

PAUL SPRING: AN INVESTIGATION OF RECHARGE
IN THE ROSWELL (N.M.) ARTESIAN BASIN *

by

Gerardo Wolfgang Gross
Professor of Geophysics
New Mexico Institute of Mining and Technology

Paul Davis
Graduate Research Assistant
New Mexico Institute of Mining and Technology

Kenneth R. Rehfeldt
Graduate Research Assistant
New Mexico Institute of Mining and Technology

PARTIAL TECHNICAL COMPLETION REPORT

Project No. A-055-NMEX

December 1979

New Mexico Water Resources Research Institute
in cooperation with the
Geophysical Research Center
New Mexico Institute of Mining and Technology

The work upon which this publication is based was supported in part by funds provided through the New Mexico Water Resources Research Institute by the U. S. Department of the Interior, Office of Water Resources Research and Technology, as authorized under the Water Resources Research Act of 1978, Public Law 95-467, under project number A-055-NMEX and by the State of New Mexico through State appropriations.

*Based in part on research performed by Paul Davis in partial fulfillment of the requirements for the degree of M. S. in Geoscience with specialization in Hydrology.

The purpose of WRRI technical reports is to provide a timely outlet for research results obtained on projects supported in whole or in part by the Institute. Through these reports we are promoting the free exchange of information and ideas and hope to stimulate thoughtful discussion and action which may lead to resolution of water problems. The WRRI, through peer review of draft reports, attempts to substantiate the accuracy of information contained in its reports but the views expressed are those of the author(s) and do not necessarily reflect those of the WRRI or its reviewers.

Contents of this publication do not necessarily reflect the views and policies of the Office of Water Research and Technology, U.S. Department of the Interior, nor does mention of trade names or commercial products constitute their endorsement or recommendation for use by the U.S. Government.

Paul Spring is the principal or sole discharge point of a perched localized aquifer of well defined boundaries. It is located on the western flank of the Roswell artesian basin, and conditions at Paul Spring are considered typical for a major portion of the basin. The recharge at Paul Spring could therefore provide insight into the recharge mechanisms controlling the basin's groundwater supply. The geology of the area was mapped in detail. Springflow was measured over a span of 453 days. Precipitation records of many years were available from a NOAA weather station in the area. Tritium was measured in spring discharge and precipitation. Numerical and stochastic analysis and cross-correlation were performed on the data. The results suggest that a deep flow component plays an important role, hitherto underestimated, in the groundwater recharge to the basin. This deep component is transmitted by the Permian Yeso Formation and the Glorieta Sandstone Member of the San Andres Formation. At Paul Spring, this accounts for as much as 80% of the discharge. No clear results were obtained for the Paul Spring aquifer's response time to precipitation events. The indications are that it is of the order of several months. This can be explained by the peculiar geologic structure, specifically the screening effect of the Glorieta sandstone, in combination with solution and collapse features in the Yeso formation which channel the recharge water. A longer series of springflow measurements under better controlled conditions is needed to clarify this problem. The measurements continue.

ABSTRACT

TABLE OF CONTENTS

Page	1	ABSTRACT
	2	TABLE OF CONTENTS
	4	LIST OF FIGURES
	6	LIST OF TABLES
	7	ACKNOWLEDGMENTS
	8	PURPOSE AND JUSTIFICATION
	10	LOCATION, PHYSIOGRAPHY AND CLIMATE
	17	HYDROGEOLOGIC SUMMARY
	20	PREVIOUS RECHARGE INVESTIGATIONS
	25	RECHARGE ESTIMATES
	29	PROCEDURE
	29	Hydrogeology
	29	Precipitation
	29	Outflow
	30	Tritium Determinations
	31	GEOLOGY OF PAUL SPRING
	31	The Permian System
	35	The Quaternary System
	37	Structure
	41	THE PERCHED SYSTEM
	44	TRITIUM IN PRECIPITATION AND SPRING WATER
	55	SPRINGFLOW MEASUREMENTS
	57	RECHARGE ESTIMATES AT PAUL SPRING
	57	Approach
	61	Recession Curve Analysis and Numerical Methods
	74	Stochastic Approach to Recharge Estimation
	81	Numerical Model with a Deep Flow Component
	84	Stochastic Method with a Deep Flow Component
	88	Discussion

COMPARISON OF FACTORS AFFECTING RECHARGE OF THE PAUL SPRING AREA AND THE PRINCIPAL INTAKE AREA.	90
RECHARGE FROM THE WESTERN PORTION OF THE ROSWELL BASIN.	93
SUMMARY OF CONCLUSIONS.	96
LIST OF REFERENCES.	98
APPENDIX A: LOCAL WELL LOG DATA FOR THE PAUL SPRING AREA . . .	102
APPENDIX B: SPRINGFLOW MEASUREMENT PROCEDURE, EQUIPMENT AND PROBLEMS	107
APPENDIX C: DAILY AVERAGE SPRINGFLOW	113
APPENDIX D: DATES OF THE SPRINGFLOW RECESSIONS AND THE COMPUTER PROGRAM USED TO CALCULATE S_y/a	116
APPENDIX E: COMPUTER PROGRAMS USED TO CALCULATE THE DAILY NET RECHARGE, AND NUMERICAL RESULTS.	123

Page

LIST OF FIGURES

11	1	Location of the study area.
13	2	Location of Paul Spring.
15	3	Coordinate system for locating wells and springs.
16	4	Precipitation at the Elk weather station.
21	5	Geologic cross-section of Sec. 11, T.16S, R.16E. After Renick (1926).
32	6	Geologic map of the Paul Spring area.
34	7	Geologic cross sections A-A' and B-B'.
36	8	Geologic cross section C-C'.
38	9	Geologic cross section D-D'.
43	10	Recharge area contributing to the Paul Spring aquifer.
49	11	Tritium activity in springflow and precipitation at Paul Spring.
51	12	Comparison of tritium activity in Paul Spring discharge with weighted tritium activity in precipitation.
53	13	Paul Spring discharge. Comparison of tritium activity with discharge volume.
56	14	Springflow vs. time. The straight lines represent two possible deep flow components.
58	15	The phreatic linear reservoir.
65	16	Recharge estimates by Simpson's rule and by finite differences.
70	17	Springflow lagged against precipitation.
73	18	Springflow lagged 191 days against precipitation.
77	19	Regression line for Eq. (28).
79	20	The two-dimensional converging flow system and its characteristic length.

Figure

Page

Page	
	Figure
21	Weekly springflow and linearly varying deep flow component vs. time, 83
22	Regression line for Eq. (32). 85
23	Idealized model of deep recharge to the San Andres Formation 95
24	Schematic of the weir and stilling well 109
25	Adjustment of flow record 112
26	Springflow recession events used for analysis. 118

LIST OF TABLES

Page	
14	I Annual Precipitation for Elk, Roswell, and the Roswell Artesian Basin.
23	II Chemical Analyses of the Paul Spring Water.
40	III Simplified Stratigraphic Column
45	IV Tritium in Precipitation at Elk
47	V Tritium in Water from Paul Spring
68	VI Cross-covariance Peaks.
72	VII Recharge Percentage as a Function of Lag for Different Deep-flow Hypotheses.
87	VIII Summary of Computed Parameters.

Table

The authors are pleased to acknowledge the assistance of numerous individuals instrumental in the completion of this study. Paul Spring and the area around it is owned by Mr. Charles Mulcock. Mr. Mulcock and his family not only gave permission for the study to be done on their land, but also helped install and maintain the springflow recording system, provided precipitation records for the area, and contributed generously of their vast knowledge of the area. Without their help this study could not have been accomplished.

Ralph Wilcox, Chris Duffy and Rich Naff assisted in all phases of this study, from construction of the recording system to advising on technical aspects of the project.

Scott Anderholm and James Counts helped with geological mapping and sample collection. Gerald Mitchell provided information pertaining to the soils of the Paul Spring area. Aerial photographs were taken by David Dorschner. Charlie Mumma and Prof. Allan Gutjahr assisted in the spectral analysis section of this report. Prof. Lynn Gelhar suggested methods of analysis and reviewed the manuscript. The responsibility for errors or omissions rests with the authors.

ACKNOWLEDGMENTS

The purpose of this investigation was to determine the amount and percentage of precipitation which recharges the Paul Spring aquifer. Paul Spring is situated near the southwestern edge of what has been referred to as the Principal Intake Area (Fiedler and Nye, 1933). This area recharges the Principal Aquifer of the Roswell artesian basin, the San Andres Formation. Factors which affect recharge at Paul Spring appear to be typical for the Principal Intake Area.

A combination of four felicitous factors determined the choice of Paul Spring for this study: (1) The spring's owner, Mr. Charles Mulcock, graciously gave his permission for the installation of necessary equipment. (2) The spring configuration is such that a weir and stilling well could be installed relatively easily. (3) The location of the spring is protected from access to vandals and cattle. (4) A preliminary study indicated that Paul Spring was the principal, if not the only outlet of a small perched aquifer of rather well defined boundaries.

The outflow from the system is assumed to be equal to the springflow. This assumption neglects transpiration from phreatophytes and possibly downward leakage of ground water through the semi-confining bottom layer of the perched system. The only phreatophytes which tap the Paul Spring aquifer are located near the point of issuance of the spring. They consist of several cottonwood trees, the amount of water they transpire is believed

PURPOSE AND JUSTIFICATION

to be small; it is therefore neglected.
The stratigraphic layer which forms the bottom of the Paul
Spring aquifer is composed of fine silts and some clay. It is not
possible to determine the amount of water which flows vertically
downward through this layer. Neglecting this flow (which other-
wise would contribute to the spring) should yield a minimum value
for the amount of recharge to the system.

LOCATION, PHYSIOGRAPHY, AND CLIMATE

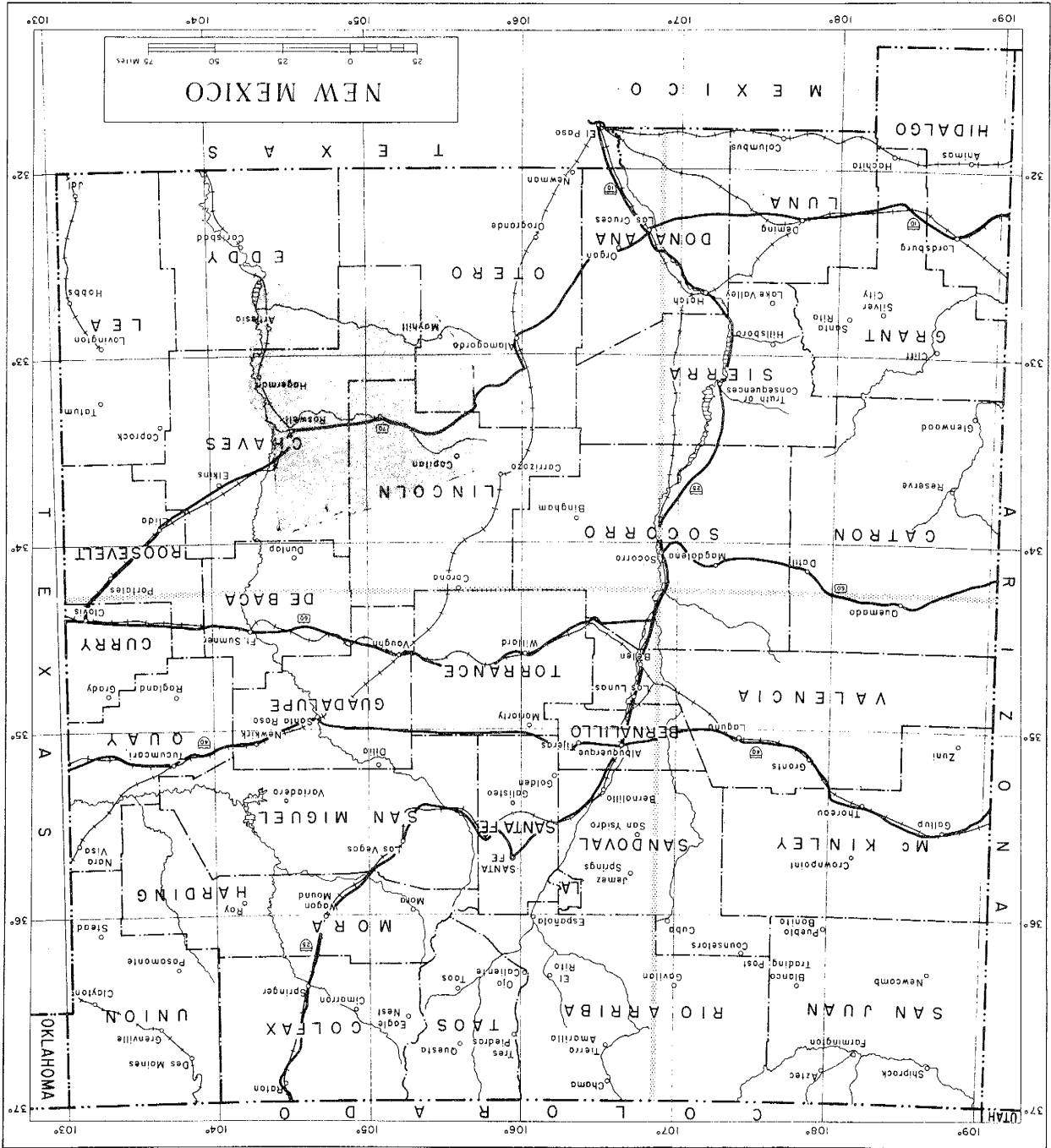
Paul Spring is located in Chaves County, southeastern New

Mexico (Figs. 1, 2). The exact location is given by the coordinates T16S.R16E.11.34213, using the New Mexico State Engineer method of locating wells and springs (Fig. 3). This perennial spring issues from a perched water body contained in a hill on the southeastern flank of the Sacramento Mountains. The hill makes up most of the area covered in this report.

Fig. 2 is a sketch map of the area we call the Roswell basin in this report. It is a sub-basin of the much larger Pecos drainage basin. It is physiographically limited by the Pecos River and the Sacramento Mountains on the east and west flanks, respectively. The mostly dry Arroyo del Macho is the northern boundary, and the Seven Rivers Hills near Carlsbad are the southern limit. The northern and southern boundaries are somewhat arbitrary in that they may not be hydrologic boundaries. Their choice is, however, justified by the surface extension of Fiedler and Nye's Principal Intake Area. It is shown in relation to the total area (enclosed by the dotted line) which, according to Bean (1949), contributes to the artesian groundwater basin. This region extends about 30 miles further north than the area shown in Fig. 2.

The amount of precipitation and the fraction of precipitation that becomes recharge are directly related to the physiography of a given area. The climate controls the amount of water available

Fig. 1. Location of the study area



NEW MEXICO BUREAU OF MINES AND MINERAL RESOURCES

for recharge, and the physiography has some control over the percentage of water that actually reaches the ground water system. Climatologically the study area lies between the semi-arid plains to the east, near Artesia, and the sub-humid region of the east flank of the Sacramento Mountains to the west. The average annual rainfall is 16 inches (Table I), most of which falls during thundershowers in the summer months. Winters are usually mild with light snow-fall. The area is characterized by plentiful sunshine, large daily temperature fluctuations, and low relative humidity. Precipitation for the period from August 1972 to March 1978 is shown in Fig. 4. These values are from the Elk, New Mexico, weather station which is within less than a mile from Paul Spring.

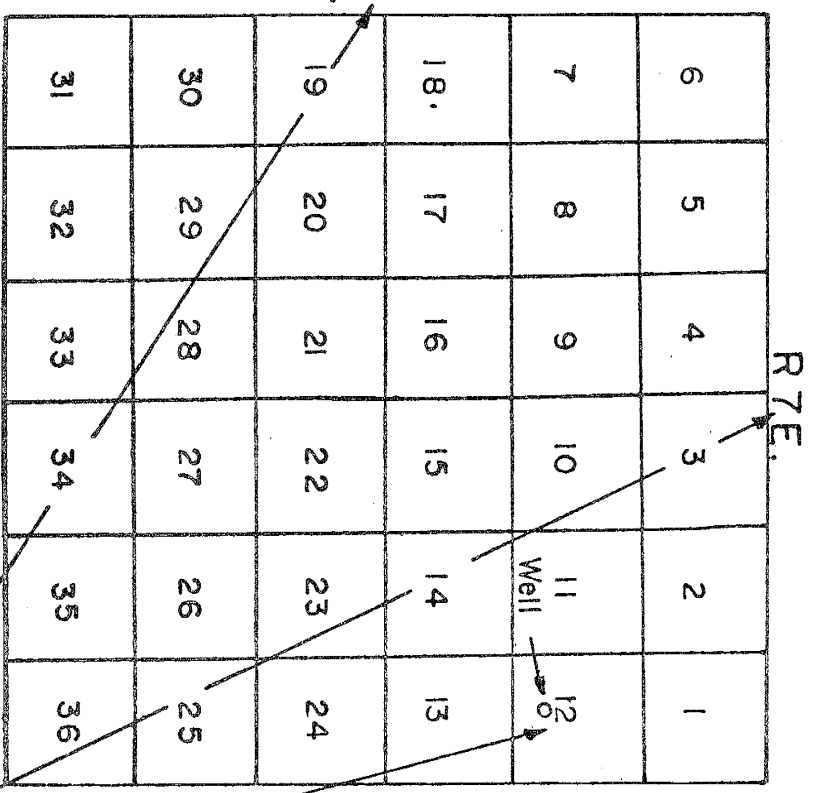
The southeastern flank of the Sacramento Mountains is part of the eastward tilted fault block known as the Sacramento uplift (Kelley, 1971). The ridge containing the perched water body trends southwest to northeast (Fig. 6). This area is drained by two arroyos, one in Paul Canyon and one in Short Canyon, which both empty into the Rio Pecos. The Rio Pecos is a major drainage of the southern Sacramento Mountains and flows perennially in the area of Paul Spring.

Local relief within the study area is as much as 500 feet between Paul Canyon and the crest of the ridge. The elevations above mean sea level range from 5670 feet at the nearly horizontal alluvial flood plain of the Rio Pecos to almost 6500 feet in the southwestern portion of the study area.

Table I. Annual Precipitation for Elk, Roswell, and the Roswell Artesian Basin.

Year	Precipitation in Inches		Average Temp. °F
	Elk	Roswell	
1955	17.78	8.75	59.9
1956	8.75	4.32	60.3
1957	18.37	9.32	60.5
1958	22.86	13.06	60.3
1959	10.43	9.52	60.1
1960	17.23	13.57	58.8
1961	13.89	7.85	57.9
1962	20.62	11.81	58.8
1963	15.77	6.30	59.3
1964	8.84	6.98	58.9
1965	14.03	6.68	60.0
1966	18.19	9.68	58.8
1967	11.45	11.06	59.1
1968	20.80	15.84	57.6
1969	18.89	13.33	60.3
1970	9.45	8.63	58.9
1971	13.57	10.04	59.6
1972	20.97	16.24	55.0
1973	10.37	11.60	59.3
1974	26.51	18.65	60.0
Average	15.88	10.66	59.39

Common system of numbering sections within a township



System of numbering tracts within a section

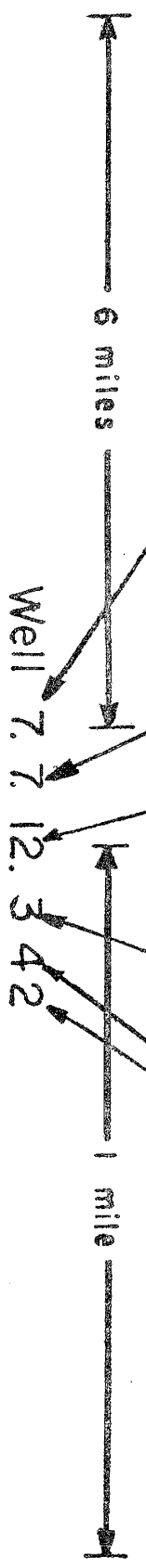
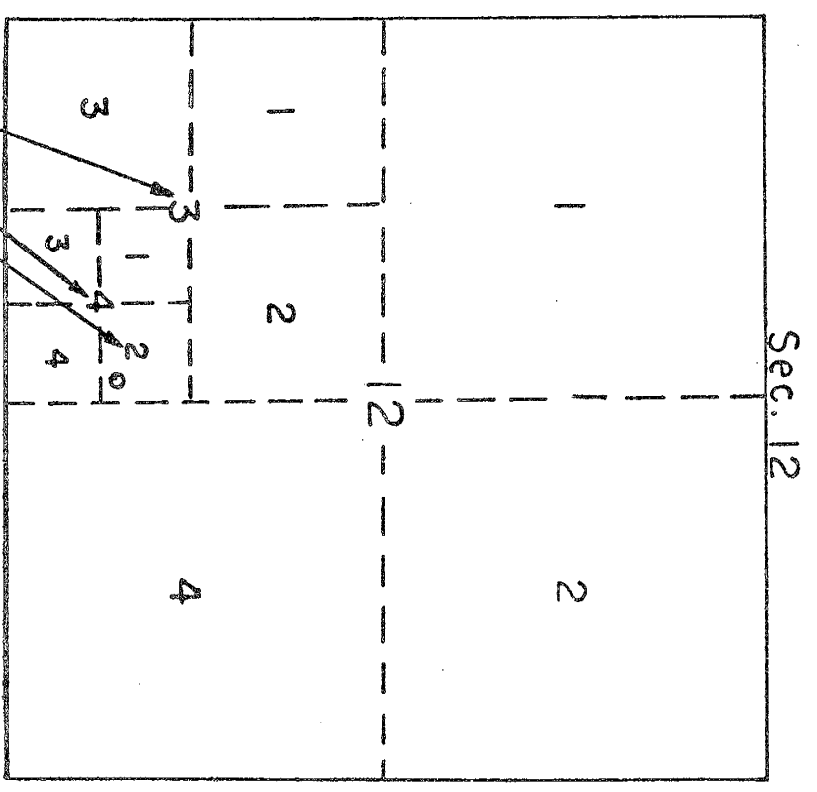


Fig. 3. Coordinate system for locating wells and springs.

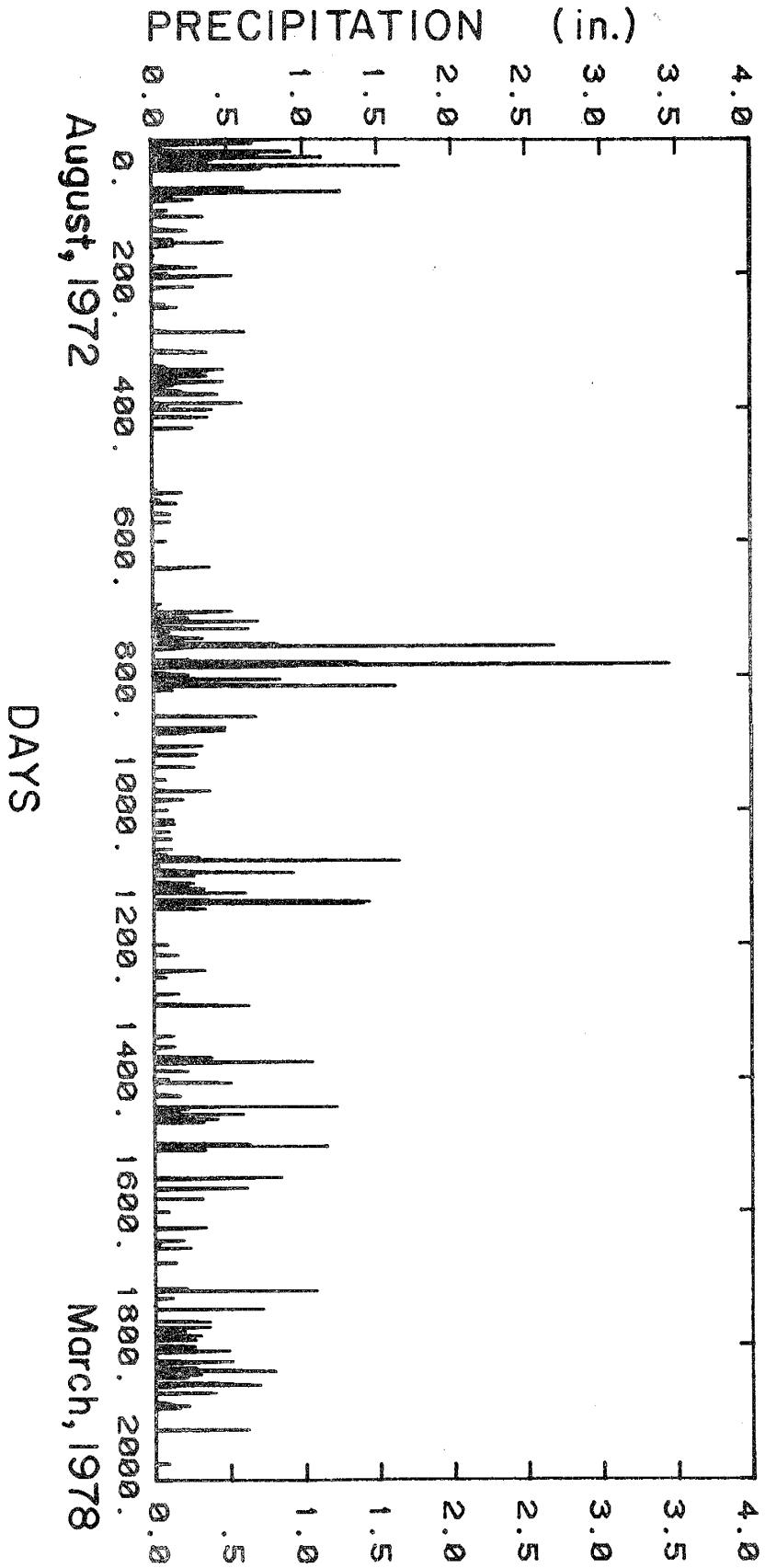


Fig. 4. Precipitation at the Elk weather station.

HYDROGEOLOGIC SUMMARY

The hydrologic problems of the Roswell basin were discussed in some detail by Gross et al. (1976). An updated report is in preparation (Gross and Hoy, 1979). The purpose of the following hydrogeologic summary is to indicate the place of the Paul Spring study in the hydrogeologic investigation of the basin as a whole. A simplified stratigraphic column is given in Table III. The Principal Aquifer of the Roswell basin is the San Andres Limestone which forms the dip slope on the east side of the Sacramento Mountains along their base. Along the west bank of the Pecos River, between Roswell and Artesia, the San Andres and Artesia are unconformably covered by a complex, up to 500 ft thick, of late Tertiary to early Pleistocene sandstones (Gatuna Formation) and Pleistocene to Holocene alluvium. These strata form a strip about 20 miles wide and contain the Shallow, or water table, Aquifer. The Artesia Group covers the San Andres along the east bank of the Pecos River. The Principal Aquifer receives recharge in three longitudinal zones, at successively lower elevation, between the Sacramento Mountains in the west and the Pecos River to the east. (1) Winter and summer precipitation falling in the mountains west of R 19 E (Fig. 2) is absorbed by the San Andres and underlying formations, notably the basal Glorieta Sandstone of the San Andres and the Yeso Formation. Moving eastward, this water rises with the water table into the upper San Andres and becomes the unconfined

Aquifer is cause of a saltwater invasion which advances on a NW-SE

(5) The depression of the piezometric head in the Principal

as of irrigation return flow.

