GROUND WATER INVESTIGATION IN THE VICINITY OF CAPULIN
COLFAX & UNION COUNTIES, NEW MEXICO

by

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Abstract

The Water Resources Division, U.S. Geological Survey, Albuquerque, New Mexico, is studying possible supplemental sources of water for the city of Raton. One such source is a well field owned by the city of Raton in Capulin village, Union and Colfax counties. Other possible source is ground water in valley alluvium in Capulin basin, an area of 125 square miles.

The geological reconnaissance following by hydrological field work were performed in summer 1977. Finally, six test wells were drilled in alluvium aquifer and three pumping tests were performed in early spring 1978. The aquifer constances were analyzed by using finite element programs of flow towards wells at the Computer Center, New Mexico Institute of Mining & Technology, Socorro, New Mexico.

The results, based on these analyses, do not agree to contribute ground water supply in Capulin as a supplemental source for water supply for the city of Raton.

1. Acknowledgements

Sincere appreciation is expressed herein to all those who have contributed in any way in the preparation of this research. The task would have been far more difficult without such assistance.

Member of the Advisory Committee, Prof. G.W. Gross, Advisor, Prof. C.R. Keizer of New Mexico Institute of Mining & Technology, and Dr. W.J. Stone of New Mexico Bureau of Mines and Mineral Resources, were especially helpful in rendering technical and editorial guidance.

Dr. P.S. Huyakorn, Department of Geoscience, New Mexico Institute of Mining & Technology gave permission to use finite element program for computation and technical advice involving two-regime flow towards wells.

Gratitude is extended to various engineers and geologists of the Water Resources Division, U.S. Geological Survey, Albuquerque, New Mexico, with special thanks to Mr. William E. Hale, District Chief, and Mr. John S. McLean, Chief of General Investigations, for permission to participate in field trip and to use field data. Thanks are also extended to Mr. Donald Hart, Jr., and Mr. Christian Smith, hydrogeologists, for encouraging and suggesting many sources of data for library research.

2. Introduction

The city of Raton presently depends on a limited supply of surface water from Lake Maloya on the Chico Rico Creek. Planned developments, such as development of coal fields west of Raton, a planned National Rifle Association Center, and planned expansion of the municipal power system are hampered by the lack of a reliable water supply. Drought conditions in 1963-1964 forced Raton to ration water, and the present drought may produce similar shortages.

The Water Resources Division, U.S. Geological Survey, Albuquerque, New Mexico, is studying possible supplemental sources of water for Raton. One such source is a well field owned by the city of Raton in Capulin, 26 miles east of Raton. Other possible ground water sources is valley alluvium within the Capulin basin.

2.1 Purpose of Investigation

The main purposes of this research are:-

1) to evaluate the hydraulic properties of the main aquifers in the basin.

2) to estimate the effect due to long term pumping of productive wells.

2.2 Location and Topography of Study Area

The study area is located in between latitude 36° 40′ N. to 37° 00′ N. and longitude 103° 56′ W. to 104° 16′ W. It covers northwestern part of Union county and northeastern part of Colfax county as seen in Figure 1. The topography of the basin consists

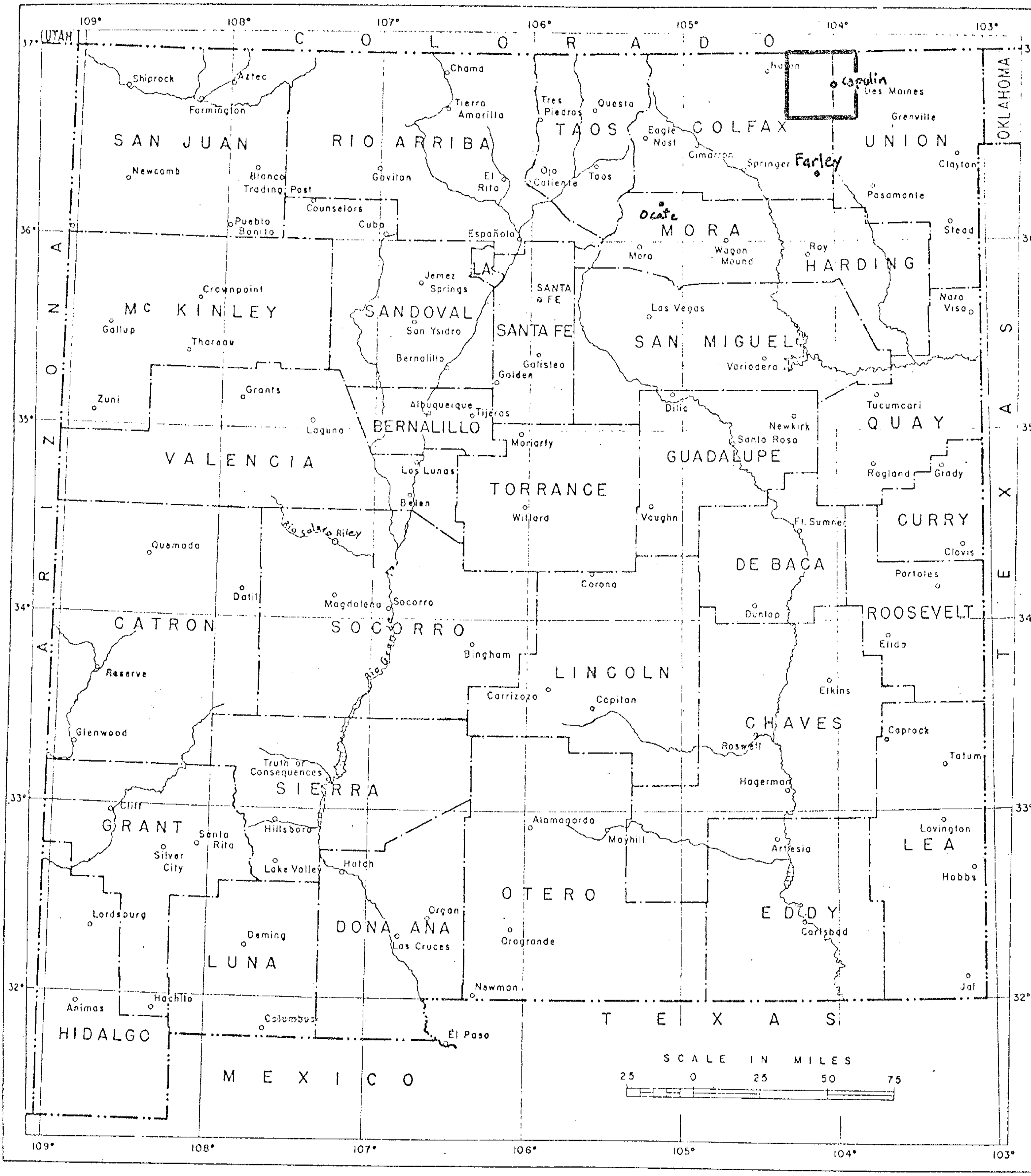


Figure 1. Location of study area.

of an erosional area with a rather poorly defined stream system draining generally northeast. The village of Capulin is located at the lowest point. The basin is bounded on the north by the high lava-capped Johnson mesa and on the northeast by Capulin National Monument, an almost perfect cinder cone. The valley floor rises gradually to the west, a slender lava-capped remnant forming part of the divide within the Chicorico drainage to the west. Laughlin peak rises in the southwestern corner of the basin and lava-capped hills and old cinder cones enclose the basin to the south and east. The drainage basin covers a total area of about 125 square miles (see Figure 2).

Surface drainage to the east is cut off by a ridge running from the shoulder of Capulin mountain to a lava-capped hill immediately southeast of Capulin village. It is probable that in geologic times a stream drained eastward but was later blocked by the eruption of Capulin volcano. The dam thus formed not only blocks surface drainage but apparently forms a low barrier to the east-ward movement of ground water also.

The bottom of the basin at Capulin lake just west of the village is 6793 feet above mean sea level. The valley floor rises to the southwest about 10 to 12 feet to the mile but the water courses are poorly defined and there are several sinks or wet-weather lakes extending for a distance of about 8 miles south and west of Capulin which hold and evaporate much of the surface runoff. Some water from these depressions is contributed to the

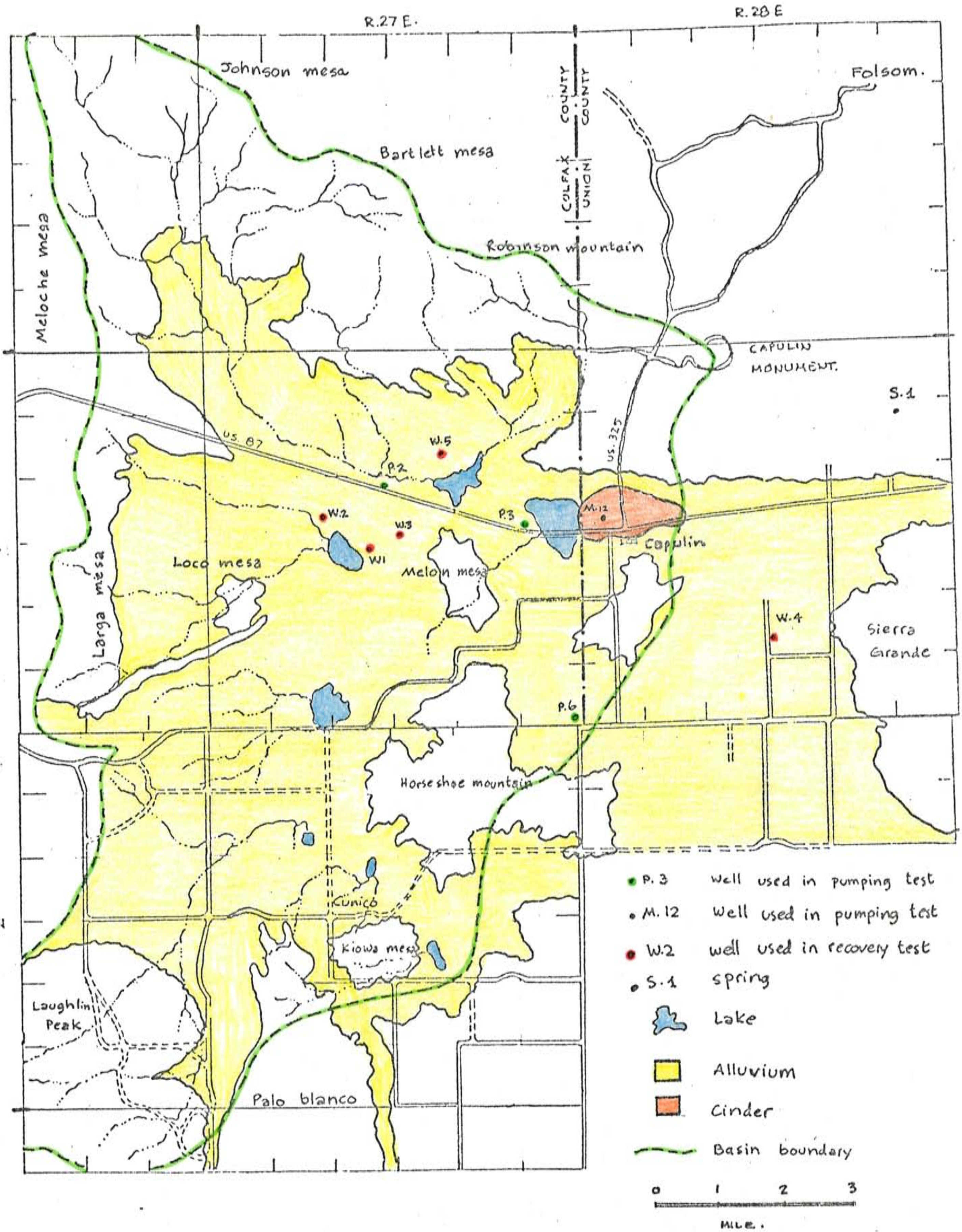


Figure 2. Capulin basin and well locations

ground water supply in the valley alluvium.

The mesas rise several hundred feet above the Laughlin valley, the highest point being Laughlin peak (8836 feet a.m.s.l.). A low divide between the hills about 2 miles south of the village lies only about 70 feet above the valley floor. The highway 87 to Raton traverse the valley crossing a lava flow of recent age and leaves the basin at an elevation of about 7040 feet about 9 miles to the west northwest of Capulin.

Because of the relatively high rainfall, pastureage is usually good and stock grazing is the chief industry in the valley. A number of stock wells have been drilled, or sometimes dug, throughout the basin and some attempt has been made to obtain groundwater for irrigation. Because of the limited water production from the alluvium, however, this effort has not been successful excepting in the immediate vicinity of the village where the character of the aquifer changes markedly.

The Colorado and Southern Railroad at Des Moines 9 miles east and the Santa Fe Railway at Raton 26 miles west serve the area. U.S. Highway 64/87 crosses the valley through Capulin in an east-west direction. Raton is the market center of the area.

According to the 1970 census Capulin has a population of 204, over half of which is concentrated in the village. The pupulation density of about 2 inhabitants per square mile is almost half that of the State as a whole, which is 4.4 inhabitants per square mile.

2.3 Climate, Precipitation, and Vegetation

The rainfall along Bartlett and Johnson mesas, which run easterly from the mountains along the Colorado-New Mexico state line, averages 16 to 20 inches per year. From 1943 to 1976 precipitation at Capulin has averaged 15.82 inches (see Table 1). The average elevation is 6900 feet, and the average temperature of the valley is 46^{o}F. Summer maximum temperatures are relatively low, seldom rising above 90^{o}F, while winter temperatures often sink below zero. The average date of the last and first killing frosts of each year are May 17 and September 29 respectively, giving an average growing season of 135 days.

The vegetation zones, of Merriam's classification (1890), of the area range from the Upper Sonoran zone to Canadian-Hudson zone. In the Upper Sonoran zone, it consists of cotton wood, mixed grass, and juniper at the elevation of 6,000-7,000 ft.a.m.s.l., and of oak and pinon at the elevation of 7,000-8,000 ft.a.m.s.l.

In Transition zone, at elevation of 8,000-9,000 ft.a.m.s.l., it consists of gamble oak and Ponderosa pine.

The Canadian-Hudson zone, above 9,000 ft, is characterized by aspen in the lower part and by spruce and fir in the upper part, and forms the cover of density forested slopes.

2.4 Previous Work

Since about 1945, there have been several studies made of ground water possibilities, for either irrigation or other purposes,

Table 1. Precipitation Record at Capulin National Monument.

Year	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1976	0.40	0.46	0.02	0.64	1.84	1.41	2.24	2.27	2.92	1.03	0.24	0.09	13.56
75	0.70	0.52	0.93	0.39	0.27	2.66	2.64	2.75	2.85	0	1.00	0.16	14.87
74	1.01	0.13	0.33	0.11	0.52	2.32	0.96	1.45	0.89	0.96	0.20	0.64	9.52
73	1.27	0.42	3.50	1.11	0.80	1.33	3.70	0.86	2.10	0.34	0.20	1.13	16.76
72	0.33	0.02	0.45	0.13	2.04	2.41	2.14	1.35	3.78	4.00	1.04	0.19	17.88
71	0.30	1.04	0.38	1.63	2.95	0.85	4.57	1.43	1.07	2.08	1.06	0.40	17.76
70	0.04	0.09	0.94	0.23	2.14	0.92	4.04	3.70	1.45	0.26	0.21	0.01	14.02
69	0	0.54	0.83	1.65	2.59	3.67	3.01	1.40	2.27	1.05	0.32	0.22	17.55
68	0.14	0.12	0.40	0.46	1.48	1.18	4.62	2.10	0.48	0.31	0.91	0.09	12.29
67	0.19	0.09	0.04	0.19	1.40	4.38	4.69	2.85	1.95	0.11	0.09	0.46	16.44
66	0	0	0.02	0.81	0.64	2.01	8.67	4.84	2.02	0.46	0.32	0.30	20.09
65	0.10	0.07	0.40	1.43	3.10	3.42	2.46	3.48	1.55	1.02	0	0.52	17.55
64	0	0.22	0.01	0.38	2.35	0.94	3.85	1.40	2.08	0	0.65	0.22	12.10
63	0.09	0.17	0.04	0	2.04	1.93	1.41	4.69	3.31	0.17	0	0.20	14.05
62	0.57	0.04	0.13	0.07	2.95	3.12	6.18	1.50	0.74	0.05	0.21	0.14	15.70
61	0	0.41	0.27	0.76	0.70	1.84	3.73	6.61	2.73	0.34	0.48	0.14	18.01
60	0.65	0.33	0.13	0.40	1.44	2.67	3.03	2.48	1.64	2.21	0.03	0.95	15.96
59	0.23	0.13	0.32	0.19	3.04	1.71	2.63	5.48	0.21	2.31	0.03	0.09	16.37
58	0.15	0.40	0.67	0.62	5.25	1.46	5.92	1.35	2.83	0.27	0.20	0.20	19.32
57	0	0	1.94	1.48	1.76	0.69	3.64	4.04	0.38	4.77	0.88	0	19.58
56	0.09	0.22	0.11	0.28	1.39	1.30	2.10	3.09	0	0.04	0.17	0	18.79
55	0	0.08	0.69	1.87	5.88	0.15	3.92	7.61	1.68	0.38	0.13	0.07	22.46
54	0.19	0.16	0.09	0.05	2.33	0.97	2.45	2.04	0.21	3.19	0	0.11	11.79
53	0.26	0.17	0.25	0.73	0.99	1.13	2.38	2.63	0.47	0.43	1.40	0.54	11.38
52	0.64	0.51	0.47	1.66	1.29	1.18	2.36	5.64	1.41	0	0.17	0.25	15.58
51	0.65	0.09	0.55	0.96	3.23	1.54	3.76	3.61	0.14	0.26	0.43	0.05	15.27
50	0.25	0.15	0	0.23	0.19	2.82	9.35	1.78	3.81	0.50	0.12	0.19	19.39
49	0.33	0.03	0.79	0.70	3.06	4.91	5.31	3.09	1.69	0	0	0.01	19.92
48	1.39	0.54	0.38	0.29	2.32	4.38	1.42	2.42	0.93	0.71	0.91	0	15.69
47	0.06	0.11	0.30	0.10	2.91	0.96	4.92	2.84	0.20	0.67	0.10	1.25	14.42
46	0.01	0.30	2.44	1.37	2.56	0.73	3.98	6.18	1.17	3.55	1.25	0.20	23.74
45	0.56	0.40	0	0.08	0.35	0.34	3.63	8.70	1.11	0	0	0	15.17
44	0.60	0.15	0	2.78	2.49	0.50	2.59	3.72	0.47	2.00	0.79	0	16.09
43	0	0	0.25	0	1.05	0.76	0.78	5.33	0.12	0	0.50	0	8.79
42	0.38	0	1.03	6.42	0	3.25	2.27	4.35	4.80	3.19	0.05	0.10	25.84
41	0.99	0.03	2.39	1.66	3.88	2.09	3.61	1.97	6.45	2.17	0.10	0.49	25.83
40	1.70	1.01	1.16	0.66	2.53	0.39	1.59	2.94	2.21	0	1.96	0.61	16.76

Average = 15.82 inches

Remarks: Data from Climatology data, U.S. Weather Bureau of the Capulin basin, either by the U.S. Geological Survey or by private engineering firms working directly for the city of Raton. In 1945, U.S. Geological Survey entered into an agreement with the Commissioners of Colfax county for a study to be made. The results are available in a report by R.L. Griggs: "Geology and Ground Water Resources of the Eastern Part of Colfax County". He presented his work in a hydrogeologic map showing availability of ground water and concluded that the chief aquifer of the area is the Dakota Sandstone. However, the transmissivity is low because of the tightly cemented character of sandstone. The specific capacity of the well completed in Dakota Sandstone is about 1 gpm./ft.

At a special request of the city of Raton and other interested citizens, a geologist of the U.S. Geological Survey spent some time in the Capulin area. This resulted in an open file report of the U.S. Geological Survey, which is known as Herrick (1951) report. He concluded that the most favorable locality for the development of irrigation is in the vicinity of three irrigation wells, namely Christ well, Pachta well, and Snead well respectively (see Table 2).

After the above studies, the city of Raton became interested in obtaining lands in the Capulin area with the idea that water of sufficient quantities could be developed and piped into the Raton for additional water supply. Consequently, a tract of land located in SW/4 of section 18, and the N/2 NW/4 of section 19, Township 29 North, Range 28 East in Union County, was

Table 2. Data of Selected Wells and One Spring Near Capulin

Well Number	Well Location	Owner	Depth of well (ft)	Diameter of well (in.)	Formation	Water level (ft.a.m.s.l.)	Date Measured	Sources of data	Remarks	Special Name
M.3	29.28.18.320	City of Raton	57.00	10	Cinder	6,787.5	May 1965	Minton 1966	Test well	Test Hole 3
M.11	29.28.18.333	" "	34.50	10	Cinder	6,787.5	May 1965	Minton 1966	Observed well	
M.12	29.28.18.323	" "	48.50	14	Cinder	6,787.1	May 1965	Minton 1966	Irrigation well, 1,800 gpm.	Pachta well
M.13	29.28.18.342	" "	77.20	16	Cinder	6,787.5	May 1965	Minton 1966	Irrigation well, 900 gpm.	Christ well
M.14	29.28.18.310	" "	77.50	10	Sand	6,788.0	May 1965	Minton 1966	Test well	
M.16	29.28.18.441	C. Wallace	37.80	-	Cinder	6,787.5	May 1965	Minton 1966	Dug well, domestic use	
M.18	29.28.18.244	James Morrow	32.50	-	Cinder	6,786.9	May 1965	Minton 1966	Dug well, domestic use	
M.19	29.28.17.331	George Snead	42.00	-	Cinder	6,787.4	May 1965	Minton 1966	Irrigation well, 700 gpm.	Snead well
M.20	29.28.17.342	" "	45.20	-	Cinder	6,779.5	May 1965	Minton 1966	Wind mill, domestic use	
M.29	29.28.18.432	City of Raton	?	-	Cinder	6,787.4	May 1965	Minton 1977	Dug well, domestic use	
M.54	29.28.18.433	" "	40.80	10	Cinder	6,787.2	May 1965	Minton 1966	Observed well	
M.61	29.28.18.344	" "	54.00	-	Cinder	6,787.0	May 1965	Minton 1966	Irrigation well, 730 gpm.	
M.64	29.28.18.410	James Morrow	?	-	Cinder	6,788.5	May 1965	Minton 1966	Irrigation well, 60 gpm.	
M.65	29.28.18.314	City of Raton	41.00	10	Cinder	6,787.4	May 1965	Minton 1966	Observed well	
M.66	29.28.18.430	Paul Hill	70.00	-	Cinder	6,788.2	May 1965	Minton 1966	Irrigation well, domestic use	
M.67	29.28.18.431	" "	?	-	Cinder	6,787.7	May 1965	Minton 1966	-	
W.1	29.27.21.212	-	31.50	6	Alluvium	6,809.8	June 1977	Field work'77	Wind mill, use in recovery test	
W.2	29.27.17.422	-	38.20	8	Alluvium	6,816.7	June 1977	Field work'77	Wind mill, use in recovery test	
W.3	29.27.15.333	-	40.10	6	Alluvium	6,814.0	June 1977	Field work'77	Wind mill, use in recovery test	
W.4	29.28.27.313	-	65.90	6	Alluvium	6,775.0	June 1977	Field work'77	Wind mill, use in recovery test	
W.5	29.27.10.423	-	42.50	8	Alluvium	6,809.0	June 1977	Field work'77	Wind mill, use in recovery test	
P.2	29.27.16.112	U.S.G.S.	190.00	12	Alluvium	6,821.4	Jan. 1978	Field work'78	Pumping well, 250 gpm.	
P.3	29.27.13.331	"	195.00	12	Alluvium	6,786.0	Jan. 1978	Field work'78	Pumping well, 50 gpm.	
P.6	29.27.36.442	"	322.00	12	Alluvium	6,775.0	Jan. 1978	Field work'78	Pumping well, 15 gpm.	
S.1	29.28.12.113	Milton Bennett	-	-	Basalt	6,637.5	May 1965	Minton 1966	Spring flow at rate 250 gpm.	Bennett spring

Remarks: This table is prepared from Minton's report, 1966 and field work in summer 1977. For convenient, well numbering in this table remains the same as in Minton's report.

purchased. This tract of land, about 245 acres, had been irrigated for some years by previous owners and two existing wells, namely Pachta well (M.12) and Christ well (M.13) were located on the property (see Table 2).

John Bliss (1957), a consulting engineer of Santa Fe, New Mexico, was authorized by the city of Raton to make a study and report on the feasibility of constructing a water line from Capulin to Raton. Their main conclusions were that the water supply in the Capulin area was quite limited in extent, and that the cost of a pipeline project, then estimated at $1,300,000, could not be justified on the basis of known water supply.

Minton (1966), a consulting engineer of Artesia, New Mexico, was employed by the city of Raton to make a detailed study of the Capulin basin ground water potential. The purpose was to make a conclusive determination as to whether water could be produced in sufficient quantities to justify the construction and operation of a pipeline to Raton for a minimum period of 20 years.

He operated a 61-day pumping test of the well M.12. The water was pumped at a constant rate of 920 gpm. producing a total of 223.8 ac.ft. A continuous water level record was maintained in the 3 observation wells and in pumping well throughout the pumping period. On the basis of his pumping and drawdown records, Minton concluded: "The city of Raton can safely produce a maximum of 1.2 million gallons of water per day from the Capulin basin, based on an 8-hour per day pumping, and it will yield a safe supply to the city of Raton for a minimum of 20 years."

2.5 Methods of Investigation

The first part, in summer 1977, consisted of making a reconnaissance of the area between Capulin and Raton to locate possible zones of alluvial fill suitable for development. It included interviewing well owners, collecting well information, measuring water levels in existing wells, and performing recovery tests at the wells completed in alluvium. The work was done by Mr. Donald Hart, Jr., and Mr. Christian Smith, hydrogeologists, Water Resources Division, U.S. Geological Survey, Albuquerque, NM, and by the writer. The results are represented in the Geologic map of Capulin area (Figure 3), Piezometric map (Figure 4), and recovery curves (Figure 5) which were constructed from recovery data in Table 3.

The second part was conducted in December 1977, through January 1978. It consisted of drilling 6 test wells, collecting and analyzing well cuttings, and observing pumping tests.

The third part, February 1978 through March 1978, consisted an evaluating hydraulic parameters from pumping tests by using finite element programs, at NM Institute of Mining & Technology, under supervision and guidance of Dr. P.S. Huyakorn, Department of Geoscience. The value of transmissivity and storage coefficient obtained from this analysis were used in the predictions of future water level declines as a function of pumping rate.

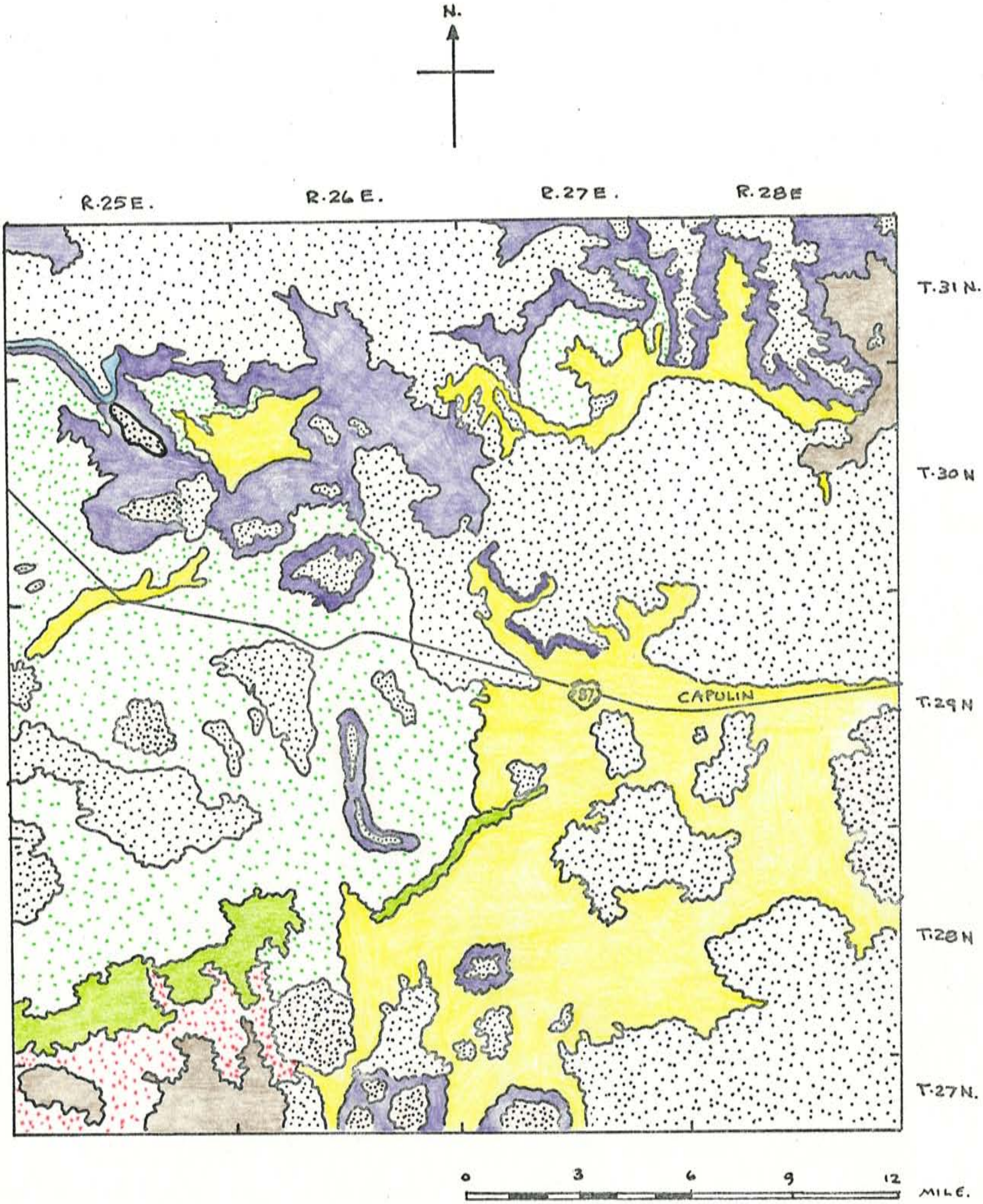


Figure 3. Geologic map of Capulin area. (Modified after Wood, Northrop, and Griggs, 1946; and Baldwin and Muehlberger, 1959)

EXPLANATION

SEDIMENTARY ROCKS

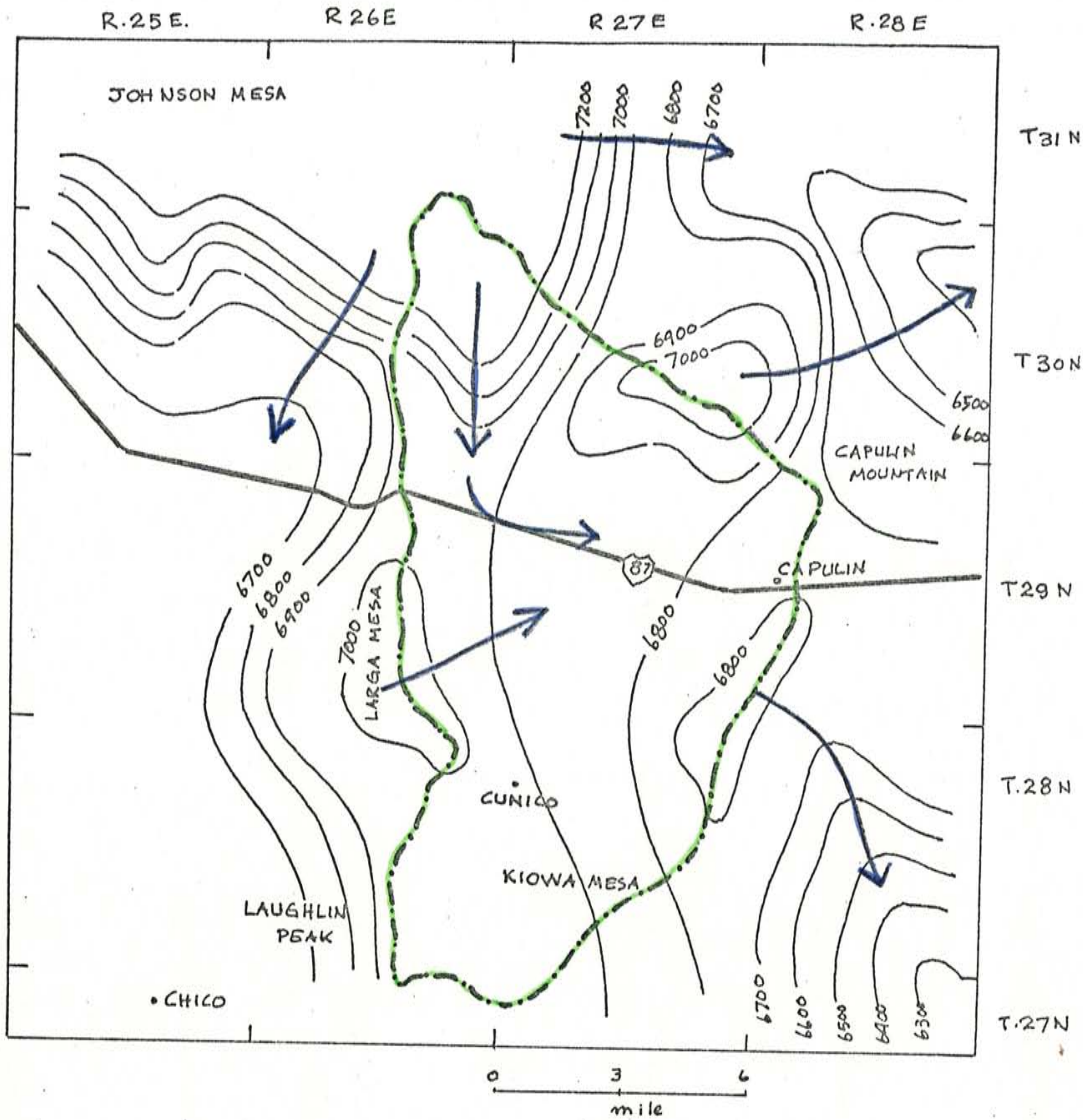
Quaternary	Pleistocene to Recent	Alluvium:	valley fill, lake deposits, sand wash, soil mantle, gravel and loess.
		Landslide:	talus debris occur where shale is overlain by lava flows.

