2 gallon)
Langmuir	Rain	1964	7	12	1110.	56.	No. 2 (1/2 gallon)
Socorro	Rain	1968	2	12	107.	5.	Collected 1130-1630 hrs.
Socorro	Snow	1968	2	12	170.	8.	Collected 1630-0300 hrs.

Monthly averaging eliminates the daily scatter of activities and brings out the large-scale effects of seasonal variations. The data show a regular seasonal variation in concentrations of tritium during the periods 1956 - 1960 and 1962 - 1968. Maximums, separated by a small dip, occur with the first winter snows and during the July-August summer rains (the twin peaks shown, e.g., in Fig. 4.14). Deep minimums are around October-November. Following the first atmospheric moratorium of 1958 (Fig. 1.1), tritium levels fell sharply. However, as a result of resumption of atmospheric testing in 1961, tritium activity began to rise again.

The distribution of the precipitation sampling stations was such that a large area as well as different elevations in central New Mexico were covered. Therefore, an average monthly sample of tritium concentrations should be representative of tritium rainout for a large region. The variations in tritium concentrations along the Rio Grande valley will be later applied as the basis for the determination of tritium input for the Roswell basin.

4.3.3 Tritium Content of Atmospheric Moisture (Appendix I). Tritiated water may be removed from the ground in the form of water vapor. This type of evaporation may modify tritium content in rain procedent from the stratospheric reservoir.

Condensed water samples were collected in Socorro and their tritium content was measured for the period June 1963 - December 1965. Three precipitation collection stations were operated in the vicinity of the condensed water station (Fig. 2.2).

Variations in tritium concentrations in both precipitation and in atmospheric moisture are very similar. This suggests recondensation of local evaporation during the early morning hours. The most striking examples of similarity between rain water and atmospheric moisture is the Mt. Withington rain of June 18, 1963 and the condensed water from the following day at Socorro. These samples measured 12,208. ± 110. and 10,398. ± 110. T.U., respectively (App. H and I). From the hourly precipitation data it was determined that both Augustine (near Mt. Withington) and Socorro had 0.06 inches of rain between 4 and 5 p.m. on June 18, 1963. No additional precipitation was reported until July. The following five condensed water samples, collected between June 18 and June 30, showed exponential decrease of their tritium content with 3 days half-life.

Tritium content of atmospheric water. Correlation analysis of 27 tritium measurements in condensed water with rain and snow (collected up to two days apart) resulted in a correlation coefficient of 0.974. The samples range from 130 to 12,200 T.U. and were collected during 1963 - 1965.

Of the two main contributions to atmospheric moisture, namely oceanic water and reevaporated continental surface water, the latter has usually higher tritium content. According to Israel et al. (1963), if for constant injection of tritium from the stratosphere the fraction of reevaporated continental surface water increases, the tritium activity of the rain will also increase. For New Mexico, the amount of reevaporated water is much higher during the summer months but the same is true of the total amount of precipitation. Therefore, the ratio of reevaporated to oceanic water should not appreciably influence the observed seasonal variations in tritium concentrations.

4.4 References

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5. ANALYSIS AND INTERPRETATION

In the present chapter an empirical tritium input function for the Roswell basin is constructed and tested with a one-dimensional dispersion model. The procedure to be followed is outlined below.

The distribution and trends of precipitation in the basin and the surrounding area (Fig. 2.1) is first investigated.

Next, variations and distribution of tritium concentration in precipitation on a continental scale are analyzed. This is done in order to fill in gaps of tritium records in precipitation or, in other words, to check the applicability of data measured at one point to a neighboring one.

The product of tritium concentration and precipitation volume (T. U. -in.) gives the tritium fallout.

Recharge into the aquifer is traced by tritium input. Tritium input is a function of tritium fallout at the surface and a precipitation/recharge relation. The empirical tritium input function is developed from climatic and geologic considerations.

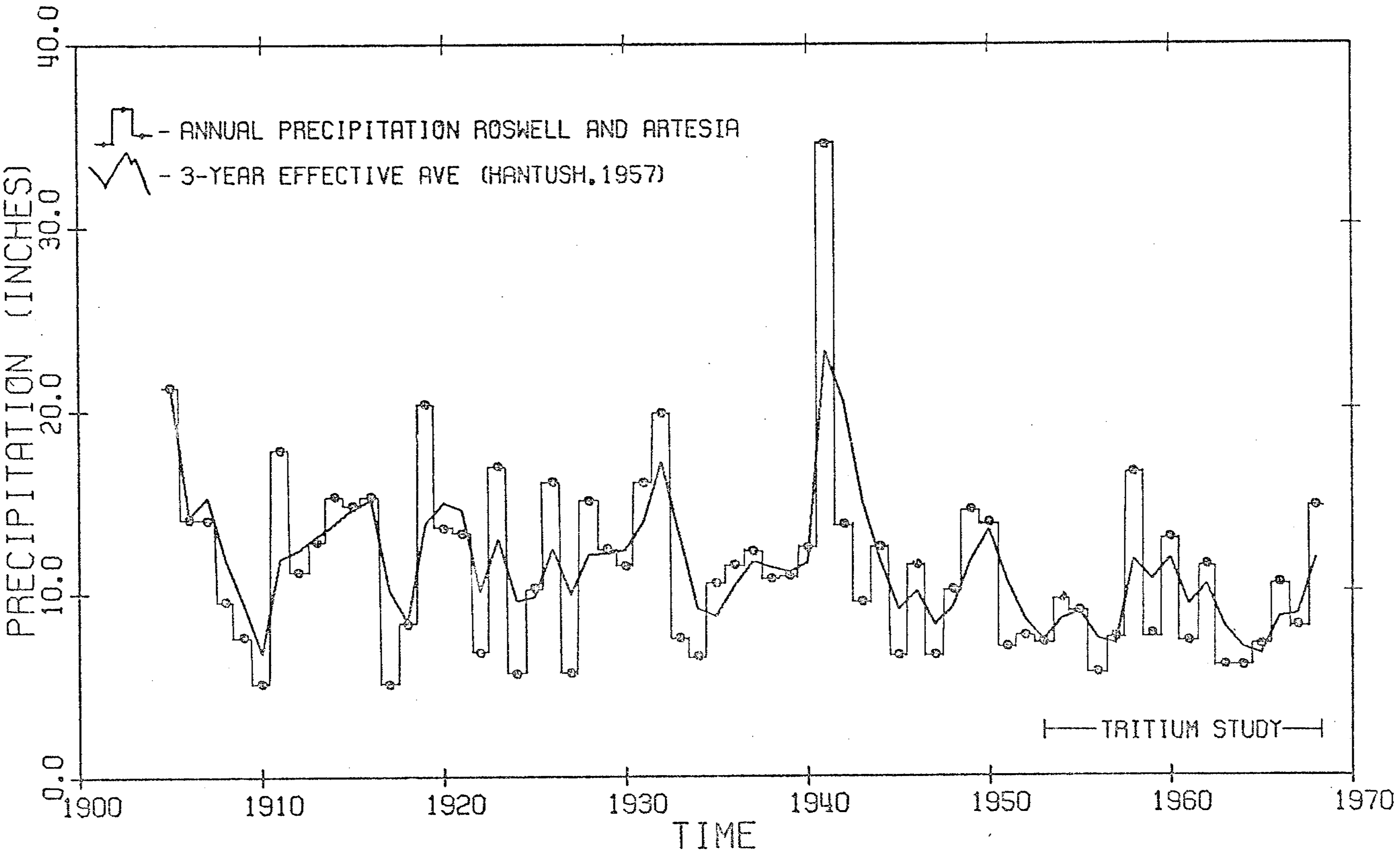
It is this tritium input function which is then correlated with the tritium-time profiles of ground water in the sampled wells.

This correlation is then the basis for computing residence time, flow velocity, and effective aquifer thickness. The actual amount of recharge and hydrologic parameters (velocity, effective thickness of the aquifer, and dispersion constant) are tested by generating a simple dispersive model for the basin.

Figure 5.1

Monthly precipitation and 3-year

effective average for Roswell and Artesia (1905 - 1968).


- ANNUAL PRECIPITATION ROSWELL AND ARTESIA
- 3-YEAR EFFECTIVE AVE (HANTUSH, 1957)
TRITIUM STUDY
PRECIPITATION (INCHES)
0.0
10.0
20.0
30.0
40.0
1900
1910
1920
1930
1940
1950
1960
1970
TIME

5.1 Construction of Empirical Tritium Input Function, Roswell Basin

In order to appraise the observed magnitude and periodicity of the tritium peaks in ground water, the meteorological conditions prevailing at the time and during previous years must be considered. The input profile expresses the relationship between tritium concentration and time as well as boundary conditions to the flow system. The profile itself is derived from experimental data obtained by monitoring tritium concentration in precipitation and by measuring the amount of precipitation. The tritium input profile is also based on the correlation between the observed fluctuations of tritium concentration in well water and precipitation distribution over the basin. Distinction must be made between tritium fallout at the land surface and tritium input into the aquifer. The tritium input function relates tritium fallout at the surface to the actual magnitude of the contribution to the system. The analytical construction of such a function is impossible without a detailed understanding of the exact recharge and tritium fractionation mechanism in the area. In this study, the purpose is to develop an empirical input function, based on meteorological and tritium data, that will be used to compute aquifer parameters.

5.1.1 Precipitation Patterns in the Roswell Basin. The climate of the Roswell basin is semi-arid (<10" normal annual precipitation) with cold winter. Summer rains supply up to 75% of the annual precipitation The trend of tritium concentration-time profiles of deep well water (Fig. 4.7 to 4.11) and the variations of tritium concentration in precipitation (Fig. 4.14) are linked by the amount of precipitation over the intake area. Precipitation occurs mainly as thundershowers, very irregular, spotty and localized, although on occasions they may cover large portions of the basin. Furthermore, the orographic effect is very pronounced. For these reasons, the precipitation patterns and amounts measured at the different stations within and around the basin (Fig. 2.1) not only show large differences among themselves (App. D) but also records taken at any one of them cannot be considered a priori to be representative of precipitation characteristics in the recharge area. In particular, the orographic effect makes it likely that precipitation in the recharge area is larger and more sustained than that measured within the basin itself (Roswell and Artesia stations). It is equally probable that precipitation patterns and amounts vary along the recharge area so that recharge input is different for different parts of the basin. The following paragraphs describe the correlation method used for and results obtained in computing precipitation in the recharge area from the precipitation records presented in Appendix D.

Figure 5.1 is a histogram of the composite annual precipitation for Roswell and Artesia from 1905 to 1968. Superposed on the histogram is the 3-year effective precipitation which was used by Hantush (1957), and Jacob and Saleem (1971) in estimating the recharge to the Roswell basin. The present tritium study covers the last 16 years of this sequence. The main features of the precipitation-time sequence are two periods, separated by the 1941 peak, each of different mean annual precipitation. This trend is emphasized by the 3-year effective precipitation. The two driest periods for the total precipitation record were 1953 - 1956 and 1963 - 1965 which are included in the tritium study period.

Linear regression and correlation analysis were performed with precipitation data available for the Roswell basin during the study period. The data used come from the six precipitation-measuring stations around the basin (Sec. 2.2.3, Fig. 2.1, and App. D). In Table 5.1 the stations are separated into three groups of two according to their geographic location and precipitation pattern. Each two stations are presented as a composite station with its monthly and annual values, and the deviations of these values from a 16-year arithmetic mean. For Dunlap and Farnsworth Ranch the deviations from the mean are also given for the individual stations. (The correlation coefficient between the two individual stations of each group is higher than 0.920.) Picacho has the same precipitation pattern as Felix and Elk and was not included in the analysis.

The linear regression expressions and their respective multiple correlation coefficients (R^2) are presented in Table 5.2. The multiple

Table 5.1. Composite precipitation and departures from the mean (in.).

COMPOSITE PRECIPITATION. ROSWELL AND ARTESIA

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.19	0.25	0.24	0.70	1.00	0.34	2.09	1.48	0.16	0.48	0.13	0.25	7.31
1954	0.10	0.0	0.0	0.47	1.75	0.19	0.23	2.59	0.24	3.93	0.0	0.19	9.70
1955	0.37	0.0	0.05	0.17	0.52	0.24	3.10	0.53	2.14	1.78	0.14	0.0	9.05
1956	0.01	0.93	0.02	0.02	0.65	1.06	0.67	1.40	0.14	0.70	0.0	0.02	5.63
1957	0.12	0.46	0.53	0.15	0.65	0.03	0.73	0.85	0.59	2.69	0.72	0.0	7.54
1958	1.50	0.99	2.30	1.01	0.45	1.59	1.00	1.66	4.16	1.38	0.44	0.13	16.63
1959	0.01	0.12	0.02	0.39	1.96	0.56	2.56	1.08	0.08	0.38	0.12	0.51	7.78
1960	1.09	0.31	0.09	0.14	0.59	1.21	3.52	0.45	0.32	3.39	0.06	1.90	13.09
1961	0.69	0.10	0.63	0.01	0.46	0.82	1.03	1.23	0.35	0.29	1.51	0.25	7.39
1962	0.41	0.46	0.12	0.38	0.44	0.94	3.38	0.76	2.91	0.77	0.44	0.38	11.38
1963	0.22	0.72	0.0	0.13	0.90	0.99	0.19	2.18	0.31	0.16	0.10	0.08	6.01
1964	0.40	0.74	0.23	0.01	0.55	1.40	0.08	0.68	1.38	0.0	0.25	0.26	6.00
1965	0.06	0.60	0.10	0.19	0.58	0.96	1.57	1.44	0.71	0.08	0.04	0.75	7.10
1966	0.51	0.02	0.41	1.60	0.46	1.71	0.27	4.78	0.78	0.0	0.0	0.0	10.55
1967	0.0	0.17	0.03	0.0	0.86	2.00	0.82	3.03	0.76	0.01	0.44	0.78	8.91
1968	1.55	1.08	1.66	0.11	0.70	0.45	5.11	2.60	0.08	0.57	1.18	0.23	15.33

COMPOSITE DEPARTURES FROM MEAN. ROSWELL AND ARTESIA

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	-0.26	-0.19	-0.16	0.36	0.22	-0.57	0.44	-0.19	-0.79	-0.56	-0.22	-0.11	-2.03
1954	-0.35	-0.43	-0.40	0.13	0.97	-0.72	-1.41	0.92	-0.71	2.90	-0.35	-0.16	0.37
1955	-0.09	-0.43	-0.35	-0.17	-0.26	-0.66	1.45	-1.14	1.20	0.74	-0.20	-0.36	-0.2
1956	-0.44	0.50	-0.39	-0.33	-0.13	0.15	-0.97	-0.27	-0.81	-0.33	-0.35	-0.34	-3.7
1957	-0.33	0.03	0.13	-0.19	-0.13	-0.88	-0.91	-0.82	-0.36	1.66	0.37	-0.36	-1.8
1958	1.05	0.56	1.90	0.67	-0.33	0.68	-0.65	-0.01	3.21	0.35	0.10	-0.23	7.2
1959	-0.44	-0.32	-0.39	0.05	1.18	-0.34	0.92	-0.59	-0.87	-0.66	-0.23	0.15	-1.5
1960	0.64	-0.13	-0.31	-0.20	-0.19	0.30	1.88	-1.22	-0.62	2.36	-0.29	1.55	3.7
1961	0.24	-0.33	0.23	-0.33	-0.32	-0.09	-0.61	-0.44	-0.59	-0.75	1.17	-0.11	-1.9
1962	-0.04	0.03	-0.29	0.04	-0.35	0.04	1.73	-0.91	1.96	-0.27	0.09	0.03	2.0
1963	-0.23	0.29	-0.40	-0.21	0.12	0.09	-1.45	0.51	-0.64	-0.88	-0.24	-0.28	-3.3
1964	-0.05	0.31	-0.17	-0.33	-0.23	0.50	-1.56	-0.99	0.43	-1.04	-0.10	-0.10	-3.3
1965	-0.39	0.17	-0.30	-0.15	-0.20	0.06	-0.08	-0.23	-0.23	-0.96	-0.31	0.39	-2.2
1966	0.06	-0.42	0.01	1.26	-0.32	0.80	-1.37	3.11	-0.17	-1.04	-0.35	-0.36	1.2
1967	-0.45	-0.26	-0.37	-0.34	0.07	1.10	-0.83	1.36	-0.18	-1.03	0.09	0.42	-0.4
1968	1.10	0.65	1.26	-0.23	-0.08	-0.46	3.46	0.92	-0.87	-0.47	0.84	-0.13	5.9

Table 5.1. Continued

COMPOSITE PRECIPITATION. FELIX AND ELK 3 E

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.10	0.13	0.36	0.73	0.71	0.95	0.93	1.04	0.0	0.55	0.14	0.94	6.59
1954	0.22	0.0	0.0	0.70	1.14	0.31	0.15	4.61	0.67	5.60	0.0	0.34	13.75
1955	0.70	0.0	0.15	0.18	0.64	0.15	8.33	2.02	3.60	2.00	0.07	0.0	17.85
1956	0.0	1.55	0.0	0.07	0.38	0.53	1.30	2.13	0.30	0.72	0.0	0.15	7.13
1957	0.06	0.56	0.59	0.89	0.72	0.10	1.98	4.99	0.23	4.42	2.02	0.0	16.59
1958	1.11	1.18	2.15	0.66	1.01	1.46	2.75	2.94	3.74	3.31	0.48	0.10	20.90
1959	0.0	0.21	0.05	0.15	2.01	0.68	1.85	3.44	0.06	0.33	0.0	1.02	9.80
1960	0.57	0.39	0.23	0.01	0.34	1.93	4.38	1.56	1.34	1.81	0.12	1.88	14.57
1961	0.69	0.06	0.75	0.02	0.33	1.47	1.70	2.95	0.89	0.15	2.32	0.29	11.66
1962	0.43	0.30	0.49	0.29	0.07	1.14	5.96	0.27	3.31	1.34	1.09	0.82	15.53
1963	0.95	0.63	0.0	1.21	1.18	1.55	1.71	5.01	0.79	0.82	0.13	0.0	13.99
1964	0.19	0.84	0.51	0.07	0.13	0.25	1.22	1.09	2.29	0.0	0.06	0.54	7.20
1965	0.01	0.90	0.41	0.77	1.87	2.36	1.81	2.46	3.79	0.07	0.21	0.91	15.59
1966	0.49	0.07	0.15	3.02	0.46	3.48	0.76	7.64	1.01	0.05	0.02	0.03	17.20
1967	0.07	0.37	0.06	0.15	0.32	2.77	2.27	1.48	2.68	0.00	0.39	1.04	11.62
1968	1.11	1.00	1.18	0.12	0.44	0.13	7.51	3.97	0.03	0.64	1.22	0.10	17.45

COMPOSITE DEPARTURES FROM MEAN. FELIX AND ELK 3 E

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	-0.32	-0.38	-0.09	0.17	-0.03	-0.25	-1.86	-1.94	-1.55	-0.81	-0.38	0.43	-7.00
1954	-0.20	-0.51	-0.44	0.13	0.40	-0.90	-2.64	1.64	-0.88	4.24	-0.52	-0.17	0.16
1955	0.28	-0.51	-0.29	-0.39	-0.09	-1.05	5.54	-0.95	2.05	0.64	-0.45	-0.51	4.26
1956	-0.42	1.03	-0.44	-0.49	-0.35	-0.68	-1.49	-0.84	-1.25	-0.64	-0.52	-0.36	-6.46
1957	-0.36	0.05	0.15	0.32	-0.02	-1.10	-0.81	2.02	-1.32	3.06	1.51	-0.51	3.00
1958	0.69	0.66	1.71	0.09	0.28	0.26	-0.04	-0.04	2.19	1.95	-0.04	-0.41	7.31
1959	-0.42	-0.30	-0.39	-0.42	1.27	-0.53	-0.94	0.47	-1.49	-1.03	-0.52	0.51	-3.79
1960	0.15	-0.12	-0.21	-0.56	-0.40	0.73	1.59	-1.42	-0.20	0.45	-0.40	1.36	0.98
1961	0.27	-0.45	0.31	-0.54	-0.40	0.27	-1.09	-0.02	-0.66	-1.21	1.81	-0.22	-1.93
1962	0.01	-0.21	0.04	-0.27	-0.66	-0.06	3.17	-2.70	1.76	-0.02	0.57	0.31	1.94
1963	0.53	0.12	-0.44	0.64	0.44	0.35	-1.08	2.03	-0.75	-0.54	-0.39	-0.51	0.40
1964	-0.23	0.32	0.07	-0.49	-0.60	-0.95	-1.57	-1.89	0.74	-1.36	-0.46	0.03	-6.39
1965	-0.41	0.39	-0.03	0.21	1.13	1.16	-0.98	-0.51	2.24	-1.29	-0.31	0.40	2.00
1966	0.07	-0.44	-0.29	2.45	-0.28	2.28	-2.03	4.67	-0.54	-1.31	-0.49	-0.48	3.61
1967	-0.35	-0.15	-0.39	-0.41	-0.41	1.56	-0.52	-1.49	1.14	-1.36	-0.12	0.53	-1.97
1968	0.69	0.49	0.74	-0.45	-0.30	-1.07	4.72	0.99	-1.51	-0.72	0.70	-0.41	3.86

Table 5.1. Continued

COMPOSITE PRECIPITAION. DUNLAP AND FARNSWORTH

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANN
1953	0.16	0.38	0.21	0.40	1.24	0.44	2.71	1.26	0.0	0.44	0.36	0.08	7.
1954	0.12	0.0	0.02	0.45	1.99	0.65	0.68	3.88	1.82	3.34	0.0	0.25	13
1955	0.14	0.01	0.08	0.73	0.27	0.30	1.61	0.42	2.32	0.49	0.0	0.05	6.
1956	0.07	0.42	0.02	0.35	0.54	1.00	1.00	0.86	0.0	0.20	0.02	0.02	4
1957	0.0	0.80	0.96	0.54	2.11	0.16	0.91	1.65	0.06	1.68	0.46	0.0	9
1958	0.85	0.60	3.34	0.93	0.53	1.52	2.27	3.86	5.79	0.81	0.06	0.15	20
1959	0.0	0.11	0.0	0.84	1.11	2.92	3.00	3.07	0.13	0.90	0.02	1.69	13
1960	0.64	0.31	0.16	0.0	0.77	2.72	10.02	0.55	0.57	3.80	0.02	1.47	21
1961	0.22	0.06	0.99	0.50	0.57	0.72	1.48	0.91	1.26	0.23	0.85	0.15	7
1962	0.21	0.22	0.14	0.26	0.02	1.75	3.15	0.87	2.02	0.43	0.27	0.21	9
1963	0.0	0.08	0.0	0.28	0.15	0.41	0.09	2.66	0.38	0.62	0.08	0.14	4
1964	0.00	0.18	0.06	0.05	0.09	0.38	0.70	0.98	1.09	0.0	0.38	0.13	4
1965	0.0	0.20	0.0	0.0	1.83	2.04	1.93	0.16	0.76	0.32	0.23	0.19	7
1966	0.21	0.06	0.0	0.30	0.44	0.14	0.56	5.03	0.02	0.0	0.08	0.06	6
1967	0.0	0.22	0.14	0.02	0.09	0.69	1.57	1.52	0.49	0.0	0.10	0.48	5
1968	1.30	1.25	0.84	0.05	0.55	0.35	4.42	4.38	0.22	0.40	0.57	0.20	14

COMPOSITE DEPARTURES FROM MEAN. DUNLAP AND FARNSWORTH

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANN
1953	-0.08	0.07	-0.23	0.04	0.47	-0.57	0.46	-0.74	-1.06	-0.41	0.14	-0.24	-2
1954	-0.13	-0.31	-0.42	0.09	1.22	-0.36	-1.57	1.87	0.76	2.49	-0.22	-0.08	3
1955	-0.11	-0.30	-0.36	0.37	-0.50	-0.72	-0.64	-1.58	1.27	-0.36	-0.22	-0.28	-3
1956	-0.18	0.11	-0.41	-0.00	-0.23	-0.01	-1.25	-1.14	-1.06	-0.65	-0.20	-0.31	-5
1957	-0.25	0.49	0.53	0.18	1.34	-0.85	-1.35	-0.36	-1.00	0.82	0.24	-0.33	-0
1958	0.60	0.29	2.90	0.57	-0.24	0.51	0.02	1.86	4.73	-0.04	-0.16	-0.18	10
1959	-0.25	-0.20	-0.44	0.48	0.34	1.91	0.74	1.06	-0.92	0.05	-0.20	1.36	3
1960	0.40	-0.00	-0.28	-0.36	0.00	1.71	7.77	-1.46	-0.49	2.95	-0.20	1.14	11
1961	-0.02	-0.24	0.56	0.14	-0.20	-0.29	-0.78	-1.09	0.20	-0.62	0.63	-0.17	-1
1962	-0.03	-0.09	-0.29	-0.10	-0.75	0.74	0.90	-1.14	0.97	-0.42	0.06	-0.12	-0
1963	-0.25	-0.22	-0.44	-0.08	-0.62	-0.60	-2.16	0.65	-0.67	-0.23	-0.13	-0.19	-4
1964	-0.24	-0.13	-0.37	-0.31	-0.68	-0.63	-1.55	-1.02	0.03	-0.85	0.16	-0.20	-5
1965	-0.25	-0.11	-0.44	-0.36	1.06	1.03	-0.33	-1.85	-0.30	-0.53	0.01	-0.14	-2
1966	-0.04	-0.25	-0.44	-0.06	-0.33	-0.87	-1.70	3.02	-1.04	-0.85	-0.14	-0.27	-2
1967	-0.25	-0.09	-0.30	-0.34	-0.68	-0.32	-0.69	-0.49	-0.57	-0.85	-0.12	0.15	-4
1968	1.05	0.94	0.40	-0.31	-0.22	-0.66	2.16	2.37	-0.84	-0.45	0.35	-0.13	4

Table 5.1. Continued

DEPARTURES FROM THE MEAN. FARNSWORTH

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	-0.07	-0.00	-0.11	0.04	0.22	-0.76	0.55	-0.53	-1.18	-0.29	0.02	-0.31	-2.43
1954	-0.06	-0.33	-0.46	0.06	1.05	-0.95	-0.78	3.20	1.43	1.72	-0.23	-0.00	4.64
1955	-0.09	-0.32	-0.39	0.19	-0.27	-0.57	0.32	-1.82	1.62	-0.67	-0.23	-0.28	-2.52
1956	-0.19	0.15	-0.43	0.10	-0.25	0.50	-0.82	-1.38	-1.18	-0.50	-0.23	-0.35	-4.59
1957	-0.22	0.73	0.42	0.15	0.63	-0.78	-1.04	0.30	-1.18	0.73	0.29	-0.38	-0.36
1958	0.48	0.56	3.15	0.65	-0.34	1.56	-0.43	2.49	4.87	0.10	-0.23	-0.28	12.57
1959	-0.22	-0.18	-0.48	0.63	0.63	1.12	-0.14	2.50	-0.91	0.27	-0.23	1.37	4.35
1960	0.23	-0.07	-0.38	-0.35	0.30	1.69	4.99	-2.25	-0.39	2.48	-0.23	1.38	7.39
1961	0.23	-0.23	1.01	0.01	-0.54	-0.06	-0.79	-1.68	-0.29	-0.32	1.47	-0.07	-1.27
1962	-0.22	-0.18	-0.36	-0.14	-0.65	0.51	2.24	-0.70	0.93	-0.26	-0.01	0.04	1.19
1963	-0.22	-0.16	-0.48	-0.10	-0.65	-0.95	-2.10	-0.37	-0.51	-0.02	-0.17	-0.38	-6.12
1964	-0.21	-0.33	-0.48	-0.25	-0.47	-0.30	-2.10	-1.59	-0.04	-0.78	-0.23	-0.12	-6.91
1965	-0.22	-0.13	-0.48	-0.35	1.18	0.98	-0.17	-2.17	-0.42	-0.46	-0.00	-0.19	-2.44
1966	-0.01	-0.27	-0.48	-0.05	-0.21	-0.92	-1.54	2.70	-1.16	-0.78	-0.15	-0.32	-3.20
1967	-0.22	-0.11	-0.34	-0.33	-0.56	-0.37	-0.53	-0.81	-0.69	-0.78	-0.13	0.10	-4.78
1968	1.08	0.92	0.36	-0.30	-0.10	-0.71	2.32	2.05	-0.96	-0.38	0.34	-0.18	4.43

DEPARTURES FROM THE MEAN. DUNLAP

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	-0.09	0.14	-0.34	0.05	0.73	-0.38	0.36	-0.95	-0.94	-0.53	0.27	-0.18	-1.88
1954	-0.20	-0.28	-0.38	0.13	1.40	0.24	-2.37	0.55	0.09	3.26	-0.20	-0.17	2.06
1955	-0.12	-0.27	-0.32	0.56	-0.73	-0.86	-1.61	-1.34	0.91	-0.05	-0.20	-0.28	-4.33
1956	-0.16	0.07	-0.39	-0.10	-0.20	-0.52	-1.69	-0.90	-0.94	-0.79	-0.17	-0.27	-6.08
1957	-0.27	0.25	0.64	0.22	2.05	-0.92	-1.66	-1.01	-0.82	0.92	0.20	-0.28	-0.70
1958	0.73	0.03	2.66	0.50	-0.14	-0.54	0.46	1.23	4.59	-0.18	-0.09	-0.08	9.15
1959	-0.27	-0.21	-0.39	0.34	0.05	2.69	1.62	-0.37	-0.94	-0.16	-0.17	1.35	3.53
1960	0.57	0.07	-0.17	-0.36	-0.29	1.73	10.54	-0.66	-0.59	3.41	-0.17	0.89	14.97
1961	-0.27	-0.25	0.11	0.27	0.15	-0.52	-0.77	-0.50	0.69	-0.92	-0.20	-0.28	-2.51
1962	0.16	0.01	-0.22	-0.05	-0.85	0.97	-0.45	-1.57	1.00	-0.58	0.13	-0.28	-1.75
1963	-0.27	-0.28	-0.39	-0.05	-0.59	-0.25	-2.23	1.68	-0.84	-0.44	-0.09	0.00	-3.77
1964	-0.27	0.07	-0.26	-0.36	-0.89	-0.96	-1.01	-0.45	0.10	-0.92	0.56	-0.28	-4.69
1965	-0.27	-0.08	-0.39	-0.36	0.94	1.07	-0.49	-1.52	-0.18	-0.60	0.03	-0.09	-1.95
1966	-0.06	-0.22	-0.39	-0.06	-0.45	-0.82	-1.86	3.35	-0.92	-0.92	-0.12	-0.22	-2.71
1967	-0.27	-0.06	-0.25	-0.34	-0.80	-0.27	-0.85	-0.16	-0.45	-0.92	-0.10	0.20	-4.29
1968	1.03	0.97	0.45	-0.31	-0.34	-0.61	2.00	2.70	-0.72	-0.52	0.37	-0.08	4.92

Table 5.2 Linear regression and correlation analysis of composite rain data for Roswell basin (16 years).

VARIABLES				LINEAR REGRESSION AND CORRELATION	
Dependent y=(inch rain)	mean rain (inches)	Independent x=(inch rain)	mean rain (inches)	Regression equation	R^2
Dunlap (4050') Farnsworth Ranch (5400')	9.85 ± 5.37	Roswell (3612') Artesia (3375')	9.34 ± 3.30	(1.298 ± .261)x - 2.268	.800
same	same	Roswell Artesia (3 yrs. effective average(1))	9.30 ± 1.86	(1.993 ± .558)x - 8.685	.690
same	same	Felix (5300') Elk (5700')	13.59 ± 4.25	(.588 ± .300)x + 1.855	.466
Felix Elk	13.59 ± 4.25	Roswell Artesia	9.34 ± 3.30	(.898 ± .248)x + 5.172	.695

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(1) values from Saleem and Jacob (1971).

(or regression) correlation coefficient is a measure of the reliability with which the dependent variable may be predicted from the knowledge of an independent variable. With the linear regression equation, the precipitation trend at a given station could be completed for years without record by knowing the precipitation history at a neighboring station. The constraint is that the regression must be linear over a certain range of values. The linear regression equations are presented in the form of $y = (A \pm a)x + B$, where A is the slope, $\pm a$ is the standard deviation of the slope, and B is the y-intercept. By interchanging the dependent and independent variables the regression expression will be modified but the regression correlation coefficient remains the same. In a case where the correlation coefficient is low (≤ 0.7000) the best fitted line through a scatter of data should be of a higher order regression.

From Table 5.2 it is clear that the best correlation in annual precipitation patterns (but not in precipitation magnitude) is between the recording stations Roswell-Artesia and Dunlap-Farnsworth Ranch. The physical explanation of their correlation is explained by the geographic location of these stations. Dunlap and Farnsworth Ranch are located north and northwest from Roswell and Artesia, respectively. The plains separating the two groups of stations gradually rise toward the northwest. By inspecting precipitation areas and amounts given by the Daily Weather Maps (U. S. Department of Commerce, 1958, 1959, and 1960) it is clear that precipitation increases over the basin from southeast to northwest especially during the summer and early fall (May-October).

There are differences between the location of Felix and Elk and the other four stations with respect to the trajectory of the incoming moisture. Elk and Felix are located on a relatively steep slope east of the Sacramento Mountains and just north of the Guadalupe Mountains outside the recharge area of the northern part of the Roswell aquifer system. The difference in precipitation amounts and trend is best seen from Table 5.1. Precipitation at Elk and Felix was fairly steady with small variations from one year to the next. Only 6 years had precipitation below average as compared to 11 years at Dunlap and Farnsworth. The overall mean annual precipitation at Elk and Felix during the study period was about 4 inches higher than at any other combination of stations.

The conclusion from the foregoing analysis is twofold:

(a) From the linear regression relation and the long record of precipitation at Roswell and Artesia, it is possible to calculate the annual precipitation amounts for Dunlap and Farnsworth Ranch where it is missing.

(b) The relatively steady precipitation pattern, observed at Elk and Felix, should be excluded from the construction of the tritium input profile for the northern part of the basin.