Leakage consists of groundwater from the alluvial aquifer as well
age from the alluvial aquifer into the San Andres Limestone. This
zone; the resultant depression of the piezometric head causes leak-
of the water from the Principal Aquifer, which is confined in this
major agricultural developments. Large-scale irrigation takes most
(4) The alluvial plain on the west bank of the Pecos River has

relatively flat, karstic interfluvial highlands.

ture. It presumably contributes to recharge, especially in the
tation. Summer thunderstorms supply the bulk of its surface mois-
(3) The Principal Recharge Area receives little winter precipi-

in this area (Duffy et al., 1978).

some detail in the Rio Hondo, the largest tributary to the Pecos
This is the second recharge component, and it has been studied in
or most of their flow due to the karstic character of this zone.
As they cross the Principal Recharge Area, these streams lose all
Rio Felix, and Rio Pecos. (Paul Spring belongs to the last-named.)
the study region, from north to south, Arroyo del Macho, Rio Hondo,
runs off through the four major tributaries of the Pecos River in
(2) Part of the precipitation falling in the western mountains

Nye's Principal Intake Area.

the dip slope; the latter is most fully developed in Fiedler and
western part of the Principal Aquifer where the San Andres forms

front from the northeast and has reached the city limits of Roswell. The progressive decline of piezometric head and of water quality are the major problems facing the basin communities. An assessment of the different recharge contributions is a necessary step if a model of the basin is to be constructed. Ultimately, such a model should help in alleviating the problems just mentioned. Recharge supplied at different elevations is characterized, in principle, by different isotopic composition which can be used to identify and to trace the several contributions. This is one purpose of the present and related investigations.

PREVIOUS RECHARGE INVESTIGATIONS

The earliest and only study which deals with the immediate area around Paul Spring was done by Renick (1926). He described the general geology and ground water conditions of the Rio Penasco above Hope. Paul Spring was described as being one of the Boyd Williams Springs. Renick also gave a geologic cross section of the spring (Fig. 5) and a chemical analysis of the spring water (Table II). The cross section given by Renick (Fig. 5) in no way resembles the cross sections constructed from geologic mapping done during this study (Figs. 7-9).

A complete geologic and hydrogeologic study of the Roswell artesian basin was published by Fiedler and Nye in 1933. They included estimates of the quantity of recharge and of the recharge fraction (the percentage of precipitation which becomes recharge water) for the entire Roswell basin. They delineated an area which they believed contributed the most water to the recharge of the Roswell artesian aquifer. This area they referred to as the Principal Intake Area (Fig. 2). They defined this area to be bounded on the east by the line of contact between the Artesia Group and the San Andres Formation. The western boundary was approximately drawn where the water table crosses the Yeso-San Andres Formation contact. Fiedler and Nye (1933) assumed that, since the Yeso Formation is relatively impermeable, ground water which was derived from precipitation west of this line would not percolate eastward and contribute to the artesian basin. The major contribution

*Probably, the contact between Gatuna and San Andres. The latter has frequently been included with the Artesia Group (Kelley, 1971, p. 31).

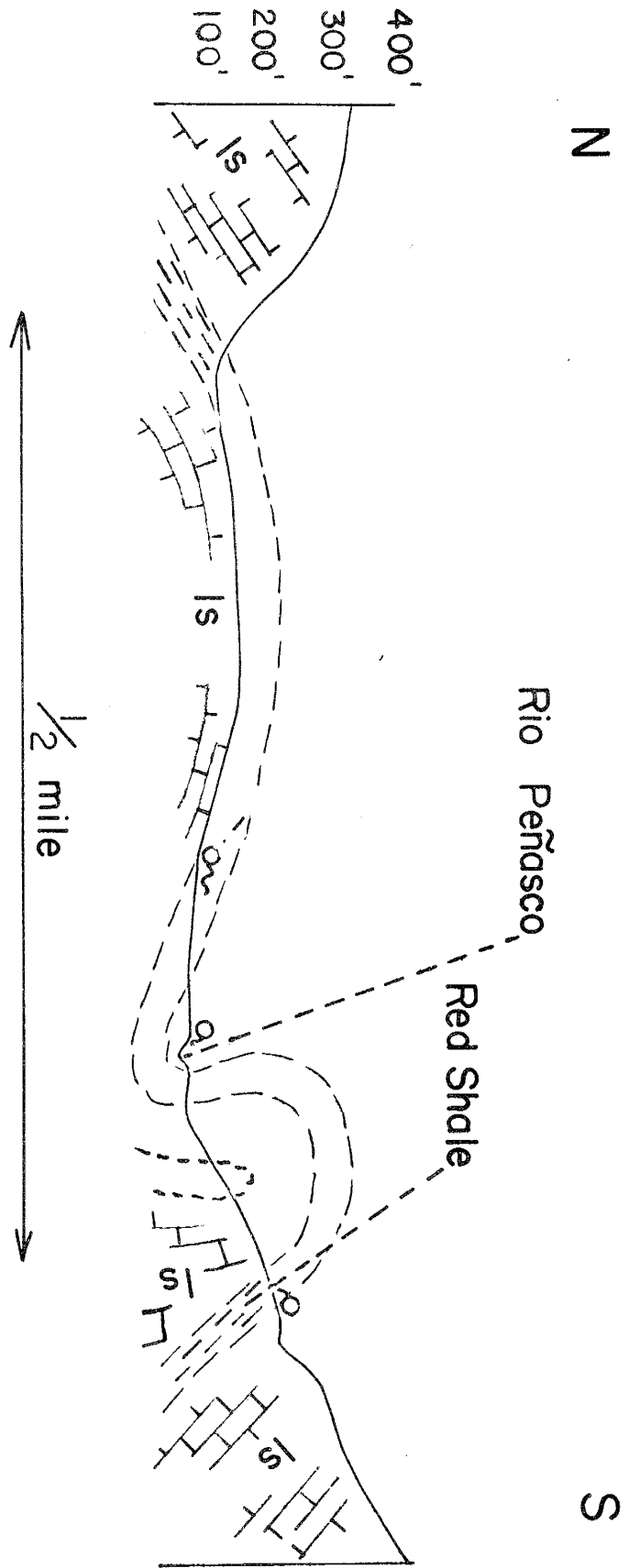


Fig. 5. Geologic cross section of Sec. 11, T.16S, R.16E. After Renick (1926). Three springs are shown. They were called Boyd-Williams Springs at the time of Renick's report. The southernmost spring is the present Paul Spring.

of water from the western region was believed by Fiedler and Nye (1933) to be from eastward flowing streams which lost their flow in the Principal Intake Area.

The recharge contribution from streams of the western portion of the Roswell basin has been studied by Bean (1949) and Mourtant (1963). Hantush (1955) calculated the total quantity of recharge for the Roswell artesian basin. Some of his results are discussed below. Duffy et al. (1978) investigated recharge from the western region in the form of stream losses and percolation from the Glorieta Sandstone and Yeso Formation.

Ground water studies involving the use of tritium data have been presented by Rabinowitz et al. (1977), and by Gross et al. (1976).

The first of these studies was based entirely on tritium measurements of precipitation and of wells located in the confined part of the Principal Aquifer and in the covering alluvium. One of the recommendations of this work was that groundwater from the Principal Recharge Area should be investigated systematically; preliminary results were reported in the second study cited above.

They indicated that a substantial fraction of the groundwater in the unconfined part of the Principal Aquifer was not derived from local precipitation and infiltration. Therefore it must come from deeper aquifers which receive their recharge in outcrop areas further west.

Table II. Chemical Analyses of the Paul Spring water, ppm. Comparison of data from 1926 and 1978.

Constituent	1926*	April 2, 1978
	Date Collected	
CO ₃	0	0
HCO ₃	226	223
Cl ⁻	8	1.0
SO ₄ ²⁻	27	100
NO ₃	.40	
Fe	.26	
SiO ₂	15	
Na ⁺	9.4	6.0
K ⁺	9.4	.35
Mg ⁺⁺	16	13.8
Ca ⁺⁺	55	88
TDS	366.5	432.2

*From Renick (1926)

The hydrogeologic studies by Havenor (1968) and Kinney et al. (1968), though not directly concerned with recharge, are fundamental to an understanding of the basin hydrology and of its problems. Similarly important is the detailed description of the surface geology and geologic map by Kelley (1971). The lumped parameter approach to phreattic aquifer modeling has been treated by several authors including Dooge (1960), Eriksson (1970) and Gelhar and Wilson (1974). Stochastic treatment of the lumped parameter model was first developed by Gelhar (1974) and then presented again by Flores and Gelhar (1976).

RECHARGE ESTIMATES

Following Fiedler and Nye (1933), recharge for the Roswell artesian basin has been assumed to come mainly from the Principal Intake Area, with the western portion of the basin contributing mainly runoff, which is lost through channel leakage in the Principal Intake Area. They considered that other contributions from the western area were not important because ground water is in the Yesso Formation, which is relatively impervious. They also felt that water moving along the Yesso-San Andres contact would contribute to surface water flow on the western flank of the basin and thereby to recharge in the Principal Intake Area. This would be the case for Paul Spring if its waters were not used for domestic purposes. Fiedler and Nye (1933, p. 246) used an estimate of the total natural outflow of the basin, prior to ground water development, as the recharge amount. This amount they calculated at 250,000 acre-ft/yr. The percentage of precipitation which becomes recharge was then calculated to be 7.3 for the "total recharge area" (estimated by Fiedler and Nye as 4,000 square miles) or 29% for the Principal Intake Area (1,200 square miles). They suggested that the true value was probably less than 25% of precipitation falling on the Principal Intake Area and that the remainder was derived from streams which lose most of their flow in the Principal Intake Area.

Another approach to the calculation of the recharge for the Roswell artesian basin was taken by Hantush (1957). Hantush considered years when he felt the system was in "dynamic equilibrium",

We can estimate a recharge percentage using Hantush's approach as follows. The average annual precipitation in the Roswell Basin for the years 1975, 1976, 1977, calculated with the Thiessen polygon method as given by Gross et al. (1976), was found to be 11.71, 12.51, and 12.01 inches, respectively. From Hantush's equation, the effective precipitation, \bar{R}_n , was calculated as 12.13 inches/year = 1.011 ft/yr. The total basin area, \bar{A} , is 8,243 mi² = 2.3×10^{11} ft² (from Gross et al., 1976, p. 182). Hence, the mean years considered by him (viz.: 1928, 1936, and 1944).

Hantush arrived at a figure of 240,000 acre-ft/yr for the $K = 3$ = number of years that rainfall of a given year is effective (Hantush, 1957, p. 49).
 R = measured precipitation (Hantush used Roswell and Artesia data)

and

$$\bar{R}_n = \frac{K}{\sum_{i=1}^K} \frac{2(K+1-i)}{K(K+1)} R^{(n+1-i)}$$

where the effective precipitation

$$\text{Recharge} = 21,000 \text{ (ac-ft/in)} \bar{R}_n$$

particular time." Following Jacob, Hantush used the equations produced the same water table profile as actually existed at that had it been maintained uninterrupted throughout the past, would have effective precipitation is equal to "the rate of precipitation which, concept of effective precipitation proposed by Jacob (1944). The effect that is inflow was equal to outflow. He also incorporated the con-

be discussed in a following section dealing with tritium measurements.

Fiedler and Nye (1933). The validity of including this flow will
mation and the Glorieta Sandstone, which was assumed negligible by
This calculation represents underflow contributed by the Yeso For-
of the western region to be approximately 133,000 acre-feet/yr.

Duffy et al. (1978, p. 58) estimated the total contribution

place, vary over a wide range.

involve the surface area over which effective precipitation takes
to 250,000 acre-ft, the estimates of recharge fraction, which in-
approach which is based on Hantush's formula all give a value close
tive precipitation by Fiedler and Nye, by Hantush, and by the above
formula, would become about 9.7%. Whereas the estimates of effec-
square miles) the recharge percentage, calculated with Hantush's
port. If we assume Fiedler and Nye's total recharge area (4,000
p. 52). In fact, Hantush does not define the basin area in his re-
total recharge volume did not involve the basin area (Hantush, 1957,
area computed by Gross et al. (1976). Hantush's computation of
In estimating this percentage we have used the total basin

$$r = \frac{250,000}{5,300,000} = 0.047 \text{ or } 4.7\%$$

and the recharge fraction

$$\bar{R}_n = 21,000 \times 12.13 = 250,000 \text{ acre-ft}$$

or total recharge volume is

acre-ft. Also, from Hantush's formula, the effective precipitation

yearly volume of precipitation falling on the basin is 5,300,000

This underflow contribution is included in both Fiedler and Nye's and Hantush's recharge calculations because they consider total basin outflow at equilibrium as a measure of recharge. Thus, the contribution to recharge from precipitation on the San Andres Formation (and the overlying alluvium) should be less than one half of total recharge. This further reduces the recharge fraction as estimated above.

These considerations serve to underscore the importance of underflow from formations underlying the San Andres (viz.: Yeso), as opposed to precipitation and direct infiltration, for the basin's hydrologic budget.

The outflow from the system was assumed to be equal to the

Outflow

local recharge area.

study. The rain gauge is located within less than a mile of the

Precipitation records from Elk (Fig. 4) were used for this

Precipitation

logic constraints of the system.

hydrologic conditions were then delineated by considering the geo-

duced in scale and is reproduced in Fig. 6. The recharge area and

in color supplemented the field mapping. The geologic map was re-

expanded to a scale of 1:800. The use of several air photographs

area was mapped in detail on a U.S.G.S. topographic map which was

characteristics, recharge area, and hydrologic connections, the

In order to determine hydrologic boundaries, hydrogeologic

Hydrogeology

relation of tritium measurements of precipitation and groundwater.

aquifer with adjacent systems; precipitation input, outflow, cor-

tics, local recharge area, hydrologic connections of the local

hydrologic boundaries of the local basin, hydrogeologic characteris-

basin characteristics and parameters had to be defined or measured:

utes recharge to the Paul Spring groundwater system, the following

In order to estimate the amount of precipitation that contrib-

PROCEDURE

discharge of Paul Spring. To measure it, a stilling pond was dug and equipped with a weir and a water level recorder. A continuous record of springflow was obtained during 453 days. The details of construction, measurement procedures, and problems encountered are given in Appendix B. The measurements are tabulated in Appendix C. The precipitation and discharge data were used to compute re-charge by a lumped parameter approach. These computations will be discussed in detail.

Tritium Determinations

These measurements were carried out at the Tritium Laboratory of New Mexico Institute of Mining and Technology as part of a systematic basinwide investigation. A comparison of tritium values in precipitation and groundwater was to yield clues concerning residence times and circulation patterns. A detailed discussion of measurement techniques, sampling procedures, and basinwide results is given in previous reports (Kabinowitz and Gross, 1972; Gross, et al., 1976).

GEOLOGY OF PAUL SPRING

Particular attention was paid to the geology in order to define the area of recharge for the Paul Spring aquifer. Two formations of Permian age are exposed along with several Quaternary units. Their surface distribution is shown on the geologic map (Fig. 6). Figs. 7, 8, and 9 give cross sections through the study area. The stratigraphic column is given in Table III.

The Permian System

Yeso Formation

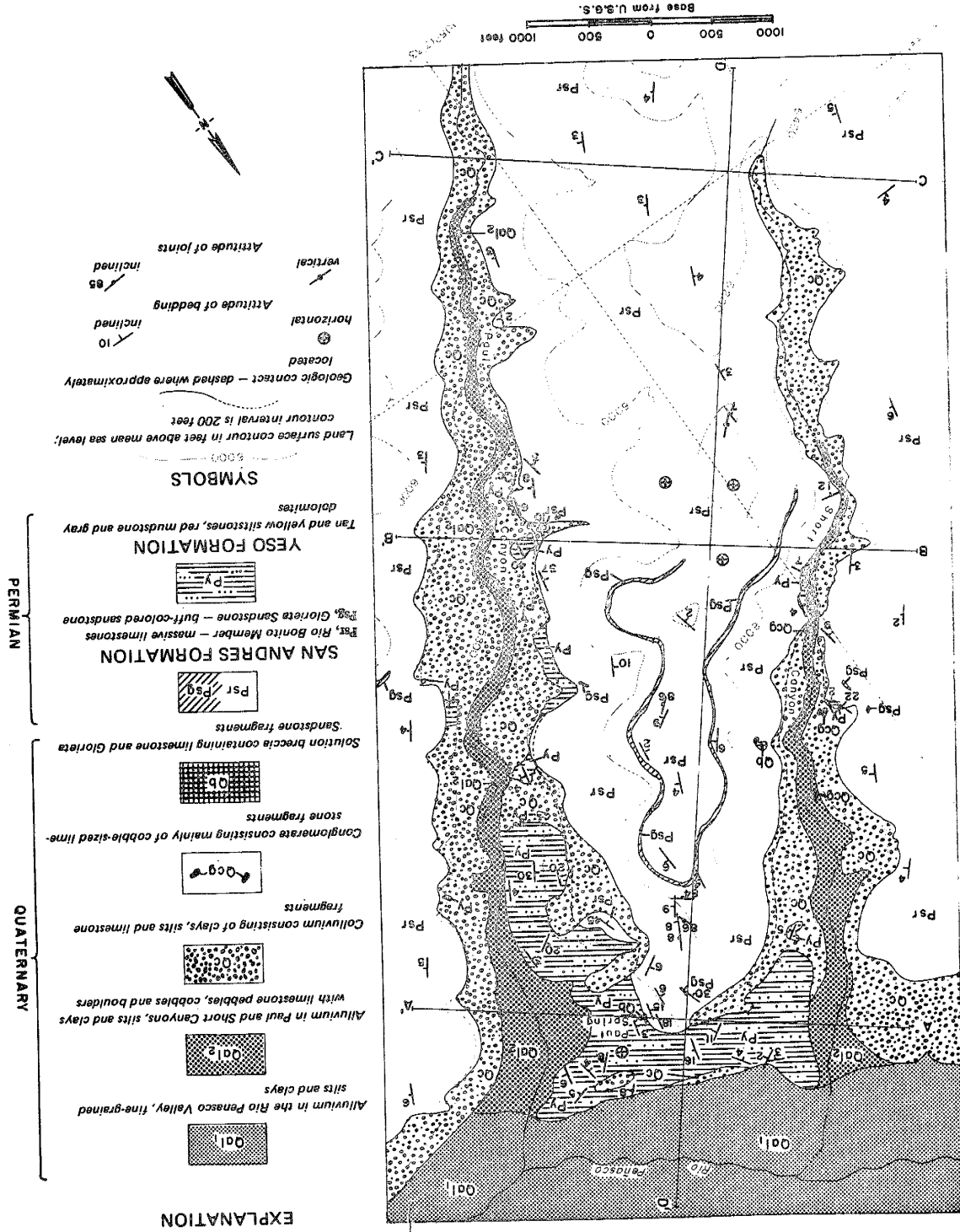
The Yeso Formation is the oldest rock unit which crops out in the study area. It is of particular hydrogeologic importance because it forms the semipermeable bottom as well as part of the aquifer of the perched system.

In the region covered by this report the Yeso is exposed along the base of the central and northeast portion of the ridge containing the perched water body.

Very friable reddish and yellowish siltstones in the upper part of this formation form the semipermeable layer holding up the perched water system. Exposures of thinly bedded limestone or dolomite which contain chert nodules are also common in this area. Significant amounts of gypsum occur in the upper Yeso Formation

(Kelley, 1971). Although gypsum was not encountered in field mapping of this region, its subsurface presence is indicated by the high sulfate content in the water issuing from Paul Spring (Table I).

FIGURE 6 -- GEOLOGIC MAP OF THE PAUL SPRING AREA, CHAVES COUNTY, NEW MEXICO



San Andres Formation
 The San Andres Formation conformably overlies the Yeso Formation in this region. It makes up the major part of the hill containing the perched water body and is the formation through which precipitation must infiltrate to recharge the perched system. In the area covered by this report the San Andres is represented by the Glorieta Sandstone Member and a portion of the Rio Bonito Member.

The Glorieta Sandstone occurs as an intertonguing unit within the Rio Bonito Member. There are two lenses of this sandstone which crop out in the study area. Both are similar in composition being medium grained, well sorted, moderately cemented, tan quartz sandstones. The lower sandstone tongues in and out near the Yeso-San Andres contact. It averages about two feet thick and at one location grades into a thin, yellow, friable siltstone below it. The upper sandstone occurs as a lens about 180 feet above the Yeso-San Andres contact. This sandstone is approximately 20 feet thick in the northeast part of the area and gradually thins until it pinches out in the central part of the study area (Fig. 9).

was not possible to measure its thickness. Since only the upper portion of this formation is exposed, it Yeso/San Andres Formation contact.

have caused these collapse features which are abundant near the Dissolution of gypsum in the upper part of the Yeso Formation could In this area, Yeso outcrops are commonly disturbed by collapse.

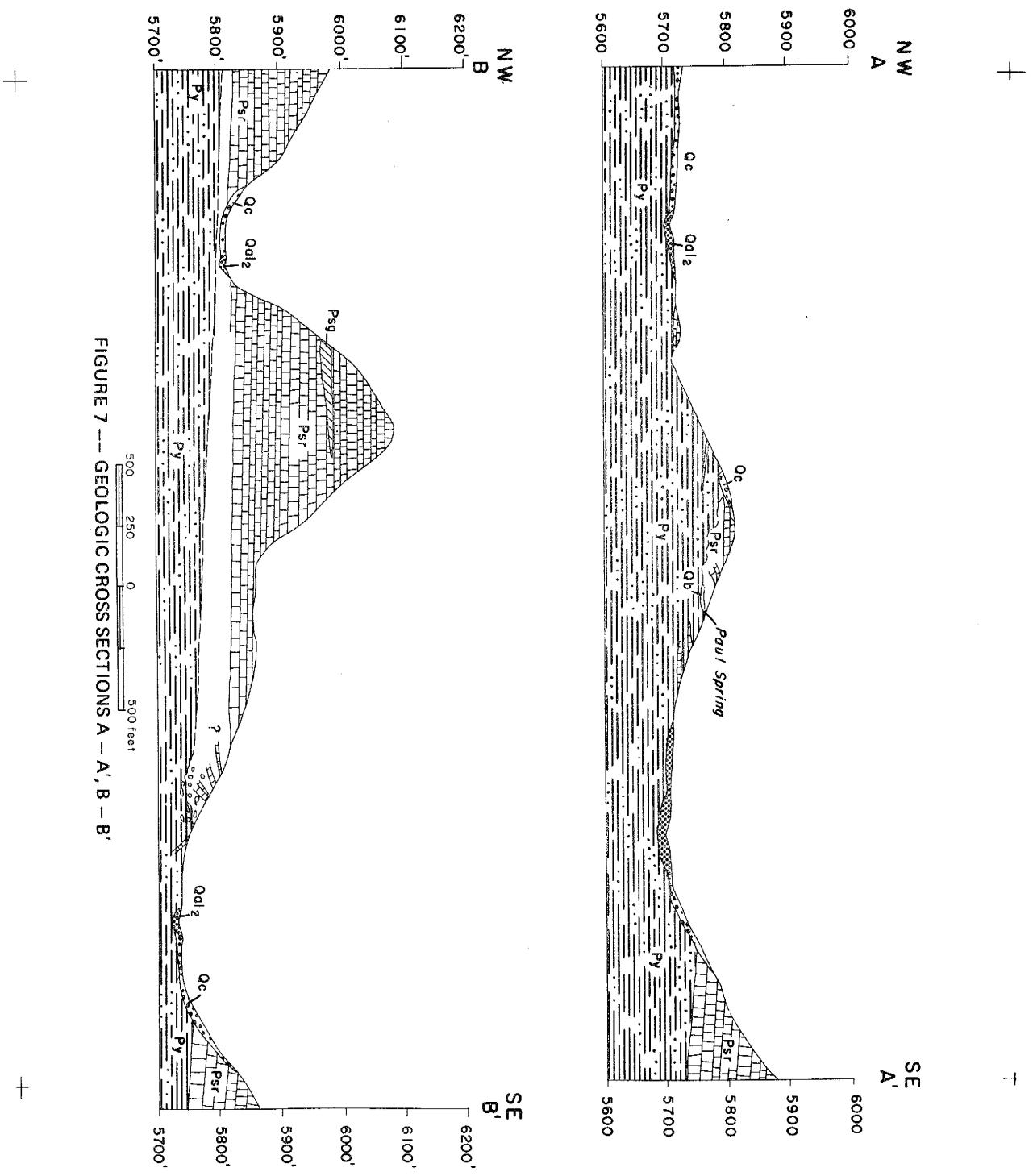


FIGURE 7 --- GEOLOGIC CROSS SECTIONS A - A', B - B'

This unit is also unnamed and occurs as isolated outcrops. It is the unit from which Paul Spring issues. At Paul Spring it contains angular boulders, cobbles, and pebbles of limestone, and angular fragments of tufa in a calcite-cemented matrix of finer limestone particles. These limestone fragments were probably derived from the San Andres Formation. This unit also occurs in the north-central part of the area and consists of angular fragments of limestone and Glorieta Sandstone in a matrix similar to the breccia at Paul Spring. It is difficult to determine when this solution breccia began forming.

Solution Breccia Unit

This unnamed unit occurs as isolated outcrops only near the dry stream bed in Short Canyon. It consists of mainly sub-angular to sub-rounded fragments of locally derived limestone in a matrix of sand, silt and clay, moderately cemented by calcite. It was probably deposited in Paul Canyon also, but later eroded away as the area underwent renewed uplift.

Conglomerate Unit

The Quaternary System

The Rio Bonito Member is exposed throughout most of this area. It consists of highly jointed limestone beds which are usually 3 to 6 feet thick and exhibit markedly parallel bedding. Some beds occur which are 10 and 20 feet thick. Since the upper boundary of this unit is not encountered in this study, an accurate total thickness cannot be reported.