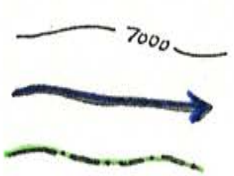
unconformity

Cretaceous	Upper Cretaceous	Trinidad Sandstone:	light buff sandstone
		Pierre Shale:	shale, sandyshale, calcareous shale.
		Fort Hays Limestone:	limestone and interbedded shale.
		Carlile Shale:	dark grey to black shale.
		Greenhorn Limestone:	limestone and interbedded shale.
		Graneros Shale:	black, fissile shale
		Dakota Sandstone:	light buff to brown quartzitic sandstone.

IGNEOUS ROCKS

Quaternary	Pleistocene to recent	Basalt:	a sequence of vesicular, light grey to black, columnar basalt flow, consists of Raton basalt, Clayton basalt, Capulin basalt.
Tertiary	Early Tertiary (?)	Sills and Dikes:	Monzonitic, locally include altered sedimentary rock.





Piezometric contour in ft. (elevation)

Flow line

Basin boundary

Figure 4. Piezometric map and regional flow of ground water in Capulin area. (After Hart, Smith, and Intrasuta, 1977)

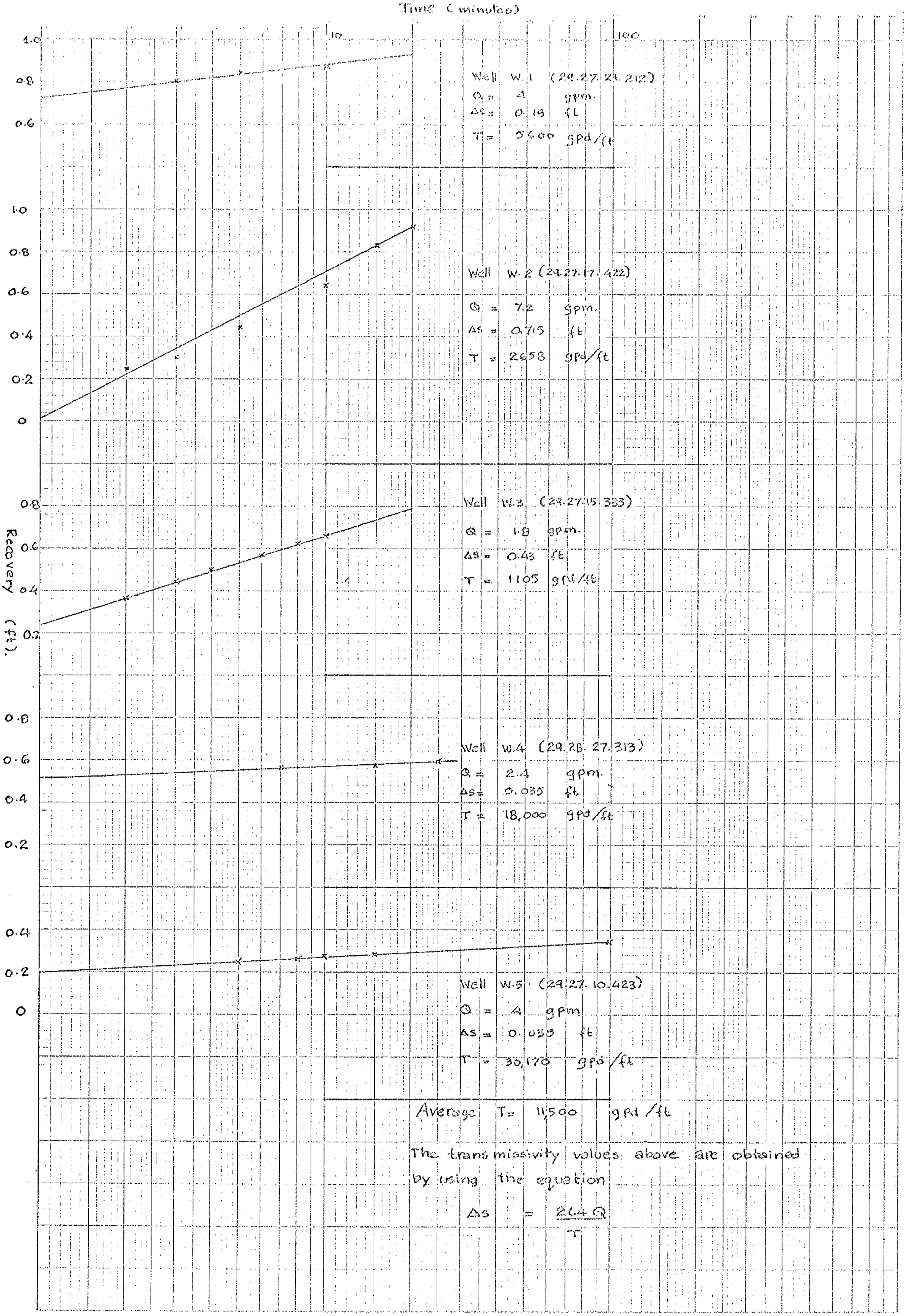


Figure 5. Recovery curves of wells completed in Alluvium.

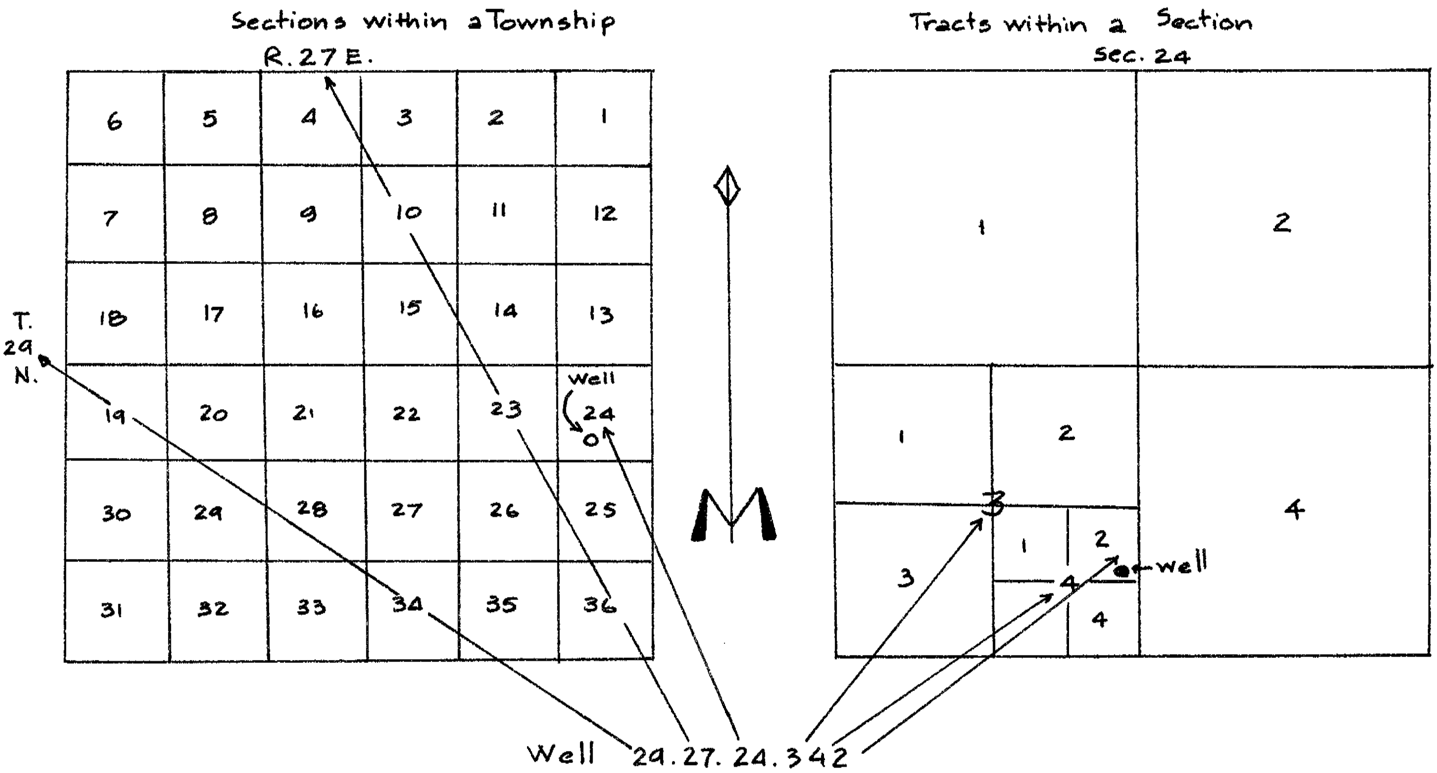
Table 3. Recovery Data for Wells Completed in Alluvium

Well No.	Location	Time (Min.)	Recovery (ft.)
W.1	29.27.21.212	3	0.80
		5	0.85
		10	0.87
W.2	29.27.17.422	2	0.25
		3	0.30
		5	0.44
		10	0.65
		15	0.83
		20	0.92
W.3	29.27.15.333	2	0.36
		3	0.44
		4	0.49
		6	0.57
		8	0.62
		10	0.66
W.4	29.28.27.313	7	0.56
		15	0.57
		25	0.59
W.5	29.27.10.423	5	0.22
		8	0.30
		10	0.35
		15	0.40

2.6 Well Numbering System in New Mexico

The system of numbering wells in New Mexico, used in all areas except for the thermal wells in Truth or Consequences, is based on the common subdivisions of public lands into sections. The well number locates the position to the nearest 10 acre tract in the survey grid. The number is divided by periods into 4 segments. The first segment denotes the township north or south of the New Mexico base line; the second denotes the range east or west of the New Mexico principal meridian; and the third denotes the section. The fourth segment of the number, which consists of 3 digits, denotes the particular 10 acre tract in which the well is situated. For this purpose, the section is divided into 4 quarters, numbered 1, 2, 3, and 4, in the normal reading order, for the northwest, northeast, southwest, and southeast quarters, respectively. The first digit of the fourth segment gives the quarter section, which is a tract of 160 acres. Similarly, the quarter section is divided into four 40-acre tracts numbered in the same manner, and the second digit denotes the 40-acre tract. Finally, the 40-acre tract is divided into four 10-acre tracts, and the third digit denotes the 10-acre tract. Thus well 29.27.24.342, in Union County is located in the NE/4 SE/4 SW/4 section 24, T29N, R27E. If a well cannot be located accurately within a 10-acre tract, a zero is used for the third digit, and if it cannot be located accurately within a 40-acre tract, zeros are used for both the second and third digits. If the well cannot be located more closely than the sections, the fourth segment of the well number is omitted.

In U.S. Geological Survey Water Supply Paper 911 and earlier reports, the digits corresponding to unknown 10-acre tracts and 40-acre tracts were simply omitted, but this practice caused some confusion in cataloging the wells.



In some land subdivisions where a section is larger or smaller than a square mile, part of the section may be subdivided into lots of as many as 40 acres. For a well located in a lot, the fourth segment of a well number consists simply of an L followed by the number of the lot.

The above figure shows the method of numbering the tracts.

3. Geology and Water Bearing Characteristics

Early studies of geology and ground water resources of Union & Colfax counties were made by Lee (1922), who noted the presence of springs around the high mesas near Raton and remarked about the sulfate water from the Pierre Shale. In this work as well as in Lee's earlier work with Knowlton (1917), the object of concern was the coal and associated formations of the coal-producing area of the county. The water resources of the eastern part of Colfax county were studied by Griggs (1945). A study of ground water occurrence in Union county was made by Cooper & Davis (1967). Collins (1949) reported on the volcanic rocks of northeastern New Mexico. Baldwin & Muehlberger (1959) studied the geology of Union county. A reconnaissance oil and gas map of Colfax county was prepared by Wood, Northrop & Griggs (1946). All the above work was used in preparing the geologic map of the area (Figure 3), with modifications by the writer.

3.1 Sedimentary rocks

Cretaceous System

Dakota Sandstone

The Dakota Sandstone is fine to medium grained quartzitic sandstone that is frequently cross bedded. Outcrops of Dakota sandstone are usually buff to reddish brown, in color, but unweathered samples are usually white to buff to light gray. Bedding is frequently up to several feet thick. The degree of cementation varies; some beds are impervious, dense quartzite, and nearly everywhere the formation has at least a moderate amount of cementing material; only a few beds are uncemented and friable. At Capulin the top of the Dakota Sandstone is about 300 to 400 feet below the land surface and ranges from 150 to 200 feet thick. Four miles east of Capulin the Dakota crops out over a vast expanse of surface area.

The Dakota aquifer receives recharge at the outcrops in both the eastern and western part of Colfax county. Griggs (1945) reported that the greater part of the recharge is taken in at the rather flat-lying outcrops north of Farley (location in Figure 1) and south of Laughlin peak. Colfax county, and perhaps almost as much is taken in at the outcrops near Ocate in northwestern Mora county. The transmissivity of the Dakota is low because of its tight cementation. Griggs (1945) also reported that a drilled well near Springer was bailed at a rate of 40 gpm. The water level declined about 40 feet during the test, which indicated a specific capacity for the well of 1 gpm./ft. This is about equal to the specific capacity found elsewhere in wells in the Dakota Sandstone.

The qualities of the water in the Dakota differs greatly from place to place. The analyses by Griggs (1945) show the water to be high in sodium chloride, sodium bicarbonate and fluoride. The cause of the poor quality of the water is probably related to the Quaternary igneous activity. Carbondioxide is one of the most common volcanic gases, and it is usually present in relatively large amounts, either free or in chemical combination, in the waters of most hot springs. Sodium bicarbonate, sodium chloride, borate, and fluoride are also common constituents of some water which almost certainly owe their character to admixtures from igneous emanations.

Graneros Shale

The Graneros Shale lies conformably upon the Dakota Sandstone. It crops out in the southern part of Colfax county. The formation consists predominantly of dark-grey to black fissile shale. Thin beds of limestone are scattered throughout the shale none of which are more than 6 to 7 inches thick. The average thickness of the Graneros is approximately 160 feet.

This fine-grained fissile shale is nearly impermeable, although a few wells produce small quantities of water from the Graneros. These wells probably obtain most of their water from thin silty laminae which have been noted within the fissile shale. One of the wells on Jaritas ranch was pumped and the indicated specific capacity was about 0.01 gpm./ft.

The quality of the water in the Graneros is poor, and the water is suitable for stock only. The water of the few wells has odor of hydrogen sulfide. The chemical analysis of the water from the Graneros also showed a high concentration of sodium bicarbonate.

Greenhorn Limestone

The formation consists of thin limestone beds separated by thin beds of shale. The limestone beds range in color from grey to black, but almost all of them weather to a light color. Essentially all of them are quite argillaceous and all are finely crystalline. In contrast to the limestone beds of the Fort Hays Limestone, the Greenhorn Limestone beds are all less than 1 foot thick. On weathering, the outer surface of the limestone beds bleaches to light grey, and foraminifera can be seen. The thickness of the formation is close to 35 feet.

Little is known of the permeability of the Greenhorn Limestone. It is doubtful that it has a specific capacity greater than 0.5 gpm./ft. The permeability of limestone is commonly erratic because it depends on connected fractures and solution channels. The Greenhorn is highly fractured at its outcrop but it shows no evidence of solution channels.

Carlile Shale

The upper part of the formation is commonly held in steep slopes by the overlying Fort Hays Limestone. The lower 100 feet of the formation is not well exposed because gentle soil-covered slopes have developed on it. The Carlile is a predominantly dark-grey to black shale that contains a few thin interbedded layers of dark grey limestone. A few thin sandstone beds occur in the upper portion of the formation and the intervening shale contains a considerable amount of silt. In this area the Carlile Shale is probably about 220 feet thick.

The Carlile is impermeable except for the silty and limey portion immediately below the Fort Hays Limestone. This part is sufficiently permeable that under favorable conditions it can supply wells of small capacity. Two wells (Sec. 12 and 14, T28N, R26E) north west of Cunico obtain their water from the upper permeable part of the Carlile. Although this water had an odor of hydrogen sulfide, it was otherwise of fair quality.

Fort Hays Limestone

The Fort Hays Limestone immediately overlies the Carlile Shale. It is from 15 to 20 feet thick, and consists of 7 or 8 limestone beds that are separated from each other by beds of calcareous shale. Nearly all the limestone beds are more than a foot thick, and fresh rock is light grey or rarely dark grey and finely crystalline. These beds weather to a creamy color, and there is a tendency for a caliche-like film to form on the weathered surface.

The Fort Hays is not a highly permeable rock, but the permeability is sufficient to supply wells of small capacity. The permeability of the Fort Hays depends upon interconnected fractures and bedding plane openings. Three analyses were made of water from the Fort Hays. All the analyses indicated the water to be good, although rather high in hardness.

Pierre Shale

The Pierre Shale is poorly exposed in this area. Over most of its extent is covered by pediment gravel, loess-like deposits, or soil, but it is known to consist predominantly of noncalcareous black fissile shale. This shale contains argillaceous limestone concretions that usually weather to yellowish grey. These concretions are noticeable because of their weathering to a rustly-orange color. There is also a sandy zone about 50 feet thick at the top of the

Pierre. The black fissile, slightly silky-lustered shale constitutes over 90 percent of the formation. This compact shale weathers to yellowish brown. The thickness of the Pierre Shale is about 1,650 feet. Because of the impermeable character of the shale no water can be yielded to wells, in spite of the fact that the shale beds are saturated with water to within a relatively short distance of the land surface. The water in the Pierre Shale is of poor quality and not suitable for human consumption. Some of the water has the odor of hydrogen sulfide, and all of it has sufficient sulfate to be tasted.

Trinidad Sandstone

The Trinidad Sandstone conformably overlies and interfingers with the Pierre Shale. It crops out in the steep slopes of Bartlett, and Johnson Mesas, and in the escarpment of Raton Mesa from Raton to the south. A few miles east of Raton the formation pinches out beneath the lava cap of Johnson mesa. The formation is approximately 100 feet thick. It is massive to thin-bedded light grey to light buff, somewhat feldspathic sandstone. No wells have been reported from the Trinidad Sandstone.

Quaternary System

Landslides

Considerable portions of this area are covered by landslide and talus debris. Slopes beneath most of the lava-capped mesas are partially or wholly obscured by landslides.

The frequency and occurrence of landslides depends upon the erodibility and plasticity of the underlying rocks. They occur most commonly where Cretaceous Shale is overlain by lava flows and rarely in areas underlain by igneous rocks or the Dakota Sandstone. These landslide materials, because of their broken condition, absorb rain-fall and particularly snow melt easily and transmit the water downward to the bedrock surface. Large landslide blocks make wide benches on the hillsides, as on the north side of Johnson mesa. At certain location, water moves from the bedrock into these surficial material forming springs, some of which are permanent but many of them are distinctly seasonal.

Alluvium

All the wells of notable capacity in this area obtain their water from the alluvium. It consists of silty clay, sand and fine gravel that has been deposited in a sheet-like form. The alluvium mantles most of the area in the vicinity of Capulin and underlies the bottoms of the ephemeral lakes. Thickness of alluvium ranges from a thin edge to about 100 feet. The alluvium overlies shales and sandstone of cretaceous age except for isolated areas where it lies directly on basaltic lavas or cinder that erupted from volcanoes on the west flank of the Sierra Grande arch during late Pliocene or early Quaternary time.

The water quality in the Alluvium is good, and there has been some consideration of its use for irrigation. The well in SW/4 sec. 13, T29N, R27E, was pumped to determine the permeability of the water bearing alluvium. The well was pumped at a rate of 6 gpm. for

2 hours, and the total drawdown was approximately 1 foot. The indicated specific capacity of 6 gpm/ft. shows that the alluvium in the vicinity of this well is not highly permeable, and it is doubtful that it is sufficiently permeable elsewhere to give wells of high specific capacity.

3.2 Igneous Rocks

Tertiary System

Dikes & Sills

The sill-complex is located mainly south of Laughlin peak and north of the Chico post office, where many sills have been emplaced in the cretaceous shales. Most of the sills are in the Graneros Shale, but some are in the Carlile Shale, and they extend up to the Fort Hays limestone. The grain boundaries of the minerals composing these monzonitic porphyries are tightly interlocked, and the small amount of water that moves through the sills follows poorly developed fractures. Hence the sills are not important as water bearing rocks.

Basaltic dikes contain no available water. However under certain conditions dikes may affect ground water movement. The steeply dipping tabular-shaped bodies may impound ground water behind them.

Quaternary System

Basalt & Cinder

The rocks consist of basaltic lava flows, commonly called "malpais," and lenses of cinders, locally forming thin layers with a limited extent. They are part of a larger volcanic province, which extends from Union county westward to Colfax county and northward into Colorado. The volcanoes were active intermittenly from Pliocene to Recent time. It is believed that activity has not finally ceased (Baldwin & Muehlberger, 1959).

The ground water movement in basalt takes place through the connected openings. Vertical movement follows the joints or fractures. The horizontal movement follows both the fractures and the interflow zones.

It is possible to develop wells in basalt, but in general the water bearing zone is too thin to support wells. Springs issue from basalts both from interflow zones and from near the base of flows. Two of these springs are on the east side of Bartlett mesa. Both issue from fractures that tap an interflow zone lying a few feet above. The flow of the larger spring is about 25 gpm. and of the smaller one is 8 gpm. The spring at Bennet's place flows from the base of a basalt flow at a rate of 250 gpm.

Ground water movement in cinder bed takes place through void spaces in the same manner as movement through coarse grained sediment. The extent of the cinder bed in the vicinity of Capulin village appears to be about 1.5 miles in the east-west direction and 0.75 miles in north south direction (see Figure 6). The volcanic material is about 25 feet thick and is covered by alluvium and soil ranging from a few feet to 40 feet in thickness. The cinders are

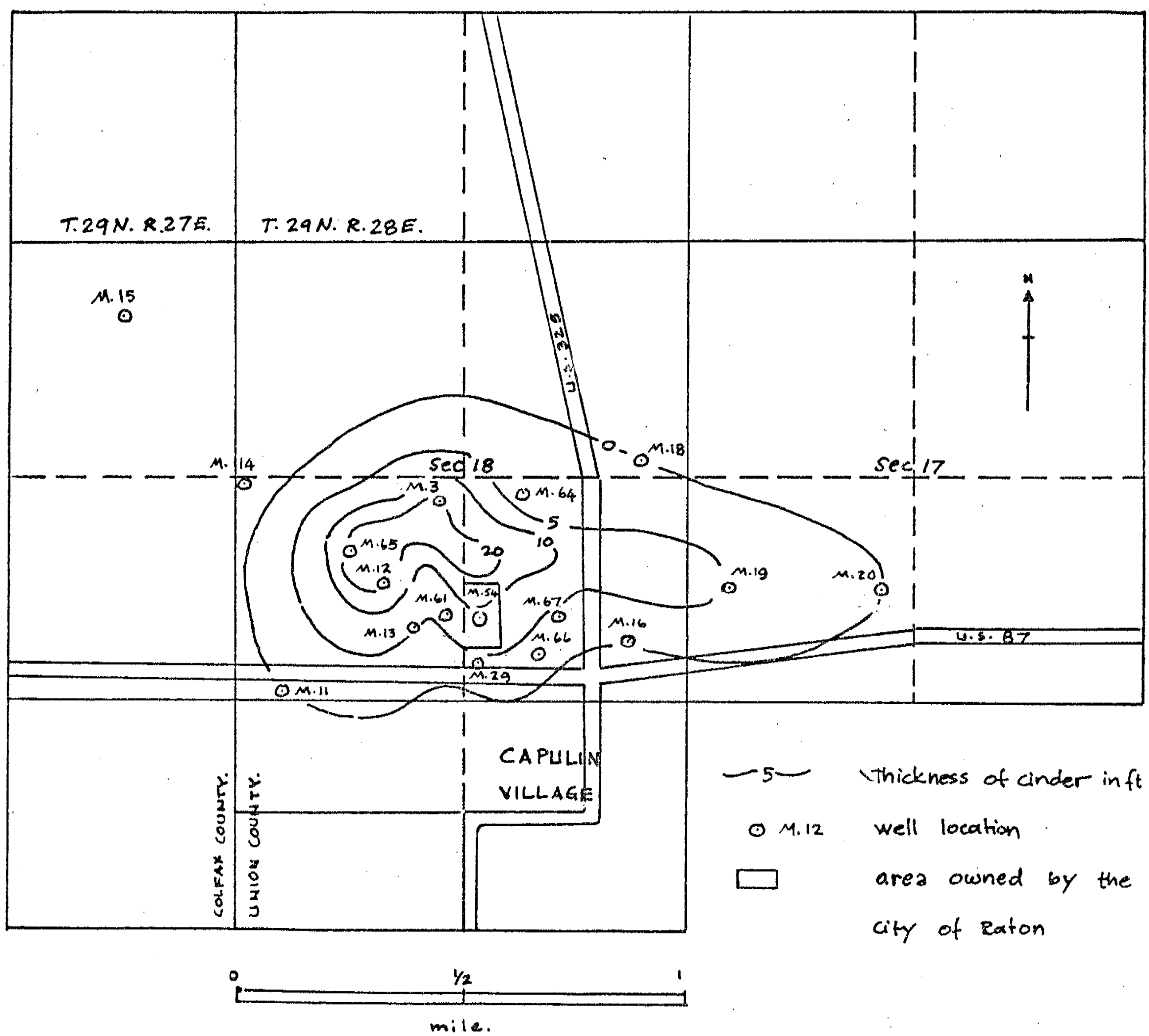


Figure 6. Isopach map of cinder at Capulin. (After Minton, 1966)

not exposed in the immediate area of Capulin village.

The cinders are very permeable. Recharge to the cinder bed is believed to be contributed from alluvium, but probably a very important part of recharge comes from the slope of Capulin mountain. Much of this water probably moves through the permeable material of the volcanic cone and finds its way to the cinders at the base.

Minton (1966) developed a pumping program for a well drilled in cinder in Capulin village. He reported a transmissivity of 528,666 gpd./ft., or 80,214 ft^2/day. (see Table 4).

4. Hydrogeologic Conditions in Capulin Basin.

The Capulin area is a poorly drained topographic basin situated on the extreme eastern flank of the Raton basin. The surficial geology in the vicinity of Capulin consists of outcrops of sandstone and shale of late Cretaceous age overlain by alluvium and extrusive basalt of Quaternary age. The Dakota Sandstone, alluvium, basalt and cinder are the potential aquifers in the Capulin area.

In T29N, R27E, nearly all the wells investigated by Griggs (1945) obtain water from Alluvium at depth up to 70 feet. A well in SE/4 section 36 is 140 feet deep and obtains water from Dakota Sandstone, as do many wells in T28N, R27E, which would yield water in a sufficient amount to irrigate more than a few acres.

In the southern part of T28N, R27E, a saturated lens of Alluvium overlies the Graneros Shale but no wells with high yields are known to be developed in Alluvium. In the remainder of the area, in T28 & 29N, R27E, most of the wells are finished in the Dakota Sandstone and Greenhorn Limestone, but none of these wells are known to have high yields.

In the vicinity of Capulin in T29N, R28E, the Alluvium narrows to less than 0.5 miles in width and is underlain by a bed of volcanic cinders and scoria at least 25 feet thick. This volcanic material is similar to the cinders and scoria that form many of the Recent volcanic cones of the region. The cinders are covered by alluvium, which is as much as 40 feet thick.

The wells producing from the cinders north of Capulin are capable of very high yields. Herrick (1951) reported, from the pumping test of the well M.12 (see the location in Table 2 and Figure 2), a drawdown of 1.3 feet at the end of 8 hours of pumping at the rate of 1,280 gpm. The specific capacity is approximately 1,000 gpm./ft. During the same period, the drawdown of the well M.13 (see Table 2), about 200 yards to the south, was 0.07 foot. There was no measurable effect on the water level in the well M.19 (see Table 2), which is about 0.9 mile east of the well M.12.

Herrick also believed that the lower capacities of the well M.13, reported to yield 900 gpm., and of the well M.19, reported to yield 700 gpm., are due to shallow depth of the wells. On the basis of the performance of the well M.12, the wells constructed at these sites should be capable of yielding at least 1,000 gpm.

4.1 Recharge

Recharge to the aquifer in the immediate area of Capulin comes mainly from the slopes of Capulin mountain. Recharge to the highly permeable cinder beds in the vicinity of Capulin is predominantly from the alluvium from the west and south. The presence of bentonite clays has the effect of causing surface runoff to be ponded in the lake bottoms nearby. The almost impermeable bentonite prevents a rapid recharge to the alluvium so that most of the ponded waters are lost by evaporation. Evapotranspiration is limited due to the lack of high water consuming vegetation in this area. Of the 15.82 inches average precipitation in the area, Theis (1937) estimated under very similar conditions in the southern High Plains that the annual recharge to the aquifer is of the order of 0.2 inches. On the slopes of Capulin mountain and in the limited areas around other cinder cones the recharge is quite rapid, reaching as high as 100% infiltration. This high recharge rate is evidenced by the fact that the larger part of the runoff of Bennett spring (see Table 2) probably originates on the south eastern slope of Capulin mountain. The area of high recharge is quite limited, however, in the Capulin basin.

The map of Figure 4 shows that the major area of ground water recharge occurs along the Larga mesa and in the north along the Bartlett & Johnson mesas. The water moves approximately from west & northwest to the east passing through Capulin village. The source of recharge in the high mesas is limited to the precipitation on them, the recharge is high because the precipitation is greater at higher altitudes and because the surface drainage is poor.

Another factor important to recharge is the presence of perched-water lakes on these mesas. These lakes have originated in several ways. Some are due to the damming of shallow valley-like depressions by later basalt flows. Some are due to subsidence caused by the lateral draining of lava from the base of a flow after the upper surface of the flow had hardened.

Using the 0.2 in. figure suggested by Theis and assuming that the precipitation is uniformly distributed over the entire basin of 125 sq. miles, the magnitude of the recharge due to precipitation is about 3.653 acre.ft./day or 1.2 million gallon/day.

4.2 Discharge

The points of natural discharge of the Capulin basin are from the springs at the Milton Bennett place, about 4 miles east of Capulin and about 1.5 miles north of U.S. 87. According to Minton (1966), these springs were reported as discharging 540 gpm in July 1951. In January 1957, these same springs were flowing at an estimated 250 gpm. Analysis of samples from the springs as compared to the samples from wells in the Capulin basin show less mineralization in the springs. The indication is that a greater portion of the discharge at the springs is derived from the slopes of Capulin mountain than from the Capulin basin itself. The decrease in discharge may be due to pumpage by irrigation wells that have operated above the natural discharge rate of the basin. The total amount of discharge cannot directly be estimated since there is no information on base flow contributed by ground water, the amount of evapo-transpiration and discharge through domestic and stock wells.

Discharge by underflow through the alluvium in the basin can be estimated by using the following formula (Ferris, 1962).

$$Q = 7.48\ KIbW$$

where:	Q	=	flow	(gallon/day)
	K	=	hydraulic conductivity	(ft/day)
	I	=	hydraulic gradient	(ft/ft)
	b	=	saturated thickness of aquifer	(ft)
	W	=	width of the section	(ft)

The average hydraulic conductivity obtained from analyzing pumping tests of Wells P.2, P.3 and P.6 (see Figures A.7, A.10, and A.13 in Appendix) of 12.9 ft/day. The value of the hydraulic gradient from Figure 5 is about 50 ft/mi. The thickness of alluvium is about 20 feet. The average width of the section measured in Figure 4 in a north-south direction is about 12.75 miles or 67,320 feet. From these data, the discharge by under flow through the alluvium is estimated at about 1.23 million gallons per day. However, this figure seems to be high since the section through which the ground water passes is not uniform in area.