It should be noted that the second conclusion has a strong bearing on the discussion concerning the short-record observations of tritium in deep wells during 1959 and 1961 which was presented in Chapter 4. Elk and Felix are located just west of Artesia in the drainage area of the Rio Felix. From Figures 4.1 and 4.2, wells located between Elk, Felix, and Artesia had lower concentrations of tritium as compared with wells north of T. 16 S. (with the exception of a few wells on the recharge boundary). Two alternative conclusions arise from these observations and the general knowledge of tritium content in precipitation during the preceding years. Either the precipitation in the southern region is of a different source (purely oceanic with little tritium) or the San Andres Limestone between Elk and Felix to the west and Artesia to the east is of different hydrologic properties as compared with the aquifer north of T. 16 S. The latter observation is supported by previous hydrologic (Motts and Cushman, 1964) and geologic (Kelley, 1971) reports. Conversely, if the central (Artesia) sector of the San Andres aquifer had the same permeability as the northern part, tritium concentrations in well water should have been much higher than in the northern sector, due to a steadier input, provided that the input in both regions was from the same tritium source.

Precipitation during 1958 - 1960 in the Roswell basin greatly exceeded the mean annual values for the period 1953 - 1968. This was certainly true in the northwest region where Dunlap and Farnsworth Ranch are located. From the data presented in Tables 5.1 and 5.2, the average percent change in precipitation for the period 1958 - 1960 (wet years) and 1962 - 1965 (dry years) was as follows:

	Dunlap and Farnsworth	Roswell and Artesia	Felix and Elk
1958:	+110	+78	+54
1959:	+40	-17	-28
1960:	+114	+40	+7
1962:	-3	+22	+14
1963:	-50	-36	+3
1964:	-59	-36	-47
1965:	-22	-24	+15

Thus, for both wet year and dry year sequences, the correlation of precipitation patterns over the Roswell basin is better with Dunlap/Farnsworth than with Felix/Elk. Moreover, during the wet sequence, precipitation at Dunlap/Farnsworth was consistently above the mean; during the dry sequence it was consistently below the mean while Felix/Elk did not show a clear trend.

Data on precipitation distribution patterns were taken from the Daily Weather Maps (U.S. Department of Commerce, 1958, 1959, 1960, 1963, and 1964) and include the basin as a whole. During 1958, 1959, 1960, 1963, and 1964, there were 111, 66, 97, 51, and 52 days with measureable precipitation, respectively. 1958 and 1960 were very wet years, 1959 was moderately wet, and 1963 - 1964 were very dry. In the wet years (1958 - 1960) precipitation was appreciable not only in summer but also during fall and spring. Precipitation during 25 days out of 51 reported in the dry years 1963 and 1964 for Dunlap, Farnsworth and Roswell, was less than 0.10" (usually between 0.01 and 0.05"). These patterns profoundly affect recharge and therefore the tritium input function (Sec. 5.1.4).

The smoothing routine of 3-year effective precipitation (Fig. 5.1), used by Hantush (1957) and Jacob and Saleem (1971), tends to overestimate recharge during dry periods and to underestimate it during wet periods. The method was originally developed by C. E. Jacob (1944) and was tested in an area where fluctuations in annual precipitation did not exceed ± 5%. For a semi-arid region such as the Roswell basin with annual variations in precipitation up to 100%, it seems that the persistence of wet or dry years is of larger consequence in the estimation and forecast of recharge to the aquifer.

5.1.2 Regional Distribution of Tritium Concentration in Precipitation.

As previously stated, an uncertainty is introduced by applying data measured at Socorro to the study area near Roswell. The procedure is unavoidable since no data are available of tritium distribution in precipitation near Roswell. In addition, because tritium measurements at Socorro did not begin until October 1956, with a few additional values missing after that data, data from another source had to be used. Since Ottawa, Canada has the longest and most complete record of tritium content of precipitation, it is customary with many investigators to apply the Ottawa record to their studies (e. g., Dincer and Payne, 1967). The justification is not always clear. The following analysis is concerned with the synoptic distribution of tritium and the local climatological considerations which influence the use of data taken at one location and applied to another.

Variations in tritium concentration are known to occur with respect to distance from oceanic source, elevation, and latitude (Israel et al., 1963). The difference in tritium content at two locations, receiving moisture from the same source is possibly a function of the difference in the length of time it takes the moisture to arrive at the two locations. For New Mexico there seem to be two principal sources for moisture, the Gulf of Mexico and the Pacific Ocean. Summer precipitation comes mostly from the Gulf of Mexico, that is, from the Atlantic. Moisture of Pacific origin usually arrives during the winter when precipitation is at its minimum. Tritium content of moisture will be modified depending on how much additional moisture was added during its movement. Tritium concentration measured in a rain sample represents a vertical integration of tritium distribution. During a thundershower, additional moisture may also be added at the top of the storm cell which could increase or decrease its tritium content. This is especially true over high mountains where the top of a convective cell may reach up to 35,000 feet and more.

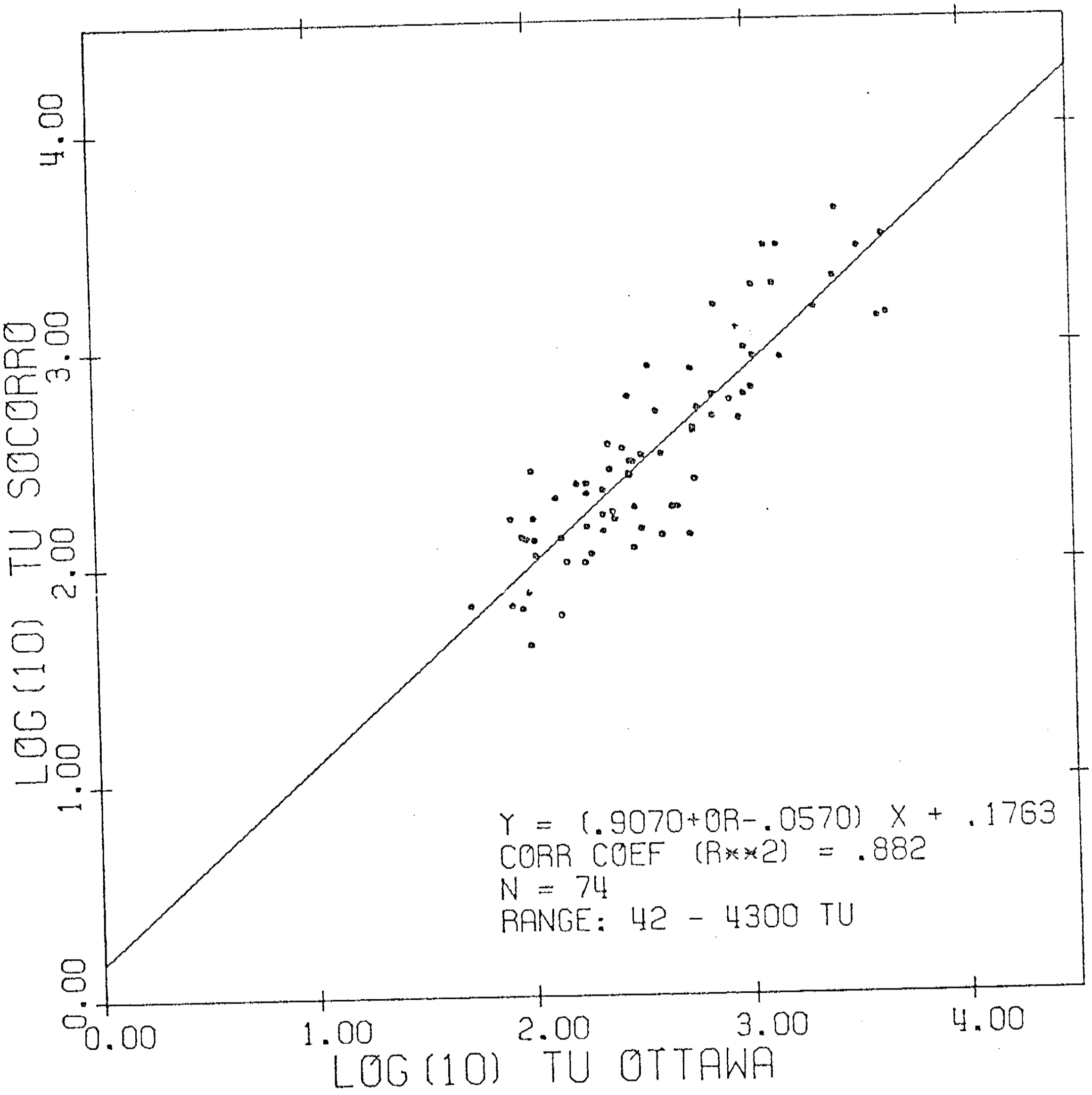
Few attempts have been made to generalize tritium content of precipitation, measured at different stations, into a synoptic distribution over the continent. Two such reports by Stewart and Farnsworth (1968) and Suess (1969) were limited to the period of high tritium activities of 1963 - 1965. Stewart and Farnsworth's report dealt with the distribution over the continental U.S. and was based on data collected at 12 stations including Albuquerque, N.M., and Denver, Colo. Their data of geographical distribution of weighted average tritium concentrations (ΣT.U. x amount precipitation / Σ amount precipitation) was presented as equal $\overline{\text{T. U.}}$ lines. Their results do not include Canada. However, from the general trend of the distribution, a correlation between Socorro and Ottawa is eminent. The lines of equal $\overline{\text{T. U.}}$ are more or less concentric with respect to a region located near the continental divide on the U.S.-Canadian border. The line of lowest concentration roughly follows the continental outline along the east and west coasts and the Gulf. Stewart and Farnsworth (1968) did not find any continental pattern to tritium fallout (T.U. x amount precipitation) partly because some of the regions with the lowest tritium concentrations have an extremely high rainfall (e.g., Boston, Mass., and Portland, Oregon).

Linear regression and correlation analysis was carried out between monthly mean values of tritium concentrations of precipitation at Socorro and Ottawa, Canada. The Ottawa data were published by the International Atomic Energy Agency, Vienna (IAEA, 1969, 1970, and 1971). The entire set of tritium concentrations of precipitation for Ottawa and Socorro is presented in Figure 1.1. There are a total of 81 mean monthly values which could be used for a linear regression analysis. The results are presented in Table 5.3. It was found that although the regression correlation coefficient is fairly good (.783) the scatter in data, due to the large range in absolute values (42 to 8700 T. U.) causes a large error in the slope of the regression equation. The logarithmic correlation coefficient is 0.930 in the range 42-4,300 T. U., that is, 87 percent of the variations in tritium concentrations of Socorro precipitation could be predicted from the observations at Ottawa. Seven data points that showed variations up to 100% between the two stations were deleted and the regression was repeated (Table 5.3 and Fig. 5.2). The regression is such that for the range of values between 100 and 1000 T. U. the Ottawa data can be used without any corrections. To recapitulate, as early as 1954, Begemann and Martell (1955) and Begemann and Libby (1957) reported the following tritium activities measured in New Mexico:

25 June, 1954	Los Alamos rain	1160 ± 100 T. U.
25 June, 1954	Los Alamos rain	1000 ± 100 T. U.
26 June, 1954	Los Alamos rain	1550 ± 120 T. U.
23 July, 1954	Mount Withington thunderstorm	100 ± 5 T. U.
27 July, 1954	Mount Withington thunderstorm	106 ± 10 T. U.
September, 1954	Mount Withington monthly sample	19 ± 1.4 T. U.

Figure 5.2

Logarithmic linear regression of tritium concentration in precipitation between Socorro, N.M., and Ottawa, Canada.



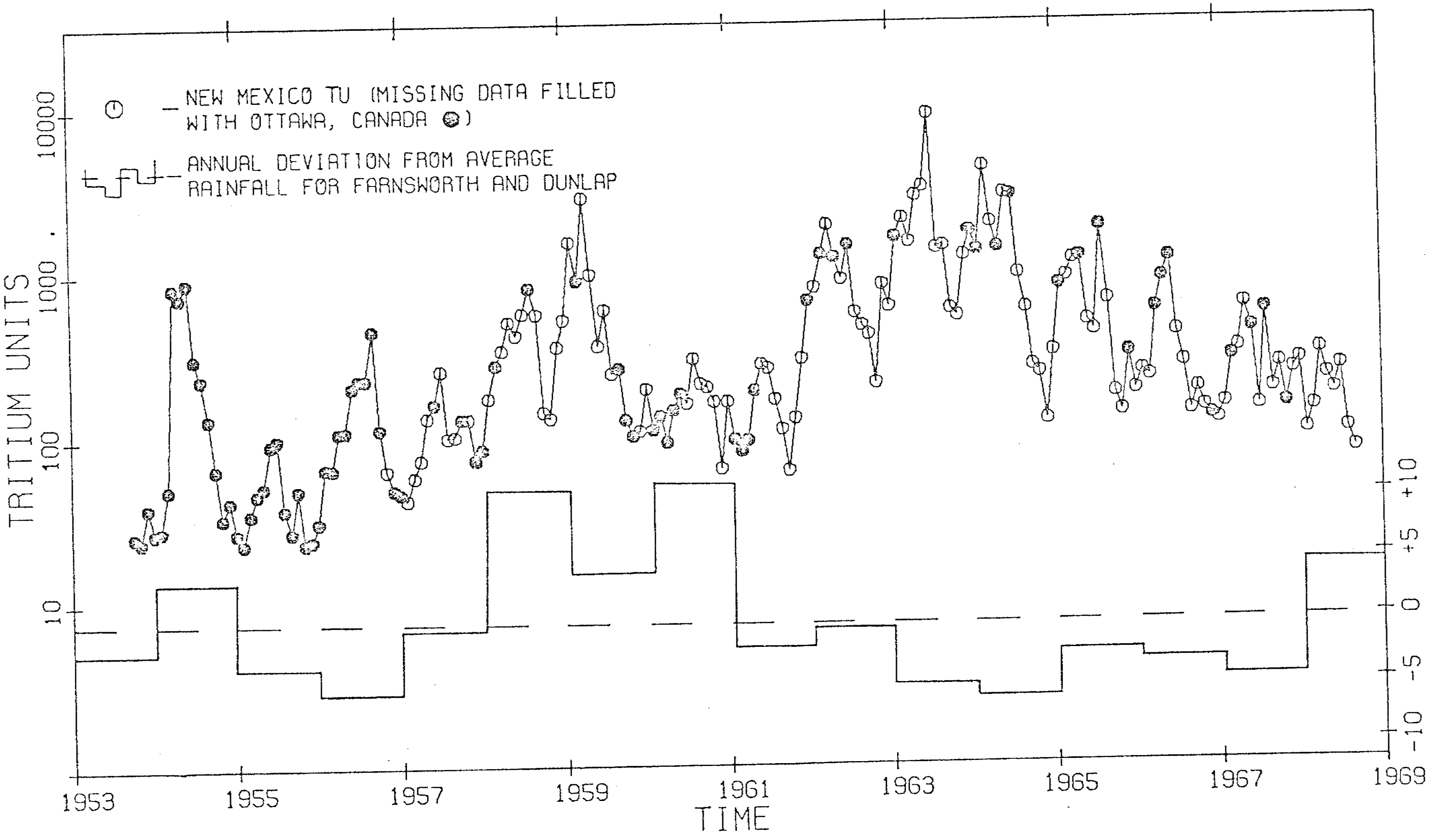
LØG(10) TU SØCØRRØ
LØG(10) TU ØTTAWA
0.00
1.00
2.00
3.00
4.00
Y = (.9070+0R-.0570) X + .1763
CØRR CØEF (R**2) = .882
N = 74
RANGE: 42 - 4300 TU

Table 5.3 Linear regression and correlation analysis of tritium concentration in precipitation.

VARIABLES			LINEAR REGRESSION AND CORRELATION		
Dependent ($y = \log$ T. U.)	Independent ($x = \log$ T. U.)	Number of monthly averages	Regression equation	R^2	R^2 for numerical values
Socorro, N. M.	Ottawa, Canada	74	$(.9070 \pm .0570)x + .1763$	.882	.759
Ottawa, Canada	Socorro, N. M.	81	$(.8820 \pm .0556)x + .3948$	.873	.783
Waco, Texas	Socorro, N. M.	46	$(.7491 \pm .0747)x + .3665$	.834	.700
Flagstaff, Arizona	Socorro, N. M.	35	$(.6728 \pm .1022)x + 1.0334$	.753	.668

Figure 5.3

Tritium concentration of precipitation (1953 - 1968) based on data measured at Socorro, N. M., and Ottawa, Canada.


NEW MEXICO TU (MISSING DATA FILLED WITH OTTAWA, CANADA ●)
ANNUAL DEVIATION FROM AVERAGE RAINFALL FOR FARNSWORTH AND DUNLAP
TRITIUM UNITS
10000
1000
100
10
TIME
1953
1955
1957
1959
1961
1963
1965
1967
1969
INCHES OF RAIN
+10
+5
0
-5
-10

The variations of tritium concentrations in Ottawa rains for this period were from 900 to 27 T. U., in the same sequence.

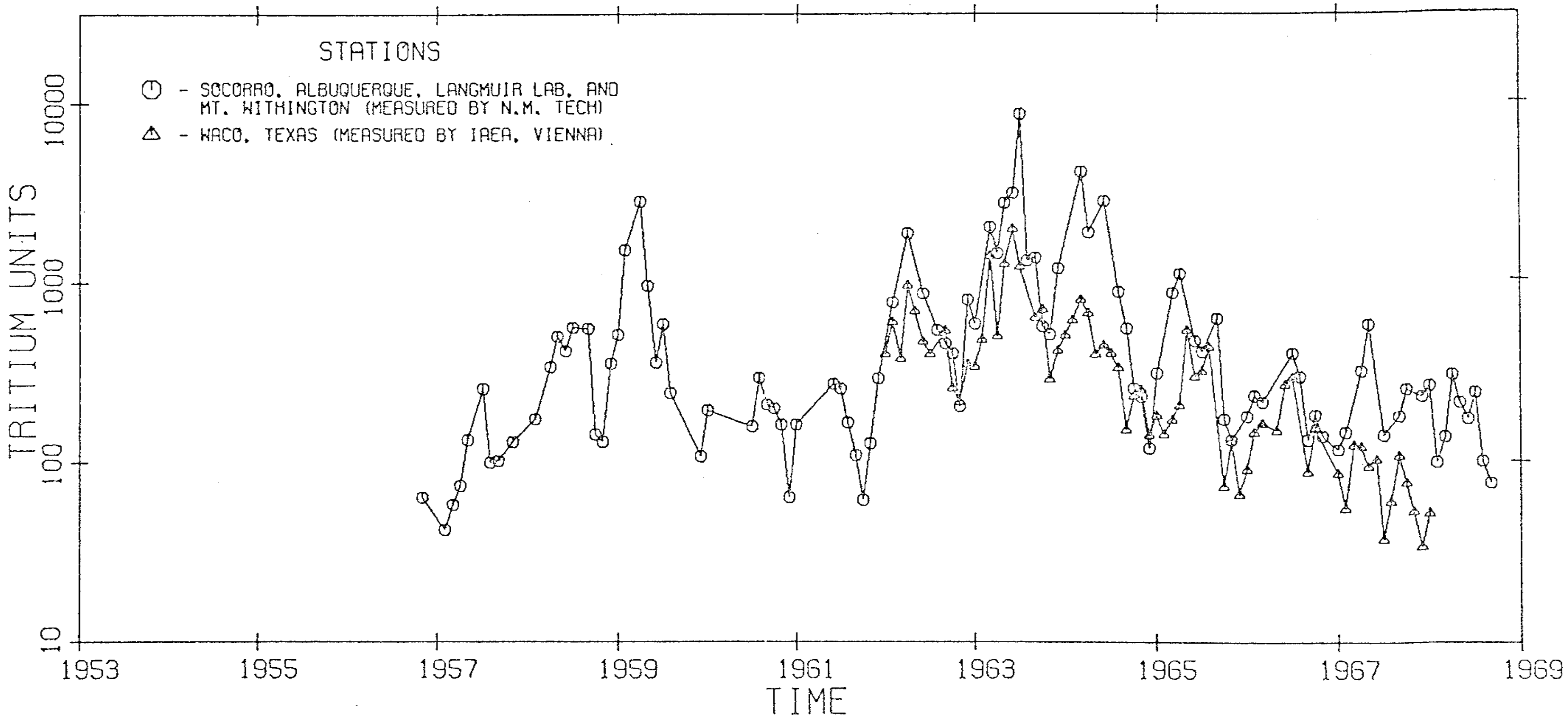
The complete reconstructed set of average monthly tritium variations in precipitation for Socorro from 1953 to 1969 is presented in Figure 5.3. These values, together with the monthly amounts of precipitation at Dunlap and Farnsworth Ranch, are the basis of the tritium fallout profile for the Roswell artesian basin. On the same plot is a histogram representing the deviation from the annual mean precipitation at the composite station of Dunlap and Farnsworth Ranch.

Two additional correlations were done between Socorro and neighboring stations: Flagstaff, Arizona (360 miles to the west) and Waco, Texas (750 miles to the east). These stations are part of a world network for which the tritium analysis is done and reported by IAEA (IAEA, 1969, 1970, and 1971). The results are also presented in Table 5.3. Waco is of special interest since its location is 600 miles east of Roswell and is included in the region for which summer precipitation draws its moisture from the Gulf. The regression equation indicates consistently higher values of tritium in New Mexico (Table 5.3 and Fig. 5.4). Tritium concentration of moisture tends to increase with the distance from its oceanic source.

In conclusion, the construction of the tritium input profile for the Roswell basin has two limiting conditions on the tritium content of

Figure 5.4

A comparison of tritium concentration in precipitation between Socorro, N. M., and Waco, Texas.


STATIONS
○ - SOCORRO, ALBUQUERQUE, LANGMUIR LAB. AND MT. WITHINGTON (MEASURED BY N.M. TECH)
△ - WACO, TEXAS (MEASURED BY IAEA, VIENNA)
TRITIUM UNITS
10000
1000
100
10
1953
1955
1957
1959
1961
1963
1965
1967
1969
TIME

precipitation. The concentrations observed at Socorro are the same or they represent an upper limit, and the concentrations at Waco, a lower limit. The earlier data for Waco (1957 - 1962) could be calculated by the regression equation.

5.1.3 Tritium Fallout Profile. In the preceding sections some preliminary conclusions were drawn based on precipitation data and the observed tritium concentrations of precipitation and ground water. The construction of a fallout profile for a selected combination of precipitation-measuring stations should very clearly indicate the availability and the amount of tritium rainout in the basin. The fallout profile is the product of the corrected monthly precipitation (from Table 5.1) with its corresponding monthly average of tritium concentration (Fig. 5.3). Although in some instances the profile may show trends parallel to the variations in precipitation, in general, the two curves are different, largely because precipitation does not necessarily have high tritium concentration and, conversely, high tritium concentrations may not be coupled to large precipitation amounts.

Table 5.4 is the annual tritium fallout (1953 - 1968) for four combinations of precipitation-measuring stations. The values are given in T. U. -in. which are the annual summation of the product T. U. -in. for each month. 1000 T. U. -in. equals 0.21 Ci/mi^2 (App. A). Corrections for evapotranspiration were not made at this stage. The vegetation on the

Table 5.4 Annual tritium fallout (T. U. -in.) for the different composite stations in the Roswell basin, T. U. values measured in Socorro.

YEAR	Dunlap and Farnsworth Ranch (1)	Dunlap, Farnsworth Ranch, Picacho, and Roswell (1)	Roswell and Artesia(1)	Roswell and Artesia	Felix and Elk (1)
1953	139(2)	140	130	153	119
1954	2993	3122	2280	2519	2291
1955	251	339	326	370	657
1956	901	916	1155	1288	1529
1957	981	1033	750	844	1691
1958	7525	6037	5170	5621	7394
1959	4645	3822	2204	2634	2698
1960	4554	3506	2367	2463	2816
1961	1180	1317	1221	1437	1948
1962	5975	5964	6340	7370	9129
1963	7772	10006	15248	17522	31411
1964	3006	6443	9072	10689	7093
1965	5179	6046	4936	5564	8965
1966	1377	2565	3399	3778	5712
1967	1379	1739	1949	2193	2973
1968	1411	1547	1653	1785	1685

---

(1) 0.1" interception loss subtracted from each monthly value.

(2) 1 T. U. -in. = 0.21 $\mathrm{mCi/mi^2}$.

outcrop of the San Andres limestone west and northwest of Roswell consists mostly of small scattered shrubs and natural grass. An amount equal to 0.1 inch (2.5 mm) was subtracted from each monthly precipitation to account for interception loss (Butler, 1959, p. 230, and Ward, 1957, p. 68). The value is very conservative especially considering that most rainfall takes place during the summer months. The fallout for the Roswell-Artesia composite station is presented with and without the 0.1 in. correction. The difference in fallout is up to 2250 T. U.-in. during 1963 and diminishes during the years of low tritium content of precipitation. (A fallout of 2250 T. U.-in. over 100 mi^2 is the equivalent of 47.3 Ci of tritium.) The effects of this correction are most pronounced during periods of low rainfall with large tritium concentrations. This was the case at Dunlap and Farnsworth Ranch during 1963 and 1964. In a year when precipitation is abundant with average tritium concentrations, this correction does not change the fallout value appreciably.

The annual weighted average tritium concentration in precipitation is defined as

$$\overline{\text{T. U.}} = \frac{\overset{12}{\Sigma}\ \text{T. U.-in./month}}{\overset{12}{\Sigma}\ \text{in./month}} \qquad (5\text{-}1)$$

These values for 1953 - 1968 were derived from data presented in tables 5.1 and 5.4. The weighted annual averages of T. U. calculated for Dunlap and Farnsworth Ranch are compared with the values for Albuquerque published by Stewart and Farnsworth (1968), and the values for Waco, Texas published by IAEA (1969, and 1970):

	Albuquerque, N. M.	Dunlap and Farnsworth Ranch	Waco, Texas
1963:	1870	1800	1129
1964:	1620	1000	377
1965:	469	700	205
1963-1965:	1220	960	465

With one exception (Dunlap/Farnsworth, 1965), the annual average tritium content of precipitation indicates the existence of a continental gradient of tritium concentration with respect to the Gulf of Mexico. The comparison is based on only three average values from three locations. It suggests that tritium measurements at Socorro may be applied to the Roswell basin without additional adjustment because the correction would be small compared to the uncertainty involved in using Dunlap and Farnsworth records as precipitation representative of the whole recharge area.

Table 5.4 exhibits the differences in fallout between Dunlap/Farnsworth and the various other combinations.

There is a marked difference between Dunlap/Farnsworth and Felix/Elk when comparing two periods: 1958-1960 and 1963-1966. For Dunlap/Farnsworth 1958-1960 was a period of excessive precipitation (the three years total 26 inches above the mean). During the dry period of 1963-1966 the accumulated deviation from the mean for Dunlap/Farnsworth was -16 inches (all 4 years below the mean). Felix/Elk had relatively small deviations during 1963 - 1966. The average annual rainfall for 1963 - 1966 at Felix/Elk was 13.3 inches as compared with 6 inches at Dunlap/Farnsworth. The difference is very clearly indicated by the total fallouts calculated for Felix/Elk during 1963 - 1966. They are at least twice as high as at Dunlap/Farnsworth. The only compatible years between the two locations (in terms of total fallout and its distribution over the measured period) were 1954 and 1958.

The tritium fallout profile for Dunlap/Farnsworth is given in Figure 5.5. The 1954, 1958, 1959, and 1960 peaks are the combination of above-average rainfall and moderate to high tritium concentrations in precipitation. On the other hand, the 1962, 1963, 1964, and 1965 peaks are the result of continuously high levels of tritium in precipitation and very low rainfall. The consistency of tritium fallout during 1954 and 1958 - 1960 is best shown by grouping the fallout as follows (values are in T. U. -in.):

	January-April	May-September	October-December
1954:	254	2628	111
1958:	1774	5631	121
1959:	741	3512	392
1960:	93	3642	819

Figure 5.5

Tritium fallout-time profile for

Dunlap-Farnsworth Ranch.

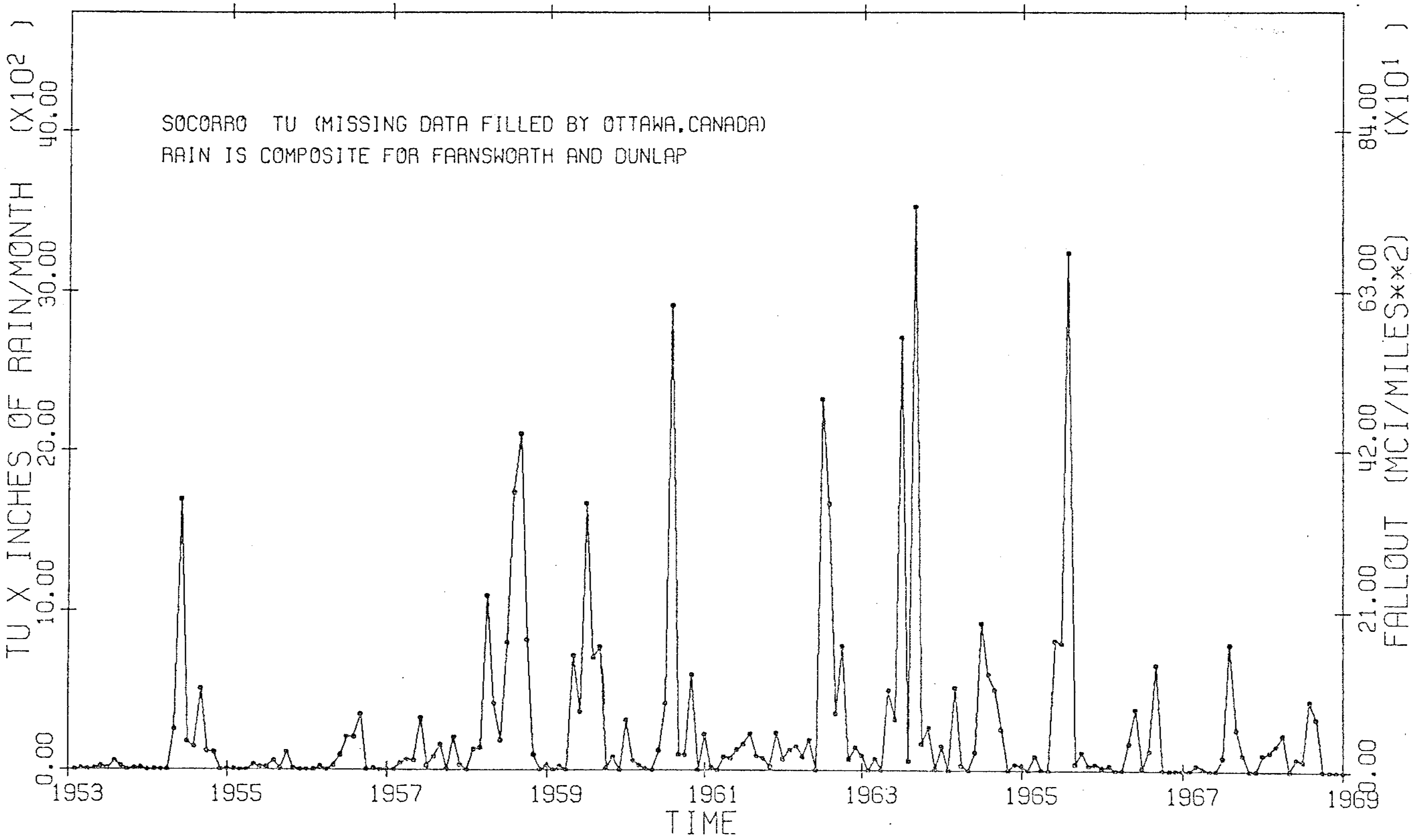

SOCORRO TU (MISSING DATA FILLED BY OTTAWA, CANADA)
RAIN IS COMPOSITE FOR FARNSWORTH AND DUNLAP
TU X INCHES OF RAIN/MONTH (X10²)
0.00
10.00
20.00
30.00
40.00
FALLOUT (MCI/MILES**2) (X10¹)
0.00
21.00
42.00
63.00
84.00
1953
1955
1957
1959
1961
1963
1965
1967
1969
TIME

Figure 5.6

Tritium fallout-time profile for

Farnsworth Ranch, Dunlap, Picacho, and Roswell.