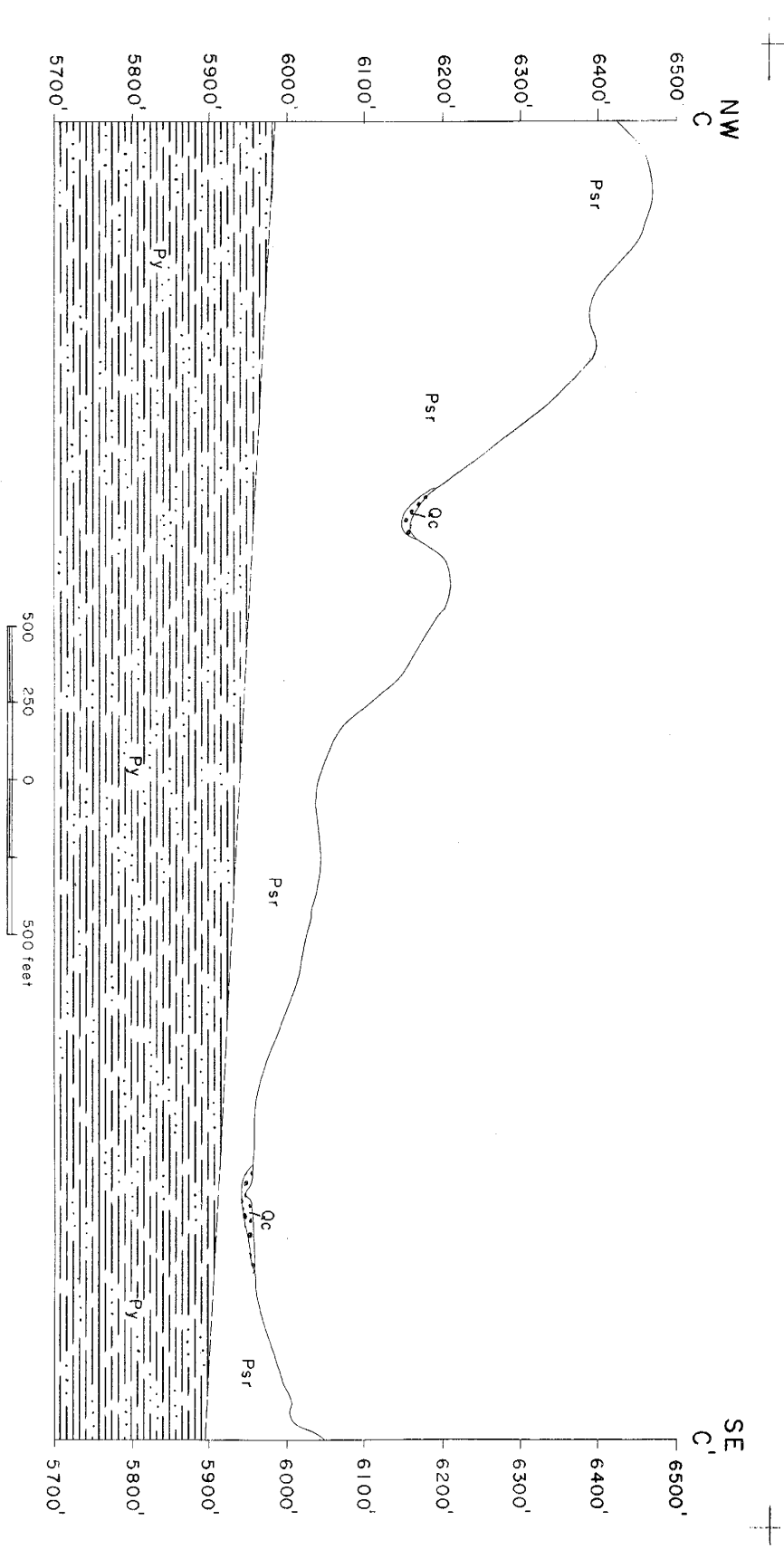


FIGURE 8 --- GEOLOGIC CROSS SECTION C - C'

As mentioned before, this area lies on the eastern dip slope of the Sacramento uplift (Kelley, 1971). More locally it is in the central portion of the Dunken uplift which is an area of several nearly north-south trending synclines and anticlines (Kelley, 1971).

Structure

The alluvium in this area was divided into two sub-units. The first sub-unit is made up of the alluvium deposited in the Rio Penasco flood plain. It consists mainly of fine silts and clays with some well rounded limestone fragments which range in size from coarse sand to cobbles. The second sub-unit is made up mostly of locally derived subangular to subrounded limestone fragments of pebble to boulder size with some sands, silts, and clays. This sub-unit is found in Paul and Short Canyons.

Alluvium Units

This unconsolidated talus slope deposit consists of locally derived material mostly from the San Andres Formation and to a lesser degree from the Yeso Formation. It commonly contains unsorted limestone fragments of pebble to boulder size covered by a thin soil layer.

Colluvium Unit

but the age is given as Recent because it is still forming at present. This is evidenced not only by tufa deposited at the mouth of the spring but also by calcium carbonate which was deposited on the weir used to monitor the springflow.

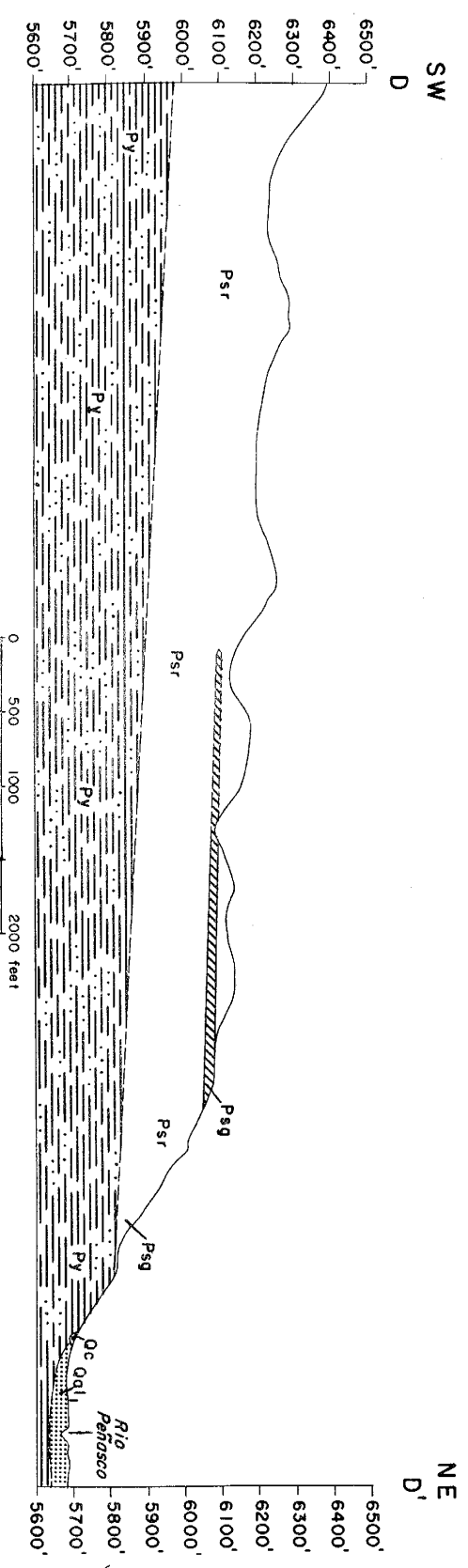


FIGURE 9 — GEOLOGIC CROSS SECTION D - D'

The study area itself is characterized by lack of any major structures. Beds within it generally dip gently toward the east (Figs. 7 and 8). The main exceptions are the beds near the contact of the Yeso and San Andres Formations. These beds generally dip in toward the hill at angles ranging from 7 to 45 degrees. Since the Yeso-San Andres contact throughout the region also dips gently toward the east, it is assumed that the bedding attitude near the contact is the result of collapse. This collapse is assumed to be due to dissolution of gypsum in the upper part of the Yeso Formation. Cross sections shown in Fig. 7 indicate this relationship. It is thought that collapse has occurred along most of the Yeso-San Andres contact but it is not shown on the cross sections due to lack of evidence. These collapse and solution features probably act to channel the ground water toward Paul Spring.

Table III. Simplified Stratigraphic Column for the Roswell Basin and the Paul Spring Area.

AGE	GROUPS, FORMATIONS, MEMBERS	DESCRIPTION
Holocene and Pleistocene	<u>Alluvium</u>	Predominantly fine-grained flood plain deposit of Rio Pecos. Coarse deposits in Paul Canyon and Short Canyon.
	<u>Colluvium Unit</u>	Talus slope deposit mostly derived from San Andres Limestone.
Pleistocene	<u>Solution Breccia Unit</u>	Angular fragments of limestone and tufa in a calcite-cemented matrix of smaller limestone particles.
	<u>Conglomerate Unit</u>	Limestone fragments in a fine-grained sandy matrix, moderately cemented by caliche.
	<u>Gatuna Formation</u>	0-250 ft. thick. Sands, clays, gravels, red color, thin layers of carbonates.
Permian	<u>Artesia group</u>	0-400 ft. thick. Upper portion: Clays, sands, evaporites. Lower portion: Clays, sands, carbonates. The Queen formation is usually considered to form the aquitard.
	<u>Tansill formation</u> <u>Yates formation</u> <u>Seven Rivers formation</u> <u>Queen formation</u> <u>Grayburg formation</u>	200-? ft. thick. Upper portion: Evaporites, sands (Lovington sandstone), carbonates. Lower portion: Carbonates, sands (Glorieta sandstone), shales.
	<u>Yeso formation</u>	
Precambrian	<u>San Andres formation</u>	Fourmile Draw member Bonney Canyon member Rio Bonito member
	<u>Yeso formation</u>	

THE PERCHED SYSTEM

Paul Spring was chosen for this recharge study because the aquifer contributing to it is perched and considered to be small in areal extent. This is important in that it should be possible to isolate this system and obtain accurate values for the percentage of rainfall which becomes recharge.

A perched groundwater body is held above the regional water table by a layer of impermeable or semi-permeable rock. In the Paul Spring area it is difficult to show the existence of a true regional water table due to the highly variable nature of the beds which make up the Yeso Formation. Kenick (1926) and Fiedler and Nye (1933) all reported that the regional water table was 500 to 1000 feet below the land surface. Appendix A gives well log data for the area around Paul Spring. These data show water being encountered at several different levels in this region. It appears that there are numerous perched water bodies at various levels, with the one contributing to Paul Spring having the highest elevation.

In order to determine the percentage of rainfall which actually enters the ground and becomes recharge water, it was necessary to delineate the boundaries of the perched system. As previously noted, the base of the aquifer is in the uppermost part of the Yeso Formation.

An examination of the geologic map (Fig. 6) and of the cross sections (Figs. 7, 8, 9) indicates that the general dip is about 3° due east or southeast in the study area. On all sides but the

southwest, the aquifer is isolated by channels that cut down to somewhat below the top of the Yeso Formation. Only the southwest side, or base, is connected to the main body of the Permian complex (Fig. 9). Lateral influx of surface water or shallow groundwater could come through this base (Fig. 10), but seems to be precluded by the general dip. A contribution from outside the recharge area seems possible only through the Yeso Formation. Solution channels and collapse features could be locally more important than the general dip in funneling lateral groundwater flow into the Paul Spring area and in controlling the point or points of discharge. The Yeso outcrops south of Paul Spring show no evidence of appreciable groundwater discharge taking place at present.* A denser vegetation, mostly of juniper trees, characterizes the slopes just below the Yeso/San Andres contact. It is probably due to greater moisture retention by the semipermeable layer rather than to lateral groundwater movement.

The recharge area, outlined in Fig. 10, follows the exposed contact between the Yeso and San Andres formations; it includes a narrow zone beyond the exposed contact that could provide water for Paul Spring through channeling. The total recharge area was measured with a planimeter and found to be 14,160,438 square feet. * A patch of solution breccia in Short Canyon (Fig. 6) indicates that other springs existed in the recent past.

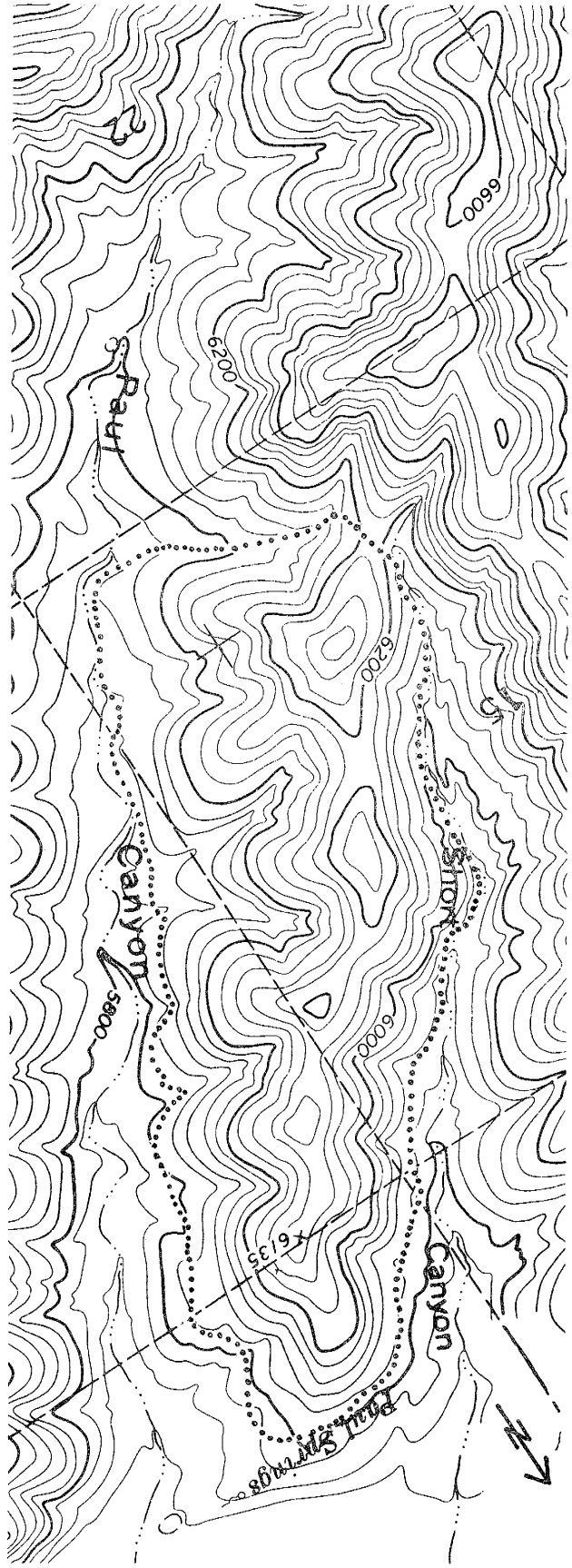


Fig. 10. Recharge area contributing to the Paul Spring aquifer.

TRITIUM IN PRECIPITATION AND SPRING WATER

Water samples from Paul Spring, collected since 1973, and precipitation samples from Elk have been analyzed for natural tritium. Tritium has a known half-life of 12.36 years. Therefore, using the available data it should be possible to calculate the flow

velocity and the age of the ground water issuing from Paul Spring. These parameters are of particular importance because they could provide an estimate of the delay between recharge and discharge and also provide additional information about the perched system.

The tritium content is reported in tritium units (TU) defined

as

$$1 \text{ TU} = 1 \text{ tritium atom per } 10^{18} \text{ hydrogen atoms.}$$

Tritium values for the area of interest are given in Tables IV and V. A graph of spring flow and precipitation tritium activity versus

time is given in Fig. 11. It should be noted that every precipi-

tation event is not represented. This is either because a sample

was not collected or several events were lumped together to obtain

enough water for tritium analysis. On examination of this plot it

is evident that the relationship between tritium in precipitation

and tritium in springflow is quite complex. Possible correlations

of peaks yield travel times that range from 150 to 500 days but the

validity of these values is questionable.

The actual amount of tritium entering the ground water system

may have more effect on the tritium content of the spring water

Table IV. Tritium in Precipitation at Elk.

Date	Amount of Precipitation (in.)	TU
07/74	.44	49.6
08/74	5.44	49.2
08/24-30/74	4.25	39.4
09/74	10.03	33.7
03/12+30/75	.54	97.2
05/11-30/75	.39	68.3
07/03-10/75	1.11	55.8
07/11/75	1.65	68.4
07/12-27, 29, 30/75	1.94	56.3
08-09/75	5.46	24.5
06/76	1.22	58.2
07/76	3.28	24.1
11/12, 28/76	.94	30.7
02/15/77	1.20	45.2
04/14/77	1.49	42.5
05/08/77	1.57	44.5
05/22/77	1.12	54.4
06/15/77	1.38	76.3
08/11/77	2.30	26.5
09/07/77	1.33	31.1
10/3, 6/77	.50	20.7

than the relative concentration of tritium in precipitation. For example, a small precipitation event with a high tritium content may cause less fluctuation in spring water tritium than a large precipitation event with relatively low tritium concentration. Therefore, individual precipitation amounts were multiplied by their corresponding tritium concentrations. These values were then plotted and compared to tritium measurements of spring water (Fig. 12). As in Fig. 11, the graphs in Fig. 12 do not show any obvious correlation.

Even though there is a lack of correlation in Figs. 11 and 12, they indicate several important features about the flow system. The fact that the plots do not correlate is evidence that the perched aquifer is a complicated system. Geologic reasons for this complexity include the collapse features of the upper Yeso Formation and the existence of the Glorieta Sandstone in the recharge area. The collapse features probably cause the ground water flow paths to be highly irregular in direction and length. This would serve to mask the effect of a tritium peak in precipitation which recharges the aquifer. As discussed below (p.89), the Glorieta Sandstone acts as a filter and dampens the aquifer response to percolation. The tritium values for springflow in Figs. 11 and 12 are an important indication of flow conditions in the Paul Spring aquifer. When considering the tritium input, that is tritium in precipitation, these measurements indicate long travel times and relatively old ground water. This would not be expected for such a small

Table V. Tritium in Water From Paul Spring.

Date	TU	Date	TU
07-11-73	20.0	02-19-77	14.1
04-08-74	10.1	05-05-77	3.5
06-15-74	10.4	06-30-77	1.6
08-23-74	13.8	07-15-77	1.5
12-19-74	1.7	08-17-77	12.1
02-21-75	1.5	09-16-77	5.5
08-28-75	13.0	10-07-77	2.1
12-19-75	5.3	10-22-77	1.9
03-27-76	10.8	11-19-77	1.4
06-05-76	5.1	12-16-77	2.3
08-10-76	10.4	01-14-78	0.9
12-03-76	9.4	02-11-78	2.5
12-22-76	7.4	03-11-78	1.8
01-04-77	2.5	04-02-78	2.0
01-29-77	3.7		

system. An apparent age can be obtained by taking a weighted average of tritium concentration in precipitation and comparing it to the average tritium value for spring flow. The formula for the weighted

average is given as

$$T_{pa} = \frac{\sum_{i=1}^n T_{pi} \times p_i}{\sum p_i} \quad (1)$$

where

T_{pa} = average tritium content of precipitation

T_{pi} = Tritium content of the i th precipitation sample

p_i = amount of precipitation contributing to the i th sample

n = number of samples.

Using Eq. (1) we obtain an average tritium content in precipi-

tation of 40.7 TU. The average tritium value of spring flow is 7.5 TU.

For a first approximation of the apparent age of the ground

water, a piston type flow equation is used (Nir, 1964). This equa-

tion is of the form:

$$C = C_0 e^{-t/t_m} \quad (2)$$

where

C = concentration of tritium in the spring water

C_0 = concentration of tritium in the precipitation

t_m = mean life of tritium, 17.8 years

t = time in years

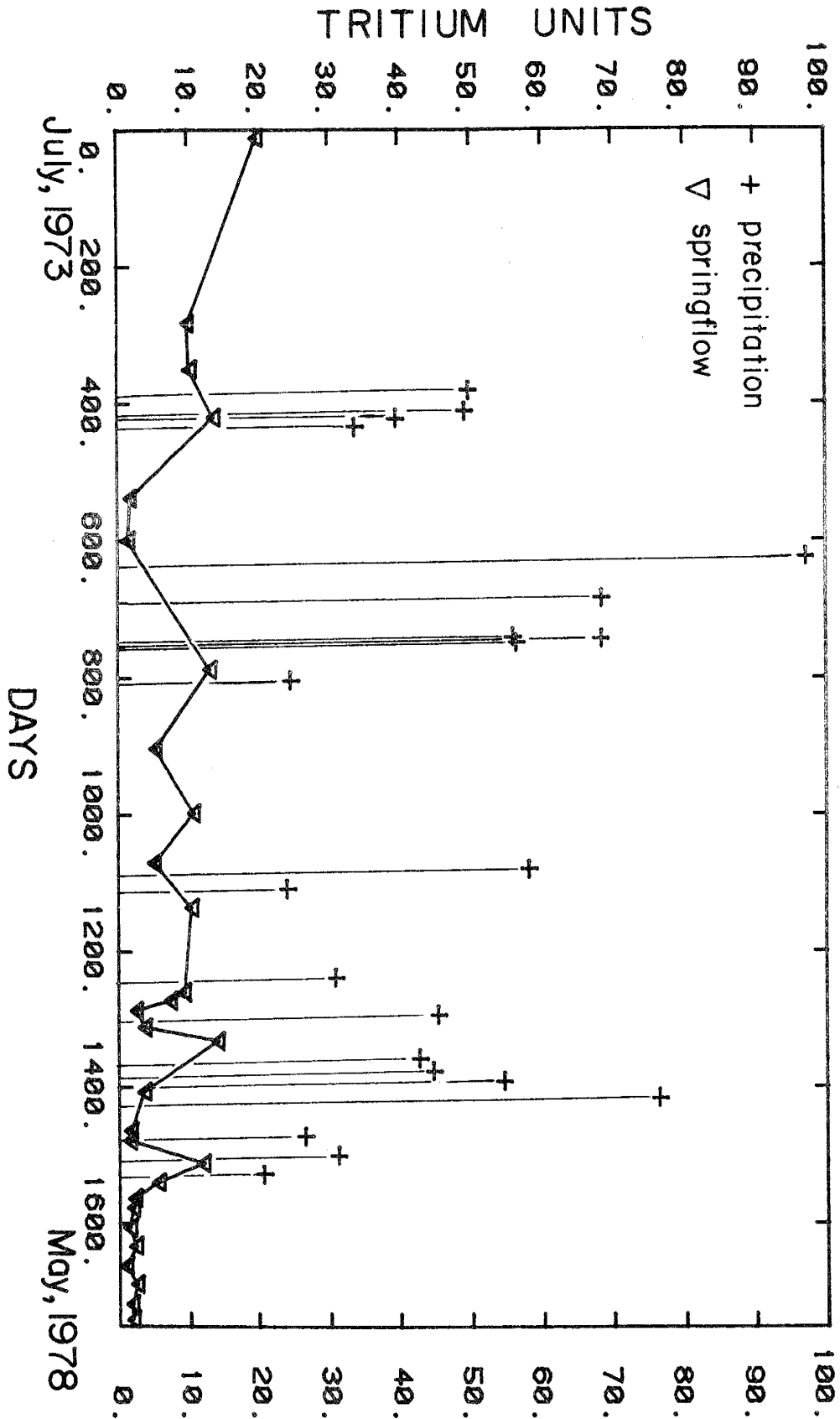


Fig. 11. Tritium activity in springflow and precipitation at Paul Spring (Eik) precipitation records).

According to Nitr (1964), a realistic value for τ is about 0.1. Using that value we obtain an apparent age of the Paul Spring water of 29.9 years, close to the value computed above. An age of 30 years seems unlikely if all or most of the water is derived from local infiltration. The water would predate the atmospheric nuclear tests of the fifties and early sixties and this is contradicted by

$$t = \frac{t_m^{2\tau} \log_e [C/C_0 (4\tau + 1)^{\frac{1}{2}}]}{1 - (4\tau + 1)^{\frac{1}{2}}}$$

Solving for t in Eq. (3) gives

$$t^* = t/t_m$$

$$v = \text{velocity}$$

$$D_m = \text{dispersion coefficient}$$

$$\tau = \frac{v t_m}{D_m}$$

where

$$C = C_0 (4\tau + 1)^{-\frac{1}{2}} \exp\left\{\frac{2\tau}{t^*} (1 - (4\tau + 1)^{\frac{1}{2}})\right\} \quad (3)$$

is given as

To take into account the effects of dispersion, an equation for a laminar flow dispersive system is used (Nitr, 1964). This equation

old for such a small system.

ground water in the Paul Spring aquifer. This appears to be quite

which leads to a value of 30.4 years for the apparent age of the

$$t = -t_m \ln \frac{C}{C_0}$$

Solving Eq. (2) for t yields

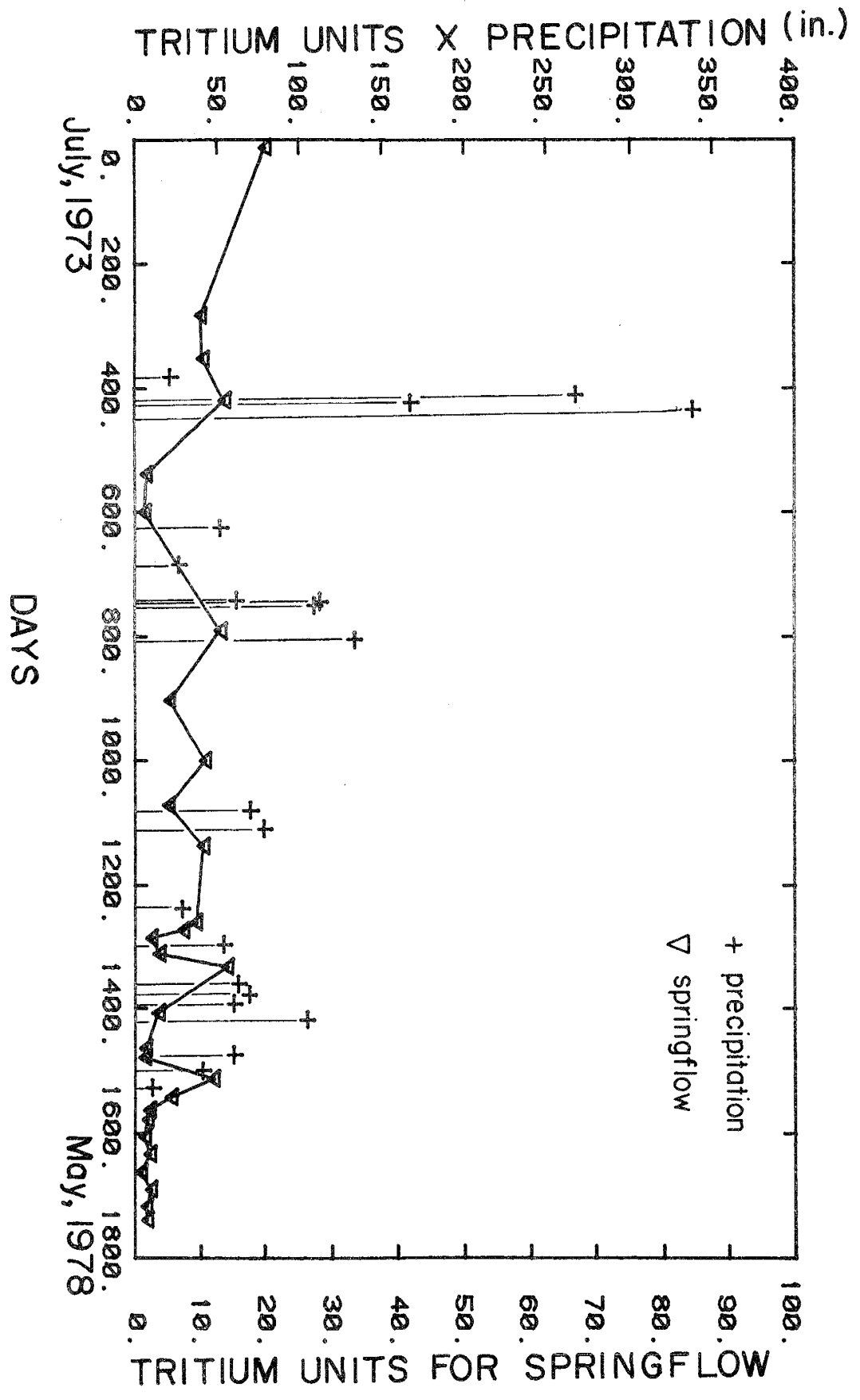


Fig. 12. Comparison of tritium activity in Paul Spring discharge with weighted tritium activity in precipitation.

the occasional post-bomb tritium values that have been measured. They indicate admixture of relatively young water. This would also account for the lack of correlation between tritium in precipitation and tritium in springflow records. The geology of the Paul Spring perched system makes this interpretation plausible. The spring issues from a point very near the Yeso-San Andres contact. If water flowed laterally through the silts of the upper Yeso Formation it would probably travel very slowly whereas water flowing mostly through the limestones of the lower San Andres Formation would travel relatively much faster. These two sources for the ground-water must be considered. Thus, if the head is low (i.e. low flow) a relatively larger amount of water should be coming from the silts of the upper Yeso Formation. When the head is higher, relatively more spring water should be derived from the lower San Andres Formation. To investigate this, tritium values of springflow are plotted in Fig. 13 along with the discharge at the time the tritium samples were taken. This plot shows a delayed relationship between increased flow and "younger" waters. When the flow increases it has a piston effect and pushes out "older" waters which are then followed by the relatively "younger" waters.