5. Aquifer Test Analyses

5.1 Alluvium

Bliss (1957) reported that the well in Section 13 of T29N, R27E, has a transmissivity of 3,960 gpd/ft. However, he did not give the thickness of the aquifer, the radius of the well, nor the length of the screen. Therefore, this well cannot be used as a representative well in alluvium.

In summer 1977, two hydrogeologists from Water Resources Division, U.S. Geological Survey, Albuquerque, and the writer used the recovery method to determine the transmissivity of Alluvium inside the Capulin basin. The tests were done at five wells completed in alluvium (see Figure 2 and Table 2).

The recovery data and graph of drawdown-recovery curves are shown in Table 3 and Figure 5. By employing the modified non-equilibrium method formulated by Cooper & Jacob (1946). The transmissivity can be obtained from

$$\Delta s = \frac{264Q}{T}$$

where:

T = Transmissivity (gpd./ft.)

Q = Discharge through well (gpm.)

Δs = Change in recovery, in feet, per log cycle of time

The tests were performed by turning on the wind mill and measuring the discharge rate with a 3-gallon bucket. Then the wind mill was turned off and the recovery was measured as a function of time. The transmissivity was calculated from the Cooper-Jacob equation.

The transmissivity value obtained from this report are shown in Figure 5. They range from 1,105 gpd./ft. to 30,170 gpd./ft. having an average value of 11,500 gpd./ft. However, these values seem to be overestimates due to inaccuracy in performing the recovery tests. The power of wind is transformed into mechanical energy to pull the cylinder in order to lift the water in the well through the discharge pipe. Then the rate of discharge is linearly proportional to the wind velocity, which was not constant over the test period. Other errors are due to water leaking through the vertical pipe. These factors cause inconsistent field data.

In January 1978, six wells were drilled in this basin. Pumping tests were performed at three wells completed in alluvium, namely wells P.2, P.3, and P.6. The well locations are listed in Table 2. Lithology logs are given in Figures A.5, A.8, and A.11 in Appendix respectively. The data obtained from these three pumping wells were analyzed by using finite element programs of flow towards a single well. The details of the programs are discussed in the Appendix. The results from these analysis are as follows:-

Well No.	Condition	T ($ft.^2$/day)	S
P.2	confined	666.66	8×10^{-5}
P.6	confined	66.66	1×10^{-4}
P.3	unconfined	276.66	1×10^{-2}

The difference of transmissivity of well P.6 from well P.2 may be due to the interlayering of clay lenses in well P.6. In well P.3 there is an effect due to partial penetration of the screen.

5.2 Cinder

Minton (1966) developed a pumping program using well M.12 (Pachta well) as pumping well and wells M.65, M.11, and M.54 (see

Table 2) as the observation wells. The well was pumped at a rate of 920 gpm. for 61 days. The results were analyzed by using the modified non-equilibrium method for both drawdown and recovery curve. He reported the results as in Table 4.

Table 4. Transmissivity of Wells Completed in Cinder. (from Minton, 1966)

Observed well no.	Method using	T.(gpd./ft)
M.65	drawdown	243,000
	recovery	1,012,000
M.11	drawdown	307,000
	recovery	675,000
M.54	drawdown	225,000
	recovery	710,000

The average transmissivity is 528,666 gpd./ft. (T = 80,214 ft^2/day, K = 4,010 ft./day). The computed storage coefficient was 7×10^{-5}.

The results obtained by using finite element programs are very close to the results obtained by the non-equilibrium method. The hydraulic conductivity and coefficient of storage are computed to be 4,000 ft./day and 3.5×10^{-4} respectively.

6. Effects of Long Term Pumping

Aquifer characteristics normally are determined by applying the proper equations to the basic data from wells tested in the field. Once the average values for these characteristics have been established, the equation may be used to predict water levels and well yields under a set of stated conditions. These predictions are useful in designing and operating well fields. All theoretical predictions are limited by assumptions of the theoretical equations. Although ideal aquifers are rarely found in the field, practical solutions to many specific field problems are attainable. Water level declines for the alluvium and cinder aquifer were predicted under a set of condition that included an aquifer system that was assumed of infinite extents. By employing the non-equilibrium formula (Theis, 1935), the water level declines can be predicted.

The Theis non-equilibrium formula

$$s = \frac{Q}{4\pi T} \int_{u}^{\infty} \frac{e^{-u}}{u} du$$

where:

s = drawdown, in feet, at any point of observation in the vicinity of a well discharging at a constant rate.

Q = discharging well (ft^3/day)

T = transmissivity (ft^2/day)

U = $r^2S/4Tt$

r = distance, in feet, from discharging well to point of observation

S = storage coefficient

t = time after pumping started (day)

The integral expression in the formula is known as an exponential integral which is referred to as the well function of U or W(U).

Figures 7, 8, and 9 show theoretical drawdown at pumping wells P.2, P.3, and P.6 respectively. By assuming that the aquifers are of uniform thickness, homogeneous and of infinite extent. The water level declines due to pumping at various distances and various times are computed from Theis's non-equilibrium formula.

Figure 7 shows the theoretical drawdown due to continuously pumping from well P.2 at a rate of 250 gpm. The drawdown at 1,000 ft distance from the well after pumping one year, two years, five years, and ten years is 50.8, 54.5, 59.6, and 63.7 feet respectively. It seems that this well can serve as a source of ground water supply for a small community since the water level does not decline very much after long continuous pumping.

Figure 8 shows the theoretical drawdown due to continuous pumping from well P.3 at a rate of 50 gpm. It is observed that there will be no drawdown at a distance of about 30,000 ft. or 6 miles even if the well is continuously pumped for 10 years.

Figure 9 shows the theoretical drawdown due to continuous pumping from well P.6 at a rate of 15 gpm. The drawdown seems to increase faster when compared with well P.3 even though this well is pumped only at 15 gpm.

As already mentioned, the cinder in Capulin village is limited in extent. The drawdown curves of observation wells M.11, M.54, M.65 while pumping well M.12 are shown in Figures 10, 11, 12. They indicate the existence of 2 boundaries. The method introduced by Ferris et al. (1962) was used to solve for the distance from

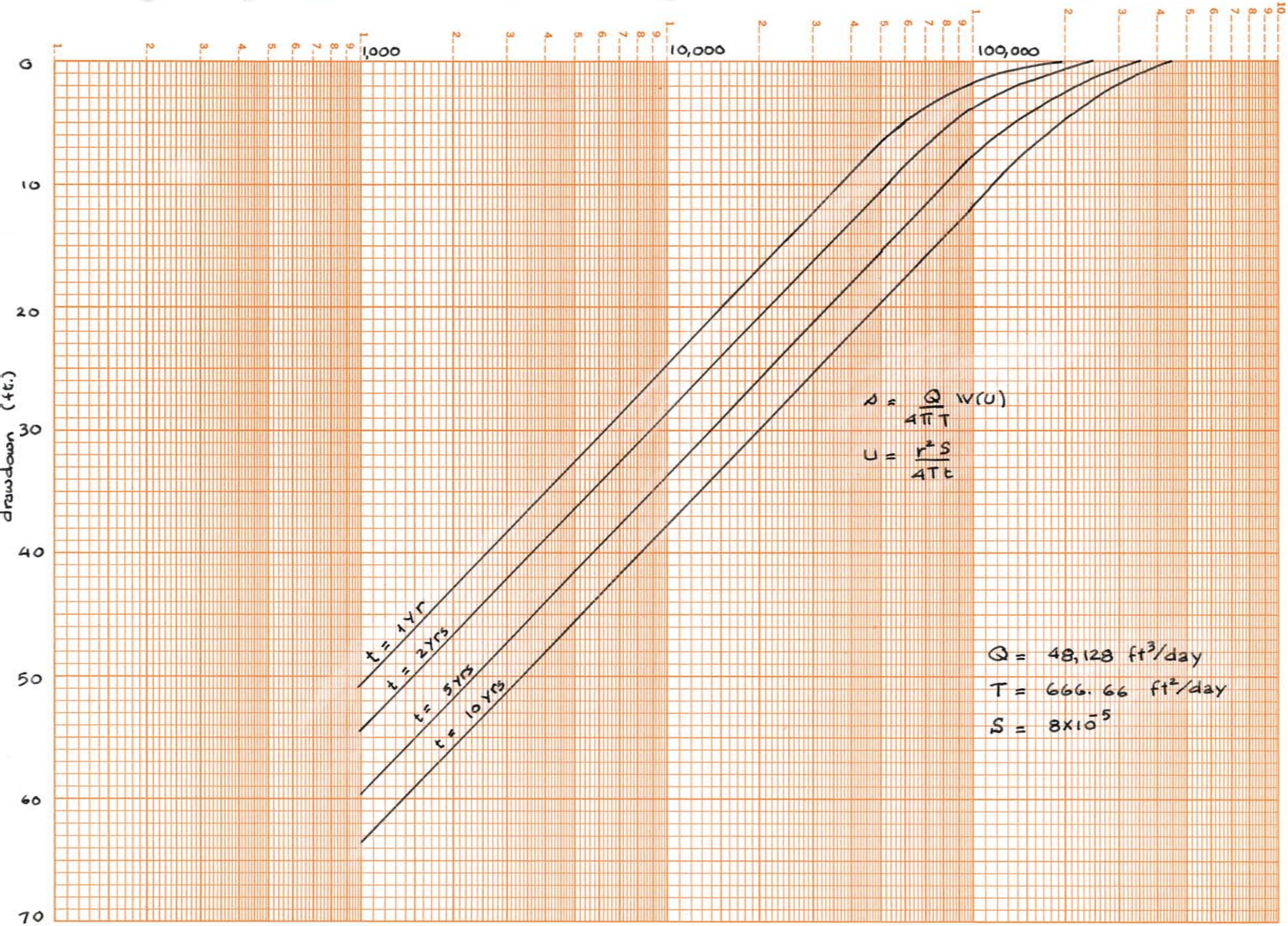


Figure 7. Theoretical drawdown due to pumping from a single well P.2 in an infinite extent

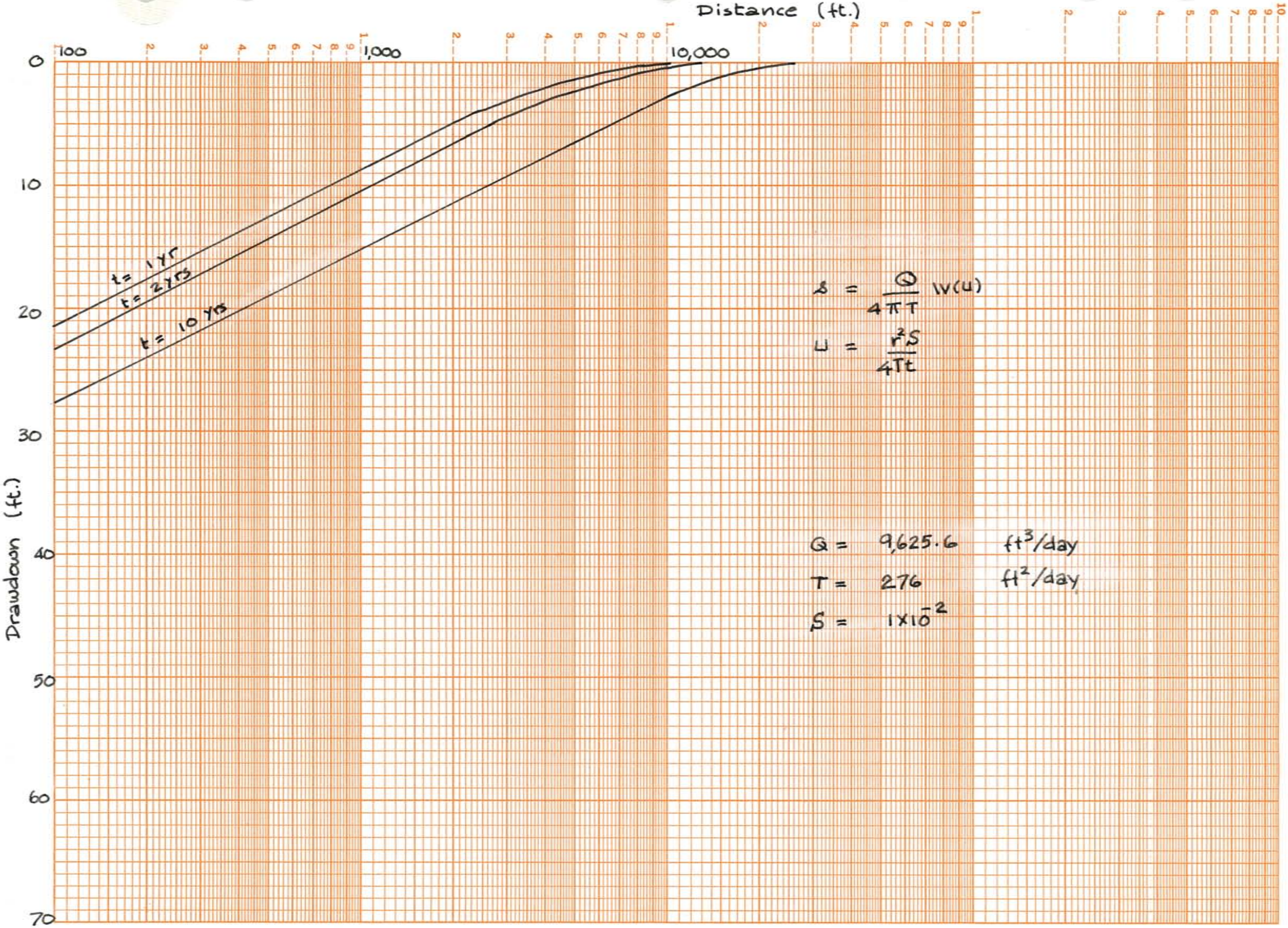


Figure 8. Theoretical drawdown due to pumping from a single well P.3 in an infinite extent.

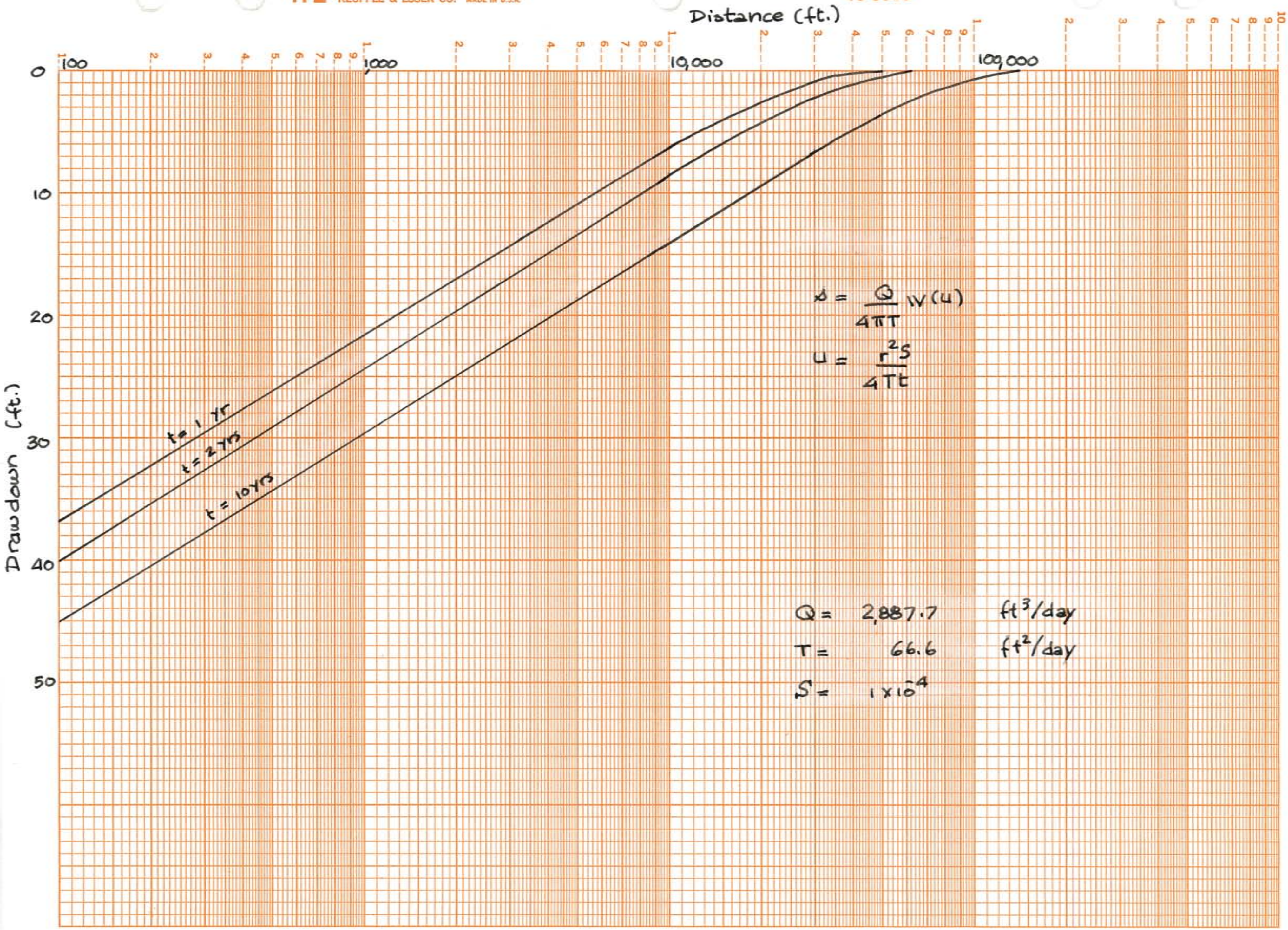


Figure 9. Theoretical drawdown due to pumping from a single Well P.6 in an infinite extent.

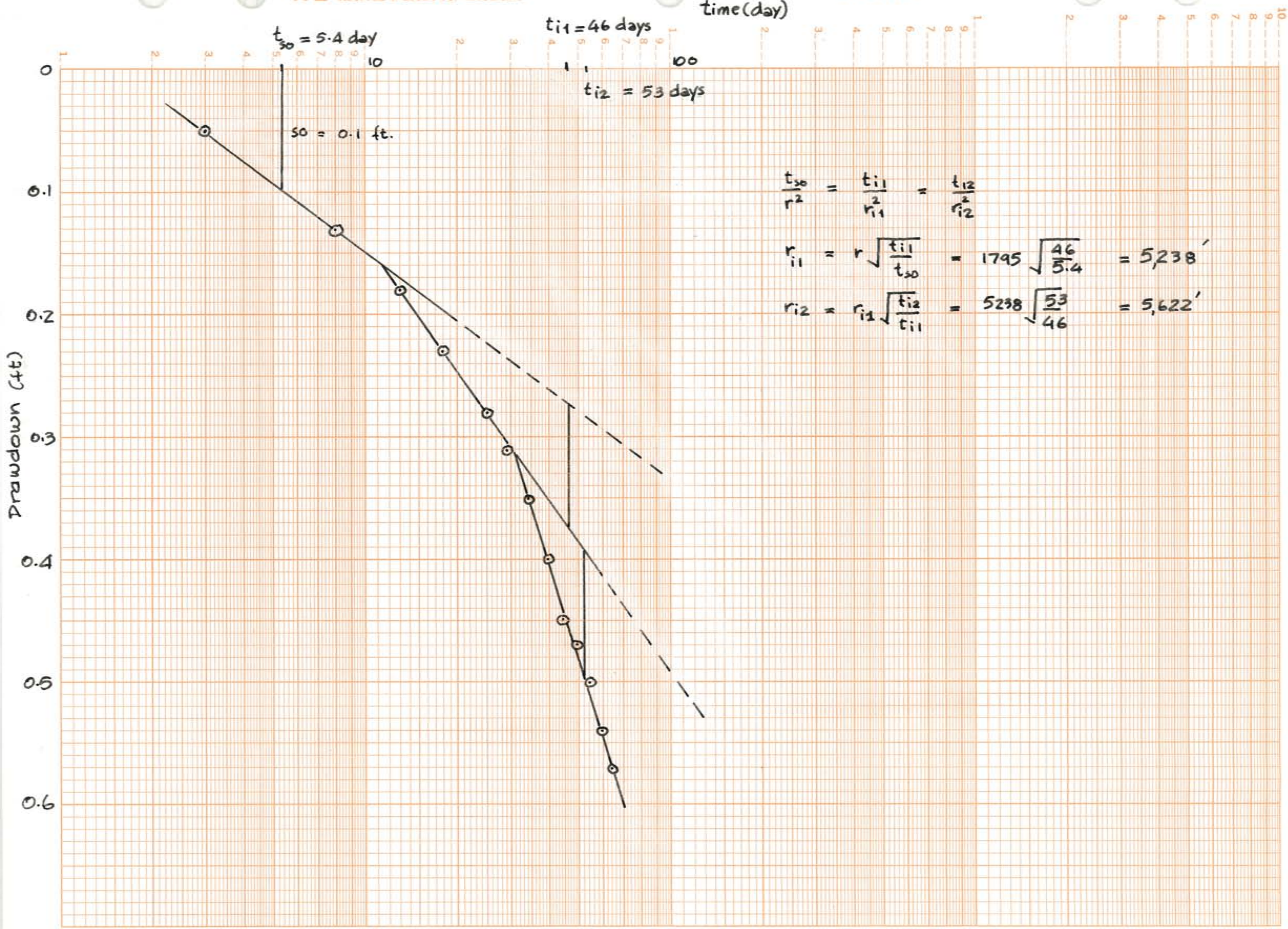


Figure 10. Effect of impermeable barrier on observed well M.11

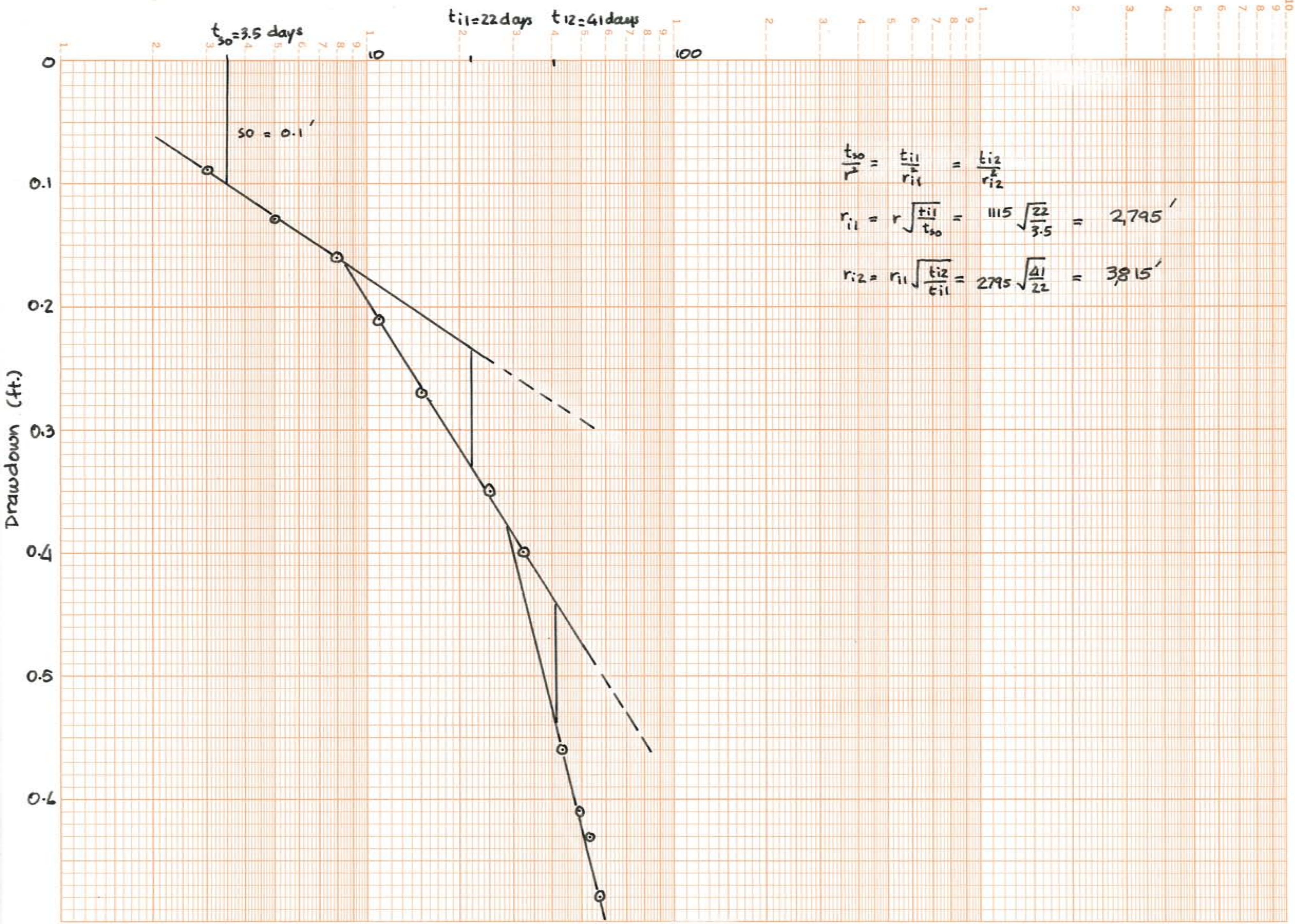


Figure 11 Effect of impermeable barrier on observed well M 54

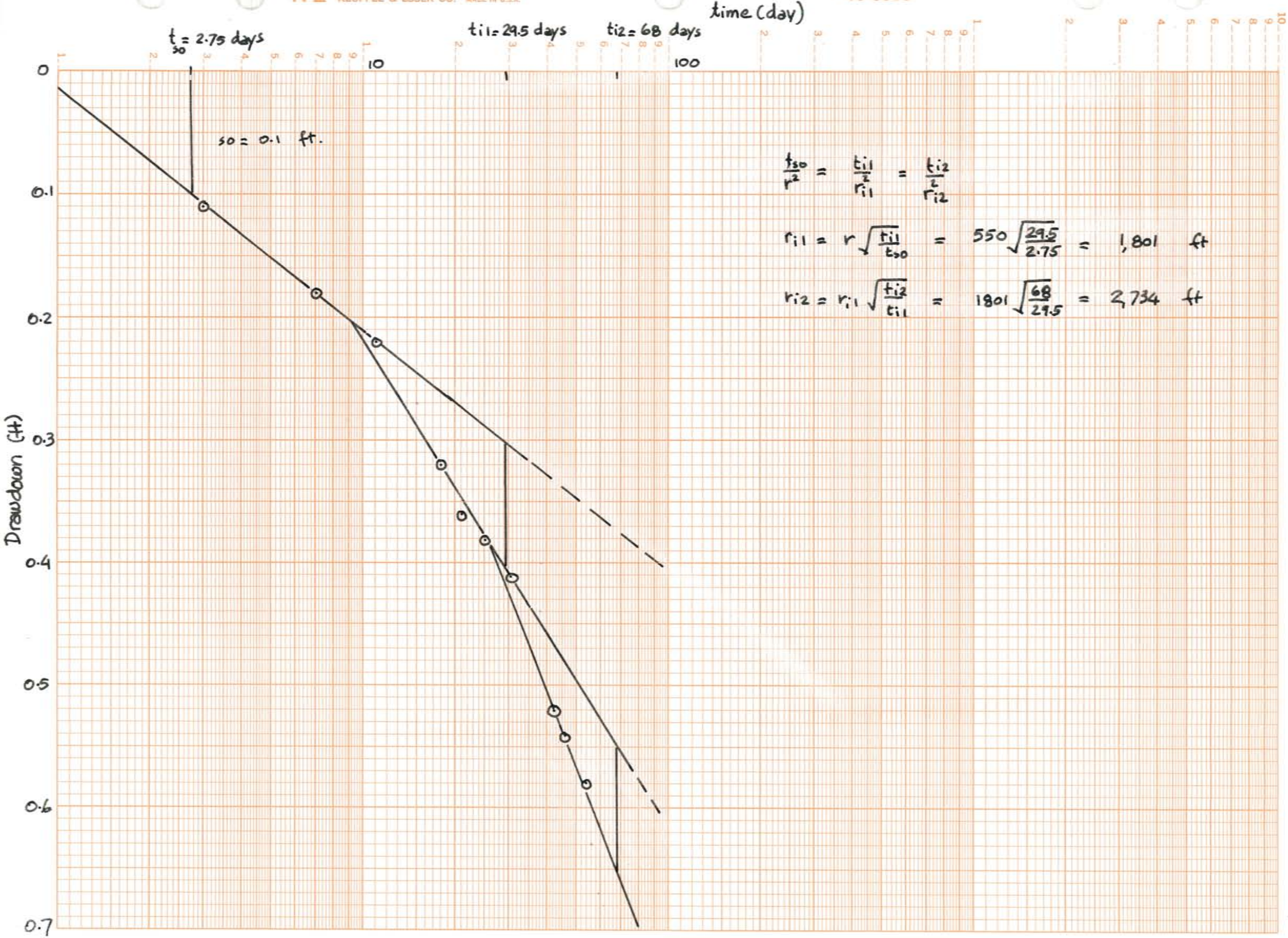


Figure 12. Effect of impermeable barrier on observed well M.65

pumping well to image well, according to the equation:

$$\frac{t_{so}}{r^2} = \frac{t_{i1}}{r_{i1}^2} = \frac{t_{i2}}{r_{i2}^2} = \text{constant}$$

where:

- t_{so} = time corresponding to a specified value of drawdown, so, caused by real well
- r = distance from real well to observation well
- r_{i1} = distance from observation well to first image well
- r_{i2} = distance from observation well to second image well
- t_{i1} = time since pumping started, at which the additional drawdown caused by the first image well is equal to the specified value of drawdown at time t_{so}
- t_{i2} = time since pumping started, at which the additional drawdown caused by the second image well is equal to the specified value of drawdown at time t_{so}

The shape of the boundary and the location of the image wells is obtained from their relation. The analysis transforms the actual well/boundary system into an equivalent system of two straight-line boundaries enclosing a 60^{o} wedge-shaped aquifer. This is shown in Figure 13. Five image wells are located on the circle which is centered at the intersection point of the boundaries and the radius of which is the distance from the intersection to pumping well M.12.

Figure 14 shows the results of the analysis. Curve 1 is the time-drawdown curve for the pumping well. It did not show a barrier effect during the pumping period (61 days).

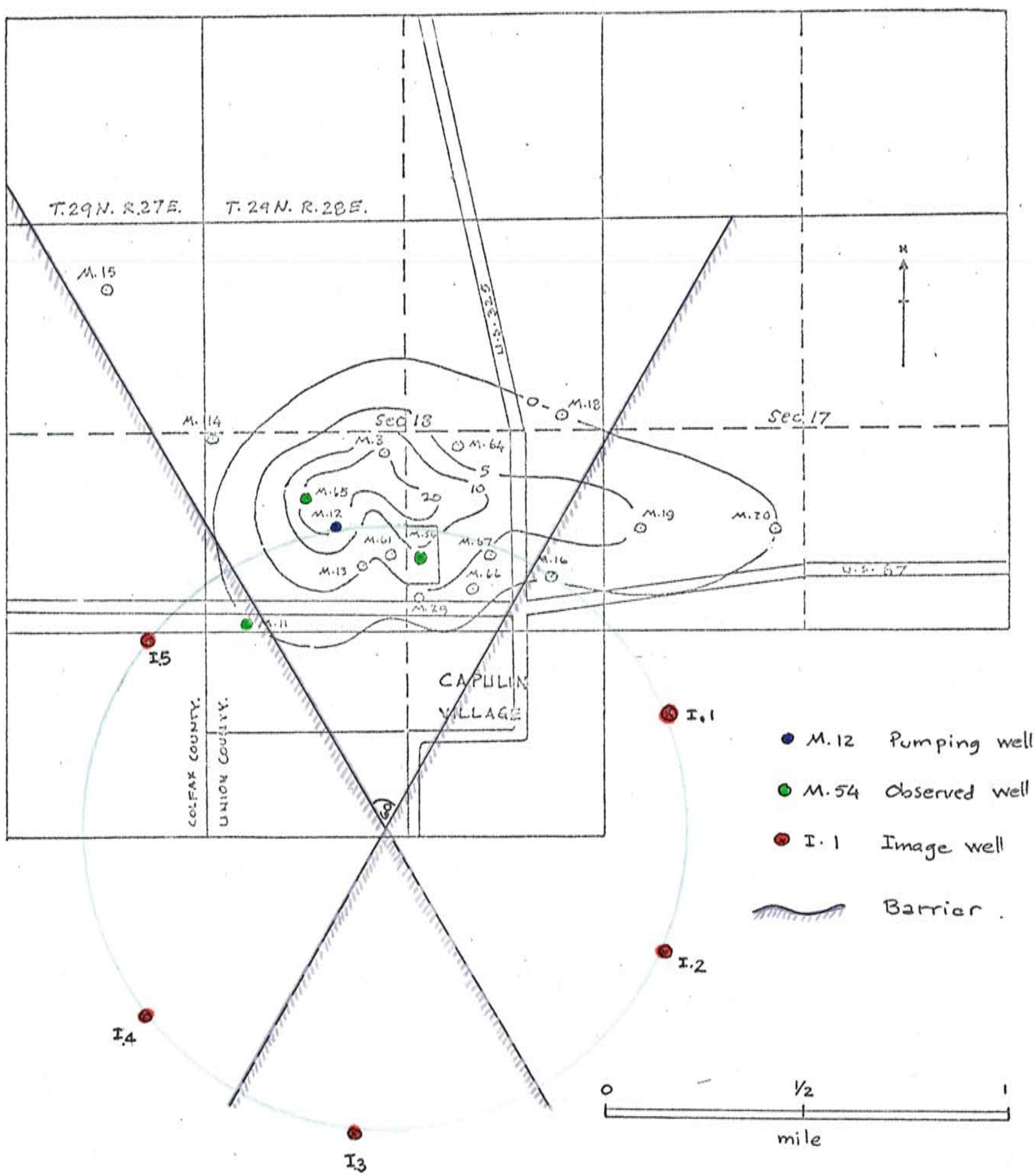


Figure 13. Map showing shape of barrier and location of image wells.

