AVAILABLE WATER FOR URBAN DEVELOPMENT IN THE PHOENIX AREA

by SAMUEL F. TURNER

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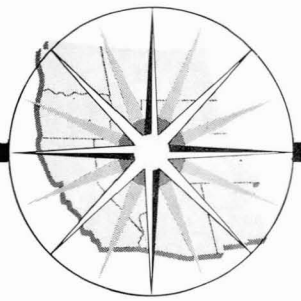
A SUPPLEMENT TO

ECONOMIC ANALYSIS AND PROJECTION FOR PHOENIX AND MARICOPA COUNTY

A Study For The
MARICOPA COUNTY PLANNING AND ZONING COMMISSION
and
CITY OF PHOENIX PLANNING COMMISSION



By
WESTERN BUSINESS CONSULTANTS INC.
PHOENIX, ARIZONA – SAN DIEGO, CALIFORNIA

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PRICE: FIVE DOLLARS

WESTERN BUSINESS CONSULTANTS, INC.
PHOENIX, ARIZONA

November 11, 1959

The Maricopa County
Planning and Zoning Commission
103 West Jefferson
Phoenix, Arizona

The City of Phoenix
Planning Commission
827 East Jefferson
Phoenix, Arizona

Gentlemen:

We are pleased to submit herewith the supplemental report "Available Water for Urban Development in the Phoenix Area" prepared for Western Business Consultants, Inc. by Samuel F. Turner of Turner and Associates, Consulting Geologists of Phoenix, Arizona.

This special study is summarized and its significance evaluated for planning purposes in Part VII of our basic report Economic Analysis and Projection for Phoenix and Maricopa County, prepared for Maricopa County Planning and Zoning Commission and the City of Phoenix Planning Commission by Western Business Consultants, Inc.

Sincerely,

WESTERN BUSINESS CONSULTANTS, INC.

William C. Turner

William C. Turner
Vice President

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SUMMARY

The principal results of this study are given in the summary table. Greatly increased pumping lifts and increased salinity are indicated. An overall cooperative water plan, including research and the development of additional water, is recommended.

The making of an electrical model of the ground-water reservior of the Salt River Valley in order to obtain better predictions of future ground-water conditions with varying amounts of development is also recommended.

Unless additional water is brought into the area by some method, industry and urban development will have to replace a large part of the area that is at present under irrigation. It would be wise if this industry and urban development could be directed toward the areas that will be retired from irrigation and again this can only be done according to some overall plan.

Research and the application of this research to salt water removal will have to be started. The need is urgent as some areas are already in distress because of the heavy concentration of salt water. This same program should be applied to the upstream areas which are at present supplying the major part of the salt in the water coming into the Salt River Basin. This includes the water coming in at the Salt Banks and in Carrizo Creek in the Salt River Basin and from several of the small hot springs in the Verde River Basin.

Research and the rapid application of this research to the control of water-loving vegetation along stream banks and to non-beneficial vegetation in upland areas should be encouraged so that more water can be developed.

Detailed studies should be started immediately of the possibilities of recovering more of the recharge from underneath the Mogollon Rim,

including lowering the outlets of artesian springs, tunneling, and the drilling of deep wells. As soon as possible some practical work should be underway.

Only the forceful carrying out of the program outlined can save this area from reaching a peak in development and then falling off from that peak as both agricultural and industrial production decreases due to lack of water and to the prevalence of salty water.

WATER AVAILABLE FOR URBAN DEVELOPMENT
PHOENIX AREA BY SUB-AREAS, 1959 AND 1980

	Use in 1959					1980 Outlook					
Area	Irrigated Area (acres)	Annual Water Use (acre-feet)	Average Daily Use (acre-feet)	Average Daily Use (m.g.d.)	Population Supported at 200 g.p.d. (in thous.)	Modification Expected	Water Available (m.g.d.)	Population Supported at 200 g.p.d. (in thous.)	Gross Area (acres)	Population Density (per acre)	Area
Litchfield Park	61,000	276,000 GW	750	245	1,225	Max. pumping lift of 750-800' in 1980. Well capacity satisfactory and economic for urban or ind. use. High salt content delete 1/2 area by 1980.	120 GW	600	70,000	8.6	Litchfield Park
Beardsley	50,000	225,000 GW SW	600	196	980	Max. pumping lift of 925-1000' in 1980. Well capacity only fair; lift too great in higher parts of area. Quality satisfactory.	100 GW SW	500	99,000	5.0	Beardsley
Deer Valley	27,000	120,000 GW	330	108	540	Max. pumping lift of 950-1000' in 1980. 1/4 area unwatered to bedrock. Well capacity satisfactory but lift too great another 1/4 area. Quality satisfactory.	50 GW	250	42,000	6.0	Deer Valley
Paradise Valley	10,000	45,000 GW	120	39	195	Pumping lifts excessive (800'+) in north. and west. part of area in 1980. Phx. Mtn. area unwatered. Quality satisfactory.	20 GW	100	170,000	0.6	Paradise Valley
Apache Junction (1/2 irrigated area has both surface water and ground water.)	7,500 7,500	34,000 GW 17,000 GW 17,000 SW	140 46	46 15	230 75	Pumping lifts excessive in all east. part of area (east of R.W.C.D.) by 1980. Part of area near mountains unwatered to bedrock. Quality satisfactory.	10 GW 12 SW	50 60	68,000	1.6	Apache Junction
Salt River Project (has both surface water and ground water.)	Avg. GW - Available for use	500,000 GW 600,000 SW	1,370 1,650	447 538-38* = 500	2,235 2,500	Pumping lifts and well production economic through 1980. Part of area near mountains unwatered to bedrock. Quality unsatisfactory for dom. and most ind. use in 1/2 area by 1980.	200 GW 475 SW	1,000 2,375	452,000	8.2	Salt River Project
Roosevelt Irr. Dist. (pumped within S.R. Proj.)		150,000 GW	410	134	670		All salty				
Municipal and Private Water Systems in Phoenix Metropolitan Area				100 SW GW	500		38 SW 25 GW	190 125 3,690			
Totals		1,984,000	5,416	1,830	9,150		1,050	5,250	901,000	5.8	