Since so much "older" water appears to be contained in the upper Yeso Formation there cannot be a large amount of vertical movement of water through this formation. If the vertical movement was much greater, the downward flowing "younger" waters would tend to

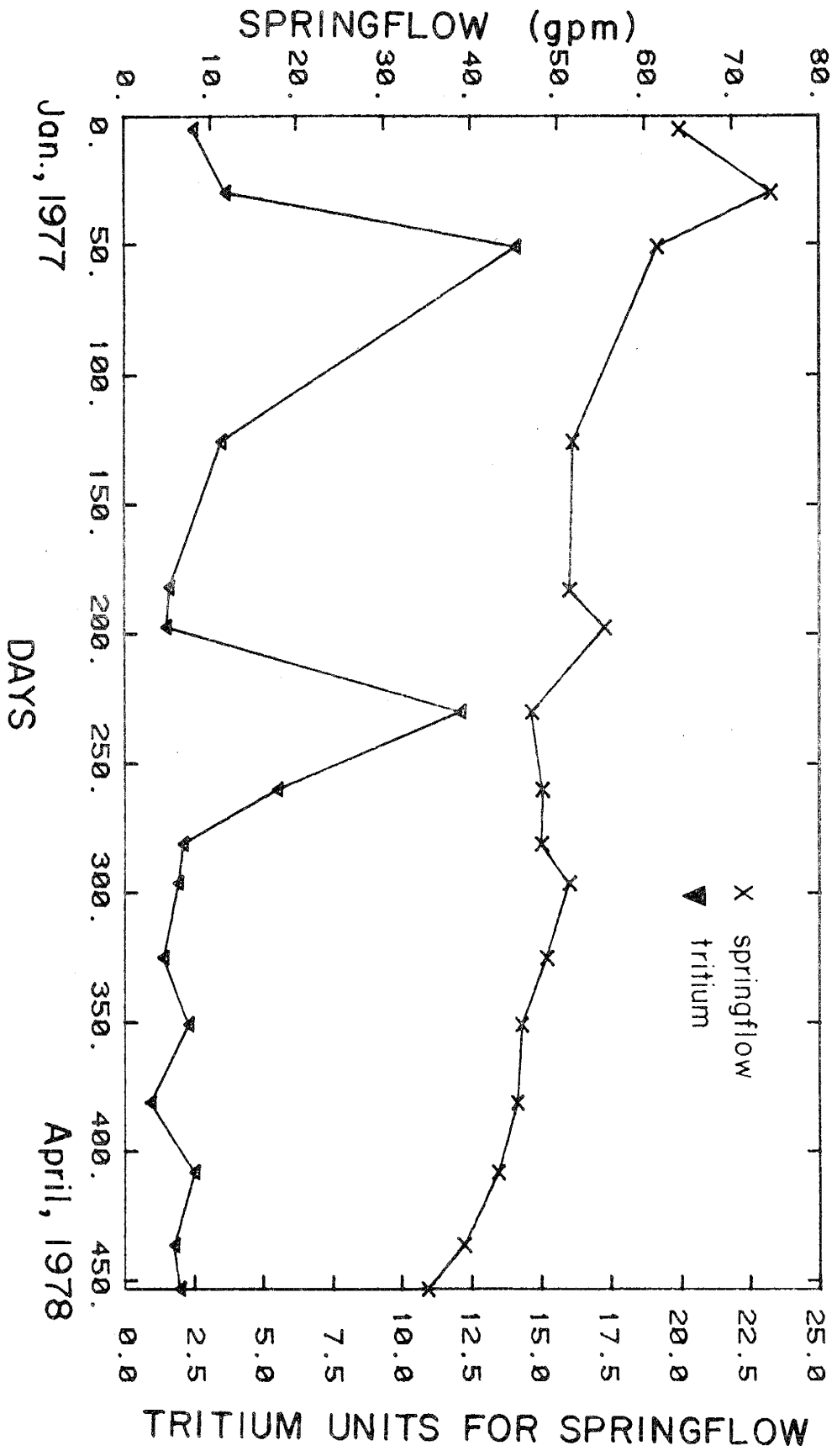


Fig. 13. Paul Spring discharge. Comparison of tritium activity with discharge volume.

Flush out these "older" waters. A low vertical flow rate through the base of the perched system should be expected. The mean tritium contents of precipitation and spring water can be used to estimate a mixing ratio

$$R_m = \frac{Q_p}{Q_p + Q_u} = \frac{7.5}{40.5} = 0.184$$

where Q_p = spring discharge derived from precipitation; Q_u = spring discharge derived from underflow.

This estimate (and it is only an estimate) indicates that only about 18% of the springflow should be used to compute a recharge fraction.

SPRINGFLOW MEASUREMENTS

The flow of Paul Spring was continuously recorded for 453 days, from January 4, 1977 to April 1, 1978. The techniques are described in Appendix B. Numerical data for daily average springflow are tabulated in Appendix C.

A graph of springflow vs. time is given in Fig. 14. Springflow is corrected for diversion, leakage and clogging of the V-notch and stilling well by debris (Appendix B). Short-term fluctuations of springflow are superposed on a monotonic decline over the whole time span of measurement.

The short-term declines were interpreted as recession curves from individual or closely spaced rainfall events. A number of these were selected for recession curve analysis. They are listed in Appendix D.

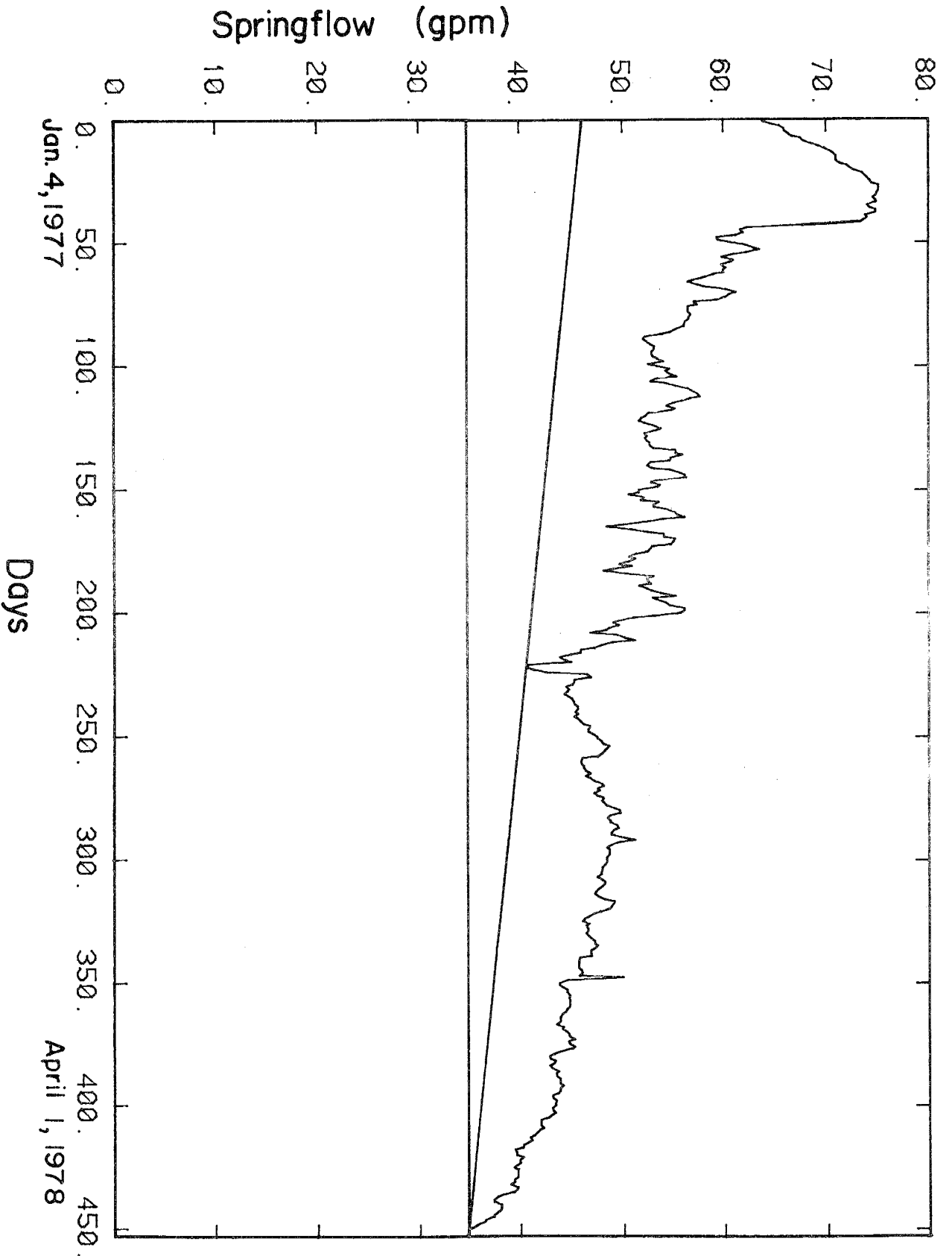


Fig. 14. Springflow vs. time. The straight lines represent two possible deep flow components.

RECHARGE ESTIMATES AT PAUL SPRING

Approach

In order to estimate the amount and percentage of precipitation

which becomes recharge it is necessary to formulate a governing equa-

tion which utilizes the available data. For the Paul Spring area

these data consist of daily precipitation records over a period of

many years and springflow measurements of 453 days. Since there is

no information on how the parameters of the Paul Spring aquifer vary

in space, i.e. wells or other springs, it is necessary to use a lumped

parameter approach. In this model the aquifer is thought of as a

phreatic linear reservoir in which the spatial variations of the

water level fluctuations are averaged (Fig. 15).

A water balance for this system can then be written in the form

$$S_y \frac{dh}{dt} + a(h-h_0) = e'$$

where

S_y = average storage coefficient (specific yield of the phreatic aquifer), a dimensionless constant

h = average water table height [L]

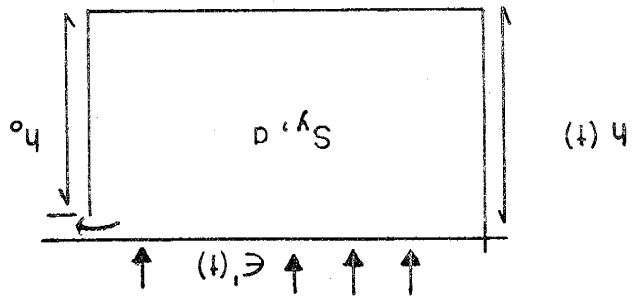
h_0 = level at which the outflow is zero [L], taken to be constant

a = outflow constant [T^{-1}]

e' = recharge rate [L/T]

t = time

Fig. 15. The phreatic linear reservoir.



The outflow is then approximated by:

$$(5) \quad q = a(h - h_0)$$

where q = outflow per unit area [L/T]

To obtain an equation in terms of the total inflow and out-

flow we first multiply Eq. (4) by the total area of the aquifer, \bar{A} .

This gives

$$(6) \quad S_y \bar{A} \frac{dh}{dt} + Aa(h - h_0) = Ae'$$

The term $Aa(h - h_0)$ can now be written as:

$$(7) \quad Aa(h - h_0) = qA = Q$$

where Q = total outflow [L³/T]

The recharge term can then be approximated as a linear function

of the precipitation, as follows:

$$(8) \quad e' = rp$$

where

r = the fraction of precipitation which becomes recharge,

a dimensionless constant.

p = precipitation [L/T]

Solving for \bar{h} in terms of \bar{Q} gives:

$$(9) \quad h = Q/Aa + h_0$$

Substituting Eqs. (7), (8), and (9) into Eq. (6) yields

$$(10) \quad S_y \bar{A} \frac{dh}{dt} + Aa(h - h_0) = Arp$$

or

$$(11) \quad S_y \frac{d\bar{h}}{dt} + \bar{h} = Arp$$

Eq. (11) relates the spring flow, Q , to the precipitation, p . The following calculations are based on this model. We will use both numerical methods and a stochastic approach.

Tritium measurements suggest that the Paul Spring discharge consists of a mixture of water derived from local precipitation and water transmitted through the Yesso Formation. Therefore we will test three hypotheses:

- (1) All springflow is derived from precipitation falling on the spring's recharge area.
- (2) Recharge by precipitation is superposed on a steady component of deep flow (34.8 gpm).
- (3) Recharge by precipitation is superposed on a deep-flow component linearly decreasing from 46.4 gpm to 34.8 gpm over the duration of the springflow measurements (453 days).

If we define the right-hand side of Eq. (11) as the net recharge R, we can write

$$S_Y \frac{dQ}{dt} + Q = R \quad (12)$$

where

$$R = Arp.$$

Now define a spring flow recession as a downward trend in the spring discharge due to the absence of recharge. Then, during periods of spring flow recession we can write Eq. (12) as

$$S_Y \frac{dQ}{dt} + Q = 0. \quad (13)$$

The solution to Eq. (13) is easily shown to be

$$Q = Q_0 e^{-\frac{t}{S_Y}} \quad (14)$$

where Q_0 is the initial flow of the recession period. The springflow record contains numerous recharge/recession events ranging from 1 to 10 days in length. A list of the dates of the spring flow recessions is given in Appendix D. For each separate recession period, the initial flow is Q_0 . Each recession period was therefore normalized on a scale of 0 to 1. Eq. (14) can now be written in finite difference form and rearranged to yield

is known for every point, \bar{I} , where \bar{I} ranges from 2 to $n-1$, and we can the total number of days of record. The left-hand side of Eq. (17) Eq. (17) will produce \bar{n} equations with $n+2$ unknowns, where \bar{n} equals

$$(17) \quad \frac{3}{a} S_Y \frac{\Delta t}{\Delta t} (Q_{j+1} - Q_{j-1}) + (Q_{j+1} + 4Q_j + Q_{j-1}) = (R_{j+1} + 4R_j + R_{j-1}).$$

or written in finite difference form

$$(16) \quad \int_{j+1}^{j-1} S_Y \frac{dQ}{dt} dt + \int_{j+1}^{j-1} Q dt = \int_{j+1}^{j-1} R dt,$$

Rule to yield

Eq. (12) is integrated over two time intervals using Simpson's

Updegraff and Gelhar (1977) for the Mesilla Valley.

the same procedure for calculating net recharge as was used by

to solve for the net recharge, \bar{R} . The first method follows much

In order to provide a check of the results, two methods were used

Method 1: Recharge estimation using Simpson's rule

response time of the system $\overline{S_Y/a}$, was found to be 48.4 days.

desired model parameter $\overline{S_Y/a}$. In the above manner, the hydraulic

An average value of a/S_Y is obtained, the inverse of which is the

program used, along with each value of $\overline{S_Y/a}$ is given in Appendix D.

Eq. (15) is solved to yield $b \times c$ values of a/S_Y . The computer

c = number of recession periods.

where b = number of points in the λ th recession period,

$$(15) \quad \left(\frac{a}{S_Y} \right)^k = \frac{-\log_e (Q_k / Q(\lambda))}{\Delta t}; \quad k = 1, b; \quad \lambda = 1, c$$

We now have \bar{n} equations with \bar{n} unknowns and can solve for the daily net recharge R_j corresponding to the daily spring flow Q_j . The

$$R_0 = \frac{S}{Y} \frac{Q_1 - Q_0}{\Delta t} + Q_1,$$

$$R_{n+1} = \frac{S}{Y} \frac{Q_{n+1} - Q_n}{\Delta t} + Q_n.$$

where R_0 and R_{n+1} are estimated by

$$(19) \quad \begin{bmatrix} 4R_1 + R_2 \\ R_1 + 4R_2 + R_3 \\ \vdots \\ R_{n-1} + 4R_n \\ A_1 - R_0 \\ \vdots \\ A_2 \\ \vdots \\ A_n - R_{n+1} \end{bmatrix} = \begin{bmatrix} 4R_1 + R_2 \\ R_1 + 4R_2 + R_3 \\ \vdots \\ R_{n-1} + 4R_n \\ A_1 - R_0 \\ \vdots \\ A_2 \\ \vdots \\ A_n - R_{n+1} \end{bmatrix}$$

The system of Eqs. (15) is easily solved using the Thomas algorithm if we write the \bar{R} matrix in tridiagonal form as

$$(18) \quad \begin{bmatrix} R_0 + 4R_1 + R_2 \\ R_1 + 4R_2 + R_3 \\ \vdots \\ R_{n-1} + 4R_n + R_{n+1} \\ A_1 \\ \vdots \\ A_2 \\ \vdots \\ A_n \end{bmatrix} = \begin{bmatrix} A_1 \\ \vdots \\ A_2 \\ \vdots \\ A_n \end{bmatrix}$$

matrix form we obtain

\bar{j} ranges from 1 to \bar{n} , and writing the resulting set of equations in Setting the left-hand side of Eq. (17) equal to a variable A_j , where flow record linearly one day, are 63.0 gpm and 34.8 gpm, respectively. For Q_0 and Q_{n+1} . These values, obtained by extrapolating the spring determine the left-hand side at $j=1$ and $j=n$ if we estimate a value

results of method 1, along with the results of the following method 2, are plotted in Fig. 16. Listings of the computer programs and numerical results are given in Appendix E.

Method 2: Recharge estimation using finite difference approximation

Method 2 is easier and shorter than method 1 and will be shown to yield essentially the same results. In method 2, Eq. (12) is written in finite difference form as

$$S_y \frac{1}{a} \frac{2\Delta t}{\Delta t} (Q_{j+1} - Q_{j-1}) + Q_j = R_j, \quad (20)$$

where

$$R_1 = \frac{S_y}{Y} \frac{1}{a} \frac{2\Delta t}{\Delta t} (Q_2 - Q_0) + Q_1,$$

$$R_n = \frac{S_y}{Y} \frac{1}{a} \frac{2\Delta t}{\Delta t} (Q_{n+1} - Q_{n-1}) + Q_n.$$

The daily net recharge calculated using method 2 is plotted in

Fig. 16 (bottom). From a visual inspection of the figure, we can

see that both methods yield about the same results. The similarity

is also demonstrated by comparing the total net recharge of each

method.

METHOD TOTAL NET RECHARGE

1 - Simpson's Rule 4.17287 x 10⁶ ft³

2 - Finite Difference 4.17531 x 10⁶ ft³

The results differ by less than .1%.

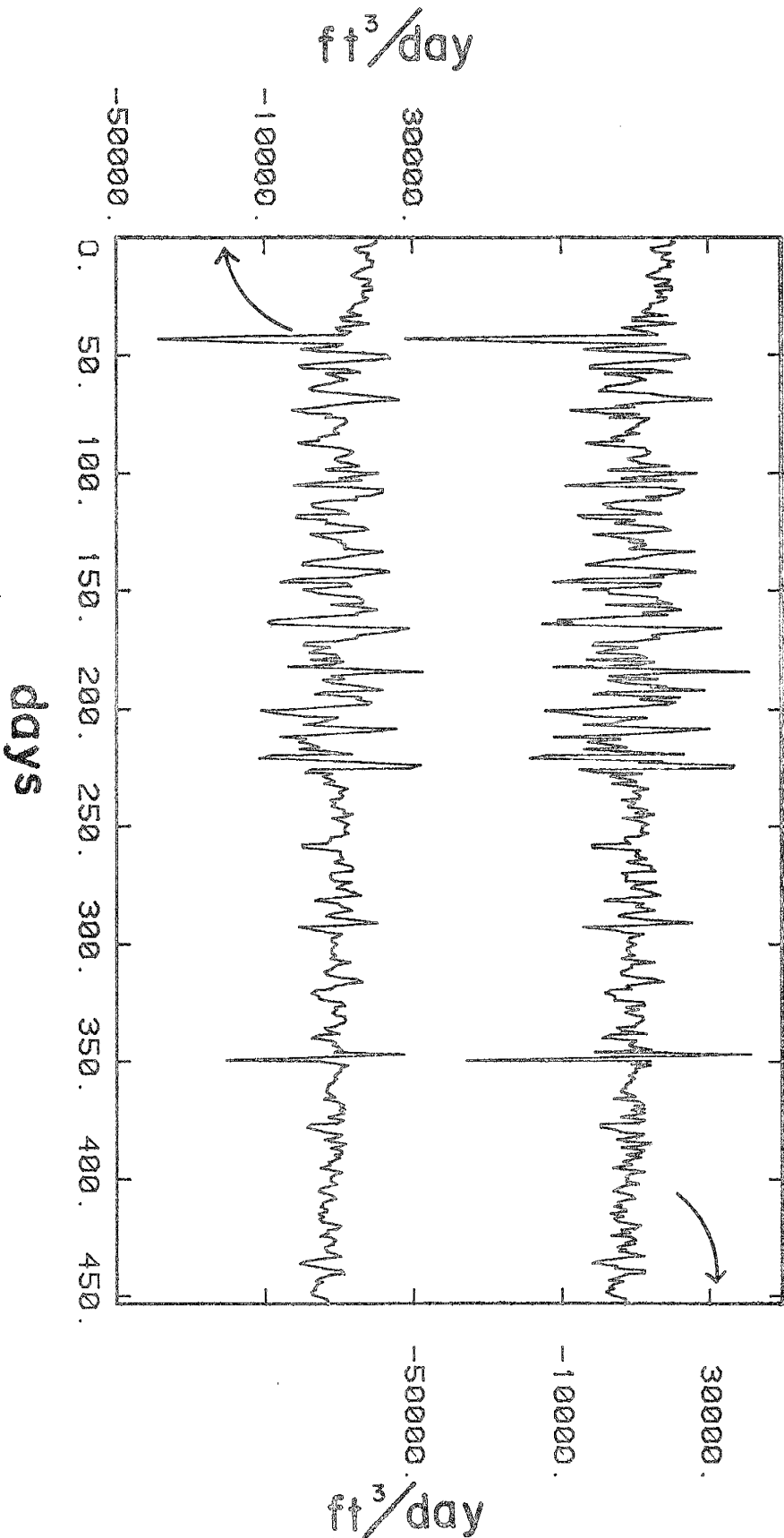


Fig. 16. Recharge estimates by Simpson's rule (top-right scale) and by finite differences (bottom-left scale).

We can also calculate the total change in storage by subtracting the total spring flow from the average total recharge calculated from methods 1 and 2.

Average Total Recharge	4.17 x 10 ⁶ ft ³	
Total Spring Flow	-4.44 x 10 ⁶ ft ³	
Total Loss From Storage	- .27 x 10 ⁶ ft ³	

Calculation of the Percentage of Precipitation that Becomes Recharge

First, we return to our original definition of net recharge

$$R = Arp, \quad (21)$$

where

R = volume of recharge

A = area where recharge occurs

r = percentage of precipitation that becomes recharge

p = precipitation (depth over the surface in feet).

We can solve for the percentage of precipitation that becomes re-

charge by rearranging terms in Eq. (21) to yield

$$r = \frac{R}{A p} = \frac{\text{Total Recharge}}{\text{Total Volume of Precipitation}}$$

We must now determine which period of precipitation corresponds to

the observed spring flow and recharge. Precipitation is unlikely

to cause an immediate fluctuation in the water table elevation,

and therefore an increase in spring flow. The physical situation

would indicate that there must be a delay between the time the pre-

cipitation event occurs and the time the spring flow increases.

Basically the time delay is the sum of two processes. First, the water must infiltrate from the ground surface down to the water table, and, second, the system must respond to the increase in hydraulic head. Therefore we will assume the observed springflow originated as precipitation that fell at an earlier time. We attempted to determine the precipitation lag time using a statistical measure called the cross covariance. The cross covariance function is

$$r_{xy} = E \{ [x(t) - \mu_x][y(t+u) - \mu_y] \}$$

where $E\{\}$ = expected value

$x(t)$ = value of the \bar{x} series at time t

$y(t+u)$ = value of the \bar{y} series at \bar{u} time counts from t (\bar{u} can be positive or negative)

μ_x = mean value of the \bar{x} series

μ_y = mean value of the \bar{y} series .

The function has a maximum value when peaks and troughs of the $x(t)$ series match peaks and troughs of the $y(t+u)$ series. A computer program developed by A. Gutjahr and C. Muma of New Mexico Institute of Mining and Technology was used. We examined the cross covariance between (1) daily recharge and daily precipitation;

(2) the 20-day moving average of recharge and the 20-day moving average of precipitation; (3) daily springflow and daily precipitation. A 20-day moving average is performed by averaging the value at time t with the 19 preceding time periods. The first 19

Table VI. Cross-Covariance Peaks

Spring Flow vs. Precipitation	
43 days	$0.41354 \times 10^{-4} \text{ cm}^2$
97 days	$0.58286 \times 10^{-4} \text{ cm}^2$
152 days	$0.96933 \times 10^{-4} \text{ cm}^2$
191 days	$1.04766 \times 10^{-4} \text{ cm}^2$
277 days	$0.18384 \times 10^{-4} \text{ cm}^2$
360 days	$0.11099 \times 10^{-4} \text{ cm}^2$
Recharge vs. Precipitation (20 day moving average)	
6 days	$0.09940 \times 10^{-4} \text{ cm}^2$
30 days	$0.07545 \times 10^{-4} \text{ cm}^2$
66 days	$0.69920 \times 10^{-4} \text{ cm}^2$
136 days	$1.69838 \times 10^{-4} \text{ cm}^2$
179 days	$1.46615 \times 10^{-4} \text{ cm}^2$
224 days	$0.02316 \times 10^{-4} \text{ cm}^2$

(Most likely range: 120-200 days)

days of record are lost in this averaging process.

We had hoped to find a single peak in the cross covariance at some lag time, but instead found multiple peaks at a variety of lag times (Table VI). The daily recharge and precipitation cross covariance contained so many peaks that the function amounted to little more than noise. We were unable to determine a lag time based on the present data. The 20-day moving average was a first attempt at accounting for the filtering effect of percolation through the unsaturated zone. It produced 6 peaks, the maximum occurring at 136 days. The lag time is a significant factor in determining the recharge percentage because the period of springflow record coincided with a period of diminished precipitation. Precipitation was generally greater prior to the 453 days of springflow record. Therefore, the longer the lag time the smaller the recharge percentage. This can be appreciated from Fig. 17 where springflow is lagged against precipitation at 50-day intervals. Recharge percentages computed from these lagged records are shown in Table VII.

The cross covariance between springflow and precipitation had a maximum at 191 days. The physical significance is uncertain since recharge is really the correlatable parameter. The recharge/precipitation function can be strongly nonlinear. Moreover, a lag time of 191 days is much greater than the response time (48 days) computed from recession curve analysis. Nonetheless, we include a recharge estimate based on this correlation because, as mentioned above, a maximum was not obtained with the recharge/springflow correlation.

