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U.S. GEOLOGICAL SURVEY Water Resources Div.

Water-Resources Investigations 4-73

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

DATA REQUIREMENTS FOR MODELING A GROUND-WATER SYSTEM IN AN ARID REGION

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle DATA REQUIREMENTS FOR MODELING A GROUND-WATER SYSTEM IN AN ARID REGION			5. Report Date 6.
7. Author(s) Fred Kunkel			8. Performing Organization Rept. No. WRI 4-73
9. Performing Organization Name and Address U.S. Geological Survey, WRD California District 345 Middlefield Rd. Menlo Park, Calif. 94025			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address Same as 9 above.			13. Type of Report & Period Covered Techniques 14.

15. Supplementary Notes

16. Abstracts

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17. Key Words and Document Analysis. 17a. Descriptors

Data processing

17b. Identifiers/Open-Ended Terms

Hydrologic models

17c. COSATI Field/Group Ø7B

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution. Available from National Technical Information Service, Springfield, Va. 22151	UNCLASSIFIED	24
	20. Security Class (This Page) UNCLASSIFIED	22. Price

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UNITED STATES DEPARTMENT OF THE INTERIOR

Rogers C. B. Morton, Secretary

GEOLOGICAL SURVEY

Vincent E. McKelvey, Director

For additional information write to:

District Chief
Water Resources Division
U.S. Geological Survey
345 Middlefield Rd.
Menlo Park, Calif. 94025

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ABSTRACT

The mathematical formulas are known and the computer capability exists that permits one to accurately model an interrelated surface- and ground-water system in an arid region, if the required data can be assembled. Existing data are often insufficient to provide the needed inputs to construct and verify a model that will be adequate for predicting future water levels. However, even unverified models may be of considerable value in providing the basis for determining the direction and scope of future data-collection programs to insure maximum return.

INTRODUCTION

Purpose and scope.--This discussion is in partial response to continuing requests to the U.S. Geological Survey by local, State, and other Federal agencies for hydrologic studies of selected areas or problems. As part of those requests the question is commonly asked, "What types of geologic and hydrologic data need be collected?"

There is no direct answer to the above question. To properly respond one must first ask, "What is the problem to be solved?" When the problem is identified then the types of data to be collected and the required degree of refinement of those data can be determined.

For some problems one may only need to determine the average-annual base flow of a stream. For other problems approximate determination of the areal extent and gross storage capacity of a ground-water basin may be adequate. However, for some problems a mathematical model or other simulation of the hydrologic system may be required. Again, the nature of the problem, for the most part, will determine the required degree of data refinement and the type of model needed. In this regard it must be kept in mind that the fundamental reason for constructing a hydrologic model is to simulate the response of a system to stresses, usually man-induced ones. Although the stresses may be hydraulic, hydrologic, ecologic, or chemical, this evaluation is confined to a general discussion of the data, the parameters, or the inputs needed to simulate or model mathematically the effect of those hydraulic or hydrologic stresses that would result from consumptive use of water and might produce such effects as a decline in ground-water levels or reduced streamflow.

Also, an essential underlying assumption is that the real system will respond to future stresses in a manner similar to its response to past stresses, and that an appropriate array of physical parameters used to simulate the real system will provide the key to predicting the effects of future stresses.

DATA REQUIREMENTS

Levels of Data

Before considering the data needed for a model it will be helpful to first consider the data as being available at two levels. For convenience of this discussion let us call the first level "raw data" and the second level "processed data."

The raw data for geohydrologic studies consist of field observations of geology--that is, the rock outcrops, alinement of faults, geologic structure, well-log data, and geophysical measurements. Other raw data consist of records of well yield, ground-water levels, ground-water pumpage, surface-water diversions, streamflow, evaporation, evapotranspiration, and precipitation. This list is not complete but it does cover the more commonly available raw data for hydrologic studies.

From these raw data the hydrologist prepares the processed data that constitute the data input to a model. In the following discussion we will refer to the raw data but we are concerned primarily with the processed data needed for input to the model.

Selection of Stress-History Period

Prior to extensive collection or processing of new raw data for simulation of the hydrologic system, the readily available raw data should be inspected and a stress-history time period should be selected for which the model will be tested and verified.

It is not always necessary but, if possible, it generally is desirable to select steady-state or natural conditions for the start of the stress-history period. That is, select a period for which the preceding hydrologic conditions reflect both average climatic conditions and conditions unaffected by man. In other words, pumping and other diversions should be nil or small and the preceding period of time should not have been one of unusually high or unusually low precipitation and runoff.

For the purposes of this discussion let us assume the year 1920 fulfills the above-described conditions for a hypothetical desert ground-water basin and thus approximates steady-state or natural conditions. Furthermore, let us assume that the nature of the available data and the history of hydrologic development permit dividing the stress-history period into two parts: Say from 1920 through 1953 and from 1954 through 1968. For the above assumed conditions, the following processed data would be required as input to simulate or model the assumed interrelated surface-water ground-water system.

Processed Data

Geologic map.--The first processed-data input needed for the assumed hydrologic study is a geologic map. That map should differentiate and show the areal extent of the water-bearing and non-water-bearing deposits, the principal faults, and other geologic features that affect the occurrence and movement of ground water (fig. 1). Sufficient geologic detail[1] is necessary to define the boundaries of the water-bearing deposits and, therefore, the boundaries of the model. Greater geologic detail, unless it relates directly to the hydrologic problem, generally is not only unneeded but may be undesirable if it adds confusing detail to an already complex problem. Also, for convenience of modeling, the boundary of the basin can be generalized by segmented straight lines, as shown in figure 1.

Maps showing transmissivity and storage coefficient.--From well-log, water-level, well-yield, and other raw data collected during the study, two additional maps must be prepared. One map (fig. 2) must show the distribution of transmissivity for the entire model area, the other (fig. 3) must show the storage coefficient for the same area.

Streamflow, precipitation, and other boundary conditions.--Additional items of processed-data input consist of estimates of streamflow, precipitation, and other boundary conditions. Streamflow estimates are needed for the principal streams at the ground-water-basin boundaries. Also, losses or gains in flow must be estimated for the various reaches of the streams within the model area. For precipitation one must estimate the quantity of direct infiltration to ground water. In addition, one must estimate ground-water inflow and outflow across aquifer boundaries and vertical leakage between aquifers, if any, plus any other gains or losses to the hydrologic system. The quantitative description of these items permits one to estimate the ground-water recharge and discharge and, along with the geologic data, to specify the hydrologic-boundary conditions (fig. 4).

Having defined the area to be modeled and the boundary conditions, a grid or nodal network for the area must be determined. For a simple problem a single node for the entire area of study might be adequate; for other areas (fig. 5) several hundred nodes might be necessary.