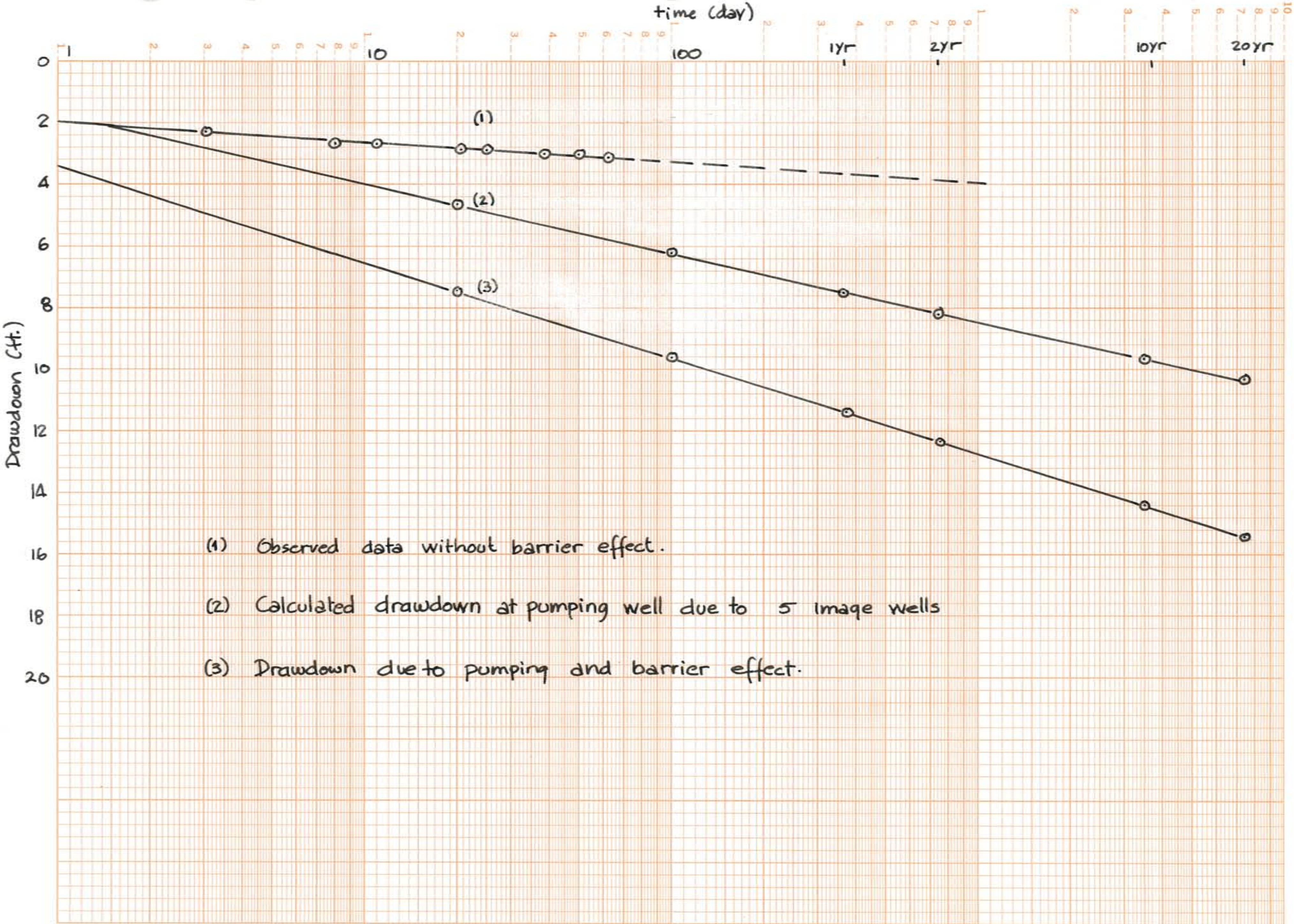


Figure 14 Drawdown at pumping well before and after corrected barrier effect.

Curve 2 is the time-drawdown curve at the pumping well caused by 5 image wells. The results were computed by using the Theis non-equilibrium formula and are shown in Table 5.

Curve 3 shows the combined effect from the pumping itself and from the image wells. It can be seen that when the well is continuously operated for a period of 10 or 20 years, the drawdowns in the well will be 14.4 and 15.4 ft respectively from the total thickness of cinder of about 20 ft.

Table 5. **Calculated** Drawdown of Pumping Well Due to Each Image Well

Image Well No.	Distance to Well M.12 (ft.)	Additional Drawdown			
		after 1 yr. (ft.)	after 2 yrs. (ft.)	after 1 yrs. (ft.)	after 20 yrs. (ft.)
I.1	5,076	1.56	1.68	1.96	2.08
I.2	7,107	1.44	1.56	1.84	1.96
I.3	7,920	1.41	1.53	1.81	1.93
I.4	6,900	1.46	1.58	1.86	1.98
I.5	2,945	1.75	1.87	2.15	2.27
		7.62	8.22	9.62	10.22

The method used: Theis non-equilibrium

Aquifer parameters: $Q = 177{,}112\ ft^3/day$

$T = 80{,}000\ ft^2/day$

$S = 3.5 \times 10^{-4}$

7. Conclusion

The pumping tests in wells P.2, P.3, and P.6 indicated that ground water from Capulin is insufficient for additional supply to the city of Raton. In Figure 2, the distance from well P.2 to P.6 is about 6 miles. Well P.3 is located about 3 miles from well P.2. From Figure 7, when well P.2, alone, is continuously pumped for 10 years, the water level in well P.6 will decline about 20 feet, and nearly 35 feet in well P.3. Consequently, if all these wells were to pumped simultaneously the effect would be many times higher than indicated above. The pumping from cinder will also cause drastic decline in water level due to the presence of impermeable boundaries.

The proposed ground water export to Raton would dry up the Capulin ground water supply. Therefore, the problem of riparian rights of the Capulin community must be considered.

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Appendix

Finite Element Calculating in Subsurface Hydrology

List of Figures

List of Tables

1. General

Problems involving flow of ground water towards pumped wells have traditionally been solved on the assumption that a linear velocity-hydraulic gradient relationship, known as Darcy's law, is valid over the entire flow region. This assumption leads to a linear field equation which has been solved analytically for several cases where the aquifer is uniform and the boundary conditions are relatively simple. A number of analytic solutions (Theis, 1935, Hantush, 1960, 1961; Boulton, 1963) and methods for evaluating aquifer properties via these solutions have been widely applied to the results of pumping tests. Recently, the rapid development of numerical methods and high speed digital computers has encouraged many workers to solve more complex cases such as those involving multi-layered aquifers, free surface and unsaturated flow. Among these workers are Javandel and Witherspoon (1965), Neuman and Witherspoon (1969, 1970, 1971), Taylor and Luthin (1969), Cooley (1971).

It has long been recognized that the linear velocity-hydraulic gradient relationship may be invalidated in the immediate vicinity of a well boundary if velocity exceed a certain limiting value (Muskat, 1937; Kristianovich, 1940; Wentworth, 1946). When derivations from Darcy's law occur, both linear and non-linear regimes must be considered in analyzing the flow over the entire region. Thus the term "two-regime flow" may be used.

Despite the increased amount of research effort which has been put into flow towards wells, there is still a lack of a theoretical basis and methods for handling the solution of two-regime flow. The need for a clearer understanding of non-Darcy flow behavior near a well and for means of predicting its effect on the well discharge-drawdown relationship has become increasingly important as a result of more intensive use of ground water and the consequent demand for improved design of extraction facilities.

2. Literature Review

2.1 Emperical Approach to Two-Regime Well Flow

A number of workers recognized that although non-Darcy flow is often restricted to a narrow zone around the well, it can affect the discharge quite considerably. On the basis of their field experience, these workers proposed empirical equations relating the drawdown in a well pumping from a confined aquifer to the discharge.

Jacob (1947) used the following equation:-

$$S_w = BQ + CQ^2 \qquad (1)$$

Where S_w is the drawdown in the well, Q is the well discharge, B and C are empirical constants.

In adopting equation (1) he assumed that flow in the aquifer obeys Darcy's law up to a certain radius, termed the effective radius of the well, and that inside this radius the flow is fully turbulent. The effective well radius was defined by Jacob as that distance, measured radially from the axis of the well, at which the theoretical drawdown based on the logarithmic distribution equals the actual drawdown just outside the screen. The term CQ^2 in equation (1) was referred to as "well loss" and represents the head loss resulting from turbulent flow inside the effective radius and the flow through the screen and inside the casing.

Rorabaugh (1953) proposed on equation slightly different from equation (1). His equation is given by:

$$S_w = BQ + CQ^n \tag{2}$$

where n is an unknown exponent. On the basis of field data from several pumping tests, he demonstrated that equation (2) predicted the total drawdown in the well more closely than Jacob's equation.

While the two empirical equations proposed by Jacob and Rorabaugh have been found to fit many field data, doubt usually exists regarding their general applicability. As pointed out by Rorabaugh himself, equation (2) and the constants B, C and n determined from analysis of data from the step-drawdown pumping test should not be applied if computations must be made for discharges greatly in excess of those used in the test.

2.2 Theoretical Analysis and Model Studies

Due to the complexity arising from the nature of the two-regime flow and from the non-linear equations required for flow in the non-linear regime, only a limited number of theoretical analyses have been made.

The earliest attempt to obtain an analytical solution to the non-linear field equation of steady state non-Darcy flow was made by Kristianovich (1940). He considered a general velocity-hydraulic gradient relation of the form

$$i = f(v) \tag{3}$$

where i is hydraulic gradient and v is velocity and described an approximate method of solution by conformal transformation.

Engelund (1953) carried out a more general theoretical investigation into steady, two-regime well flow. He employed the following equation to describe both Darcy and non-Darcy flow in the aquifer

$$\vec{\nabla} h = -F(|V|)\,\vec{V} \tag{4}$$

where h is the hydraulic gradient vector, $\vec{V}$ is the velocity vector and $F(|V|)$ is a scala function of the absolute velocity $|V|$ and the aquifer properties.

The function $F(|V|)$ is given by:

$$F(|V|) = \frac{1}{K} \qquad \text{for } |V| \leq V_{cr}$$

$$F(|V|) = a + b|V| \qquad \text{for } |V| > V_{cr}$$

where K is the coefficient of hydraulic conductivity, a and b are termed linear and non-linear coefficients of hydraulic resistance of the aquifer respectively, and V_{cr} is the critical velocity at which transition from the linear to a non-linear regime occurs.

By combining equation (3) with the continuity equation, Engelund obtained a general field equation which is valid for both Darcy and non-Darcy flow. He transformed this equation into a linearized form by introducing new variables and employing the technique of conformal transformation. However, the transformed equation still remains virtually intractable to direct analytical solution for complex boundary conditions encountered in practice. Engelund was able to obtain solutions for only simple cases of steady one-dimensional two-regime flow towards a well in a confined aquifer and two-dimensional turbulent flow at high Reynolds number.

Recognizing the difficulties encountered in the theoretical analysis of two-regime well flow, a number of workers resorted to experimental studies using either an electrical or hydraulic model of the flow system.

Grcic (1961) used a sand box model to study steady flow towards a well in an unconfined aquifer. He investigated the effect of non-Darcy flow on base pressure heads and free surface heights in the immediate vicinity of the well.

Baturic-Rubcic (1966) used an electrical analog model to study steady two-regime flow towards a fully screened well in a confined aquifer. His model was a network consisting of discrete non-linear elements with electrical properties analogous to the hydraulic properties of the aquifer material. He compared the model results with the theoretical solution given earlier by Engelund (1953) and obtained good agreement.

2.3 Finite Element Solutions

The difficulties which render the two-regime flow problems intractable to analytical solution can now be overcome by applying a numerical technique known as "the finite element method". Recently, a number of workers have employed this technique to obtain numerical solutions to several complex problems of flow through porous media.

Zienkiewicz et al (1966) were the first workers to use the finite element method to solve problems of steady state Darcy flow through porous media. Their work was later extended by Finn (1967) and Taylor and Brown (1967) to treat more complex problems involving a free surface.

Among the first workers who applied the method to problems of transient Darcy flow towards wells in confined aquifers were Parekh (1967), Javandel and Witherspoon (1968) and Neuman and Witherspoon (1969). The last two workers, Neumann and Witherspoon (1970), (1971), also developed the generalized variational principles for transient confined and unconfined flows and solved several cases of flow in multilayer confined systems and flow in an unconfined aquifer. The usefulness and validity of their finite element approach was demonstrated by comparing the computer results with known analytical solutions.

In all the work mentioned, the finite element analysis was based on the assumption that flow in the entire region of the system obeyed Darcy's law. Problems involving non-Darcy flow received little attention until very recently when the non-linear field equations suitable for numerical solutions were derived. These workers include Fenton (1968), Volker (1969), McCorquodale (1969), (1970) and Parkin (1971).

Trollope et al (1970) were the first to analyze the steady cases of non-Darcy well flow using the field equations and the finite element technique outlined by Volker (1969). Their analysis was based on the assumption that the Forchheimer non-linear velocity-hydraulic gradient relationship (Forchheimer, 1901) may be used to describe flow in the entire aquifer region. No attempt was made to investigate the practical problems of two-regime well flow where the non-Darcy flow behavior prevails only in the immediate vicinity of the well boundary.

In the work by Huyakorn (1973), the finite element method was used to obtain numerical solutions to the general problems of transient and steady state two-regime flow. To bring into focus the localized nature of non Darcy-flow, the Forchheimer relation was applied only in the near well zone when computed velocities exceed a certain critical value. For a given aquifer material the critical value may be determined by permeability tests. Alternatively, the value may be based on a critical Reynolds number in the range of 1 to 10, as it has been shown by many investigators that the transition from Darcy to non-Darcy flow generally occurs within this range (Todd, 1959).

3. Finite Element Method of Solution

3.1 General Description

The programs employ the variational approach and finite element method, written by Huyakorn (1973), to obtain numerical solutions of flow problems. The procedures consist of first replacing the initial boundary value problem, described by the field equations, initial and boundary conditions, by an equivalent variational problem which is that of finding a hydraulic head function that minimizes a certain functional. Secondly, an approximate solution is then obtained as follows:

1) The continuous region of the flow system is discretized into a finite number of closed subregions termed "finite elements". The finite elements are assumed to be interconnected at a discrete number of nodal points situated on their boundaries.

2) A piecewise function is chosen for each element. The function defines uniquely the hydraulic head distribution within the element in terms of its nodal parameters.

3) The functional over the entire flow region is assumed to be contributed by each element and the process of minimization is accomplished by evaluating the elemental contributions, adding all such contributions, differentiating the resulting functional with respect to the nodal parameters and equating the differentials to zero. This gives rise to a system of simultaneous algebraic equations which can be readily solved by direct elimination or iterative methods.

For steady flow problems, numerical solutions are obtained in terms of nodal values of hydraulic head, element velocities and total discharge into the well. For transient flow problems, solutions are obtained for each time step in terms of the nodal values of hydraulic head, dimensionless nodal drawdowns and element velocities.

3.2 Automatic Mesh Generation Schemes

A number of schemes for automatic discretization of one-dimensional and two-dimensional flow regions are to avoid the tedious preparation and checking of the mesh data. The schemes are described as follows:

1) Discretization of one-dimensional region

The region is divided into a number of line segments, each of which is further subdivided into a number of 3 node quadratic elements. The length of the first line segment and the number of elements for each segment are to be specified. The lengths of the remaining line segments are generated from

$$\Delta r_i = f \times \Delta r_{i-1} ,$$

where f is a scale factor. Nodal co-ordinates and element nodal connections can be readily established once all the lengths have been computed.

2) Discretization of two-dimensional regions

Figure A.1 shows the discretization pattern generated for a single aquifer with a fully penetrating well. The region is divided

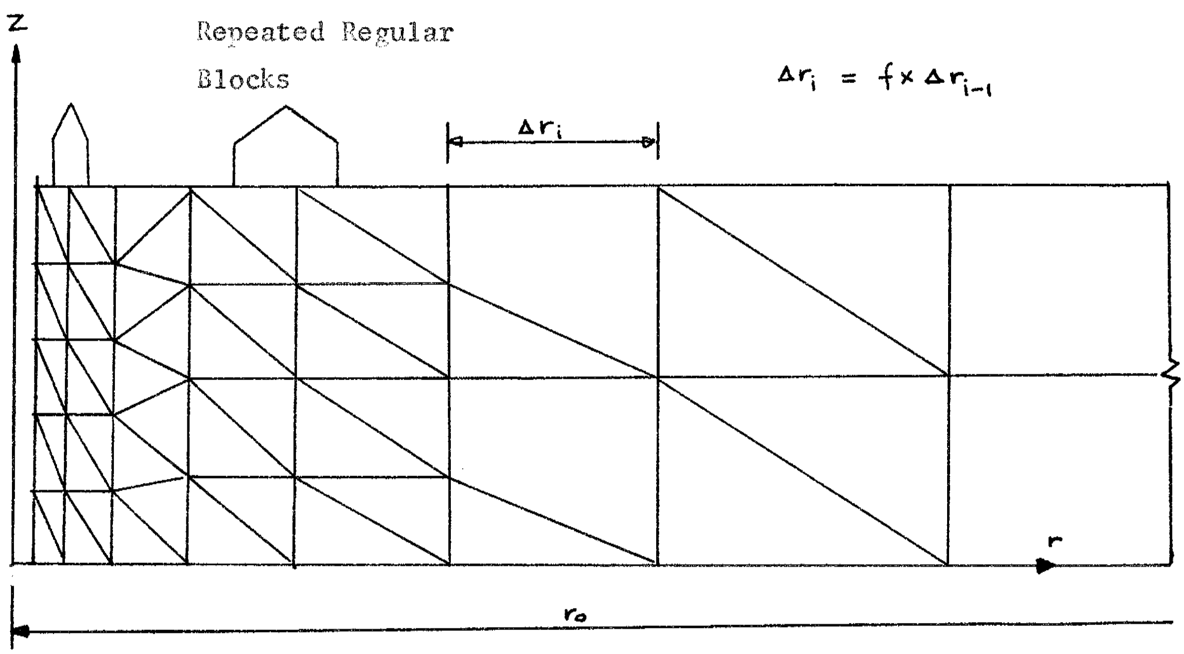


Figure A.1 Discretization pattern for a single aquifer with a fully penetrating well. (After Huyakorn, 1974) into a number of vertical blocks, each of which is further subdivided into a number of triangular elements. The horizontal width of the first block Δr_1 , the number of vertical subdivisions of this block and the number of repeated regular blocks before grading of the subdivision takes place are to be specified. The widths of the remaining blocks are generated from $\Delta r_i = \Delta r_{i-1} \times f$, and the number of vertical subdivisions in the next repeated blocks is extablished by reducing the number in the previous blocks by half or by one. Node numbering traverses vertically across the aquifer from bottom to top. For each vertical block, nodal co-ordinates and node connections of elements in the block are also established.

Figure A.2 shows the discretization pattern for a single aquifer with a partially penetrating well. The zone immediately surrounding the well is specially discretized while the rest of the flow region is discretized in the manner described above.

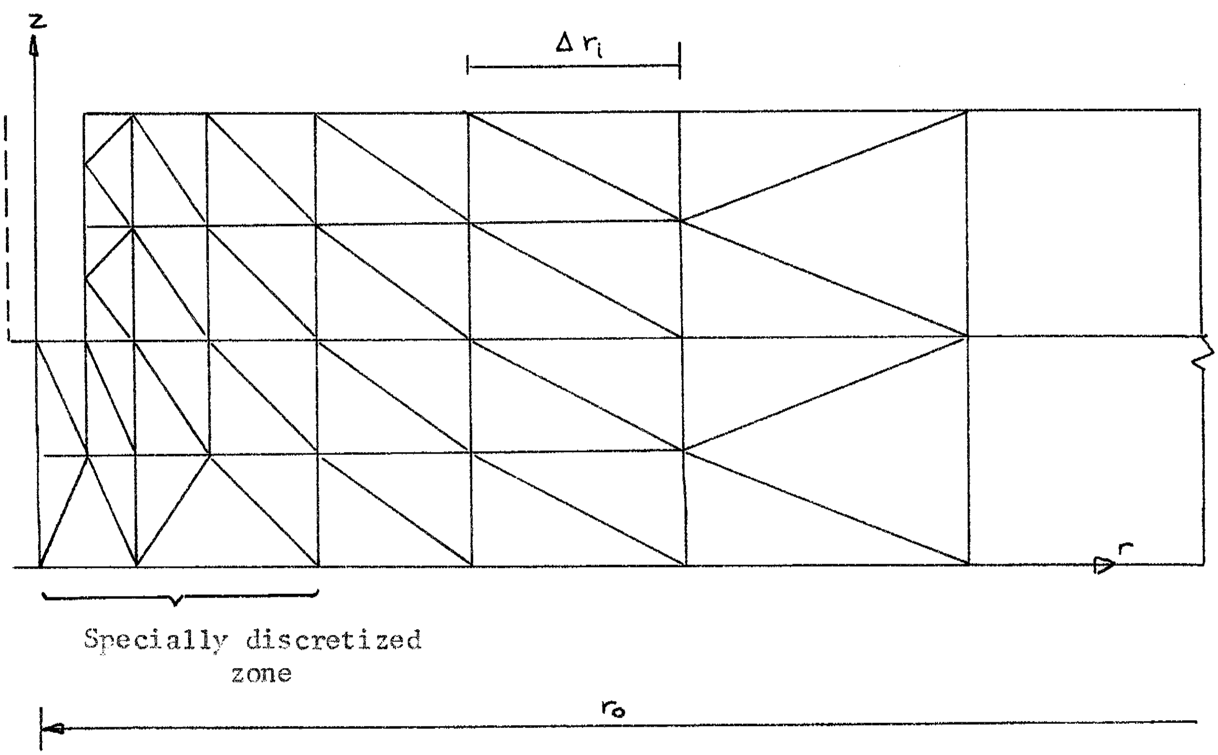


Figure A.2 Discretization pattern for a single aquifer with a partially penetrating well. (After Huyakorn, 1974)

Fig A.3 show the discretization pattern for multilayer system with a fully penetrating well. The entire region is divided into a number of vertical blocks, each of which is further split up into sub blocks which belong to separate layers. The sub block in each layer is then is subdivided into rectangular or triangular elements. The latter are used when grading is required.

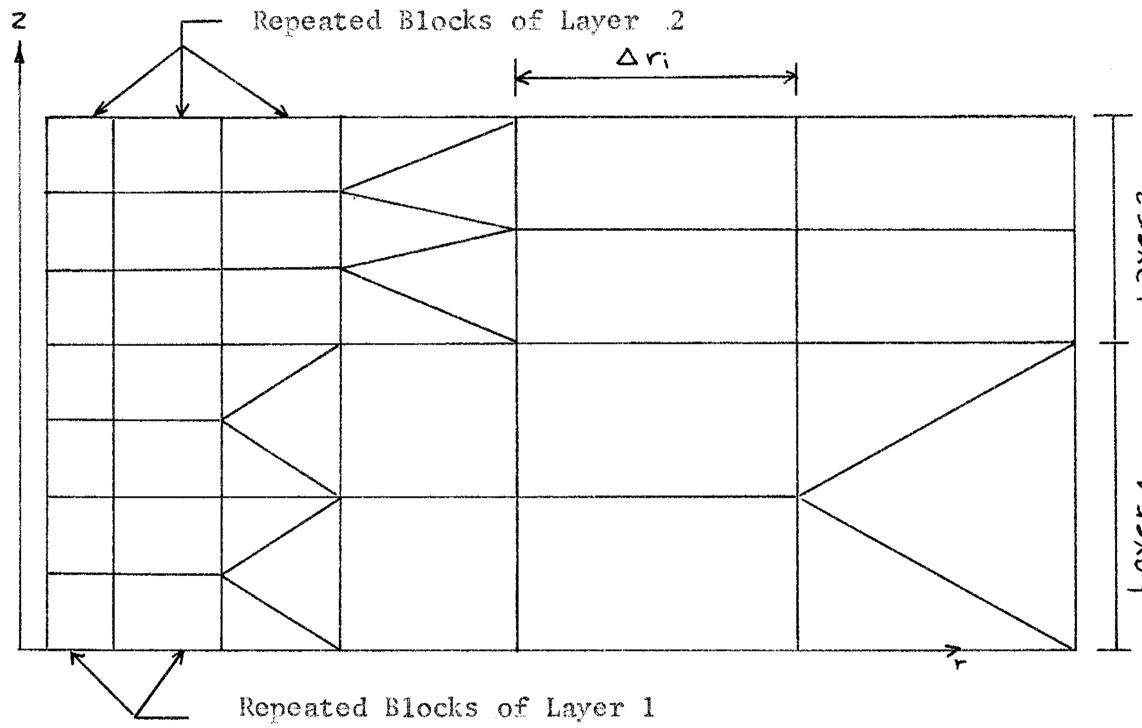
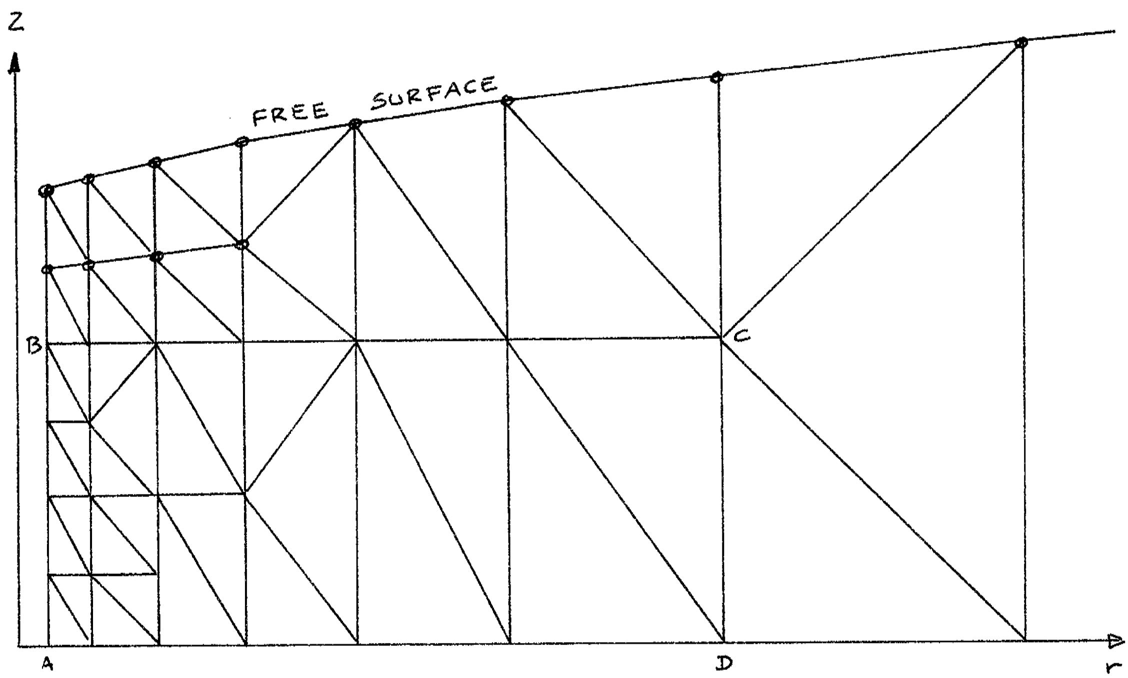


Fig. A.3 Discretization pattern for a multi-layer system with a fully penetrating well. (After Huyakorn, 1974)

Figure A.4 shows the discretization pattern for an unconfined aquifer with a fully penetrating well. To accommodate the movement of



ABCD - Subregion of Fixed Mesh

o - Node of Variable Z-Coordinate

Fig. A.4 Discretization pattern for an unconfined aquifer with a fully penetrating well. (After Huyakorn, 1974)

the free surface, the saturated flow region is divided into 2 zones, one where the mesh is fixed and another where the mesh is allowed to contract or expand. Each zone is then discretized into triangular elements in the manner described previously. The two zones are merged into one at a radial distance where the number of their vertical subdivisions are equal to 2.

4. Finite Element Programs

A list of the programs, prepared by Huyakorn, 1974, and their functions is given in table A.1. All programs are written in FORTRAN IV and can be operated on an IBM 360/50 machine with a G and H level compiler and on a CDC 6600 machine. The core storage required by each of the one-dimensional flow programs is approximately 120K. The core storage required by each of the remaining six two-dimensional flow programs is approximately 150K. In the programs, a brief definition of all input/output variables is given in order of their presence in the FORMAT statements. Wherever possible, recommended values are also included.

Table A.1 List of Programs (After Huyakorn, 1974)

Program Name	Function
STCON1	Solves steady, one-dimensional flow by employing line elements.
TRCON1	Solves transient, one-dimensional flow by employing line elements.
STCON1	Solves steady, two-dimensional flow by employing triangular elements.
TRCON3	Solves transient, two-dimensional flow by employing triangular elements.
STCOND	Solves steady, two-dimensional flow by employing rectangular and triangular elements.
TRCOND	Solves transient, two-dimensional flow by employing rectangular and triangular elements.
STFREE	Solves steady, two-dimensional, free surface flow by employing triangular elements.
TRFREE	Solves transient, two-dimensional, free surface flow by employing triangular elements.

5. Field Application of Transient Flow Solutions

The finite element analysis of transient, two-regime flow was applied to four sets of data from pumping tests in wells drilled especially for this propose in the Capulin basin by the Water Resources Division of the U.S.G.S., Albuquerque, N.M.

1. Pumping well P.2

The well is located in the central part of the Capulin drainage basin about six miles west of the village of Capulin along Highway 87 (see Figure 2). The well is completed in alluvium having a total depth of 190 feet.

The upper 155 ft. of the driller's log (Figure A.5) are composed of clay and clayey sand. The productive zone extends from 155 to 187 ft. The formation consists of sand and gravel. A 12" casing was installed with perforations from 155 to 175 feet. The water level was at 18.6 ft.

Pumping was started at 11.25 a.m. on January 16, 1978 and was continued for a period of 110 minutes at an approximate rate of 250 gpm. At the same time, the water levels in the production well were measured by steel tape. Based on the lithology and construction of the well, the flow was simulated by finite elements as shown in Figure A.6. The well is treated as a confined well. Program TRCOND midified for a confined case was employed and the effect of partial screening from 175 ft. down to 185 ft. was taken into account. The results obtained from this simulation are shown in Figure A.7.