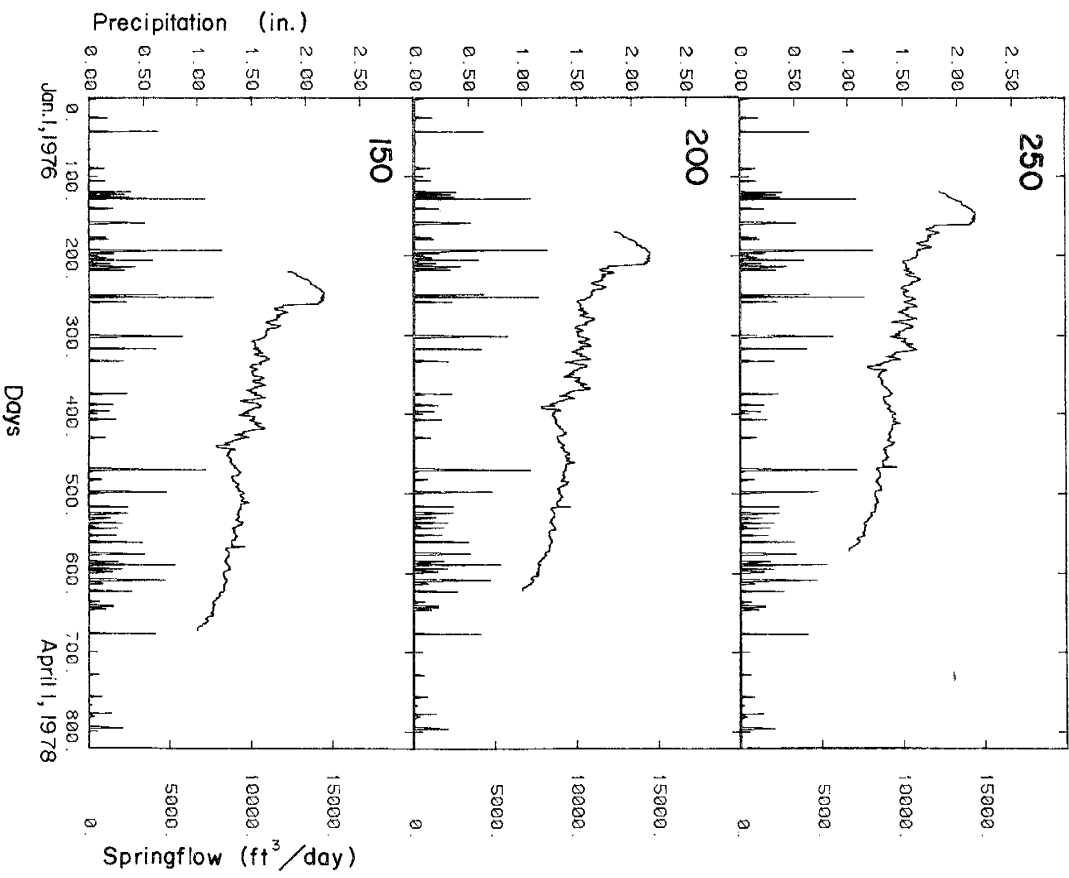
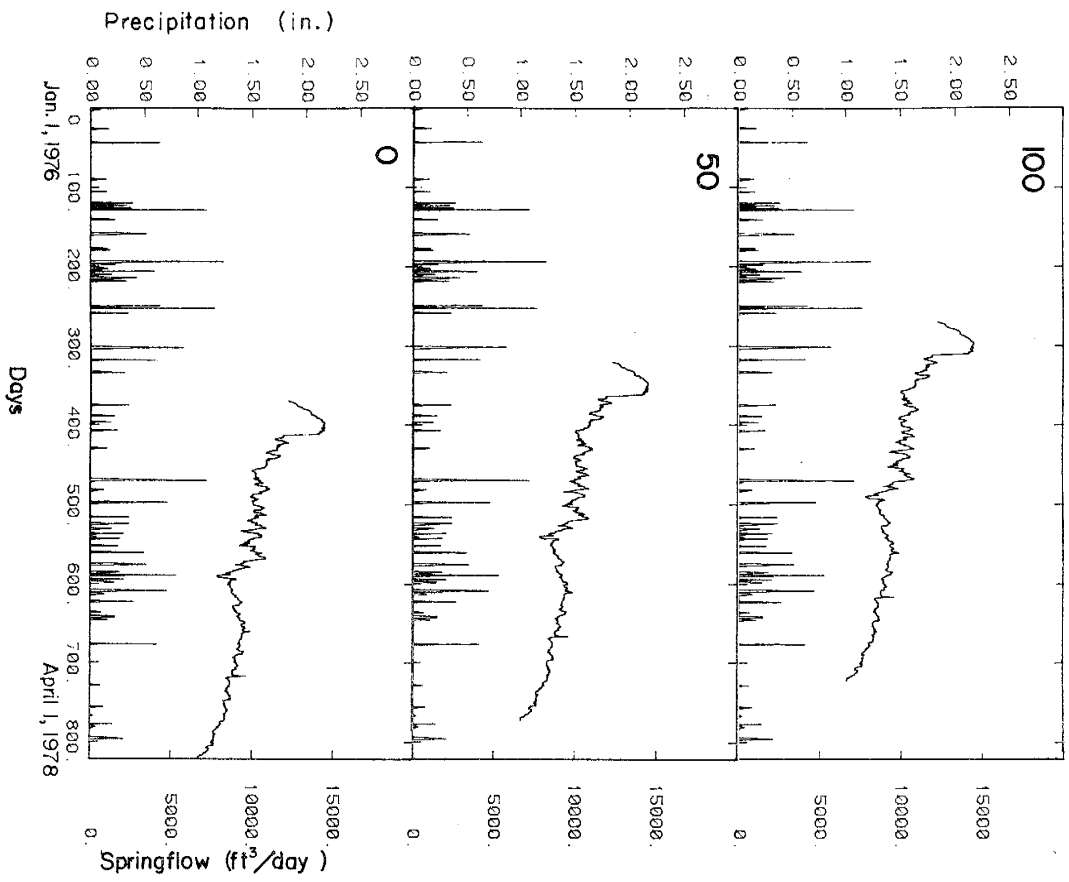


Fig. 17. Springflow lagged against precipitation by the number of days indicated on top left corner of each graph.

A plot of the springflow and of the precipitation that occurred 191 days before, as a function of time, is given in Fig. 18.

Total precipitation, $p = 1.6109 \text{ ft}$

Total volume of precipitation, $A \times p = 2.28 \times 10^7 \text{ ft}^3$

Total springflow, $R = 4.17 \times 10^6 \text{ ft}^3$

$$r = \frac{R}{A \times p} = \frac{4.17 \times 10^6 \text{ ft}^3}{2.28 \times 10^7 \text{ ft}^3} \times 100 = 18.3\%$$

The percentage is high. It is typical of values obtained when recharge is assumed to be derived totally from local precipitation.

Lag	No Deep Flow	Constant Deep Flow	Linear Deep Flow
0	27.7	7.6	4.9
50	28.7	7.8	5.1
100	25.1	6.9	4.5
150	22.7	6.2	4.0
200	18.1	5.0	3.2
250	18.8	5.1	3.3

Table VII. Recharge Percentage as a function of lag for different deep-flow hypotheses.

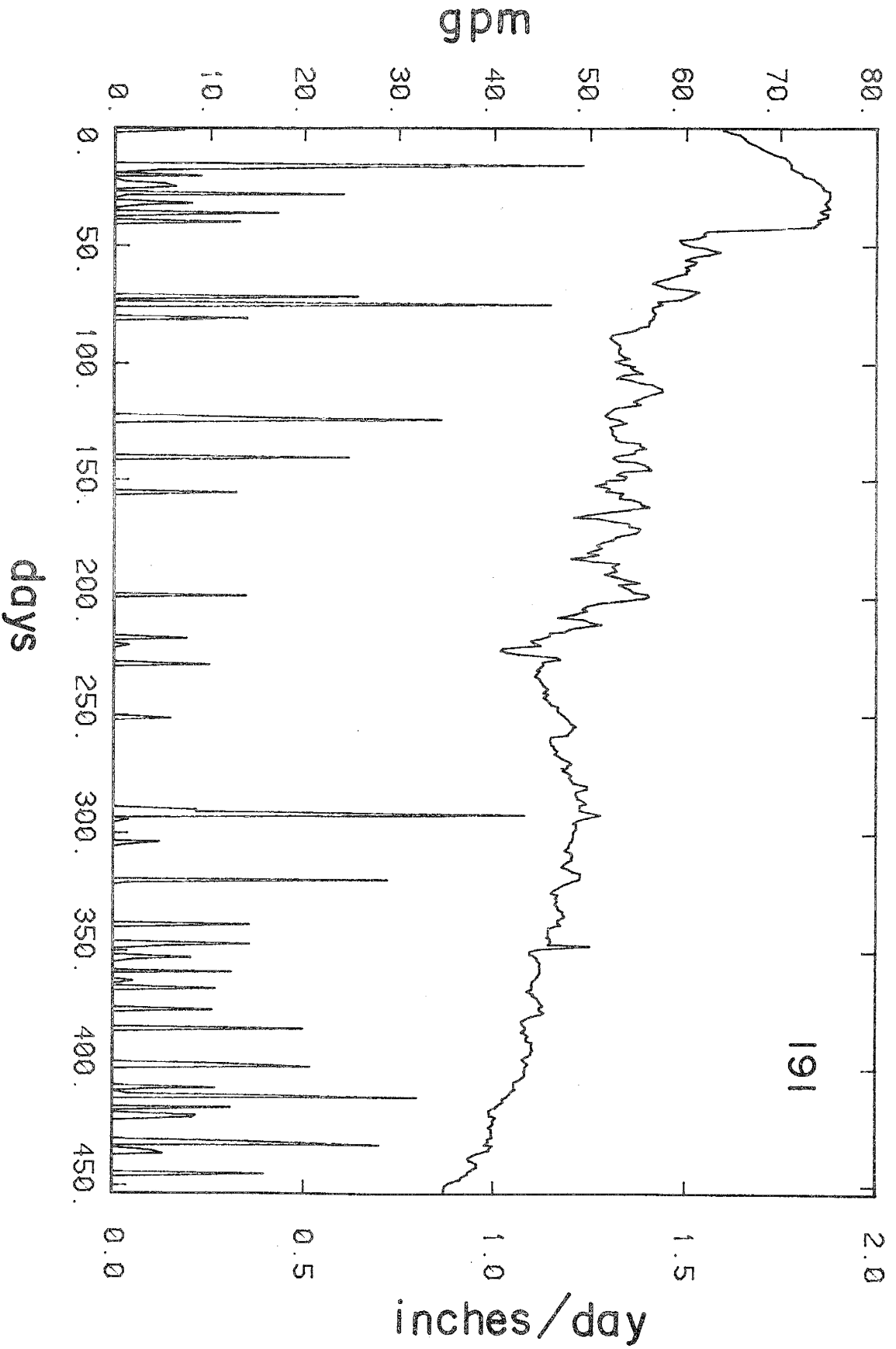


Fig. 13. Springflow lagged 191 days against precipitation.

Stochastic Approach to Recharge Estimation

In this section a stochastic approach to calculate recharge parameters is attempted. This is done to serve as a check on the previously obtained values, and to evaluate other parameters of the Paul Spring aquifer. Considering that the input to the system, precipitation, appears to be random in time, this approach should yield reasonable estimates.

The basis of this approach for a linear reservoir, lumped parameter system was presented by Gelhar (1974). Assuming that we are dealing with a stationary random process, equations will be developed which relate the input spectrum (precipitation) to the output spectrum (springflow). For complete coverage of the mathematics of this approach the reader is referred to Jenkins and Watts (1968). The ordinary partial differential equation which governs this system was given in Eq. (11) as

$$S_y \frac{dQ}{dt} + Q = A y_p$$

We now let $A y_p = \epsilon$ and Eq. (11) becomes

$$S_y \frac{dQ}{dt} + Q = \epsilon \tag{22}$$

S_y and \bar{a} are taken to be constants with \bar{Q} and $\bar{\epsilon}$ being stationary random functions of time. Following Lumley and Panofsky (1964), \bar{Q} and $\bar{\epsilon}$ can be represented by Fourier-Stieltjes integrals of the form

$$Q(t) = \int_{-\infty}^{\infty} e^{i\omega t} dZ(\omega) \tag{23}$$

and

$$r(t) = \int_{-\infty}^{\infty} e^{i\omega t} dZ^{\epsilon}(\omega) \quad (24)$$

where ω is the frequency and $dZ^{\epsilon}(\omega)$ and $dZ^{\eta}(\omega)$ may be thought of

as the Fourier amplitudes of the process.

The processes $Z^{\eta}(\omega)$ and $Z^{\epsilon}(\omega)$ have "orthogonal increments"

(Lumley and Panofsky, 1964), which is to say that nonoverlapping

differences are not correlated:

$$\langle dZ^{\eta}(\omega_1) dZ^{\eta*}(\omega_2) \rangle = \begin{cases} 0 & \text{for } \omega_1 \neq \omega_2 \\ \phi^{\eta} d\omega & \text{for } \omega_1 = \omega_2 \end{cases} \quad (25)$$

$$\langle dZ^{\epsilon}(\omega_1) dZ^{\epsilon*}(\omega_2) \rangle = \begin{cases} 0 & \text{for } \omega_1 \neq \omega_2 \\ \phi^{\epsilon} d\omega & \text{for } \omega_1 = \omega_2 \end{cases} \quad (26)$$

where

* \equiv complex conjugate

$\langle \rangle \equiv$ expected value

$\phi \equiv$ spectral density function (spectrum).

Substituting Eqs. (23) and (24) into Eq. (22) gives

$$S_y \frac{d}{dt} \int_{-\infty}^{\infty} e^{i\omega t} dZ^{\eta}(\omega) + \int_{-\infty}^{\infty} e^{i\omega t} dZ^{\eta}(\omega) - r \int_{-\infty}^{\infty} e^{i\omega t} dZ^{\epsilon}(\omega) = 0$$

which can be written as

$$0 = \int_{-\infty}^{\infty} e^{i\omega t} \left[\frac{1}{S_y} + 1 \right] dZ^{\eta}(\omega) - r dZ^{\epsilon}(\omega)$$

Since $e^{i\omega t}$ is composed of a combination of sines and cosines, the integral of $e^{i\omega t}$ must always be different from zero.

Therefore

$$(27) \quad \left[\frac{1}{1 - i\omega S_Y} + 1 \right] \text{dZ}^{\text{Q}}(\omega) = \text{rdZ}^{\text{E}}(\omega) \cdot$$

Multiplying Eq. (27) by its complex conjugate

$$\left[\frac{1}{-1 - i\omega S_Y} + 1 \right] \text{dZ}^{\text{Q}}(\omega) = \text{rdZ}^{\text{E}}(\omega)$$

and taking the expected value of both sides, yields

$$\left[\frac{1}{\omega^2 S_Y^2} + 1 \right] \phi^{\text{Q}} + r^2 \phi^{\text{E}}$$

which may be written

$$(28) \quad \frac{\phi^{\text{Q}}}{\phi^{\text{E}}} = \frac{\omega^2 S_Y^2}{1} + \frac{r^2}{1} \cdot$$

It should now be possible to plot the ratio of the spectrum

of ϵ to the spectrum of Q versus the frequency squared and obtain values for $\frac{a}{S_Y}$ and r (Fig. 19).

The best fit for the above linear regression was attained

using weekly totaled values for the ϵ and Q spectrums. This procedure was 64 data points. Following Wastler (1969), the number of lags used was 10 percent, or 6 lags. Values obtained from a least squares linear regression are given below.

Coherence = .985

$1/r^2 = 128.48$

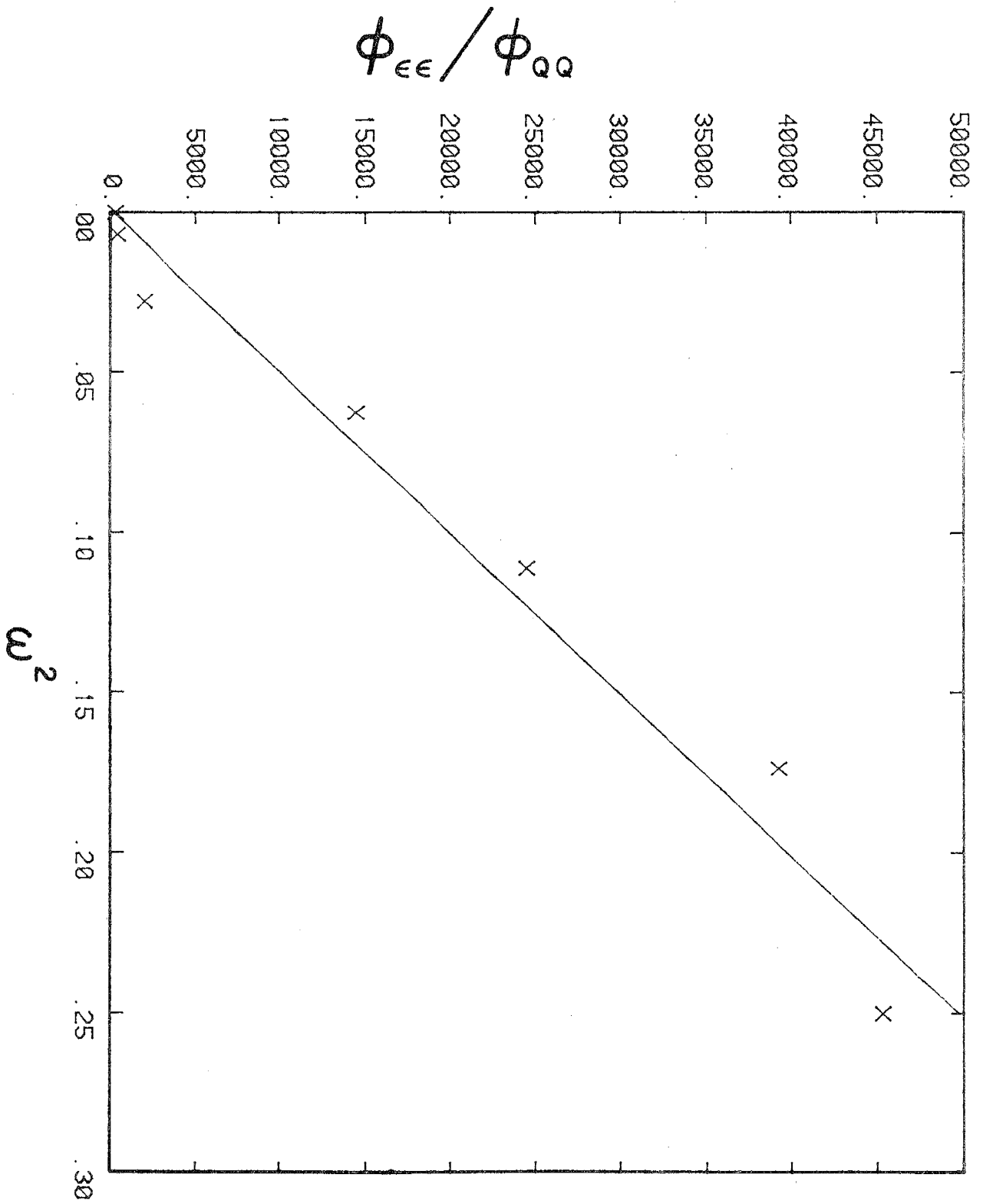


Fig. 19. Regression line for Eq. (28).

or

$$r = 8.82 \%$$

$$S_y^2 \frac{a^2 r^2}{2} = 198294.95 \text{ weeks}^2$$

or

$$S_y^2 \frac{a^2}{2} = 1542.58 \text{ weeks}^2$$

$$\frac{S_y}{a} = 275 \text{ days} \quad (29)$$

To compute S_y we must first estimate \bar{a} , the outflow constant.

We approximate the Paul Spring aquifer by a converging flow system

(Fig. 20). The spring is located at the point of convergence, the

single point of outflow. Two lines are drawn from this point of

convergence to enclose the aquifer (Fig. 10). Using the angle be-

tween these two lines and the area of the aquifer (assumed to be

0.8 x recharge area) a characteristic length, \bar{L} , is computed (Fig.

20). For a converging flow system the outflow constant, \bar{a} , is

(Flores and Gelhar, 1976)

$$a = 1.07 T/L^2 \quad (30)$$

where

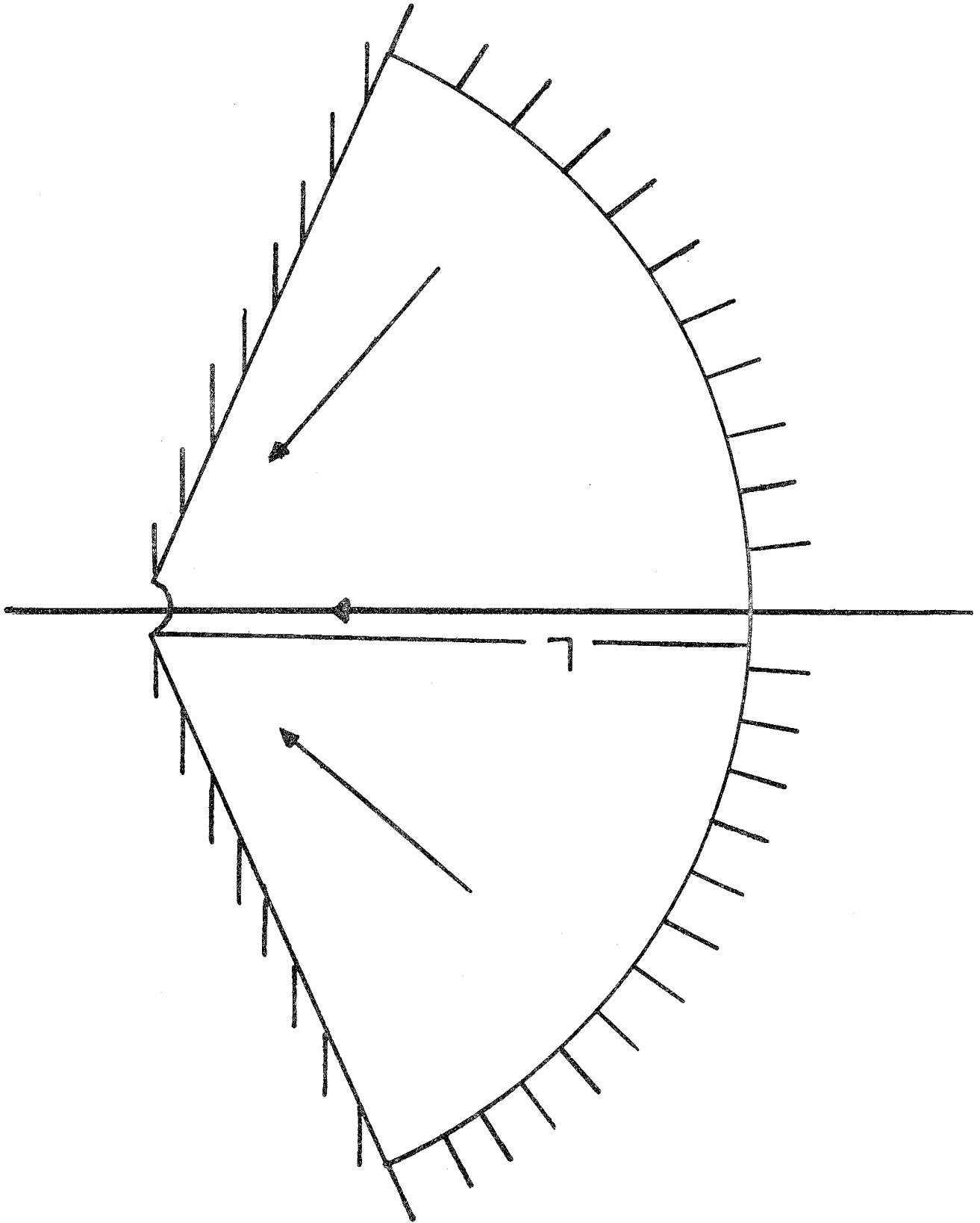
$$T = \text{transmissivity } [L^2/T]$$

also

$$T = Kh_0$$

where

Fig. 20. The two-dimensional converging flow system and its characteristic length (L).



K = hydraulic conductivity [L/T]

h_0 = saturated thickness [L] .

Assuming an average value for \bar{K} of 10^{-4} gal/d-ft², and an aquifer thickness of 25 ft.

$$T = 33,422 \text{ ft}^2/\text{d};$$

also, from Figs. 10 and 20

$$L = 6090 \text{ ft.}$$

Substituting these values of \bar{T} and \bar{L} into Eq. (30)

$$a = 0.000964/\text{day} = 0.00675/\text{week.}$$

and, from Eq. (29)

$$S_y = 6.9\%$$

Numerical Model with a Deep Flow Component

In this model we assume that the springflow is derived from two sources. The first is recharge from precipitation, and the second is water from a deep regional flow system. At present, we are unable to measure the deep flow component (D) directly, so we estimate it in two different ways. The first estimate of \bar{D} is a constant taken as the lowest recorded spring flow, and the second is a linear function that follows the long-term trend of the springflow (Fig. 14). The constant value of \bar{D} is 34.8 gpm. The linear function is given by the sloping line in Fig. 14.

$$D = 34.8 + 0.02554(453-N) \text{ gpm}$$

where N = number of days after the first day of record.

We can now write Eq. (11) in terms of a new variable \bar{QD} , where $\bar{QD} \equiv Q - D$.

The new equation is

$$(31) \quad S \frac{d(\bar{QD})}{dt} + \bar{QD} = R = Arp$$

Eq. (31) is solved by the same methods used to solve Eq. (12). The daily recharge values and graphical results of the solution of Eq. (31) using the Simpson rule and finite difference methods closely resemble the results of Eq. (12) and are not presented here. The final results are shown in Table VIII (p. 87).

As in the case described above, there is no clearly defined maximum in the cross covariance. Table VII (p. 71) gives some re-charge percentages calculated for different lag times.

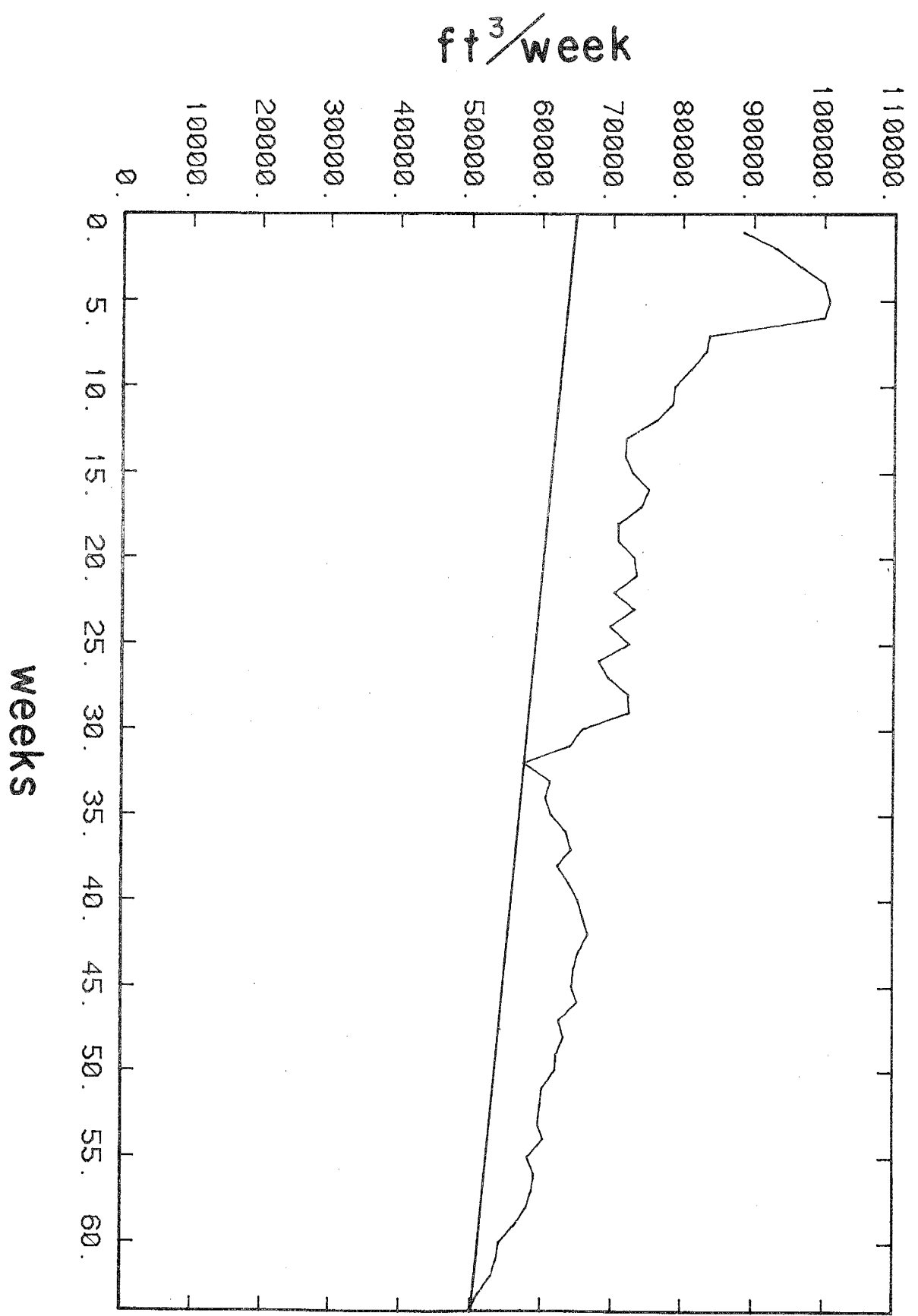


Fig. 21. Weekly springflow and linearly varying deep flow component vs. time.