* Included in use of municipal and private water systems of Phoenix Metropolitan Area.
Source: Prepared by Turner and Associates, Consulting Geologists.

GW - Ground Water.
m.g.d. - Million gallons per day.

SW - Surface water.
g.p.d. - Gallons per day.

INTRODUCTION

Purpose

The purpose of this report is to describe the water resources presently available to the Phoenix Area, the rate of depletion of the present sources, what may be expected from them in the future, and what additional or new sources may be found. Suggestions will be given as to the action that should be taken to insure a water supply for the future.

Sub-Areas

For the purpose of this report the area has been divided into six sub-areas, (see Figure 1). Five of these depend almost entirely on underground water at the present time, but the sixth has both underground water and surface-water resources.

Avondale-Goodyear-Litchfield Park-Luke Air Force Base Area

This area is located west of Phoenix and west of the western boundary of the Salt River Project. The south boundary is the Gila River. The eastern boundary is the Agua Fria River, north from the Gila River to the junction with New River and then along the New River to the Santa Fe Railroad. The western boundary is the Beardsley Canal or the western edge of the cultivated land. The northern boundary is an east-west line along Olive Avenue or one mile north of the north line of T. 2 N. In the interest of brevity, this area will be called the Litchfield Park area.

El Mirage-Beardsley-Wittman Area

This area is located along the Santa Fe Railroad, northwest and west of Peoria. The south line is the north boundary of the Litchfield Park area. The east line is along New River north to the intersection with 83rd Avenue or Lateral 21 and then due north along 83rd Avenue. The north line is an east-west section line, three miles north of Bell Road, which locates the north line in the center of T. 4 N. The west line is the Beardsley Canal. The northwest extension of this area constitutes an area extending three miles on each side of the Santa Fe Railroad or six miles wide northwest to include Wittman. This area will be designated as the Beardsley area.

Deer Valley-Moon Valley-Sunnyslope Area

This area is located north and northwest of Phoenix with the south line being the Arizona Canal, the northernmost canal of the Salt River Project. The east line is 7th Street or its northward extension. The west line is the east line of the Beardsley area or along New River north to 83rd Avenue or Lateral 21. The north line is along the mountainous areas called Hedgepeth Hills, Adobe Mountain and Union Hills. This line, although irregular, runs approximately in an east-west line two miles south of the north line of T. 4 N. This area will be called the Deer Valley Area.

Paradise Valley-Pinnacle Peak-Cave Creek Area

This area is located to the northeast of Phoenix. The south line is again the Arizona Canal. The east and northeast line is along the crest of the McDowell Mountains. The west line is 7th Street or its equivalent extension to the north and the north line is the mountainous area near Cave Creek, but the area specifically includes the area immediately adjacent to the settlement of Cave Creek. This area will be called the Paradise Valley area in this report.