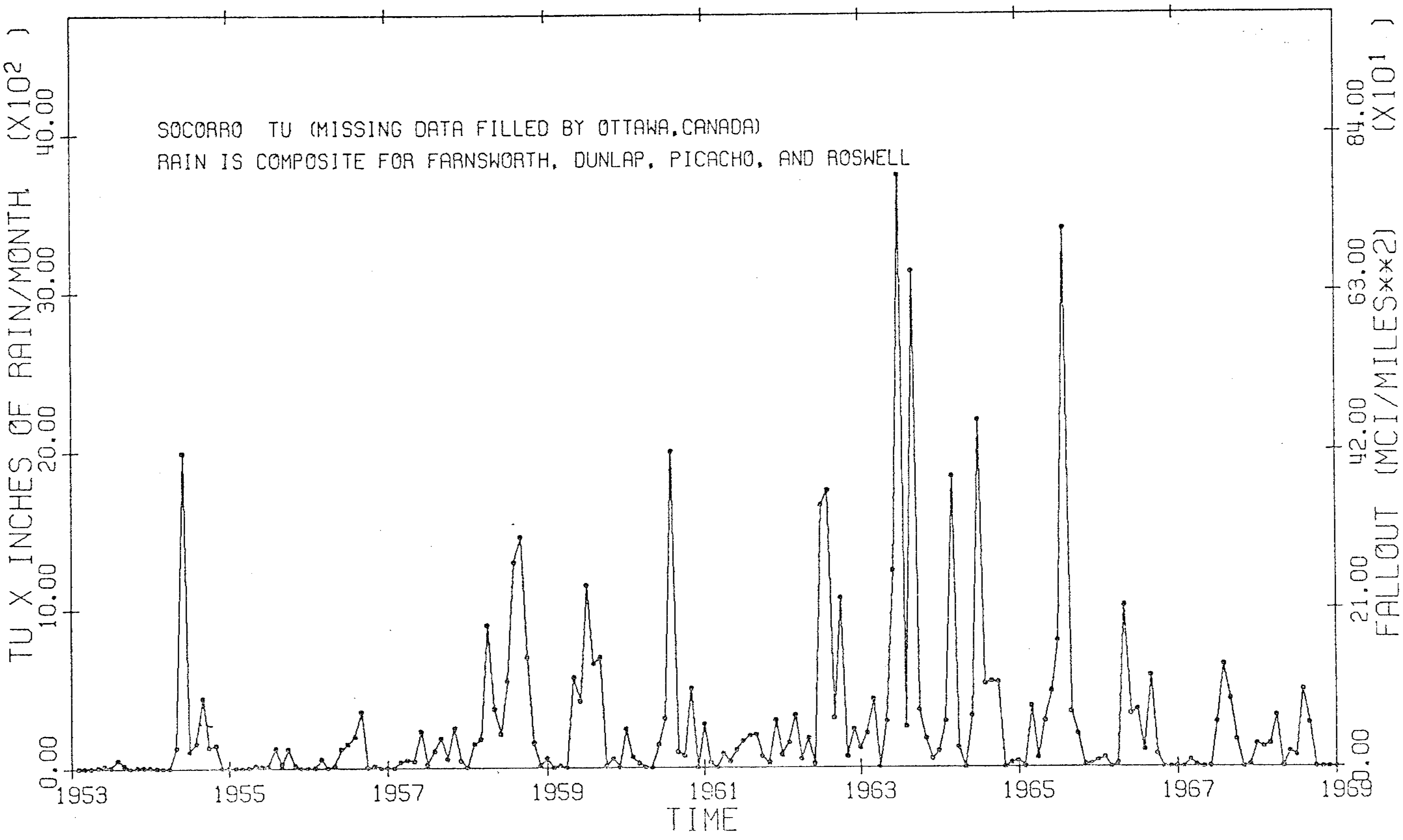

SOCORRO TU (MISSING DATA FILLED BY OTTAWA, CANADA)
RAIN IS COMPOSITE FOR FARNSWORTH, DUNLAP, PICACHO, AND ROSWELL
TU X INCHES OF RAIN/MONTH (X10²)
0.00
10.00
20.00
30.00
40.00
FALLOUT (MCI/MILES**2) (X10¹)
0.00
21.00
42.00
63.00
84.00
1953
1955
1957
1959
1961
1963
1965
1967
1969
TIME

Figure 5.6 is the fallout profile for a combination of the four northern stations of the Roswell artesian basin, namely: Dunlap, Farnsworth, Picacho, and Roswell. Some decrease in 1958 - 1960 peaks and increase in the 1963 - 1966 peaks is apparent with respect to Dunlap/Farnsworth (Fig. 5.5). It is mainly the inclusion of Picacho in this profile which causes the difference which is minor and would not appreciably affect the results obtained in this study.

5.1.4 Tritium Input Function. The empirical tritium input function is constructed from the fallout profile (Fig. 5.5) and a functional relationship relating amount of precipitation to its effective recharge. The validity of the precipitation/recharge relationship will be tested in Section 5.4 with the presentation of the dispersive model for the Roswell artesian basin. The tritium input function capability to predict the observed variations of tritium concentrations in ground water should test a quantitative estimate of recharge. This function should also have some value in estimating recharge in areas other than the Roswell basin with similar climatic and hydrologic conditions.

The functional relationship that was assumed for calculating the amount of recharge is

$$R = f\,Pi \qquad (5\text{-}2)$$

where,

$$f = k\frac{Pi}{\overline{P}} \qquad (5\text{-}3)$$

and,

R - annual recharge (inches)

Pi - annual precipitation of the i^{th} year (inches)

f - proportionality factor (fraction of annual precipitation that is recharge)

$\overline{p}$ - mean annual precipitation

The proportionality factor is the product of a sliding factor depending on the fractional mean precipitation, Pi / $\overline{p}$, and a normalizing index, k. The normalizing index is a constant for a given recharge area and is determined by the type of terrain and its general slope. For the Roswell artesian basin its numerical value was found to be 0.1.

Using precipitation data (Table 5.1) for Dunlap and Farnsworth Ranch and Eqs. (5-3) and (5-2), the recharge/precipitation relationship is established (Table 5.5, Fig. 5.7). The curve has two limiting values. With a decrease in precipitation, the lower limit of recharge rapidly approaches zero (< 4" precipitation); the upper limit is given by a precipitation probability of less than 1% for 21 in. /year or more. The curve is quadratic and the rate of net increase of recharge with precipitation has different values in different segments of the curve (e.g. for precipitation ranges of 4"-10", 10"-16", and 14"-20", the increase is 1", 1.5", and 2" respectively). In regions where the precise conditions of evaporation-interception are known, the proportionality factor should be further

Table 5.5 Precipitation and recharge for the Roswell artesian basin (1953-1968).

YEAR	TOTAL PRECIPITATION (in.)	$f = \frac{kPi}{\overline{p}}$ (1)	R = fPi (in.)
1953	7.7	.078	.602
1954	13.20	.134	1.769
1955	6.43	.065	.420
1956	4.52	.046	.207
1957	9.32	.095	.882
1958	20.71	.210	4.354
1959	13.79	.140	1.930
1960	21.03	.214	4.490
1961	7.96	.081	.643
1962	9.57	.097	.930
1963	4.91	.050	.245
1964	4.05	.041	.166
1965	7.66	.078	.596
1966	6.90	.070	.483
1967	5.32	.054	.287
1968	14.53	.148	2.143
Mean	9.85		

---

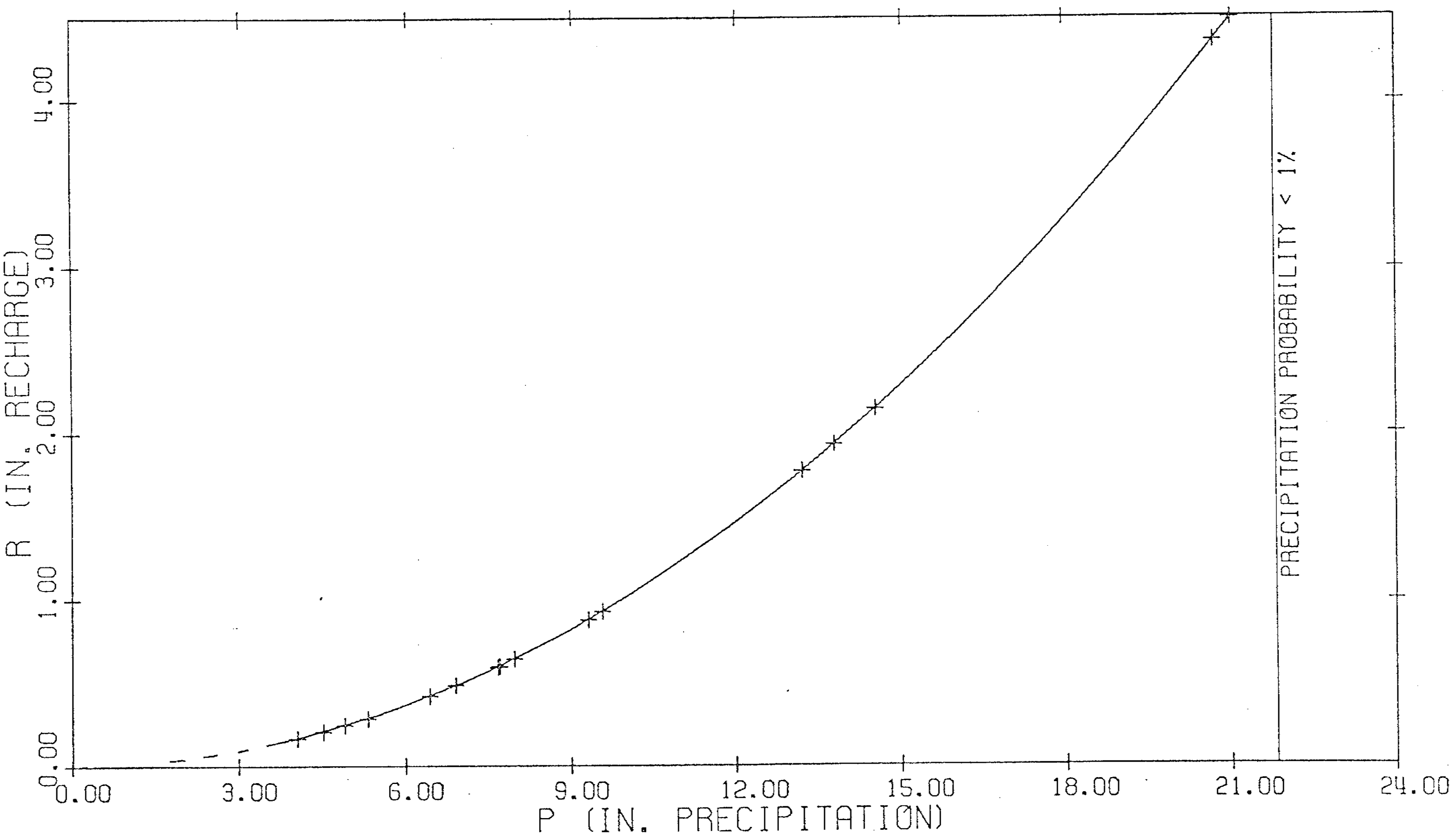
(1) k = 0.1

Figure 5.7

Precipitation/recharge relation

for the Roswell artesian basin

(1963-1968, k=0.1).


R (IN. RECHARGE)
0.00
1.00
2.00
3.00
4.00
P (IN. PRECIPITATION)
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
PRECIPITATION PROBABILITY < 1%

refined to read

$$f = k \frac{Pi - C}{\overline{P}} \tag{5-4}$$

where C is the limiting precipitation value below which no measureable recharge takes place. This correction is necessary in semi-arid regions where potential evapotranspiration usually exceeds the total amount of rainfall. A further correction could be made for surface runoff; it does not appear warranted in this case.

The empirical tritium input function is obtained by multiplying the surface fallout of each month by the appropriate annual proportionality factor, f. The resulting function is shown in Figure 5.8. The outstanding tritium peaks are the combination of either large amounts of rainfall with moderate tritium content (1960), small amounts of rainfall with high levels of tritium (1963) or high tritium and high precipitation (1958, 1959). There were seven periods in all of appreciable tritium injections into the aquifer. The most continuous injection between March of 1958 and October 1960 can be correlated with the observed tritium peaks in ground water (Figs. 4.7 - 4.11). The gap created by the first testing moratorium is most clearly seen during 1961 (or 1963/1964 in the ground water profiles).

The monthly inputs are given in Table 5.6. The individual input values will be lumped together by season and will be used as the input mass of tritium to the one-dimensional time-dependent dispersion equation.

Figure 5.8

Empirical tritium input function for the northern part of the Roswell basin (vertical scale expanded).

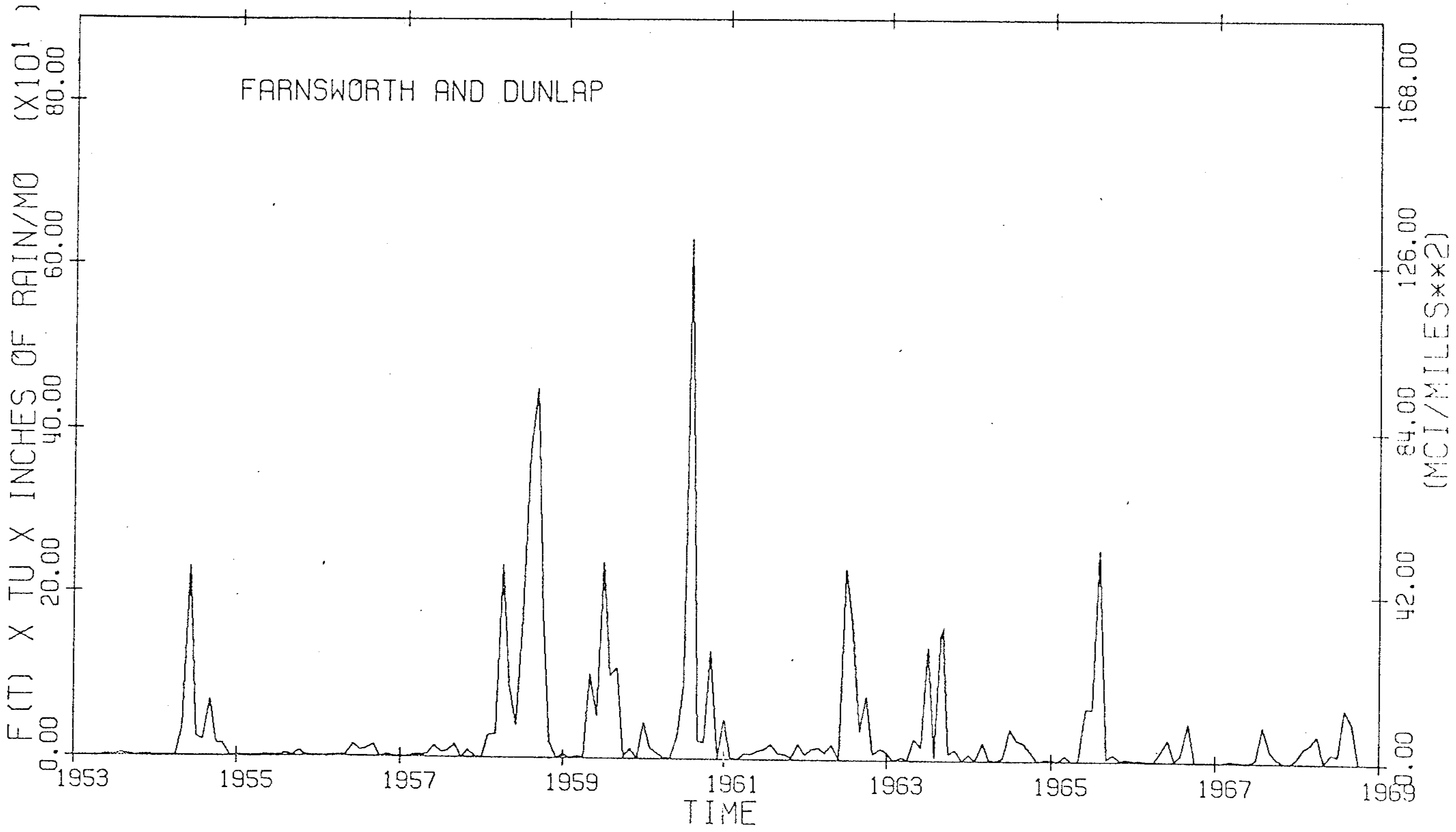

FARNSWORTH AND DUNLAP
F(T) X TU X INCHES OF RAIN/MO (X10^1)
0.00
20.00
40.00
60.00
80.00
(MCI/MILES**2)
0.00
42.00
84.00
126.00
168.00
1953
1955
1957
1959
1961
1963
1965
1967
1969
TIME

Table 5.6 Monthly and annual tritium inputs (T. U. -in.) in the Roswell artesian basin.

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
1953	0	0	0	0	2	1	4	2	0	1	1	0
1954	0	0	0	34	230	23	19	69	15	15	0	1
1955	0	0	0	2	1	1	4	1	7	1	0	0
1956	0	1	0	1	4	10	10	16	0	0	0	0
1957	0	4	6	6	31	2	8	15	0	20	3	0
1958	28	29	234	89	39	170	372	450	174	20	0	5
1959	0	3	0	102	51	237	100	110	2	12	0	44
1960	13	6	1	0	27	90	632	21	20	130	0	48
1961	1	0	7	6	11	13	19	7	6	2	19	6
1962	13	15	8	19	0	230	165	35	77	7	14	9
1963	0	4	0	26	16	138	3	180	8	14	0	0
1964	0	22	1	0	5	39	25	21	11	0	2	1
1965	0	7	0	0	64	63	256	3	9	2	3	1
1966	2	0	0	12	27	1	9	47	0	0	0	0
1967	0	2	1	0	0	5	44	14	5	0	0	6
1968	18	24	34	0	12	9	66	49	0	0	0	0

In addition to certain other parameters, the model will test the validity ar uniformity of the normalization index, k. (Program listing, App. J).

Discussion. The preceding analysis demonstrates that for a given set of conditions such as the tritium-time profile of ground water, precipitation pattern over a basin, and some knowledge of tritium content fluctuations in precipitation, it is possible to single out an area in which precipitation is the most likely to contribute to the recharge of the aquifer in question. Thus, for the northern part of the Roswell basin, the area surrounding the Farnsworth and Dunlap precipitation stations was found to be the likeliest source of recharge. The applicability of tritium concentrations of precipitation measured at Socorro to the Roswell basin was also demonstrated.

An empirical expression relating precipitation and recharge to the deep aquifer was presented. It is not linear and it is dependent on the fractional mean annual rainfall. The range of annual recharge values assigned during the study period lies between .166 in. (4.05 in. annual precipitation) and 4.5 in. (21.03 in. annual precipitation). The majority of recharge values are between .3 and .9 in. annually. A year with mean rainfall contributes about 1 in. to recharge. These values, although deri from an empirical expression, agree with reported recharge estimations in the region. Hantush obtained an effective precipitation/recharge relationship based on dynamic equilibrium considerations which is a linear function of three-year effective rain as defined by Hantush (1957) with an intercept at 4.5 in. as the lower limiting value. Figure 5.7 presents practically the same lower limit. However, the recharge/effective precipitation relation derived by Hantush allows for the same fraction of precipitation to contribute to recharge regardless of the total amount of precipitation. Theis (1937) in his study of ground water recharge in the high plains (eastern New Mexico - west Texas) arrived at a value of 0.25 to 0.5 in. a year. The rainfall on the high plains was between 14 and 22 in. annually; in contrast with the Roswell basin, the tributary terrain is fine sand and silt. Fiedler and Nye (1933) estimated up to 25% recharge to the San Andres limestone aquifer. This value was considered too high by Bean (1949). In the period 1953 - 1968, the highest value obtained in this study was 21% of 21 in. precipitation in 1960.

5.2 Correlation of Precipitation with Ground Water

The first buildup of the tritium concentrations in wells along the Pecos River began during 1961 or 1962 and continued, in varying degree, for about three years. This increase was very pronounced and produced some strong tritium peaks. Since tritium concentrations in rain water before 1962 were only moderately high ($\leq$ 1000 T. U.), the observed increase of tritium content in ground water must have been the result of a series of wetter than average years.

In an analysis of this kind the natural starting point is to identify the appearance of the highest tritium peak observed in precipitation with a ground water peak at some fixed point in the basin. The most conspicuous peak, actually a series of three peaks, in precipitation occurred between 1962 - 1964. The most conspicuous ground water peaks were observed during the same period in 5 of the 7 major sampling wells. The well distribution over the basin, with respect to the geologic conditions of the various formations, is such that any direct recharge of precipitation over the basin or leakage through the well casing would have shown up. In fact, the orderly fashion in which the tritium peaks are seen to arrive at each observation point rule out this possibility. These 1962 - 1964 ground water peaks can therefore only be related to the 1958 - 1960 precipitation and tritium peaks (Fig. 5.3). This must be true because it was shown in Sec. 4.2.1 that increased tritium levels measured in well samples in 1959 were due to the first atmospheric tritium peak which was the result of the first atmospheric testing series (Castle) in 1954. Th sharp separation and proper correlation of these peaks is largely due to the fortunate circumstance that the atmospheric peaks of 1954 and 1958 - 1960 occurred in years that were wetter than normal in the recharge area of the Roswell basin, while the intervening years were drier than normal (See Fig. 5.3).

Given the above correlation, it follows that the ground water eaks of 1966/1967 were caused by the tritium peaks in precipitation hat occurred in 1962-1964. The size of those peaks is much smaller han the preceding ones because 1962-1964 were years of below-average recipitation in the recharge area (Fig. 5.3).

5.3 Hydrologic Parameters

Combining tritium observations in ground water with hydrologic and geologic data, quantitative determinations of velocity and porosity become possible. The numerical values should be treated as large-scale averages for the northern part of the Roswell basin (north of T. 16 S.). The numerical values of velocity and porosity are important to most hydrologic studies. It is very seldom that these values are obtainable on a large scale. In this study the velocity is needed for testing the applicability of the dispersive flow model for predicting variations in tritium concentrations of ground water in fractured rock.

The local inhomogeneity of the fractured limestone aquifer has been demonstrated time and again by well logs. Probably the best example was reported by Havenor (1968, App. A and B) of a complete core analysis from a well, 10.24.34.444. The core analysis which includes core recovery, permeability and porosity indicates the following:

(a) Core recovery from the top 250 feet of the San Andres Limestone (250 - 500 feet below the surface) was very poor due to highly cavernous rock.

(b) Porosity determinations for about 270 core sections (between 250 - 1100 feet) showed the majority of the values to fall between 1% and 8%.

(c) The higher values of porosity for the upper section were estimated in part from the poor recovery and rock fracturing.

(d) In the section between 500 and 1100 feet below the surface, porosity was consistently more uniform.

Effectively there seems to be a high permeability zone of about 200 feet in thickness.

According to Darcy's law, the velocity of a particle along a streamline at any point may be described by:

$$V = \left(\frac{K}{\theta}\right)\left(\frac{d\Phi}{ds}\right) \qquad (5\text{-}5)$$

where,

K - hydraulic conductivity of the medium (L/T)

θ - porosity of the medium

Φ - the piezometric head (L)

$\frac{d\Phi}{ds}$ - the hydraulic gradient along direction of flow.

group of peaks whose passage through these four wells was traced in its entirety by tritium measurements began to arrive between August 1961 and January 1962. This first group of peaks resulted from the 1958-1960 precipitation as was shown previously.

For a first approximation, the winter recharge of 1958, in order to have arrived at the wells in October 1961 from a distance of 15 to 20 miles, had to flow at a velocity between 62 and 83 feet/day. Although this approach ignores the changes in hydraulic gradient especially between the unconfined/confined parts of the aquifer, its validity can be tested with the tritium peaks that arrived later. From the tritium concentration/ time profiles for the four above wells and Elk, it can be seen that the following periods of injection are all spaced with the same time delay of about three and one half years. Although a more unique determination could have been carried out by having a number of wells located along a flow path, with the available data limits of determination could be considered. Arrival time of the first peak was clearly the result of 1958 recharge. Therefore any increase in distance between the recharge area and the location of the wells would require flow velocities in excess of 100 feet/day. In addition, any allowance larger than a few months for unsaturated flow (seepage from surface to aquifer) will also increase the flow velocity considerably. Because of the proximity of the recharge boundary to the heavily pumped section of the aquifer, changes in hydraulic gradients will influence the incoming water. Summer recharge primarily takes place during the irrigation season in the region. Pumpage causes steeper gradients at the recharge boundary. Therefore, summer recharge is faster than winter recharge. Furthermore, such variations in recharge velocity may introduce some irregularity in the spacing of successive tritium pulses.

There are a few observation wells for which the flow velocity and direction can be calculated from a tritium peak traveling through the aquifer.

(a) From the 1959 data it was determined that the observed highs at Wiggins (145. T. U. January 1959) and Pollard (42. T. U. March 1959) originated with the 1954 recharge. By contrast, Clardy showed only 8 T. U. in January 1959. The conclusion reached in Chapter 4 (Sec. 4. 2. 1) was that a tritium peak due to the June 1954 rainout (Table 5. 6) had swept through the region from west to east. Because of the higher transmissivity in the northern part of the basin where Clardy well is located, it appears that the low value at that well represents the wake of this tritium peak. Considering the approximate limits and approximate extension of the recharge area, the peak traveling at about 70 feet/day should have passed through Wiggins and Pollard early in 1959.

(b) From data presented in Appendix E, well NO 23 (Kerr Bros.), about 6 miles west of Wiggins, showed a tritium peak during 1962; March - 250. T. U.; April - 284. T. U.; and May - 192. T. U. With a flow velocity of 70 feet/day, this peak should have been observed at Wiggins 15 months later (or about July/September 1963). Indeed, a peak was observed at

Wiggins between May and August 1963 as follows: May - 160 T. U.; July - 263. T. U.; August - 110. T. U.

(c) The similarity between Clardy and Allison is very striking; especially for July-November 1961. A very sharp peak was observed in Clardy during September (201. T. U.) and in Allison during October (135. T. U.). Both dropped to about 3. T. U. in November. From potentiometric-surface contours (Saleem and Jacob, 1971) and the tritium peak, it seems that the flow in that region is from north northwest to south southeast. Therefore, at 70 feet/day the peak should have been observed in Allison a month after its appearance in Clardy. The data seem to bear this out. A similar relation was observed between August 1965 and March 1966. The tritium peak, much broader in this case, was slightly earlier in Clardy than in Allison.

Not all of the peaks can be correlated or explained with respect to the flow direction. The tritium peak observed in Patterson March 1962 could be the same peak observed in NO 13 May 1962. The time delay is in accordance with the distance and velocity but not with the location in relation to the recharge boundary. In spite of being located much closer to the recharge boundary, the tritium-time profile of Woods well is almost identical to that of wells along the Pecos River; this may be explained by the low transmissivity of the unconfined part of the aquifer. Woods is located on a hill 6 miles west of the limestone-alluvium boundary

(Fig. 4.5). The three highest tritium peaks (raw data) at Clardy, Wiggins and Pollard were 662. T.U. February 1962; 582. T.U. November 1962; and 486. T.U. July 1963, respectively. A movement from northwest to southeast through the three wells at a velocity of about 58 feet/day would account for this. The decrease in peak magnitude is also in the correct direction.

In these calculations, the velocity always has about the same magnitude. This is true even where more than one correlation could be made between peaks or flow directions in neighboring wells. The value is 70 ± 10 feet/day on the average in the northern part of the basin. This value will be checked further in the following sections. The average velocity obtained does not vary with time, as was indicated by the equal time delay of at least five peaks that were measured in the different wells.

5.3.2 Porosity. The porosity value can be calculated by using the average velocity in Equations (5-5) and (5-6), some known local transmissivities, and the measured hydraulic gradient. Transmissivities obtained by pumping tests varied from 16,000 to 2,500,000 gpd/ft and are presented as an idealized equal transmissivity map (Fig. 2.3). The hydraulic gradients are taken from the potentiometric-surface contour maps for the years 1954-1969 (Saleem and Jacob, 1971). The porosity calculations will be separated for three locations: the immediate vicinity of Roswell, Hagerman, and west of Roswell near Woods well. The calculated and adjusted values are summarized in Table 5.7, where K_v/θ is calculated by Eq. (5-5) using the average tritium velocity, K_T is calculated by Eq. (5-6) using average transmissivity values obtained from pumping tests.

By varying transmissivity or average flow velocity within the reported or calculated limits, the porosity of the San Andres limestone aquifer in the vicinity of Roswell is about 1%. Transmissivity values of the order of 250,000 ft^2/d computed from pumping tests are somewhat conservative. Some of these tests have indicated transmissivities as high as 400,000 ft^2/d (e.g. Clardy well). By decreasing the transmissivity to 200,500 ft^2/d, the porosity is still of the same order of magnitude when adjusting the velocity to 60 feet/d.

The area near Hagerman has a much higher hydraulic gradient (25 feet/mile) and transmissivities are of at least one order of magnitude lower than near Roswell. For an average transmissivity of 10,000 ft^2/d and velocity of 50 ft/d the porosity should be only 0.5%. However, from well log data and the rock type, porosity of less than 1% is not likely. Assuming that 1% is the lower limit of porosity in this area, a velocity of about 35 feet/day gives the best agreement with the measured transmissivity, hydraulic gradient, and well penetration. This is a relatively small adjustment of the regional velocity calculated for the basin as a whole from first arrivals of tritium peaks.

Table 5.7 Calculated and adjusted hydrologic parameters for three regions in the Roswell basin.

T ft^2/d	d_Φ/ds ft/mi	b ft	V ft/d	K_v/θ ft/d (1)	$K_T = T/b$ ft/d (2)	θ	REMARKS
Roswell (T. 10/11 S., R. 23/25 E.)							
267,400	2.5	200	70	147,840	1337	.01	high limit of T
267,400	2.0	200	60	158,400	1337	.01	
200,500	2.5	200	60	126,720	1003	.008	average T, lower V
Hagerman (T. 13/15 S., R. 25/26 E.)							
10,000 (3)	25	200	50	10,550	50	.005	
13,370	25	200	50	10,550	67	.005	
10,000	25	200	35	7,385	50	.01	
Woods well							
267,400 (4)	1.67	200	4 (5)	---	1337	.10 (4)	Water movement is
267,400 (4)	1.67	200	10 (5)	---	1337	.05 (4)	about 3 mi/3.5 yr.

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(1) this study
(2) from pumping tests
(3) Hantush (1957)
(4) estimated by Theis (1951).
(5) calculated from Theis' data only.

For the area of Woods well, tritium arrival was observed almost at the same time as in the wells near the Pecos River. Recharge to the latter is from north northwest, recharge to the former directly from the west.

Calculations are based on porosity and transmissivity values which were reported by Theis (1951). The purpose of the calculations is to show that the flow west of the recharge boundary is much slower than in the confined part of the aquifer. Theis (1951) had estimated the limits of porosity in the vicinity of the Hondo Reservoir between 5% and 10% and average transmissivity about 267,400 ft^2/d. The hydraulic gradient for 1964 was about 10 feet per 6 miles. Based on these values tritium measured at Woods well traveled the distance of one to three miles in 4 years (4 - 10 ft/day).

From the flow velocity and porosity the amount of recharge that can be transmitted eastward by the aquifer under the present conditions can be calculated. For one mile width and 2 feet effective thickness of the aquifer and flow velocity of 70 feet/day, this amounts to 17 acre-feet per day or over 6,000 acre-feet per year. This value agrees with Theis' estimate of 5,000 acre-feet per year per mile in the northern part of the artesian basin.

5.3.3 Residence Time. Residence time of water in the northern part of the basin (north of T. 16 S.) between the recharge area and just east of the Pecos River is at most 4 years. As far south as T. 15 S., R. 26 E. (Pollard well), tritium levels were high even during 1959. The different wells along the Pecos River sampled at different times gave the same water ages. The observations appear to be systematic with respect to the fallout pattern over the recharge area. Some slight differences could be expected from purely hydrologic considerations where during the pumping season more water is drawn from deeper levels of the aquifer.

In the region south of the Chaves-Eddy county line there was no appreciable increase in tritium levels east of R. 23 E. as late as September 1961. Therefore, the residence time of ground water just east of the Village of Hope (well NO 45) is at least 7 years.

The significance of the short residence time in the northern part of the basin is that water from the recharge area west of Roswell moves at a fast rate toward the heavily pumped region. As a result, the ground water potential of the Roswell artesian basin will have to be reevaluated. The second implication is the possible movement of any contaminant from the recharge area to the center of the pumped area in less than 4 years. From the observed tritium peaks in ground water, it may be deduced that any such contaminant will not be appreciably dispersed and consequently little dilution will take place.

5.3.4 Recharge Estimations. The precipitation/recharge relationship presented in Section 5.1.4 is not a linear function. The physical meaning of this is that during dry years the fraction of the total precipitation which contributes to recharge is much smaller than during wet years. The relationship developed by Hantush (1957) and used unmodified by Saleem and Jacob (1971) was linear. For these authors, the same fraction of total rain always is effective recharge. This has the effect of overestimating recharge during dry years and underestimating it in wet years. Hantush's budget calculations were based on a dynamic equilibrium concept where no change in water levels implied that the recharge of that year was equal to discharge. This type of water budget takes into account leakage to the aquifer from the adjacent formations which is not accounted for by the actual amount of recharge. Computation of recharge to the San Andres Limestone depends on the surface extension one assumes for the so-called principal intake area. The calculation is simplified by the karstic nature of the limestone terrain, because most of the rain runs off for short distances only before it is absorbed. As observed by Motts and Cushman (1964) and Bean (1949), these conditions exist primarily north of the Rio Hondo. The tributary area to the principal recharge area of the San Andres Limestone aquifer is probably larger than 2500 mi^2. The western boundary of this area is a north-south line through Picacho.

Even though the recharge area is large (2,500 mi^2), Saleem and Jacob overestimated aquifer replenishment for dry years. The agreement between the present method and Hantush's method is much better during years of high precipitation.

5.4 The Dispersive Model

5.4.1 General. The mixing and spreading of recharging water into the aquifer water is called hydrodynamic dispersion. This phenomenon can be observed only when the incoming waters are either of different chemical quality or are tagged with a tracer. In the case under study, the incoming waters are tagged with a natural tracer of different concentration from the aquifer water. Hydrodynamic dispersion is an unsteady process in which the tracer is continuously mixed. The dispersion equation (Bear and Bachmat, 1965) is a mathematical expression which describes the mixing process. The process depends on the properties of the porous medium and the transport of the tagged water in the flow field. The general equation of dispersion in a homogeneous porous medium is given by

$$\frac{\partial C_\alpha}{\partial t} = \frac{\partial}{\partial x_i}\left(D_{ij} \frac{\partial C_\alpha}{\partial x_j} \right) - \overline{V_i} \frac{\partial C}{\partial x_i} \qquad (5\text{-}7)$$

where

C_α - tracer concentration of the α-component

$x_{i,j}$ - cartesian coordinate system

D_{ij} - components of the dispersion coefficient (second rank tensor)

$\overline{V}_i$ - average velocity in the i^{th} direction

The dispersion coefficient has two parts:

$$D = D' + Dd \qquad [L^2/T] \qquad (5\text{-}8)$$

where

D' - coefficient of mechanical dispersion

Dd - coefficient of molecular diffusion

The dispersion coefficient is a measure of the rate of spreading of a tracer in moving water. At very low velocities the predominant mechanism of mixing is due to molecular diffusion so that D = Dd. At high velocities where the mechanical dispersion predominates D can be considered equal to D'.