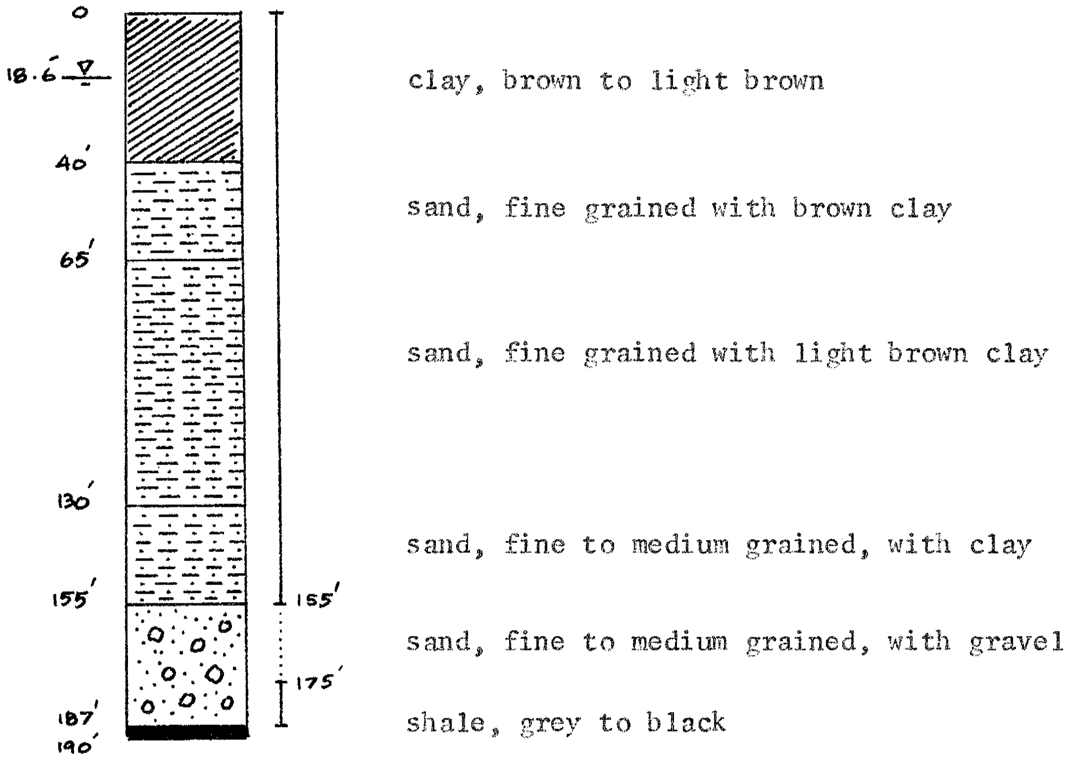


Figure A.5. Driller's log of well P.2

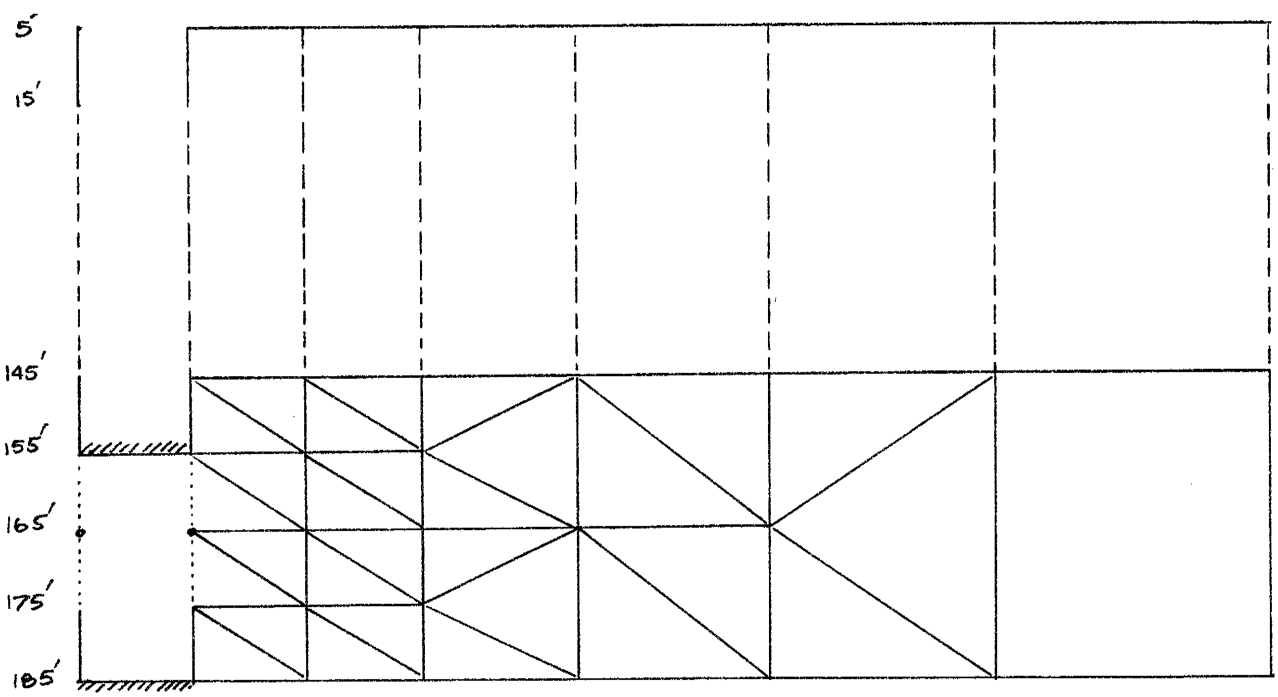


Figure A.6. Model of pumping well P.2

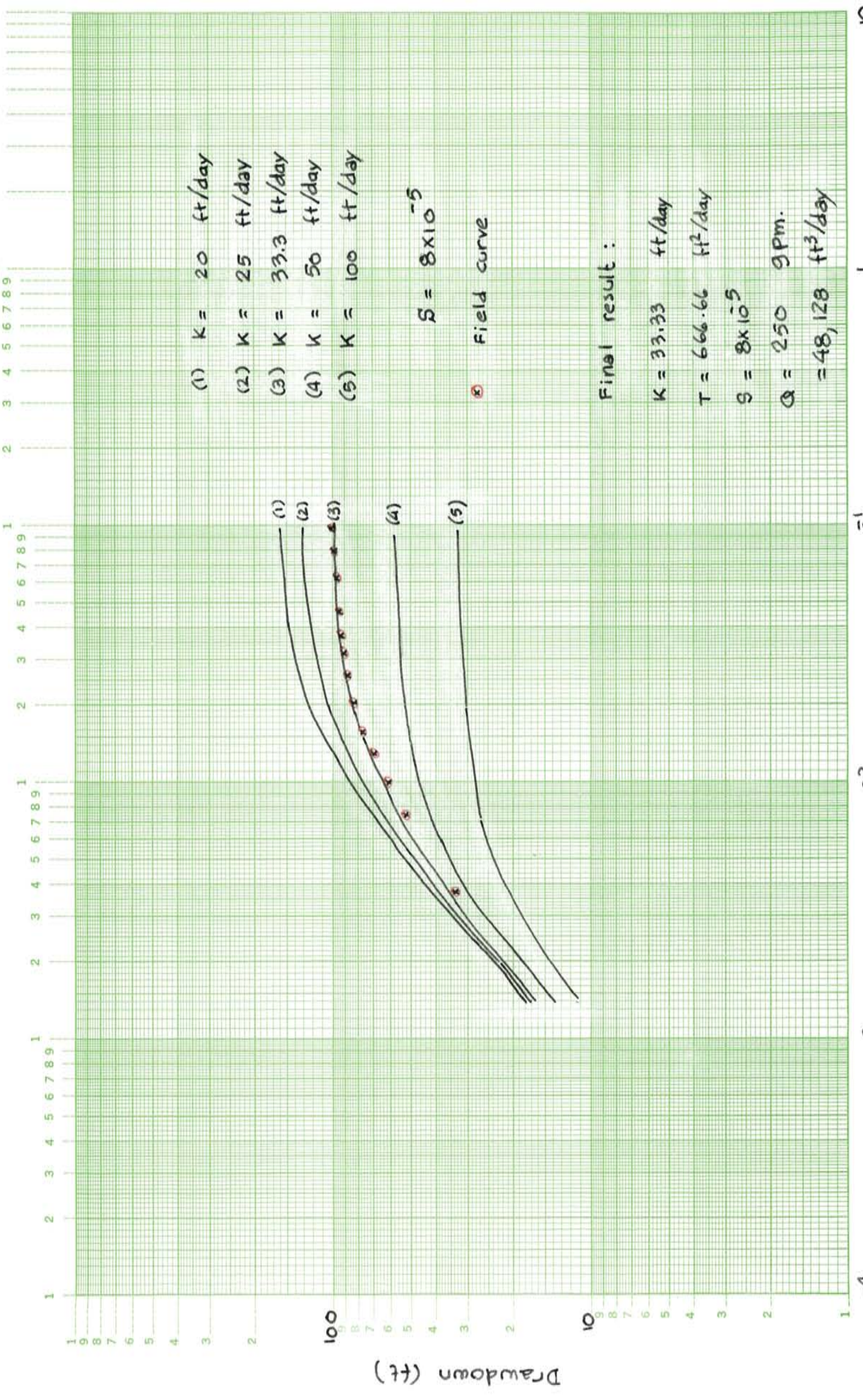


Figure A.7 Computed curve and field curve of pumping well P.2

The results for well P.2 are as follows:-

$K = 33.33$ ft./day

$T = 666.66$ ft^2/day

$S = 8 \times 10^{-5}$

$Q = 250$ gpm. or 48,128 ft^3/day

This set of data is taken to calculate the effect of draw-down due to long term pumping.

2. Pumping well P.3

This well is located 3 miles west of Capulin village, very close to Capulin lake. The well is also completed in alluvium having a total depth of 195 feet. The uppermost part of the driller's log shows 160 ft. of sand (see Figure A.8). Between 160 ft. and 170 ft. the formation changes to clay and shale. The water level was at 30 ft. A 12" casing was installed to 165 ft. with screening at 2 intervals, 105 to 125 ft. depth, and 135 to 155 ft. depth.

Pumping was started at 11.25 a.m. on January 23, 1978 and was continued for a period of 455 minutes at an approximate rate of 50 gpm. At the same time, the water levels in the pumping well were measured by steel tape.

The finite element model is shown in Figure A.9. It reflects the partial screening effect and unconfined condition. The family of curves created by computer program TRCOND is shown in Figure A.10. After plotting the field curve on to the set of these curves, the hydraulic parameters of the aquifer were obtained as follows:-

$K = 2.12$ ft./day
$T = 276$ ft^2/day
$S = 1 \times 10^{-2}$
$Q = 50$ gpm. or 9625 ft^3/day

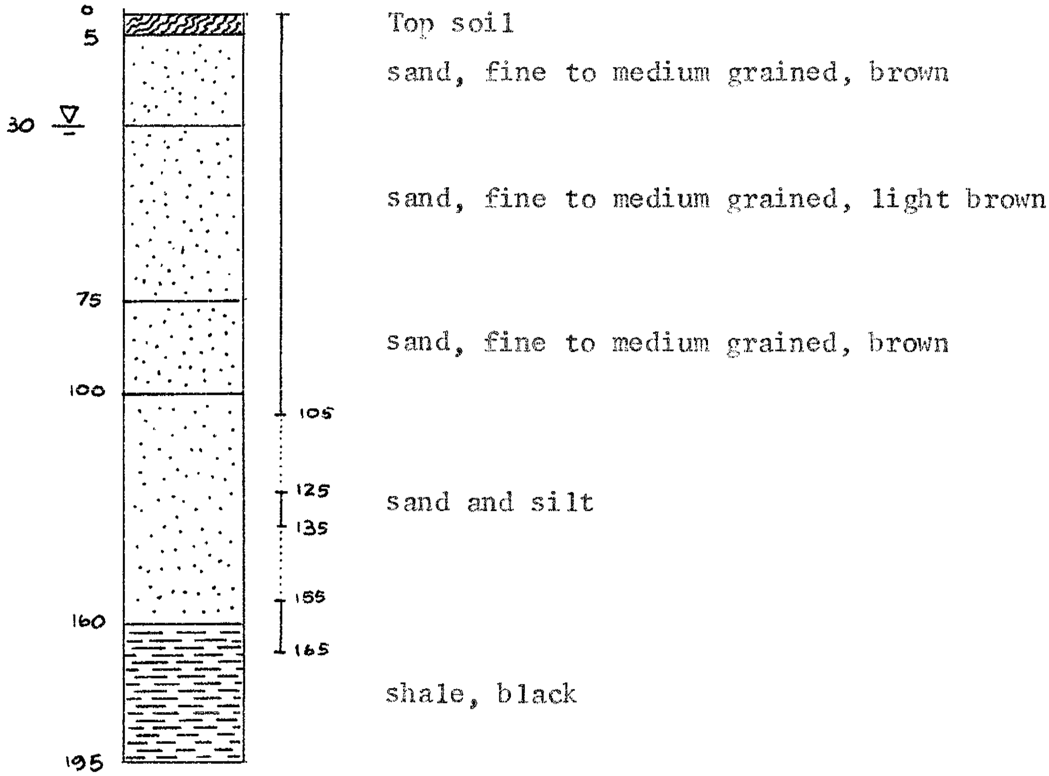


Figure A.8. Driller's log of well P.3

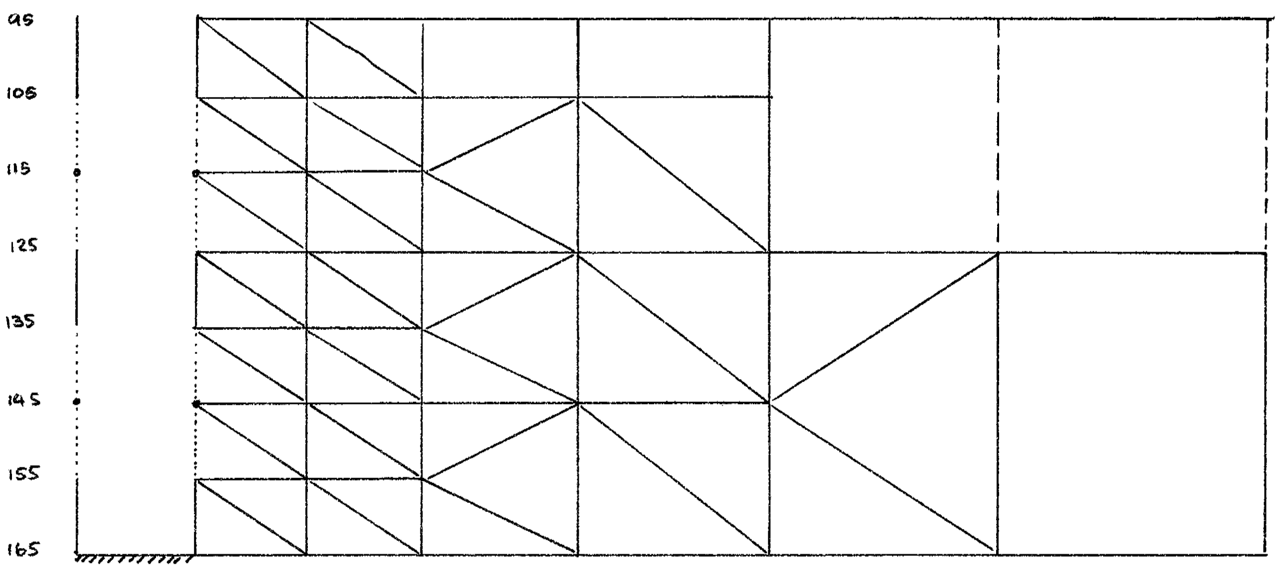


Figure A.9. Model of pumping well P.3

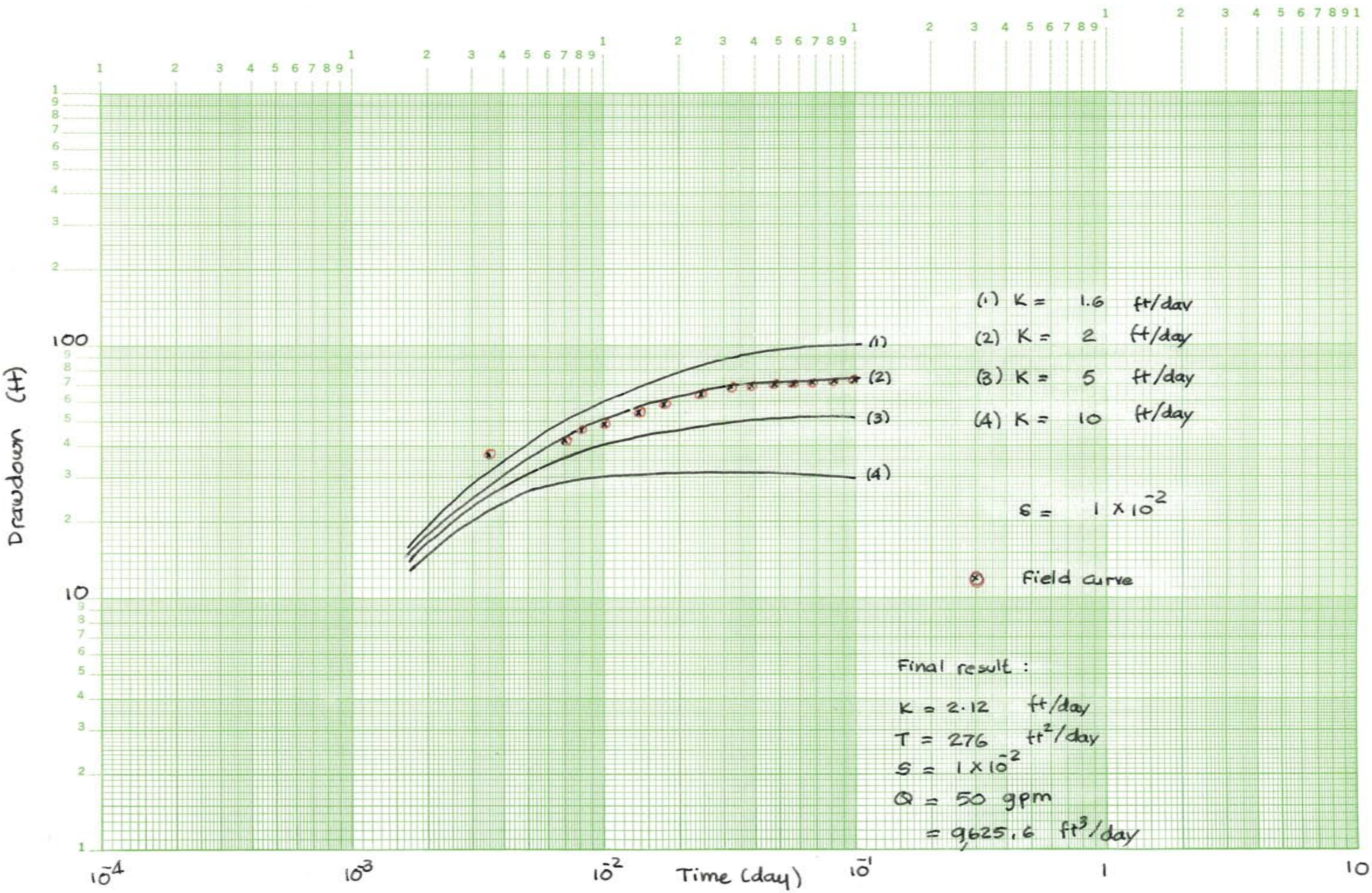


Figure A.10 Computed curve and field curve of pumping well P.3

3. Pumping well P.6

This well is located near the eastern border of the basin, approximately 3 miles south of the Capulin village. The driller's log is shown in Figure A.11. The upper part is composed of clay with impermeable character down to a depth of 290 ft. The aquifer appears at 290-310 ft. and consists of medium grained white sand underlain by impermeable shale. The water level was at 215 feet. This well is treated as a confined well.

Pumping was started at 3.45 p.m. on January 25, 1978 and was continued for a period of 1440 minutes at an approximate rate of 15 gpm. The water levels were measured by steel tape. The finite element model is shown in Figure A.12. The results of the analyses are shown in Figure A.13.

By using the same method as previously mentioned, the results are as follows:-

$K = 3.3$ ft/day

$T = 66.6$ ft^2/day

$S = 1 \times 10^{-4}$

$Q = 15$ gpm. or 2887 ft^3/day

4. Pumping well M.12

This well is located in the village of Capulin (see Figure 2 and Figure 6). It is completed in cinder. The upper part of the driller's log (Figure A.14) is a mixture of clay and clinkers. The cinder extends from 26.4 ft. to 48.5 ft. depth. This well belonged to Mr. Pachta before the city of Raton purchased the land (section 19, T29N, R28E). In 1966, E.G. Minton under contract by the city of Raton

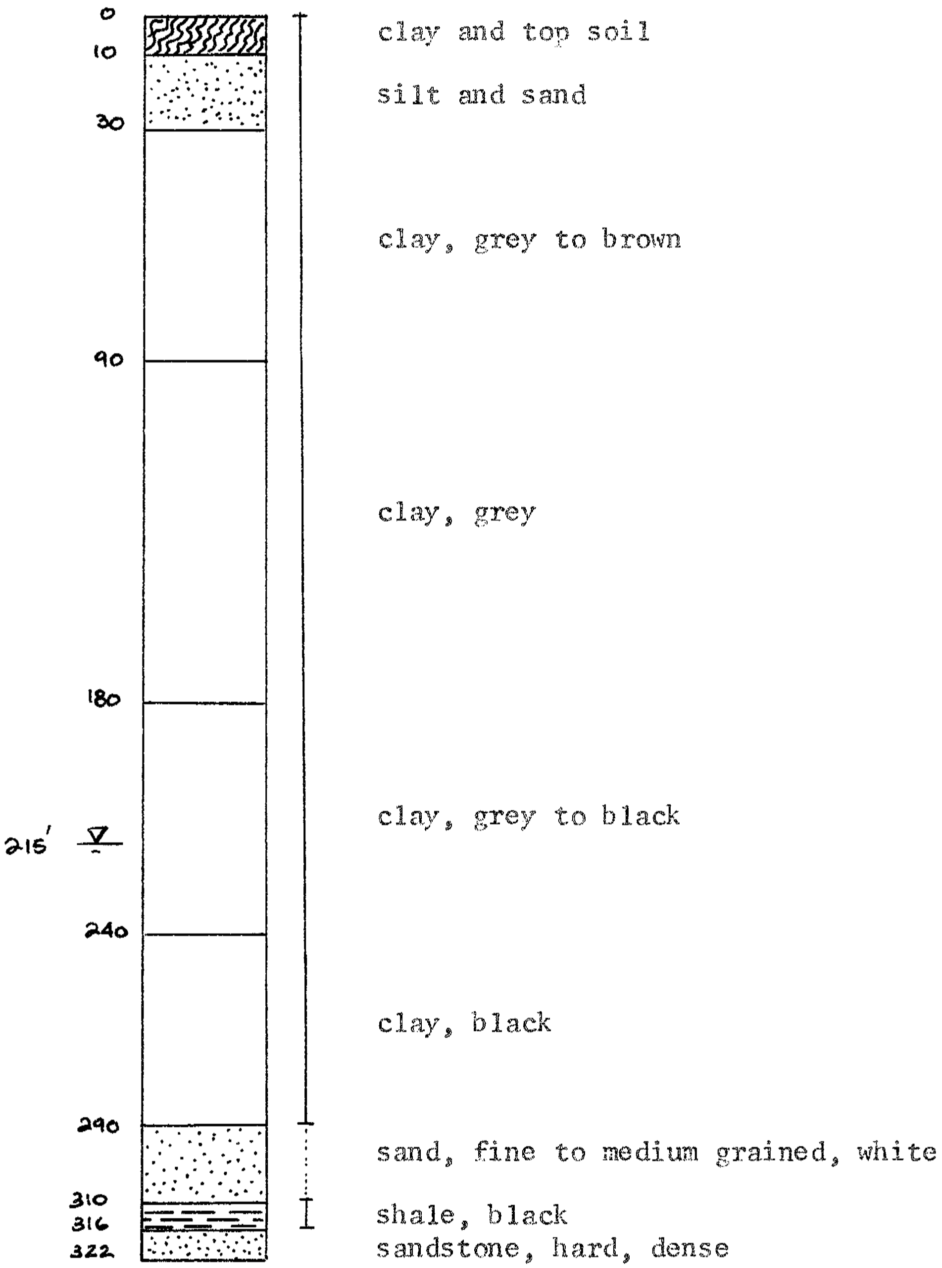


Figure A.11. Driller's log of well P.6

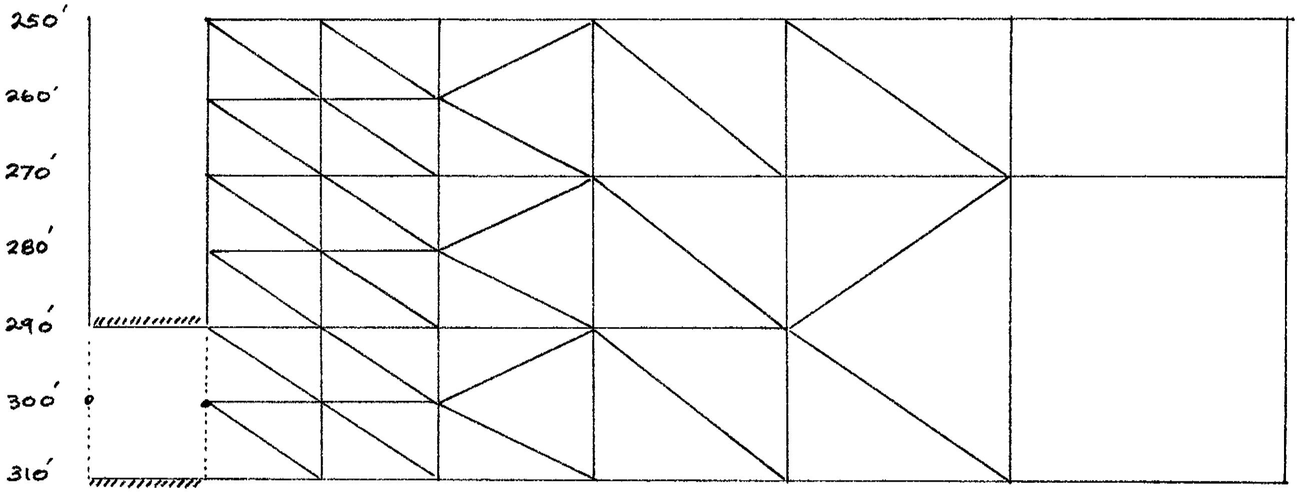


Figure A.12. Model of pumping well P.6

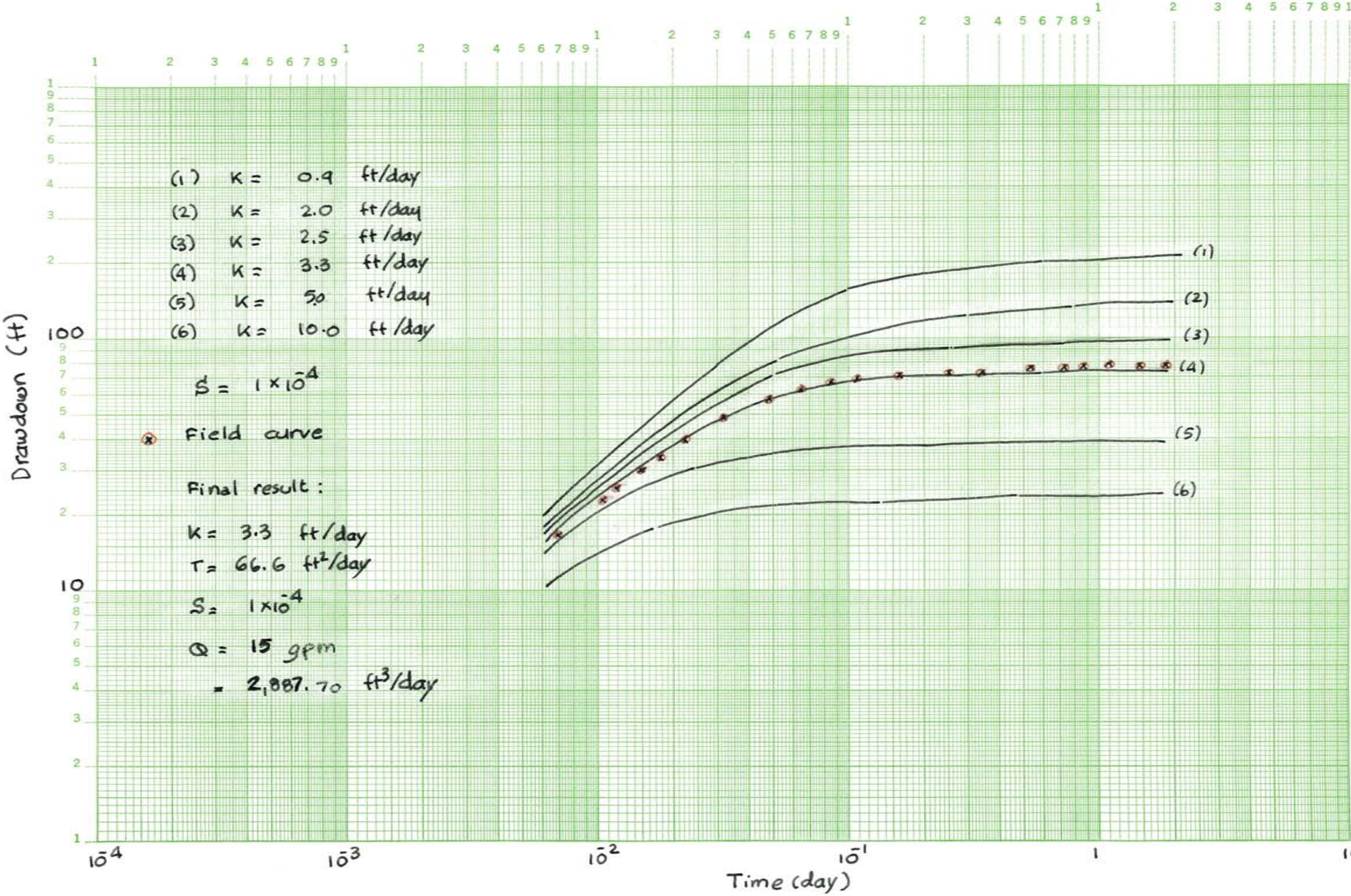


Figure A.13 Computed curve and field curve of pumping well P.6

made a long term pumping test from March 7, 1966 to May 7, 1966 at an approximate rate of 920 gpm. By using the drawdown data in pumping well itself and driller's log from his report, a finite element model was constructed as in Figure A.15. The results are presented in Figure A.16.

$$K = 4{,}000 \text{ ft/day}$$

$$T = 80{,}000 \text{ ft}^2\text{/day}$$

$$S = 3.5 \times 10^{-4}$$

$$Q = 920 \text{ gpm. or } 177{,}112 \text{ ft}^3\text{/day}$$

6. Conclusion

The finite element programs developed for evaluating hydrologic parameters seem to produce results that agree with field observation. However, it should be noted that this program is based on the assumption of axisymmetry of the flow field about the well. The anisotropic effect within the non-Darcy flow is not considered due to its complexity. The effect of well storage, proposed by Papadopulos & Cooper (1966), is also taken into consideration. This effect occurs when the well diameter is large enough that the rate at which the water is pumped from the well is not equal to the rate at which the water flows into the well. This results in smaller drawdown as seen in Figure A.17 graph 2 as compared with the larger drawdown in in graph 1 when there is no effect of well storage.