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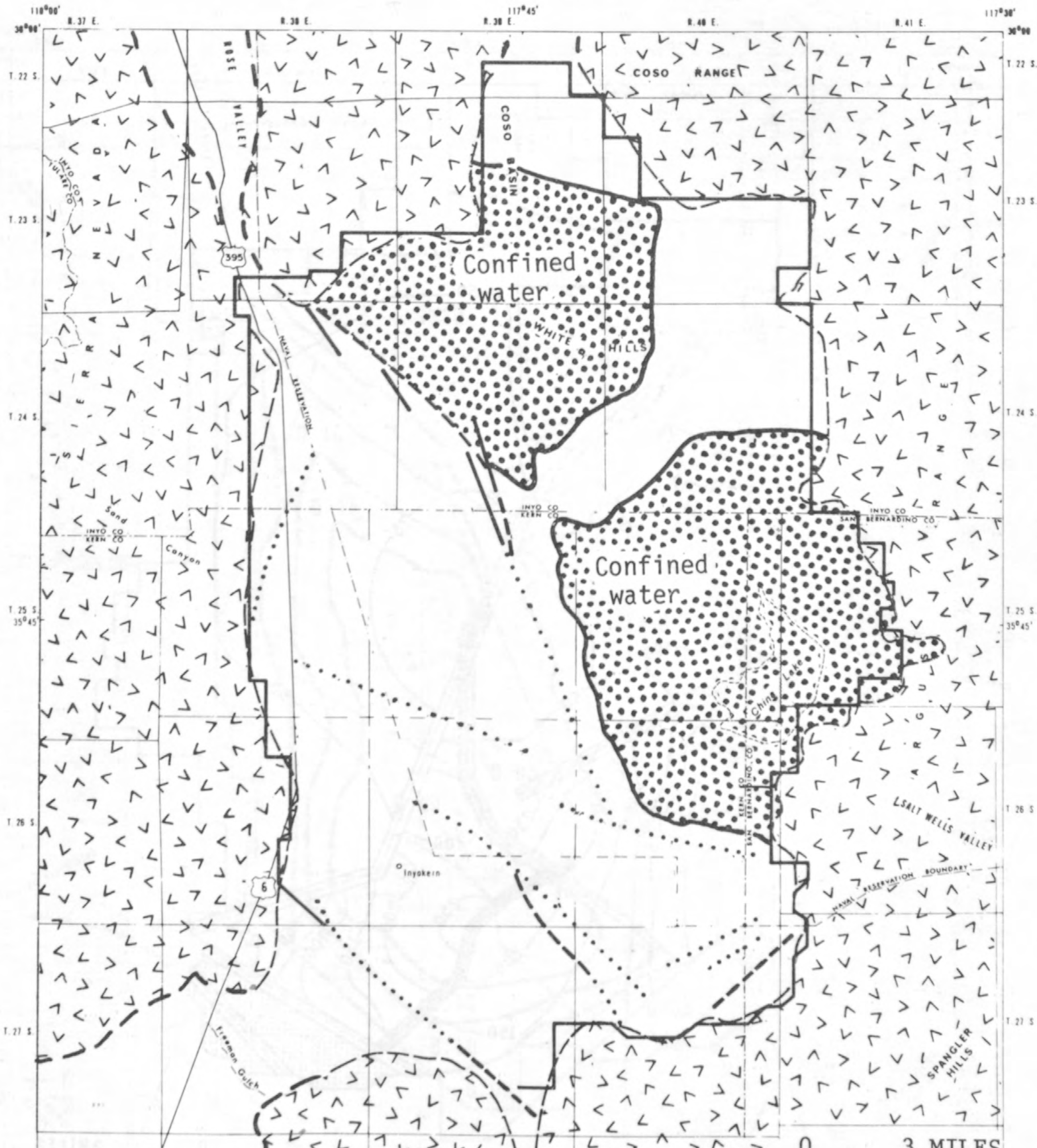
[1]For a ground-water system where about 10 percent or more of the water-yielding deposits are dewatered, geologic sections may also be needed to provide the basis for estimating the decrease in transmissivity as the water table declines.



EXPLANATION

Water-bearing deposits
Stippled where water is confined

Non-water-bearing deposits

Fault
Dashed where inferred, dotted where concealed

Generalized boundary of ground-water basin and boundary of area to be modeled

FIGURE 1.--Geology of the study area.

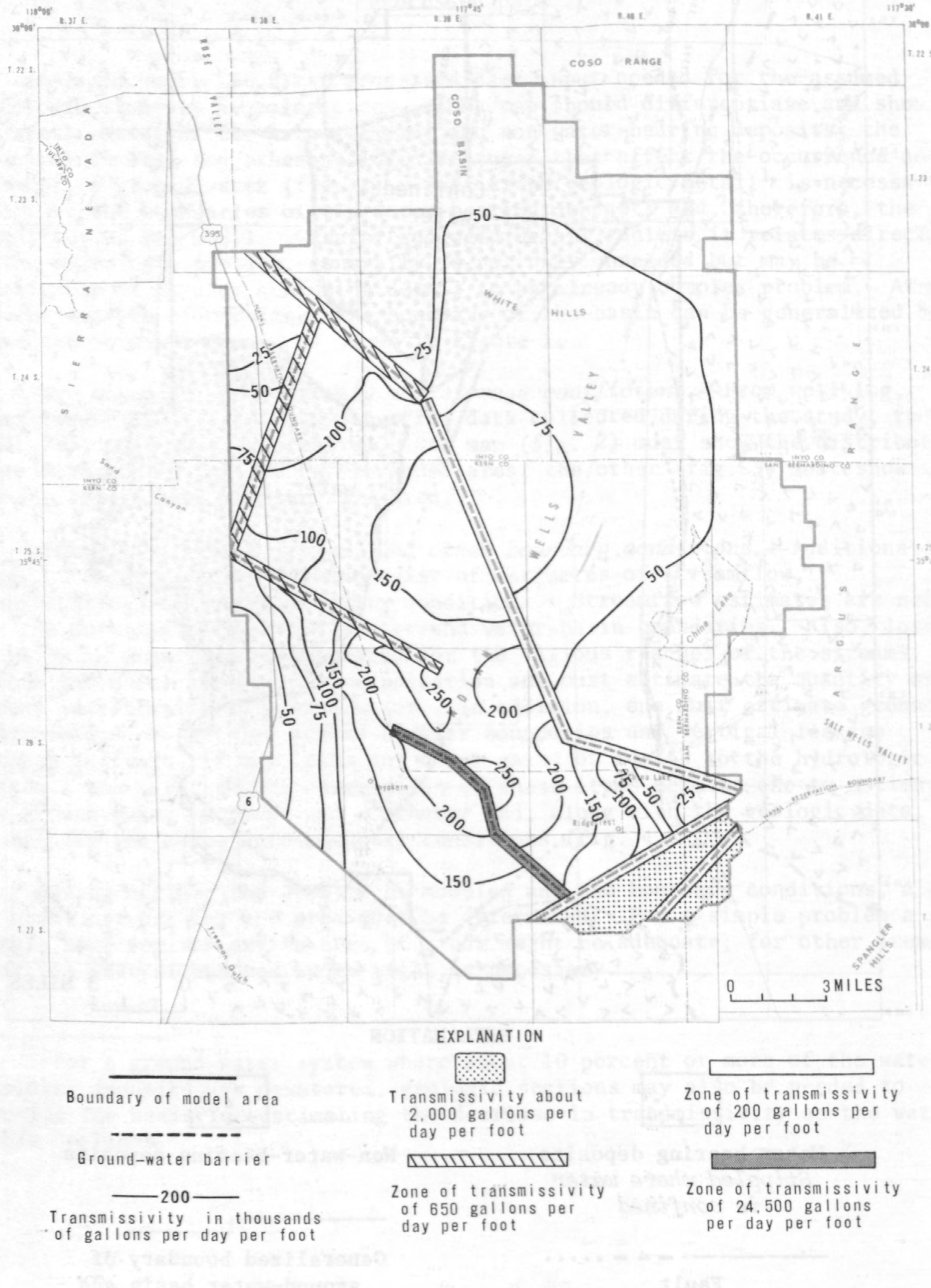


FIGURE 2.--Transmissivity.