The macroscopic relation for the conservation of a dispersed tracer is represented by a convective-dispersion equation. This equation reproduces the tracer distribution and allows determination of the dispersion coefficients. For unidirectional miscible displacement, equation (5-7) can be written as

$$\frac{\partial C}{\partial t} = D_L \frac{\partial^2 C}{\partial x^2} - \overline{V} \frac{\partial C}{\partial x} \qquad (5-9)$$

where

D_L - longitudinal dispersion coefficient, scalar

$\overline{V}$ - average seepage velocity ($Q/\theta A$).

At the present, analytical solutions of the general dispersion equation are available for specific oversimplified cases only. Work in the field of dispersion resulted in analytical solutions of longitudinal and transverse dispersion in homogeneous isotropic media (de Josselin de Jong, 1958). Some approximate solutions have been obtained for a twodimensional flow field. Numerical solutions of more complicated cases were presented by Shamir and Harleman (1967). The dependence of the dispersion coefficient on the velocity and the medium is given by

$$D = Dm \, \bar{\bar{V}} \tag{5-10}$$

where Dm is the dispersion constant or the medium's geometrical dispersivity (L). The dispersion constant is a measure of the medium's properties. The importance of determining the dispersive properties of an aquifer is mainly in waste disposal and artificial recharge. These operations require the ability to predict the patterns of mixing for an efficient management of the underground reservoir. The major difficulty in applying the theory to field situations is that the flow velocity and the dispersion constant of the medium are required. Attempts to apply dispersion constants measured in laboratory experiments or obtained from theoretical considerations to actual field situations showed differences of more than two orders of magnitude (Fried, 1972). The reason for the discrepancies is that the basic assumptions for the derivation of the dispersionsion equation include a highly uniform flow field. In actuality, the aquifer is inhomogeneous and anisotropic. Flow is mostly nonsteady and non-uniform due to variations in recharge, pumpage, and flow velocity. This puts the problem beyond the reach of rigorous mathematical techniques presently available. Since the ultimate goal is to solve practical problems the following simplified approach attempts to test the usefulness of the results obtained by environmental tritium in a unidimensional dispersion model.

5.4.2 The Dispersion of a Pulse. Nir (1964) discussed the application of a well known solution of Equation (5-9) for the prediction of tritium distribution in a porous medium. Based on laboratory and field experiments, it appears that tracer distribution in laminar flow through a granular porous medium can best be described by a type of nonsymmetric distribution, which relates dispersivity to time, distance, and the physical characteristics of the medium (Rafai et al., 1956; Scheidegger, 1961). In order to check the applicability to the present study and the validity of the tritium input function, use is made of the solutions of the dispersion equation presented by Scheidegger (1960) and Nir (1964). The solution of Eq. (5-9) for the progress of a thin slug with the initial condition

$$C(x, 0) = Q \ \delta(x) \qquad (5\text{-}11)$$

is

$$C(x_o, t) = \frac{Q}{\theta A \sqrt{4 \ \pi Dt}} \ \exp \left[- \frac{(x_o - vt)^2}{4 \ Dt} \right] \qquad (5\text{-}12)$$

where

$C(x, 0)$ - linear concentration (concentration/unit length)

δ - Dirac distribution of the unit impulse

Q - the total amount of tracer contained in the slug

$C(x_o, t)$ - tracer concentration at any distance and time

θA - effective cross section area perpendicular to the direction of flow (θ bw)

t - elapsed time since injection

x_o - distance traveled in the x-direction

Equation (5-12) describes an instantaneous pulse (or delta distribution) under the assumption that the tracer was introduced as a line source uniformly distributed over the land surface as a pulse of short duration (Bennett and Kaufman, 1967). With the relationship (5-10), Eq. (5-12) can be written in terms of the dispersion constant and the average distance traveled ($x = \overline{v}t$) rather than as a function of elapsed time

$$C(x_o, x) = \frac{Q}{\theta A\sqrt{4\pi D m x}} \exp\left[-\frac{(x_o - x)^2}{4\ Dmx}\right] \qquad (5\text{-}13)$$

In the case of a radioactive tracer, the correction for time decay ($e^{-t/\tau}$) should be applied, where τ is the mean life of the tracer. In this study Eq. (5-12) is used since the observed tritium concentration-time profiles are available for various fixed observation wells in the basin (Figs. 4.7 - 4.13).

5.4.3 The Physical System, Roswell Basin. For the purpose of testing the dispersive model, the entire hydrologic complex, from the exposed limestone where precipitation infiltrates toward the water table to the point of discharge or sampling, is treated as one unit. The real test, of course, is the success in reproducing the tritium concentration-time profiles as they were observed in ground water.

Equation (5-12) considered the longitudinal dispersion only with an initial tritium profile being a step function of a short duration. The validity of its application to the Roswell basin and its boundary conditions is discussed next. From the observed tritium concentrations in neighboring wells it was concluded that no gradient of tritium concentration exists perpendicular to the flow direction. It was also shown that for most of the study area ground water flow is in an easterly direction. In the same region, the recharge boundary of the limestone aquifer is approximately along a north-south line. On the average, recharge to the aquifer takes place only four months (June-September). Summer rains produce a pulse input of tritium into the system. It was also shown (Ch. 4) that the observed tritium-time profile for the long-record wells is the result of a series of pulses (seasonal inputs) which were introduced in a sequence.

The tributary area of the San Andres Limestone aquifer extends from the recharge boundary to the west. However, effective recharge takes place mostly through vertical fissures and sinkholes in an area near the structure zones close to the recharge boundary. The slow arrival of tritium at Woods well as compared with the wells near the Pecos River (Sec. 5.3.2) indicates that fast recharge takes place east of the location of Woods (less than 6 miles west of the recharge boundary).

From the short-record data of 1959 (Sec. 4.2.1) it was shown that in the confined part of the San Andres Limestone aquifer tritium is uniformly distributed along the vertical section of the aquifer. These observations support the notion that the recharging water, which enters the aquifer near the recharge boundary, flows under confined conditions a short time (on the order of a few months) later. Therefore the flow in the unconfined part can be neglected and the confined part is treated as a uniform velocity field.

The high velocity in the confined part of the aquifer also assures the separation of the incoming pulses. The general solution, therefore, is an equation which sums by the principle of superposition the effect of each tritium pulse at a point in space and time.

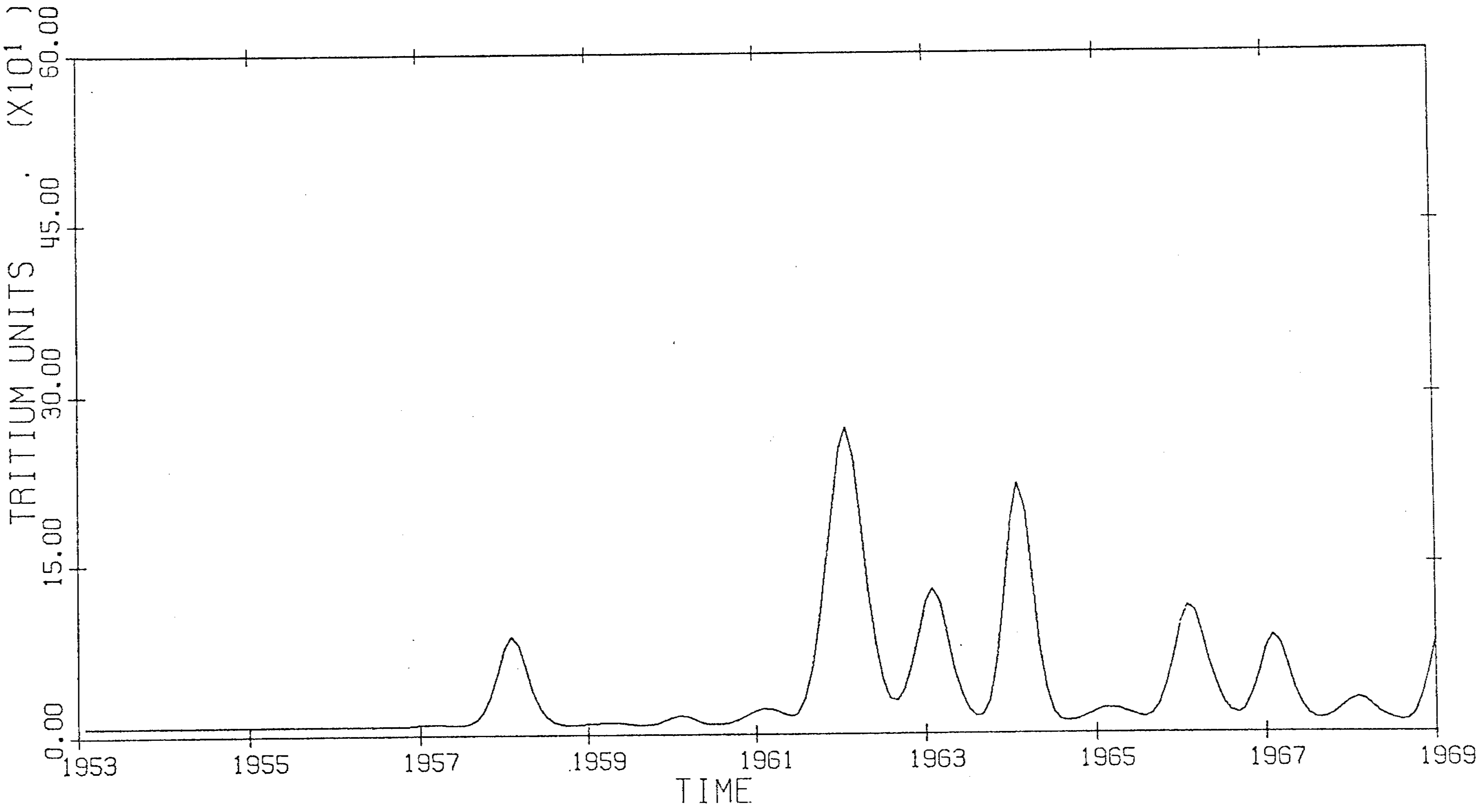
5.4.4 Calibration. The observed tritium concentrations and the calculated average regional velocity were first used to calculate the order of magnitude of the dispersion constant Dm. This was done by solving Equation (5-12) for a range of Dm values. It was found that the best fit was obtained for Dm = 70 ± 5 feet. The computations were accomplished by digital computer.

In the calibration, two other quantities were utilized: the amount of tracer input per pulse (Q_i); and the effective cross section of the medium ($\theta A = \theta bw$). These two quantities are not entirely independent of one another and will be discussed in the next section. It should be made clear, however, that the model is more sensitive to variations in the effective thickness of the aquifer (θb) than to variations in the width of a flow path (w=6 miles produced the best results).

5.4.5 Application. The dispersion equation (5-12) was numerically solved by digital computer. It was slightly modified to take into account the time decay correction for tritium. The solution is in the form of summed tritium concentration at any distance and time due to the total number of pulses injected into the aquifer (See program listing, App. J). For practical results the distance was limited to 24 miles and the calculations carried out to 10 years. The conversion of units used in the scheme are given in Appendix A. The input tritium pulses were calculated directly from Table 5.6 (or Fig. 5.8). The input quantities were converted from T.U.-in. to mCi/mi^2 (100 T.U.-in. = 21 mCi/mi^2). During the calibration procedure it was found that the most consistent set of results was obtained by dividing the recharge area into strips of 6 miles by 12 miles, north-south and west-east, respectively. The total activity of tritium input per pulse (Q_i) was then determined by multiplying the amount of tritium input (per square mile) by the fallout area (72 square miles). In all, 38 seasonal pulses were used to generate the dispersion equation for the entire study period. The results are in the form of tritium concentration-time profiles for any given distance from an injection. Figure 5.9 is such a profile for a well located 20 miles from the recharge boundary.

Figure 5.9

Predicted tritium concentration-time profile at a well 20 miles from the recharge boundary (28 input pulses, Dm=70 feet, $\overline{v}$=70 feet).


TRITIUM UNITS (X10¹)
0.00
15.00
30.00
45.00
60.00
1953
1955
1957
1959
1961
1963
1965
1967
1969
TIME

5.4.6 Results. Although the scheme may not be a true representation of the flow system and its boundary conditions, it does reproduce the observed output tritium profiles and the width of the disperse tritium pulses about 4 years since injection. The velocity term and effective thickness of the aquifer used in the solution of Equation (5-12) were independently obtained from the combination of tritium and hydrological data (Secs. 5.3.1 and 5.3.2).

The use of each monthly tritium input in the generation of the dispersion equation did not duplicate the correct tritium output profile. Only by combining the inputs into seasonal pulses the predicted profile came close to the observed one. This result may point toward the unsaturated percolation mechanism in the limestone terrain. One conclusion is that at such fast rates of percolation all individual pulses derived from a particular summer precipitation are lumped together as they reach the saturated zone of the aquifer.

The applicability of the dispersion theory, derived for a granular medium, to a fractured aquifer has important consequences.. What this study has demonstrated is that with all the uncertainties of inhomogeneity, anisotropy, and the prevailing conditions at the recharge area, it is possible to determine a dispersion constant in situ for a large basin. Furthermore, knowing the input to the system and regional flow velocity the behavior of a tracer (or contaminant) could be predicted using a simple model.

The dispersion constant determined for the San Andres Limestone aquifer (≈70 feet) is in good agreement with the values reported by Harpaz et al. (1968) for a similar medium. From injection and pumping tests in a karstic limestone aquifer, they obtained an average value of Dm = 10 - 20 m. In this case no laboratory experiments were carried out. For a sandstone aquifer they reported Dm = 0.001 m and Dm = 0.2 - 0.5 m from a sand model in the laboratory and in situ determinations, respectively. With a two-well tracer method, Grove and Beetem (1971) measured Dm = 125 feet in dolomite of the Rustler Formation near Carlsbad, New Mexico. Since the distance between tracer injection and pump was only 180 feet and their calculated porosity 12%, the obtained dispersion constant (= 125 feet) could have been influenced by the geometry of the experiment.

5.5 References

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6. SUMMARY

6.1 Summary of Conclusions

This study was a quantitative attempt to obtain hydrologic characteristics of a limestone aquifer and its recharge area based on environmental tritium. The investigation relates three topics for study: tritium tracing and dating techniques, geohydrologic concepts of water movement, and the precipitation/recharge relationship in a semi-arid region. More specifically, natural tritium tracing was made possible by ground water recharge of a fractured limestone aquifer. These topics are combined for a quantitative appraisal of the variations in tritium concentrations observed in precipitation and well waters. The aim was twofold: (a) to determine if results obtained by tritium tracing and dating methods confirm existing physical characteristics of the system and (b) to explore the possibilities of obtaining hydrologic parameters which could be determined primarily by the tracer method.

The analysis yielded mainly average values of hydrologic parameters for the northern part of the Roswell artesian basin. The major contribution of the tritium tracing method is in its integrated presentation of the region between the recharge area and the observation wells. It was found to be very effective in a carbonate aquifer where transit time is relatively short ($\leq$4 years) as compared to the tritium mean life (=18 years).

By utilizing precipitation data and the measured tritium concentrations of precipitation, fallout patterns for two areas in the basin were established. From these, together with the observed tritium output profiles in ground water, a precipitation/recharge relation was found which is a function of the ratio of annual precipitation to mean annual precipitation. This relation was tested by constructing an empirical tritium input function which in turn was used to generate a unidirectional dispersion model. The order of magnitude and trends of the predicted tritium output profiles as compared with the observed ones, are within reasonable accuracy for the purpose of hydrologic investigation.

The results of this study are summarized in the following paragraphs.

(a) The general direction of ground water flow became apparent from the observed variations in tritium concentration of ground water in the northern subregion from about the Rio Hondo to the Chaves-Eddy county line. In the northern zone centered in Roswell, the flow is from north-northwest. The flow is toward the east in the zone between Hagerman and Lake Arthur.

(b) 70 ± 10 feet/day was calculated as the average value for ground water flow velocity in the confined part of the San Andres Limestone in the northern subregion.

(c) From pumping test data and the ground water velocity calculated from tritium pulse tracing, an average regional effective porosity of 1% was derived.

From this and well penetration data the effective thickness of the producing unit of the aquifer was determined to be 2 feet ($=\theta b$). This number was verified by the dispersion model of this study and by geochemical model (A. Mercado, personal communication, 1972).

(d) On the basis of tritium residence times, two ground water subregions were delineated within the basin. The northern subregion (north of T. 16 S.) is characterized by a residence time of 4 years. The central subregion (south of T. 15 S.) shows residence times of at least seven years. These results are partially substantiated by hydrologic studies and geologic mapping.

(e) Tritium was used as a tracer in determining the area where recharge to the northern zone of the limestone aquifer occurs most readily. This was done by correlating the observed tritium in ground water with precipitation patterns at Dunlap and Farnsworth Ranch. This was facilitated by the fact that recharge in this region takes place mainly during the time when tritium levels in precipitation are at their yearly highs. The principal intake area to the northern subregion of the basin covers approximately 2500 mi^2 and extends from about T. 1 S. to T. 15 S. and from R. 18 E. to R. 21 E.

(f) Results obtained by the dispersive model indicate that the theory of hydrodynamic dispersion is valid in a fractured and layered medium under the assumed conditions of flow and tracer input. The sharp tritium peaks observed in various wells are also indicative of a system which does not have much mixing between the recharging water and the older water. The dispersion constant was calculated to be 70 ± 10 feet.

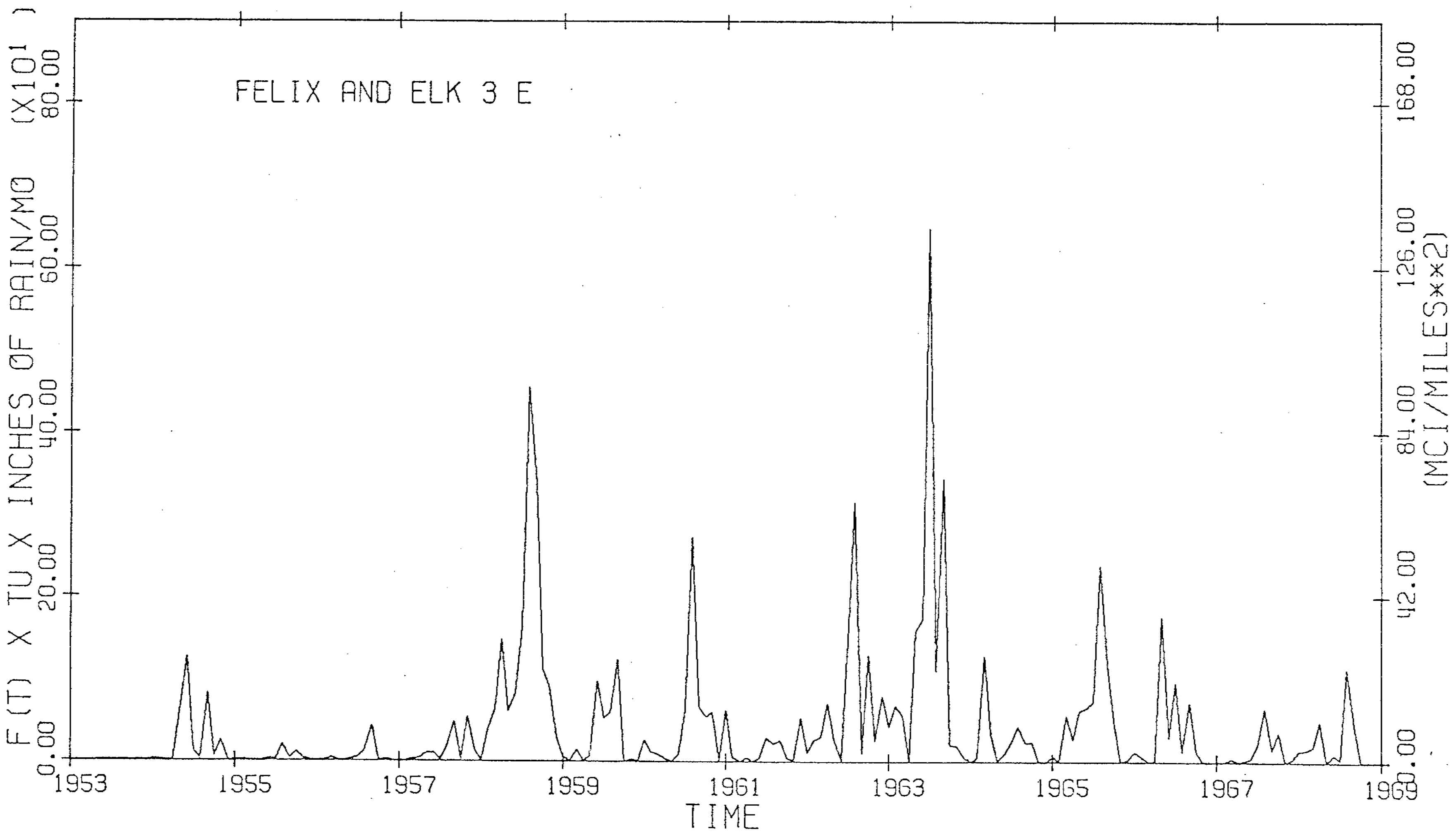
6.2 Recommendations for Further Study

During the course of this study several areas became apparent which should be the subject of additional investigations.

(a) A more extensive survey of tritium content of ground water in the central subregion of the basin (west of Artesia). The early sampling of 1959/1961 indicated a low permeability with a much longer residence time for tritium than in the northern part of the basin. Precipitation on the recharge area of this subregion during 1953 - 1968 was constantly higher and with less variations than in the northern subregion. The tritium input function constructed for the central subregion (Fig. 6.1) indicates large tritium input during 1962, 1963, and 1965. A sampling program for tritium in this subregion would be used for testing the validity of the precipitation/recharge relationship which was developed for the northern subregion of much higher permeability.

Figure 6.1

Empirical tritium input function for the central part of the Roswell basin.

FELIX AND ELK 3 E
F(T) X TU X INCHES ØF RAIN/MØ (X10¹)
0.00
20.00
40.00
60.00
80.00
(MCI/MILES**2)
0.00
42.00
84.00
126.00
168.00
1953
1955
1957
1959
1961
1963
1965
1967
1969
TIME

(b) Further development of the tritium tracing and dating method in the study of recharge mechanisms in a karstic terrain. Preliminary results (Sec. 4.2.1) have indicated that the unsaturated percolation in the northern recharge area of the Roswell artesian basin is rather fast (4 to 12 months). Thus, a conclusive study on the actual recharge rate should be possible in a relatively short time.

(c) The installation and operation of additional precipitation measurin stations northwest of the basin (between Roswell and Farnsworth Ranch) is essential for a more realistic forecast of potential recharge to the San Andr Limestone aquifer.

(d) Revision of the ground water budget for the entire artesian basin on the basis of the precipitation/recharge relation and a more precise definition of the effective recharge area.

(e) The *in situ* determination of the dispersion constant (Dm) should be expanded to include its dependence on velocity and distance from the recharge boundary. These additional determinations are extremely important especially in light of recommendations for artificial recharge of imported water. The dispersion constant is critical in predicting the water quality to be produced after a time span at some distance from the injection site.

(f) In a regional investigation of ground water systems the stable isotopes O^{18} and deuterium should be used in conjunction with tritium tracing and dating. The depletion of O^{18} and deuterium in precipitation and ground water can be used as an indicator of geographic origin of precipitation (in this case, from the Pacific and the Gulf of Mexico, respectively) and as an additional criterion for correlation between ground water and precipitation.

APPENDICES

Appendix A

Units and Conversion Factors

1 T.U. = 1 tritium atom/10^{18} hydrogen atoms
= 7.2 x 10^{-3} dpm/ml
= 3.24 x 10^{-15} Ci/ml
1 liter = 1000 ml
1 gallon = 3785 ml
1 mi^2 = 2.590 Km^2
= 640 acres
1 acre-feet = 43,560 ft^3
= 3.26 x 10^5 gallons
1 ft/mi = 1.89 x 10^{-4} ft/ft
1000 gpd/ft = 133.7 ft^2/d
= 12.5 m^2/d

Conversion of fallout units. The concentration of tritium in rain is measured in T.U. Rainfall is reported in inches which could be regarded as the measured depth of water on land surface. The product T.U.-in. is the tritium fallout. The following units were used in this study:

$$1 \text{ T.U. x inch} = 3.24 \times 10^{-15} \text{ Ci/ml} \times 2.54 \text{ cm/inch}$$

$$= 8.23 \times 10^{-15} \text{ Ci/cm}^2$$

$$1 \text{ mile} = 160,000 \text{ cm}$$

$$1 \text{ mile}^2 = 2.56 \times 10^{10} \text{ cm}^2$$

$$1 \text{ T.U. x inch} = 0.2107 \text{ mCi/mi}^2$$

For example, if 1 inch of rain with the concentration of 100 T. U. fell over an area of 6 miles x 12 miles, the total activity of tritium is:

$$Q = 21.07 \times 10^{-3} \text{ Ci/mi}^2 \times 72 \text{ mi}^2$$

$$= 1.5 \text{ Ci}$$

The calculated Q is the total activity deposited by rain.

Conversion of total tritium input to concentration. Tritium input (Q) in equation (5-12) is given in Curies (Ci) and the predicted concentration distribution at any point, C(x, t), is in units of concentration (T. U.). From C(x, t) in Ci/ft the following conversion is used:

$$\text{T.U.} = \frac{C \text{ (Ci/ft)}}{b \text{ (ft)} \times w \text{ (ft)} \times \theta} \cdot \frac{1}{28,320 \text{ (cm}^3/\text{ft}^3)} \cdot \frac{309 \times 10^{12} \text{ (T.U.}}{\text{(Ci/ml)}}$$

where,

b = thickness of the aquifer (200 feet)

w = the width of a strip equivalent to a pathline (6 miles)

θ = porosity (0.01)

Appendix B

Theory of Tritium Enrichment

During the course of this study, three methods were used for the electrolytic enrichment of tritium. The main difference between these methods was the method of determining the enrichment factor. The magnitude of enrichment was dictated by the sensitivity of the counter used at the particular time and the origin of the sample measured. Depending on initial volume, one of three electrolysis procedures was used:

(a) A large initial volume (2000-6000 ml) was reduced to less than one milliliter in four to five stages. The final product was recovered by vacuum distillation and its quantity was determined by weighing.

(b) A moderate initial volume (500-2000 ml) was reduced to 2 ml, or 7 ml in two or three stages. The final sample was recovered either by regular or vacuum distillation and its quantity was determined by volume.

(c) A small initial volume (constant = 250 ml) was reduced to 2.5 ml by periodic additions being made to the same electrolysis cell until the whole sample was used up. The final product was recovered by vacuum distillation into a weighing bottle.

The basic enrichment theory was the same for all methods used. Differences resulted from the fact that the determination of tritium enrichment for (a) and (b) depended on deuterium enrichment which was measured by the falling drop method, whereas (c) provided a direct measure of tritium enrichment. The falling drop method is described in Appendix C.

For solutions low in deuterium concentration, the enrichment equations are (Kaufman and Libby, 1954):

$$\frac{dp}{p} = \alpha \frac{dd}{d} = \beta \frac{dt}{t} \qquad \text{(B-1)}$$

which has the solution

$$\frac{p}{p_o} = \left(\frac{d}{d_o}\right)^{\alpha} = \left(\frac{t}{t_o}\right)^{\beta} \qquad \text{(B-2)}$$

where p/p_o can be replaced by V/V_o, and $p \gg d \gg t$.

The symbols used are:

V_o and V initial and final volumes, in ml, respectively;

p_o and p initial and final number of moles of protium, respectively;

d_o and d initial and final number of moles of deuterium, respectively;

t_o and t initial and final number of moles of tritium, respectively;

α and β are the separation factors for deuterium and tritium with respect to protium, respectively.

B.1 Multi-Stage Electrolysis.

The enrichment factor for tritium, in terms of the measured quantities, is obtained by solving the second equality of Equation (B-2). The form of solution adopted by this laboratory for tritium enrichment is as follows:

$$\frac{\tau}{\tau_o} = \left(\frac{V_o}{V}\right)\left(\frac{D}{0.015} \cdot \frac{V}{V_o}\right)^{\alpha/\beta} \qquad \text{(B-3)}$$

where, τ_o and τ are initial and final tritium concentrations of the sample, respectively; D is the deuterium concentration in mole percent; 0.015 is the assumed concentration of deuterium (in mole%) in natural water and therefore the deuterium concentration at the beginning of the electrolysis process.

In Equation (B-3), depending on the method of electrolysis used, the final quantity of sample was measured by weight or volume. For method (a), Equation (B-3) becomes

$$\frac{\tau}{\tau_o} = \left(\frac{V_o}{W}\right)\left(\frac{D}{0.015} \cdot \frac{W}{V_o}\right)^{\alpha/\beta} \qquad \text{(B-4)}$$

where W is the final weight of the sample in grams. The density (ρ) of the enriched sample is calculated from the increase in deuterium concentration (the effect of tritium enrichment on the density is negligible).

The conversion from volume/weight to volume/volume is then,

$$\frac{V_o}{V} = \rho \frac{V_o}{W} \qquad \text{(B-5)}$$

The matter is further complicated when a sample had to be diluted prior to the determination of its density by falling drop. As will be shown in Appendix C, the validity of the falling drop assay for the density of enriched samples holds only for deuterium concentrations of less than 8 mole percent. For that reason samples are diluted with deionized water at preassigned ratios depending on the value of V/W. In this report, samples with LAB NO less than 600 have been analyzed by such procedure.

The quantities τ, V_o/V (or V_o/W), and D are determined by direct measurements in Equations (B-3) and (B-4). An uncertainty is introduced by the ratio β/α (or α/β). Kaufman and Libby (1954) reported the weighted average value for β/α as 2.1 ± 0.10. Since then Bigeleisen (1962), and Ostlund and Werner (1962) have reported that a more constant relationship between the deuterium and tritium separation factors is the ratio of their logarithms. According to Roy (1962) the ratio is,

$$\log\beta \,/ \log\alpha = 1.41 \pm 0.01 \qquad \text{(B-6)}$$

The procedure for calculations is first, from Equation (B-2), to determine α from the relation

$$\frac{V}{V_o} = \left(\frac{d}{d_o}\right)^{\alpha}$$

by taking the logarithm of both sides and replacing d and d_o by their respective concentrations the expression for α becomes

$$\alpha = \frac{\ln\left(\frac{V_o}{V}\right)}{\ln\left(\frac{V_o}{V} \cdot \frac{0.015}{D}\right)}$$

or

$$\alpha = \frac{1}{1 + \frac{\ln(0.015/D)}{\ln(V_o/V)}} \qquad \text{(B-7)}$$

with α known, β is calculated by the relationship (B-6),

$$\beta = \alpha^{1.41}$$

The ratio β/α for samples enriched by method (a) (V/W-enrichment) was found to lie between 1.4 and 2.2. The error is mainly in the recovery and recording at the last stage where the size of the sample is less than one gram. The β/α ratio for samples processed by method (b) (V/V-enrichment) was more consistent and on the average equal to 2.0.

B.2 Electrolysis by Periodic Additions.

Ostlund and Werner (1962) and Ostlund (1966) described the periodic addition electrolysis cell. For each batch of 10 to 15 cells one or two cells are initially filled with a sample of known tritium concentration. From the initial and final concentrations, initial sample volume, and final sample weight, the apparent enrichment factor can be determined (apparent because not all of the sample is in contact with the electrodes all of the time). Every 24 hours an additional 25 ml of the sample is added to the remaining volume.

The separation factor (β) is calculated by the relationship,

$$\beta = \frac{\ln\left(\frac{V}{V_o}\right)}{\ln\left(\frac{\tau}{\tau_o} \cdot \frac{V}{V_o}\right)} \qquad \text{(B-8)}$$

where, V_o and V are volume of the sample before and after electrolysis, and τ_o and τ tritium concentrations before and after electrolysis. Equation (B-8) can be solved for samples of known τ_o. Furthermore, V the final volume of the sample, although determined by weight is not corrected for density differences. The assumption is that for such low enrichment ratios ($V_o/V = 100$, whereas multi-stage ratios are as high as 2000), the density does not change appreciably.

The enrichment equation for the batch, once β was determined, is then,

$$\tau_o = \tau \left(\frac{V}{V_o}\right)\left(\frac{V}{V_o}\right)^{-1/\beta}$$

or,

$$\frac{\tau}{\tau_o} = \left(\frac{V_o}{V}\right)^{1-1/\beta} \qquad \text{(B-9)}$$

By measuring V_o, V, and τ and calculating β, τ_o can then be determined.

During the course of this study β gradually changed from 8.4 to 16.2 and appeared to remain constant after that. The largest error is still being introduced in the determination of the final volume of the sample. This error affects each sample twice, once in the determination of β and then in the determination of the unknown sample concentration.

B. 3 References.

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Appendix C

Falling Drop Assay for Deuterium in Water

For most of the samples presented in this study, the enrichment factor was determined by measuring the deuterium content of the enriched samples. The deuterium and tritium separation factors were then calculated from Equations (B-7) and (B-6), respectively.

In general, the density (in mole fraction or mole% deuterium) of an enriched water sample may be determined accurately by the falling drop method. This consists in timing the fall of a sample drop through a fixed distance and at constant temperature in an immiscible liquid. The density of the medium should be very close to but lower than that of the sample. To a first approximation, the rate of fall of the drop is governed by Stokes' law (Kirshenbaum, 1951).