Apache Junction Area

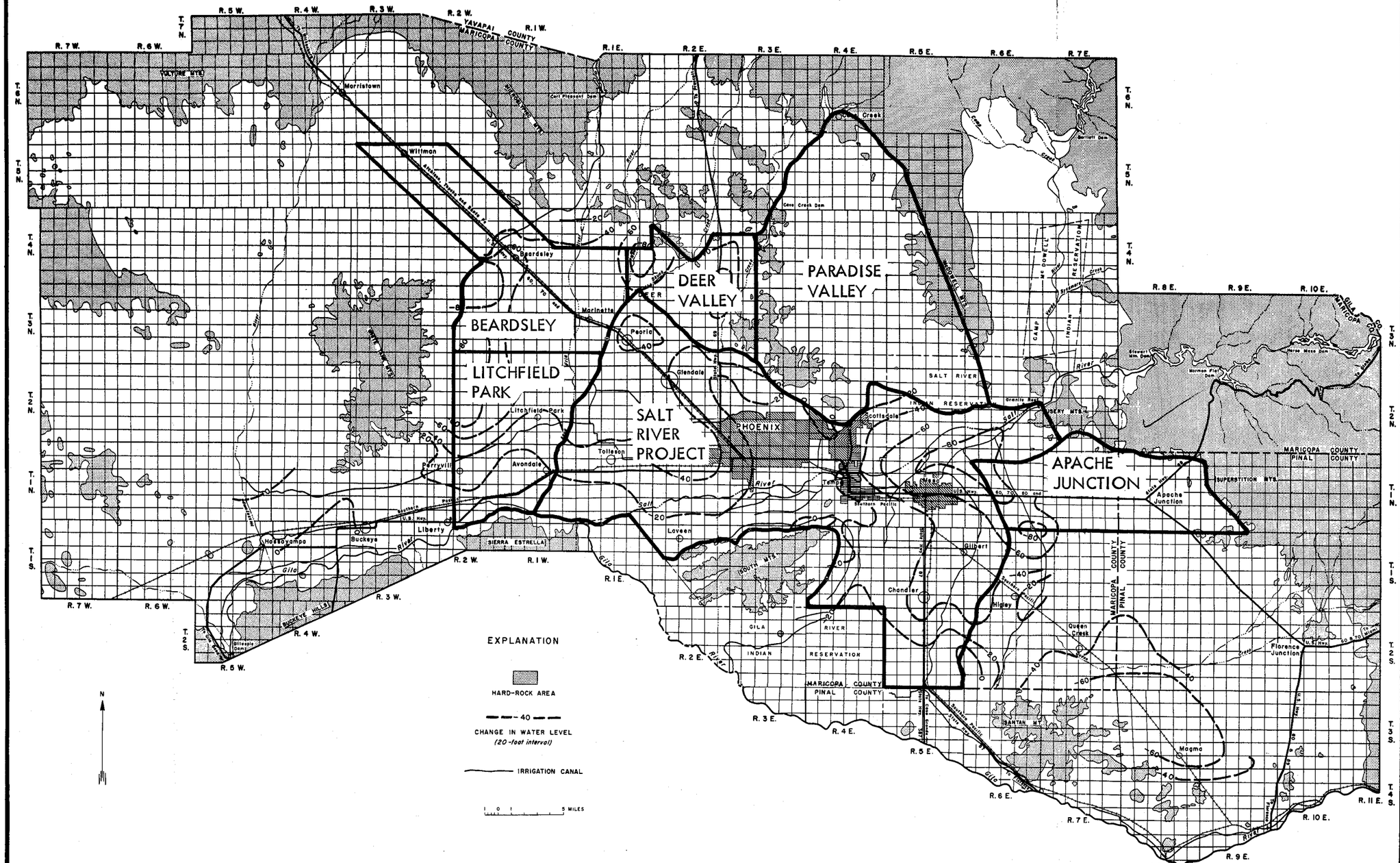
This area is located east of the town of Mesa. The west line is the Eastern Canal of the Salt River Project. The south line is Baseline Road or its eastward extension. The east line is the Superstition Mountains. The north line is McKellips Road or its equivalent except that the area is carried far enough to the north to include the Falcon Field area. This area includes the northern part of the Roosevelt Water Conservation District which does have some surface water rights obtained from the Salt River Project, but the major part of the area, to the east of the Roosevelt Water Conservation District Canal, depends entirely on ground water.

Salt River Project and City of Phoenix Area

The limits of this area are approximately those of the Salt River Project and include the largest part of the City of Phoenix. Because

FIGURE 1

MAP OF SALT RIVER VALLEY SHOWING SUB-AREAS COVERED BY THIS WATER STUDY



Note: Adaptation of Figure 9 of Annual Report on Ground Water in Arizona, Spring 1957 to Spring 1958, Arizona State Land Department, 1958, showing change in ground water level from 1953 to 1958.

this report deals primarily with water, the name Salt River Project will be used for this area in the remainder of this report.

Sources of Data

This report is based on data derived from many sources. The three major sources are the records of the Salt River Valley Water Users Association, the open file of the United States Geological Survey, and the open file of the Arizona State Land Department. The published reports of the United States Geological Survey and of the Arizona State Land Department have been of tremendous value. The knowledge gained from work for many private parties and irrigation districts in the areas concerned has provided a large amount of background data that have been of great assistance in the preparation of this report. Our deep electrical resistivity probes together with the few deep wells that have been drilled in the area have provided our only knowledge of the characteristics of the deep aquifers.

Field and Office Work for this Report

The funds available were not sufficient to cover any field work for this report. The work consisted of compiling information from the sources mentioned previously and preparing the illustrations that are included in this report.

DESCRIPTION OF PRESENT WATER RESOURCES AND ESTIMATE OF FUTURE SUPPLIES

The water resources presently available to the entire area discussed in this report consist of the ground water that is now in storage under the area, plus the water that is recharged into the ground water reservoirs each year, and the surface water that is brought into the area by the Salt River Project and by the Beardsley Project. To this should be added the annual precipitation on the area. The additional water that may be brought into the area in the future will be discussed in another section.

The history of water use in the area may be stated briefly as follows: Surface water irrigation has been going on to an ever increasing extent since the 1880's. The first knowledge we have of the ground-water supply in the area was that published in the U. S. Geological Survey Water-Supply Paper 136 by W. T. Lee. His work was carried out in 1902-1903. The use of surface water for irrigation was greatly increased following completion of Roosevelt Dam in 1910.