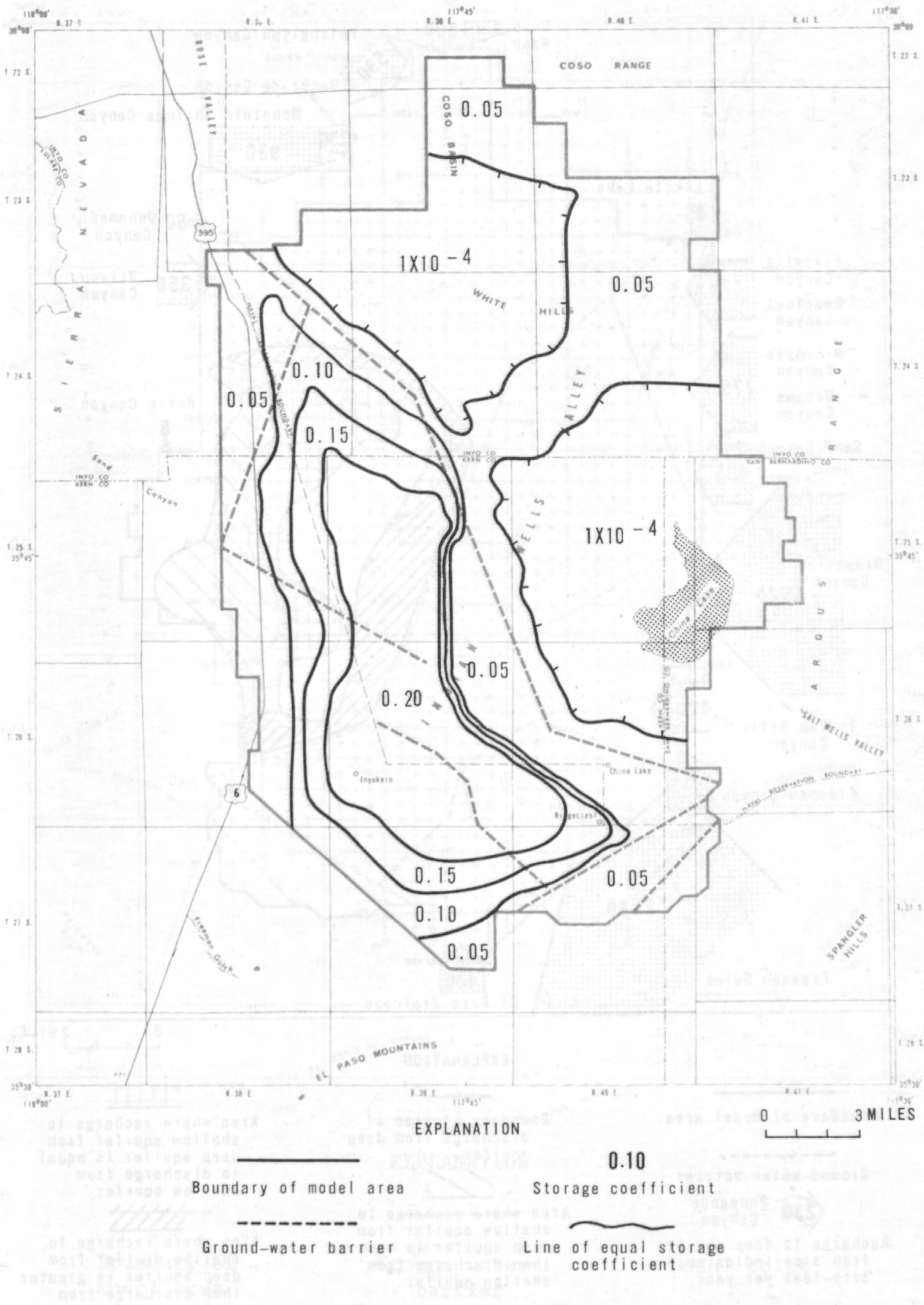


FIGURE 3.--Storage coefficient.

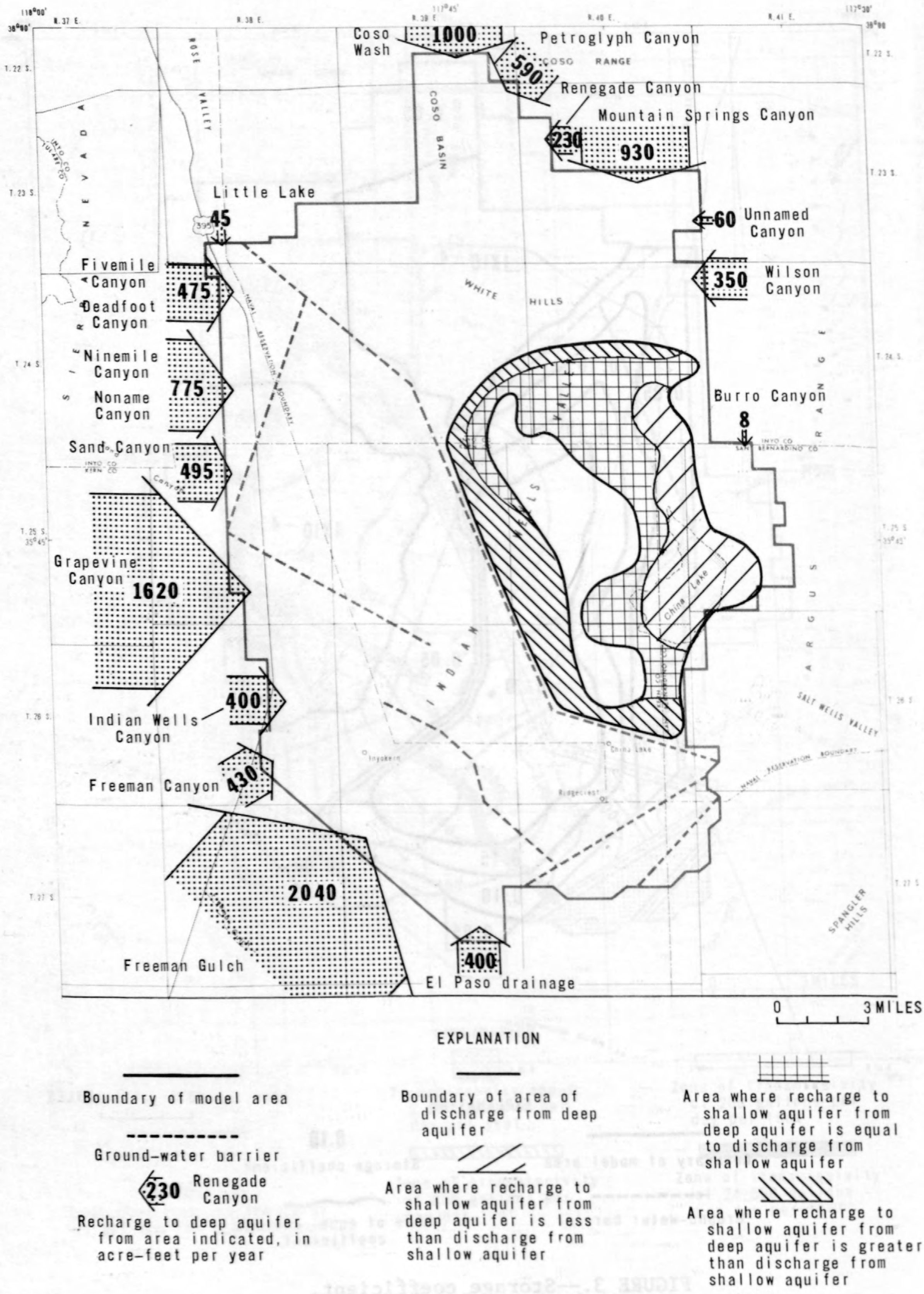
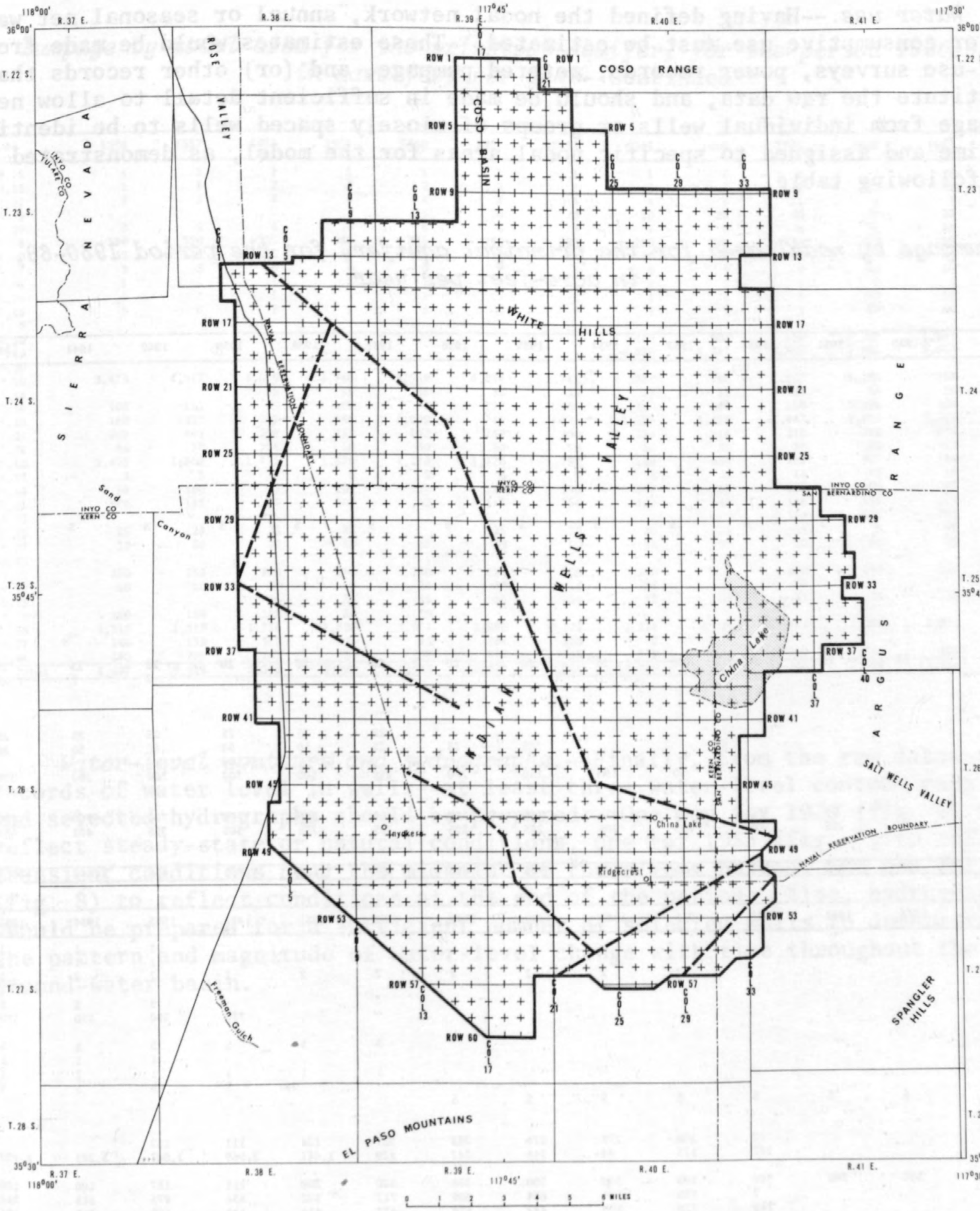