Stokes' law states that when a small sphere falls under the action of gravity through a viscous medium, the sphere acquires a terminal velocity

$$V_t = \frac{2\ g\ r^2\ (d_i - d_o)}{9\ \eta} \qquad \text{(C-1)}$$

where,

V_t = terminal velocity

r = radius of the sphere

g = acceleration due to gravity

d_i = density of the sphere (unknown)

d_o = density of the medium

η = coefficient of viscosity

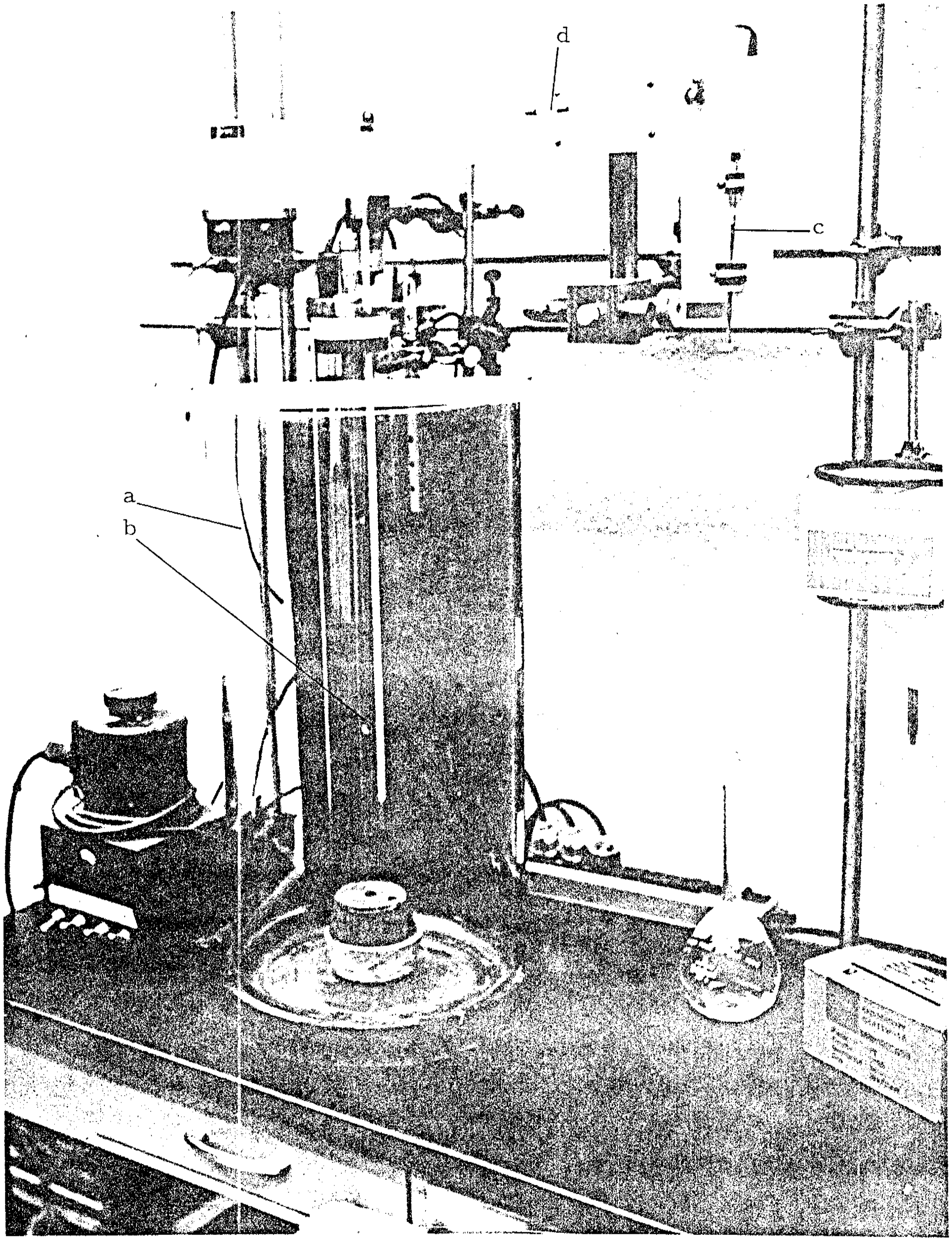
For a small difference in density between the liquid being measured and the liquid through which it is falling, the rate of fall of the drop (V_t) is directly proportional to the difference in density of the two liquids. The construction of the apparatus is such that all variables in Equation (C-1) are kept constant and the time of fall is inversely proportional to the density of the drop.

The accuracy in determining the enrichment, and eventually the initial concentration of tritium in a sample, is most sensitive to the deuterium measurements. Deuterium, being non-radioactive and present at fairly high concentrations in the enriched samples (0.4 to about 4 mole%) is very conveniently measured by the falling drop technique. The technique is straightforward and the results are obtainable by calibration with standard samples.

Figure C.1

General view of the falling drop apparatus.

- a. Constant temperature bath.
- b. Fall tube.
- c. Micropipette and capillary tube assembly.
- d. Slide to control drop size.


d
c
a
b

C.1 Falling Drop Apparatus.

Figure C.1 is a general view of the falling drop apparatus constructed at New Mexico Institute of Mining and Technology and used in this study. The main parts of the apparatus are:

(a) Constant temperature bath (10 gallons capacity) which includes thermostat, heater, and stirrer.

(b) Drop fall tube. Two marks are on the fall tube, 20 cm and 50 cm below the top. At the bottom is a 100 ml reservoir to collect the timed drops.

(c) The sample holder is a capillary tube micropipette arrangement. The tip of the capillary tube is at a point directly above the center of the fall tube. A slider, with 2.2 cm window, is mounted on the capillary tube and assures uniform drop size.

The operation of the apparatus begins when the constant temperature bath is at $30.4 \pm 0.05\ ^{\circ}C$. This temperature is above the range of room temperature fluctuations. The micropipette is filled with mercury which in turn either pushes or pulls the water sample inside the capillary tube. The capillary tube is rinsed with the sample to be timed, and then filled again. To deliver a drop below the surface of the liquid, the tip of the capillary is lowered into the liquid in the fall tube, the sample is pushed one window length (the water-mercury interface is the indicator) with the micropipette and the capillary is raised. By raising the capillary tip from the liquid, the drop which was held on the tip is caused to fall through the column. A stopwatch is used to time the fall of the drop between the two marks on the fall tube. This step is repeated until the falling time of eleven consecutive drops has been timed. The first drop is usually discarded and the average time for the ten remaining drops is calculated.

It is important that the tube be closely aligned vertically so that the drop falls through the same path each time and does not strike the sides of the tube. The fall column is shielded with a larger tube from the agitation within the constant temperature bath surrounding it.

C. 2 Fall Column and Standards.

There are very few liquids immiscible with water which have both the proper density and viscosity to make them suitable to fill the fall column. A single pure compound is necessary, so that there will be no change in density due to differential evaporation. Two such organic substances were used in the fall column during this study. Until May 1967 the liquid in the column was o-fluorotoluene (Eastman organic chemical #2967) with density 1.0041 g/ml (at 25 °C), and boiling point 114 °C. During May 1967 this was changed to iso-butyl benzoate (Eastman organic chemical #1183) with density 1.002 g/ml (at 25 °C), and boiling point at 237 °C. The falling distance and temperature remained the same.

The main difference between the two liquids was found to be the fall time. A sample (standard D-10) which traveled the distance between the two marks in 30.13 ± .14 seconds when the tube was filled with o-fluorotoluene needed 55.55 ± .30 seconds to fall the same distance in iso-butyl benzoate. Samples that were previously diluted because of a very short fall time could be run without dilution. The dilution of falling drop samples (usually no larger than 0.2 grams) was a source of large errors in the calculations.

Standard deuterium samples were purchased from Stuart Oxygen Co., San Francisco, California, and later from Euratom, Geel, Belgium. The first sample had a concentration of D_2O 99.5% and the one from Euratom 99.77 mole% D_2O. The density of 99.77% D_2O at 25 °C is 1.108. The two standards were diluted and checked against each other. Both were found to be in agreement. From the concentrated standard sample, samples for the calibration of the falling drop apparatus are diluted. Their concentrations depend on the amount of deuterium in the enriched samples and the fall time. Standard samples are usually between 0.2 and 5 mole% deuterium. The samples are prepared by weight.

C. 3 Calibration

The calibration of the falling drop apparatus is done with a set of standard samples. Each calibration is done with a range of different samples with one or two repetitions. The basis of the calibration is the linear relationship between the samples' deuterium concentrations (in mole%) to the reciprocal of their fall times (in min^{-1}). There is an upper limit of deuterium concentration above which the departure from linearity becomes so great that the method is no longer valid.

The calibration line is determined by a simultaneous solution of a set of linear equations (least squares fit) and the calculations are done with the aid of a computer. The computer program treats each individual fall time and the corresponding deuterium concentration as a data point. The results are given as the best fitted first and second order algebraic equations, and the sum of errors squared for each of the equations. The variance of the deviation for the best fit of the individual drops is the quantity used to evaluate how well the linear or quadratic fits, through the points, are in agreement. The orientation of the coordinates is such that the Y-axis is the reciprocal time and the X-axis is the concentration. In addition, for each case an equation in terms of mole% D_2O is given where the only unknown is the fall time in seconds. In order to determine the deuterium concentration of an enriched sample, one needs to know only the average fall time for a particular sample.

C. 3.1 Example. Table C-1 is an example of a computer output to program TRITIUM VI (routine program in this laboratory) for the calibration of the falling drop apparatus. Data were obtained in February 1968 and the purpose was to compare the newly diluted Euratom samples with those used for the previous 6 years. Seven different samples were used (Euratom: D-40, D-41, and D-42; Stuart Oxygen Co.: D-2, D-11, D-13, and D-32) and the concentration ranged from 0.579 to 5.434 mole% D_2O. There was a total of 70 drops and the fall time varied from about 36 to 62 seconds. At the bottom of Table C-1 there are two sets of results:

(a) The linear or straight line equation and its solution in terms of deuterium concentration (%) and falling time (T=seconds).

(b) The quadratic equation and its solution.

Figure C.2 is a plot of these equations which may be rewritten in the following manner:

(a) The linear equation

$$y = 0.895 + 0.136\,x \qquad (\sigma^2 = 0.0002)$$

(b) The quadratic equation

$$y = 0.887 + .147\,x - 0.002\,x^2 \qquad (\sigma^2 = 0.001)$$

There is no visible separation between the linear and quadratic plots.

Table C.1 Falling drop calibration and comparison between two standards.

```
 70(1)        TRIT VI 30.4C BENZOATE EURATOM & OLD STD.  7 FEB 68
   0.5786 (2) 62.1500 (3) 62.0000    62.0500    62.0100    62.1200    62.2700    62.1000
  62.0000     62.0700     62.2900
   0.5880     61.6200     61.6000    61.5200    61.5800    61.5400    61.6900    61.5000
  61.5100     61.6900     61.5800
   0.9942     57.6300     57.6700    57.9200    58.0000    58.1400    57.9500    58.2000
  58.1100     57.9200     58.0000
   0.7520     60.1400     60.3000    60.0200    60.4000    60.3900    60.3000    60.2100
  60.2100     60.3700     60.0500
   2.1007     50.7200     50.6500    50.8700    50.4100    50.4300    50.7900    50.5400
  50.9000     50.8200     50.5000
   4.4900     39.6200     39.6500    39.8000    39.7800    39.9000    39.7000    39.8000
  40.0200     39.9200     39.8100
   5.4340     36.8400     36.9300    36.8700    36.8000    36.8400    36.8000    36.8900
  36.8500     37.0500     36.9400
 THE COEFFICIENT OF X** 0  IS   0.895054D 00
 THE COEFFICIENT OF X** 1  IS   0.135570D 00
 THE SUM OF ERRORS SQUARED IS   0.208569D-02
D20 MOLE%=(60- 0.89505T)/ 0.13557T
 THE COEFFICIENT OF X** 0  IS   0.886612D 00
 THE COEFFICIENT OF X** 1  IS   0.146887D 00
 THE COEFFICIENT OF X** 2  IS  -0.195165D-02
 THE SUM OF ERRORS SQUARED IS   0.118943D-02
D20 MOLE%=  37.63152-256.19385SQRT(   0.02850  -0.46839/T)
```

---

(1) Total number of drops

(2) Concentration (in mole% D_2O)

(3) Fall time (in seconds)

Figure C.2

Falling Drop Calibration for February 7, 1968.

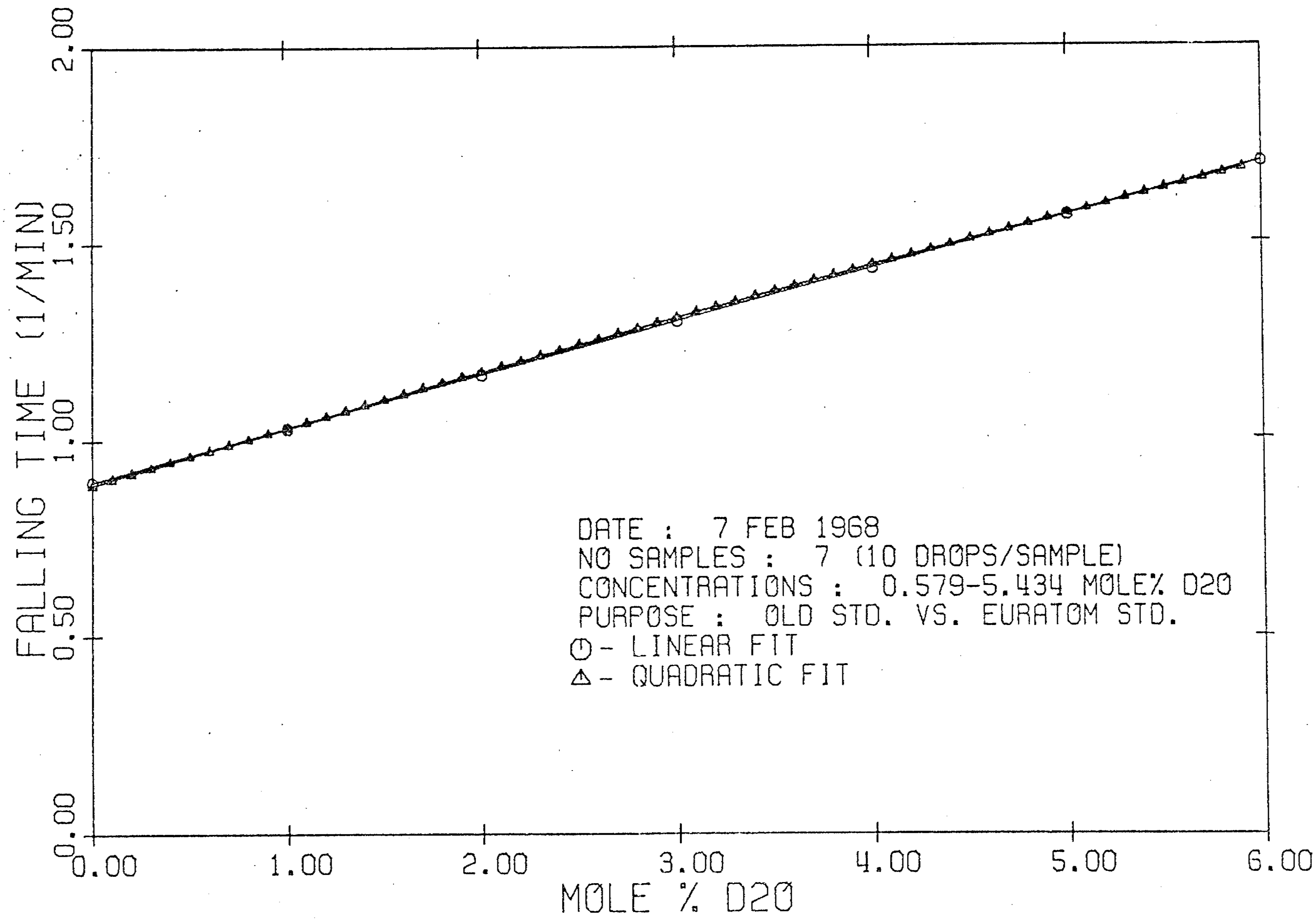

DATE : 7 FEB 1968
NO SAMPLES : 7 (10 DROPS/SAMPLE)
CONCENTRATIONS : 0.579-5.434 MOLE% D20
PURPOSE : OLD STD. VS. EURATOM STD.
○ - LINEAR FIT
△ - QUADRATIC FIT
FALLING TIME (1/MIN)
0.00
0.50
1.00
1.50
2.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
MOLE % D20

Table C. 2 Falling drop calibration

with repetitions.

```
130          VII 30.4 BENZOATE RANGE 0.774-4.49 DEC 19 67 - JAN 2 68
     4.4900    40.0200    39.5200    39.7900    39.7700    39.9900    40.0000    39.9000
    39.8700    40.0500    39.6200
     1.7400    52.6200    52.7500    52.7500    53.0800    52.9400    52.8200    52.8400
    52.6600    52.9300    52.6800
     1.7400    53.0000    52.7800    52.7000    52.8100    53.0000    53.0600    52.6900
    52.8700    52.9300    52.7700
     0.7740    59.6200    59.9800    59.4600    59.9600    59.8200    59.8400    59.9800
    59.6900    59.5100    59.4700
     4.4900    39.9500    39.6300    39.9300    39.6000    39.7700    39.7800    39.7200
    39.7100    39.5700    39.9100
     1.7400    52.6800    52.3000    52.6600    52.5600    52.5700    52.4000    52.1700
    52.6600    52.2700    52.4900
     0.7740    59.3200    60.1500    60.2200    59.9000    59.9800    59.7200    59.7000
    59.6600    59.4400    59.9400
     0.7740    59.8400    59.6100    59.5000    59.4100    59.5300    59.7200    59.7000
    59.6200    59.5100    59.2900
     1.0360    56.1400    56.3000    56.3100    56.1000    56.3000    56.4800    56.1100
    56.0100    55.9900    55.9900
     4.4900    39.7300    39.8800    39.8000    39.7800    39.7400    39.8800    39.8300
    39.9500    39.7300    39.7800
     1.7400    52.9900    52.4600    52.8000    52.7200    52.8600    52.5200    52.8100
    52.5100    52.3900    52.3700
     0.7740    59.7400    59.3800    59.3400    59.4400    59.3800    59.2800    59.5000
    59.3400    59.0300    59.2900
     3.4570    43.9200    43.5900    43.7800    43.6100    43.8200    43.6800    43.6800
    43.7900    43.6300    43.6200
 THE COEFFICIENT OF X** 0  IS  0.907004D 00
 THE COEFFICIENT OF X** 1  IS  0.133865D 00
 THE SUM OF ERRORS SQUARED IS  0.868523D-02
D2O MOLE%=(60- 0.90700T)/ 0.13387T
 THE COEFFICIENT OF X** 0  IS  0.903795D 00
 THE COEFFICIENT OF X** 1  IS  0.137491D 00
 THE COEFFICIENT OF X** 2  IS -0.680265D-03
 THE SUM OF ERRORS SQUARED IS  0.858863D-02
D2O MOLE%= 101.05690-735.00757SQRT(   0.02136  -0.16326/T)
```

This indicates, in addition to consistency in the operation of the apparatus, good agreement in the preparation of the standard samples which were diluted from two different sources.

Table C.2 shows the results obtained by redetermining the calibration line over a two weeks period. Several of the standard samples were remeasured to check the constancy of the calibration with time. During this period deuterium concentrations for a large number of unknown samples were determined.

C.3.2 Limitations. To check the limits of application of the falling drop method, some experiments with extreme concentrations of deuterium were carried out. By using standards of 8, 10, 12.5, and 25 mole% D_2O, together with the set of 0.2 to 5 mole% D_2O, it was found that with 8.32 mole% D_2O the best fit was a quadratic curve through the points. On the other hand, using deionized water with the assumption of 0.015 mole% D_2O concentration did not produce consistent results from one calibration to the next.

C.4 Conclusions.

It is demonstrated by Tables C.1 and C.2 that the falling drop method for the determination of deuterium concentrations is a reliable and reproducible technique. For all practical purposes, the linear fit through a set of data points can be used. From the tables it is seen that the Y-intercept and the slope of the calibration line do not change from one calibration to the next. Samples should not be concentrated above 8 mole% deuterium when the falling drop method is used. Calibration should be repeated before each batch of unknown samples.

The enrichment factor for most of the tritium data presented in this study was calculated from the deuterium enrichment. Very few samples had deuterium concentrations above 8 mole%.

C.5 References.

Kirshenbaum, I., Physical Properties and Analysis of the Heavy Water, McGraw-Hill Book Co., N. Y., pp. 324-344, 1951.

Appendix D
Monthly and annual precipitation (in.) for the study area and Socorro.

NAME: ROSWELL
LOCATION: CHAVEZ COUNTY LAT. 33.24 LONG.104.24
ELEVATION:3612.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.24	0.49	0.25	0.72	0.70	0.48	2.48	2.11	0.0	0.30	0.26	0.21	8.24
1954	0.21	0.0	0.0	0.11	2.65	0.09	0.33	1.61	0.47	4.44	0.0	0.27	10.18
1955	0.29	0.0	0.10	0.19	0.41	0.15	2.25	0.51	2.95	1.71	0.05	0.0	8.71
1956	0.02	1.42	0.03	0.03	0.40	0.04	0.54	1.13	0.16	0.54	0.0	0.04	4.35
1957	0.09	0.64	0.80	0.31	0.43	0.06	0.87	1.23	1.18	2.91	0.80	0.0	9.32
1958	1.57	0.84	1.93	0.84	0.77	0.20	0.66	1.27	3.56	0.98	0.19	0.25	13.06
1959	0.02	0.10	0.03	0.59	1.44	0.82	2.98	1.87	0.16	0.52	0.24	0.74	9.51
1960	1.26	0.43	0.04	0.0	1.03	1.24	3.31	0.16	0.45	3.53	0.0	2.12	13.57
1961	0.68	0.04	0.81	0.02	0.44	0.65	1.06	1.37	0.44	0.44	1.62	0.19	7.78
1962	0.38	0.51	0.12	0.09	0.21	0.97	3.44	1.31	3.51	0.15	0.62	0.15	11.46
1963	0.44	0.77	0.0	0.16	0.68	0.60	0.21	2.26	0.62	0.15	0.05	0.16	6.30
1964	0.80	1.25	0.15	0.02	0.30	1.10	0.17	0.57	2.05	0.0	0.33	0.24	6.98
1965	0.12	0.84	0.21	0.38	0.35	1.09	1.50	0.83	0.76	0.05	0.08	0.47	6.68
1966	0.53	0.03	0.25	1.97	0.54	2.35	0.15	2.89	0.97	0.0	0.0	0.0	9.68
1967	0.0	0.20	0.07	0.0	0.11	3.55	0.97	4.00	0.85	0.02	0.22	1.07	11.06
1968	1.50	1.17	1.93	0.06	0.57	0.60	5.50	2.67	0.10	0.41	1.11	0.22	15.84
MEAN	0.51	0.55	0.42	0.34	0.70	0.87	1.55	1.62	1.14	1.01	0.35	0.33	9.54

NAME: ARTESIA
LOCATION: EDDY COUNTY LAT. 32.51 LONG.104.24
ELEVATION:3375.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.14	0.0	0.23	0.68	1.30	0.20	1.70	0.36	0.32	0.66	0.0	0.29	6.38
1954	0.0	0.0	0.0	0.83	0.85	0.29	0.14	3.57	0.0	3.43	0.0	0.12	9.23
1955	0.44	0.0	0.0	0.15	0.63	0.34	3.95	0.45	1.34	1.85	0.24	0.0	9.39
1956	0.0	0.45	0.0	0.0	0.91	2.08	0.31	1.68	0.12	0.87	0.0	0.0	6.92
1957	0.15	0.28	0.26	0.0	0.83	0.0	0.60	0.47	0.0	2.48	0.64	0.0	5.76
1958	1.44	1.14	2.67	1.19	0.14	2.97	1.34	2.36	4.76	1.79	0.70	0.0	20.20
1959	0.0	0.13	0.0	0.19	2.48	0.31	2.15	0.29	0.0	0.23	0.0	0.28	6.06
1960	0.92	0.18	0.14	0.29	0.16	1.18	3.74	0.74	0.20	3.26	0.11	1.69	12.61
1961	0.71	0.16	0.45	0.0	0.48	0.99	0.99	1.10	0.27	0.14	1.41	0.30	7.00
1962	0.45	0.41	0.11	0.67	0.56	0.92	3.31	0.21	2.31	1.39	0.25	0.62	11.31
1963	0.0	0.68	0.0	0.11	0.92	1.39	0.18	2.11	0.0	0.17	0.16	0.0	5.72
1964	0.0	0.23	0.32	0.0	0.81	1.71	0.0	0.80	0.71	0.0	0.17	0.23	5.03
1965	0.0	0.36	0.0	0.0	0.82	0.54	1.64	2.05	0.67	0.11	0.0	1.03	7.52
1966	0.50	0.0	0.58	1.23	0.39	1.07	0.40	6.57	0.59	0.0	0.0	0.0	11.43
1967	0.0	0.15	0.0	0.0	1.50	0.46	0.67	2.06	0.68	0.0	0.65	0.49	6.76
1968	1.61	0.99	1.39	0.16	0.84	0.30	4.72	2.52	0.06	0.73	1.26	0.24	14.82
MEAN	0.40	0.32	0.38	0.34	0.87	0.94	1.65	1.73	0.75	1.07	0.35	0.33	9.13

NAME: FELIX
LOCATION: CHAVEZ COUNTY LAT. 33.00 LONG.105.06
ELEVATION:5300.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.0	0.10	0.42	0.60	0.50	0.47	0.54	0.45	0.0	0.39	0.18	0.67	4.32
1954	0.0	0.0	0.0	0.45	0.51	0.0	0.10	3.89	0.49	6.90	0.0	0.26	12.60
1955	0.60	0.0	0.0	0.16	1.23	0.0	7.64	1.25	4.80	2.24	0.14	0.0	18.06
1956	0.0	1.56	0.0	0.0	0.0	0.0	1.08	2.36	0.30	0.50	0.0	0.0	5.80
1957	0.0	0.53	0.70	0.95	0.54	0.0	1.72	3.44	0.11	5.23	1.60	0.0	14.82
1958	1.05	1.02	2.07	0.64	1.12	0.50	2.44	3.10	3.34	3.30	0.36	0.0	18.94
1959	0.0	0.22	0.0	0.18	2.71	0.0	1.65	3.23	0.0	0.25	0.0	0.97	9.21
1960	0.54	0.40	0.18	0.0	0.26	2.07	3.57	0.32	0.82	2.08	0.24	1.43	11.91
1961	0.81	0.0	0.93	0.0	0.30	1.30	2.43	1.88	0.26	0.15	1.97	0.40	10.43
1962	0.34	0.0	0.47	0.04	0.15	1.08	4.49	0.0	0.78	0.95	1.33	0.82	10.45
1963	1.16	0.55	0.0	0.09	1.05	2.00	1.05	5.31	0.39	0.61	0.0	0.0	12.21
1964	0.17	0.41	0.33	0.0	0.0	0.51	0.30	1.05	2.25	0.0	0.0	0.54	5.56
1965	0.0	0.76	0.38	0.98	2.33	2.68	2.51	3.28	3.22	0.0	0.38	0.64	17.16
1966	0.36	0.0	0.11	2.76	0.31	2.27	0.31	9.44	0.66	0.0	0.0	0.0	16.22
1967	0.10	0.25	0.10	0.17	0.30	4.02	2.38	1.10	2.42	0.0	0.20	0.76	11.80
1968	1.07	1.04	0.90	0.13	0.60	0.0	7.90	1.04	0.0	0.51	0.92	0.0	14.11
MEAN	0.39	0.43	0.41	0.45	0.74	1.06	2.51	2.57	1.24	1.44	0.46	0.41	12.10

NAME: ELK 3 E
LOCATION: CHAVEZ COUNTY LAT. 32.56 LONG.105.17
ELEVATION:5700.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.20	0.17	0.29	0.87	0.92	1.44	1.32	1.63	0.0	0.71	0.10	1.22	8.87
1954	0.45	0.0	0.0	0.95	1.77	0.61	0.21	5.34	0.85	4.30	0.0	0.43	14.91
1955	0.81	0.0	0.30	0.19	0.06	0.31	9.02	2.80	2.39	1.76	0.0	0.0	17.64
1956	0.0	1.53	0.0	0.15	0.77	1.05	1.52	1.91	0.30	0.94	0.0	0.30	8.47
1957	0.12	0.60	0.49	0.83	0.90	0.21	2.25	6.55	0.35	3.62	2.45	0.0	18.37
1958	1.18	1.33	2.23	0.68	0.91	2.42	3.07	2.77	4.14	3.33	0.60	0.20	22.86
1959	0.0	0.21	0.10	0.12	1.30	1.35	2.06	3.66	0.12	0.41	0.0	1.07	10.40
1960	0.60	0.38	0.28	0.02	0.42	1.80	5.19	2.80	1.87	1.55	0.0	2.32	17.23
1961	0.58	0.13	0.58	0.05	0.37	1.64	0.98	4.03	1.52	0.15	2.68	0.18	12.89
1962	0.53	0.60	0.50	0.55	0.0	1.21	7.43	0.55	5.84	1.73	0.85	0.83	20.62
1963	0.75	0.71	0.0	2.33	1.30	1.11	2.37	4.71	1.20	1.03	0.26	0.0	15.77
1964	0.22	1.26	0.70	0.15	0.27	0.0	2.14	1.12	2.33	0.0	0.11	0.54	8.84
1965	0.02	1.05	0.44	0.57	1.41	2.04	1.11	1.65	4.36	0.15	0.05	1.18	14.03
1966	0.62	0.15	0.20	3.27	0.61	4.69	1.22	5.85	1.36	0.10	0.05	0.07	18.19
1967	0.05	0.48	0.01	0.14	0.35	1.51	2.17	1.87	2.95	0.01	0.59	1.32	11.45
1968	1.16	0.96	1.46	0.10	0.27	0.26	7.13	6.89	0.07	0.78	1.52	0.20	20.80
MEAN	0.46	0.60	0.47	0.69	0.73	1.35	3.07	3.38	1.85	1.29	0.58	0.62	15.08

NAME: FARNSWORTH
LOCATION: LINCOLN COUNTY LAT. 33.54 LONG.105.00
ELEVATION:5400.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.15	0.33	0.37	0.39	0.87	0.30	2.65	1.80	0.0	0.49	0.25	0.07	7.67
1954	0.16	0.0	0.02	0.41	1.70	0.11	1.32	5.53	2.61	2.50	0.0	0.38	14.74
1955	0.13	0.01	0.09	0.54	0.38	0.49	2.42	0.51	2.80	0.11	0.0	0.10	7.58
1956	0.03	0.48	0.05	0.45	0.40	1.56	1.28	0.95	0.0	0.28	0.0	0.03	5.51
1957	0.0	1.06	0.90	0.50	1.28	0.28	1.06	2.63	0.0	1.51	0.52	0.0	9.74
1958	0.70	0.89	3.63	1.00	0.31	2.62	1.67	4.82	6.05	0.88	0.0	0.10	22.67
1959	0.0	0.15	0.0	0.98	1.28	2.18	1.96	4.83	0.27	1.05	0.0	1.75	14.45
1960	0.45	0.26	0.10	0.0	0.95	2.75	7.09	0.08	0.79	3.26	0.0	1.76	17.49
1961	0.45	0.10	1.49	0.36	0.11	1.00	1.31	0.65	0.89	0.46	1.70	0.31	8.83
1962	0.0	0.15	0.12	0.21	0.0	1.57	4.34	1.63	2.11	0.52	0.22	0.42	11.29
1963	0.0	0.17	0.0	0.25	0.0	0.11	0.0	1.96	0.67	0.76	0.06	0.0	3.98
1964	0.01	0.0	0.0	0.10	0.18	0.76	0.0	0.74	1.14	0.0	0.0	0.26	3.19
1965	0.0	0.20	0.0	0.0	1.83	2.04	1.93	0.16	0.76	0.32	0.23	0.19	7.66
1966	0.21	0.06	0.0	0.30	0.44	0.14	0.56	5.03	0.02	0.0	0.08	0.06	6.90
1967	0.0	0.22	0.14	0.02	0.09	0.69	1.57	1.52	0.49	0.0	0.10	0.48	5.32
1968	1.30	1.25	0.84	0.05	0.55	0.35	4.42	4.38	0.22	0.40	0.57	0.20	14.53
MEAN	0.22	0.33	0.48	0.35	0.65	1.06	2.10	2.33	1.18	0.78	0.23	0.38	10.10

NAME: DUNLAP
LOCATION: DE BACA COUNTY LAT. 34.05 LONG.104.32
ELEVATION:4050.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.18	0.42	0.05	0.41	1.62	0.58	2.78	0.73	0.0	0.39	0.47	0.10	7.73
1954	0.07	0.0	0.01	0.49	2.29	1.20	0.05	2.23	1.03	4.19	0.0	0.11	11.67
1955	0.15	0.01	0.07	0.92	0.16	0.10	0.81	0.34	1.85	0.87	0.0	0.0	5.28
1956	0.11	0.35	0.0	0.26	0.69	0.44	0.73	0.78	0.0	0.13	0.03	0.01	3.53
1957	0.0	0.53	1.03	0.58	2.94	0.04	0.76	0.67	0.12	1.84	0.40	0.0	8.91
1958	1.00	0.31	3.05	0.86	0.75	0.42	2.88	2.91	5.53	0.74	0.11	0.20	18.76
1959	0.0	0.07	0.0	0.70	0.94	3.66	4.04	1.31	0.0	0.76	0.03	1.63	13.14
1960	0.84	0.35	0.22	0.0	0.60	2.70	12.96	1.02	0.35	4.34	0.03	1.17	24.58
1961	0.0	0.03	0.50	0.63	1.04	0.44	1.65	1.18	1.63	0.0	0.0	0.0	7.10
1962	0.43	0.29	0.17	0.31	0.04	1.93	1.97	0.11	1.94	0.34	0.33	0.0	7.86
1963	0.0	0.0	0.0	0.31	0.30	0.71	0.19	3.36	0.10	0.48	0.11	0.28	5.84
1964	0.0	0.35	0.13	0.0	0.0	0.0	1.41	1.23	1.04	0.0	0.76	0.0	4.92
1965	0.0	0.20	0.0	0.0	1.83	2.04	1.93	0.16	0.76	0.32	0.23	0.19	7.66

NAME: PICACHO
LOCATION: LINCOLN COUNTY LAT. 33.21 LONG.105.08
ELEVATION:4965.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.26	0.0	0.45	0.34	0.54	0.37	3.42	0.57	0.0	0.17	0.21	1.00	7.33
1954	0.24	0.0	0.0	0.12	2.67	0.35	1.39	4.34	4.39	7.15	0.0	0.32	20.97
1955	0.21	0.0	0.12	0.0	0.0	0.26	8.56	2.27	2.78	1.02	0.05	0.0	15.27
1956	0.0	1.60	0.0	0.0	1.28	0.98	1.32	0.73	0.0	0.34	0.0	0.18	6.43
1957	0.0	0.86	0.32	0.33	1.54	0.20	1.95	3.29	0.68	2.00	1.14	0.0	12.31
1958	0.63	1.00	2.44	0.69	0.60	1.06	1.66	1.80	4.77	2.70	0.13	0.32	17.30
1959	0.0	0.0	0.0	0.48	1.50	1.52	2.26	3.09	0.0	0.37	0.11	1.30	10.63
1960	0.24	0.14	0.17	0.0	1.01	1.61	4.29	0.99	0.29	1.75	0.02	2.16	12.67
1961	0.29	0.10	1.29	0.13	0.48	0.93	1.21	4.75	1.92	0.19	1.10	0.28	12.67
1962	0.30	0.53	0.08	0.41	0.0	0.62	3.46	0.10	3.36	0.73	0.44	0.55	10.58
1963	0.32	0.21	0.0	0.05	0.69	0.69	0.66	1.90	1.55	0.43	0.27	0.01	6.80
1964	0.31	0.47	0.28	0.09	0.28	1.57	1.02	1.69	4.55	0.04	0.15	0.28	10.73
1965	0.0	0.91	0.19	0.83	0.47	2.99	2.71	1.45	2.91	0.12	0.0	0.44	13.02
1966	0.45	0.01	0.0	2.62	0.18	1.42	0.77	4.75	0.95	0.0	0.0	0.02	11.17
1967	0.03	0.33	0.06	0.0	0.11	3.56	1.08	2.93	1.24	0.07	0.20	0.56	10.17
1968	1.38	1.01	1.09	0.13	0.98	0.27	5.56	3.51	0.11	0.46	0.89	0.23	15.62
MEAN	0.29	0.45	0.41	0.39	0.77	1.15	2.58	2.38	1.84	1.10	0.29	0.48	12.14

NAME: SOCORRO
LOCATION: SOCORRO COUNTY LAT. 34.04 LONG.106.54
ELEVATION:4617.FEET

YR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
1953	0.0	0.91	0.83	1.52	0.05	1.74	1.58	1.55	0.24	0.53	0.26	0.10	9.31
1954	0.16	0.0	0.46	0.35	0.57	0.23	0.55	3.58	1.24	0.16	0.0	0.0	7.30
1955	0.49	0.0	0.0	0.0	0.06	0.60	2.29	1.69	0.14	0.95	0.0	0.18	6.40
1956	0.18	0.35	0.0	0.0	0.03	0.43	1.36	0.16	0.0	0.52	0.0	0.0	3.03
1957	0.21	0.60	0.80	0.40	0.20	0.15	1.92	2.73	0.12	3.34	0.56	0.06	11.09
1958	0.55	0.05	1.89	1.25	0.60	0.63	0.57	0.49	2.56	2.48	0.16	0.27	11.50
1959	0.02	0.06	0.34	0.35	0.50	0.08	1.26	1.30	0.0	1.87	0.11	1.75	7.64
1960	0.11	0.36	0.19	0.0	0.33	1.35	1.80	0.78	0.46	2.66	0.01	2.34	10.39
1961	0.22	0.19	0.27	0.24	0.33	0.70	1.96	1.69	1.15	0.15	0.97	0.49	8.36
1962	0.73	0.04	0.36	0.14	0.0	0.40	1.58	0.16	1.07	0.81	0.09	0.28	5.66
1963	0.08	0.55	0.15	0.25	0.11	0.09	0.28	2.16	1.03	0.98	0.27	0.0	5.95
1964	0.03	0.58	0.04	0.91	0.33	0.0	2.41	0.62	1.20	0.08	0.05	0.15	6.40
1965	0.19	0.07	0.09	0.19	0.28	0.39	0.97	1.55	1.80	0.0	0.02	1.52	7.07
1966	0.69	0.10	0.10	0.13	0.0	1.77	1.35	0.66	1.13	0.0	0.0	0.06	5.99
1967	0.0	0.25	0.08	0.0	0.0	0.75	1.77	1.90	2.24	0.20	0.51	1.54	9.24
1968	0.40	0.48	0.91	0.06	0.71	0.05	3.32	2.81	0.90	0.59	1.08	0.20	11.51
MEAN	0.25	0.29	0.41	0.36	0.26	0.58	1.56	1.49	0.95	0.96	0.26	0.56	7.93

Appendix E.