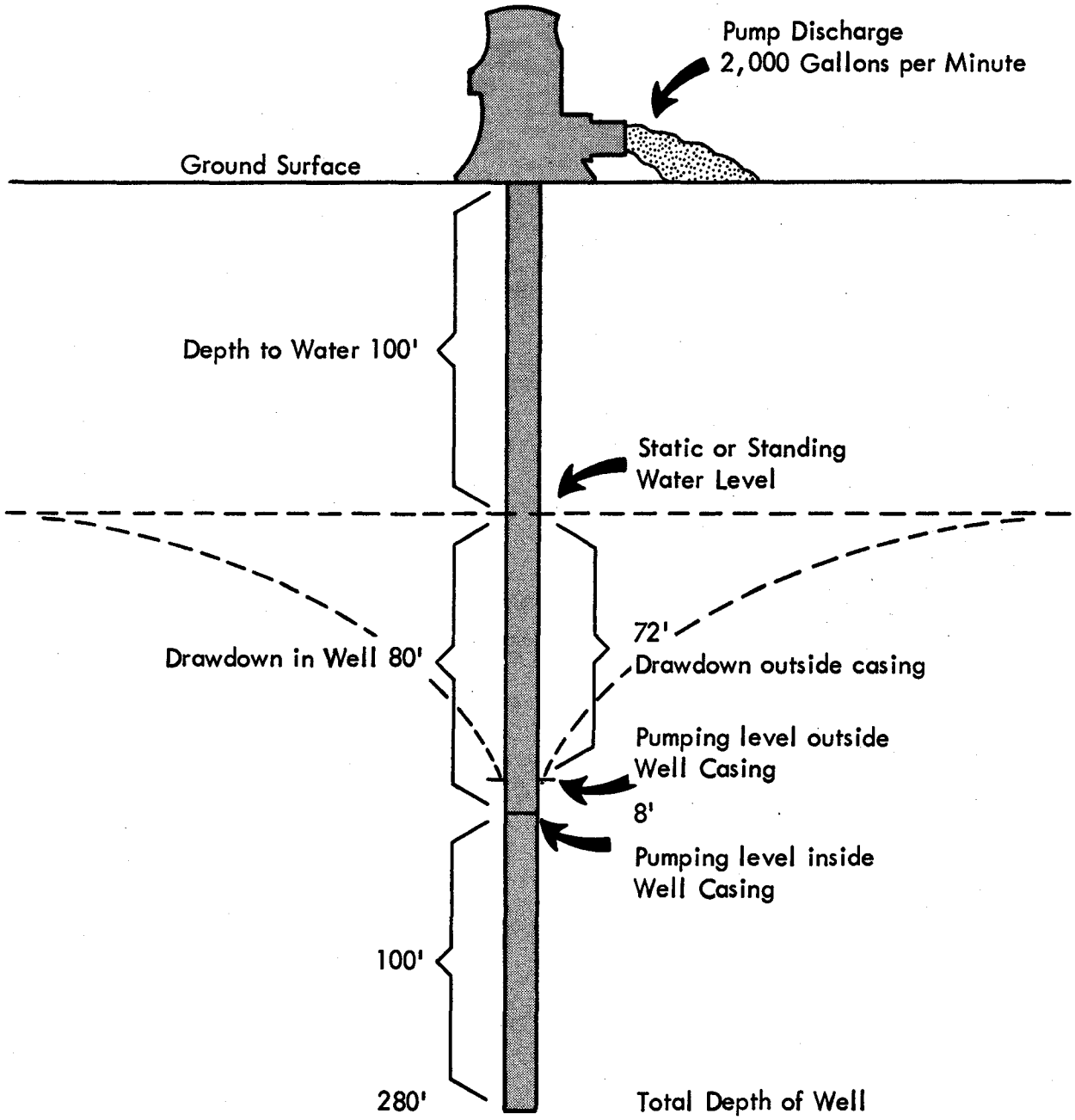
Ground-water levels show that the water level in the area rose steadily, starting with the first observations by W. T. Lee, and that these levels reached a peak in 1920 when a large part of the Salt River Project was approaching water-logging. Pumping for drainage was started and additional pumping for irrigation. The drain water pumped was also used for irrigation. The amount of water pumped increased gradually through 1941, when the rate of pumping started increasing rapidly until the area was declared critical and the development slowed.

One of the most important factors noted, as the ground-water levels lowered and wells had to be deepened to obtain an adequate supply, was that the deeper formations produced much less water than the shallow formations. If the amount of water stored in the deeper formations is less than that stored in the shallow formation, it can be disastrous to the parts of this area that depend on underground water. These questions will be discussed in detail for each of the sub-areas.

In discussing the yield from the wells at the present time and the expected yield in the future, a new term, the formation coefficient, will

FIGURE 1A.

SKETCH ILLUSTRATING TECHNICAL TERMS



$$\text{Well Efficiency} = \frac{\text{Drawdown outside casing}}{\text{Drawdown inside casing}} = \frac{72}{80} = 90\%$$

$$\text{Specific Capacity} = \frac{\text{Discharge in g.p.m.}}{\text{Drawdown inside casing}} = \frac{2,000}{80} = 25 \text{ g.p.m. per ft. of dd.}$$

$$\text{Formation Coefficient} = \frac{\text{Specific Capacity}}{\text{Total depth below static level or below top of perforations}} = \frac{25}{180} = 0.14$$

be used. The term specific capacity of a well is in rather common usage. This is defined as the yield in gallons per minute per foot of drawdown (see Figure 1A). The drawdown means the difference between the static level in the well and the pumping level.