FIGURE 4.--Hydrologic-boundary conditions.



EXPLANATION

Boundary of model area	Ground-water barrier	Nodal point

FIGURE 5.--Nodal network.

Water use.--Having defined the nodal network, annual or seasonal net water use or consumptive use must be estimated. These estimates would be made from land-use surveys, power records, metered pumpage, and (or) other records that constitute the raw data, and should be made in sufficient detail to allow net pumpage from individual wells or groups of closely spaced wells to be identified in time and assigned to specific nodal areas for the model, as demonstrated by the following table.

Pumpage by nodal area for the principal aquifer, for the period 1930-68, in acre-feet per year

Node	1930	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	1941	1942
29,15													
30,15													
31,21													
36, 9													
36,19													
37, 8													
38, 9													
39,17													
40,12													
41,24													
42,18													
43, 9		5	5	5	5	5	5	5	5	5	5	5	5
46,10													
46,19													
46,20													
47,10													
47,14													
47,19													
47,20													
47,21													
47,22													
48,10	20	20	20	20	20	20	20	20	20	20	25	25	25
48,17											2	2	2
48,19													
48,21													
48,22													
48,25								25	25	25	25	25	25
48,27						25	25	25	50	50	50	50	50
49,20										100			
49,21				50	100	150	200	250	300	300	300	300	300
49,27													
50,23													
50,26		75	175	225	275	300	350	400	500	700	700	700	700
51,26	105	205	205	205	205	205	205	205	255	305	355	405	455
51,27													
52,26													
Total	125	305	405	505	605	705	805	930	1,155	1,505	1,462	1,512	1,562

Node	1943	1944	1945	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955
29,15											1	1	1
30,15											1	1	1
31,21				2	2	2	2	2	2	2	2	2	2
36, 9													
36,19											5	5	5
37, 8										350	350	350	350
38, 9													
39,17								5	5	5	5	5	5
40,12											1	1	1
41,24								1	1	1	1	1	1
42,18										5	5	5	5
43, 9	5	5	5	5	5	5	5						
46,10													
46,19													
46,20			72	208	277	276	283	227	128	111	132		
47,10			182	123	44	246	742	829	1,441	2,069	2,007	3,221	2,720
47,14													
47,19	300	300	300	300	300	300	300	300	200	211	187	100	100
47,20			7	180	401	644	685	712	592	536	475	311	314
47,21			149	220	500	482	534	677	416	547	558	411	384
47,22				180	271	302	257	340	263	237	222	130	100
48,10	25	25	25	25	28	35	35	36	1,034	738	1,192	1,040	1,847
48,17	2	2	2	2	2	2	2	5	5	5	5	5	5
48,19									100	100	100	100	100
48,21												100	100
48,22													
48,25	25	25	25	25	25	25	25	25	25	25	25	25	25
48,27	50	50	50	50	50	50	50	50	50	50	50	50	50
49,20													
49,21	300	300	300	300	300	300	300	300	300	300	300	300	300
49,27									35	40	40	45	45
50,23													
50,26	700	700	700	700	700	700	700	600	500	400	350	300	250
51,26	505	540	650	775	850	925	1,000	1,070	935	960	987	1,132	1,246
51,27			190	19	243	236	301	613	139	69	147	37	123
52,26									140	150	160	170	175
Total	1,912	1,947	2,657	3,114	3,998	4,530	5,221	5,792	6,311	6,911	7,306	7,848	8,255

Pumpage by nodal area for the principal aquifer, for the period 1930-68, in acre-feet per year--Continued

Node	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968
29,15	1	1	1	1	1	1	1	1	1	1	2	2	3
30,15	1	1	2	2	2	2	2	2	2	2	12	13	9
31,21	2	2	4	4	4	4	4	4	4	1	9	7	5
36, 9					35	20	20	20	20	20	20	20	20
36,19	5	5	6	6	6	6	6	6	6	6	31	31	18
37, 8	350	350	385	385	385	280	280	280	280	280	280	280	280
38, 9	35	35	35	35	35.	20	20	20	20	20	20	20	20
39,17	5	5	9	9	9	9	9	9	9	9	15	15	11
40,12	1	1	1	1	1	1	1	1	1	1	3	2	2
41,24	1	1	1	1	1	1	1	1	1	1	10	11	11
42,18	5	5	5	5	5	5	5	5	5	5	18	26	29
43, 9													
46,10								765	904	459	1,107	1,241	964
46,19								4,026	3,387	3,565	2,933	3,665	3,161
46,20													
47,10	3,473	4,017	3,079	3,780	3,989	4,034	3,741	372	766	1,237	1,186	864	1,727
47,14			35	35	35	35	35	35	35	35	35	35	35
47,19	100	111	99	103	92	117	150	162	165	168	198	225	251
47,20	180	251	747	583	1,009	716	971	1,303	1,450	1,447	1,081	1,259	887
47,21	297	441	338	237	142	167	200	212	215	218	248	275	251
47,22	86	50	115	50	50	50	50	50	50	50	50	50	
48,10	1,628	1,308	1,475	1,570	1,279	1,426	1,792	138	635	282	917	199	822
48,17	5	5	5	5	5	6	7	8	9	10	11	14	16
48,19	98	100	99	103	92	117	150	162	165	168	198	225	251
48,21	100	111	99	103	92	117	150	162	165	168	198	225	251
48,22										154	662	735	914
48,25	25	25	25	25		25	25	25	25	25	25	25	
48,27	50	50	50	50	25	50	50	50	50	50	50	50	
49,20													
49,21	250	250	250	250	250	250	250	250	250	250	250	250	
49,27	50	50	30	30	30	32	34	34	36	28			
50,23			35	35	35	35	35	35	35	35	35	35	
50,26	250	150	100	50	50								
51,26	1,319	1,319	1,714	1,896	1,911	1,980	2,122	2,214	2,059	2,164	2,012	2,014	1,998
51,27	165	139	313	245	45	254	368	2					
52,26	185	205	261	295	298	318	338	379	431	481	449	403	466
Total	8,697	9,018	9,353	9,929	9,913	10,078	10,817	10,733	11,181	11,340	12,065	12,216	12,437

Water-level contours and hydrographs.--Finally, from the raw data--the records of water level in wells--at least three water-level contour maps and selected hydrographs should be prepared: One map for 1920 (fig. 6) to reflect steady-state or natural conditions, one for 1953 (fig. 7) to reflect transient conditions near the midpoint of the stress period, and one for 1968 (fig. 8) to reflect conditions at the end of the period. Also, hydrographs should be prepared for a sufficient number of selected wells to demonstrate the pattern and magnitude of water-level change with time throughout the ground-water basin.