Short-record observations of tritium in deep wells.

NO		OWNER	WELL NO	DATE			TU	+OR-	LAB NO
				YR	MO	DY			
1	(1)	SAN ANDRES LS	DEPTH 640' CASED TO 614'						TEMP 70F
1	A	E.P.N.G.(2)	6 24 31 344	1960	10		104.	5.	441
1	B	E.P.N.G.	6 24 31 344	1961	8		5.	2.	479
2		SAN ANDRES LS	DEPTH 820' CASED TO 289'				PUMP	1500GPM	TEMP 69F
2	A	I.GARNER	9 23 36 133	1961	4	7	29.	2.	446
2	B	I.GARNER	9 23 36 133	1961	6	9	12.	2.	462
2	C	I.GARNER	9 23 36 133	1961	7	11	9.	2.	465
2	D	I.GARNER	9 23 36 133	1961	8	21	4.	2.	474
2	E	I.GARNER	9 23 36 133	1962	2	20	21.	4.	702
2	F	I.GARNER	9 23 36 133	1962	3	19	31.	1.	626
2	G	I.GARNER	9 23 36 133	1962	4	23	85.	2.	685
2	H	I.GARNER	9 23 36 133	1962	5	21	93.	2.	691
2	I	I.GARNER	9 23 36 133	1962	6	11	95.	2.	652
3		GLORIETA SS	DEPTH 603'				PUMP	5GPM	TEMP 66F
3	A	M&W RANCH	10 21 24 322A	1959	3		23.	2.	329
4		SAN ANDRES LS	DEPTH 561' CASED TO 180'						
4	A	ROSWELL #11	10 23 34 432A	1961	8		10.	2.	480
5		SAN ANDRES LS	DEPTH> 833'						
5	A	USGS WELL	10 24 4 410	1965	11		111.	3.	1061
5	B	USGS WELL	10 24 4 410	1966	2		176.	4.	1053
6		SAN ANDRES LS	DEPTH 379' SAMPLE 259'- 379' NM TECH TEST						FLOW
6	A	C. NELSON	10 24 26 143A	1966	12	20	33.	3.	1376

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(1) Numbers refer to well localities on Figure 2 7. Each capital letter represents one sample in chronological sequence.

(2) El Paso Natural Gas

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 NO        OWNER            WELL NO          DATE         TU      +OR-       LAB NO
                                           YR  MO DY
-----  -------------  -------------    ----------    -------    ----    ----------
 7      SAN ANDRES LS  DEPTH  328' SAMPLE  257'- 328' NM TECH TEST        FLOW
 7 A      C. NELSON    10 24 26 148    1966 12 19    32.          3.      1152

 8      SAN ANDRES LS  DEPTH  670' CASED TO  585'    FLOW   470GPM     16,400PPM
 8 A      PVACD        10 25 14 312    1961  7       47.          2.       458

 9      CHALK BLUFF+SA DEPTH  533' CASED TO 533'     FLOW               TEST WELL
 9 A      ROSWELL #2   10 25 32 423    1961  4       58.          2.       453
 9 B      ROSWELL #2   10 25 32 423    1961  8        6.          2.       483

10      CHALK BLUFF+SA DEPTH 595'                    FLOW 2500GPM
10 A      ROSWELL      10 25 33 423    1961  8        5.          2.       484

11      YESO FM        DEPTH  800' CASED TO  791'    FLOW     3GPM      TEMP 62F
11 A      JONES PERRY  11 15 12 112    1959  4 24    20.          1.       378

12      YESO FM        DEPTH  650'                   FLOW     2GPM      TEMP 62F
12 A      E. MCDANIEL  11 15 34 142    1959  4 24    31.          1.       381

13      SAN ANDRES LS  DEPTH  233' CASED TO   85'    PUMP 1200GPM
13 A      BROWN BROS.  11 23 22 444    1959  2 10    23.          3.       328
13 B      BROWN BROS.  11 23 22 444    1959  4 10     9.          1.       370
13 C      BROWN BROS.  11 23 22 444    1961  4  7    67.          3.       445
13 D      BROWN BROS.  11 23 22 444    1961  8 21     3.          1.       477
13 E      BROWN BROS.  11 23 22 444    1962  5 21   198.          6.       621
13 F      BROWN BROS.  11 23 22 444    1962  7 19    49.         14.       677
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NO	OWNER	WELL NO	DATE			TU	+OR-	LAB NO
			YR	MO	DY			
14	SAN ANDRES LS	DEPTH 796'	CASED TO 595'			FLOW (ALSO FLOW 477'-487')		
14 A	(1) PVACD 2 FLOW	11 25 8 422	1959	1	27	11.	2.	323
14 B	PVACD 3 FLOW	11 25 8 422	1959	1	27	9.	2.	319
14 C	PVACD 2 FLOW	11 25 8 422	1961	4	29	20.	1.	449
14 D	PVACD 3 FLOW	11 25 8 422	1961	4	29	15.	1.	452
14 E	PVACD 2 FLOW	11 25 8 422	1961	8	30	10.	1.	503
14 F	PVACD 3 FLOW	11 25 8 422	1961	8	30	18.	1.	507
15	SAN ANDRES LS	DEPTH 845'	CASED TO 687'			NM TECH TEST		FLOW
15 A	E. KING	11 25 14 332	1967	1	21	41.	2.	1146
16	SAN ANDRES LS	DEPTH 853'	SAMPLE A)0-752'			B)755-790'	C)793-853'	FLOW
16 A	E. KING	11 25 14 333	1963	11	22	435.	16.	816
16 B	E. KING	11 25 14 333	1963	11	22	159.	7.	815
16 C	E. KING	11 25 14 333	1963	11	22	272.	7.	818
17	SAN ANDRES LS	DEPTH 843'	CASED TO 643'			NM TECH TEST		FLOW
17 A	CLARDY #2	11 25 15 343	1967	1	18	40.	2.	1136
18	SAN ANDRES LS	DEPTH 847'				PUMP 1000GPM		
18 A	W.T. CLARDY	11 25 23 111	1971	10	26	11.	1.	1407
19	YESO FM	DEPTH 900'	SAMPLE 850'- 900'					
19 A	T.SLAUGHTER	12 18 14 311	1959	3		15.	2.	344
20	SAN ANDRES LS	DEPTH ---						
20 A	W&C RANCH	12 23 24 233	1961	8		12.	1.	481

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(1) Pecos Valley Artesian Conservancy District

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 NO        OWNER             WELL NO              DATE          TU        +OR-           LAB NO
                                               YR  MO DY
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21        SAN ANDRES LS   DEPTH    ---   WATER LEVEL 530' BELOW SURFACE        WINDMILL
21 A        H.H.MCGEE     13 22 20 133    1959  5        101.          10.          389

22        SAN ANDRES LS   DEPTH    ---   WATER LEVEL 300' BELOW SURFACE        WINDMILL
22 A        R.POLLARD     13 23 35 333    1959  3         20.           2.          374
22 B        R.POLLARD     13 23 35 333    1961  8         12.           1.          485

23        SAN ANDRES LS   DEPTH   853'   CASED TO 649'
23 A        KERR BROS.    13 25 28 421A   1961  8 21      13.           3.          472A
23 B        KERR BROS.    13 25 28 421A   1961 10  3      41.          29.          751
23 C        KERR BROS.    13 25 28 421A   1962  3  5     250.          12.          639
23 D        KERR BROS.    13 25 28 421A   1962  3 30     284.           3.          610
23 E        KERR BROS     13 25 28 421A   1962  5 15     192.           6.          623

24        SAN ANDRES LS   DEPTH   965' CASED TO   738'     NM TECH TEST          FLOW
24 A        BOSWELL FMS.  13 25 36 241    1967  1 26      19.           2.          1148

25        SAN ANDRES LS   DEPTH 1208'   CASED TO 880'     NM TECH TEST          FLOW
25 A        M. PIRTLE     13 26  3 144    1967  2 16      39.           2.          1143

26        SAN ANDRES LS   DEPTH   975' CASED TO   940'    PUMP-FLOW
26 A        TOWN-DEXTER   13 26 17 333    1961  9          7.           1.          486

27        SAN ANDRES LS   DEPTH   380' SAMPLE   368'- 380'                      WINDMILL
27 A        J.PRICE       14 22 13 444    1959  5         18.           2.          385
27 B        J.PRICE       14 22 13 444    1961  8          5.           1.          487
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NO	OWNER	WELL NO	DATE YR	MO	DY	TU	+OR-	LAB NO
28	SAN ANDRES LS	DEPTH 365'				PUMP 3000GPM		
28 A	CASAVEZ	14 23 24 122	1959	3		18.	2.	376
28 B	CASAVEZ	14 23 24 144	1961	8		11.	1.	489
29	SAN ANDRES LS?	DEPTH 951' CASED TO 724'				NM TECH TEST(LOW-K)PUMP		
29 A	LANGNEGGER	14 25 14 131	1967	1	20	5.	5.	1177
30	SAN ANDRES LS	DEPTH 1108'						
30 A	J.CHADWICK	14 25 28 113	1961	9	11	4.	1.	490
30 B	J.CHADWICK	14 25 28 113	1961	10	19	87.	18.	766
30 C	J.CHADWICK	14 25 28 113	1961	11	20	65.	3.	739
30 D	J.CHADWICK	14 25 28 113	1962	2	19	159.	10.	794
30 E	J.CHADWICK	14 25 28 113	1962	3	30	25.	4.	683
30 F	J.CHADWICK	14 25 28 113	1962	4	23	196.	2.	662
30 G	J.CHADWICK	14 25 28 113	1962	5	15	58.	2.	688
30 H	J.CHADWICK	14 25 28 113	1962	7	19	179.	8.	613
31	SAN ANDRES LS	DEPTH 306' CASED TO 300'				FLOW 1800GPM WL ABOVE LSD		
31 A	C.HENDRICKS	15 18 17 312	1959	5	11	113.	11.	394
32	SAN ANDRES LS	DEPTH 1022' CASED TO 757'				NM TECH TEST		
32 A	R. PEARSON	15 25 23 122	1967	1	27	15.	1.	1377
33	SAN ANDRES LS	DEPTH 1053' CASED TO 778'				NM TECH TEST		
33 A	H. MILLS	15 25 24 212	1967	2	2	29.	2.	1149
34	SAN ANDRES LS?	DEPTH 904' CASED TO 610'				NM TECH TEST		
34 A	M. PEARSON	15 25 33 333	1967	2	5	17.	2.	1147

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 NO          OWNER             WELL NO            DATE           TU        +OR-          LAB NO
                                               YR   MO DY
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35        SAN ANDRES LS    DEPTH   1155' CASED TO 875'       PUMP  1000GPM
35 A        W.NEEDHAM      15 26 18 122    1961   9           1.           1.              492

36        SAN ANDRES LS    DEPTH   830' CASED TO    20'  WL 810'BELOW LSD  WINDMILL 68F
36 A        R.J.PARKS      16 20 16 210    1959   5  6      23.           2.               390
36 B        R.J.PARKS      16 20 16 210    1961   9 12       1.           1.               493

37        SAN ANDRES LS    DEPTH   760' CASED TO    20'  WL 710'BELOW LSD  WINDMILL 66F
37 A        R.J.PARKS      16 21 19 220    1959   5  6      61.           3.               391
37 B        R.J.PARKS      16 21 19 220    1961   9 12       5.           1.               494

38        SAN ANDRES LS    DEPTH   685' CASED TO    20'  WL 660'BELOW LSD  WINDMILL 68F
38 A        D.W.RUNYUN     16 21 23 420    1959   5  6      13.           2.               343
38 B        D.W.RUNYUN     16 21 23 420    1961   9 12       5.           1.               497

39        SAN ANDRES LS? DEPTH   415'                        PUMP 2500GPM        TEMP 66F
39 A        C&M RANCH      16 24  4 230    1959   3 11       9.           2.               340
39 B        C&M RANCH      16 24  4 230    1961   9 15      10.           2.               518

40        SAN ANDRES LS    DEPTH   1156' CASED TO 490'       CONTAINS H2S
40 A        R.PEARSON      16 25  5 433    1959   3 10      32.           3.               332
40 B        R.PEARSON      16 25  5 433    1961   9 11      14.           1.               501

41        GRAYBURG FM+SA DEPTH   950'  CASED TO 950'       PUMP 1500 GPM
41 A        HAL BOGLE      16 26 14 342    1959   3 10       3.           5.               331
41 B        HAL BOGLE      16 26 14 342    1961   9  5      13.           3.               536
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  NO          OWNER           WELL NO          DATE          TU        +OR-       LAB NO
                                            YR   MO DY
-----    -------------  -------------   ----------   -------     ----     ----------
42         DEVONIAN DOLOM DEPTH 13395' SAMPLE 13368'-13395'  WATER FROM OIL WELL
42 A         "DEVONIAN"   16 32  2 412   1966 12  8      6.         1.          111C

43         SAN ANDRES LS  DEPTH   ---
43 A         SCHARBAUR    17 20   5 420   1961   9 12     17.         1.          498

44         SAN ANDRES LS  DEPTH  750'                    WINDMILL            TEMP 63F
44 A         E.F. HARRIS  17 21 17 410    1959   5        21.         2.          386

45         SAN ANDRES LS  DEPTH  600'
45 A         HOPE         17 23 30 123    1959   3 11     29.         3.          330
45 B         HOPE         17 23 30 123    1961   5 18     40.         2.          459A
45 C         HOPE         17 23 30 123    1961   9 12      2.        18.          538

46         SAN ANDRES LS  DEPTH   ---
46 A         P.CLEMENTS   17 24 16 433    1959   3 11     18.         2.          342
46 B         P.CLEMENTS   17 24 16 433    1961   9 18      4.         1.          475

47         GRAYBURG FM+SA DEPTH 1040'  CASED TO 643'                         TEMP 66F
47 A         O.HAYNES     17 26 11 433    1959   3 10     10.         2.          372

48         GRAYBURG FM    DEPTH 1220' CASED TO 1090'
48 A         K. STOUT     17 27 16 344    1961   9 20      9.         3.          559