The term specific capacity is very useful but it is often misleading because, if a well that is 200 feet deep has the same specific capacity as a well that is 1,000 feet deep, the materials in the deep well must be much tighter with regard to water production than the materials in the shallow well. The shallow well would have principally gravels and the deep well, cemented gravels and sandstones. Therefore, we have taken the specific capacity of a well and divided it by the vertical feet of water producing formation in the well. This means the depth from static or standing water level to the bottom of the well or the depth from the top of the casing perforations to the bottom. This section often includes clays that are probably non-productive, but some wells where only clay was reported in the well logs have had good production. Therefore, we have used the total depth from the static water level or the top of perforations down to the bottom of the well. The resulting coefficient has been called the formation coefficient because it is the best figure available to describe the production qualities of the formations in the well. This formation coefficient is similar to the coefficient of permeability as used in many technical ground-water papers. As the term is derived and used in this report, it also includes the well efficiency and therefore it does not exactly equal the coefficient of permeability.

The well efficiency may be described as the ratio between the drawdown inside the well casing and drawdown outside the well casing when the well is pumping. In many wells, the well efficiency is only 50 percent. This means that the drawdown just outside the casing is only one-half the drawdown inside the casing. The improvement of well efficiency is one of the hopes for the future, for, as the water levels are lowered, the pumping costs become greater. One method of decreasing the pumping costs would be to increase the well efficiency by using better well casing, screening and developing methods.

Litchfield Park Area

The Litchfield Park area extends north from the Gila River. Since divergent conditions exist in various parts of this area, it has been sub-divided into the south half which includes all of the area in T. 1 N. and might be called the Goodyear Sub-division, and the north half which includes T. 2 N. and the south line of Sections in T. 3 N.

Present and Future Depth to Water

In the south half of the Litchfield Park area, that is in T. 1 N., the present depth to static water level varies from 30 to 50 feet near the Gila River to 175 feet beneath the surface along the north line of the Township.

Figure 19 of Water Resources Report No. 1, the Arizona State Land Department, published in October 1956 and prepared by the United States Geological Survey, shows that the decline in ground-water level in this area from the Spring of 1942 to the Spring of 1956 varied from zero to a maximum of a little more than 50 feet. The depth to water in 38 wells in this area was graphed for the years 1954-58, inclusive. These records were from the files of the U. S. Geological Survey. The results are shown on Figure 2. Because of the comparative shortness of these detailed records, the accumulative net change in average water level in the Litchfield-Beardsley-Marinette area has been added covering the time before 1954. This average water level was taken from Figure 7 of a report entitled "Pumpage and Ground-Water Levels in Arizona in 1954" published by the United States Geological Survey in cooperation with the State Land Department. Because the average water level includes the area north of T. 1 N. the decline in level is a little steeper than that shown for the south part of this area.

Extending this decline in water level on a straight line basis into the future, using the maximum and minimum as shown on Figure 2, it is found that in 1980 the minimum water level to be expected in this area is 110 feet and the maximum is 290 feet.

The northern part of the Litchfield Park area has been sub-divided into townships. In T. 2 N., R. 1 W., which includes Litchfield Park,

the records of 56 wells were graphed on Figure 3. The average depth to water at the present time varies from 120 feet in the southern part of the township to 300 feet in the northwestern part of the township. Again, the average water level taken from the Geological Survey Publication has been placed leading into the center of the graph to show that the rates of drawdown are a continuation of the rates previously existing.

The depth to water in 1980 in this Township, predicted by extending the rates of decline, varies from 180 feet at the south part of the Township to 550 feet in the northwestern part of the Township.

In T. 2 N., R. 2 W., the records of 35 wells were graphed and are shown on Figure 4. The depth to water at the present time varies from 235 feet to 400 feet. The shallowest water levels are in the southeastern part of the township and the deepest water levels along the north line.

Again the average water level from the Geological Survey illustration has been placed at the left hand side of the graph showing that these declines are a continuation of the decline shown on the average water level graph since the year 1946. The depth to water predicted for 1980 by extending the rates of decline varies from a minimum of 330 feet to 700 feet in 1980.

The records of five wells were graphed for the south row of sections in T. 3 N. Those in R. 1 W. fall within the range shown by Figure 3 for T. 2 N., R. 1 W. Those for R. 2 W. fall within the range shown on Figure 4 for T. 2 N., R. 2 W. Therefore no additional graph has been included and the predictions for this part of the area would be the same as those for the previous townships. The continuous decline in water level in all parts of the area indicated that water is being mined from the ground-water reserves.

Present and Future Production Rates for Litchfield Park Area

The area will not be sub-divided in this discussion of production rates. In the early days during the first development of wells in this area, the production rate was very high with formation coefficients varying from 0.5 to 1.0. However, the wells to the west away from the river,

never has high coefficients. Their original coefficients ranged from 0.02 to 0.07. These coefficients represent the coefficients of the poorly sorted valley fill deposited by side streams and washes as against the higher coefficients of materials deposited by the major rivers.

The question of maximum depth to which wells can be drilled and obtain water that can be used for irrigation becomes important as the static water level is lowered. Based on deep geophysical probes and on deep wells, the maximum depth of drilling is assumed as 1,400 feet, as highly mineralized water occurs at greater depths. Using an estimated average formation coefficient of 0.05, the production from wells drilled to 1,400 feet would be no problem in wells in the south part of the area.