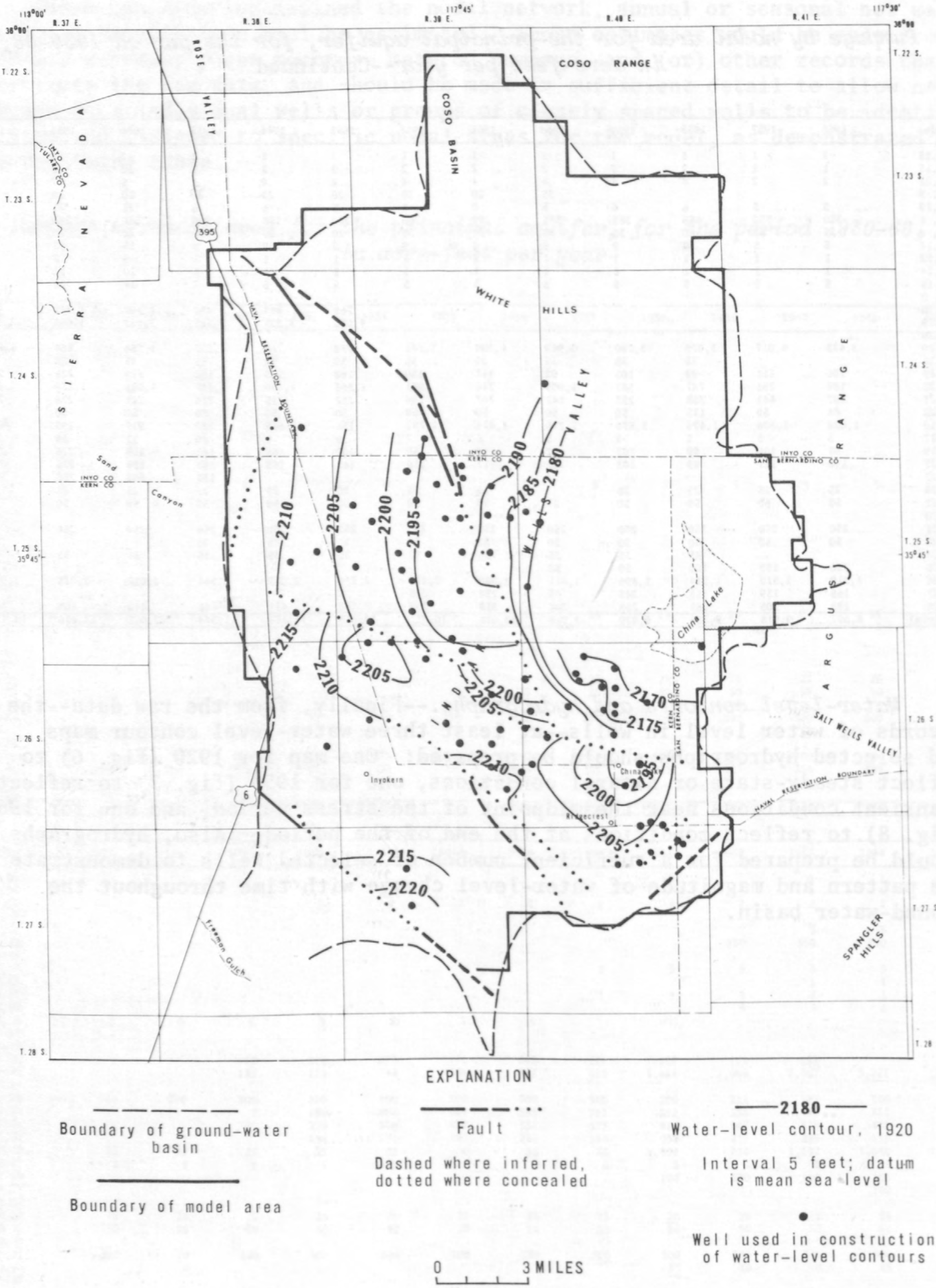
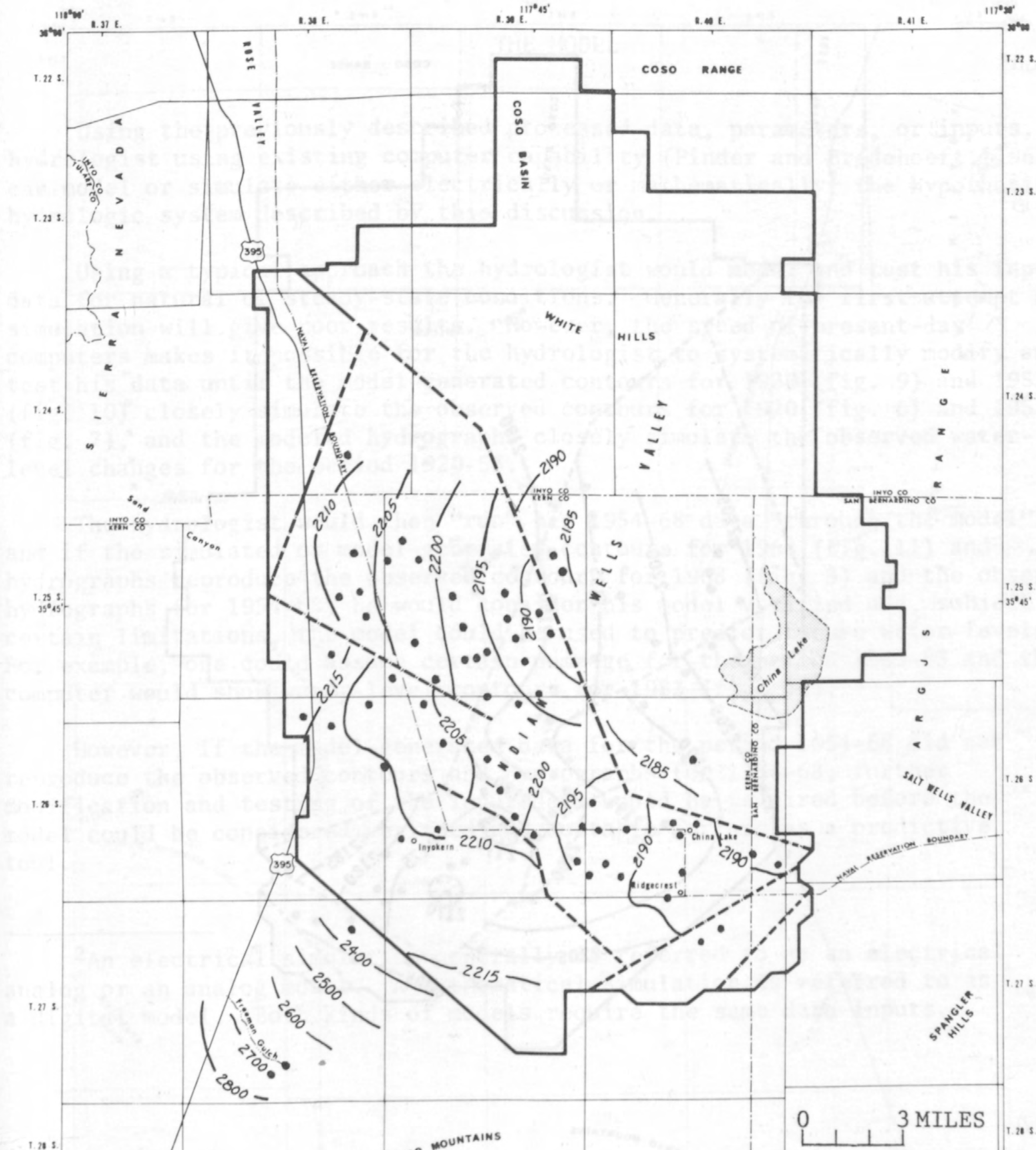


FIGURE 6.--Water-level contours, 1920, from water-level data.