Stochastic Method with a Deep Flow Component

The case where \bar{D} is a constant will yield the same results as when \bar{D} was neglected because the theory of the stochastic method

assumes that the data series has a zero mean. The TIMANL computer

program subtracts the mean value from every term in the series.

Subtracting a constant from each term in the series changes the

mean value but does not alter the zero mean series. The linear

function \bar{D} , however, does change the zero mean series. The weekly

totalled spring flow and the linear estimates of \bar{D} are given in

Fig. 21. The equation for the line in Fig. 21 is

$$D = 49899.47 + 235.82875(64-M) \text{ ft}^3/\text{week}$$

where

$$64 = \text{total number of weeks}$$

$$M = \text{number of weeks from the beginning.}$$

We rewrite Eq. (11) in terms of the new variable \bar{QD} defined

above, and obtain Eq. (31).

The derivation of the solution is identical to that of (22) with

\bar{Q} now replaced by \bar{QD} . The new spectral equation is

$$(32) \quad \frac{\phi_{\bar{QDQD}}}{\phi_{\epsilon\epsilon}} = \frac{w^2 S_y^2}{a_2 r^2} + \frac{r^2}{1}$$

The regression line for Eq. (32) is presented in Fig. 22. The value of \bar{r} obtained from the regression is 2.6%. This value is less than those calculated with numerical methods. However, the record

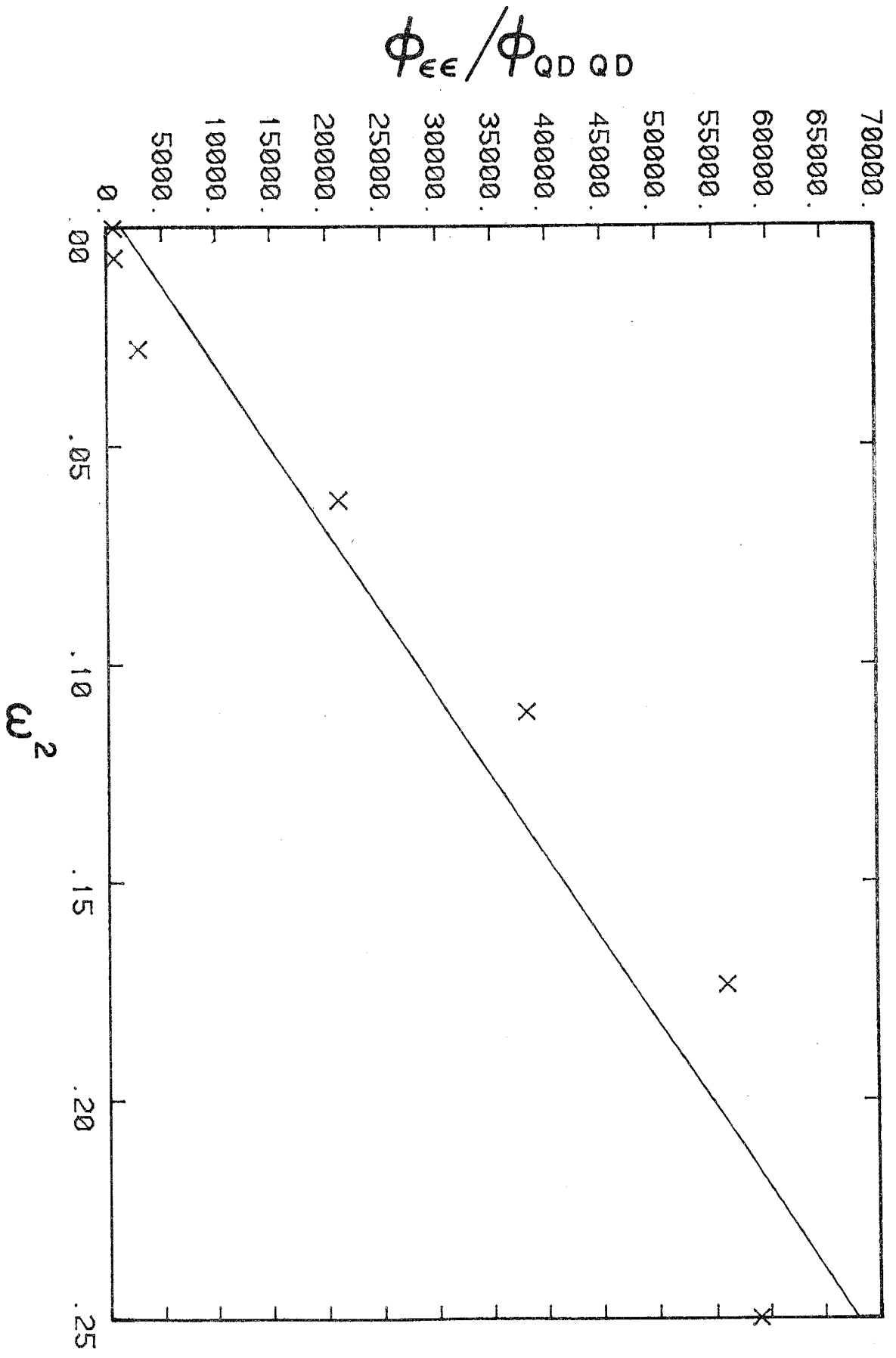


Fig. 22. Regression line for Eq. (32).

is not long enough for a satisfactory application of the stochastic method.
The response time, computed from the regression line slope, is 94 days.
All computational results are summarized in Table VIII.

Table VIII. Summary of Computed Parameters

	<u>Recession curve anal.</u>	<u>Simpson's rule</u>	<u>Finite difference</u>	<u>Cross covariance Recharge/spring</u>	<u>Precip/spring</u>	<u>Spectral analysis</u>
Hypothesis 1: all springflow is derived from precipitation falling on the spring's recharge area						
Response time (d)	48					275
Total net recharge (ft ³)	4.17 x 10 ⁶		4.18 x 10 ⁶			
Recharge fraction (%)				28-18*	18.3	8.8
Lag time (d)				0-200*	191	
Hypothesis 2: recharge by precipitation is superposed on a deep flow component of 34.8 gpm						
Response time (d)						275
Total net recharge (ft ³)	1.14 x 10 ⁶		1.14 x 10 ⁶			
Recharge fraction (%)				7.6-5.0*		8.8
Lag time (d)				0-200*		
Hypothesis 3: recharge by precipitation is superposed on a deep flow component linearly decreasing from 46.4 gpm to 34.8 gpm						
Response time (d)						94
Total net recharge (ft ³)	7.43 x 10 ⁵		7.43 x 10 ⁵			
Recharge fraction (%)				4.9-3.2*		2.6
Lag time (d)				0-200*		

*See Table VII.

explanations for the computed parameters.

measurements now in progress, we suggest some plausible physical
Given these uncertainties, which we hope to clear up by further

periodic inspections of the system.

sing the weir, for example. This again was not apparent to careful

fact, caused by progressively developing leakage ahead of or bypas-

The long-term decline of the springflow could also be an arti-

of the setup.

apparent from the records and undetected in our periodic inspection

of the weir or of the stilling well by debris or bacterial growth, not

from the spring or to periodic plugging and spontaneous unplugging

They could be due to unrecognized changes in man-caused withdrawals

possibility can not be discounted that these features are artifacts.

with precipitation was obtained but it is questionable. Thus, the

with temperature, atmospheric pressure, and recharge. A correlation

events. Unsuccessful attempts were made to correlate these features

recession curves following individual or closely spaced rainfall

The short-term fluctuations of springflow were interpreted as

hydrogeologic conditions that might be invoked to justify the results.

light of the techniques used to obtain the measurements and of

We now discuss the possible significance of these results in the

for the total recharge, the recharge percentage, and the lag time.

The calculations have yielded a rather wide range of numbers

Discussion

The lag time seems to be quite long for such a small system in highly fractured limestone, even if allowance is made for the uncertainty in the statistical correlation. This may be the effect of the Glorieta Sandstone. The upper tongue of the massive fractured sandstone lies between the land surface and the water table throughout most of the recharge area. It is thickest in the vicinity of Paul Spring and thins out southwestward away from the spring (Fig. 9). This sandstone is thought to slow down the movement of the recharge waters percolating through the limestone. The sandstone could act like a filter and increase the nonlinearity of the recharge/precipitation relation. A lag time of the order of 100 to 200 days is at least possible.

The recharge percentage corresponding to a lag of 200 days is about 18%, assuming that all of the springflow is derived from local precipitation. The tritium measurements, however, indicate that, on the average, only about 18% of the springflow should be assigned to local precipitation. Thus, the actual recharge percentage would be of the order of $0.18 \times 0.18 \approx 0.03$, or 3%. This is of the same order as computed stochastically with the assumption of a linear underflow contribution to the springflow.

Clearly, further measurements and better control of the experimental parameters are called for. As of now, we have obtained some rough estimates that can help us in planning future research.

COMPARISON OF FACTORS AFFECTING
RECHARGE OF THE PAUL SPRING AREA AND
THE PRINCIPAL INTAKE AREA

In order to estimate whether or not recharge percentages obtained for the Paul Spring area are applicable to the entire Roswell basin we must examine the physical factors which affect the recharge process. Among these many factors are climate, topography, vegetation and soil type, and/or outcrop type. In discussing these parameters it is necessary to distinguish between the Principal Intake Area, defined by Fiedler and Nye (1933, p.246), who estimated it at 1,200 square miles, and the total recharge area, which they estimated at 4,000 square miles.

The climate of the Paul Spring area has been previously discussed. General comments about the climate are applicable to the entire basin with the exception that a significant amount of snow falls in the higher elevations during the winter months. Table I shows a comparison of precipitation amounts for Elk, which is within 1 mile of Paul Spring, for Roswell, and for the basin average (Gross et al., 1976). Roswell is located near the northeastern edge of the Principal Intake Area (Fig. 2). This table also shows average annual temperatures for Elk and Roswell.

From Table I it can be seen that the Paul Spring region, i.e., Elk, is more humid than either Roswell or the basin in general. It should be mentioned, however, that climatic conditions at Roswell represent the lowest and therefore the driest part of the Principal Intake Area. Table I suggests that in just considering climate

factors alone the recharge percentage for the Paul Spring area could be higher than for the Principal Intake Area.

The topography of an area has a direct effect on the runoff and therefore on the recharge. As mentioned earlier, the Paul Spring area lies on the southeastern edge of the Sacramento Mountains. The slopes in this area are generally steeper than those commonly found in the basin and considerably steeper than the slopes encountered in most of the Principal Intake Area. This suggests that runoff in the study area is greater and that the Paul Spring recharge estimates, adjusted for climate, may be too low for the Principal Intake Area and for the basin in general. Therefore the effect of steeper slopes could possibly cancel out the previously discussed effect of climate. One of the most important physical factors influencing recharge is probably the type of soil covering the recharge area. The soil types in the recharging areas of the basin (that is, excluding a 15-25 mi. strip adjacent to the Pecos River) fall into three great groups (Anderson et al., 1974). Going from west to east as the elevation decreases and mean annual temperature increases, these are the Haploborolls-Cryoborolls of the western mountainous region, the frigid and mesic Calcistolls-Rockland soils of a north-south strip which includes the Paul Spring area, and the Thermic Calcistolls-Rockland soils of the Principal Intake Area (Anderson et al., 1974). There are significant differences between the soils of the Paul Spring area and those of the mountains to the west. The Haploborolls-Cryoborolls are much thicker, generally about 20 inches thicker, and

contain much more organic material and clayey loam than do the
Calciustolls-Rockland soils. This would cause the recharge percent-
ages for Paul Spring to be too high for the western mountainous
region of the Roswell artesian basin.

The change from frigid and mesic temperature Calciustolls-
Rockland soils to Thermic Temperature Calciustolls-Rockland soils
is related to climate and vegetation. The latter soils occur in a
drier area with less vegetation. They are 4 to 20 inches thick,
composed of 35-75% angular limestone fragments, and well drained
(Anderson et al., 1974). Even though the climate is dryer in the
Principal Intake Area, the slopes are flatter and soils more per-
meable than at Paul Spring. It is therefore assumed that recharge
percentages calculated for this study are typical for most of the
Roswell artesian basin except the higher Sacramento Mountains and
the alluvial strip adjacent to the Pecos River.

The preceding discussion is, admittedly, highly speculative.
It is offered as a guide to future research.

RECHARGE FROM THE WESTERN PORTION OF THE ROSWELL BASIN

Fiedler and Nye (1933) assumed that the Yeso Formation was too impervious to allow much water to flow laterally eastward and into the San Andres Formation.

Paul Spring provides a model demonstrating on a small scale

the viability of such flow.

A most important feature of this model is the Yeso Formation's anisotropy. Downward percolation through the lower San Andres

(Glorieta Sandstone) and upper Yeso formations appears to be restricted. After passing through this semipermeable zone, the water then flows through a relatively unsaturated zone below the semipermeable layer until it intersects another boundary or the regional

water table.

On the other hand, the longitudinal conductivity of the silts in the upper Yeso Formation is not negligible; it is aided by solution and collapse features of associated gypsum beds (see section on Geology). In the semipermeable zone, this longitudinally transmitted water then mingles with water recharged directly from the surface, especially where aided by solution and collapse features. The

tritium measurements at Paul Spring indicate that this direct contribution is only about a fifth of the total.

At the western boundary of the Principal Intake Area the dip of the Yeso and San Andres formations is small and toward the east.

Hence, the most important permeability for movement of water from

the Yeso into the San Andres Formation is the longitudinal permeability

(Fig. 23). The lithology of the Yeso Formation over the entire basin is variable but does not change drastically from place to place (Kelley, 1971). The most impermeable beds within the Yeso appear to be siltstones such as those found in the Paul Spring area. The observation well logs from the interfluvial divides in the Principal Intake Area (Gross et al., 1976) indicate that groundwater is transmitted primarily through the same stratigraphic horizons as at Paul Spring. With Paul Spring, they share relatively low tritium values. If a substantial amount of water were flowing through the upper part of the Yeso Formation into the San Andres Formation, mixing of these "old" waters with "young" locally originated recharge waters could yield low tritium concentrations, consistent with the picture here outlined and with the tritium concentrations actually recorded.

The previous considerations suggest that flow variations at Paul Spring may be correlatable with water level changes in the interfluvial observation wells. Much longer springflow records than we have available would be required for this purpose.

West

East

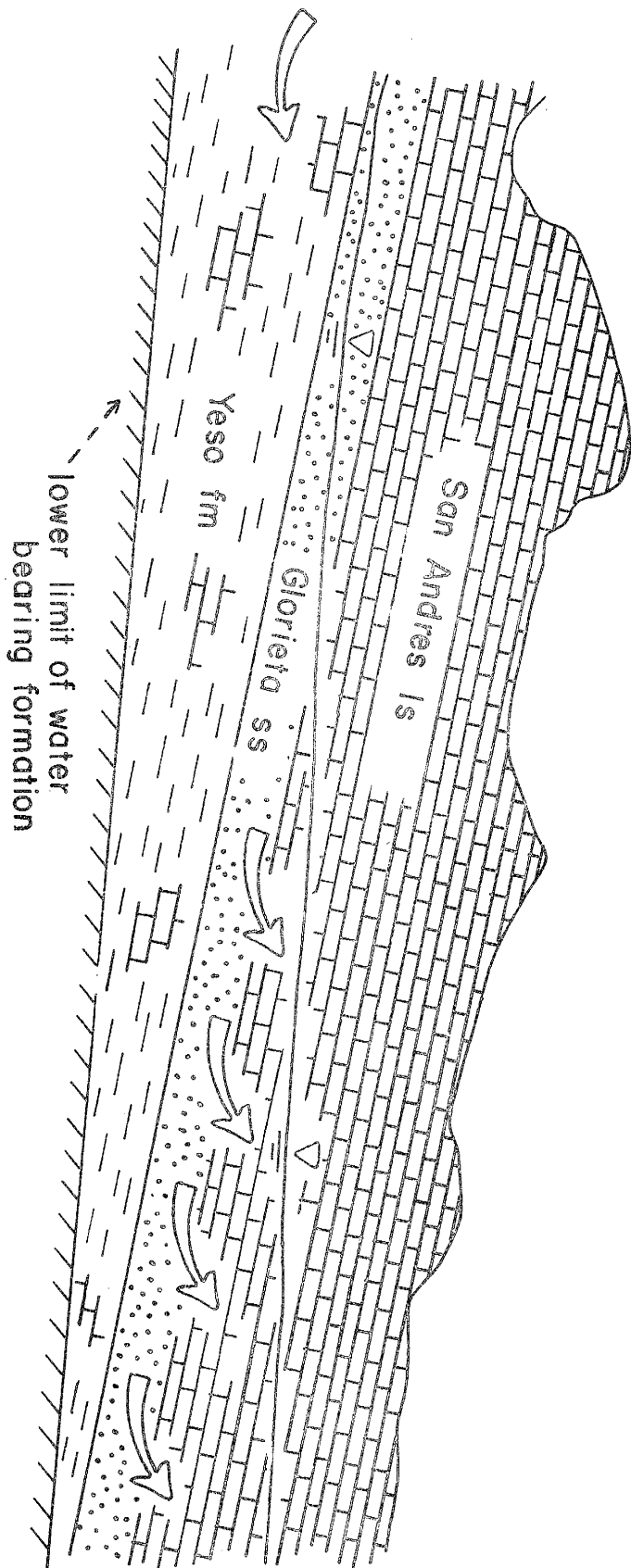


Fig. 23. Idealized model of deep recharge to the San Andres Formation.

SUMMARY OF CONCLUSIONS

Paul Spring issues from a perched body of ground water which is held above other water tables in this area by the upper portion of the Yeso Formation.

The recharge area for Paul Spring is approximately 14,160,440 square feet.

The Glorieta Sandstone acts as a filter, dampening the effect of individual precipitation events on the springflow record.

Dissolution and redeposition of lime and gypsum is presently occurring in the Paul Spring ground water system.

Channeling of water through collapse features and solution breccias is the main factor controlling lateral movement of ground water in the Paul Spring aquifer.

The lag time between precipitation input and springflow output could not be estimated with certainty. It seems to lie between 90 and 200 days.

The average percentage of precipitation which becomes recharge to the Paul Spring aquifer is 3%.

Stochastic representation of the recharge process of the Paul Spring aquifer requires a longer series of springflow measurements than was available. Besides yielding values of the recharge percentage, this method could give an estimate of an average specific yield of the aquifer.

Tritium analyses indicate that there are two components of flow contributing to waters issuing from Paul Spring. One component is

the flow of relatively "older" water from the upper Yesso Formation (about 80%) and the remainder is relatively "younger" water of the lower San Andres Formation.

Eastward ground water flow through the upper Yesso Formation is the cause of low tritium values in the Principal Intake Area. Recharge in the western Roswell artesian basin contributes a significant amount of water to the Principal Aquifer of the Roswell artesian basin.

The conclusions reached in this work are only tentative. To affirm them it is necessary to have a longer series of springflow measurements. Springflow measurements at Paul Spring should then be compared to water level changes in observation wells of the Principal Intake Area.

- Anderson, J. U., V. G. Link, H. E. Dregne, and H. J. Maker (1974):
Soils of New Mexico. Research Report 285. New Mexico State
University. Agricultural Experiment Station. Las Cruces, NM.
- Bean, R. T. (1949): Geology of the Roswell Artesian Basin, New
Mexico, and Its Relation to the Hondo Reservoir. Technical
Report No. 9. State of New Mexico, State Engineer Office.
Santa Fe, NM, 1951. (36 pp.).
- Dooge, J. C. I. (1960): The Routing of Linear Recharge Through
Typical Elements of Linear Storage. Publication 52, pp. 286-
300. International Association of Scientific Hydrology (IASH),
Helsinki.
- Duffy, C. J., L. W. Gelhar, and G. W. Gross (1978): Recharge and
Groundwater Conditions in the Western Region of the Roswell
Basin. Report No. 100. New Mexico Water Resources Research
Institute. New Mexico State University Las Cruces, NM (111 pp.).
- Eriksson, E. (1970): Groundwater Time Series: An Exercise in
Stochastic Hydrology. J. Nord. Hydrol. 1 (3), 181-205.
- Fiedler, A. G., and S. S. Nye (1933): Geology and Ground-Water
Resources of the Roswell Artesian Basin, New Mexico. U.S.G.S.
Water Supply Paper 639. (372 pp.).
- Flores, W., A. E. Z., and L. W. Gelhar (1976): A Stochastic Manage-
ment Model for the Operation of a Stream-Aquifer System. Report
No. 075. New Mexico Water Resources Research Institute. New
Mexico State University, Las Cruces, NM. (209 pp.).

LIST OF REFERENCES

- Gelhar, L. W. (1974): Stochastic Analysis of Phreatic Aquifers. Water Resour. Res. 10 (3), 539-545.
- Gelhar, L. W., and J. L. Wilson (1974): Ground Water Quality Modeling. Groundwater 12 (6), 399-408.
- Gross, G. W., R. N. Hoy, and C. J. Duffy (1976): Application of Environmental Tritium in the Measurement of Recharge and Aquifer Parameters in a Semi-Arid Limestone Terrain. Report No. 080. New Mexico Water Resources Research Institute, New Mexico State University. Las Cruces, NM (212 pp.).
- Gross, G. W., and R. N. Hoy (1979): Recharge in Semiarid Mountain Environments. Technical Completion Report (Project A-055-NMEX). New Mexico Water Resources Research Institute, New Mexico State University. Las Cruces, NM. (In preparation).
- Hantush, M. S. (1957): Preliminary Quantitative Study of the Roswell Ground-Water Reservoir, New Mexico. New Mexico Institute of Mining and Technology Research and Development Division. Socorro, NM (118 pp.).
- Havenor, K. C. (1968): Structure, Stratigraphy, and Hydrogeology of the Northern Roswell Artesian Basin, Chaves County, New Mexico. Circular 93. State Bureau of Mines and Mineral Resources. New Mexico Institute of Mining and Technology. Socorro, NM (30 pp.).
- Jacob, C. E. (1944): Correlation of Ground-Water Levels and Precipitation on Long Island, New York. Trans. A. G. U. 25, 564-573.

- Kelley, V. C. (1971): Geology of the Pecos Country, Southeastern New Mexico. Memor 24. State Bureau of Mines and Mineral Resources. New Mexico Institute of Mining and Technology. Socorro, NM (75 pp.).
- Kinney, E. E., J. D. Nations, B. J. Oliver, P. G. Wagner, T. A. Situla, and R. E. Renner (1968): The Roswell Artesian Basin. The Roswell Geological Society. Roswell, NM (32 pp.).
- Leupold and Stevens, Inc. (1975): Stevens Water Resources Data Book. Leupold and Stevens, Inc., Beaverton, Oregon.
- Lumley, J. L., and H. A. Panofsky (1964): The Structure of Atmospheric Turbulence. Wiley, New York, NY (239 pp.).
- Mourant, W. A. (1963): Water Resources and Geology of the Rio Hondo Drainage Basin. Technical Report 28. New Mexico State Engineer. Santa Fe, NM (85 pp.).
- Nir, A. (1964): On the Interpretation of Tritium Age Measurements of Groundwater. Jour. Geophys. Res. 69, 2589-2595.
- Rabinowitz, D. D., and G. W. Gross (1972): Environmental Tritium as a Hydrometeorologic Tool in the Roswell Basin, New Mexico. Report No. 016. New Mexico Water Resources Research Institute. New Mexico State University. Las Cruces, NM (268 pp.).
- Rabinowitz, D. D., G. W. Gross, and C. R. Holmes (1977): Environmental Tritium as a hydrometeorologic tool in the Roswell Basin, N.M. Jour. Hydrol. 32, 3-46.

Renick, B. C. (1926): Geology and Ground-Water Resources of the Drainage Basin of the Rio Penasco above Hope, New Mexico. 7th. Biennial Report, pp. 103-138. New Mexico State Engineer. Santa Fe, NM.

Updegraff, C. D., and L. W. Gelhar (1978): Parameter Estimation for a Lumped-Parameter Ground-Water Model of the Mesilla Valley, New Mexico. Report No. 097. New Mexico Water Resources Research Institute. New Mexico State University. Las Cruces, NM (69 pp.).

Wastler, T. A. (1969): Spectral Analysis; Application in Water Pollution Control. CWT-3. Federal Water Pollution Control Administration. U. S. Dept. Int.