In the north part of the area, where the depth to static water level is forecast as being 700 feet in 1980, a maximum depth of 1,400 feet would leave 700 feet of water-producing material. Multiplying this 700 feet by the formation coefficient of 0.05, it is found that the well would produce 35 gallons per minute per foot of drawdown and, assuming a drawdown of 50 feet, the production would be 1,750 gallons per minute. Therefore, we can assume that water can be produced from deep wells in this area in 1980. The question becomes one of how much users can afford to pay for pumping.

Quality of Water at Present and Predicted for the Future in the Litchfield Park Area

The shallow ground water in the Litchfield Park area has been concentrated by irrigation use until it is quite saline. The salt content in the water produced by the shallow wells along the Gila River at the south edge of the area has been doubled and tripled during the past 20 years. There has been no change observable in the quality of the water produced from the deep formations.

Very saline water was found in formations below 1,400 feet near the town of Buckeye southwest of the area. The water at 1,700 feet at Goodyear is a sodium chloride water with total solids of about 2,500 parts per million. The high sodium ratio precludes the satisfactory use of this water for irrigation. To the north of the area, a deep test well encount-

ered solid salt. Therefore, the maximum depth of drilling for future wells in this area was established at 1,400 feet.

In the future the shallow water or that closest to the surface may be expected to continue to increase in mineral content due to the concentration by irrigation use. Many farmers have already started to cut off the shallow water and pump only from the deeper strata. This helps that particular farmer but allows the salt water to accumulate. One of the promising fields for future research is the desalting of this shallow water for irrigation use. If this is not done and additional water is not brought into the area to flush out this salt water, the lower half of this area will face extreme peril within the next 20 years. Treated sewage effluent might be used for this purpose.

Present and Future Use of Water

The present use of water in the Litchfield Park area has been estimated by taking the irrigated area from the latest maps and multiplying this area by an average rate of use of 4-1/2 acre-feet of water per acre. The irrigated area was measured as 61,000 acres, including town and industrial area. Multiplying this by 4-1/2 gave 276,000 acre-feet of water as the annual use. This equals an average daily use of 750 acre-feet or 245 million gallons per day (m.g.d.). Using a rate of 200 gallons per day per capita, this would support a population of 1,225,000. As the ground-water reservior is large, the maximum daily use simply requires more wells be pumped at that time. It is the total use during the year that is important in this study.

As discussed previously, the predicted maximum pumping lift of 750-800 feet and the well capacity will be satisfactory for urban or industrial use in 1980, but the increasing salt content of the water will cause the abandonment for this type of use of about one-half the area by 1980. Salt-removal plants probably will modify this to some extent. See Summary Table for population supported in 1980.

Beardsley Area

Present and Future Depth to Water

The depth to water increases as we proceed from the south part of this area to the north and to the northwest toward Wittman. Therefore, the depth to water and the decline in the water level will be discussed by townships within this area.

Figure 19 of the 1955 Water Level Report mentioned previously shows that the ground-water level has had a lowering of 100 to 150 feet from the Spring of 1942 to the Spring of 1956. Thus, the minimum decline in the area was somewhat less than 100 feet and the maximum decline was somewhat more than 150 feet in that period.

On Figure 5 of this report the depth to water in two wells in T. 3 N., R. 1 E., two wells in T. 4 N., R. 1 E. and six wells in T. 3 N., R. 1 W. has been graphed. Again we have added the average water level graph from the 1954 U. S. Geological Survey Water Level Report for the Litchfield-Beardsley-Marinette area to show that the short trend we have used is typical for the area. The depth to water in the area at the present time varies from 270 feet to 365 feet. The extension of the decline in level to 1980 shows the minimum depth to water in 1980 as 450 feet and the maximum as 710 feet.

On Figure 6 of this report the depth to water in 29 wells located in T. 3 N., R. 2 W. has been graphed. The depth to water at the present time in this Township varies from a minimum of 340 feet to a maximum of 450 feet. The extension of the rate of decline to the year 1980 gives a minimum level in 1980 of 670 feet and a maximum of 925 feet.

The water level records of 11 wells in T. 4 N., R. 1 W. and of nine wells in T. 4 N., R. 2 W. have been graphed on Figure 7. The minimum depth to water in the Spring of 1959 was 320 feet and the maximum was 410 feet.

Extending the trend of the decline in static water level through 1980 gives a minimum of 510 feet and a maximum of 750 feet. The continuous decline in water level in all parts of the area indicates that water is with-

drawn much faster than it is recharged and that the ground-water reserves are being mined.

Present and Future Water Production in the Beardsley Area

The original production rates from shallow wells near the Agua Fria and New Rivers in the area were as high as 0.5 to 1.0 in formation coefficient, but the wells to the west of the river never had this high a coefficient. This area is similar to that described below where most of the material developed by the wells has not been sorted by a major stream. Therefore, the formation coefficients range from 0.01 to 0.08 and an average is about 0.05.

Practically all of the shallow river gravels have been dewatered. Therefore, the average coefficient of 0.05 probably applies to most of the wells in the area today and applies to any deepening or new wells that may be drilled to greater depths, with the exception that better well screens and development probably will increase the well efficiency and increase the formation coefficients that we have been using.