EXPLANATION

Boundary of model area	Ground-water barrier	—— 2185 —— Water-level contour, 1953 *Intervals 5 and 100 feet; datum is mean sea level*	• Well used in construction of water-level contours

FIGURE 7.--Water-level contours, 1953, from water-level data.

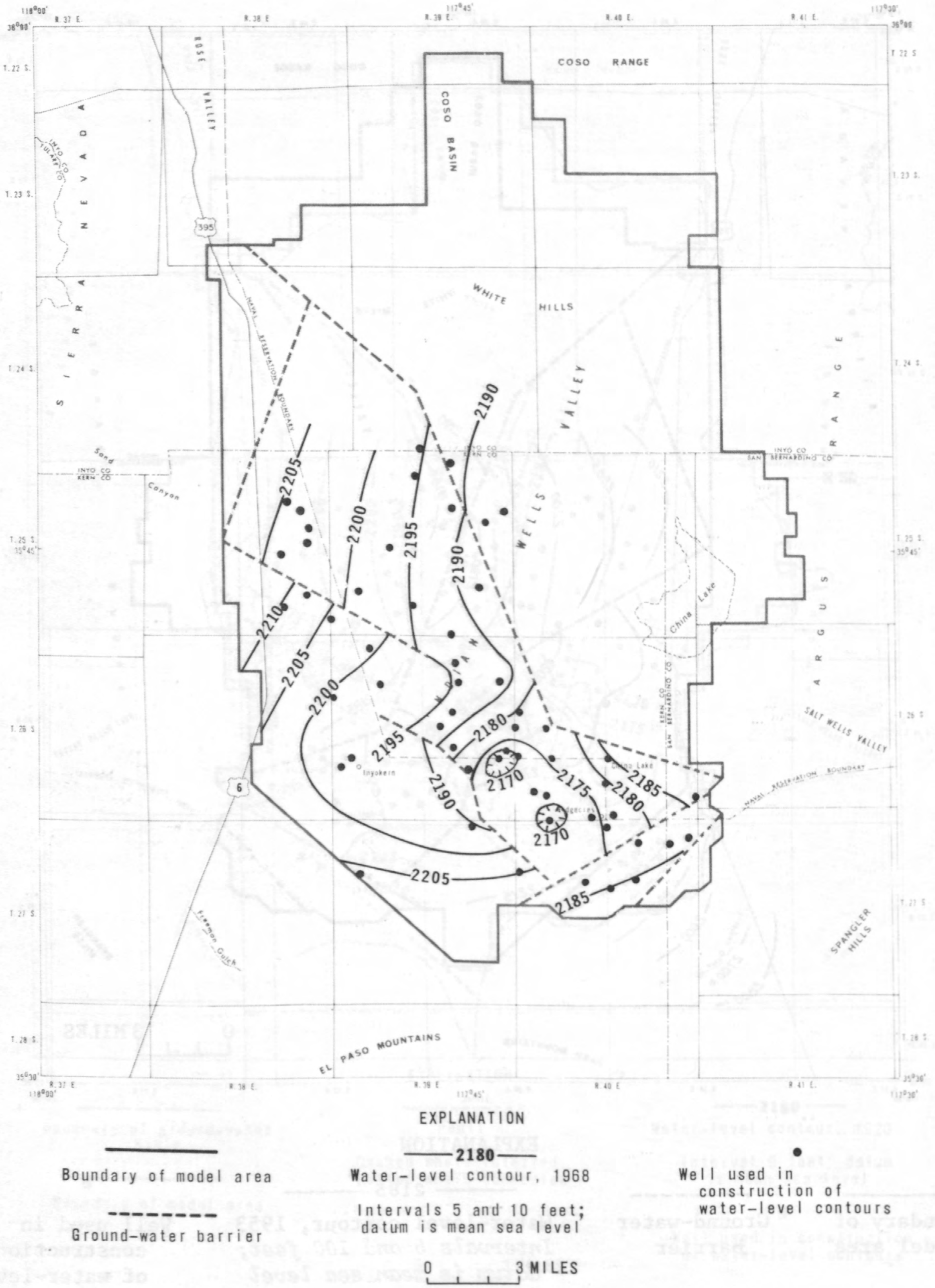


FIGURE 8.--Water-level contours, 1968, from water-level data.

THE MODEL

Using the previously described processed data, parameters, or inputs, a hydrologist using existing computer capability (Pinder and Bredehoeft, 1968) can model or simulate either electrically or mathematically[2] the hypothetical hydrologic system described by this discussion.

Using a typical approach the hydrologist would model and test his input data for natural or steady-state conditions. Generally the first attempt at simulation will give poor results. However, the speed of present-day computers makes it possible for the hydrologist to systematically modify and test his data until the model-generated contours for 1920 (fig. 9) and 1953 (fig. 10) closely simulate the observed contours for 1920 (fig. 6) and 1953 (fig. 7), and the modeled hydrographs closely simulate the observed water-level changes for the period 1920-53.

The hydrologist would then "run" his 1954-68 data "through the model" and if the simulated or model-generated contours for 1968 (fig. 11) and hydrographs reproduce the observed contours for 1968 (fig. 8) and the observed hydrographs for 1954-68, he would consider his model verified and, subject to certain limitations, the model could be used to predict future water levels. For example, one could assume certain pumpage for the period 1969-83 and the computer would show water-level contours for 1983 (fig. 12).

However, if the model-generated data for the period 1954-68 did not reproduce the observed contours and hydrographs for 1954-68, further modification and testing of the input data would be required before the model could be considered verified and suitable for use as a predictive tool.

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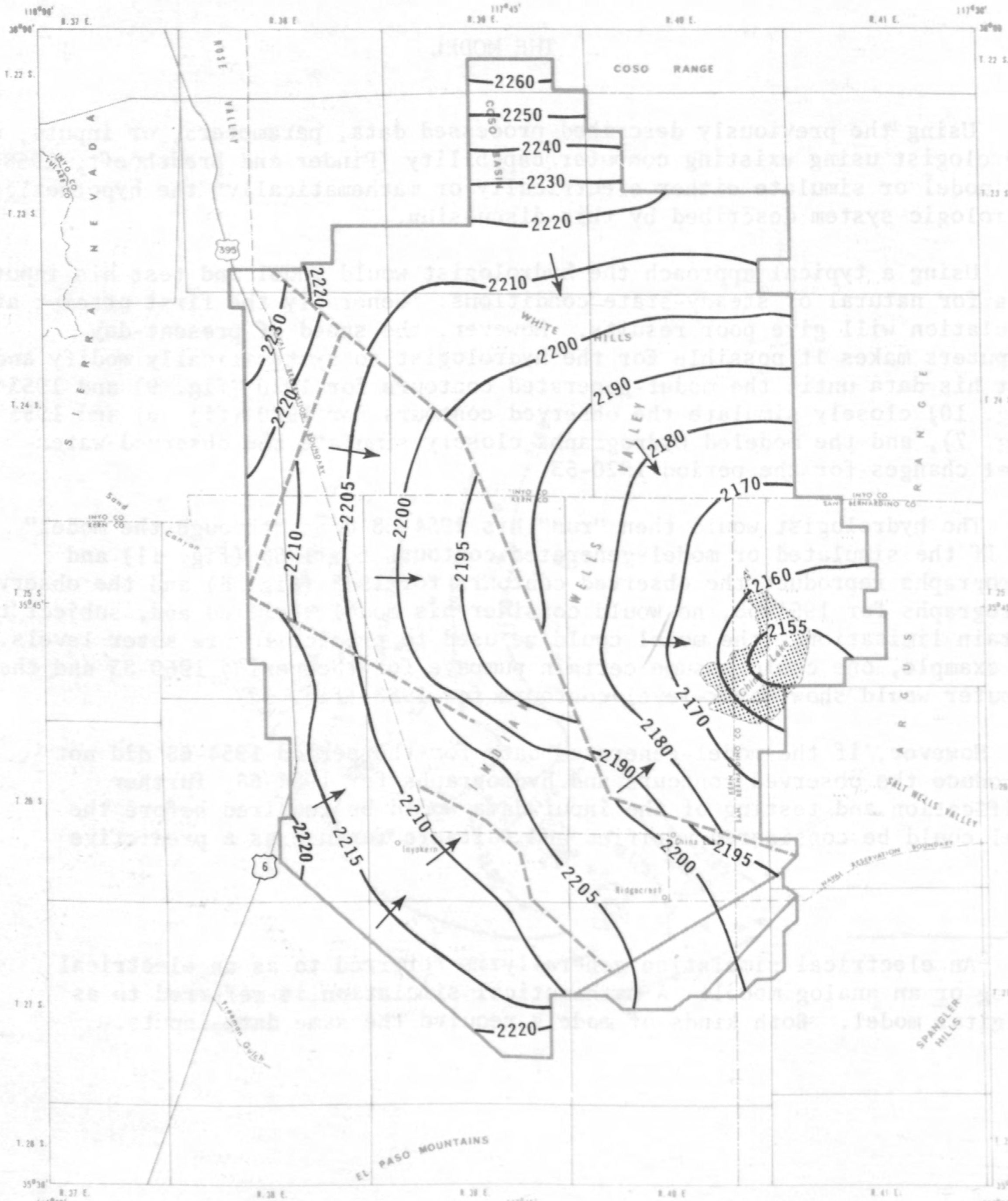
[2]An electrical simulation generally is referred to as an electrical analog or an analog model. A mathematical simulation is referred to as a digital model. Both kinds of models require the same data inputs.