LOCAL WELL LOG DATA FOR THE PAUL SPRING AREA
(from open files at the New Mexico State
Engineer office, Santa Fe, New Mexico)

APPENDIX A

Location: 16.16.5.434

Approximate water table elevation: 5680'

Depth to water: 130'

Description	Color	Thickness (Ft)	Depth (Ft)	
			To	From
top soil	black	2	2	0
caliche and gravel	white	8	10	2
rock and gravel	gray	50	60	10
lime	gray	15	75	60
gravel	gray	5	80	75
lime	gray	30	110	80
clay	yellow	30	140	110
clay	red	25	165	140
rack and gravel	gray	25	190	165
lime	gray	37	227	190
sand, lime, water	brown	7	235	227
lime	gray	10	245	235
clay	red	20	265	245
gravel	gray	10	275	265
clay	red	12	287	275

Location: 16.16.10.24131

Approximate water table elevation: 5706'

Depth to water: 14'

Description	Color	Thickness (ft)	Depth (ft)	
			From	To
dirt		5	0	5
lime		9	5	14
gravel and boulders; water		69	14	85
lime		35	85	120
sand; water	yellow	20	120	140

Location: 16.16.11.41111

Approximate water table elevation: 5658'

Depth to water: 12'

Description	Color	Thickness (ft)	Depth (ft)	
			From	To
rock; water	gray	15	0	15
rock	black	70	15	85
gravel; water		12	85	97
rock	gray	33	97	130
clay	yellow	60	130	190
rock	black	35	190	225
no sample; water		5	225	230
clay	blue	5	230	235

Location: 16.16.12.31143

- Approximate water table elevation: 5666'

Depth to water: 9'

Description	Color	Thickness (ft)	Depth (ft)	
			From	To
rock	gray	45	0	45
rock, water	yellow	5	45	50
rock	gray	308	50	358
crevice-no sample; water		16	358	374

Location: 16.16.12.320

Approximate water table elevation: 5640'

Depth to water: 20'

Description	Color	Thickness (ft)	Depth (ft)	
			From	To
rock		30	0	30
gravel-water		5	30	35
rock		7	35	42

Location: 16.16.17.33322

Approximate water table elevation: 5718'

Depth to water: 182'

Description	Color	Thickness (ft)	Depth (ft)	
			From	To
lime	gray	10	182	192
lime	brown	15	192	207
sandy lime; water		10	207	217
lime	gray	8	217	225

Location: 16.16.30.441422

Approximate water table elevation: 5240'

Depth to water: 260'

Description	Color	Thickness (ft)	Depth (ft)	
			From	To
top soil		15	15	0
hard lime		245	260	15
sand; water		10	270	260
lime		5	275	270
clay	red	5	280	275

Location: 16.16.8.314

Approximate water table elevation: 5768'

Depth to water: 92'

Description	Color	Thickness (ft)	Depth (ft)	
			From	To
gravel and dirt		42	42	0
limestone		70	112	42
rock with crevices; water		5	117	112
limestone		73	190	117
coarse gravel; water		10	200	190
limestone		4	204	200

SPRINGFLOW MEASUREMENT PROCEDURE,
EQUIPMENT AND PROBLEMS

APPENDIX B

The flow from Paul Spring was monitored with the aid of a

Stevens Type-F water level recorder. A stilling pond was constructed approximately 25 feet downstream of the spring's point of issuance.

All equipment used is shown in Figure 24. This pond was lined with plastic to prevent leakage. The pond's dam consisted of a 2 foot

by 4 foot sheet of plywood with an aluminum 90° V-notch weir mounted on it. In order to increase the sensitivity of measurement, the

notch angle was changed to 22½° after 1½ months. The Type-F recorder was then placed on top of a stilling well installed in the pond. The Type-F recorder was equipped with a 30-day battery-powered clock

drive unit. The recorder chart was changed every 30 days and the

water level was measured by hand to insure continued accuracy. The formula used to calculate the quantity of flow thru a 22½° weir is

(Leupold & Stevens, Inc., 1975):

$$\text{gallons per minute} = 225.05 \times H^{5/2}$$

where

H = height of the water in the V-notch.

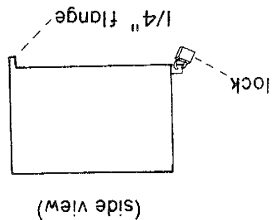
It is important to discuss the difficulties with flow measurement encountered in this study. The springflow is assumed to be the total flow from this perched system. Therefore, the accuracy of the recharge percentages obtained is directly related to the

accuracy of the flow measurement.

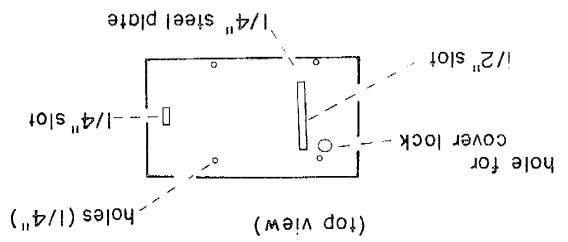
The first difficulty in measuring the flow of Paul Spring was the existence of a pipe at the mouth of the spring. Water flowing

SPRINGFLOW RECORDING EQUIPMENT

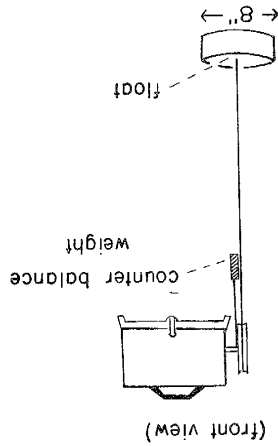
RECORDER COVER



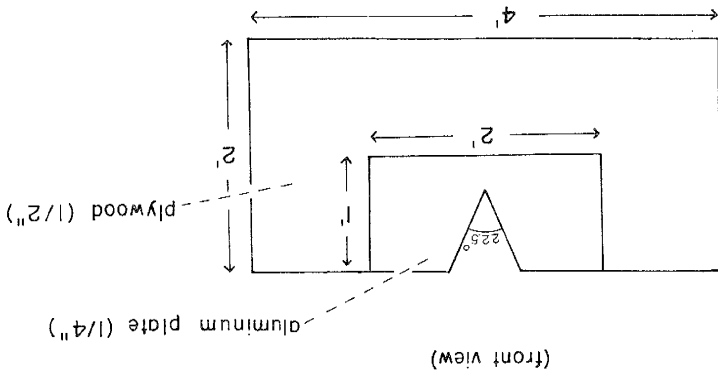
RESTING PLATE FOR RECORDER



STEVENS F - TYPE RECORDER



V-NOTCH WEIR



STILLING WELL

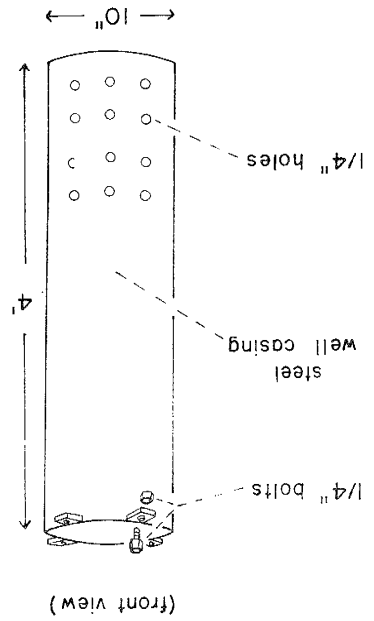


Fig. 24. Schematic of the weir and stilling well.

continually through this pipe provides water for domestic use at the Charles Mulcock residence. The pipe is 1 inch in diameter and, according to Mr. Mulcock, calcium carbonate has considerably clogged the pipe. The flow from this pipe was measured several times during the course of this study. The amount of water flowing through this pipe was found to be a nearly constant value of one percent of the total flow. This quantity was added into the total flow calculations. Other flow not measured by the Stevens recorder includes what appeared to be leakage through the walls of the pond. Since the pond was lined with plastic it is doubtful that this water was actually derived from the pond. It is more likely that this water represented direct flow from the perched system. The amount of water escaping in this manner was not large. It was estimated to be a nearly constant quantity of 2% of the springflow. This amount was also taken into account in total flow calculations.

There were several factors which adversely affected the records obtained using the Type-F recorder. The most serious of these resulted from debris clogging the 22½° V-notch. This problem was overcome by covering part of the stilling pond, including the V-notch, with chicken wire. Another error in flow records was a result of the stilling well design. Since there were several rows of holes in the stilling well, some water flowed through the well. This water brought in debris which clogged the stilling well holes. To remedy this problem all but one row of holes in the stilling well were plugged. A small mesh wire was also placed around the stilling well about 2

difference to be adjusted for was about .02 inches. that for the charts subjected to linear interpolation, the largest the chart values to match the field measurements. It should be noted these values did not match, linear interpolation was used to adjust the field measurements made at the time the charts were changed. When For most of the records this method produced values which matched record across them. An example is shown in Fig. 25.

then constructed by neglecting these jumps and realigning the flow holes in the stilling well or of the V-notch weir. A new record was were assumed to have been caused by the actual clogging of either the for abrupt changes or jumps in the flow record. The fluctuations flow measurement was as follows. First, the charts were inspected corder charts. The procedure used to correct for these errors in 30-day period. These differences were evident on several of the re-made at the time the charts were changed, that is at the end of each measurements recorded on the Type-F chart and the field measurements The problems mentioned above caused discrepancies between the be washed away.

placed in the stilling well to retard bacterial growth would soon This problem was more difficult to overcome because any chemical film over the stilling well holes, probably bacterial in nature. inches from it. Clogging was also caused by the formation of a thin

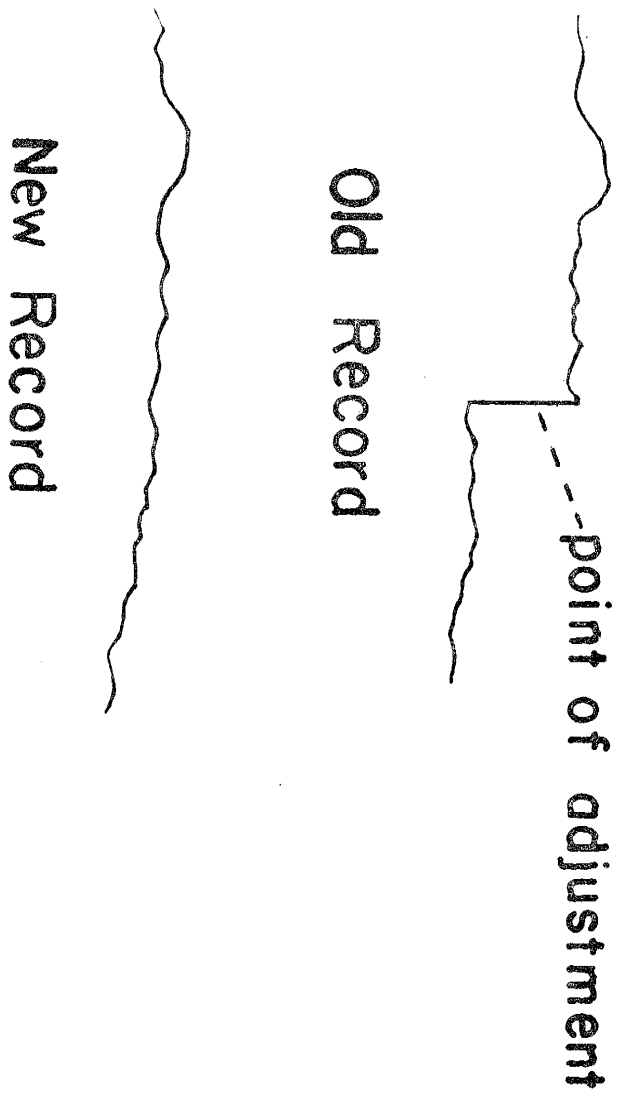


Fig. 25. Adjustment of flow record.

DAILY AVERAGE SPRINGFLOW

APPENDIX C

DAILY AVERAGE SPRINGFLOW 1977, gpm

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT.	NOV	DEC
01		75.1	61.1	52.3	54.9	53.5	50.7	50.2	45.6	47.6	48.2	46.8
02		75.0	60.8	52.1	52.6	51.7	49.7	51.3	45.2	47.7	48.0	47.2
03		74.9	59.9	52.4	52.3	51.7	51.0	49.0	45.6	47.2	47.9	47.2
04	63.9	74.6	60.3	52.9	51.9	50.6	49.2	47.9	45.8	47.6	47.8	47.4
05	64.7	74.8	60.0	53.2	51.6	52.2	48.1	47.3	46.1	48.1	47.8	47.1
06	65.6	75.0	60.1	53.3	52.2	51.8	50.3	45.8	46.8	47.9	47.4	46.7
07	66.0	74.0	59.1	53.0	53.1	53.6	53.1	45.8	46.6	48.1	48.0	46.7
08	66.1	74.3	58.3	53.0	53.9	53.1	52.5	44.9	46.6	48.3	48.2	46.9
09	66.4	74.9	57.1	53.1	53.4	53.1	52.6	43.8	47.0	49.1	48.1	45.7
10	66.8	74.8	56.6	53.5	52.2	54.6	52.8	44.4	47.4	49.7	48.0	45.6
11	67.6	73.8	57.5	54.2	52.5	55.2	51.6	44.9	47.6	49.8	47.6	45.6
12	67.8	74.0	58.1	52.6	52.3	55.5	52.4	40.8	47.9	48.6	47.3	45.6
13	68.6	73.6	60.3	53.5	52.4	56.2	52.8	40.7	48.1	48.5	47.1	45.5
14	69.2	73.4	61.3	54.8	52.7	54.1	53.9	41.3	48.6	48.7	47.6	45.8
15	69.9	68.1	60.7	54.3	52.7	52.3	55.3	42.5	48.3	48.8	48.2	45.9
16	70.4	62.2	60.2	54.7	53.1	50.0	53.0	46.5	48.2	49.4	49.1	45.7
17	70.7	61.7	59.5	55.5	55.3	48.4	53.8	46.9	47.9	49.6	49.0	50.0
18	71.0	62.0	57.1	53.5	55.2	50.9	54.3	45.1	47.6	49.1	48.9	44.5
19	71.0	61.2	57.5	52.8	56.0	52.6	54.7	45.2	45.9	48.9	48.6	43.7
20	71.0	59.4	56.5	54.3	54.9	54.2	56.1	45.0	45.8	48.9	47.7	43.7
21	71.4	59.6	56.5	55.3	54.7	54.2	56.2	44.5	45.9	49.9	47.2	44.1
22	72.1	60.5	56.7	56.7	52.7	55.2	55.7	44.8	46.1	51.2	46.6	44.5
23	72.4	62.1	56.8	56.9	52.5	55.1	53.3	44.5	46.2	49.7	46.2	44.5
24	72.7	63.1	56.7	57.5	53.0	54.8	51.1	44.2	46.4	48.9	45.9	44.8
25	73.5	63.6	56.7	57.7	54.8	53.0	49.7	44.8	46.7	48.3	46.6	44.7
26	73.8	62.3	56.3	56.8	55.8	52.7	49.2	45.0	46.3	48.6	46.4	44.8
27	74.0	60.9	56.2	55.9	56.1	52.4	49.7	45.1	46.8	48.6	45.5	44.8
28	74.3	59.9	56.1	55.1	56.4	51.4	48.6	45.3	47.2	48.6	46.5	44.8
29	74.5		55.3	54.5	53.4	50.7	48.3	45.6	47.9	48.3	46.3	44.7
30	75.1		54.8	55.2	52.9	51.3	46.7	45.6	48.1	48.3	46.6	44.5
31	75.1		54.0	55.2	53.8		49.4	45.3		48.3		44.3

DAILY AVERAGE SPRINGFLOW 1978, gpm

DAY	JAN	FEB	MAR	APR
01	44.0	43.8	39.9	34.8
02	43.8	43.6	40.0	
03	43.9	43.0	39.7	
04	43.8	43.2	39.4	
05	43.4	43.5	39.7	
06	44.1	43.3	39.7	
07	44.0	43.3	39.7	
08	44.5	43.1	39.8	
09	44.6	43.2	39.3	
10	44.8	43.3	39.5	
11	45.1	42.9	39.0	
12	44.7	42.6	39.8	
13	44.8	42.0	39.6	
14	45.2	42.0	39.4	
15	44.9	42.0	38.1	
16	43.8	42.2	37.7	
17	43.3	41.9	37.3	
18	42.8	41.6	37.4	
19	42.9	41.3	38.1	
20	43.3	40.9	38.2	
21	43.2	41.0	38.1	
22	42.8	40.6	37.7	
23	43.1	40.2	37.3	
24	43.6	40.1	37.3	
25	43.4	39.5	36.6	
26	43.4	39.6	36.4	
27	43.9	39.6	35.8	
28	43.8	40.2	35.4	
29	43.9		34.9	
30	44.1		34.8	
31	43.8		34.8	

APPENDIX D
DATES OF THE SPRING FLOW RECESSIONS
AND
THE COMPUTER PROGRAM USED
TO CALCULATE S_y/a

SPRING FLOW RECESSIONS
(See Figure 26)

LENGTH IN DAYS

1977	DATES	LENGTH IN DAYS
Feb 10 - Feb 20		10
Feb 25 - Feb 28		3
Mar 2 - Mar 3		1
Mar 6 - Mar 10		4
Mar 14 - Mar 21		6
Mar 28 - Apr 1		4
Apr 11 - Apr 12		1
Apr 17 - Apr 19		2
Apr 25 - Apr 29		4
Apr 30 - May 4		4
May 9 - May 10		1
May 19 - May 22		3
May 28 - May 30		2
Jun 1 - Jun 4		3
Jun 5 - Jun 6		1
Jun 13 - Jun 17		4
Jun 23 - Jun 29		6
Jun 30 - Jul 2		2
Jul 3 - Jul 5		2
Jul 7 - Jul 8		1
Jul 10 - Jul 11		1
Jul 21 - Jul 26		5
Jul 27 - Jul 30		3
Aug 3 - Aug 9		6
Aug 17 - Aug 18		1
Aug 20 - Aug 21		1
Sep 1 - Sep 2		1
Sep 17 - Sep 19		2
Sep 25 - Sep 26		1
Sep 30 - Oct 1		1
Oct 2 - Oct 3		1
Oct 5 - Oct 6		1
Oct 11 - Oct 12		1
Oct 22 - Oct 25		3
Nov 19 - Nov 20		1
Dec 8 - Dec 9		1
Dec 18 - Dec 19		1
Jan 4 - Jan 5		1
Jan 11 - Jan 12		1
Jan 15 - Jan 18		3
Jan 21 - Jan 22		1
Feb 2 - Feb 3		1
Feb 10 - Feb 13		3
Feb 24 - Feb 25		1
Mar 8 - Mar 9		1
Mar 10 - Mar 11		1
Mar 14 - Mar 17		3
Mar 24 - Mar 25		1
Mar 26 - Mar 29		3

1978

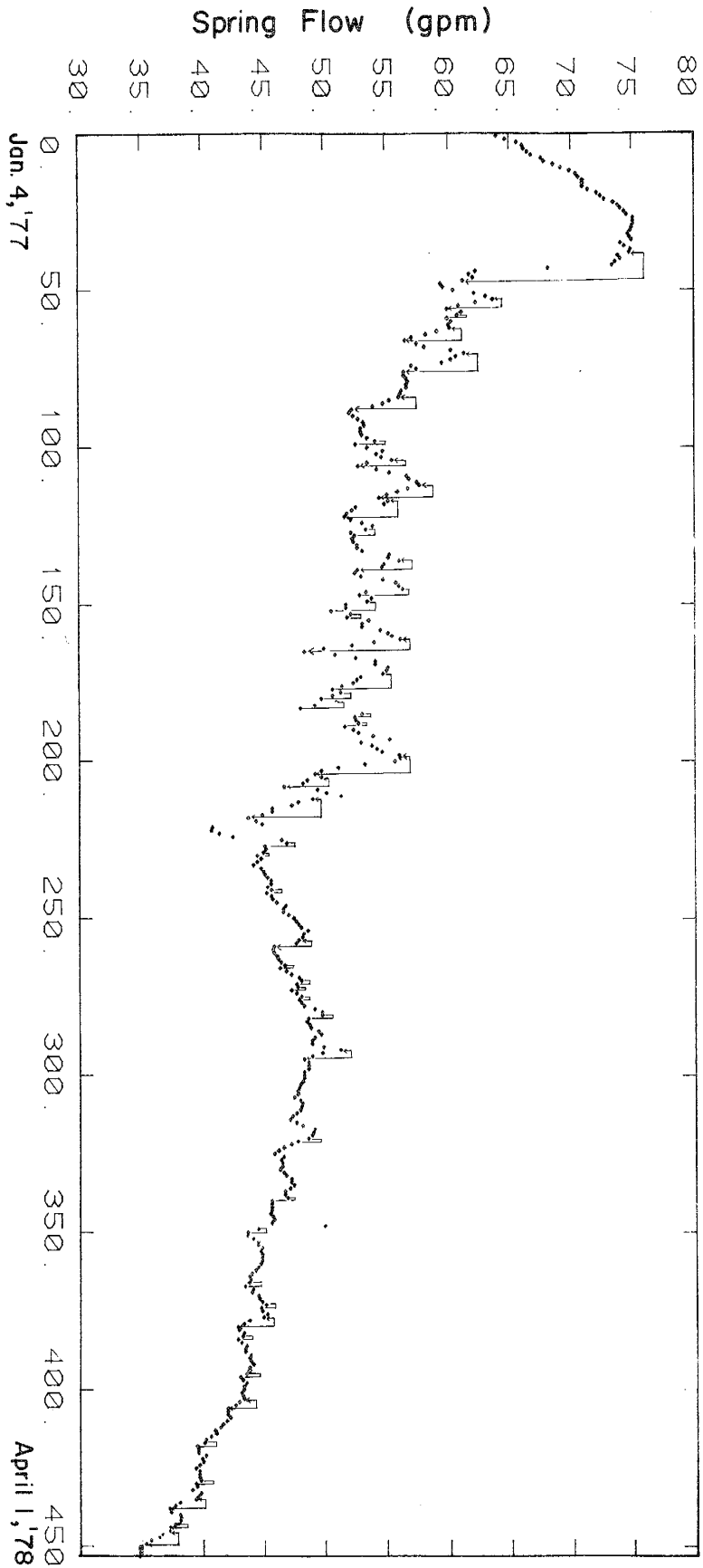


Fig. 26. Springflow recession events used for analysis.

```

C PROGRAM TO CALCULATE THE AVERAGE VALUE OF THE
C HYDRAULIC RESPONSE TIME SY/A.
C
OPEN (UNIT=1,ACCESS='SEQIN',FILE='RECESS.DA',
      K=-1
      NUNIT=5
      WRITE (NUNIT,150)
      READ (1,100,END=12) Q
      K=K+1
      J=J+1
      IF (K.GT.1.AND.Q.EQ.1.00000) K=0
      IF (Q.EQ.1.00000) GO TO 10
      AS=ALOG(Q)/-FLOAT(K)
      SA=1./AS
      SASUM=SASUM+SA
      WRITE (NUNIT,200) K,AS,SA
      GO TO 10
100  FORMAT (F8.5)
150  FORMAT (20X,'A',15X,'S',13,'DELTA T',10X,'---',13X,
      1,'---',121,'S',15X,'A')
200  FORMAT (4X,12,'9X',E12.6,'6X',F12.6)
300  FORMAT (//,' THE AVERAGE VALUE OF S/A IS ',F12.6)
12  AVE$A=SASUM/J
      WRITE (NUNIT,300) AVE$A
      WRITE (5,300) AVE$A
STOP
END

```

DELTA T

A	S
1	134602E-01
2	537883E-02
3	539001E-02
4	472436E-02
5	187677E-01
6	307440E-01
7	275042E-01
8	234600E-01
9	222970E-01
10	230521E-01
1	206518E-01
2	216887E-01
3	199804E-01
1	149106E-01
1	167800E-01
2	152038E-01
3	170697E-01
4	150012E-01
1	984834E-02
2	905144E-02
3	993321E-02
4	177451E-01
5	127989E-01
6	135892E-01
1	143627E-01
2	117213E-01
3	127162E-01
4	175359E-01
1	299645E-01
1	367055E-01
2	249366E-01
1	157230E-01
2	158485E-01
3	153689E-01
4	142643E-01
1	544479E-02
2	241227E-01
3	179902E-01
4	154103E-01
1	227263E-01
1	198354E-01
2	117418E-01
3	202459E-01
1	74.293194
185	914050
185	528410
211	668900
53	283168
32	526699
36	358067
42	625771
44	849102
43	380053
48	421964
46	107018
50	049129
67	066338
59	594755
65	772895
58	583352
66	661323
101	539970
110	479700
100	672400
56	353456
78	131507
73	587589
69	625023
85	314601
78	640068
57	025925
33	372844
27	243888
40	101660
63	601240
63	097283
65	066367
70	105037
183	661680
41	454804
55	585865
64	891464
44	001894
50	414847
85	165853
49	392671

18,295972	31,216200	1
58,447333	27,223667	2
53,826409	58,447333	3
130,047640	26,256256	1
26,256256	27,810612	2
25,664402	26,770734	3
183,323180	51,473185	1
51,473185	67,359392	2
79,615902	71,931206	4
72,099281	84,969128	6
63,117835	27,833643	1
34,164355	87,994646	2
87,994646	43,492804	1
111,858780	37,750859	1
37,750859	31,534070	2
32,543166	37,618186	4
37,618186	44,685668	5
44,685668	69,992760	2
48,186226	207528E-01	3
44,041537	227058E-01	1
56,647618	176530E-01	2
44,417887	225135E-01	3
59,223850	168851E-01	4
57,222173	174757E-01	5
53,483687	186973E-01	6
25,551977	391359E-01	1
89,508066	111722E-01	1
113,524400	880868E-02	1
159,243880	627968E-02	2
46,897086	213233E-01	1
116,185390	860693E-02	1
95,653000	104545E-01	1
94,918955	105353E-01	1

THE AVERAGE VALUE OF S/A IS 48,422208

239,884160	.416868E-02	1
40,991745	.243952E-01	1
33,627218	.297378E-01	1
43,515940	.229801E-01	2
51,451527	.194358E-01	3
53,494129	.186936E-01	1
38,575600	.259231E-01	1
55,115835	.181436E-01	1
109,028250	.917194E-02	1
112,238850	.890957E-02	1
40,314264	.248051E-01	1
55,126422	.181401E-01	2
62,631709	.159664E-01	3
107,490600	.930314E-02	1
72,173262	.138555E-01	1
107,724320	.928296E-02	1
122,683100	.815108E-02	2
98,425762	.101599E-01	3
66,343671	.150730E-01	1
79,116765	.126395E-01	1
78,487900	.127408E-01	1
29,809419	.335464E-01	1
45,342590	.220543E-01	2
54,771485	.182577E-01	3
52,774921	.189484E-01	1
60,178230	.166173E-01	1
71,802056	.139272E-01	2
71,287338	.140277E-01	3

NUMERICAL RESULTS
THE DAILY NET RECHARGE, AND
COMPUTER PROGRAMS USED TO CALCULATE

APPENDIX E

ESTIMATION OF RECHARGE USING THE METHOD GIVEN BY UDEGRAFF
AND BELLAR (1977).

```
      dummy variable in tridassional error solution  
      d= solution of d-e with recharge = 0  
      date= month and day  
      ss= dummy variable in tridassional error solution  
      lambda= hydraulic rate constant  
      n= # of observations  
      precip= amount of each precip event in inches  
      precip= input of daily precip in inches  
      q= spring flow in gallons per minute  
      qin= estimated initial flow  
      qout= estimated final flow  
      u= recharge in cu-ft per day  
      z= spring flow in cu-ft per day  
      real g,lambda  
      DIMENSION DATE(2,500),D(500),Q(500),G(500),S(500)  
      DIMENSION U(500),R(500),Z(500)  
      data unit/3/  
      OPEN (UNIT=31,ACCESS='SEQIN',FILE='SPRING.DAT')  
      OPEN (UNIT=32,ACCESS='SEQOUT',FILE='RECHG.DAT')  
      OPEN (UNIT=33,ACCESS='SEQOUT',FILE='DAT8.DAT')  
      file rechg.dat contains recharge values for each day  
      file precip.dat contains precip data for each day  
      1  
      read (31,101) n,lambda  
      format (13,f8.4)  
      101  
      GINIT=43.0  
      QOUT=34.8  
      NN=N  
      ZINIT=QINIT*60.0*24.0*13368  
      ZOUT=QOUT*60.0*24.0*13368  
      read (31,102) (date(1,i),date(2,i),g(i),i=1,nn)  
      format (2a3,f5.1)  
      Change the flow from spm to cu-ft per day  
      NN=N  
      do 69 k=1,nn  
      Z(K)=Q(K)*60.0*24.0*13368  
      69  
      Calculate the D-E with R=0 and set it equal to 'd'  
      D(1)=3.*LMDA*(Z(2)-ZINIT)+Z(2)+4.*Z(1)+ZINIT-LMDA*  
      1*(Z(1)-ZINIT)-ZINIT  
      D(N)=3.*LMDA*(ZOUT-Z(N))-ZOUT+4.*Z(N)+Z(N-1)  
      1-LMDA*(ZOUT-Z(N))-ZOUT  
      do 79 l=2,nn-1  
      d(l)=3.*LMDA*(z(l+1)-z(l-1))+z(l+1)+4.*z(l)+z(l-1)  
      79  
      Thomas algorithm for solving a tridassional array  
      bb(1)=4.0  
      aa(1)=d(1)/4.0  
      NN=N  
      do 10 l=2,nn  
      ll=l-1  
      bb(l)=4.0-1.0/bb(ll)  
      aa(l)=(d(l)-aa(ll))/bb(l)  
      10  
      Perform back substitution  
      u(nn)=aa(nn)  
      do 15 j=1,nn-1  
      u(j)=aa(j)-u(j+1)/bb(j)  
      15  
      write (unit,10)  
      format (/5x,'RECHARGE ESTIMATES',//2x,'DATE',19x,  
      &,'RECHARGE',23x,'FLOW')  
      NN=N  
      do 22 l=1,nn  
      write (32,760) l,u(l)  
      write (33,761) z(l)  
      format (/,'13',2x,e12.6)  
      760  
      format (/,'e12.6)  
      761  
      WRITE (unit,11) DATE(1,1),DATE(2,1),U(1),Z(1),Q(1)  
      format (1x,2a3,8x,e12.6,4x,8x,e12.6,4x,f4.1)  
      111  
      close (unit=31)  
      close (unit=32,device='disk',access='seqout',  
      &file='rechd.dat')  
      close (unit=33,device='disk',access='seqout',  
      &file='dat8.dat')  
      stop  
      end
```