The advantage of this program is that it can be modified for use with a wide range of different aquifer conditions and well constructions (e.g. single-multi layer, confined-unconfined, fully-partially

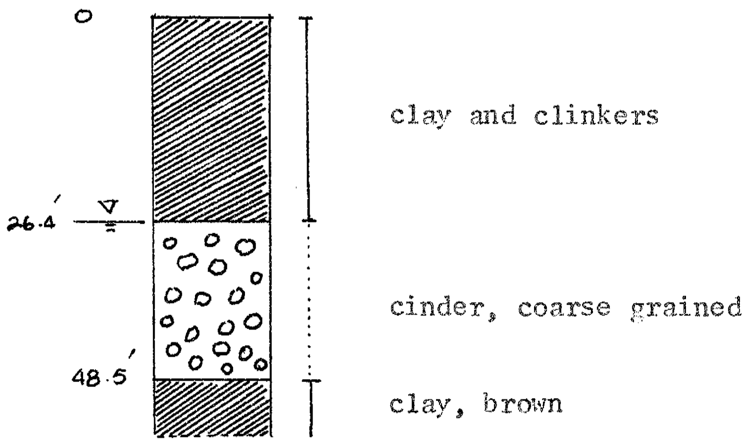


Figure A.14. Driller's of well M.12 (After Minton, 1966)

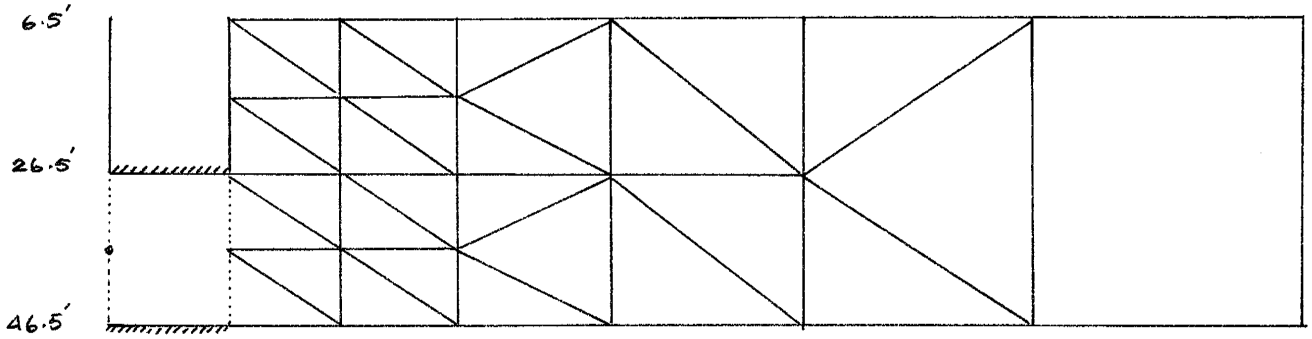


Figure A.15. Model of pumping well M.12

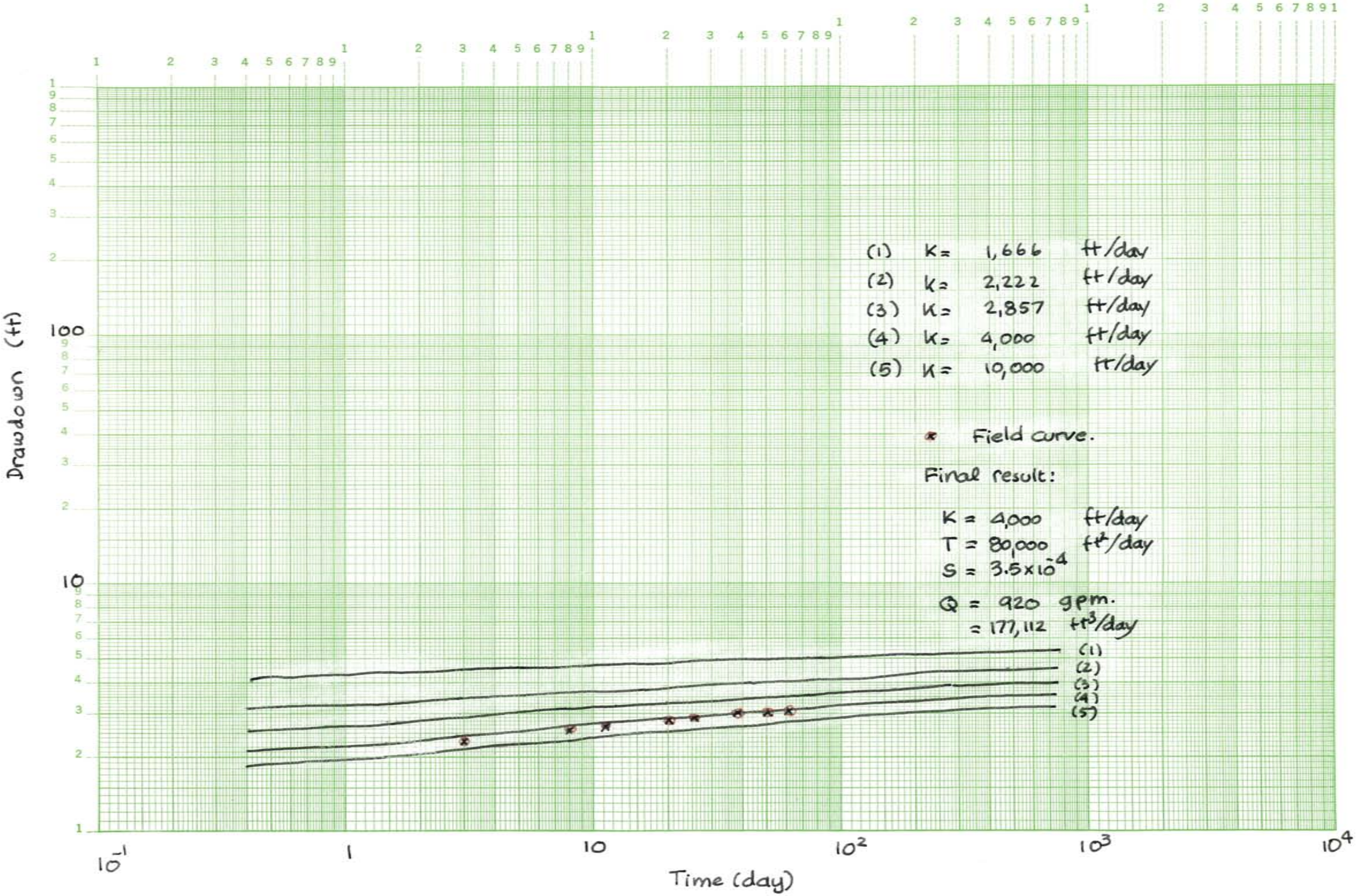


Figure A.16 Computed curve and field curve of pumping well M.12

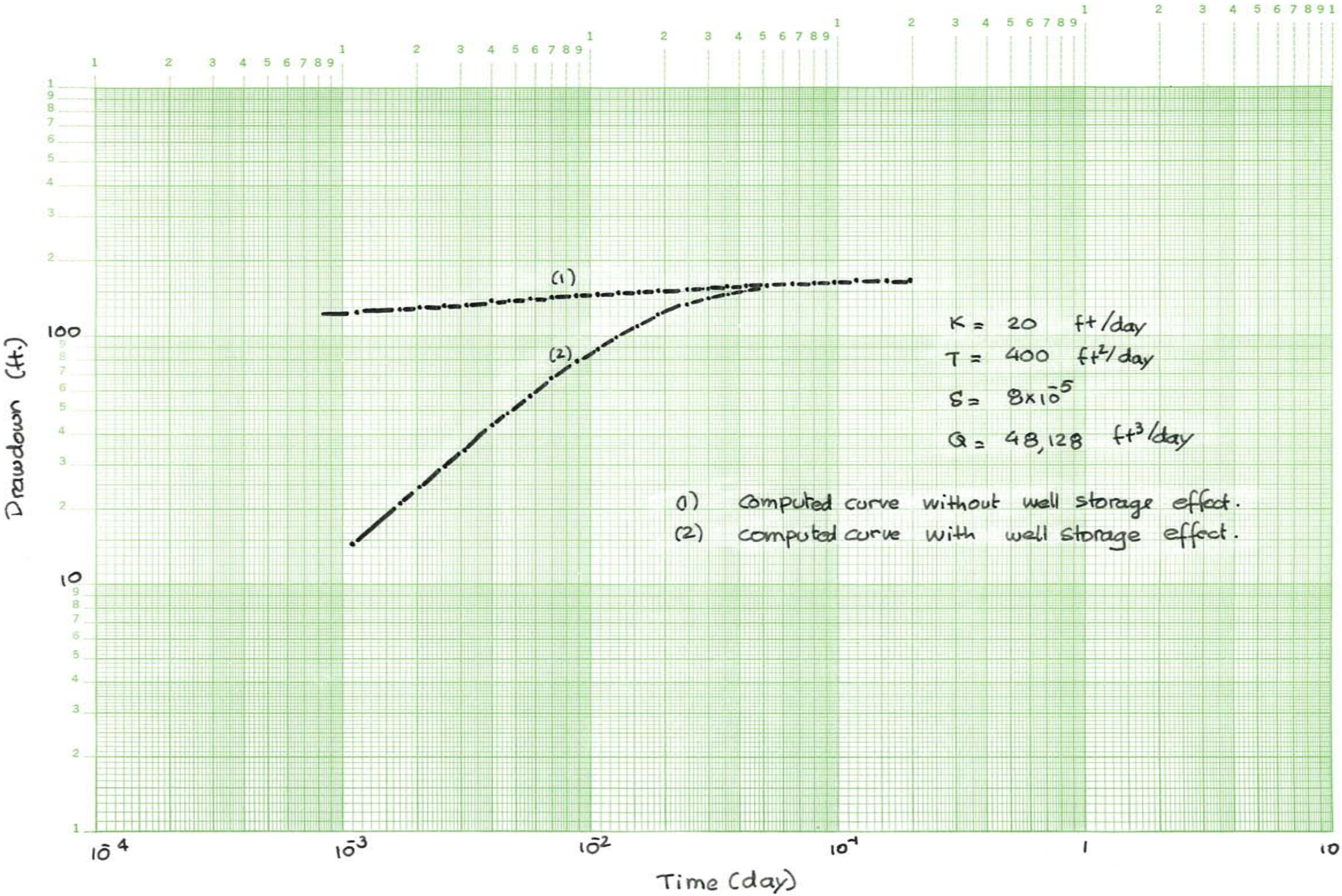


Figure A.17 Computed curve of well P.2 with and without well storage effect.

screened wells). The flow can be either transient or steady. The program has been designed to handle specific flow cases encountered in practice with a minimum of input data.

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MAIN PROGRAM MNTRCD

```
C       INTEGRATED WELL-AQUIFER SOLUTION SYSTEM.
C
C       DEVELOPED BY P.S. HUYAKORN.
C
C       TRCOND,PROGRAM FOR SOLVING TRANSIENT,TWO-DIMENSIONAL,DARCY OR TWO-REGIME
C
C       FLOW USING RECTANGULAR ELEMENTS OR A COMBINATION OF RECTANGULAR AND
C
C       TRIANGULAR ELEMENTS.
C
C       VERSION DATED OCTOBER,1973.
C
C        FOR FURTHER INFORMATION,CONTACT
C
C          P.S. HUYAKORN OR C.R. DUDGEON
C
C          WATER RESEARCH LABORATORY
C
C          KING ST.,MANLY VALE
C
C          SYDNEY,N.S.W. 2093,AUSTRALIA.
C
C-------------------------------
C       LIST OF INPUT VARIABLES
C-------------------------------
C
C----------------ALL READ STATEMENTS ARE LOCATED IN THE MAIN-------------------
C
C----------------PROGRAM AND INDICATED BY  $1 OR $1,SK  SIGN-------------------
C
C***    PROBLEM VARIABLES  ***
C
C       NPROB   =  NUMBER OF PROBLEMS TO BE SOLVED
C       IVEL    =  VELOCITY PRINT-OUT INDEX
C                  FEED IN IVEL=0 IF VELOCITY PRINT-OUT IS NOT REQUIRED OTHERWISE
C                  FEED IN IVEL=1
C       IDISCR  =  DISCRETISATION DATA PRINT-OUT INDEX
C                  FEED IN IDISCR=0 IF DISCRETISATION PRINT-OUT IS NOT REQUIRED
C                  OTHERWISE FEED IN IDISCR=1
C       ORELAX  =  OVER-RELAXATION FACTOR FOR NON-LINEAR HEAD ITERATION
C                  SUGGESTED VALUE LIES BETWEEN 1.50 TO 1.85
C       RW      =  RADIUS OF WELL SCREEN
C       RO      =  EXTERNAL RADIUS OR RADIUS OF INFLUENCE
C       HO      =  INITIAL HEIGHT OR DRAWDOWN OF WATER TABLE
C       HTOL    =  HEAD TOLERANCE FOR NON-LINEAR ITERATION ON HEAD VALUES
C                  SUGGESTED VALUE IS 0.10 OR A FEW PERCENT OF HO-HW
C       NLAYR   =  NUMBER OF LAYERS OF WATER BEARING FORMATIONS
C       QFIX    =  PRESCRIBED WELL DISCHARGE
C       RCSNG   =  RADIUS OF WELL CASING
C       QRTOL   =  RATIO OF DISCHARGE TOLERANCE TO PRESCRIBED WELL DISCHARGE
C                  SUGGESTED VALUE LIES BETWEEN 0.01 AND 0.02
C       IGP     =  GRAVEL PACK INDEX,IGP=1 FOR GRAVEL PACKED WELL,
C                  IGP=0 FOR NON-GRAVEL PACKED WELL
C       IBOUND  =  EXTERNAL BOUNDARY INDEX
C                  IBOUND=0 FOR BARRIER BOUNDARY OTHERWISE IBOUND =1
C       IWBC    =  WELL BOUNDARY CONDITION INDEX
C                  IWBC=0 IF EFFECT OF WELL STORAGE IS TO BE NEGLECTED OTHERWISE
C                  IWBC=1
C       IKMAX   =  LAYER OF MAXIMUM PERMEABILITY OR MINIMUM VALUE OF AKL(I)
C       IWAT    =  INDEX USED TO INDICATE WHETHER THE TOP LAYER IS CONFINED OR
```

```
C                 UNCONFINED
C       THL(I)  = THICKNESS OF LAYER NUMBER I
C       AKL(I)  = FORCHHEIMER LINEAR HYDRAULIC COEFFICIENT OF AQUIFER OR AQUITARD
C                 LAYER I
C                 FOR AQUITARD I,FEED IN AKL(I)=1./PML(I) WHERE PML(I) IS ITS
C                 HYDRAULIC CONDUCTIVITY
C       BKL(I)  = FORCHHEIMER NON-LINEAR COEFFICIENT OF AQUIFER LAYER I
C                 FOR AQUITARD I,FEED IN BKL(I)=0.0
C       VCRL(I) = CRITICAL VELOCITY OF AQUIFER LAYER I
C                 FOR AQUITARD I FEED IN VCRL(I)=0.0
C       SSL(I)  = SPECIFIC STORAGE OF AQUIFER OR AQUITARD I
C       AGP     = LINEAR HYDRAULIC COEFFICIENT OF GRAVEL PACK MATERIAL
C       BGP     = NON-LINEAR HYDRAULIC COEFFICIENT OF GRAVEL PACK MATERIAL
C       VGP     = CRITICAL FLOW VELOCITY FOR GRAVEL PACK MATERIAL
C       THGP    = THICKNESS OF GRAVEL PACK
C       BTGP    = HEIGHT OF THE BASE OF GRAVEL PACK
C       SY      = COEFFICIENT OF SPECIFIC YIELD OF TOP LAYER WATER TABLE AQUIFER
C                 OR AQUITARD
C       DINDEX  = RECIPROCAL OF DELAYED YIELD INDEX FOR WATER TABLE AQUIFER OR
C                 AQUITARD
C
C***    DISCRETISATION PARAMETERS   ***
C
C       NTICR   = TOTAL NUMBER OF TIME STEPS
C       ITST    = STARTING TIME STEP NUMBER
C       TFACTR  = VALUE OF THE FIRST TIME STEP,EXPRESSED IN DIMENSIONLESS FORM
C       TMUL    = TIME MULTIPLIER,SUGGESTED VALUE VARIES FROM 1.50 TO 2.00
C       DTMUL   = INCREMENT OF TIME MULTIPLIER
C                 SUGGESTED VALUE LIES BETWEEN 0. TO 0.02
C       FRLEN   = LENGTH OF FIRST SUBREGION
C                 SUGGESTED VALUE IS FRLEN=RW
C                 FOR GRAVEL PACKED WELL,FRLEN MUST NOT EXCEED THICKNESS OF PACK
C       SCFAC   = SCALE FACTOR TO BE USED IN COMPUTING THE LENGTHS OF REMAINING
C                 SUBREGIONS.SUGGESTED VALUE IS SCFAC=1.50
C       XLMAX   = MAXIMUM LENGTH OF A BLOCK,PRESCRIBED TO AVOID ILL-CONDITIONED
C                 ELEMENTS.MAXIMUM VALUE OF XLMAX SHOULD NOT EXCEED 25.*TH
C       NOSC    = TOTAL NUMBER OF NODES ON WELL SCREEN(S)
C                 NDSC IS TO BE GREATER OR EQUAL TO 2
C       NSCREN  = NUMBER OF SCREENED INTERVAL
C       IREGL(I)= NUMBER OF REPEATED REGULAR BLOCKS WITH THE SAME NUMBER OF NODES
C         -1      ON THE LEFT AND RIGHT VERTICAL LINES ACROSS LAYER I
C                 SUGGESTED VALUE IS IREG=2
C       NMINL(I)= MINIMUM NUMBER OF NODES ALONG A VERTICAL LINE ACROSS LAYER I
C                 TO MINIMISE THE TOTAL NUMBER OF NODES,SUGGEST NMIN=2
C       NFRL(I) = NUMBER OF NODES ON PORTION OF WELL BOUNDARY PENETRATING AQUIFER
C                 OR AQUITARD LAYER I
C       XSCR(I) = Z-COORDINATE OF BASE OF SCREEN I ABOVE DATUM
C       HSCR(I) = LENGTH OF SCREENED INTERVAL I
C-------------------------------------
C       LIST OF OUTPUT VARIABLES
C-------------------------------------
C       NNODE   = TOTAL NUMBER OF NODES IN THE FINITE ELEMENT NETWORK
C       NELEM   = TOTAL NUMBER OF ELEMENTS IN THE NETWORK
C       IT      = TIME STEP NUMBER
C       TMM     = REAL TIME VALUE AT THE MID-POINT OF TIME STEP IT
C       TM      = REAL TIME VALUE AT THE END OF TIME STEP IT
C       X       = RADIAL AND VERTICAL NODAL COORDINATES
C       H       = NODAL HEAD OR DRAWDOWN VALUES
C       TLESS   = NODAL VALUES OF DIMENSIONLESS TIME,1/U
C       HLESS   = NODAL VALUES OF WELL FUNCTION FOR TRANSIENT FLOW,W(U)
```

```
C      IU      =  DISCHARGE THROUGH [illegible]
C      SP      =  [illegible] AT CURRENT [illegible]
C      QSUPR   =  DISCHARGE FROM [illegible] AT [illegible]
C      QETPGA  =  DISCHARGE FROM [illegible]
C      QCALC   =  TOTAL CALCULATED DISCHARGE
C                 QCALC = [illegible]
C      QDIFF   =  [illegible] DISCHARGE
C                 QDIFF = THE ABSOLUTE DIFFERENCE BETWEEN PRESCRIBED AND
C                 DISCHARGE AND CALCULATED DISCHARGE
C      [illegible] =  [illegible] CONDITIONS [illegible]
C      [illegible] =  [illegible]
C      VCURV1  =  RADIAL CURVATURE OF [illegible]
C      VCURV2  =  VERTICAL CURVATURE OF [illegible]
C      ISARCH  =  INDEX TO INDICATE IF A PARTICULAR [illegible]
C                 IN [illegible] ZONE, ISARCH=0 FOR ELEMENTS IN THE [illegible] ZONES,
C                 ISARCH=1 FOR ELEMENTS IN THE [illegible] ZONE
C
C
C
C
C
       DIMENSION ISARCH(300)
       COMMON /[illegible]
       [illegible]
       COMMON /[illegible]
      1[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
      1[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       COMMON /[illegible]
       DOUBLE PRECISION [illegible]
       DATA [illegible]
       [illegible]
       [illegible]
C
C      ***************
C      *             *
C      *  [illegible] *
C      *             *
C      ***************
C
C      [illegible]
C
       [illegible]
 [illegible] FORMAT [illegible]
       [illegible]
       [illegible]
       [illegible]
       [illegible]
       [illegible]
```

```
      WRITE(NPRINT,1013)
      WRITE(NPRINT,1003)
 1003 FORMAT(5X,51H ***************************************************)
 1013 FORMAT(5X,51H *                                                 *)
 1023 FORMAT(5X,51H *    FINITE ELEMENT ANALYSIS OF WELL PROBLEMS     *)
 1033 FORMAT(6X,'* TRANSIENT,TWO REGIME FLOW TOWARD A SINGLE WELL *')
      READ(NREAD,1011)NPROB,IVEL,IDISCR,ORELAX                           $1
 1011 FORMAT(3I10,F10.2)
      DO 4800 JPRO=1,NPROB
      WRITE(NPRINT,9003)JPRO
 9003 FORMAT(///,20X,50('*'),/,20X,'*',13X,'PROBLEM NUMBER  =',
     1           I6,12X,'*',/,20X,50('*'))
C
C     READ AND PRINT GENERAL DATA.
C
      READ(NREAD,2001)RW,RO,HO,HTOL,NLAYR
 2001 FORMAT(4F10.2,I10)
      READ(NREAD,201)QFIX,RCSNG,QRTOL
  201 FORMAT(3F10.2)
      READ(NREAD,111)IGP,IBOUND,IWBC,IKMAX,IWAT                          $1
  111 FORMAT(5I10)
      IAQTA=IWAT
      WRITE(NPRINT,23)RW,RO,HO,RCSNG
      WRITE(NPRINT,2193)QFIX,QRTOL,ORELAX,HTOL
      WRITE(NPRINT,193)IGP,IBOUND,IWBC,IKMAX
      QRTOL=QRTOL*QFIX/2.0
   23 FORMAT(///,20X,'GENERAL DATA',///,
     1           10X,'RADIUS OF WELL    =',F10.2,//,
     2           10X,'RADIUS OF INFLUENCE     =',F10.2,//,
     3           10X,'HEIGHT OF WATER TABLE    =',F10.2,//,
     4           10X,'RADIUS OF WELL CASING    =',F10.2,//)
 2193 FORMAT(10X,'DISCHARGE INTO WELL     =',F10.2,//,
     1           10X,'DISCHARGE TOLERANCE RATIO    =',F12.4,//,
     2           10X,'OVER RELAXATION FACTOR    =',F12.4,//,
     3           10X,'HEAD TOLERANCE RATIO    =',F12.4,//)
  193 FORMAT(10X,'GRAVEL PACK INDEX    =',I5,//,
     1           10X,'BOUNDARY INDEX    =',I5,//,
     2           10X,'WELL B.C. INDEX    =',I5,//,
     3           10X,'LAYER OF MAX PERMEABILITY    =',I5)
C
C     READ AND PRINT MATERIAL DATA
C
      WRITE(NPRINT,6013)
 6013 FORMAT(///,10X,'FORMATION PROPERTIES',//,
     1           10X,'LAYER NO.',5X,'THICKNESS',5X,'COEFF-A',
     2  5X,'COEF-B',5X,'CRIT. VELOCITY',5X,'SPECIFIC STORAGE',//)
      DO 17 I=1,NLAYR                                                    *NLAYR**
      READ(NREAD,3013)THL(I),AKL(I),BKL(I),VCRL(I),SSL(I)                $1
 3013 FORMAT(5E10.2)
      GCR=AKL(I)*VCRL(I)+BKL(I)*VCRL(I)**2
      PML(I)=1./AKL(I)
      IF(GCR.GT.0.) PML(I)=VCRL(I)/GCR
      WRITE(NPRINT,7013)I,THL(I),AKL(I),BKL(I),VCRL(I),SSL(I)
 7013 FORMAT(10X,I5,9X,F9.2,3(5X,E9.2),9X,E9.2)
      SSL(I)=SSL(I)*1000.
   17 CONTINUE                                                           /*
      RGP=RW
      IF(IGP.EQ.0) GO TO 29
      READ(NREAD,331)AGP,BGP,VGP,THGP,BTGP                               $1,SK
  331 FORMAT(5F10.3)
```

```
      RGP=THGP+RW
      GRGP=AGP*VGP+BGP*VGP**2
      PMGP=1./AGP
      IF(GRGP.NE.0) PMGP=VGP/GRGP
      WRITE(NPRINT,153)AGP,BGP,VGP,PMGP
  153 FORMAT(///,20X,'GRAVEL PACK PROPERTIES'///
     1             10X,'COEFFICIENT A =',F10.4//
     2             10X,'COEFFICIENT B = ',F10.4//
     3             10X,'CRITICAL VELOCITY = ',F10.4//
     4             10X,'COEFFICIENT K = ',F10.4)
      WRITE(NPRINT,163)THGP,RGP
  163 FORMAT(10X,'THICKNESS OF PACK = ',F10.2//
     1             10X,'RADIUS OF PACK = ',F10.2)
   29 CONTINUE
C
C     FOR WATER TABLE AQUITARD READ DELAYED YIELD DATA.
C
      IF(IAQTA.EQ.0) GO TO 117
      READ(NREAD,173)SY,DINDEX                                        $1,SK
  173 FORMAT(2E10.2)
      SFAC=DINDEX*SY/6.
      DINDEX=DINDEX/1000.
  117 CONTINUE
C
C     READ AND PRINT DISCRETIZATION DATA.
C
      READ(NREAD,121)NTICR,ITST,TFACTR,TMUL,DTMUL                     $1
  121 FORMAT(2I10,3F10.2)
      NNODS=1
C
C     GENERATE ELEMENTS OF VECTOR TIME.
C
      TH=THL(IKMAX)
      PM=PML(IKMAX)
      SS=SSL(IKMAX)
      BK=BKL(IKMAX)
      BKMAX=BK
      TPAT=1
      NTICP=NTICR+1
      CALL TIGEN(NTICP,TFACTR,TMUL,DTMUL,RW,PM,SS,IWBC,QFIX,TPAT)
C
C     READ AND PRINT DISCRETIZATION DATA.
C
      READ(NREAD,901)FRLEN,SCFAC,XLMAX                                $1
  901 FORMAT(3F10.2)
      READ(NREAD,801)NDSC,NSCREN                                      $1
  801 FORMAT(2I10)
      IPENTR=0
      DO 602 I=1,NLAYR                                                *NLAYR**
      READ(NREAD,1901)IREGL(I),NMINL(I),NFRL(I)                       $1
 1901 FORMAT(3I10)
  602 CONTINUE                                                        /*
C
C     READ WELL SCREEN DATA
C
      WRITE(NPRINT,553)
  553 FORMAT(///,5X,'SCREEN NO.',10X,'BASE HEIGHT',14X,'LENGTH',//)
      SCLEN=0.0
      DO 702 I=1,NSCREN                                               *NSCREN*
      READ(NREAD,601)XSCR(I),HSCR(I)                                  $1
```

```
  601 FORMAT(2X,[illegible])
      [illegible]
      [illegible]
  302 FORMAT(7X,[illegible])
  702 CONTINUE
C
C     [illegible]
C
      CALL [illegible]
     1 [illegible])
C
C     [illegible]
C
      DO 1544 I=1,[illegible]
      J1=[illegible](I,1)
      J2=[illegible](I,2)
      XCR1=(X(J1,1)+X(J2,1))*0.5
      IF([illegible]) GO TO 1545
      XCR2=(X(J1,2)+X(J2,2))*0.5
      [illegible]
 1544 CONTINUE
 1545 CONTINUE
      IF([illegible]) GO TO 166
      CALL [illegible]
      DO 170 I=1,[illegible]
      [illegible]
  170 CONTINUE
  166 CONTINUE
C
C     [illegible]
C
      CALL [illegible]
      WRITE([illegible])
  243 FORMAT(//////,10X,[illegible] = ,I4,//)
      DO 130 I=1,[illegible]
      [illegible]=0.0
  130 CONTINUE
      [illegible]=0
      [illegible]=0
      DO 135 IJ=1,[illegible]
      [illegible]
      [illegible]
      IF([illegible]) [illegible]
      [illegible]
      IF([illegible]) GO TO 335
      CALL [illegible]
      GO TO 335
  336 CONTINUE
      CALL [illegible]
  335 CONTINUE
      CALL [illegible]
  135 CONTINUE
C
C     CALCULATE [illegible]
C
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
```

```
      NST=NDVEC(1)
      LSTEL=NDVEC(1)
      NELTO=NELEM
      DO 642 I=1,LVEC
      HCOLD(I)=0.
      HF(I)=0
      FINT(I,1)=0.
  642 QLEAK(I)=0.
      IF(ITST.EQ.1) GO TO 1245
      CALL HREAD(NNODS,1,1)
      CALL HPUNCH(NNODS,3,1)
      CALL HREAD(NNODS,1,2)
      CALL HPUNCH(LVEC,3,2)
      IST=NNODS+1
      DO 1345 I=IST,NNODE
      H(I)=HO
 1345 CONTINUE
      GO TO 1445
 1245 CONTINUE
      DO 3545 I=1,NNODE
      H(I)=HO
 3545 CONTINUE
 1445 CONTINUE
      DO 245 I=1,NNODE
      HINT(I,1)=H(I)
  245 CONTINUE
      DELT=TIME(1)
      NDTO=NNODE
      ITMIN=NTICR
      QAQFR=2.*QRTOL
      SWOLD=0.0
C
C     ESTIMATE WELL DRAWDOWN FOR FIRST TIME STEP.
C
      CALL DSWINT(DSOLD,BK,QFIX,TMIS,TH,RW,SCLEN,DIFFUS,CUNST)
      DSOLD=0.6*DSOLD
      IST=1
      FQ=0.0
      NQITER=5
      IF(IWBC.EQ.0) RCSNG=0.0
C
C     SET JDARCY.
C
      DO 299 I=1,NELEM
      JDARCY(I)=0
  299 CONTINUE
C
C     LOOPING WITH LOOP PARAMETER IT=1,NTICR
C
      DO 7007 IT=ITST,NTICR
      ITCUR=IT
      IF(IT.GT.1) DELT=TIME(IT)-TIME(IT-1)
      TM=TIME(IT)
      LVST=LVEC
      NST=NNODE
      TMM=TM-DELT*0.5
      WRITE(NPRINT,683)IT
  683 FORMAT(///,10X,35('*'),/,10X,'*',4X,
     1              'TIME STEP NUMBER  =',I5,5X,'*',/,10X,35('*'))
      TMIL=TMM/1000.
```

```
      WRITE(NPRINT,333)TMIL
  333 FORMAT(///,10X,41('*'),/,10X,'*',9X,'TIME  =',
     1          E14.3,9X,'*',/,10X,41('*'),//)
      WRITE(NPRINT,343)RO,NNODE,NELEM,LVST
  343 FORMAT(/,10X,'ESTIMATED RADIUS OF INFLUENCE  =',F10.2,
     1//,10X,'CORRESPONDING NO. OF NODES   =',I5,//,
     210X,'CORRESPONDING NO. OF ELEMENTS    =',I5,//,
     310X,'CORRESPONDING COMPONENT OF VECTOR NDVEC    =',I5,//)
C
C     COMPUTE DIMENSIONLESS TIME.
C
      CONS=4.0*DIFFUS*TMM
      DO 709 I=1,NNODE
      TLESS(I)=CONS/X(I,1)**2
  709 CONTINUE
C
C     FOR WATER TABLE AQUITARD,COMPUTE BOULTON'S INCREMENTAL DELAYED YEILD.
C
      IF(IAQTA.EQ.0) GO TO 777
      ARGU=-DINDEX*DELT*0.5
      TERM=DEXP(ARGU)
      ES=SY*(1.0-TERM)
      WRITE(NPRINT,903) ES
      ES=ES*1000.
  903 FORMAT(///,'EFFECTIVE SPECIFIC YIELD    =',E14.4)
  777 CONTINUE
C
C     INITIALISE HEAD VALUES.
C
      IF(IT.EQ.1) GO TO 165
  677 CONTINUE
      DO 155 I=1,NNODE
      HINT(I,1)=H(I)
  155 CONTINUE
  165 CONTINUE
      CALL EBFINR(LEN,NELEM,NN,NNODE)
      DO 2722 I=LVST,LVEC
      IF(NST.GT.NDVEC(I)) GO TO 2722
      JJ=NDVEC(I-1)
      JF=I
      GO TO 2822
 2722 CONTINUE
 2822 CONTINUE
      LMB=NDVEC(JF)-JJ
C
      CALL VECMUL(NNODE,LEN)
C
C     FOR WATER TABLE AQUITARD,ADD BOULTON'S DELAYED YIELD.
C
      IF(IAQTA.EQ.0) GO TO 278
      CALL GVMOD(LVST,ES,1)
      IF(IT.EQ.1) GO TO 278
      FTERM=0.5*DELT*SFAC
      CALL GKMOD(LVST,FTERM)
  278 CONTINUE
      HW=HO
      NDW=NDVEC(1)
      NDRO=LMB
      CALL BMDFIX(HW,HO,NNODE,NBD,NDW,NDRO,NBW,NSCREN,RW)
      IF(IBOUND.EQ.0) JBD(NBW+1)=0
```

```
C
C     STORE ELEMENTS OF MATRIX [illegible] FOR [illegible] COMPUTATION.
C
      DO 1372 I=1,[illegible]
      J=[illegible](I)
 1372 [illegible](I)=[illegible](J,I)
C
C     SET UP LOOP FOR [illegible] (DISCHARGE COMPUTATION.
C
      DO 999 [illegible]=1,[illegible]
      DO 1559 I=1,[illegible]
      [illegible](I)=[illegible](I,1)
 1559 CONTINUE
C
C     SET [illegible]
C
      DO 99 I=1,[illegible]
      [illegible](I)=[illegible](I)
   99 CONTINUE
C
C     ADJUST VALUE OF [illegible] PRESSURE.
C
      WRITE([illegible],5003)
 5003 FORMAT(/,5X,95('-'))
      CALL [illegible](IP,[illegible],[illegible],[illegible])
      CALL [illegible]([illegible],IP,[illegible],[illegible],[illegible],[illegible],[illegible],[illegible],[illegible])
      WRITE([illegible],833)[illegible],[illegible](IG),[illegible](IT)
  833 FORMAT(///,10X,'DISCHARGE ITERATION NUMBER     =',I10,//,
     1          10X,'[illegible] INCREMENT       =',F10.5,//,
     2          10X,'[illegible] VALUE         =',F10.3)
C
C     SET UP LOOP FOR ITERATION ON HEAD
C
      DO 1177 I=1,[illegible]
      [illegible](I)=S[illegible](IP)+[illegible]
 1177 CONTINUE
      [illegible]=5
      IF([illegible],[illegible],[illegible]) [illegible]=1
      V([illegible])=0
      DO 999 [illegible]=1,[illegible]
C
C     INITIALISE VECTOR C.
C
      DO 305 I=1,[illegible]
      C[illegible](1,I)=[illegible](I,1)
  305 CONTINUE
C
C     FORM VECTOR [illegible].
C
      DO 300 I=1,[illegible]
      [illegible](I)=0.0
  300 CONTINUE
      [illegible]=0
      [illegible]=1
      CALL [illegible]([illegible],[illegible])
      DO 350 I=1,[illegible]
      [illegible]=[illegible](I)
      IF([illegible](I),[illegible],[illegible]) GO TO 755
      [illegible]=[illegible](I)
      [illegible]=[illegible](I)
```

```
      BKK=BKL(L)
      PKK=PML(L)
      GO TO 365
  755 CONTINUE
      AKK=AGP
      BKK=BGP
      PKK=PMGP
  365 CONTINUE
      IF(NN.EQ.3) GO TO 465
      CALL ELGNCR(I,III,AKK,BKK,NT,PKK)
      GO TO 565
  465 CONTINUE
      NT=NREP(I)
      CALL ELGNCT(I,III,AKK,BKK,NT,VCOUNT,PKK)
  565 CONTINUE
      CALL MERB3(NN,I)
  350 CONTINUE
C
C     INITIALISE VECTOR VK.
C
      DO 978 I=1,LEN
      VK(I)=0.0
  978 CONTINUE
      IF(IAQTA.EQ.0) GO TO 555
      CALL GVMOD(LVST,ES,0)
  555 CONTINUE
      DO 530 I=1,LEN
      VK(I)=VCORE(I)*DELT*0.5+VD(I)+VK(I)
  530 CONTINUE
      NLEN=0
      JJ=JBD(NBW)
      DO 98 I=1,JJ
      NLEN=NLEN+NBAND(I)
   98 CONTINUE
      DO 378 I=1,NLEN
  378 VS(I)=VK(I)
C
C     SOLVE EQNS BY BANDED ELIMINATION SCHEME
C
      NLL=1
      CALL SYMSOL(NNODE,NLL)
C
      IF(III.EQ.1) GO TO 900
  415 CONTINUE
      NCOUNT=0
      EMAX=0.0
      DO 450 I=1,NNODE
      EPSI=CK(I,1)-H(I)
      IF(ABS(EPSI).GT.EMAX) EMAX=ABS(EPSI)
      IF(ABS(EPSI).LE.HTOL)  GO TO 460
      NCOUNT=NCOUNT+1
      H(I)=H(I)+ORELAX*EPSI
      GO TO 450
  460 CONTINUE
      H(I)=CK(I,1)
  450 CONTINUE
      IF(NCOUNT.EQ.0) GO TO 1000
      GO TO 1999
  900 CONTINUE
      DO 950 I=1,NNODE
```

```
      H(I)=CK(I,1)
  950 CONTINUE
 1999 CONTINUE
      IF(NITER.EQ.1) GO TO 999
      DO  199 I=1,NELEM
      NT=NREP(I)
      NN=ITYPE(I)
      IF(IPROP(I).EQ.0) L=1
      IF(IPROP(I).NE.0) L=IPROP(I)
      AK=AKL(L)
      BK=BKL(L)
      PMK=PML(L)
      VCR=VCRL(L)
      CALL SETARG(AGP,BGP,PMGP,VGP,AK,BK,PMK,VCR,I)
      IF(NN.EQ.3) GO TO 399
      CALL VCHECR(I,AK,BK,NT,PMK,VCR,HRRX,HRRY,NN)
      GO TO 499
  399 CONTINUE
      J1=NOD(I,1)
      J2=NOD(I,2)
      J3=NOD(I,3)
      CALL VCHEC3(I,AK,BK,J1,J2,J3,NT,PMK,VCR,HRRX,HRRY)
  499 CONTINUE
  199 CONTINUE
  999 CONTINUE
 1000 CONTINUE
      WRITE(NPRINT,413) III
  413 FORMAT(///,10X,'NUMBER OF ITERATIONS REQUIRED  =',I5)
      WRITE(NPRINT,473)NCOUNT,EMAX
  473 FORMAT(//,10X,'TOLERANCE COUNTER FOR HEAD     =',I3,//,
     1             10X,'ABSOLUTE MAXIMUM ERROR IN HEAD    =',F12.4)
      DO 470 I=1,NNODE
      H(I)=CK(I,1)
      IF((ITCUR.GT.IT).AND.(IQ.EQ.1)) TLESS(I)=TLESS(I)*TM/TMM
      HLESS(I)=(HO-H(I))/CONST
  470 CONTINUE
C
C     CHECK FOR ACCURACY OF DISCHARGE RATIO.
C
      DWD=DSW(IQ)
      CALL AQDIS(NBW,QAQFR,QRDIF,DELT,TH,RCSNG,IQ,QFIX,DWD)
C
C
C     PRINT FINAL DISCHARGE VALUES.
C
      QCALL=QCALC(IQ)
      QSTRGE=QCALL-QAQFR
      WRITE(NPRINT,1203)QAQFR,QSTRGE,QCALL,QRDIF
 1203 FORMAT(///,10X,'DISCHARGE FROM AQUIFER INTO WELL   =',F12.4,//,
     1          10X,'DISCHARGE FROMM WELL STORAGE    =',F12.3,//,
     1             10X,'TOTAL CALCULATED DISCHARGE      =',F14.3,//,
     210X,'RESIDUAL DISCHARGE RATIO     =',F10.4)
      IF(QRDIF.LE.QRTOL) GO TO 1102
  998 CONTINUE
 1102 CONTINUE
C
C     RESET JDARCY.
C
      DO 3359 I=1,NELEM
      JDARCY(I)=IDARCY(I)
```

```
 3999 CONTINUE
      [illegible]
      CALL [illegible]
C
C       [illegible] VELOCITIES
C
      IF([illegible]) GO TO 567
      WRITE([illegible])
 4203 FORMAT(///,[illegible],'*******************************************'/
     1                    [illegible],'*          [illegible] VELOCITIES          *'/
     2                    [illegible],'*******************************************'///
     3[illegible]///)
      DO 4000 I=1,[illegible]
      [illegible]
      [illegible]
      IF([illegible]) I=1
      IF([illegible]) [illegible]
      [illegible]
      [illegible]
      [illegible]
      VCR=VCH([illegible])
      CALL [illegible]
      IF([illegible]) GO TO [illegible]
      CALL [illegible]
      GO TO 4[illegible]
 3999 CONTINUE
      J1=NOD(I,1)
      J2=NOD(I,2)
      J3=NOD(I,3)
      CALL VCN[illegible](I,[illegible],J1,J2,J3,[illegible])
 4999 CONTINUE
      [illegible]
      VCOMP2=-V[illegible]
      [illegible]
 1103 FORMAT([illegible])
 3000 CONTINUE
  567 CONTINUE
      IF([illegible]) GO TO 577
C
C       [illegible]
C
      IF([illegible]) GO TO [illegible]
      [illegible]
      [illegible]
      [illegible]
      GO TO 577
  577 CONTINUE
C
C       [illegible]
C
      [illegible]
      [illegible]
      DO 477 I=1,[illegible]
      [illegible]
      [illegible]
      [illegible]
  477 CONTINUE
      [illegible]
      [illegible]
      [illegible]
```

```
      DWTEMP=SWOLD-SWTEMP
      QAQFR=QFR*SWOLD/SWTEMP
      ACSNG=22.*RCSNG**2/7.
      TRM=ABS(ACSNG*DWTEMP*2./DELT)
      QCALL=QAQFR+TRM*10.**3
      QRDIF=ABS(QFIX-QCALL)
      SW(IT)=SWOLD
      QSTRGE=QWSTR
      WRITE(NPRINT,1203)QAQFR,QSTRGE,QCALL,QRDIF
 7009 CONTINUE
      CALL ROUT(NNODE)
 7000 CONTINUE
C
C     FOR WATER TABLE AQUITARD,COMPUTE FIRST PORTION OF BOULTON'S INTEGRAL.
C
      IF(IAQTA.EQ.0) GO TO 6007
      DO 9007 I=1,LVST
      L=NDVEC(I)
      HF(I)=H(L)
      FINT(I,1)=HINT(L,1)
 9007 CONTINUE
      CALL BSIMP(LVST,TH,DINDEX,SY,DELT,IT,0)
      DO 8007 I=1,LVST
      L=NDVEC(I)
      HCOLD(I)=H(L)
 8007 CONTINUE
 6007 CONTINUE
 7007 CONTINUE
C
C     PUNCH OUT SOLUTION AT FINAL TIME.
C
      CALL HPUNCH(NNODE,2,1)
      CALL HPUNCH(LVEC,2,2)
 5000 CONTINUE
 4800 CONTINUE
      CLOSE(UNIT=1)
      CLOSE(UNIT=3)
      STOP
      END
```