EXPLANATION

Boundary of model area

2190 — Water-level contour based on model readout. Intervals 5 and 10 feet; datum is mean sea level

Direction of flow

Ground-water barrier

0 3 MILES

FIGURE 9.--Water-level contours, 1920, steady-state conditions, model generated.

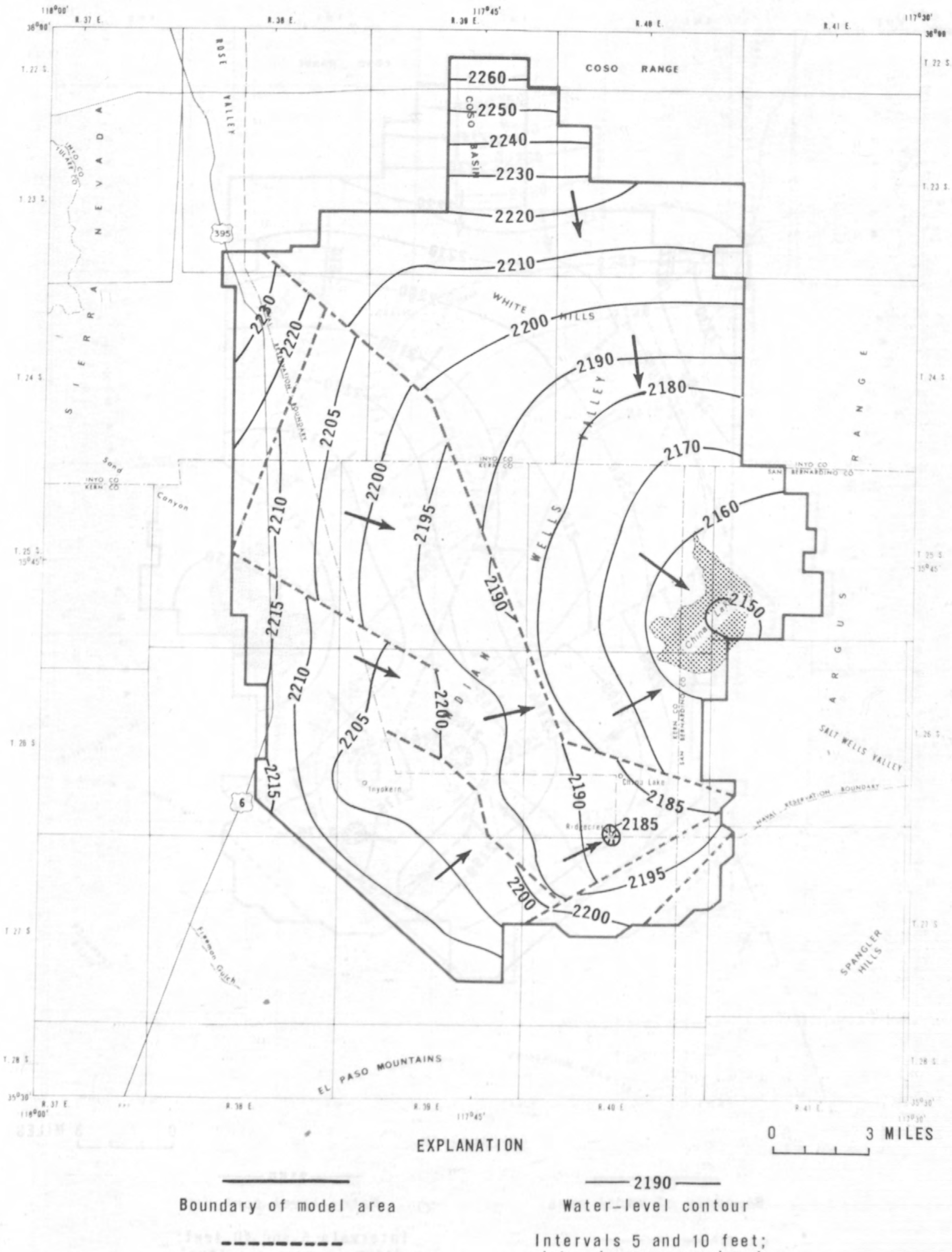


FIGURE 10.--Water-level contours, 1953, model generated.