Jan 04	•200158E+05	•180884E+05
Jan 05	•207435E+05	•180884E+05
Jan 06	•192961E+05	•520262E+05
Jan 07	•140966E+05	•846075E+04
Jan 08	•144714E+05	•158637E+05
Jan 09	•155868E+05	•132738E+05
Jan 10	•194669E+05	•108024E+05
Jan 11	•173328E+05	•661506E+04
Jan 12	•171280E+05	•181976E+05
Jan 13	•205433E+05	•209507E+05
Jan 14	•190422E+05	•904081E+04
Jan 15	•195857E+05	•903139E+04
Jan 16	•168670E+05	•188563E+05
Jan 17	•165904E+05	•131224E+05
Jan 18	•165904E+05	•121165E+05
Jan 19	•152080E+05	•136968E+05
Jan 20	•151417E+05	•141282E+05
Jan 21	•197865E+05	•137148E+05
Jan 22	•189967E+05	•177526E+05
Jan 23	•153885E+05	•186776E+05
Jan 24	•198490E+05	•160321E+05
Jan 25	•200400E+05	•169729E+05
Jan 26	•155471E+05	•155471E+05
Jan 27	•169729E+05	•155471E+05
Jan 28	•160321E+05	•165561E+05
Jan 29	•186776E+05	•192295E+05
Jan 30	•177526E+05	•190779E+05
Jan 31	•137148E+05	•167089E+05
Feb 01	•141282E+05	•184992E+05
Feb 02	•136968E+05	•188276E+05
Feb 03	•121165E+05	•155154E+05
Feb 04	•131224E+05	•136674E+05
Feb 05	•188563E+05	•150522E+05
Feb 06	•903139E+04	•163817E+05
Feb 07	•904081E+04	•172479E+05
Feb 08	•209507E+05	•189997E+05
Feb 09	•181976E+05	•193281E+05
Feb 10	•661506E+04	•196734E+05
Feb 11	•108024E+05	•176714E+05
Feb 12	•132738E+05	•176329E+05
Feb 13	•158637E+05	•184029E+05
Feb 14	•846075E+04	•160147E+05
Feb 15	•520262E+05	•145722E+05
Feb 16	•180884E+05	•150161E+05
Feb 17	•180884E+05	•186327E+05
Feb 18	•180884E+05	•203075E+05
Feb 19	•180884E+05	•201547E+05
Feb 20	•180884E+05	•175945E+05
Feb 21	•180884E+05	•386324E+05
Feb 22	•180884E+05	•112794E+05
Feb 23	•180884E+05	•113959E+05
Feb 24	•180884E+05	•133209E+05
Feb 25	•180884E+05	•105104E+05
Feb 26	•180884E+05	•931570E+04
Feb 27	•180884E+05	•167270E+05
Feb 28	•180884E+05	•184619E+05
Feb 29	•180884E+05	•110121E+05
Feb 30	•180884E+05	•107414E+05
Feb 31	•180884E+05	•162469E+05

*182921E+05	feb 17
*107444E+05	feb 18
-.385352E+04	feb 19
*245727E+04	feb 20
*182742E+05	feb 21
*241784E+05	feb 22
*249334E+05	feb 23
*204033E+05	feb 24
*818288E+04	feb 25
-.239461E+04	feb 26
-.216948E+04	feb 27
*143759E+05	feb 28
*198665E+05	mar 01
*160694E+04	mar 02
*102575E+05	mar 03
*128157E+05	mar 04
*107875E+05	mar 05
*781838E+04	mar 06
*197516E+04	mar 07
*224505E+04	mar 08
*376439E+03	mar 09
*147958E+05	mar 10
*172679E+05	mar 11
*244326E+05	mar 12
*307131E+05	mar 13
*116139E+05	mar 14
*450984E+04	mar 15
*971411E+04	mar 16
-.743050E+04	mar 17
*171535E+04	mar 18
*111309E+05	mar 19
*312545E+04	mar 20
*138533E+05	mar 21
*123498E+05	mar 22
*106056E+05	mar 23
*107929E+05	mar 24
*893392E+04	mar 25
*769722E+04	mar 26
*113793E+05	mar 27
*610341E+04	mar 28
*370016E+04	mar 29
*667211E+04	mar 30
-.350544E+04	mar 31
-.363112E+03	apr 01
*125219E+05	apr 02
*133435E+05	apr 03
*142196E+05	apr 04
*109532E+05	feb 17
*962620E+04	feb 18
-.231000E+03	feb 19
*404250E+04	feb 20
*165538E+05	feb 21
*231950E+05	feb 22
*239662E+05	feb 23
*190755E+05	feb 24
*854690E+04	feb 25
-.480102E+03	feb 26
*635200E+03	feb 27
*124547E+05	feb 28
*159209E+05	mar 01
*616000E+04	mar 02
*921950E+04	mar 03
*120709E+05	mar 04
*106260E+05	mar 05
*741000E+04	mar 06
*306070E+04	mar 07
*198270E+04	mar 08
*313890E+04	mar 09
*127435E+05	mar 10
*179975E+05	mar 11
*241202E+05	mar 12
*263917E+05	mar 13
*136482E+05	mar 14
*660390E+04	mar 15
*604450E+04	mar 16
-.286950E+04	mar 17
*175170E+04	mar 18
*829670E+04	mar 19
*625620E+04	mar 20
*118002E+05	mar 21
*123019E+05	mar 22
*109340E+05	mar 23
*104515E+05	mar 24
*906670E+04	mar 25
*852890E+04	mar 26
*989450E+04	mar 27
*664000E+04	mar 28
*464040E+04	mar 29
*454420E+04	mar 30
-.115620E+04	mar 31
*128850E+04	apr 01
*104924E+05	apr 02
*133222E+05	apr 03
*138600E+05	apr 04

apr 05	.131328E+05	apr 05	.125498E+05
apr 06	.861923E+04	apr 06	.933620E+04
apr 07	.828185E+04	apr 07	.881770E+04
apr 08	.111368E+05	apr 08	.106633E+05
apr 09	.112015E+05	apr 09	.125305E+05
apr 10	.194272E+05	apr 10	.153819E+05
apr 11	.369997E+04	apr 11	.627670E+04
apr 12	.276361E+04	apr 12	.689030E+04
apr 13	.269050E+05	apr 13	.204627E+05
apr 14	.130058E+05	apr 14	.142450E+05
apr 15	.639012E+04	apr 15	.998950E+04
apr 16	.215269E+05	apr 16	.160737E+05
apr 17	.431411E+04	apr 17	.513970E+04
apr 18	-.877650E+04	apr 18	-.217410E+04
apr 19	.173324E+05	apr 19	.138600E+05
apr 20	.232251E+05	apr 20	.220015E+05
apr 21	.222963E+05	apr 21	.217332E+05
apr 22	.186508E+05	apr 22	.183067E+05
apr 23	.130998E+05	apr 23	.146492E+05
apr 24	.171174E+05	apr 24	.147647E+05
apr 25	.713695E+04	apr 25	.787440E+04
apr 26	.119171E+04	apr 26	.261800E+04
apr 27	.336527E+04	apr 27	.290550E+04
apr 28	.239239E+04	apr 28	.413870E+04
apr 29	.115947E+05	apr 29	.109544E+05
apr 30	.172225E+05	apr 30	.124740E+05
may 01	-.573613E+04	may 01	-.144380E+04
may 02	-.395940E+04	may 02	-.188650E+04
may 03	.100058E+05	may 03	.683227E+04
may 04	.474844E+04	may 04	.675695E+04
may 05	.113893E+05	may 05	.113199E+05
may 06	.173546E+05	may 06	.169783E+05
may 07	.194866E+05	may 07	.180745E+05
may 08	.130485E+05	may 08	.117629E+05
may 09	-.128752E+04	may 09	.242670E+04
may 10	.610526E+04	may 10	.588930E+04
may 11	.122786E+05	may 11	.105670E+05
may 12	.811766E+04	may 12	.960690E+04
may 13	.129184E+05	may 13	.119350E+05
may 14	.119545E+05	may 14	.115295E+05
may 15	.846307E+04	may 15	.119227E+05
may 16	.263239E+05	may 16	.222337E+05
may 17	.206237E+05	may 17	.203484E+05
may 18	.133337E+05	may 18	.138612E+05
may 19	.954497E+04	may 19	.939280E+04
may 20	.441127E+04	may 20	.456100E+04
may 21	.396365E+02	may 21	.365700E+03
may 22	-.325823E+04	may 22	-.193000E+02

may 23	.126879E+05	.114934E+05
may 24	.216678E+05	.208297E+05
may 25	.264224E+05	.234850E+05
may 26	.140808E+05	.167446E+05
may 27	.179212E+05	.135712E+05
may 28	-.419213E+04	-.161580E+04
may 29	-.121482E+05	-.589170E+04
may 30	.170699E+05	.120312E+05
may 31	.164230E+05	.131285E+05
Jun 01	-.407573E+04	.595739E+03
Jun 02	.265967E+04	.163645E+04
Jun 03	.316210E+04	.487021E+04
Jun 04	.134334E+05	.120514E+05
Jun 05	.160489E+05	.155925E+05
Jun 06	.158334E+05	.164395E+05
Jun 07	.200189E+05	.163238E+05
Jun 08	.190893E+04	.791050E+04
Jun 09	.197900E+05	.171529E+05
Jun 10	.224954E+05	.202137E+05
Jun 11	.118414E+05	.147828E+05
Jun 12	.190041E+05	.153037E+05
Jun 13	.428499E+04	.435050E+04
Jun 14	-.109215E+05	-.760500E+04
Jun 15	-.711429E+04	-.887406E+04
Jun 16	-.149625E+05	-.839280E+04
Jun 17	.157904E+05	.134750E+05
Jun 18	.336594E+05	.292032E+05
Jun 19	.256549E+05	.253725E+05
Jun 20	.167346E+05	.178255E+05
Jun 21	.144412E+05	.150535E+05
Jun 22	.162574E+05	.147828E+05
Jun 23	.924034E+04	.875870E+04
Jun 24	-.802515E+03	.848201E+03
Jun 25	-.174907E+04	.499299E+03
Jun 26	.105785E+05	.737270E+04
Jun 27	.352518E+04	.408124E+04
Jun 28	-.644988E+03	.203950E+04
Jun 29	.109410E+05	.929771E+04
Jun 30	.128932E+05	.987521E+04
Jul 01	-.349347E+04	.236771E+04
Jul 02	.148200E+05	.109532E+05
Jul 03	.104485E+05	.750746E+04
Jul 04	-.122879E+05	-.392704E+04
Jul 05	.145688E+05	.143412E+05
Jul 06	.409634E+05	.327825E+05
Jul 07	.196081E+05	.203855E+05
Jul 08	.280016E+04	.779740E+04
Jul 09	.159814E+05	.115127E+05

.554304E+04	.243528E+04	JUL 10
.808496E+04	.702802E+04	JUL 11
.156320E+05	.182499E+05	JUL 12
.170928E+05	.139736E+05	JUL 13
.219245E+05	.289199E+05	JUL 14
.648840E+04	.256822E+04	JUL 15
.327370E+04	-.120107E+04	JUL 16
.163613E+05	.221020E+05	JUL 17
.146095E+05	.112268E+05	JUL 18
.188457E+05	.208549E+05	JUL 19
.177304E+05	.190588E+05	JUL 20
.897050E+04	.940040E+04	JUL 21
-.267700E+04	-.305065E+04	JUL 22
-.109916E+05	-.143251E+05	JUL 23
-.679505E+04	-.668239E+04	JUL 24
.789210E+03	-.440449E+03	JUL 25
.947096E+04	.128897E+05	JUL 26
.679521E+04	.590022E+04	JUL 27
.288746E+04	.382727E+04	JUL 28
.519710E+03	-.407151E+04	JUL 29
.140717E+05	.148637E+05	JUL 30
.256795E+05	.301426E+05	JUL 31
.184415E+05	.191297E+05	AUG 01
.433121E+04	.450824E+04	AUG 02
-.627554E+04	-.121223E+05	AUG 03
.136671E+04	.573022E+04	AUG 04
-.596790E+03	-.291632E+04	AUG 05
.188646E+04	.166930E+04	AUG 06
.465846E+04	.748110E+04	AUG 07
-.596505E+03	-.403548E+04	AUG 08
.612147E+04	.455421E+04	AUG 09
.136287E+05	.227528E+05	AUG 10
-.798855E+04	-.135429E+05	AUG 11
-.115498E+05	-.182767E+05	AUG 12
.101447E+05	.170958E+05	AUG 13
.162662E+05	.110182E+05	AUG 14
.322050E+05	.369827E+05	AUG 15
.292790E+05	.360886E+05	AUG 16
.256021E+04	-.528248E+04	AUG 17
.827710E+03	-.362072E+03	AUG 18
.823896E+04	.116485E+05	AUG 19
.542846E+04	.311970E+04	AUG 20
.764221E+04	.821513E+04	AUG 21
.862396E+04	.997832E+04	AUG 22
.579421E+04	.349989E+04	AUG 23
.989446E+04	.106412E+05	AUG 24
.123200E+05	.135485E+05	AUG 25
.100485E+05	.920245E+04	AUG 26

.998631E+04	aug 27	.998631E+04
.113510E+05	aug 28	.113510E+05
.109322E+05	aug 29	.109322E+05
.591945E+04	aug 30	.591945E+04
.961078E+04	aug 31	.961078E+04
.807343E+04	sep 01	.807343E+04
.783195E+04	sep 02	.783195E+04
.129586E+05	sep 03	.129586E+05
.974134E+04	sep 04	.974134E+04
.149760E+05	sep 05	.149760E+05
.116408E+05	sep 06	.116408E+05
.632337E+04	sep 07	.632337E+04
.113343E+05	sep 08	.113343E+05
.134248E+05	sep 09	.134248E+05
.116224E+05	sep 10	.116224E+05
.115721E+05	sep 11	.115721E+05
.110680E+05	sep 12	.110680E+05
.134427E+05	sep 13	.134427E+05
.103487E+05	sep 14	.103487E+05
.673416E+04	sep 15	.673416E+04
.735399E+04	sep 16	.735399E+04
.829666E+04	sep 17	.829666E+04
-.199460E+04	sep 18	-.199460E+04
-.153742E+04	sep 19	-.153742E+04
.111319E+05	sep 20	.111319E+05
.994713E+04	sep 21	.994713E+04
.105022E+05	sep 22	.105022E+05
.965906E+04	sep 23	.965906E+04
.126307E+05	sep 24	.126307E+05
.741119E+04	sep 25	.741119E+04
.873174E+04	sep 26	.873174E+04
.141078E+05	sep 27	.141078E+05
.140391E+05	sep 28	.140391E+05
.150696E+05	sep 29	.150696E+05
.607796E+04	sep 30	.607796E+04
.764997E+04	oct 01	.764997E+04
.722994E+04	oct 02	.722994E+04
.722256E+04	oct 03	.722256E+04
.157725E+05	oct 04	.157725E+05
.985185E+04	oct 05	.985185E+04
.862977E+04	oct 06	.862977E+04
.110304E+05	oct 07	.110304E+05
.139896E+05	oct 08	.139896E+05
.168768E+05	oct 09	.168768E+05
.143240E+05	oct 10	.143240E+05
.270869E+04	oct 11	.270869E+04
.134965E+04	oct 12	.134965E+04
.118844E+05	oct 13	.118844E+05
.100677E+05		.100677E+05
.110302E+05		.110302E+05
.101640E+05		.101640E+05
.739196E+04		.739196E+04
.872021E+04		.872021E+04
.831596E+04		.831596E+04
.870096E+04		.870096E+04
.115500E+05		.115500E+05
.111265E+05		.111265E+05
.134942E+05		.134942E+05
.113190E+05		.113190E+05
.804646E+04		.804646E+04
.108185E+05		.108185E+05
.127435E+05		.127435E+05
.118965E+05		.118965E+05
.114730E+05		.114730E+05
.115307E+05		.115307E+05
.124932E+05		.124932E+05
.102795E+05		.102795E+05
.744971E+04		.744971E+04
.743046E+04		.743046E+04
.644871E+04		.644871E+04
-.770400E+02		-.770400E+02
.519710E+03		.519710E+03
.881646E+04		.881646E+04
.102217E+05		.102217E+05
.102602E+05		.102602E+05
.102795E+05		.102795E+05
.112420E+05		.112420E+05
.852771E+04		.852771E+04
.937471E+04		.937471E+04
.131670E+05		.131670E+05
.141680E+05		.141680E+05
.133787E+05		.133787E+05
.787321E+04		.787321E+04
.731496E+04		.731496E+04
.733421E+04		.733421E+04
.862396E+04		.862396E+04
.133210E+05		.133210E+05
.106452E+05		.106452E+05
.922071E+04		.922071E+04
.111072E+05		.111072E+05
.139177E+05		.139177E+05
.159197E+05		.159197E+05
.128013E+05		.128013E+05
.450446E+04		.450446E+04
.334946E+04		.334946E+04
.979821E+04		.979821E+04

107607E+05	998417E+04	oct	14
126280E+05	127971E+05	oct	15
132055E+05	148622E+05	oct	16
816196E+04	710499E+04	oct	17
621771E+04	548175E+04	oct	18
848921E+04	816144E+04	oct	19
140332E+05	127975E+05	oct	20
202317E+05	252839E+05	oct	21
893196E+04	807521E+04	oct	22
105879E+04	458078E+04	oct	23
294521E+04	346941E+04	oct	24
791171E+04	807174E+04	oct	25
107415E+05	118141E+05	oct	26
935546E+04	913617E+04	oct	27
796946E+04	777405E+04	oct	28
791171E+04	745354E+04	oct	29
929771E+04	986669E+04	oct	30
883571E+04	886598E+04	oct	31
789246E+04	764002E+04	nov	01
785396E+04	783633E+04	nov	02
829671E+04	808457E+04	nov	03
873946E+04	955692E+04	nov	04
735346E+04	611939E+04	nov	05
100485E+05	991181E+04	nov	06
129360E+05	147654E+05	nov	07
974046E+04	876036E+04	nov	08
833521E+04	860256E+04	nov	09
692996E+04	679195E+04	nov	10
592896E+04	562981E+04	nov	11
679521E+04	611124E+04	nov	12
104527E+05	105939E+05	nov	13
142450E+05	144373E+05	nov	14
162085E+05	174141E+05	nov	15
131477E+05	135805E+05	nov	16
850846E+04	715265E+04	nov	17
756521E+04	881093E+04	nov	18
381146E+04	285890E+04	nov	19
271421E+04	221426E+04	nov	20
400396E+04	430513E+04	nov	21
435046E+04	430168E+04	nov	22
565946E+04	438572E+04	nov	23
106837E+05	119609E+05	nov	24
112805E+05	121630E+05	nov	25
846996E+04	701854E+04	nov	26
941321E+04	106160E+05	nov	27
802721E+04	700180E+04	nov	28
937471E+04	945280E+04	nov	29
112805E+05	115559E+05	nov	30

dec 01	.121090E+05	.117810E+05
dec 02	.108787E+05	.109340E+05
dec 03	.100006E+05	.100100E+05
dec 04	.926601E+04	.866246E+04
dec 05	.478950E+04	.583271E+04
dec 06	.638239E+04	.714171E+04
dec 07	.125107E+05	.991371E+04
dec 08	.314417E+04	.440821E+04
dec 09	.848660E+03	.279121E+04
dec 10	.101034E+05	.831596E+04
dec 11	.862841E+04	.877796E+04
dec 12	.805076E+04	.831596E+04
dec 13	.902074E+04	.968271E+04
dec 14	.140883E+05	.106645E+05
dec 15	-.132824E+04	.837371E+04
dec 16	.413848E+05	.277392E+05
dec 17	.408966E+04	.408096E+04
dec 18	-.354366E+05	-.205395E+05
dec 19	.137875E+05	.471646E+04
dec 20	.854281E+04	.102600E+05
dec 21	.137770E+05	.121850E+05
dec 22	.965554E+04	.104142E+05
dec 23	.101067E+05	.995221E+04
dec 24	.976198E+04	.954796E+04
dec 25	.810494E+04	.860471E+04
dec 26	.948506E+04	.908596E+04
dec 27	.847575E+04	.862396E+04
dec 28	.835571E+04	.816196E+04
dec 29	.702954E+04	.721871E+04
dec 30	.674604E+04	.671821E+04
dec 31	.619812E+04	.621771E+04
jan 01	.562667E+04	.616020E+04
jan 02	.815239E+04	.796947E+04
jan 03	.961395E+04	.845071E+04
jan 04	.405761E+04	.612171E+04
jan 05	.107048E+05	.974023E+04
jan 06	.118508E+05	.112610E+05
jan 07	.945141E+04	.103180E+05
jan 08	.124643E+05	.113382E+05
jan 09	.878983E+04	.997146E+04
jan 10	.122975E+05	.109340E+05
jan 11	.776507E+04	.821971E+04
jan 12	.580137E+04	.721871E+04
jan 13	.123649E+05	.109340E+05
jan 14	.105226E+05	.916296E+04
jan 15	.412177E+03	.217545E+04
jan 16	.384816E+03	.103971E+04
jan 17	.401093E+04	.371522E+04

Jan 18	561904E+04
Jan 19	118767E+05
Jan 20	104630E+05
Jan 21	457558E+04
Jan 22	709052E+04
Jan 23	138329E+05
Jan 24	976709E+04
Jan 25	571084E+04
Jan 26	119621E+05
Jan 27	106457E+05
Jan 28	722957E+04
Jan 29	110633E+05
Jan 30	762968E+04
Jan 31	646059E+04
Feb 01	878539E+04
Feb 02	335538E+04
Feb 03	570291E+04
Feb 04	124663E+05
Feb 05	832872E+04
Feb 06	716122E+04
Feb 07	748348E+04
Feb 08	728493E+04
Feb 09	104185E+05
Feb 10	652972E+04
Feb 11	498857E+04
Feb 12	350994E+04
Feb 13	494938E+04
Feb 14	853962E+04
Feb 15	940195E+04
Feb 16	799360E+04
Feb 17	447182E+04
Feb 18	573518E+04
Feb 19	385703E+04
Feb 20	694418E+04
Feb 21	731269E+04
Feb 22	267451E+04
Feb 23	651110E+04
Feb 24	378779E+04
Feb 25	498222E+04
Feb 26	805853E+04
Feb 27	112986E+05
Feb 28	937863E+04
Mar 01	583355E+04
Mar 02	785573E+04
Mar 03	327358E+04
Mar 04	812504E+04
Mar 05	984857E+04
Mar 06	666537E+04
Jan 18	639097E+04
Jan 19	105682E+05
Jan 20	972122E+04
Jan 21	600597E+04
Jan 22	777697E+04
Jan 23	119927E+05
Jan 24	977897E+04
Jan 25	743047E+04
Jan 26	106642E+05
Jan 27	102987E+05
Jan 28	843147E+04
Jan 29	983647E+04
Jan 30	802745E+04
Jan 31	704571E+04
Feb 01	750747E+04
Feb 02	469697E+04
Feb 03	642947E+04
Feb 04	106260E+05
Feb 05	883572E+04
Feb 06	741122E+04
Feb 07	741122E+04
Feb 08	783472E+04
Feb 09	923997E+04
Feb 10	694922E+04
Feb 11	502422E+04
Feb 12	404247E+04
Feb 13	531297E+04
Feb 14	808497E+04
Feb 15	900897E+04
Feb 16	766147E+04
Feb 17	529372E+04
Feb 18	523597E+04
Feb 19	471622E+04
Feb 20	648722E+04
Feb 21	650647E+04
Feb 22	411947E+04
Feb 23	542847E+04
Feb 24	448522E+04
Feb 25	529372E+04
Feb 26	808497E+04
Feb 27	103950E+05
Feb 28	912447E+04
Mar 01	675672E+04
Mar 02	677597E+04
Mar 03	487022E+04
Mar 04	758447E+04
Mar 05	902822E+04
Mar 06	764222E+04

mar 07	* 934327E+04	
mar 08	* 463050E+04	
mar 09	* 680259E+04	
mar 10	* 529611E+04	
mar 11	* 911141E+04	
mar 12	* 119424E+05	
mar 13	* 567337E+04	
mar 14	- * 835993E+02	
mar 15	- * 198947E+04	
mar 16	* 468173E+04	
mar 17	* 443490E+04	
mar 18	* 123671E+05	
mar 19	* 117799E+05	
mar 20	* 677405E+04	
mar 21	* 520623E+04	
mar 22	* 236675E+04	
mar 23	* 649912E+04	
mar 24	* 360960E+04	
mar 25	* 243444E+04	
mar 26	* 385438E+04	
mar 27	* 174193E+04	
mar 28	* 260154E+04	
mar 29	* 355214E+04	
mar 30	* 679800E+04	
mar 31	* 667256E+04	
apr 01	* 670557E+04	
STOP		
mar 07	* 810422E+04	
mar 08	* 581347E+04	
mar 09	* 617922E+04	
mar 10	* 621772E+04	
mar 11	* 889347E+04	
mar 12	* 104335E+05	
mar 13	* 577497E+04	
mar 14	* 654470E+03	
mar 15	- * 519780E+03	
mar 16	* 356122E+04	
mar 17	* 579422E+04	
mar 18	* 108955E+05	
mar 19	* 110302E+05	
mar 20	* 735347E+04	
mar 21	* 502422E+04	
mar 22	* 356122E+04	
mar 23	* 533222E+04	
mar 24	* 394622E+04	
mar 25	* 288747E+04	
mar 26	* 331097E+04	
mar 27	* 227147E+04	
mar 28	* 265647E+04	
mar 29	* 394622E+04	
mar 30	* 623697E+04	
mar 31	* 669897E+04	
apr 01	* 669902E+04	