49         GRAYBURG FM+SA DEPTH 1450'                                        TEMP 73F
49 A         D.W. RUNYUN  18 23 32 442    1961   9 19      4.         1.          524
```

NO	OWNER	WELL NO	DATE YR MO DY	TU	+OR-	LAB NO
50 50 A	GRAYBURG FM W.C.BRADSHAW	DEPTH 1108' 18 26 2 111	CASED TO 720' 1961 9 15	FLOWN 1959 11.	2.	520
51 51 A	GRAYBURG FM+SA J.E.WALDRIP	DEPTH 871' 18 26 34 313	CASED TO 500' 1961 9 15	ALWAYS PUMP 10.	1.	ODOR OF OIL 519
52 52 A	GRAYBURG FM K&W OIL CO.	DEPTH 2359' 18 28 8 243	SAMPLE 2330'-2335' 1962 5 29	16.	1.	TEMP 85F 512
53 53 A	SAN ANDRES LS? "BUNTING"	19 23 30 144	1961 9 19	PUMP 18.	5GPM 1.	TEMP 70F 523
54 54 A	GRAYBURG FM NEDS WELL	DEPTH 1500' 19 24 12 414	1961 9 20	PUMP 13.	3GPM 1.	TEMP 70F 504
55 55 A	GRAYBURG FM HNULIN	DEPTH 950' 19 26 34 312	1961 9	40.	7.	ODOR OF H2S 533

Appendix F.

Short-record observations of tritium in springs and shallow wells.

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  NO        OWNER      WELL OR SPRING     DATE          TU       +OR-        LAB NO
                            NO          YR  MO DY
-----   ------------- --------------  ----------  --------    ----       ----------
1 (1)  MICRO-GRANITE         SPRING    100GPM                              TEMP 48F
1 A      GRANTHAM SPR  8 16 30 342    1959  4            10.       2.          377

2      QUATERNARY ALLUVIUM SPRING       15 GPM HEAD OF LOST RIVER
2 A      ROSWELL SPR   9 25 31 443    1961  9             5.       3.          537

3      SAN ANDRES LS         SPRING              FRITZ SPRING
3 A      A.PFINGSTEN  10 17 29 414    1959  2            13.       2.          339

4      QUATERNARY ALLUVIUM SPRING       30 GPM ROSWELL COUNTRY CLUB
4 A      ROSWELL SPR  10 24 22 441    1961  8            25.       5.          521

5      QUATERNARY ALLUVIUM SPRING                NEAR BANK OF RIO HONDO    TEMP 63F
5 A      LANDER SPR   10 24 34 221A   1959  1            29.       4.          321
5 B      LANDER SPR   10 24 34 221A   1961  9            53.       3.          551

6      MANCOS SHALE          DEPTH  119'          GREEN MEADOW RUIDOSO     TEMP 54F
6 A      GREEN MGC    11 13 22 344    1959  4 24         13.       1.          380

7      YESO FM               SPRING    250GPM RUIDOSO
7 A      RUIDOSO SPR  11 14 28 321    1959  4 24         17.       1.          382

8      QUATERNARY ALLUVIUM SPRING                 SOJTH SPRING ROSWELL
8 A      SOUTH SPRING 11 25 18 111    1961  8            14.       1.          500

9      QUATERNARY ALLUVIUM DEPTH  235' CASED TO 235'
9 A      ST. N.M.     11 25 36 213C   1961  8            11.       3.          534
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(1) Numbers refer to well localities on Figure 2.7.

NO	OWNER	WELL OR SPRING NO	DATE YR MO DY	TU	+OR-	LAB NO
10	QUATERNARY ALLUVIUM DEPTH 262' CASED TO 262'					
10 A	F.PFEIFFER	13 25 14 231A	1961 11	52.	2.	731
11	QUATERNARY ALLUVIUM DEPTH 135' WATER LEVEL 12' BELOW SURFACE					
11 A	U.S.GOVT	13 26 16 114A	1961 11	106.	3.	735
12	QUATERNARY ALLUVIUM DEPTH 95' CASED TO 89'					
12 A	H. MENEFEE	14 26 3 433	1961 11	44.	4.	733
13	QUATERNARY ALLUVIUM DEPTH -- WATER LEVEL 25' BELOW SURFACE 50CGPM					
13 A	LANGNEGGER	15 26 29 342	1961 11	65.	5.	729
14	QUATERNARY ALLUVIUM DEPTH 200' SAMPLE 70'-200'					
14 A	A.J.TERRY	16 25 11 311	1961 11	31.	4.	727

Appendix G.

Long-record observations of tritium in deep wells.

G.1 Elk #1

Well field: 10-25-22-324

Location: NE of Roswell, Chaves Co., New Mexico

Owner: State Engineer Office

Date drilled: 1961

Elevation: 3650 feet

Water bearing formation: San Andres limestone

Total depth: 650 feet

Production interval: 621 to 650 feet (open hole)

Yield: flowing 1000 gpm (estimated) during winter (reported with samples 1058, 1072)

Use: observation well

Remarks: (a) This well was drilled for oil test and plugged back to 650 feet, it became an observation well in 1962.

(b) Although the well is not used regularly the silcock is rusty and leaks over 10 gallons per hour. The well casing contained about 1000 gallons so that water is replaced every 4 days and a monthly sample represents the formation water.

(c) Water is slightly salty, 2600 ppm chloride.

NO	OWNER	WELL NO	DATE			TU	+OR-	LAB NO
			YR	MO	DY			
1	ELK OIL CO.	10 25 22 324	1964	4		44.	2.	927
2	ELK OIL CO.	10 25 22 324	1964	5		45.	2.	948
3	ELK OIL CO.	10 25 22 324	1964	6		25.	12.	911
4	ELK OIL CO.	10 25 22 324	1964	9		21.	24.	924
5	ELK OIL CO.	10 25 22 324	1964	10		33.	5.	909
6	ELK OIL CO.	10 25 22 324	1964	11		18.	23.	925
7	ELK OIL CO.	10 25 22 324	1964	12		76.	2.	972
8	ELK OIL CO.	10 25 22 324	1965	5		51.	1.	971
9	ELK OIL CO.	10 25 22 324	1965	6		20.	1.	994
10	ELK OIL CO.	10 25 22 324	1965	7		40.	1.	1002
11	ELK OIL CO.	10 25 22 324	1965	8		52.	1.	1009
12	ELK OIL CO.	10 25 22 324	1965	10		107.	5.	1014
13	ELK OIL CO.	10 25 22 324	1965	11		102.	5.	1059
14	ELK OIL CO.	10 25 22 324	1966	1		127.	3.	1058
15	ELK OIL CO.	10 25 22 324	1966	3		98.	7.	1072
16	ELK OIL CO.	10 25 22 324	1966	4		67.	6.	1074
17	ELK OIL CO.	10 25 22 324	1966	5		28.	7.	1102
18	ELK OIL CO.	10 25 22 324	1966	6		5.	5.	1099
19	ELK OIL CO.	10 25 22 324	1966	7		58.	6.	1103
20	ELK OIL CO.	10 25 22 324	1966	8		22.	6.	1105
21	ELK OIL CO.	10 25 22 324	1966	9		85.	5.	1132
22	ELK OIL CO.	10 25 22 324	1966	10		48.	5.	1141
23	ELK OIL CO.	10 25 22 324	1966	11		93.	6.	1135
24	ELK OIL CO.	10 25 22 324	1966	12		21.	7.	1176
25	ELK OIL CO.	10 25 22 324	1967	2		15.	5.	1162
26	ELK OIL CO.	10 25 22 324	1967	3		19.	5.	1174
27	ELK OIL CO.	10 25 22 324	1968	1		14.	1.	1396
28	ELK OIL CO.	10 25 22 324	1968	6		26.	3.	1388
29	ELK OIL CO.	10 25 22 324	1971	2		23.	2.	1373
30	ELK OIL CO.	10 25 22 324	1971	7		9.	1.	1366

G.2 H. L. Woods (1)

Well field: 11-22-9-321 (SW 1/4)

Location: West of Roswell, Chaves Co., New Mexico

Owner: H. L. Woods

Date drilled: ----

Elevation: 3954 feet

Water bearing formation: San Andres limestone

Total depth: 435 feet

Production interval: unknown

Yield: 5 to 10 gpm, windmill

Use: stock, domestic and swimming pool

Remarks: Water was pumped into a closed storage tank with a capacity of 1000 gallons. Daily use between 1500 to 2500 gallons. Well mixed and composite sample. Located 1000 feet north of the Hondo creek. Sampled as Woods well until the end of 1964 when Woods (2) was drilled.

G.2 continued H. L. Woods (2)

Well field: 11-22-9-321 (NW 1/4)

Location: West of Roswell, Chaves Co., New Mexico

Owner: Mr. Wright

Date drilled: October 1964

Elevation: 3954 feet

Water bearing formation: San Andres limestone

Total depth: 578 feet

Production interval: 511 to 578 feet (perforated), pump at 555 feet below the surface.

Yield: depending on the season, from 1500 to 3500 gallons per day

Use: stock, domestic, and swimming pool

Remarks: The well is located 100 feet east from the abandoned Woods (1). Water level at completion was 420 feet below the surface which may explain the drilling of a new well (Woods (1) total depth = 435 feet). Pumped into a 3400 gallons closed pressure tank.

NO	OWNER	WELL NO	DATE YR MO DY	TU	+OR-	LAB NO
1	H.L.WOODS	11 22 9 321	1959 3	22.	3.	329
2	H.L.WOODS	11 22 9 321	1961 7	7.	3.	466A
3	H.L.WOODS	11 22 9 321	1961 8	8.	3.	535
4	H.L.WOODS	11 22 9 321	1961 9	215.	5.	607(1)
5	H.L.WOODS	11 22 9 321	1962 2	45.	5.	700
6	H.L.WOODS	11 22 9 321	1962 3	44.	4.	696
7	H.L.WOODS	11 22 9 321	1962 4	230.	9.	609
8	H.L.WOODS	11 22 9 321	1962 5	100.	5.	689
9	H.L.WOODS	11 22 9 321	1962 6	25.	5.	723
10	H.L.WOODS	11 22 9 321	1962 7	95.	45.	808
11	H.L.WOODS	11 22 9 321	1962 8	122.	3.	674
12	H.L.WOODS	11 22 9 321	1962 9	62.	2.	693
13	H.L.WOODS	11 22 9 321	1962 10	32.	28.	780
14	H.L.WOODS	11 22 9 321	1962 11	97.	2.	654
15	H.L.WOODS	11 22 9 321	1962 12	233.	7.	812
16	H.L.WOODS	11 22 9 321	1963 1	80.	7.	705
17	H.L.WOODS	11 22 9 321	1963 3	139.	18.	783
18	H.L.WOODS	11 22 9 321	1963 4	64.	14.	831
19	H.L.WOODS	11 22 9 321	1963 5	139.	18.	882
20	H.L.WOODS	11 22 9 321	1963 7	730.	32.	814
21	H.L.WOODS	11 22 9 321	1963 8	196.	50.	809
22	H.L.WOODS	11 22 9 321	1964 2	118.	5.	962
23	H.L.WOODS	11 22 9 321	1964 3	48.	2.	850
24	H.L.WOODS	11 22 9 321	1964 4	21.	2.	947
25	H.L.WOODS	11 22 9 321	1964 5	43.	2.	917
26	H.L.WOODS	11 22 9 321	1964 6	65.	6.	914
27	H.L.WOODS	11 22 9 321	1964 7	53.	3.	920
28	H.L.WOODS	11 22 9 321	1964 9	87.	13.	918
29	H.L.WOODS	11 22 9 321	1964 10	112.	18.	922
30	H.L.WOODS	11 22 9 321	1964 12	42.	2.	978
31	H.L.WOODS	11 22 9 321	1965 5	24.	2.	988
32	H.L.WOODS	11 22 9 321	1965 6	31.	2.	991
33	H.L.WOODS	11 22 9 321	1965 7	29.	3.	1000
34	H.L.WOODS	11 22 9 321	1965 8	47.	5.	1010
35	H.L.WOODS	11 22 9 321	1965 10	114.	5.	1012
36	H.L.WOODS	11 22 9 321	1965 11	84.	6.	1056

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(1) Questionable data (LAB NO 607)

NO	OWNER	WELL NO	DATE YR	 MO	 DY	TU	+OR-	LAB NO
37	H.L.WOODS	11 22 9 321	1966	2		105.	3.	1055
38	H.L.WOODS	11 22 9 321	1966	3		156.	7.	1073
39	H.L.WOODS	11 22 9 321	1966	4		92.	8.	1075
40	H.L.WOODS	11 22 9 321	1966	5		13.	5.	1160
41	H.L.WOODS	11 22 9 321	1966	6		4.	6.	1166
42	H.L.WOODS	11 22 9 321	1966	7		21.	6.	1159
43	H.L.WOODS	11 22 9 321	1966	8		17.	6.	1171
44	H.L.WOODS	11 22 9 321	1966	9		49.	9.	1168
45	H.L.WOODS	11 22 9 321	1966	10		13.	5.	1157
46	H.L.WOODS	11 22 9 321	1966	11		10.	5.	1158
47	H.L.WOODS	11 22 9 321	1966	12		51.	6.	1144
48	H.L.WOODS	11 22 9 321	1967	2		16.	5.	1163
49	H.L.WOODS	11 22 9 321	1967	3		11.	5.	1170
50	H.L.WOODS	11 22 9 321	1967	6		19.	5.	1230
51	H.L.WOODS	11 22 9 321	1967	10		13.	1.	1415
52	H.L.WOODS	11 22 9 321	1968	2		14.	1.	1397A
53	H.L.WOODS	11 22 9 321	1968	4		10.	1.	1394
54	H.L.WOODS	11 22 9 321	1968	5		16.	2.	1392
55	H.L.WOODS	11 22 9 321	1968	7		80.	8.	1386
56	H.L.WOODS	11 22 9 321	1968	8		10.	1.	1390
57	H.L.WOODS	11 22 9 321	1969	1		17.	2.	1420
58	H.L.WOODS	11 22 9 321	1971	7		8.	4.	1368
59	H.L.WOODS	11 22 9 321	1971	10		8.	1.	1404
60	H.L.WOODS	11 22 9 321	1971	10		10.	1.	1411

G. 3 B. T. Allison

Well field: 11-24-25-341 (RA - 1015/1012)

Location: SW of Roswell, Chaves Co., New Mexico

Owner: Mrs. B. T. Allison

Date drilled: February 1952

Elevation: 3575 feet

Water bearing formation: Grayburg-Queen (depth to top of Grayburg - 454 feet)

Total depth: 678 feet

Production interval: 461 to 678 feet

Yield: 1200 to 2000 gpm pump estimated (reported with samples 542, 701 737, 745, 762, 778, 801)

Use: irrigation

Remarks: This well is not flowing at any time so that sample collection can be done only during irrigation.

NO	OWNER	WELL NO	DATE YR	 MO	 DY	TU	+OR-	LAB NO
1	B.T.ALLISON	11 24 25 341	1959	1		16.	3.	314
2	B.T.ALLISON	11 24 25 341	1961	8		16.	4.	542
3	B.T.ALLISON	11 24 25 341	1961	9		67.	2.	762
4	B.T.ALLISON	11 24 25 341	1961	10		135.	19.	768
5	B.T.ALLISON	11 24 25 341	1961	11		3.	25.	747
6	B.T.ALLISON	11 24 25 341	1962	2		45.	3.	753
7	B.T.ALLISON	11 24 25 341	1962	3		207.	6.	680
8	B.T.ALLISON	11 24 25 341	1962	4		119.	6.	719
9	B.T.ALLISON	11 24 25 341	1962	5		79.	3.	737
10	B.T.ALLISON	11 24 25 341	1962	6		27.	3.	745
11	B.T.ALLISON	11 24 25 341	1962	7		67.	2.	653
12	B.T.ALLISON	11 24 25 341	1962	8		202.	10.	649
13	B.T.ALLISON	11 24 25 341	1962	9		46.	10.	709
14	B.T.ALLISON	11 24 25 341	1962	10		19.	5.	701
15	B.T.ALLISON	11 24 25 341	1962	11		78.	8.	642
16	B.T.ALLISON	11 24 25 341	1962	12		132.	50.	779
17	B.T.ALLISON	11 24 25 341	1963	1		58.	28.	771
18	B.T.ALLISON	11 24 25 341	1963	3		221.	24.	801
19	B.T.ALLISON	11 24 25 341	1963	4	2	82.	24.	778
20	B.T.ALLISON	11 24 25 341	1963	4	26	59.	13.	869
21	B.T.ALLISON	11 24 25 341	1963	5		21.	1.	877
22	B.T.ALLISON	11 24 25 341	1963	8		395.	9.	811
23	B.T.ALLISON	11 24 25 341	1963	10		229.	14.	847
24	B.T.ALLISON	11 24 25 341	1964	2		83.	1.	939
25	B.T.ALLISON	11 24 25 341	1964	3		126.	12.	849
26	B.T.ALLISON	11 24 25 341	1964	4		16.	4.	912
27	B.T.ALLISON	11 24 25 341	1964	5		37.	16.	923
28	B.T.ALLISON	11 24 25 341	1964	6		40.	1.	946
29	B.T.ALLISON	11 24 25 341	1964	7		49.	1.	945
30	B.T.ALLISON	11 24 25 341	1964	8		40.	4.	910
31	B.T.ALLISON	11 24 25 341	1964	10		25.	1.	926
32	B.T.ALLISON	11 24 25 341	1964	12		70.	1.	979
33	B.T.ALLISON	11 24 25 341	1965	2		55.	1.	968
34	B.T.ALLISON	11 24 25 341	1965	3		12.	1.	983
35	B.T.ALLISOM	11 24 25 341	1965	4		24.	1.	987
36	B.T.ALLISON	11 24 25 341	1965	6		16.	1.	995

NO	OWNER	WELL NO	DATE YR	MO	DY	TU	+OR-	LAB NO
37	B.T.ALLISON	11 24 25 341	1965	7		74.	1.	1004
38	B.T.ALLISON	11 24 25 341	1965	8		40.	1.	1011
39	B.T.ALLISON	11 24 25 341	1965	10		130.	5.	1057
40	B.T.ALLISON	11 24 25 341	1965	11		164.	3.	1052
41	B.T.ALLISON	11 24 25 341	1966	3		164.	3.	1064
42	B.T.ALLISON	11 24 25 341	1966	4		97.	3.	1066
43	B.T.ALLISON	11 24 25 341	1966	6		26.	5.	1100
44	B.T.ALLISON	11 24 25 341	1966	7		35.	4.	1101
45	B.T.ALLISON	11 24 25 341	1966	8		46.	7.	1090
46	B.T.ALLISON	11 24 25 341	1966	9		57.	6.	1124
47	B.T.ALLISON	11 24 25 341	1967	7		12.	1.	1417
48	B.T.ALLISON	11 24 25 341	1967	11		17.	2.	1418
49	B.T.ALLISON	11 24 25 341	1968	5		17.	2.	1225
50	B.T.ALLISON	11 24 25 341	1971	7		16.	2.	1364

G.4 W. T. Clardy (Oasis well)

Well field: 11-25-15-343 (RA - 1102)

Location: SW of Roswell, Chaves Co., New Mexico

Owner: W. T. Clardy

Date drilled: February 1931

Elevation: 3475 feet

Water bearing formation: San Andres limestone (depth to top of ls 565')

Total depth: 843 feet

Production interval: 643 to 843 feet

Yield: 2000 to 3000 gpm flow estimated (reported with samples 464, 617, 648, 704, 743, 930, 932)

Use: irrigation

Remarks: casing (12.5") to 643 feet, open hole below that. Pump installed 31 May 1963. Considered as the best flowing well in the basin.

NO	OWNER	WELL NO	DATE YR	MO	DY	TU	+OR-	LAB NO
1	W.T.CLARDY	11 25 15 343	1959	1		8.	1.	327
2	W.T.CLARDY	11 25 15 343	1961	7		6.	2.	464
3	W.T.CLARDY	11 25 15 343	1961	8		5.	1.	499
4	W.T.CLARDY	11 25 15 343	1961	9		201.	4.	799
5	W.T.CLARDY	11 25 15 343	1961	10		21.	2.	547
6	W.T.CLARDY	11 25 15 343	1961	11		1.	27.	756
7	W.T.CLARDY	11 25 15 343	1962	2		662.	26.	757
8	W.T.CLARDY	11 25 15 343	1962	3		79.	24.	761
9	W.T.CLARDY	11 25 15 343	1962	4		107.	4.	743
10	W.T.CLARDY	11 25 15 343	1962	5		86.	7.	648
11	W.T.CLARDY	11 25 15 343	1962	6		66.	3.	754
12	W.T.CLARDY	11 25 15 343	1962	7		180.	5.	617
13	W.T.CLARDY	11 25 15 343	1962	8		60.	6.	704
14	W.T.CLARDY	11 25 15 343	1962	9		96.	1.	636
15	W.T.CLARDY	11 25 15 343	1962	10		176.	1.	628
16	W.T.CLARDY	11 25 15 343	1962	11		13.	19.	775
17	W.T.CLARDY	11 25 15 343	1962	12		216.	34.	782
18	W.T.CLARDY	11 25 15 343	1963	1		102.	32.	773
19	W.T.CLARDY	11 25 15 343	1963	3		124.	1.	669
20	W.T.CLARDY	11 25 15 343	1963	4	3	119.	7.	791
21	W.T.CLARDY	11 25 15 343	1963	4	26	48.	7.	890
22	W.T.CLARDY	11 25 15 343	1963	5	31	90.	13.	864
23	W.T.CLARDY	11 25 15 343	1963	5	31	81.	10.	862
24	W.T.CLARDY	11 25 15 343	1964	2		59.	1.	963
25	W.T.CLARDY	11 25 15 343	1964	3		7.	5.	1165
26	W.T.CLARDY	11 25 15 343	1964	4		90.	1.	952
27	W.T.CLARDY	11 25 15 343	1964	5		68.	1.	932
28	W.T.CLARDY	11 25 15 343	1964	6		90.	1.	936
29	W.T.CLARDY	11 25 15 343	1964	7		54.	1.	950
30	W.T.CLARDY	11 25 15 343	1964	9		41.	1.	930
31	W.T.CLARDY	11 25 15 343	1964	11		32.	2.	929
32	W.T.CLARDY	11 25 15 343	1964	12		25.	2.	969
33	W.T.CLARDY	11 25 15 343	1965	5		24.	2.	989
34	W.T.CLARDY	11 25 15 343	1965	6		16.	2.	992
35	W.T.CLARDY	11 25 15 343	1965	7		27.	1.	1007
36	W.T.CLARDY	11 25 15 343	1965	8		106.	3.	1013

NO	OWNER	WELL NO	DATE YR	MU	DY	TU	+OR-	LAB NO
37	W.T.CLARDY	11 25 15 343	1965	10		88.	2.	1015
38	W.T.CLARDY	11 25 15 343	1965	11		147.	3.	1063
39	W.T.CLARDY	11 25 15 343	1966	1		100.	3.	1050
40	W.T.CLARDY	11 25 15 343	1966	3		91.	7.	1069
41	W.T.CLARDY	11 25 15 343	1966	4		169.	8.	1068
42	W.T.CLARDY	11 25 15 343	1966	5		32.	7.	1093
43	W.T.CLARDY	11 25 15 343	1966	7		22.	9.	1089
44	W.T.CLARDY	11 25 15 343	1966	8		61.	6.	1094
45	W.T.CLARDY	11 25 15 343	1966	9		73.	5.	1133
46	W.T.CLARDY	11 25 15 343	1966	10		103.	8.	1134
47	W.T.CLARDY	11 25 15 343	1966	12		31.	4.	1139
48	W.T.CLARDY	11 25 15 343	1967	2		54.	5.	1138
49	W.T.CLARDY	11 25 15 343	1967	3		24.	6.	1167
50	W.T.CLARDY	11 25 15 343	1967	8		13.	1.	1416
51	W.T.CLARDY	11 25 15 343	1968	3		50.	5.	1399
52	W.T.CLARDY	11 25 15 343	1968	5		16.	2.	1379
53	W.T.CLARDY	11 25 15 343	1968	6		11.	1.	1378
54	W.T.CLARDY	11 25 15 343	1968	7		26.	5.	1231
55	W.T.CLARDY	11 25 15 343	1968	8		18.	2.	1389
56	W.T.CLARDY	11 25 15 343	1968	9		16.	2.	1400
57	W.T.CLARDY	11 25 15 343	1969	1		13.	1.	1419
58	W.T.CLARDY	11 25 15 343	1971	7	6	8.	4.	1365
59	W.T.CLARDY	11 25 15 343	1971	7	6	11.	1.	1370
60	W.T.CLARDY	11 25 15 343	1971	10	26	13.	1.	1408
61	W.T.CLARDY	11 25 15 343	1971	10	26	9.	1.	1409

G. 5 J. Patterson

Well field: 12-23-6-214 (RA - 2888)

Location: SW of Roswell, Chaves Co., New Mexico

Owner: J. Patterson

Date drilled: ----

Elevation: 3835 feet

Water bearing formation: Grayburg + San Andres limestone

Total depth: 665 feet

Production interval: 275 to 665 feet (open hole)

Yield: Pump 900 gpm (reported with samples 460, 476)

Use: irrigation well

Remarks: See Patterson Bros.

G. 5 continued Patterson Bros.

Well field: 12-23-6-441 (RA - 1777)

Location: SW of Roswell, Chaves Co., New Mexico

Owner: J. Patterson (drilled by Patterson Bros.)

Date drilled: 1961

Elevation: 3822 feet

Water bearing formation: San Andres limestone

Total depth: 640 feet

Production interval: 315 to 640 feet

Yield: ----

Use: irrigation

Remarks: The distance between J. Patterson well and Patterson Bros. well is about 2000 feet. They were sampled depending on which well was pumped at the time.

NO	OWNER	WELL NO	DATE YR	MO	DY	TU	+OR-	LAB NO
1	J.PATTERSON	12 23 6 214	1959	3		12.	2.	373
2	J.PATTERSON	12 23 6 214	1961	4		11.	2.	447
3	J.PATTERSON	12 23 6 214	1961	6		10.	2.	460
4	J.PATTERSON	12 23 6 214	1961	7		5.	2.	467
5	J.PATTERSON	12 23 6 214	1961	8		5.	2.	476
6	PATT. BROS.	12 23 6 441	1962	2		21.	2.	713
7	PATT. BROS.	12 23 6 441	1962	3		142.	5.	645
8	J.PATTERSON	12 23 6 214	1962	4		85.	3.	697
9	PATT. BROS.	12 23 6 441	1962	5		9.	13.	767
10	PATT. BROS.	12 23 6 441	1962	7		18.	5.	707
11	J.PATTERSON	12 23 6 214	1962	7		57.	2.	666
12	J.PATTERSON	12 23 6 214	1962	8		54.	21.	765
13	PATT. BROS.	12 23 6 441	1962	9		18.	30.	758
14	PATT. BROS.	12 23 6 441	1962	10		93.	3.	742
15	PATT. BROS.	12 23 6 441	1962	11		236.	34.	796
16	PATT. BROS.	12 23 6 441	1962	12		62.	27.	800
17	PATT. BROS.	12 23 6 441	1963	1		342.	13.	738
18	PATT. BROS.	12 23 6 441	1963	3		235.	22.	785
19	PATT. BROS.	12 23 6 441	1963	4		35.	13.	883
20	PATT. BROS.	12 23 6 441	1963	5		59.	18.	871
21	PATT. BROS.	12 23 6 441	1964	7		57.	10.	842
22	PATT. BROS.	12 23 6 441	1971	7		4.	4.	1363
23	J.PATTERSON	12 23 6 214	1971	10		20.	2.	1405

G. 6 M. Wiggins

Well field: 13-26-3-114 (RA - 555)

Location: East of Dexter, Chaves Co., New Mexico (east of the Pecos River).

Owner: Max Wiggins

Date drilled: June 1952

Elevation: 3419 feet

Water bearing formation: San Andres limestone (depth to top of ls 739')

Total depth: 1135 feet

Production interval: 601 - 1135 feet

Yield: 1000 to 1500 gpm pumped (reported with samples 461, 720, 721); 1000 gpm flow (reported with sample 692)

Use: irrigation

Remarks: (a) Static water level in winter 60' above land surface

(b) Since 1966 strong sulphur smell and turbid appearance were reported.

(c) Casing corroded.

(d) Well was abandoned in 1968.

NO	OWNER	WELL NO	DATE			TU	+OR-	LAB NO
			YR	MO	DY			
1	M.WIGGINS	13 26 3 114	1959	1		145.	19.	313
2	M.WIGGINS	13 26 3 114	1961	4		21.	2.	444
3	M.WIGGINS	13 26 3 114	1961	6		19.	2.	461
4	M.WIGGINS	13 26 3 114	1961	7		13.	2.	463
5	M.WIGGINS	13 26 3 114	1961	8		2.	1.	473
6	M.WIGGINS	13 26 3 114	1961	10		182.	44.	776B
7	M.WIGGINS	13 26 3 114	1961	11		0.	24.	748
8	M.WIGGINS	13 26 3 114	1962	2		109.	3.	746
9	M.WIGGINS	13 26 3 114	1962	3		30.	2.	690A
10	M.WIGGINS	13 26 3 114	1962	4		33.	3.	692
11	M.WIGGINS	13 26 3 114	1962	5		68.	2.	721
12	M.WIGGINS	13 26 3 114	1962	8		177.	29.	770
13	M.WIGGINS	13 26 3 114	1962	10		174.	36.	797
14	M.WIGGINS	13 26 3 114	1962	11		582.	47.	795
15	M.WIGGINS	13 26 3 114	1962	12		151.	39.	792
16	M.WIGGINS	13 26 3 114	1963	1		231.	21.	786
17	M.WIGGINS	13 26 3 114	1963	3		61.	2.	694
18	M.WIGGINS	13 26 3 114	1963	4		27.	2.	698
19	M.WIGGINS	13 26 3 114	1963	5		160.	6.	899
20	M.WIGGINS	13 26 3 114	1963	7		263.	21.	805
21	M.WIGGINS	13 26 3 114	1963	8		110.	2.	804
22	M.WIGGINS	13 26 3 114	1963	10		74.	9.	848
23	M.WIGGINS	13 26 3 114	1963	12		44.	4.	933
24	M.WIGGINS	13 26 3 114	1964	2		21.	1.	966
25	M.WIGGINS	13 26 3 114	1964	3		60.	1.	944
26	M.WIGGINS	13 26 3 114	1964	4		44.	3.	908
27	M.WIGGINS	13 26 3 114	1964	5		26.	6.	913C
28	M.WIGGINS	13 26 3 114	1964	6		46.	15.	915
29	M.WIGGINS	13 26 3 114	1964	8		54.	11.	919
30	M.WIGGINS	13 26 3 114	1964	11		41.	1.	934
31	M.WIGGINS	13 26 3 114	1964	12		102.	2.	976
32	M.WIGGINS	13 26 3 114	1965	6		97.	2.	999
33	M.WIGGINS	13 26 3 114	1965	7		31.	1.	1003
34	M.WIGGINS	13 26 3 110	1965	11		108.	3.	1062
35	M.WIGGINS	13 26 3 110	1966	3		77.	8.	1071
36	M.WIGGINS	13 26 3 110	1966	4		54.	3.	1065

NO	OWNER	WELL NO	DATE YR	MO	DY	TU	+OR-	LAB NO
37	M.WIGGINS	13 26 3 114	1966	5		53.	6.	1123
38	M.WIGGINS	13 26 3 110	1966	6		23.	5.	1104
39	M.WIGGINS	13 26 3 110	1966	7		24.	6.	1098
40	M.WIGGINS	13 26 3 110	1966	8		27.	4.	1092
41	M.WIGGINS	13 26 3 110	1966	9		66.	5.	1131
42	M.WIGGINS	13 26 3 110	1966	10		78.	4.	1137
43	M.WIGGINS	13 26 3 110	1966	12		75.	5.	1145
44	M.WIGGINS	13 26 3 110	1967	3		43.	7.	1173
45	M.WIGGINS	13 26 3 114	1968	3		14.	1.	1395
46	M.WIGGINS	13 26 3 114	1968	4		34.	3.	1387
47	M.WIGGINS	13 26 3 114	1968	5		43.	4.	1380
48	M.WIGGINS	13 26 3 114	1968	6		15.	2.	1383
49	M.WIGGINS	13 26 3 114	1968	7		28.	3.	1382

G. 7 H. B. Pollard

Well field: 15-26-13-121 (RA - 165)

Location: NE of Lake Arthur, Chaves Co., New Mexico

Owner: H. B. Pollard

Date drilled: August 1955

Elevation: 3362 feet

Water bearing formation: San Andres limestone (depth to top of ls 1173')

Total depth: 1381 feet

Production interval: 1100 to 1381 feet (open hole)

Yield: 2000 gpm flow estimated during the winter (reported with samples 717, 798, 973). 1200 to 1500 gpm pumped during irrigation season (reported with samples 491, 631, 695, 699, 711, 1121).

Use: irrigation, domestic, and livestock

Remarks: 1500 gallon closed storage tank which is filled and then used to cool the pump. Sampled when well was not pumped or flowing.

NO	OWNER	WELL NO	DATE			TU	+OR-	LAB NO
			YR	MO	DY			
1	H.B.POLLARD	15 26 13 121	1959	3		42.	7.	341
2	H.B.POLLARD	15 26 13 121	1961	9		8.	2.	491
3	H.B.POLLARD	15 26 13 121	1961	10	3	22.	22.	703
4	H.B.POLLARD	15 26 13 121	1961	10	19	66.	7.	764
5	H.B.POLLARD	15 26 13 121	1961	11		23.	2.	755
6	H.B.POLLARD	15 26 13 121	1962	2		49.	6.	715
7	H.B.POLLARD	15 26 13 121	1962	3		60.	7.	717
8	H.B.POLLARD	15 26 13 121	1962	4		58.	22.	763
9	H.B.POLLARD	15 26 13 121	1962	5		54.	8.	699
10	H.B.POLLARD	15 26 13 121	1962	6		18.	2.	695
11	H.B.POLLARD	15 26 13 121	1962	7	19	90.	27.	749
12	H.B.POLLARD	15 26 13 121	1962	7	31	143.	16.	637
13	H.B.POLLARD	15 26 13 121	1962	8		46.	7.	711
14	H.B.POLLARD	15 26 13 121	1962	9		102.	25.	750
15	H.B.POLLARD	15 26 13 121	1962	10		188.	5.	631
16	H.B.POLLARD	15 26 13 121	1962	12		52.	26.	798
17	H.B.POLLARD	15 26 13 121	1963	1		73.	2.	620
18	H.B.POLLARD	15 26 13 121	1963	3		28.	36.	774
19	H.B.POLLARD	15 26 13 121	1963	4		228.	38.	787
20	H.B.POLLARD	15 26 13 121	1963	5		70.	8.	830
21	H.B.POLLARD	15 26 13 121	1963	6		49.	8.	865
22	H.B.POLLARD	15 26 13 121	1963	7		486.	7.	819
23	H.B.POLLARD	15 26 13 121	1963	10		88.	17.	856
24	H.B.POLLARD	15 26 13 121	1963	12		82.	2.	964
25	H.B.POLLARD	15 26 13 121	1964	2		13.	1.	965
26	H.B.POLLARD	15 26 13 121	1964	3		31.	1.	967
27	H.B.POLLARD	15 26 13 121	1964	4		19.	2.	907
28	H.B.POLLARD	15 26 13 121	1964	7		60.	1.	935
29	H.B.POLLARD	15 26 13 121	1964	10		52.	3.	921
30	H.B.POLLARD	15 26 13 121	1964	11		49.	1.	931
31	H.B.POLLARD	15 26 13 121	1964	12		34.	1.	982
32	H.B.POLLARD	15 26 13 121	1965	2		258.	7.	973A
33	H.B.POLLARD	15 26 13 121	1965	3		22.	1.	985
34	H.B.POLLARD	15 26 13 121	1965	4		78.	1.	977
35	H.B.POLLARD	15 26 13 121	1965	6		77.	1.	996
36	H.B.POLLARD	15 26 13 121	1965	7		20.	1.	1001

NO	OWNER	WELL NO	DATE YR	MO	DY	TU	+OR-	LAB NO
37	H.B.POLLARD	15 26 13 121	1965	8		50.	2.	1008
38	H.B.POLLARD	15 26 13 121	1965	10		57.	3.	1054
39	H.B.POLLARD	15 26 13 121	1965	11		171.	5.	1060
40	H.B.POLLARD	15 26 13 121	1966	1		130.	3.	1051
41	H.B.POLLARD	15 26 13 121	1966	3		137.	3.	1067
42	H.B.POLLARD	15 26 13 121	1966	4		89.	6.	1070
43	H.B.POLLARD	15 26 13 121	1966	5		25.	6.	1111
44	H.B.POLLARD	15 26 13 121	1966	6		36.	4.	1122
45	H.B.POLLARD	15 26 13 121	1966	7		59.	5.	1140
46	H.B.POLLARD	15 26 13 121	1966	8		46.	6.	1112
47	H.B.POLLARD	15 26 13 121	1966	9		55.	5.	1125
48	H.B.POLLARD	15 26 13 121	1966	10		31.	5.	1142
49	H.B.POLLARD	15 26 13 121	1966	11		28.	4.	1121
50	H.B.POLLARD	15 26 13 121	1967	2		33.	5.	1172
51	H.B.POLLARD	15 26 13 121	1967	3		28.	6.	1169
52	H.B.POLLARD	15 26 13 121	1968	3		13.	1.	1398
53	H.B.POLLARD	15 26 13 121	1968	4		16.	2.	1391
54	H.B.POLLARD	15 26 13 121	1968	5		27.	3.	1381
55	H.B.POLLARD	15 26 13 121	1968	6		46.	5.	1385
56	H.B.POLLARD	15 26 13 121	1968	7		16.	2.	1384A
57	H.B.POLLARD	15 26 13 121	1969	1		13.	1.	1421
58	H.B.POLLARD	15 26 13 121	1971	7		19.	1.	1367
59	H.B.POLLARD	15 26 13 121	1971	7		17.	4.	1369
60	H.B.POLLARD	15 26 13 121	1971	10		10.	1.	1410

Appendix H.

Tritium concentrations in New Mexico precipitation.

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
1	SOCORRO	RAIN	1956	10	17	64.	6.	50
2	SOCORRO	RAIN	1957	1	4	42.	4.	74
3	SOCORRO	RAIN	1957	2	17	58.	6.	89
4	SOCORRO	RAIN	1957	3	20	74.	7.	99
5	SOCORRO	RAIN	1957	4	29	133.	13.	113
6	SOCORRO	RAIN	1957	6	6	260.	26.	137
7	SOCORRO	RAIN	1957	6	7	252.	25.	139
8	SOCORRO	RAIN	1957	7	4	95.	10.	141
9	SOCORRO	RAIN	1957	7	13	162.	16.	142
10	SOCORRO	RAIN	1957	7	25	81.	8.	192
11	SOCORRO	RAIN	1957	7	26	64.	6.	147
12	SOCORRO	RAIN	1957	8	2	166.	16.	153
13	SOCORRO	RAIN	1957	8	3	135.	14.	154
14	SOCORRO	RAIN	1957	8	3	145.	15.	194
15	SOCORRO	RAIN	1957	8	8	90.	9.	155
16	SOCORRO	RAIN	1957	8	14	53.	5.	156
17	SOCORRO	RAIN	1957	8	18	73.	7.	157
18	SOCORRO	RAIN	1957	8	21	53.	5.	175
19	SOCORRO	RAIN	1957	10	11	170.	17.	168
20	SOCORRO	RAIN	1957	10	12	179.	18.	167
21	SOCORRO	RAIN	1957	10	16	108.	11.	171
22	SOCORRO	RAIN	1957	10	21	62.	6.	173
23	SOCORRO	SNOW	1958	1	4	173.	17.	196
24	SOCORRO	SNOW	1958	3	3	500.	50.	213
25	SOCORRO	SNOW	1958	3	4	179.	18.	209
26	SOCORRO	RAIN	1958	3	6	331.	33.	216
27	SOCORRO	RAIN	1958	3	24	338.	34.	223
28	SOCORRO	RAIN	1958	4	12	790.	79.	225
29	SOCORRO	RAIN	1958	4	16	210.	21.	226
30	SOCORRO	RAIN	1958	5	2	407.	41.	229
31	SOCORRO	RAIN	1958	5	2	540.	54.	230
32	SOCORRO	RAIN	1958	5	2	314.	31.	236
33	SOCORRO	RAIN	1958	5	16	416.	42.	238
34	SOCORRO	RAIN	1958	6	7	561.	56.	243
35	ALBUQUERQUE	RAIN	1958	8	7	644.	64.	283

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
36	ALBUQUERQUE	RAIN	1958	8	15	500.	50.	278
37	ALBUQUERQUE	RAIN	1958	8	16	431.	43.	279
38	ALBUQUERQUE	RAIN	1958	8	20	591.	59.	280
39	ALBUQUERQUE	RAIN	1958	8	21	625.	63.	281
40	ALBUQUERQUE	RAIN	1958	9	10	165.	17.	284
41	ALBUQUERQUE	RAIN	1958	9	15	186.	19.	287
42	ALBUQUERQUE	RAIN	1958	9	27	77.	8.	301
43	SANDIA CREST	RAIN	1958	10	4	83.	8.	293
44	SOCORRO	RAIN	1958	10	16	81.	8.	291
45	SOCORRO	RAIN	1958	10	16	94.	9.	291
46(1)	SANDIA CREST	RAIN	1958	10	18	149.	15.	297
47	M.WITHINGTON	RAIN	1958	10	23	125.	13.	298
48	SOCORRO	RAIN	1958	10	26	164.	16.	299
49	ALBUQUERQUE	RAIN	1958	10	27	218.	22.	303
50	ALBUQUERQUE	RAIN	1958	11	16	354.	35.	305
51	ALBUQUERQUE	SNOW	1958	12	29	514.	51.	308
52	ALBUQUERQUE	SNOW	1959	1	20	1526.	152.	383
53	ALBUQUERQUE	SNOW	1959	3	4	2850.	285.	384
54	SOCORRO	RAIN	1959	4	18	484.	2.	409
55	SOCORRO	RAIN	1959	4	25	1458.	2.	410
56(2)	ROSWELL	RAIN	1959	5	7	357.	36.	371
57	SOCORRO	RAIN	1959	6	21	591.	2.	416
58	M.WITHINGTON	RAIN	1959	7	9	242.	3.	404
59	M.WITHINGTON	RAIN	1959	11	13	109.	3.	405
60	M.WITHINGTON	RAIN	1959	12	10	141.	3.	406
61	SOCORRO	SNOW	1959	12	14	250.	3.	403
62	M.WITHINGTON	RAIN	1960	6	8	108.	1.	408
63	M.WITHINGTON	RAIN	1960	6	15	209.	1.	407
64	SOCORRO	RAIN	1960	7	25	220.	4.	422
65	M.WITHINGTON	RAIN	1960	7	29	367.	3.	419
66	M.WITHINGTON	RAIN	1960	8	4	164.	3.	420
67	SOCORRO	RAIN	1960	8	11	162.	2.	412
68	SOCORRO	SURFACE RUNOFF	1960	8	11	192.	1.	414
69	SOCORRO	HAIL	1960	8	11	211.	2.	413
70	M.WITHINGTON	RAIN	1960	8	18	239.	3.	421

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(1) Six miles west of Albuquerque (>10,000 feet)

(2) Roswell Weather Bureau

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
71	SOCORRO	RAIN	1960	8	27	286.	4.	426
72	M.WITHINGTON	RAIN	1960	9	2	132.	3.	425
73	M.WITHINGTON	RAIN	1960	9	17	245.	5.	427
74	SOCORRO	RAIN	1960	9	20	253.	3.	429
75	SOCORRO	RAIN	1960	9	30	168.	6.	433
76	SOCORRO	RAIN	1960	10	1	138.	4.	431
77	M.WITHINGTON	RAIN	1960	10	1	226.	3.	432
78	SOCORRO	RAIN	1960	10	3	160.	8.	434
79	SOCORRO	RAIN	1960	10	17	123.	5.	436
80	M.WITHINGTON	RAIN	1960	11	9	64.	4.	438
81	SOCORRO	SNOW	1960	12	8	162.	2.	439
82	SOCORRO	RAIN	1961	5	24	271.	27.	457
83	M.WITHINGTON	RAIN	1961	6	15	173.	4.	456
84	SOCORRO	RAIN	1961	6	15	228.	9.	531
85	M.WITHINGTON	RAIN	1961	6	19	374.	8.	530
86	SOCORRO	RAIN	1961	7	2	309.	8.	540
87	SOCORRO	RAIN	1961	7	3	127.	9.	532
88	SOCORRO	RAIN	1961	7	4	252.	2.	571
89	SOCORRO	RAIN	1961	7	9	141.	2.	514
90	SOCORRO	RAIN	1961	7	10	205.	24.	663
91	SOCORRO	RAIN	1961	7	14	197.	2.	581
92	M.WITHINGTON	RAIN	1961	7	23	130.	8.	557
93	ST.AUGUSTINE	RAIN	1961	7	24	85.	3.	556
94	M.WITHINGTON	RAIN	1961	7	24	146.	5.	565
95	M.WITHINGTON	RAIN	1961	7	30	73.	2.	517
96	M.WITHINGTON	RAIN	1961	8	11	19.	1.	553
97	M.WITHINGTON	RAIN	1961	8	13	96.	2.	468
98	M.WITHINGTON	RAIN	1961	8	15	133.	25.	672
99	M.WITHINGTON	RAIN	1961	8	16	100.	13.	673
100	SOCORRO	RAIN	1961	8	17	26.	3.	515
101	M.WITHINGTON	RAIN	1961	8	17	62.	3.	588
102	M.WITHINGTON	RAIN	1961	8	28	140.	5.	576
103	SOCORRO	RAIN	1961	8	31	304.	28.	646
104	M.WITHINGTON	SNOW	1961	9	2	63.	10.	545
105	M.WITHINGTON	RAIN	1961	9	11	61.	2.	577

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
106	SOCORRO	RAIN	1961	9	14	61.	8.	544
107	SOCORRO	RAIN	1961	10	8	48.	4.	605A
108	SOCORRO	RAIN	1961	10	29	60.	3.	469
109	SOCORRO	RAIN NO. 1 OF 2	1961	10	30	185.	20.	647
110	SOCORRO	RAIN NO. 2 OF 2	1961	10	30	219.	78.	759I
111	M.WITHINGTON	COMPOSITE RAIN	1961	11	5	132.	3.	587
112	SOCORRO	RAIN NO. 1 OF 2	1961	11	8	270.	29.	643
113	SOCORRO	RAIN NO. 2 OF 2	1961	11	8	451.	3.	616
114	SOCORRO	RAIN AND SNOW	1961	11	12	318.	2.	603
115	SOCORRO	SNOW	1962	1	10	788.	3.	478
116	SOCORRO	RAIN NO. 1 OF 2	1962	1	24	858.	6.	618
117	SOCORRO	RAIN NO. 2 OF 2	1962	1	24	690.	39.	793I
118	SOCORRO	SNOW	1962	3	14	1874.	2.	488
119	M.WITHINGTON	COMPOSITE RAIN	1962	5	8	872.	3.	584
120	M.WITHINGTON	RAIN	1962	7	7	641.	3.	583
121	SOCORRO	RAIN	1962	7	11	960.	3.	506
122	SOCORRO	RAIN	1962	7	12	427.	1.	508
123	M.WITHINGTON	RAIN	1962	7	20	530.	4.	573
124	SOCORRO	RAIN	1962	7	21	266.	2.	509
125	SOCORRO	RAIN	1962	7	23	388.	2.	510
126	SOCORRO	RAIN	1962	7	25	585.	1.	511
127	M.WITHINGTON	RAIN	1962	8	5	647.	3.	564
128	M.WITHINGTON	RAIN	1962	8	19	610.	2.	574
129	SOCORRO	RAIN	1962	8	28	116.	3.	591
130	M.WITHINGTON	RAIN	1962	9	1	1502.	11.	561
131	SOCORRO	RAIN	1962	9	13	68.	4.	570
132	M.WITHINGTON	RAIN	1962	9	15	250.	4.	560
133	SOCORRO	RAIN	1962	9	18	351.	3.	568
134	SOCORRO	RAIN	1962	9	23	90.	20.	543
135	M.WITHINGTON	RAIN	1962	9	30	169.	3.	575
136	M.WITHINGTON	RAIN	1962	10	13	120.	9.	539
137	SOCORRO	RAIN	1962	10	17	193.	1.	606
138	SOCORRO	RAIN	1962	10	17	232.	23.	638
139	SOCORRO	RAIN	1962	10	27	263.	7.	541
140	M.WITHINGTON	RAIN	1962	10	27	214.	3.	572

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
141	M.WITHINGTON	RAIN	1962	11	26	1038.	3.	635
142	SOCORRO	RAIN	1962	11	30	571.	53.	640
143	SOCORRO	RAIN	1962	12	1	522.	3.	634
144	SOCORRO	SNOW	1962	12	25	662.	5.	567
145	SOCORRO	RAIN	1963	2	10	2237.	3.	592
146	SOCORRO	SNOW	1963	2	11	1681.	5.	593
147	SOCORRO	SNOW	1963	2	14	1603.	7.	597
148	SOCORRO	SNOW	1963	2	22	2248.	3.	599
149	SOCORRO	RAIN	1963	2	22	2385.	6.	633
150	SOCORRO	RAIN	1963	3	29	1464.	22.	644
151	SOCORRO	RAIN	1963	4	14	2781.	3.	632
152	SOCORRO	RAIN	1963	5	10	3154.	16.	1107
153	SOCORRO	RAIN	1963	6	16	5277.	30.	1106
154	M.WITHINGTON	RAIN	1963	6	18	12208.	260.	651
155	SOCORRO	RAIN	1963	7	3	1828.	32.	661
156	SOCORRO	RAIN	1963	7	4	993.	61.	940I
157	M.WITHINGTON	RAIN	1963	7	9	707.	54.	876I
158	SOCORRO	RAIN	1963	7	11	1679.	42.	664
159	SOCORRO	RAIN	1963	7	13	1049.	47.	941I
160	SOCORRO	RAIN	1963	7	18	1691.	14.	667
161	M.WITHINGTON	RAIN	1963	7	30	1372.	35.	880I
162	SOCORRO	RAIN	1963	8	3	1579.	16.	676
163	SOCORRO	RAIN	1963	8	7	1106.	10.	682
164	SOCORRO	RAIN	1963	8	13	2115.	1.	722
165	SOCORRO	RAIN	1963	8	16	1614.	14.	712
166	SOCORRO	RAIN	1963	8	17	2832.	34.	720
167	SOCORRO	RAIN	1963	8	18	1321.	10.	730
168	SOCORRO	RAIN	1963	8	22	680.	92.	777I
169	SOCORRO	RAIN	1963	8	26	732.	1.	956
170	SOCORRO	RAIN	1963	8	30	430.	32.	875I
171	SOCORRO	RAIN	1963	9	10	410.	81.	891I
172	SOCORRO	RAIN	1963	9	19	589.	4.	957
173	SOCORRO	RAIN	1963	9	21	707.	1.	958
174	SOCORRO	RAIN	1963	10	19	497.	1.	959
175	SOCORRO	RAIN	1963	10	31	524.	2.	942I

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
176	SOCORRO	RAIN	1963	11	7	1200.	26.	901I
177	SOCORRO	SNOW	1964	2	3	4147.	14.	738
178	SOCORRO	SNOW	1964	3	3	1794.	1.	997
179	SOCORRO	SNOW	1964	3	3	2000.	200.	903U
180	SOCORRO	RAIN	1964	5	20	2847.	62.	1109
181	SOCORRO	RAIN	1964	7	9	326.	79.	821I
182	SOCORRO	RAIN	1964	7	10	674.	16.	822I
183	LANG LAB(1)	NO. 1 OF 2 RAIN	1964	7	12	1220.	29.	825I
184	LANG LAB	NO. 2 OF 2 RAIN	1964	7	12	1110.	56.	826I
185	SOCORRO	RAIN	1964	7	13	1611.	53.	823I
186	M.WITHINGTON	RAIN	1964	7	16	1278.	30.	839I
187	SOCORRO	RAIN	1964	7	17	342.	95.	829I
188	M.WITHINGTON	RAIN	1964	7	19	1021.	60.	833I
189	SOCORRO	RAIN	1964	7	21	816.	49.	834I
190	SOCORRO	RAIN	1964	7	27	953.	55.	837I
191	SOCORRO	RAIN	1964	7	31	746.	75.	838I
192	LANG LAB	NO 1 OF 9 RAIN	1964	8	1	805.	26.	843
193	LANG LAB	NO. 5 OF 9 RAIN	1964	8	1	588.	47.	844
194	LANG LAB	NO. 9 OF 9 RAIN	1964	8	1	568.	26.	845
195	M.WITHINGTON	RAIN	1964	8	2	653.	121.	840
196	SOCORRO	RAIN	1964	8	3	500.	83.	841I
197	SOCORRO	RAIN	1964	8	5	424.	94.	846I
198	SOCORRO	RAIN	1964	8	13	345.	35.	852I
199	M.WITHINGTON	RAIN	1964	8	16	656.	32.	853
200	LANG LAB	NO. 1 OF 10 RAIN	1964	9	9	192.	36.	857
201	LANG LAB	NO. 4 OF 10 RAIN	1964	9	10	201.	29.	858
202	LANG LAB	NO. 7 OF 10 RAIN	1964	9	10	253.	26.	859
203	LANG LAB	NO.10 OF 10 RAIN	1964	9	10	187.	34.	860
204	SOCORRO	RAIN	1964	9	11	269.	34.	866I
205	SOCORRO	RAIN	1964	9	22	437.	29.	867I
206	M.WITHINGTON	RAIN	1964	9	25	250.	32.	868I
207	SOCORRO	RAIN	1964	10	17	298.	33.	878I
208	M.WITHINGTON	RAIN	1964	10	25	167.	52.	881I
209	SOCORRO	RAIN	1964	11	16	120.	39.	898I
210	SOCORRO	RAIN	1964	12	2	314.	14.	906I

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(1) Langmuir Laboratory

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
211	SOCORRO	SNOW	1965	2	23	885.	156.	937I
212	SOCORRO	SNOW	1965	3	4	1116.	97.	938I
213	SOCORRO	RAIN	1965	5	30	471.	1.	998
214	SOCORRO	RAIN	1965	6	9	410.	1.	970
215	SOCORRO	RAIN	1965	8	2	418.	2.	980A
216	LANG LAB	NO. 1 OF 8 RAIN	1965	8	9	674.	9.	1175A
217	LANG LAB	NO. 2 OF 8 RAIN	1965	8	9	662.	11.	1178
218	LANG LAB	NO. 3 OF 8 RAIN	1965	8	9	665.	10.	1179
219	LANG LAB	NO. 4 OF 8 RAIN	1965	8	9	642.	10.	1175B
220	LANG LAB	NO. 8 OF 8 RAIN	1965	8	9	679.	10.	1175C
221	LANG LAB	NO. 1 OF 11 RAIN	1965	8	14	521.	12.	1180A
222	LANG LAB	NO. 5 OF 11 RAIN	1965	8	14	721.	10.	1180B
223	LANG LAB	NO.10 OF 11 RAIN	1965	8	14	715.	10.	1180C
224	LANG LAB	NO. 1 OF 10 RAIN	1965	9	2	189.	8.	1181A
225	LANG LAB	NO. 5 OF 10 RAIN	1965	9	2	233.	5.	1181B
226	LANG LAB	NO.10 OF 10 RAIN	1965	9	2	219.	7.	1181C
227	LANG LAB	NO. 1 OF 6 RAIN	1965	9	4	148.	7.	1182A
228	LANG LAB	NO. 6 OF 6 RAIN	1965	9	4	135.	7.	1182B
229	LANG LAB	RAIN	1965	9	5	159.	8.	1183
230	SOCORRO	RAIN	1965	9	11	129.	1.	993
231	SOCORRO	RAIN	1965	10	16	134.	1.	1006
232	SOCORRO	RAIN	1965	12	9	157.	4.	1046
233	SOCORRO	SNOW	1965	12	17	203.	5.	1033
234	SOCORRO	SNOW	1966	1	18	234.	3.	1045
235	SOCORRO	RAIN	1966	2	7	217.	12.	1044
236	SOCORRO	RAIN	1966	6	28	139.	8.	1078
237	LANG LAB	RAIN	1966	6	30	663.	12.	1080
238 (1)	SNAKE FLATS	COMPOSITE RAIN	1966	7	1	187.	9.	1083
239	LANG LAB	RAIN AND SNOW	1966	7	14	318.	7.	1084
240	LANG LAB	RAIN	1966	7	25	281.	7.	1186
241	LANG LAB	RAIN	1966	8	4	213.	6.	1187
242	LANG LAB	RAIN	1966	8	26	55.	6.	1190
243	SOCORRO	RAIN	1966	9	2	132.	5.	1117
244	LANG LAB	RAIN	1966	9	6	230.	8.	1191
245	SOCORRO	RAIN	1966	10	5	140.	7.	1113

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(1) 10 miles west of Socorro

NO	LOCATION	TYPE OF PRECIPITATION	DATE YR	MO	DY	TU	+OR-	LAB NO
246	LANG LAB	SNOW	1966	12	7	117.	5.	1114
247	SOCORRO	RAIN	1967	1	23	147.	14.	1119
248	SOCORRO	SNOW	1967	3	5	529.	8.	1155
249	SOCORRO	RAIN	1967	3	18	109.	11.	1130
250	LANG LAB	SNOW	1967	4	13	583.	10.	1153
251	SOCORRO	RAIN	1967	6	2	181.	7.	1151
252	SOCORRO	RAIN	1967	6	19	101.	8.	1154
253	SOCORRO	RAIN	1967	8	11	180.	6.	1218
254	SOCORRO	RAIN	1967	9	6	253.	6.	1217
255	SOCORRO	RAIN AND SNOW	1967	11	28	232.	10.	1189
256	SOCORRO	SNOW	1967	12	13	83.	8.	1192
257	SOCORRO	SNOW	1967	12	14	450.	51.	1193
258	SOCORRO	SNOW	1968	1	7	100.	5.	1233
259	SOCORRO	RAIN	1968	2	12	107.	5.	1212
260	SOCORRO	SNOW	1968	2	13	170.	8.	1226
261	SOCORRO	SNOW	1968	3	10	169.	6.	1213
262	SOCORRO	SNOW	1968	3	20	441.	10.	1227
263	SOCORRO	RAIN AND SNOW	1968	4	12	214.	6.	1210
264	SOCORRO	RAIN	1968	5	11	174.	6.	1207
265	SOCORRO	RAIN	1968	6	2	244.	7.	1208
266	SOCORRO	RAIN	1968	7	2	110.	6.	1205
267	SOCORRO	RAIN	1968	7	10	95.	7.	1200
268	SOCORRO	RAIN	1968	7	22	100.	7.	1206
269	SOCORRO	RAIN	1968	7	31	100.	6.	1232
270	SOCORRO	RAIN	1968	8	11	80.	5.	1210
271	SOCORRO	RAIN	1968	8	13	74.	5.	1211
272	SOCORRO	RAIN	1971	7	8	138.	7.	1374
273	SOCORRO	RAIN	1971	8	4	144.	7.	1375

Appendix I.

Tritium concentrations in atmospheric moisture (condensed water).

NO	LOCATION	RELATIVE HUMIDITY	TIME COLLECTED	DATE YR	DATE MO	DATE DY	TU	+OR-	LAB NO
1	(1) SOCORRO		0700-1000	1963	6	19	10398.	110.	650
2	SOCORRO			1963	6	25	2510.	75.	653
3	SOCORRO	5%-21%	0600-1000	1963	6	26	1499.	45.	1085
4	SOCORRO	18%-25%		1963	6	28	1394.	42.	1040
5	SOCORRO			1963	6	30	911.	18.	655
6	SOCORRO	30%-22%	0700-1000	1963	7	1	1572.	14.	657
7	SOCORRO	50%-34%	0800-1130	1963	7	5	1222.	36.	660
8	SOCORRO	58%-40%	0800-0900	1963	7	9	1299.	17.	671
9	SOCORRO	48%-39%	0800-1000	1963	7	12	725.	21.	1042
10	SOCORRO	30%-20%	0800-1200	1963	7	14	2388.	45.	665I
11	SOCORRO		1030-1200	1963	7	22	1947.	40.	1041
12	MERRITT MINE		2200-2400	1963	8	1	1692.	16.	675
13	MERRITT MINE		2200-2330	1963	8	2	1301.	25.	1039
14	MERRITT MINE		2300-2400	1963	8	6	645.	12.	687
15	MERRITT MINE		2000-2130	1963	8	9	1293.	14.	706
16	MERRITT MINE		2200-2330	1963	8	12	1670.	19.	714
17	MERRITT MINE		2200-2330	1963	8	15	1116.	15.	724
18	MERRITT MINE		2200-2300	1963	8	18	1768.	30.	732
19	MERRITT MINE		2200-2330	1963	8	21	984.	35.	740I
20	MERRITT MINE		2200-2330	1963	8	23	921.	35.	760I
21	MERRITT MINE		2200-2300	1963	8	26	538.	125.	781I
22	MERRITT MINE		2200-2300	1963	8	27	704.	14.	1043
23	MERRITT MINE		2200-2300	1963	9	1	669.	44.	799I
24	MERRITT MINE		2200-2330	1963	9	2	706.	21.	953
25	MERRITT MINE		2200-2330	1963	9	3	626.	18.	954I
26	MERRITT MINE		2200-2330	1963	9	6	527.	34.	892I
27	MERRITT MINE		2200-2300	1963	9	10	661.	12.	1038
28	MERRITT MINE		2200-2330	1963	9	13	1170.	25.	960
29	MERRITT MINE		2200-2330	1963	9	19	625.	18.	961
30	MERRITT MINE		1030-1200	1963	10	25	635.	18.	1036
31	MERRITT MINE		1400-1600	1963	11	2	707.	13.	1086
32	MERRITT MINE		1200-1600	1963	11	13	487.	12.	1037
33	MERRITT MINE		1200-1600	1963	12	19	1089.	30.	1035

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(1) Backyard of Workman Center, NMIMT Campus

NO	LOCATION	RELATIVE HUMIDITY	TIME COLLECTED	DATE YR	DATE MO	DATE DY	TU	+OR-	LAB NO
34	MERRITT MINE			1963	12	27	2142.	24.	1087
35	MERRITT MINE	15%		1964	6	9	1906.	38.	803I
36	MERRITT MINE	22%		1964	6	16	791.	33.	806I
37	MERRITT MINE	15%		1964	6	19	784.	30.	807I
38	MERRITT MINE	18%		1964	6	23	4404.	80.	810I
39	MERRITT MINE	23%		1964	6	26	2160.	26.	813I
40	MERRITT MINE	28%		1964	6	30	1526.	106.	817I
41	MERRITT MINE	46%		1964	7	8	484.	28.	820I
42	MERRITT MINE	68%		1964	7	13	862.	154.	824
43	MERRITT MINE			1964	7	14	1683.	101.	828I
44	MERRITT MINE	39%		1964	7	24	541.	89.	836I
45	MERRITT MINE			1964	8	11	634.	69.	851I
46	MERRITT MINE			1964	8	25	565.	15.	1030
47	MERRITT MINE	40%		1964	9	9	221.	36.	863I
48	MERRITT MINE			1964	10	13	478.	42.	874I
49	MERRITT MINE	17%		1964	10	21	274.	34.	879I
50	MERRITT MINE			1964	10	27	320.	39.	886I
51	MERRITT MINE			1964	11	4	891.	40.	894I
52	MERRITT MINE			1964	11	11	367.	27.	897I
53	MERRITT MINE	18%		1964	11	24	472.	45.	902I
54	MERRITT MINE			1964	12	1	410.	71.	904I
55	MERRITT MINE			1964	12	11	642.	18.	1031
56	MERRITT MINE			1965	1	2	279.	30.	916I
57	MERRITT MINE			1965	1	14	1114.	35.	1019
58	MERRITT MINE			1965	2	9	692.	15.	1018
59	MERRITT MINE			1965	3	17	774.	25.	1022
60	MERRITT MINE			1965	4	2	484.	13.	1023
61	MERRITT MINE			1965	5	12	726.	21.	1025
62	MERRITT MINE		0430-0830	1965	7	17	336.	10.	1026
63	MERRITT MINE		0400-0800	1965	7	29	388.	10.	981
64	MERRITT MINE		1630-2030	1965	8	19	317.	10.	1027
65	MERRITT MINE		0400-0830	1965	9	10	135.	14.	990
66	MERRITT MINE		0400-0830	1965	9	17	215.	7.	1028

NO	LOCATION	RELATIVE HUMIDITY	TIME COLLECTED	DATE			TU	+OR-	LAB NO
				YR	MO	DY			
67	MERRITT MINE		2030-0030	1965	10	15	173.	25.	1005
68	MERRITT MINE		2030-0030	1965	10	18	345.	17.	1029
69	MERRITT MINE		2030-0030	1965	11	15	189.	6.	1032
70	MERRITT MINE		2030-0030	1965	11	24	194.	6.	1024I
71	MERRITT MINE		2030-0030	1965	12	14	172.	5.	1034

Appendix J. Program listings for results presented in sections 5.1.4 and 5.4.5.

TRITIUM INPUT FUNCTION