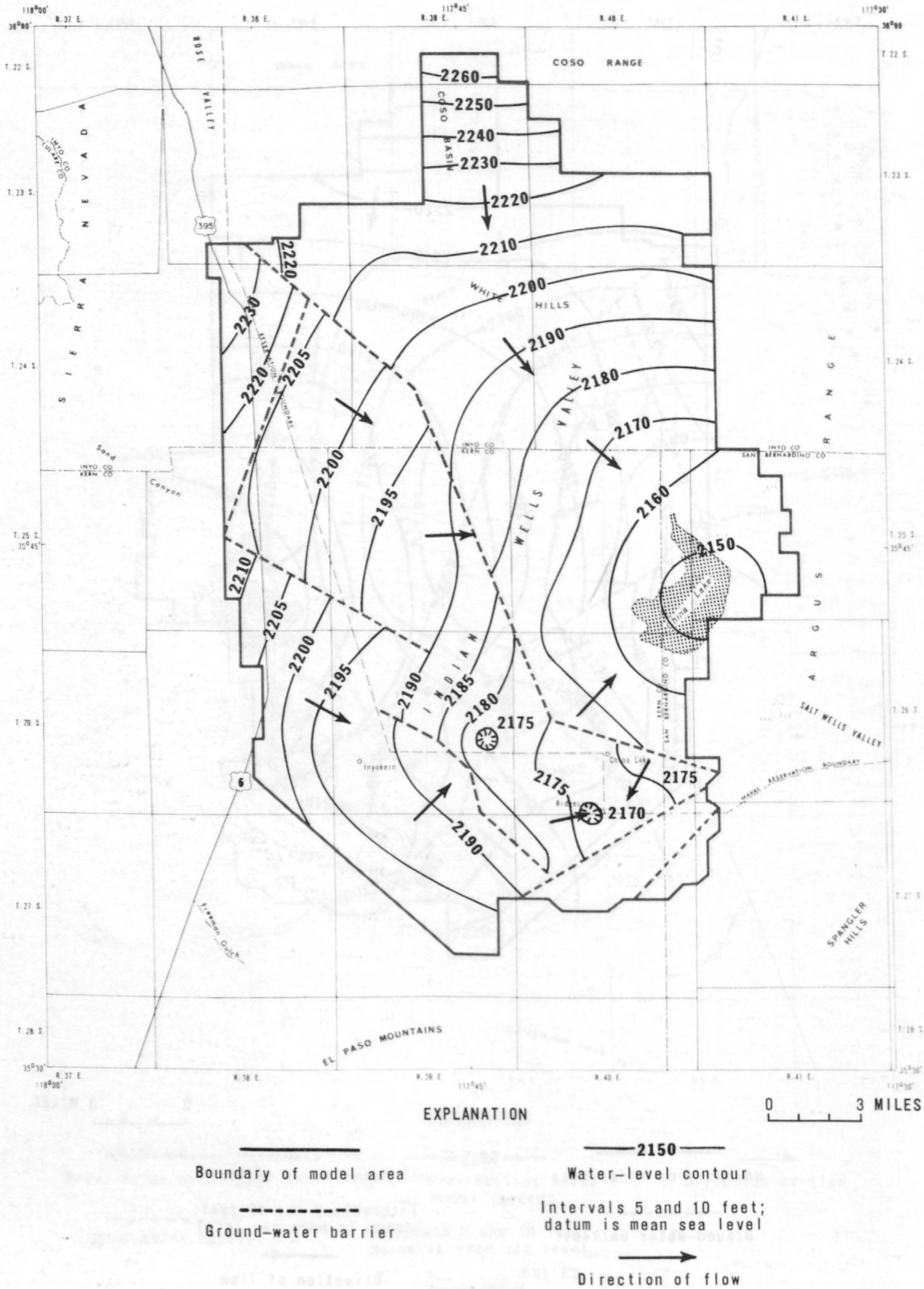


FIGURE 11.--Water-level contours, 1968, model generated.

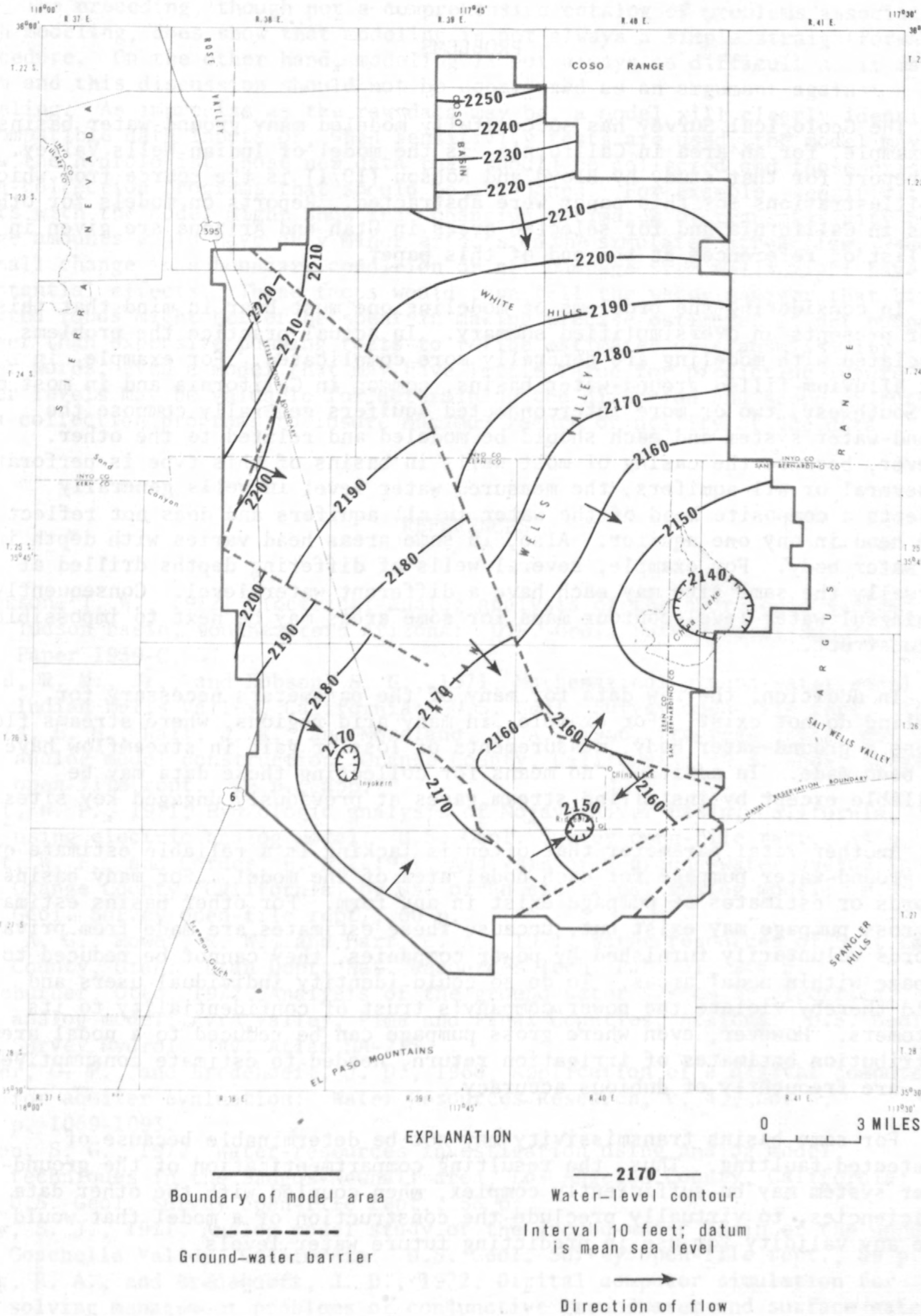


FIGURE 12.--Water-level contours, 1983, model generated.

PROBLEMS

The Geological Survey has successfully modeled many ground-water basins. An example, for an area in California, is the model of Indian Wells Valley. The report for that study by Bloyd and Robson (1971) is the source from which the illustrations for this paper were abstracted. Reports on models for other areas in California and for selected areas in Utah and Arizona are given in the list of references at the end of this paper.

In considering the problems of modeling one must bear in mind that this paper presents an oversimplified summary. In actual practice the problems associated with modeling are generally more complicated. For example, in most alluvium-filled ground-water basins, common in California and in most of the Southwest, two or more interconnected aquifers generally compose the ground-water system and each should be modeled and related to the other. However, because the casing of most wells in basins of this type is perforated in several or all aquifers, the measured water level in wells generally reflects a composite head of the water in all aquifers and does not reflect the true head in any one aquifer. Also, in some areas head varies with depth in the water body. For example, several wells of differing depths drilled at virtually the same site may each have a different water level. Consequently, meaningful water-level-contour maps for some areas may be next to impossible to construct.

In addition, the raw data for many of the parameters necessary for modeling do not exist. For example, in many arid regions, where streams flow across a ground-water body, measurements of loss or gain in streamflow have not been made. In addition, no means for collecting these data may be available except by installing stream gages at previously ungaged key sites.

Another vital parameter that often is lacking is a reliable estimate of net ground-water pumpage for each nodal area of the model. For many basins no records or estimates of pumpage exist in any form. For other basins estimates of gross pumpage may exist but, because these estimates are made from private records voluntarily furnished by power companies, they cannot be reduced to pumpage within nodal areas. To do so could identify individual users and would thereby violate the power company's trust of confidentiality to its customers. However, even where gross pumpage can be reduced to a nodal area, distribution estimates of irrigation return, needed to estimate consumptive use, are frequently of dubious accuracy.

For some basins transmissivity may not be determinable because of undetected faulting. Thus, the resulting compartmentization of the ground-water system may be sufficiently complex, when coupled with the other data deficiencies, to virtually preclude the construction of a model that would have any validity for use in predicting future water levels.

The preceding, though not a comprehensive catalog of problems associated with modeling, does show that modeling is not always a simple straightforward procedure. On the other hand, modeling is not always as difficult as it may seem and this discussion should not be considered as an argument against modeling. As imprecise as the raw data may be, a model will clearly identify incompatible data inputs or, when sensitivity tests are used, the model may show the hydrologist those new data that should be collected and those existing data-collection programs that should be abandoned. For example, sensitivity tests with the model might show that changing estimates of transmissivity by large amounts would have only minor effects on the simulated streamflow, whereas a small change in a boundary condition or net pumpage from wells might have substantial effects. These facts would then tell the water manager that his limited funds might better be spent in making precise estimates of net pumpage rather than expensive pumping tests to refine estimates of transmissivity. In other words, even a model that may have little value for predicting future water levels may be valuable for determining the direction and scope of future data-collection programs to insure maximum return or utility of the data.

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