As in the Litchfield area, it is estimated that about 1,400 feet is the maximum depth of production of usable water. The predicted decline in water level in all of this area indicates that the cost of pumping water for irrigation will be a very important factor by 1980. The maximum or greatest depth to water predicted was 925 feet as given on Figure 6. This leaves 475 feet of water-bearing material and multiplying this by the formational coefficient of 0.05 gives a specific capacity of 23.75 gallons per minute per foot of drawdown. Using a drawdown of 50 feet would give a production of about 1,200 gallons per minute. This is a small production for a 1,400 foot well for irrigation use indicating that the cost limit for irrigation use has been exceeded.

Quality of Water and Future Quality of Beardsley Area

The water in most of the Beardsley area is of good quality at the present time. Two deep test wells have encountered rock salt at depths below 1,400 feet and oil tests have encountered salt and salty water at great depth, but it is probable that wells kept above 1,400 feet, except in one small area, will have no quality of water troubles through 1980.

There may be some concentration of salty water by irrigation use but with the great depth to water there is a decided probability that the salty water recharged by irrigation use will move to the south out of this area before reaching the water that is being pumped.

Present and Future Use of Water

It was estimated that, at the time of preparation of this report, 50,000 acres were irrigated in the Beardsley area. This represents an annual water use of 225,000 acre-feet and a daily use of 600 acre-feet or 196 m.g.d. A part of this area uses some surface water from the Agua Fria River and this is included in the estimated use. This would support a population of 980,000 people if used for urban or industrial use.

The maximum pumping lift will be 925-1,000 feet by 1980. Thus, the lift will be too great and the well production or capacity too small for economic use in about half the area. The water available in 1980 is estimated as 100 m.g.d., (see Summary Table).

Deer Valley Area

The Deer Valley area depends entirely on underground water. Development started in this area in 1942 and picked up pace in 1946 and 1947. Originally, the natural recharge into the valley was backed up by a ground-water ridge formed by recharge under the Arizona Canal. This ridge was completely removed by the Spring of 1952. Now the Deer Valley area is drawing water back to the north from under the Salt River Project. Thus, the depth to water is the least at the south line of the area near the Arizona Canal.

Present and Future Depth to Water

The depth to water in this area varied from a minimum of 260 feet near the Arizona Canal to a maximum of 430 feet at the north end of Deer Valley in the early Spring of 1959. The static water-level records on twenty six wells are shown on Figure 8. These records show that the decline has been at a relatively steady rate. Extending these declines into the future, we find that a minimum water level in 1980 will be about 540 feet and the maximum will be 850 feet below ground level. The

ground-water reserves are being mined in this area.

Present and Future Water Production in Deer Valley Area

A few of the wells drilled in the Deer Valley area near Cave Creek had fairly large formation coefficients producing as much as two tenths of a gallon per minute, per foot of formation producing, per foot of drawdown. The range in value of formation coefficients is from 0.01 to 0.22 with the higher coefficients being given by the shallower wells drilled near Skunk Creek or near Cave Creek. The deeper formations in the area have coefficients ranging from 0.01 to 0.07 and the average appears to be about 0.04.

In the northeastern part of the area wells have bottomed on bedrock or a very hard nonwater-bearing conglomerate, but in three-fourths of the area wells have obtained production down to 1,800 feet. Therefore, this has been used as the effective depth.

Using the average formational coefficient of 0.04, a well in 1980 that was 1,800 feet deep and had a static water level of 850 feet would have 950 feet of water producing formation and would produce 38 gallons per minute per foot of drawdown. Multiplying this by a 50 foot drawdown gives a potential production of 1,900 gallons per minute. This means that sufficient water production can be secured from wells in the southern and western parts of the area, providing that they are drilled deep enough. The northern part of the area will have excessive pumping lifts.

Present and Future Quality of Water in the Deer Valley Area

The quality of the ground-water in the Deer Valley area at the present time is very good for irrigation use. The only deterioration has been in the southern part of the area where more salty water concentrated by irrigation use has been drawn to the north from under the Salt River Project. However, this water was satisfactory for irrigation use. There is nothing to indicate that the water will not remain satisfactory through the period 1980.

Present and Future Use of Water

The latest maps show 27,000 acres of land under irrigation or used for industrial purposes in Deer Valley. This represents an annual use of 120,000 acre-feet. The average daily use was 330 acre-feet or 108 m.g.d. This would supply a population of 540,000 people.

By 1980, about one-fourth of the area will be unwatered to bedrock and in another fourth the pumping lift will be excessive. Therefore, the water available in 1980 is estimated as 50 m.g.d., (see Summary Table).

Paradise Valley Area

This area has many different types of water conditions. In the southern part of the area, next to the Arizona Canal, the water levels were quite near the surface before pumping started. The elevation of the ground surface rises rapidly to the north and northwest and the ground-water level does not rise as rapidly. Therefore, the depth to water increases rapidly to the north. Just south of the mountains, south of Cave Creek, the depth to water is more than 800 feet below ground level. Back in the mountains, in the Cave Creek area, the depth to water often is less than 50 feet, as the water is held up by the hard granitic rock.

Before the development of irrigation in the Salt River Valley, the ground-water level in Paradise Valley sloped very gently from the north and northwest to the south and southeast, This was the condition of the water level when it was first mapped by W. T. Lee in 1902-1903. Recharge from the Arizona Canal and irrigation in the Salt River Project raised the water level rapidly in the area to the south and backed up the normal recharge from the north so that when the water table was mapped in 1920 by O. E. Meinzer, of the U. S. Geological Survey, the water table was practically flat in the southern part of the valley.