```
C      ************************************************************
       COMMON SUM(16,12),TIME(900),R1(16,12),R2(16,12),R3(16,12)
       DIMENSION TUR1(300),TUR2(300),TUR3(300),REALTI(300)
       DIMENSION XLAB(20),YLAB1(20),YLAB2(20),HEAD1(20),HEAD2(20)
       DIMENSION MONTH(900),YEAR(900),XMONTH(900),IYEAR(900)
       DIMENSION TU(900),TUAV(900),TUAV(16,12),TOTAL(300)
       DIMENSION F(300),MCI(20)
       CALL IFPCK(-1)
100    NREAD=5
101    NPRINT=6
102    TMIN=1953.
103    JMAX=192
C
C      READ NUMBER OF DATA SETS, DATA POINTS IN EACH SET,
C      LABELS FOR X AND Y AXES , AND FRACTIONAL
C      ANNUAL PRECIPITATION F(T).
C
104    READ(NREAD,106) NSETS
105    READ(NREAD,106) NDATA
106    FORMAT(6X,I4)
107    READ(NREAD,109)XLAB,YLAB1,YLAB2
108    WRITE(NPRINT,109)XLAB,YLAB1,YLAB2
109    FORMAT(20A4)
120    READ(NREAD,125)(F(L),L=1,16)
125    FORMAT(8F10.4)
C
C      DEFINE COORDINATES OF ORIGIN FOR THE PLOT
C
201    CALL PLOT(11.0,-11.0,-3)
202    CALL PLOT(0.0,1.0,-3)
203    X0=0.0
204    Y0=0.0
205    IPEN=-3
206    CALL PLOT(X0,Y0,IPEN)
C
C      LABEL AND DRAW AXES
C      X-AXIS   TIME IN YEARS
C      Y1-AXIS  EFFECTIVE RECHARGE IN (T.U.-IN.)
C      Y2-AXIS  EFFECTIVE RECHARGE IN (MCI/MILE**2)
C      SET X AXIS
C
301    X=0.
302    Y=0.
303    NCX=-40
304    AXLEN=16.
305    THETX=0.
306    DELTAT=1.
307    DIVX=5.
308    CALL AXIS(X,Y,XLAB,NCX,AXLEN,THEHX,TMIN,DELTAT,DIVX)
309    CALL PLOT(16.0,0.0,3)
C
C      SET Y2 AXIS AND BOX
C
400    MCIMIN=0.
401    X=16.
402    Y=0.
403    NCY=-40
404    AYLEN=9.
405    THETY=90.
406    DLMCI=21.
407    DIVY=5.
408    CALL AXIS(X,Y,YLAB2,NCY,AYLEN,THETY,MCIMIN,DLMCI,DIVY)
409    CALL PLOT(16.0,9.0,3)
```

```
410    CALL PLOT(0.00,9.0,2)
411    CALL PLOT(0.00,0.0,3)
C
C      SET Y1 AXIS
C
500    TUMIN=0.0
501    X=0.
502    Y=0.
503    NCY=+40
504    AYLEN=9.0
505    THETY=90.
506    DLTU=100.
507    DIVY=5.
508    CALL AXIS(X,Y,YLAB1,NCY,AYLEN,THETY,TUMIN,DLTU,DIVY)
C
C      LEGEND
C
509    CALL SYMBOL(2.0,8.00,0.25,'FELIX AND ELK 3 E',0.0,17)
C
C
C      CALCULATE AVERAGE MONTHLY T.U., AND SCALE TIME
C
600    DO 675 NN=1,NSETS
601    DO 608 I=1,NDATA
602    READ(NREAD,603,END=604)IYEAR(I),MONTH(I),TU(I)
603    FORMAT(12X,I4,I2,19X,F6.0)
604    CONTINUE
605    XMONTH(I)=MONTH(I)
606    TUAV(I)=TU(I)
607    YEAR(I)=IYEAR(I)
608    CONTINUE
609    J=1
610    AV=1
611    DO 622 I=1,NDATA
612    IF(XMONTH(I).EQ.XMONTH(I+1)) AV=AV+1
613    IF(XMONTH(I).EQ.XMONTH(I+1)) TUAV(I+1)=TUAV(I)+TUAV(I+1)
614    IF(XMONTH(I).EQ.XMONTH(I+1)) GO TO 622
615    TIME(J)=YEAR(I)+XMONTH(I)/12.
616    TUAV(J)=TUAV(I)/AV
617    WRITE(NPRINT,618)(TIME(J),TUAV(J))
618    FORMAT(10X,F8.3,5X,F6.0)
619    TIME(J)=TIME(J)-TMIN
620    AV=1
621    J=J+1
622    CONTINUE
623    JMAX=J-1
C
C      CALCULATE FALLOUT FOR EACH PRECIPITATION STATION,
C      (R1,R2,R3), COMPOSITE PRECIPITATION FOR ALL STATIONS,
C      AND COMPOSITE FALLOUT FOR ALL STATIONS.
C      THE COMPOSITE FALLOUT IS MULTIPLIED BY THE
C      FRACTIONAL ANNUAL PRECIPITATION TO OBTAIN THE
C      TRITIUM INPUT FUNCTION.
C
624    CALL RAIN
625    DO 637 L=1,16
626    TOTAL(L)=0.0
627    DO 637 K=1,12
628    J=(L-1)*12+K
629    TUR1(J)=(TUAV(J))*(R1(L,K))
630    TUR2(J)=(TUAV(J))*(R2(L,K))
631    TUR3(J)=(TUAV(J))*(R3(L,K))
632    REALTI(J)=TIME(J)+TMIN
```

```
633   TUAVE(L,K)=TUAV(J)
634   TUAV(J)=(TUAV(J))*(SUM(L,K))
635   TUAV(J)=TUAV(J)*F(L)
636   TOTAL(L)=TUAVE(L,K)+TOTAL(L)
637   CONTINUE
638   WRITE(6,639)
639   FORMAT('1',25X,'TU X RAIN FOR STATION #1')
640   DO 642 J=1,JMAX
641   WRITE(NPRINT,643)REALTI(J),TUR1(J)
642   CONTINUE
643   FORMAT(' ',25X,F8.3,10X,F8.1)
644   WRITE(NPRINT,645)
645   FORMAT('1',25X,'TU X RAIN FOR STATION #2')
646   DO 648 J=1,JMAX
647   WRITE(NPRINT,643)REALTI(J),TUR2(J)
648   CONTINUE
649   WRITE(NPRINT,650)
650   FORMAT('1',25X,'TU X RAIN FOR STATION #3')
651   DO 653 J=1,JMAX
652   WRITE(NPRINT,643)REALTI(J),TUR3(J)
653   CONTINUE
654   WRITE(NPRINT,655)
655   FORMAT('1'/'-'/'-'/'-'/'-',55X,'TOTAL TRITIUM FALLOUT')
656   WRITE(NPRINT,657)
657   FORMAT(24X,4('-'),2X,78('-')/25X,'YEAR',2X,
658  &'JAN',3X,'FEB',3X,'MAR',3X,'APR',3X,'MAY',3X,'JUN',3X,
659  &'JUL',3X,'AUG',3X,'SEPT',3X,'OCT',3X,'NOV',3X,
660  &'DEC',2X,'ANNUAL'/25X,4('-'),2X,78('-'))
661   IYEAR(1)=1953
662   DO 666 L=1,16
663   WRITE(NPRINT,664)IYEAR(L),(TUAVE(L,K),K=1,12),TOTAL(L)
664   FORMAT(' ',24X,I4,1X,8(F5.0,1X),1X,4(F5.0,1X),F6.0)
665   IYEAR(L+1)=IYEAR(L)+1
666   CONTINUE
667   TIME(JMAX+1)=0.0
668   TIME(JMAX+2)=1.
669   TUAV(JMAX+1)=0.0
670   TUAV(JMAX+2)=100.
671   INC=1
672   JSYM=0
673   ISYM=NN
674   CALL LINE(TIME,TUAV,JMAX,INC,JSYM,ISYM)
675   CONTINUE
676   CALL PLOT(20.,-1.,999)
677   CALL EXIT
678   END
      SUBROUTINE RAIN
C     ***************
      COMMON SUM(16,12),TIME(900),R1(16,12),R2(16,12),R3(16,12)
      DIMENSION MONTH(300),YR(300),IYR(300),TTIME(16,12)
      DIMENSION NAME1(3),NAME2(3),ELEV(6)
      DIMENSION TU(300),R(16,12)
701   LMAX=16
702   KMAX=12
703   TMIN=1953.
704   DO 755 I=1,3
705   READ(5,706) NAME1,NAME2,ELEV(I)
706   FORMAT(4A3,4A4,6X,F5.0)
707   WRITE(6,708)
708   FORMAT('1'/'4',28X,'LOCATION:',12X,'ELEV=')
709   WRITE(6,710) NAME1,NAME2,ELEV(I)
710   FORMAT('+',38X,3A3,A1,8X,F6.0)
711   DO 712 J=1,17
```

```
712   READ(5,713,END=714)IYR(J),(R(J,K),K=1,12)
713   FORMAT(10X,I4,5X,12(F5.2))
714   J=J-1
715   DO 719 L=1,J
716   DO 719 K=1,12
717   TTIME(L,K)=IYR(L)+K/12.
718   TTIME(L,K)=TTIME(L,K)-TMIN
719   CONTINUE
720   GO TO (721,732,744),I
721   DO 726 L=1,J
722   DO 726 K=1,12
723   R1(L,K)=R(L,K)-0.1
724   IF (R1(L,K).LT.0.0) GO TO  725
724   GO TO 726
725   R1(L,K)=0.0
726   CONTINUE
727   DO 730 L=1,J
728   WRITE(6,729)(R1(L,K),K=1,12)
729   FORMAT(' ',26X,12(F5.2,2X))
730   CONTINUE
731   GO TO 755
732   DO 738 L=1,J
733   DO 738 K=1,12
734   R2(L,K)=R(L,K)-0.1
735   IF(R2(L,K).LT.0.0) GO TO 737
736   GO TO 738
737   R2(L,K)=0.0
738   CONTINUE
739   DO 742 L=1,J
740   WRITE(6,741)(R2(L,K),K=1,12)
741   FORMAT(' ',26X,12(F5.2,2X))
742   CONTINUE
743   GO TO 755
744   DO 750 L=1,J
745   DO 750 K=1,12
746   R3(L,K)=R(L,K)-0.1
747   IF(R3(L,K).LT.0.0) GO TO 749
748   GO TO 750
749   R3(L,K)=0.0
750   CONTINUE
751   DO 753 L=1,J
752   WRITE(6,729)(R3(L,K),K=1,12)
753   CONTINUE
754   GO TO 755
755   CONTINUE
756   DO 759 L=1,16
757   DO 759 K=1,12
758   SUM(L,K)=(R1(L,K)+R2(L,K)+R3(L,K))/I
759   CONTINUE
760   WRITE(6,761)
761   FORMAT('-'/'-',40X,'COMPOSITE RAIN')
762   DO 764 L=1,16
763   WRITE(6,765)(SUM(L,K),K=1,12)
764   CONTINUE
765   FORMAT(' ',26X,12(F6.2,2X))
766   DO 770 L=1,LMAX
767   DO 770 K=1,KMAX
768   J=(L-1)*KMAX+K
769   TIME(J)=TTIME(L,K)
770   CONTINUE
771   RETURN
772   END
```

DISPERSION PLOT

```
C       ************************************
        COMMON CONCT(24,250),TIME(250),NDATA
        DIMENSION Q(100),TIMQ(100)
100     NREAD=5
101     NPRINT=6
C
C       READ CONSTANTS FOR DISPERSION EQUATION
C
C
102     PHI=3.1416
103     TMIN=1954.
104     VELOC=70.
105     D=4900.
106     IMAX=250
107     KMAX=24
108     TSTEP=30.
C
C       VELOC   FLOW VELOCITY (FEET/DAY)
C       D       DISPERSION COEFF (FEET**2/DAY)
C       TSTEP   TIME STEP (DAYS)
C       IMAX    TOTAL NUMBER OF TIME STEPS
C       KMAX    MAXIMUM DISTANCE (MILES)
C
C       SET GRID POINTS AT 8 T.U.
C
200     DO 203 I=1,IMAX
201     DO 203 K=1,KMAX
202     CONCT(K,I)=8.0
203     CONTINUE
C
C       READ AND WRITE DATA
C
C       NDATA    NUMBER OF PULSES
C       Q(J)     J-TH PULSE (CI)
C       TIMQ(J)  INJECTION TIME OF THE J-TH PULSE
C
300     READ(NREAD,301) NDATA
301     FORMAT(6X,I2)
302     READ(NREAD,303)(Q(J),TIMQ(J),J=1,NDATA)
303     FORMAT(10X,F10.3,F10.3)
304     WRITE(NPRINT,305) NDATA, TSTEP, TMIN
305     FORMAT('1',10X,'NDATA=',I2,3X,'TSTEP=',F3.0,'DAYS',5X,
306    &'TMIN=',F5.0)
307     WRITE(NPRINT,308) VELOC, D
308     FORMAT('-',10X,'V=',F3.0,1X,'(FT/DY)',2X,'D=',F5.0,
309    &'(FT**2/DY)')
310     DO 312 J=1,NDATA
311     WRITE(NPRINT,311) (Q(J),TIMQ(J))
312     FORMAT(10X,F10.3,F10.3)
313     CONTINUE
C
C       SOLVE DISPERSION EQUATION WITH TIME DECAY
C       STORE RESULTS IN 2-D ARRAY OF TIME AND DISTANCE
C
C
C       STIM    ACCUMULATED TIME (DAYS)
C       DIST    DISTANCE FROM INJECTION(FEET)
C       TIMLAG  TIME SINCE INJECTION
C
400     STIM=0.0
401     DO 426  I=1,IMAX
402     STIM=STIM+TSTEP
403     DIST=0.0
404     DO 425 K=1,KMAX
405     DIST=DIST+5280.
```

```
406     DO 424 J=1,NDATA
407     TIME(I)=STIM/360.
408     TIMCHK=(STIM/360.)+TMIN
409     IF ((TIMCHK-TIMQ(J)) .LE. 0.0) GO TO 422
410     TIMLAG=(TIMCHK-TIMQ(J))*360.
411     IF (TIMLAG .LE. 1.E-04) GO TO 422
412     C1=Q(J)/SQRT(4*D*PHI*TIMLAG)
413     E1=-(DIST-(VELOC*TIMLAG))**2
414     E2=4*D*TIMLAG
415     E=EXP(E1/E2)
416     C=C1*E
C
C       CONVERT ACTIVITY TO T.U. FOR CROSS-SECTION
C       AREA OF 6 MILES X 200 FEET AND POROSITY OF 1%
C
417     CONC=C*((309./(0.01*200.*3.168*2.832))*1.E+04)
C
C       TDCAY  TIME DECAY CORRECTION (MEAN LIFE=212 MO.)
C
418     TDCAY=EXP(-(TIMLAG/30.)/212.)
419     CONC=CONC*TDCAY
420     IF (CONC .LE. 1.E-03) GO TO 424
421     GO TO 423
422     CONC=0.0
423     CONCT(K,I)=CONCT(K,I)+CONC
424     CONTINUE
425     CONTINUE
426     CONTINUE
427     WRITE(NPRINT,428)
428     FORMAT('1')
429     DO 432 I=1,IMAX
430     WRITE(NPRINT,431)I,(CONCT(K,I),K=1,KMAX)
431     FORMAT(1X,I3,24(F5.0))
432     CONTINUE
C
C       PLOT TRITIUM CONCENTRATION-PROFILE FOR
C       ANY DISTANCE FROM INJECTION
C
500     CALL PLOT1
501     STOP
502     END
503     SUBROUTINE PLOT1
C       ****************
504     COMMON CONCT(24,250),TIME(250),NDATA
505     DIMENSION XLAB(20),YLAB(20),HEAD1(80),CONCTP(250)
506     CALL IFPCK(-1)
507     NPRINT=6
508     NREAD=5
509     KMAX=192
510     READ(NREAD,511) NSETS
511     FORMAT(6X,I4)
512     DO 712 NN=1,NSETS
513     CALL PLOT(20.0,-11.0,-3)
514     CALL PLOT(0.0,1.0,-3)
515     READ(NREAD,516,END=101) XLAB,YLAB
516     FORMAT(20A4)
517     WRITE(NPRINT,516)XLAB,YLAB
C
C       DEFINE COORDINATES OF ORIGIN
C
518     X0=0.0
519     Y0=0.0
520     IPEN=-3
```

```
521     CALL PLOT(XO,YO,IPEN)
C
C       LABEL AND DRAW AXES
C       X-AXIS TIME IN YEARS
C       Y-AXIS CONCENTRATION IN T.U.
C       CONCT(20,J) DATA STORED FOR PLOTTING
C                   20 DISTANCE TO WELL (MILES)
C                   J  NUMBER OF MONTHLY VALUES TO BE PLOTTED
C
600     X=0.
601     Y=0.
602     NCX=-80
603     AXLEN=16.
604     NCY=+32
605     THETX=0.
606     THETY=90.
607     TMIN=1953.
608     DELTAT=1.
609     DIVX=5.0
610     CALL AXIS(X,Y,XLAB,NCX,AXLEN,THEHX,TMIN,DELTAT,DIVX)
611     CALL PLOT(16.,0.,3)
612     CALL PLOT(16.,8.,2)
613     CALL PLOT(0.,8.,2)
614     CALL PLOT(0.,0.,3)
615     AYLEN=8.0
616     TUMIN=0.0
617     DELTU=75.
618     DIVY=5.0
619     CALL AXIS(X,Y,YLAB,NCY,AYLEN,THETY,TUMIN,DELTU,DIVY)
700     JMAX=NDATA
701     INC=1
702     JSYM=0
703     DO 705 J=1,192
704     CONCTP(J)=CONCT(20,J)
705     CONTINUE
706     TIME(KMAX+1)=0.0
707     TIME(KMAX+2)=1.0
708     CONCTP(KMAX+1)=0.0
709     CONCTP(KMAX+2)=75.
710     ISYM=NSETS
711     CALL LINE(TIME,CONCTP,KMAX,INC,JSYM,ISYM)
712     CONTINUE
713     CALL PLOT(20.,-1.,999)
714     END
```

This dissertation is accepted on behalf of the faculty of the

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