SRTRC

FOR

START User [illegible] Job SRTRC Seq. 561 Date 10-May-78 [illegible] Monitor New Mexico Tech [illegible] System
File: [illegible] Created: 25-Feb-78 [illegible] Printed: 10-May-78 11:00:01
QUEUE Switches: /PRINT:ASCII /COPIES:1 /SPACING:1 /LIMIT:[illegible] /FORMS:[illegible]

```
      SUBROUTINE GXNODR(FRLEN,SCFAC,XLMAX,RW,RO,NNODE,NELEM,LVEC,NLAYR,
     1IPENTR,IDISCR)
C
C     GENERATES DISCRETIZATION DATA.
C
      COMMON /CSOLV/VD(6500),HINT(300,1),IPROP(300)
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /BDISC/RVEC(50),NDVEC(50),XLEN(100)
      COMMON /ALAYR/AKL(5),BKL(5),VCRL(5),SSL(5),THL(5),IREGL(5),
     1NMINL(5),NFRL(5),PML(5)
      COMMON /AELEM/NTRAN(4,100),NH1(4,100),NH2(4,100),NDB1(4,100),NDB2(
     14,100),NDWB(22)
      DATA NPRINT/3/
      CALL DCRGN3(RO,RW,SCFAC,FRLEN,NRR,XLMAX)
      NRST=1
      THTO=0.
      NSTFR=1
      NDWB(1)=0
      DO 10 I=1,NLAYR
      THTO=THTO+THL(I)
      NFR=NFRL(I)
      NDWB(1)=NDWB(1)+NFR
      IREG=IREGL(I)
      NMIN=NMINL(I)
      CALL NCRGR1(NFR,IREG,NRR,NMIN,NSTFR,NRST,IPENTR,I)
   10 CONTINUE
      CALL NCRGR2(NRST,NRR,NLAYR,NSTFR)
      IF(IDISCR.EQ.0) GO TO 94
      WRITE(NPRINT,33)NLAYR,NRR
   33 FORMAT('1',20X,'DISCRETISATION DATA',//,
     1            10X,'NUMBER OF LAYERS    =',I5,//,
     2            10X,'NUMBER OF SUBREGIONS  =',I5)
   94 CONTINUE
C
C     DISCRETISE ENTIRE REGION INTO RECTANGULAR ELEMENTS.
C
      KCREP=1
      NSTOR=1
      NTSEL=1
      DO 65 I=NRST,NRR
      DO 691 L=1,NLAYR
      N1=NH1(L,I)
      N2=NH2(L,I)
      NFND1=NDB1(L,I)
      NFND2=NDB2(L,I)
      NPAT=NTRAN(L,I)
      IF(NPAT.NE.0) GO TO 791
      CALL RBLOCK(KCREP,N1,NFND1,NFND2,NPAT,NTSEL)
      GO TO 891
  791 CONTINUE
      CALL BBLOCK(KCREP,N1,NFND1,NFND2,NPAT,NTSEL)
  891 CONTINUE
      NELEM=NTSEL-1
      DO 68 IE=NSTOR,NELEM
      IPROP(IE)=L
   68 CONTINUE
      NSTOR=NTSEL
  691 CONTINUE
   65 CONTINUE
C
```

```
C     PRINT OUT ELEMENT DATA.
C
      NELEM=NTSEL-1
      IF(IDISCR.EQ.0) GO TO 104
      WRITE(NPRINT,83)
   83 FORMAT(///,10X,'IDENTIFICATION OF ELEMENT-NODE CONNECTIONS',///,
     112X,'ELEM NO',5X,'ITYPE',5X,'NREP',5X,'IPROP',5X,'NODE1',5X,
     1'NODE2',5X,'NODE3',5X,'NODE4',//)
      DO 80 I=1,NELEM
      NN=ITYPE(I)
      WRITE(NPRINT,93)I,ITYpE(I),NREP(I),IPROP(I),(NOD(I,K),K=1,NN)
   93 FORMAT(12X,9(I5,5X))
   80 CONTINUE
  104 CONTINUE
C
C     GNERATE NODE COORDINATES.
C
      RI=RW
      NS=1
      MM=1
      DO 75 I=NRST,NRR
      DXG=XLEN(I)
      ZI=0.0
      DO 87 L=1,NLAYR
      TH=THL(L)
      NN=NH1(L,I)
      CALL COORDC(NS,MM,NN,DXG,TH,RI,ZI)
      ZI=TH+ZI
      NS=NS-1
      RI=RI-DXG
   87 CONTINUE
      RI=RI+DXG
      NS=NS+1
   75 CONTINUE
      ZI=0.0
      DO 877 L=1,NLAYR
      TH=THL(L)
      NN=NH2(L,NRR)
      CALL COORDC(NS,MM,NN,DXG,TH,RI,ZI)
      ZI=TH+ZI
      NS=NS-1
      RI=RI-DXG
  877 CONTINUE
C
C     PRINT OUT NODE COORDINATES.
C
      NNODE=NS
      IF(IDISCR.EQ.0) GO TO 114
      WRITE(NPRINT,103)
  103 FORMAT(///,10X,'NODAL COORDINATES',//,10X,'NODE',5X,
     1'R-COORD',5X,'Z-COORD',//)
      DO 85 I=1,NNODE
      WRITE(NPRINT,113)I,X(I,1),X(I,2)
  113 FORMAT(10X,I4,2F11.2)
   85 CONTINUE
  114 CONTINUE
C
C     GENERATE TOP BOUNDARY COORDINATE VECTORS.
C
      NDTO=NS
```

```
C
C     PRINT OUT BOUNDARY COORDINATE VECTORS.
      WRITE(NPRINT,223)
  223 FORMAT(///,20X,'TOP BOUNDARY NODES AND RADIAL COORDINATES',///,
     110X,'NODE NUMBER',20X,'R-COORDINATE',//)
      DO 335 I=1,LVEC
      WRITE(NPRINT,333)NDVEC(I),RVEC(I)
  335 CONTINUE
  333 FORMAT(10X,I7,25X,F10.2)
      RETURN
      END
      SUBROUTINE NCRGR1(NFR,IREG,NRR,NMIN,NSTFR,NRST,IPENTR,L)
C
C     GENERATES DISCRETIZATION PARAMETERS:- NTRAN,NH1,NH2,NDB1,NDB2
C
      COMMON /AELEM/NTRAN(4,100),NH1(4,100),NH2(4,100),NDB1(4,100),
     1NDB2(4,100),NDWB(22)
      NC=NFR
      NCOUNT=0
      DO 10 I=NRST,NRR
      IRGG=IREG
      IF((I.EQ.NRST).AND.(IPENTR.NE.0)) IRGG=0
      NCOUNT=NCOUNT+1
      IF(NCOUNT.LT.IRGG) GO TO 20
      NCOUNT=0
      NHALF=NC/2
      NREM=NC-2*NHALF
      IF(NREM.GT.0) GO TO 15
      NC1=NC-1
      IF(NC1.LT.NMIN) GO TO 20
      NTRAN(L,I)=2
      NC=NC1
      NH2(L,I)=NC
      NH1(L,I)=NC+1
      GO TO 10
   15 CONTINUE
      NC1=NHALF+1
      IF(NC1.LT.NMIN) GO TO 20
      NTRAN(L,I)=1
      NC=NC1
      NH2(L,I)=NC
      NH1(L,I)=2*NH2(L,I)-1
      GO TO 10
   20 CONTINUE
      NH2(L,I)=NC
      NTRAN(L,I)=0
      NH1(L,I)=NH2(L,I)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE NCRGR2(NRST,NRR,NLAYR,NSTFR)
C
C     MODIFIES THE VALUES OF NDB1 AND NDB2.
C
      COMMON /AELEM/NTRAN(4,100),NH1(4,100),NH2(4,100),NDB1(4,100),
     1NDB2(4,100),NDWB(22)
      NDBC=NSTFR
      DO 50 J=NRST,NRR
      NDB1(1,J)=NDBC
      IF(NLAYR.LT.2) GO TO 56
```

```
      DO 55 L=2,NLAYR
      NDB1(L,J)=NDB1(L-1,J)+NH1(L-1,J)-1
   55 CONTINUE
   56 CONTINUE
      L=NLAYR
      NDBC=NDB1(L,J)+NH1(L,J)
   50 CONTINUE
      NR1=NRR-1
      DO 60 J=NRST,NR1
      DO 65 L=1,NLAYR
      NDB2(L,J)=NDB1(L,J+1)
   65 CONTINUE
   60 CONTINUE
      NDB2(1,NRR)=NDBC
      DO 75 L=2,NLAYR
      NDB2(L,NRR)=NDB2(L-1,NRR)+NH2(L-1,NRR)-1
   75 CONTINUE
      RETURN
      END
      SUBROUTINE DCRGN3(RO,RW,SCFAC,FRLEN,NRR,XLMAX)
C
C     GENERATES DISCRETIZATION PARAMETERS:= NRR,XLEN
C
      COMMON /BDISC/RVEC(50),NDVEC(50),XLEN(100)
      MAXNR=89
      XLEN(1)=FRLEN
      RLEN=RO-RW
      SUM=XLEN(1)
      DO 10 I=2,MAXNR
      XLEN(I)=XLEN(I-1)*SCFAC
      IF(XLEN(I).GT.XLMAX) XLEN(I)=XLMAX
      SUM=XLEN(I)+SUM
      IF(SUM.GT.RLEN) GO TO 20
   10 CONTINUE
   20 CONTINUE
      XREM=RLEN+XLEN(I)-SUM
      NRR=I
      DENOM=1.+SCFAC+SCFAC**2
      XLEN(I-2)=(XREM+XLEN(I-1)+XLEN(I-2))/DENOM
      XLEN(I-1)=XLEN(I-2)*SCFAC
      XLEN(I)=XLEN(I-1)*SCFAC
      RETURN
      END
      SUBROUTINE RBLOCK(KCREP,N1,NFND1,NFND2,NPAT,NTSEL)
C
C     GENERATES ELEMENT CONNECTIVITIES IN BASIC RECTANGULAR BLOCKS.
C
      DIMENSION ND(1,6)
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      ND(1,1)=NFND1
      ND(1,2)=NFND2
      ND(1,3)=NFND2+1
      ND(1,4)=NFND1+1
      IF(NPAT.EQ.1) GO TO 200
      NTEMP=N1-2
      NST=NTSEL
      NLST=NST+NTEMP
      DO 40 J1=NST,NLST
      NREP(J1)=KCREP
      ITYPE(J1)=4
```

```
      [illegible]
      [illegible]
   50 [illegible]
   40 [illegible]
      [illegible]
      [illegible]
      [illegible]
  200 [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
  210 [illegible]
      [illegible]
      [illegible]
  400 [illegible]
      [illegible]
      [illegible]
      [illegible]
C
C     [illegible]
C
      [illegible]
      [illegible]
      [illegible]
      [illegible]
   20 [illegible]
      [illegible]
   50 [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
   70 [illegible]
   60 [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
   90 [illegible]
   80 [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
C
```

```
C         COMPUTES RADIAL COORDINATES FOR NODES ALONG THE TOP BOUNDARY.
C
          COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
          COMMON /BDISC/RVEC(50),NDVEC(50),XLEN(100)
          J=0
          DO 10 I=1,NDTO
          ZDIF=ABS(TH-X(I,2))
          IF(ZDIF.GT.0.001) GO TO 10
          J=J+1
          NDVEC(J)=I
          RVEC(J)=X(I,1)
       10 CONTINUE
          LVEC=J
          RETURN
          END
          SUBROUTINE EBFINR(LEN,NM,NN,LL)
C
C         SUBROUTINE TO COMPUTE BANDWIDTHS OF THE BANDED SYMMETRIC GROSS
C         MATRIX. NBAND CONTAINS THE BANDWIDTHS, ID THE POSITION OF THE
C         TERM ON THE DIAGONALS OF THE ORIGINAL MATRIX, LEN IS THE LENGTH
C         THE VECTOR
C
          DIMENSION LV(6)
          COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
          COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
C
          DO 20 I=1,LL
          NBAND(I)=1
          ISTART(I)=I
       20 CONTINUE
C
C         SCAN THROUGH THE LOCATION VECTOR FOR EACH MEMBER TO FIND
C         THE POSITION OF THE TERM FURTHEREST FROM THE DIAGONAL IN EACH ROW
C
          DO 25 I=1,NM
          NN=ITYPE(I)
          NF2=NN
          DO 30 J=1,NF2
          LV(J)=NOD(I,J)
       30 CONTINUE
          DO 45 J=1,NF2
          IF(LV(J).EQ.0)GO TO 45
          DO 40 K=1,NF2
          IF(LV(J).GT.LV(K)) GO TO 40
          NW=LV(K)-LV(J)+1
          NR=LV(J)
          IF(NW.GT.NBAND(NR))  NBAND(NR)=NW
       40 CONTINUE
       45 CONTINUE
C          SEARCH FOR THE FURTHEREST OFF-LEFT TERM
C
          DO 55 J=1,NF2
          IF(LV(J).EQ.0) GO TO 55
          DO 65 K=1,NF2
          IF(LV(J).LT.LV(K)) GO TO 65
          NW=LV(K)
          NR=LV(J)
          IF(NW.LT.ISTART(NR)) ISTART(NR)=NW
       65 CONTINUE
       55 CONTINUE
```

```
   25 CONTINUE
C
C     [illegible]
C     [illegible]
C
      [illegible]
      DO 50 [illegible]
      IF([illegible]) [illegible]
      [illegible]
   50 CONTINUE
      [illegible]
      [illegible]
   60 [illegible]
      RETURN
      END
      [illegible]
C
C     [illegible]
C
      [illegible]
      [illegible]
     1[illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      IF([illegible]) GO TO 30
      [illegible]
      DO 10 [illegible]
      DO 20 [illegible]
      IF([illegible]) GO TO 20
      [illegible]
      [illegible]
   20 CONTINUE
   10 CONTINUE
   30 CONTINUE
      IF([illegible]) GO TO 70
  500 CONTINUE
      CALL [illegible]
      GO TO 90
   70 CONTINUE
      [illegible]
   90 CONTINUE
      DO 40 [illegible]
      DO 50 [illegible]
      IF([illegible]) GO TO 60
      [illegible]
      GO TO 50
   60 [illegible]
   50 CONTINUE
   40 CONTINUE
      RETURN
      END
      [illegible]
C
C     [illegible]
C
      [illegible]
      DO 200 [illegible]
      [illegible]
```

```
      J=I
      GO TO (10,30),J
C
C     4-NODES ELEM
C
   10 CONTINUE
      DO 150 K=1,4
      E(K,K,J)=1./3.
  150 F(K,K,J)=E(K,K,J)
      E(1,2,J)=-1./3.
      E(1,3,J)=-1./6.
      E(1,4,J) = 1./6.
      E(2,3,J)=1./6.
      E(2,4,J)=-1./6.
      E(3,4,J)=-1./3.
      F(1,2,J)=1./6.
      F(1,3,J)=-1./6.
      F(1,4,J)=-1./3.
      F(2,3,J)=-1./3.
      F(2,4,J)=-1./6.
      F(3,4,J)=1./6.
      GO TO 500
C
C     5 NODES LEFT INCLUDED
C
   30 CONTINUE
      E(1,1,J) =   2./15.
      E(1,2,J) =   -1./6.
      E(1,3,J) = 0.0
      E(1,4,J)=     -1./30.
      E(1,5,J) =   1./15.
      E(2,2,J) =   1./3.
      E(2,3,J) =   1./6.
      E(2,4,J) =   0.0
      E(2,5,J) =   -1./3.
      E(3,3,J) =   1./3.
      E(3,4,J) =   -1./6.
      E(3,5,J) = -1./3.
      E(4,4,J) = 2./15.
      E(4,5,J) = 1./15.
      E(5,5,J) =   8./15.
      F(1,1,J) =   7./9.
      F(1,2,J) =   1./6.
      F(1,3,J) =   -1./6.
      F(1,4,J)=    1./9.
      F(1,5,J) =   -8./9.
      F(2,2,J) =   1./3.
      F(2,3,J) =   -1./3.
      F(2,4,J) =   -1./6.
      F(2,5,J) =   0.0
      F(3,3,J) = 1./3.
      F(3,4,J) =   1./6.
      F(3,5,J) =   0.0
      F(4,4,J) =     7./9.
      F(4,5,J) =   -8./9.
      F(5,5,J) =   16./9.
  500 CONTINUE
  200 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INFLUD(NN)
C
C     GENERATES THE SECOND SET OF INFLUENCE COEFFICIENTS FOR RECTANGULAR
C     ELEMENTS.
C
      DIMENSION ZEN(6,2),ZE(1,2)
      COMMON /BELEM/E(6,6,3),G(6,6,3),DSHFZ(2,6)
      JP=1
      K=NN-3
      ZEN(1,1)=-1.
      ZEN(2,1)=1.
      ZEN(3,1)=1.
      ZEN(4,1)=-1.
      ZEN(1,2)=-1.
      ZEN(2,2)=-1.
      ZEN(3,2)=1.
      ZEN(4,2)=1.
      ZEN(5,1)=0.
      ZEN(5,2)=-1.
      ZE(1,1)=0.
      ZE(1,2)=0.
      IF(K.EQ.2) GO TO 50
C
C     4-NODE ELEMENT.
C
      DO 2 I=1,NN
      T1=1.+ZEN(I,1)*ZE(JP,1)
      T2=1.+ZEN(I,2)*ZE(JP,2)
      DSHFZ(1,I)=.25*T2*ZEN(I,1)
      DSHFZ(2,I)=.25*T1*ZEN(I,2)
      G(I,I,K)=4./9.
      IF(I.LE.3) G(I,I+1,K)=2./9.
      IF(I.LE.2) G(I,I+2,K)=1./9.
      IF(I.EQ.1) G(I,4,K)=2./9.
    2 CONTINUE
      GO TO 100
   50 CONTINUE
C
C
C     5-NODE ELEMENT WITH MIDDLE NODE ON SIDE 1-4
C
      Z1=ZE(JP,1)
      Z2=ZE(JP,2)
      P1=1.0+Z1
      S1=1.0-Z1
      P2=1.0+Z2
      S2=1.0-Z2
      DSHFZ(1,1)=0.25*Z2*S2
      DSHFZ(1,4)=-0.25*Z2*P2
      DSHFZ(2,1)=-0.25*S1*(S2-Z2)
      DSHFZ(2,4)=0.25*S1*(P2+Z2)
C
      DSHFZ(1,2)=0.25*S2
      DSHFZ(1,3)=0.25*P2
      DSHFZ(2,2)=-0.25*P1
      DSHFZ(2,3)=-DSHFZ(2,2)
C
      DSHFZ(1,5)=-0.5*S2*P2
      DSHFZ(2,5)=-Z2*S1
C
```

```
      G(1,1,K)=0.177777
      G(1,2,K)=0.111111
      G(1,3,K)=0.00000
      G(1,4,K)=-0.444444E-01
      G(1,5,K)=0.888886E-01
      G(2,2,K)=0.444444
      G(2,3,K)=0.222222
      G(2,4,K)=0.372529E-08
      G(2,5,K)=0.222222
      G(3,3,K)=0.444444
      G(3,4,K)=0.111111
      G(3,5,K)=0.222222
      G(4,4,K)=0.177777
      G(4,5,K)=0.888886E-01
      G(5,5,K)=0.711111
  100 CONTINUE
      RETURN
      END
      SUBROUTINE ELGNDR(NT,SC,M,DET,NNP)
C
C     GENERATES ELEMENT MATRIX D FOR RECTANGULAR ELEMENTS.
C
      DIMENSION TJ(2,2)
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /AELEM/BA(200),SLX(200,4),SLY(200,4),SELK(4,4),EK(4,4)
     1,VEX(190)
      COMMON /BELEM/E(6,6,3),G(6,6,3),DSHFZ(2,6)
      COMMON /VCOM/DRX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      J1=NOD(M,1)
      J2=NOD(M,2)
      J3=NOD(M,3)
      J4=NOD(M,4)
      DRX(M)=(X(J1,1)+X(J2,1))*0.5
      IF(NREP(M).EQ.NT) GO TO 50
      NT=NREP(M)
      NN=ITYPE(M)
      K=NN-3
      BB=ABS(X(J4,2)-X(J1,2))
      AA=ABS(X(J3,1)-X(J1,1))
      BA(NT)=BB/AA
      DET= AA*BB/4.
      TJ(1,1)=2./AA
      TJ(2,2)=2./BB
      IF(NNP.EQ.NN) GO TO 15
      CALL INFLUD(NN)
   15 CONTINUE
      NNP=NN
      DO 10 I=1,NN
      SLX(NT,I)=TJ(1,1)*DSHFZ(1,I)
      SLY(NT,I)=TJ(2,2)*DSHFZ(2,I)
   10 CONTINUE
C
C     FORM ELEMENT MATRIX:-D
C
      DO 100 I=1,NN
      DO 100 J=1,NN
      IF(J-I) 105,110,110
  110 D(I,J)=DRX(M)*SC*DET*G(I,J,K)
      GO TO 100
  105 D(I,J)=D(J,I)
```

```
  100 CONTINUE
   50 CONTINUE
      RETURN
      END
      SUBROUTINE [illegible]
C
C     COMPUTES THE [illegible]
C
      COMMON /[illegible]/[illegible]
      COMMON /[illegible]/[illegible]
     1,[illegible]
      COMMON /[illegible]/[illegible]
      [illegible]=0.0
      [illegible]=0.0
      DO 10 J=1,[illegible]
      J=[illegible]
      [illegible]
      [illegible]
   10 CONTINUE
      [illegible]=ABS([illegible])
C
C     [illegible]
C
      [illegible]
      [illegible]
      [illegible]
      RETURN
      END
      SUBROUTINE [illegible]
C
C     COMPUTES [illegible]
C     [illegible]
C
      COMMON /[illegible]/[illegible]
     1,[illegible]
      COMMON /[illegible]/[illegible]
      COMMON /[illegible]/[illegible]
      [illegible]=0.0
      [illegible]=0.0
      DO 10 J=1,[illegible]
      J=[illegible]
      [illegible]
      [illegible]
   10 CONTINUE
      [illegible]
      [illegible]
      [illegible]
      IF([illegible]) GO TO 20
      [illegible]
      [illegible]
      IF([illegible]
      GO TO 30
   20 CONTINUE
      [illegible]
      IF([illegible]
   30 CONTINUE
      RETURN
      END
      SUBROUTINE [illegible]
C
```

```
      C      IDENTIFIES NODES WHERE HEAD VALUES ARE PRESCRIBED.
      C
             COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
             COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
             COMMON /WSCREN/XSCR(5),HSCR(5)
             K=0
             NFND=1
             DO 30 I=1,NSCREN
             XST=XSCR(I)-0.01
             XEND=XST+HSCR(I)+0.02
             DO 40 J=1,NNODE
             L=NFND+J-1
             IF(L.EQ.1) GO TO 222
             IF(X(L,1).GT.RW) GO TO 30
         222 CONTINUE
             IF((X(L,2).LT.XST).OR.(X(L,2).GT.XEND)) GO TO 70
          22 K=K+1
             JBD(K)=L
             DISP(K)=HW
             GO TO 40
          70 IF(X(L,2).GT.XEND) GO TO 30
          40 CONTINUE
             NFND=L+1
          30 CONTINUE
             J=K
             NBW=J
             NST=NNODE-NDRO+1
             DO 25 I=NST,NNODE
             J=J+1
             JBD(J)=I
             DISP(J)=HO
          25 CONTINUE
             NBD=J
             RETURN
             END
             SUBROUTINE BNDFIX(IPENTR,ZB,HW,HO,NNODE,NBD,NDW,NDRO,NBW)
      C
      C      LOCATES NODES WHERE HEAD VALUES ARE FIXED.
      C
             COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
             COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
             ZTOL=0.01
             J=0
             DO 10 I=1,NDW
             ZDIF=X(I,2)-ZB
             IF(IPENTR.NE.0) ZDIF=-ZDIF
             IF(ZDIF.GT.ZTOL) GO TO 10
             J=J+1
             JBD(J)=I
             DISP(J)=HW
          10 CONTINUE
             NBW=J
             NST=NNODE-NDRO+1
             DO 25 I=NST,NNODE
             J=J+1
             JBD(J)=I
             DISP(J)=HO
          25 CONTINUE
             NBD=J
             RETURN
```

```
      END
      SUBROUTINE MERB3(N,M)
C
C     MERGES ELEMENT MATRIX SELK INTO GROSS VECTOR VCORE.
C
      COMMON /AELEM/BA(200),SLX(200,4),SLY(200,4),SELK(4,4),EK(4,4)
     1,VEX(190)
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
      COMMON /ACORE/VCORE(6500)
      DO 10 I=1,N
      IK=NOD(M,I)
      IF(IK.EQ.0)  GO TO 10
      DO 20 J=1,N
      JK=NOD(M,J)
      IF(IK.GT.JK)  GO TO 20
      IPOS=ID(IK)+JK-IK
      VCORE(IPOS)=VCORE(IPOS)+SELK(I,J)
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
      SUBROUTINE MERBD(N,M)
C
C     MERGES ELEMENT MATRIX D INTO GROSS VECTOR VD.
C
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
      COMMON /CSOLV/VD(6500),HINT(300,1),IPROP(300)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      DO 10 I=1,N
      IK=NOD(M,I)
      IF(IK.EQ.0)  GO TO 10
      DO 20 J=1,N
      JK=NOD(M,J)
      IF(IK.GT.JK)  GO TO 20
      IPOS=ID(IK)+JK-IK
      VD(IPOS)=VD(IPOS)+D(I,J)
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
      SUBROUTINE SYMSOL(LL,NLL)
C
C     SOLVES A LINEAR SYMMETRIC SYSTEM OF LINEAR EQUATIONS BY BANDED GAUSSIAN
C     ELIMINATION SCHEME.
C
      DIMENSION VTEMP(90)
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      COMMON /ASOLV/ISTART(300),N(300),IDUM(300)
      COMMON /BSOLV/C(300,1),V(6500)
      DOUBLE PRECISION TEMP,VTEMP
      JBOUN=1
      ID=1
      DO 10 I=1,LL
      TEMP=V(ID)
      NEB=ID+N(I)-1
      ID1=ID+1
      IF(I.EQ.JBD(JBOUN)) GO TO 16
C
```

```
C       [illegible]
C
        [illegible]
        [illegible]
        IF([illegible]) [illegible]
        DO 20 [illegible]
        [illegible]
        [illegible]
     20 [illegible]
     20 CONTINUE
        DO 25 [illegible]
        [illegible]
     25 CONTINUE
        GO TO [illegible]
     16 CONTINUE
        IF([illegible]) GO TO [illegible]
        [illegible]
        DO 120 [illegible]
        [illegible]
        [illegible]
    120 [illegible]
     12 CONTINUE
        DO 126 [illegible]
    126 [illegible]
        [illegible]
C
C       [illegible]
C
     46 CONTINUE
        [illegible]
        IF([illegible]) GO TO 35
        [illegible]
        DO 50 [illegible]
        [illegible]
        [illegible]
        [illegible]
        IF([illegible]) [illegible]
     50 CONTINUE
        IF([illegible]) GO TO [illegible]
        [illegible]
        IF([illegible]) GO TO [illegible]
    210 [illegible]
        DO 40 [illegible]
        [illegible]
     40 [illegible]
    130 CONTINUE
        [illegible]
        DO 32 [illegible]
        [illegible]
     32 CONTINUE
     30 CONTINUE
     35 CONTINUE
        [illegible]
     16 CONTINUE
C
C       BACK SUBSTITUTION
C
        [illegible]
        [illegible]
        DO 7[illegible] [illegible]
```

```
      I=LL1-IB+1
      ID=ID-N(I)
      IS=I+1
      IN=I+N(I)-1
      DO 80 J=IS,IN
      NJ=ID+J-I
      DO 75 L=1,NLL
      C(I,L)=C(I,L)-C(J,L)*V(NJ)
   75 CONTINUE
   80 CONTINUE
   70 CONTINUE
      RETURN
      END
      SUBROUTINE VDFB(LVEC)
C
C     GENERATES VECTOR VDTOP.
C
      DIMENSION D(2,2)
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
      COMMON /ADPARA/TLESS(300),HLESS(300),GK(300,1),VDTOP(200)
      NELTOP=LVEC-1
      NN=2
      ID(1)=1
      DO 10 I=2,LVEC
   10 ID(I)=ID(I-1)+2
      LENT=2*LVEC-1
      DO 108 I=1,LENT
      VDTOP(I)=0.0
  108 CONTINUE
      DO 208 IE=1,NELTOP
      IN=NDVEC(IE)
      IP=NDVEC(IE+1)
      RAVE=0.5*(X(IP,1)+X(IN,1))
      RDIF=X(IP,1)-X(IN,1)
      D(1,1)=RAVE*RDIF/3.0
      D(2,2)=D(1,1)
      D(1,2)=D(1,1)*0.5
      D(2,1)=D(1,2)
      DO 308 I=1,2
      IK=IE+(I-1)
      DO 408 J=1,2
      JK=IE+(J-1)
      IF(IK.GT.JK) GO TO 408
      IPOS=ID(IK)+JK-IK
      VDTOP(IPOS)=VDTOP(IPOS)+D(I,J)
  408 CONTINUE
  308 CONTINUE
  208 CONTINUE
      RETURN
      END
      SUBROUTINE GVMOD(LACT,SY,IGK)
C
C     MODIFIES VECTORS VK AND GK TO ACCOUNT FOR LEAKAGE FLUX ACROSS TOP
C     BOUNDARY.
C
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
      COMMON /BSOLV/CK(300,1),VK(6500)
```

```
      COMMON /CSOLV/VD(6500),HINT(300,1),IPROP(300)
      COMMON /ADPARA/TLESS(300),HLESS(300),GK(300,1),VDTOP(200)
      DO 1078 L=1,LACT
      IP1=(L-1)*2+1
      IP2=IP1+1
      IPM=IP1-1
      VF1=VDTOP(IP1)*SY
      VF2=0.0
      VFM=0.0
      IF(L.GT.1) VFM=VDTOP(IPM)*SY
      IF(L.LT.LACT) VF2=VDTOP(IP2)*SY
      I=NDVEC(L)
      J1=I
      J2=J1
      JM=J1
      IF(L.LT.LACT) J2=NDVEC(L+1)
      IF(L.GT.1) JM=NDVEC(L-1)
      SUM=VF1*HINT(J1,1)+VF2*HINT(J2,1)+VFM*HINT(JM,1)
      IF(IGK.GT.0) GK(J1,1)=GK(J1,1)+SUM
      IF(IGK.GT.0) GO TO 1078
      IS=ID(I)
      VK(IS)=VK(IS)+VF1
      IL=IS+NBAND(I)-1
      VK(IL)=VK(IL)+VF2
 1078 CONTINUE
      RETURN
      END
      SUBROUTINE GKMOD(LACT,SY)
C
C     MODIFIES MATRIX GK TO TAKE INTO ACCOUNT LEAKAGE FLUXES.
C
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      COMMON /ALEAK/QLEAK(50),HCOLD(50),HF(50),FINT(50,1),GP(40)
      COMMON /ADPARA/TLESS(300),HLESS(300),GK(300,1),VDTOP(200)
      DO 1078 L=1,LACT
      IP1=(L-1)*2+1
      IP2=IP1+1
      IPM=IP1-1
      VF1=VDTOP(IP1)*SY
      VF2=0.0
      VFM=0.0
      IF(L.GT.1) VFM=VDTOP(IPM)*SY
      IF(L.LT.LACT) VF2=VDTOP(IP2)*SY
      I=NDVEC(L)
      J1=I
      LM=L
      LP=L
      IF(L.LT.LACT) LP=L+1
      IF(L.GT.1) LM=L-1
      SUM=VF1*QLEAK(L)+VF2*QLEAK(LP)+VFM*QLEAK(LM)
      GK(J1,1)=GK(J1,1)+SUM
 1078 CONTINUE
      RETURN
      END
      SUBROUTINE BBLOCK(KCREP,N1,NFND1,NFND2,NPAT,NTSEL)
C
C     GENERATES ELEMENT CONNECTIVITIES IN BASIC BLOCKS.
C
      DIMENSION ND(3,3)
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
```

```
      DD(1,1)=[illegible]
      DD(1,2)=[illegible]
      DD(1,3)=[illegible]
      DD(2,1)=[illegible]
      DD(2,2)=[illegible]
      DD(2,3)=[illegible]
      IF([illegible]) GO TO [illegible]
      IF([illegible]) GO TO [illegible]
      [illegible]
      DO 40 [illegible]
      [illegible]
      [illegible]
      DO 30 [illegible]
      [illegible]
      [illegible]
      DO 50 [illegible]
      [illegible]
   50 CONTINUE
      [illegible]
   60 CONTINUE
      [illegible]
      [illegible]
   90 CONTINUE
      GO TO [illegible]
  200 CONTINUE
      DD(3,1)=[illegible]
      DD(3,2)=[illegible]
      DD(3,3)=[illegible]
      [illegible]
      [illegible]
      [illegible]
      DO 250 [illegible]
      [illegible]
      IF([illegible]
      [illegible]
      [illegible]
      DO 260 [illegible]
      [illegible]
      [illegible]
      DO 270 [illegible]
      IF([illegible]
      IF([illegible]
      IF([illegible]
      [illegible]
  270 CONTINUE
  260 CONTINUE
      [illegible]
      [illegible]
  250 CONTINUE
      GO TO [illegible]
  265 CONTINUE
      [illegible]
      DO [illegible]
      [illegible]
      [illegible]
      DO [illegible]
      [illegible]
      IF([illegible]
      DO [illegible]
      [illegible]
```

```
  150 CONTINUE
  140 CONTINUE
      KCREP=KCREP+1
      NTSEL=NLST+1
  190 CONTINUE
  400 CONTINUE
      RETURN
      END
      SUBROUTINE HREAD(NNODE,L,INDEX)
C
C     READS IN INITIAL NODAL VALUES.
C
      COMMON /WORKA/VWORK(500)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      COMMON /ALEAK/QLEAK(50),HCOLD(50),HF(50),FINT(50,1),GP(40)
      READ(L,3)NNODE
      NPOINT=NNODE
    3 FORMAT(I10)
      NCARD=NPOINT/6
      NCARDT=NCARD+1
      IST=1
      DO 10 J=1,NCARD
      IEND=IST+5
      READ(L,13)(VWORK(I),I=IST,IEND)
   13 FORMAT(6E13.5)
      IST=IEND+1
   10 CONTINUE
      NREM=NPOINT-NCARD*6
      IEND=IST+NREM-1
      READ(L,13)(VWORK(I),I=IST,IEND)
      DO 15 I=1,NPOINT
      IF(INDEX.EQ.1) H(I)=VWORK(I)
      IF(INDEX.EQ.2)QLEAK(I)=VWORK(I)
   15 CONTINUE
      RETURN
      END
      SUBROUTINE ELGND3(NT,SC,M)
C
C     GENERATES MATRIX D FOR TRIANGULAR ELMENTS.
C
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /CELEM/ELK(3,3,200),B(200,3),C(200,3),AREA(200)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      J1=NOD(M,1)
      J2=NOD(M,2)
      J3=NOD(M,3)
      ORX(M)=(X(J1,1)+X(J2,1)+X(J3,1))/3.
      IF(NREP(M).EQ.NT) GO TO 50
      NT=NREP(M)
      XJ=X(J2,1)-X(J1,1)
      XM=X(J3,1)-X(J1,1)
      YJ=X(J2,2)-X(J1,2)
      YM=X(J3,2)-X(J1,2)
      AREA(NT)=0.5*(XJ*YM-XM*YJ)
      AFUN=2.*AREA(NT)
      B(NT,1)=(YJ-YM)/AFUN
      B(NT,2)=    (YM)/AFUN
      B(NT,3)=   (-YJ)/AFUN
      C(NT,1)=(XM-XJ)/AFUN
      C(NT,2)=   (-XM)/AFUN
```

```
      C(NT,3)=    (XJ)/AFUN
      DO 100 I=1,3
      DO 100 J=1,3
      IF(J-I) 105,110,110
  110 ELK(I,J,NT)=B(NT,I)*B(NT,J)+C(NT,I)*C(NT,J)
      GO TO 100
  105 ELK(I,J,NT)=ELK(J,I,NT)
  100 CONTINUE
C
C     FORM ELEMENT MATRIX:= D
C
      D(1,1)=0.5*ORX(M)*AREA(NT)*SC/3.
      D(2,2)=D(1,1)
      D(3,3)=D(1,1)
      D(1,2)=D(1,1)*0.5
      D(2,1)=D(1,2)
      D(1,3)=D(1,2)
      D(3,1)=D(1,3)
      D(2,3)=D(1,2)
      D(3,2)=D(2,3)
   50 CONTINUE
      RETURN
      END
      SUBROUTINE ELGNCT(M,III,AK,BK,NT,VCOUNT,PMK)
C
C     GENERATES MATRIX SELK FOR TRIANGULAR ELEMENTS.
C
      COMMON /AELEM/BA(200),SLX(200,4),SLY(200,4),SELK(4,4),EK(4,4)
     1,VEX(190)
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /CELEM/ELK(3,3,200),B(200,3),C(200,3),AREA(200)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      IF(IDARCY(M).EQ.0) GO TO 70
  500 CONTINUE
      J1=NOD(M,1)
      J2=NOD(M,2)
      J3=NOD(M,3)
      CALL CONSTT(M,AK,BK,ACONST,J1,J2,J3,NT)
      GO TO 80
```

```
   70 CONTINUE
      [illegible]
      ACURV(J)=[illegible]
   80 CONTINUE
C
C     CALCULATE [illegible] MATRIX
C
      DO 200 I=1,3
      DO 200 J=1,3
      S(I,J)=[illegible]
  200 CONTINUE
      RETURN
      END
      SUBROUTINE [illegible]
C
C     COMPUTES [illegible] COEFFICIENTS FOR [illegible]
C
      COMMON /[illegible]/[illegible]
      COMMON /[illegible]/[illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
  500 CONTINUE
      RETURN
      END
      SUBROUTINE [illegible]
C
C     COMPUTES [illegible] PROPERTIES [illegible]
C
      COMMON /[illegible]/[illegible]
      COMMON /[illegible]/[illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      IF([illegible]) GO TO 20
      [illegible]
      [illegible]
      IF(ABS([illegible]).[illegible]) [illegible]
      GO TO 30
   20 CONTINUE
      [illegible]
      IF(ABS([illegible]).GE.[illegible]) [illegible]
   30 CONTINUE
      RETURN
      END
      SUBROUTINE [illegible]
C
C     [illegible] IN THE GRAVEL PACKED ZONE.
C
      COMMON /[illegible]/[illegible]
      IF([illegible]) GO TO 20
      GO TO 10
   20 CONTINUE
      [illegible]
      [illegible]
```

```
      PKK=PMGP
      VCR=VGP
   10 CONTINUE
      RETURN
      END
      SUBROUTINE AQDIS(NLEN,QAQFR,QRDIF,DELT,TH,RCSNG,IQ,QFIX,DWD)
C
C     COMPUTES TOTAL DISCHARGE INTO THE WELL.
C
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      COMMON /BQCAL/VS(2000),QWB(50)
      COMMON /ATIME/TIME(60),SW(60),DSW(5),QCALC(5)
      QSUM=0.0
      TWPI=44./7.
      CALL QMULT(NLEN,QSUM)
      QSUM=ABS(TWPI*QSUM)/(0.5*DELT)
      QAQFR=QSUM
      ACSNG=0.5*TWPI*RCSNG**2
      TRM=ABS(ACSNG*DWD*2./DELT)
      QCALX=QAQFR+TRM*10.**3
      QRDIF=ABS(QFIX-QCALX)
      QCALC(IQ)=QCALX
      RETURN
      END
      SUBROUTINE QMULT(NBW,QSUM)
C
C     COMPUTES NODAL FLUXES AT WELL BOUNDARY.
C
      COMMON /ALEAK/QLEAK(50),HCOLD(50),HF(50),FINT(50,1),GP(40)
      COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
      COMMON /BQCAL/VKQ(2000),QWB(50)
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      DO 10 L=1,NBW
      I=JBD(L)
      IS = ID(I)
      IL = ID(I)+NBAND(I)-1
      QWB(L)=0.0
      DO 20 J = IS, IL
      K=I+J-IS
      QWB(L)=QWB(L)+VKQ(J)*H(K)
   20 CONTINUE
      IF(I.EQ.1) GO TO 15
      I1 = I-1
      IST= ISTART(I)
      DO 30 J= IST,I1
      K  = I1- J+1
      IP =   ID(J) + K
      QWB(L)=QWB(L)+VKQ(IP)*H(J)
   30 CONTINUE
   15 CONTINUE
      QWB(L)=QWB(L)-GP(L)
      QSUM=QSUM+QWB(L)
   10 CONTINUE
      RETURN
      END
      SUBROUTINE ROUT(NNODE)
C
```

```
C     PRINTS OUT HEAD VALUES.
C
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      COMMON /ADPARA/TLESS(300),HLESS(300),VKD(300,1),VDTOP(200)
      DATA NPRINT/3/
      WRITE(NPRINT,53)
   53 FORMAT(///)
      WRITE(NPRINT,3)
      WRITE(NPRINT,13)
      WRITE(NPRINT,23)
      WRITE(NPRINT,13)
      WRITE(NPRINT,3)
    3 FORMAT(5X,50('*'))
   13 FORMAT(5X,'*',48X,'*')
   23 FORMAT(5X,'*',11X,'FINAL RESULTS OF ANALYSIS',12X,'*')
      WRITE(NPRINT,33)
      DO 10 I=1,NNODE
      WRITE(NPRINT,43)I,X(I,1),H(I),TLESS(I),HLESS(I)
   10 CONTINUE
   33 FORMAT(///,20X,'HEAD .VS. RADIUS AND 1/U .VS. W(U)',///,
     1          10X,'NODE',10X,'R-COORD',10X,'HEAD',14X,'1/U',19X,
     1'W(U)',//)
   43 FORMAT(10X,I3,6X,F10.2,8X,F10.4,7X,E11.4,10X,F10.4)
      RETURN
      END
      SUBROUTINE ROEST(DIFFUS,TM,LVEC,QFIX,TMIS,RO,NELEM,NNODE,NELTO,
     1   LST,LSTEL,LVST)
C
C     ESTIMATES RADIUS OF INFLUENCE AT TIME TM.
C
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      COMMON /VCOM/ORX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      FPI=88./7.
      CONST=QFIX/(FPI*TMIS)
      DO 10 I=LVST,LVEC
      U=RVEC(I)**2/(4.*DIFFUS*TM)
      WW=W(U)
      SDRAW=CONST*WW
      IF(SDRAW.GT.0.001) GO TO 10
      NNODE=NDVEC(I)
      RO=RVEC(I)
      GO TO 20
   10 CONTINUE
      NNODE=NDVEC(LVEC)
      RO=RVEC(LVEC)
   20 CONTINUE
      LST=NNODE
      LVST=I
      DO 30 I=LSTEL,NELTO
      IF(ORX(I).LT.RO) GO TO 30
      NELEM=I-1
      GO TO 40
   30 CONTINUE
      NELEM=NELTO
   40 CONTINUE
      LSTEL=NELEM
      RETURN
      END
      SUBROUTINE TIGEN(NTICR,TFACTR,TMUL,DTMUL,RW,PM,SS,IWBC,QFIX,TPAT)
```

```
C
C     [illegible]
C
      COMMON /[illegible]/[illegible]
      [illegible]
      [illegible]
      [illegible]
      IF(IBAK.EQ.2) GO TO 15
      DO 10 I=2,[illegible]
      [illegible]
      [illegible]
   10 CONTINUE
      GO TO 17
   15 CONTINUE
      DO 20 I=2,[illegible]
      [illegible]
      [illegible]
   20 CONTINUE
      DO 25 I=2,[illegible]
      [illegible]
   25 CONTINUE
   17 CONTINUE
      [illegible]
      [illegible]
      [illegible]
      DO 30 I=1,[illegible]
      [illegible]
   30 CONTINUE
      RETURN
      END
      [illegible]
C
C     [illegible] FUNCTION.
C
      [illegible]=0.577*[illegible]
      [illegible]
      [illegible]
      J=0
      DO 10 I=1,30
      [illegible]
      IF([illegible]) GO TO 20
      [illegible]
      J=0
      GO TO 30
   20 CONTINUE
      [illegible]
      J=1
   30 CONTINUE
      [illegible]
      IF([illegible]) GO TO 40
      [illegible]
   10 CONTINUE
   40 CONTINUE
      RETURN
      END
      SUBROUTINE [illegible]
C
C     [illegible]
C     [illegible]
C
```

```
      COMMON /ASOLV/ISTART(300),NBAND(300),ID(300)
      COMMON /CSOLV/VK(6500),D(300,1),IPROP(300)
      COMMON /ADPARA/TLESS(300),HLESS(300),VKD(300,1),VDTOP(200)
      L=1
      DO 10 I=1,NNODE
      IS = ID(I)
      IL = ID(I)+NBAND(I)-1
C
      VKD(I,1) = 0.0
      DO 20 J = IS, IL
      K=I+J-IS
      VKD(I,1)=VKD(I,1)+VK(J)*D(K,L)
   20 CONTINUE
C
      IF(I.EQ.1) GO TO 40
      I1 = I-1
      IST= ISTART(I)
C
      DO 30 J= IST,I1
      K  = I1- J+1
      IP =    ID(J) + K
      VKD(I,1)=VKD(I,1)+VK(IP)*D(J,L)
   30 CONTINUE
   40 CONTINUE
   10 CONTINUE
      RETURN
      END
      SUBROUTINE FQSET(IT,ITCUR,DELT,FQ,TPAT)
C
C
      COMMON /ATIME/TIME(60),SW(60),DSW(5),QCALC(5)
      IF(TPAT.EQ.1) GO TO 20
      IF(IT.GE.3) GO TO 10
      IF((IT.EQ.1).AND.(ITCUR.GT.IT)) FQ=SW(IT)
      GO TO 20
   10 CONTINUE
      DO 15 I=1,IT
      HDLTA=0.499*DELT
      IF(HDLTA.GT.TIME(I)) GO TO 15
      FQ=SW(I)
      GO TO 20
   15 CONTINUE
   20 CONTINUE
      RETURN
      END
      SUBROUTINE SWMOD(IQ,IT,RCSNG,DLTA,QFIX,QAQFR,SWOLD,DSOLD,TPAT,FQ)
C
C     ADJUSTS THE VALUE OF WELL DRAWDOWN.
C
      COMMON /ATIME/TIME(60),SW(60),DSW(5),QCALC(5)
      COMMON /ALEAK/QLEAK(50),HCOLD(50),HF(50),FINT(50,1),GP(40)
      DELT=DLTA/10.**3
      ACSNG=22.0*RCSNG**2/7.0
      IF(IQ.NE.1) GO TO 15
      IF(ACSNG.GT.0.0) GO TO 35
      IF(IT.GT.5) GO TO 10
      DSW(IQ)=-DSOLD
      GO TO 20
   35 CONTINUE
      IF(IT.GT.5) GO TO 10
```

```
      QRATIO=QAQFR/QFIX
      IF(ABS(QRATIO).GE.0.8) GO TO 10
      TMM=TIME(IT)-0.5*DLTA
      FACTR=0.5*DELT/ACSNG
      QDEL=QFIX-QAQFR*0.95*TIME(IT)/TMM
      IF(ABS(QRATIO).GE.0.5) QDEL=QFIX-QAQFR
      DSW(IQ)=FACTR*QDEL
      DSW(IQ)=-DSW(IQ)
      GO TO 20
   10 CONTINUE
      TOLD=TIME(IT-2)
      ARGL1=(TIME(IT)-0.5*DLTA)/TOLD
      ARGL2=TIME(IT-1)/TOLD
      TLOG=ALOG(ARGL1)/ALOG(ARGL2)
      DSW(IQ)=(SW(IT-1)-SW(IT-2))*(1.-TLOG)
      DSW(IQ)=-DSW(IQ)
      IF(DSW(IQ).GT.0.) DSW(IQ)=0.0
      GO TO 20
   15 CONTINUE
      IF(IQ.GT.2) GO TO 25
      IF(TPAT.EQ.2) GO TO 62
      IF(QFIX.GT.0.) GO TO 52
      DSW(IQ)=0.5*DSW(1)
      IF(QCALC(1).LT.QFIX) DSW(IQ)=1.5*DSW(1)
      GO TO 20
   52 CONTINUE
      DSW(IQ)=DSW(IQ-1)*QFIX/QCALC(IQ-1)
C**** IF(ACSNG.LE.0.) DSW(IQ)=SW(IT)*QFIX/QCALC(IQ-1)-SWOLD
      GO TO 20
   62 CONTINUE
      IF((ACSNG.LE.0.).AND.(FQ.LT.0.)) GO TO 40
      DSW(IQ)=DSW(1)*QFIX/QCALC(1)
      GO TO 20
   40 CONTINUE
      SWCOR=SW(IT)-FQ*(QCALC(1)-QFIX)/QFIX
      DSW(IQ)=SWCOR-SWOLD
      GO TO 20
   25 CONTINUE
      DDSW=DSW(IQ-1)-DSW(IQ-2)
      TERM1=QFIX-QCALC(IQ-1)
      TERM2=QCALC(IQ-1)-QCALC(IQ-2)
      DQR=TERM1/TERM2
      DSW(IQ)=DSW(IQ-1)+DDSW*DQR
   20 CONTINUE
      SW(IT)=DSW(IQ)+SWOLD
      DSOLD=-DSW(IQ)
      RETURN
      END
      SUBROUTINE HPUNCH(NNODE,L,INDEX)
C
C     PUNCHES OUT HEAD VALUES AT FINAL TIME.
C
      COMMON /WORKA/VWORK(500)
      COMMON /VCOM/QRX(300),VEL(300),H(300),IDARCY(300),D(4,4)
      COMMON /ALEAK/QLEAK(50),HCOLD(50),HF(50),FINT(50,1),GP(40)
      NPOINT=NNODE
      DO 15 I=1,NPOINT
      IF(INDEX.EQ.1) VWORK(I)=H(I)
      IF(INDEX.EQ.2) VWORK(I)=QLEAK(I)
   15 CONTINUE
```

```
      [illegible]
      [illegible]
      WRITE(6,23)[illegible]
   23 FORMAT(///,10X,'TOTAL NUMBER OF [illegible] CARDS = ',I5)
      WRITE(6,3)[illegible]
    3 FORMAT(1H1)
      [illegible]
      DO 10 I=1,[illegible]
      [illegible]
      WRITE(6,13)(VP[illegible](I),I=[illegible])
   13 FORMAT([illegible])
      [illegible]
   10 CONTINUE
      [illegible]
      [illegible]
      WRITE(6,13)([illegible](I),I=[illegible])
      RETURN
      END
      SUBROUTINE [illegible]
C
C     [illegible] CONVENTIONAL [illegible]
C
      DIMENSION [illegible]
      COMMON /[illegible]/[illegible]
      COMMON /[illegible]/[illegible]
C
      [illegible]
C
      WRITE(6,3)
    3 FORMAT(///,[illegible],'[illegible]',///,[illegible],'[illegible]',
     1 [illegible],'[illegible] VALUE',//)
      [illegible]
      IF([illegible]) GO TO [illegible]
      [illegible]
      [illegible]
      GO TO 16
    5 [illegible]
      [illegible]
   16 [illegible]
C
      DO 70 I=1,[illegible]
      [illegible]
      [illegible]
      [illegible]
   20 CONTINUE
      [illegible]
      [illegible]
      [illegible]
      DO 30 [illegible]
      IF([illegible].GT.[illegible]) GO TO 40
      [illegible]
      [illegible]
      [illegible]
      [illegible]
      GO TO 50
   40 CONTINUE
      [illegible]
   50 CONTINUE
      [illegible]
      [illegible]
```

```
      QLEAK(I)=QCUNT+DQ
      WRITE(3,13)I,QLEAK(I)
   13 FORMAT(10X,I5,20X,E13.3)
   30 CONTINUE
      WRITE(3,13) NNODE,QLEAK(NNODE)
      RETURN
      END
      FUNCTION HPW(U,RM,SCLEN,TH)
C
C     EVALUATES HANTUSH'S WELL FUNCTION FOR PARTIALLY PENETRATING WELLS.
C
      DOUBLE PRECISION U,HWF,DSUM,SUM
      DIF=TH-SCLEN
      PI=22./7.
      PISQ=PI**2
      FACTR=2.*TH*TH/(PISQ*SCLEN**2)
      SUM=0.0
      DO 30 I=1,50
      APSI=3.14*I*RM
      ARGU=I*3.14*DIF/TH
      TERM=SIN(ARGU)**2/I**2
      DSUM=TERM*HWF(U,APSI)
      SUM=SUM+DSUM
      IF((I.GT.15).AND.(SUM.LT.1.D-10)) GO TO 40
      IF(SUM.LT.1.D-20) GO TO 30
      SR=DSUM/SUM
      STOL=ABS(SR)
      IF(STOL.LT.0.0001) GO TO 40
   30 CONTINUE
   40 CONTINUE
      UX=U
      SUM=SUM*FACTR+W(UX)
      HPW=SUM
      RETURN
      END
      FUNCTION HJW(U,RB,Y)
C
C     EVALUATES INTEGRAND EXPRESSION OF HANTUSH'S WELL FUNCTION.
C
      DOUBLE PRECISION U,F,DEXP,HJW,TERM
      TERM=-Y-RB**2/(4.*Y)
      F=DEXP(TERM)/Y
      HJW=F
      RETURN
      END
      FUNCTION HWF(U,APSI)
C
C     EVALUATES HANTUSH FUNCTION BY SIMSON'S 3-POINT FORMULA.
C
      DOUBLE PRECISION HDW,U,HWF,DSUM,SUM,DW1,DW2,DW3,DABS,DY,HJW
      TMUL=1.4
      Y1=U
      SUM=0.0
      DO 30 I=1,50
      Y3=Y1*TMUL
      Y2=(Y1+Y3)/2.
      DY=Y3-Y1
      DW1=HJW(U,APSI,Y1)
      DW2=HJW(U,APSI,Y2)
      DW3=HJW(U,APSI,Y3)
```

```
      DSUM=DY*(DW1+4.*DW2+DW3)/6.
      SUM=SUM+DSUM
      Y1=Y3
      IF((I.GT.15).AND.(SUM.LT.1.D-10)) GO TO 40
      IF(SUM.LT.1.D-20) GO TO 30
      SR=DSUM/SUM
      STOL=ABS(SR)
      IF(STOL.LT.0.0001) GO TO 40
   30 CONTINUE
   40 CONTINUE
      HWF=SUM
      RETURN
      END
      SUBROUTINE DSWINT(DSOLD,BK,QFIX,TMIS,TH,RW,SCLEN,DIFFUS,CUNST)
C
C     ESTIMATES WELL DRAWDOWN FOR FIRST TIME STEP.
C
      COMMON /ATIME/TIME(60),SW(60),DSW(5),QCALC(5)
      DOUBLE PRECISION UW
      DLAMDA=BK*QFIX*TMIS/(TH*TH*RW)
      DLAMDA=7.*DLAMDA/44.
      RM=RW/TH
      GAMMA=SCLEN/TH+0.01
      CONS=4.0*DIFFUS*0.5*TIME(1)
      UW=CONS/RW**2
      V=UW
      UW=1./UW
      U=UW
      TERM=0.25*DLAMDA*(ALOG(V)-3.0)
      WW=W(U)
      IF(GAMMA.LT.1.) WW=HPW(UW,RM,SCLEN,TH)
      DSOLD=WW+1.5*DLAMDA+TERM
      IF(U.GT.0.1E-01) DSOLD=WW
      DSOLD=DSOLD*CUNST
      RETURN
      END
      SUBROUTINE DISMOD(NBW,HO,HW)
C
C     MODIFIES VECTOR DISP TO ACCOUNT FOR CONVERSION TO WATER TABLE AQUIFER
C     CONDITION.
C
      COMMON /ADISC/X(300,2),NOD(300,4),NREP(300),ITYPE(300)
      COMMON /BDISC/RVEC(50),NDVEC(50),JBD(50),DISP(50)
      DO 10 I=1,NBW
      NDW=JBD(I)
      IF(X(NDW,2).GT.HW) DISP(I)=X(NDW,2)
   10 CONTINUE
      RETURN
      END
```