By 1945, all the water recharged during the irrigation period had been pumped out and the water level was 10 to 15 feet lower than the water level of 1903. Figure 13 of the 1955 Water Level Report issued by the Arizona State Land Department shows that the unwatering or lowering of ground-water level between the Spring of 1942 and the Spring of 1956 varied from 25 to 75 feet in the lower part of this area. No data

are available regarding the lowering of the water level in the northern part of the area or in the Cave Creek area.

Present and Future Depth to Water in the Paradise Valley Area

The depth to water below ground level in the southern part of the area varied from 170 feet to 250 feet in the Spring of 1959. The depth to water became greater to the north with the depth to water in the valley four or five miles south of Cave Creek being more than 800 feet. However, there has been very little drawdown in this part of the area.

On Figure 9, the records of 12 observation wells have been graphed. The ones with the deeper water levels, showing very little drawdown, are toward the northern part of the Valley. No records were available for water levels in the vicinity of Cave Creek.

The extension of the trend of these water levels shows drawdowns varying from 60 to 100 fett lower than the present levels by 1980. It seems probable that this is too optimistic because additional urban development is going on rapidly in the Paradise Valley and Cave Creek areas and the rate of lowering will certainly increase. Water is being mined from the ground-water reserves in the area.

Present and Future Production Rates in the Paradise Valley Area

It is probable that Paradise Valley never had a major stream flowing through it as there is no evidence of productive shallow gravels like those deposited by Cave Creek, the Agua Fria River and other streams. Therefore, the formational coefficients in the Paradise Valley area have always been low varying from 0.01 to 0.07. We can use an average of 0.04. No salt water has been found in the area and the maximum depth of productive material indicated by some wild-cat oil tests is 1,800 feet. Thus in a large part of this valley the future of water production through 1980 is governed entirely by the cost of pumping, because even with water levels as low as 1,000 feet, the 800 feet of water-bearing material remaining gives a production of 32 gallons per minute per foot of drawdown or 1,600 gallons per minute with a drawdown of 50 feet.

Present and Future Quality of Water in the Paradise Valley Area

The water supplies developed in the Paradise Valley area are reasonably good for irrigation or domestic use. The deep wildcat tests have not indicated any salt water. Therefore, it does not appear that there will be any water-quality problems develop in the Paradise Valley area in the period up to 1980.

Present and Future Use of Water

The latest maps show less than 10,000 acres of land irrigated in the Paradise Valley area but a figure of 10,000 acres has been used to make up for the domestic water use on non-irrigated land in the area. Thus, the amount of water used in the area is estimated as 45,000 acre-feet per annum. This equals an average daily use of 120 acre-feet or 39 m.g.d. which is sufficient for a population of 195,000 people.

By 1980, parts of the area near the Phoenix and the McDowell Mountains will be unwatered to bedrock. The pumping lift will be excessive in the northern and northwestern part of the area. Therefore, in 1980 the amount of water available is estimated as only half the present use of 20 m.g.d., (see Summary Table).

Apache Junction Area

The Apache Junction Area contains the northern part of Roosevelt Water Conservation District, which has some surface water brought in by a canal and the rest of the water is pumped. All of the area to the east of the Roosevelt Water Conservation District Canal depends entirely on wells. This area also has an interesting hot-well resort known as "Buckhorn Hot Wells".

This area is similar to the Paradise Valley area in that originally the water levels were raised because of the recharge from the Salt River Project canals and irrigation, but this increased water storage has already been pumped out and the area is now drawing on what might be called geologic storage and is mining water. Figure 13 of the 1955 Water Level Report of the Arizona State Land Department indicates that the drawdown in static water levels from the Spring of 1942 to the Spring of 1956 has

varied from 25 feet near the Maricopa-Pinal County line increasing to the west to a maximum of 150 feet in the northern part of the Roosevelt Irrigation District.

Present and Future Water Levels in the Apache Junction Area

The water level fluctuation in eleven wells has been graphed on Figure 10. This indicates that the present depth to water in the area ranges from 325 feet to 410 feet, but all of these wells are in the western part of the area. The depth to water increases to the east and in the extreme eastern part of the area, it may be 600 to 800 feet to water.

The trend of the decline in water level has been extended on Figure 10 and this indicated that the minimum depth to water that may be expected in 1980 is 565 feet and that the maximum in the irrigated area will be about 880 feet. However, in the eastern part of the area, if the development continues in that part of the area, the water levels may be expected to decline to 1,000 feet or more.

The continuous decline in water level in all parts of area indicates that water is being withdrawn much faster than it is recharged. The ground-water reserves will be mined out to bedrock by 1980 in the part of the area near the mountains.

Present and Future Production in the Area

The present rate of production in the western part of the area is reasonably high. The Salt River apparently has deposited coarse gravels in the western part of the Apache Junction area and the shallow wells developed in these gravels had large formation coefficients, sometimes as great as 1.0 to 2.0. However, most of this material has been unwatered by the lowering of the water level and the present yields in the area are in the neighborhood of 0.03 to 0.09 for an average of 0.06. This yield may be expected to continue to depths of 1,000 to 1,200 feet and possibly as much as 1,800 feet in the extreme southwestern corner of the area.

A large part of this area is underlaid by hard, non-productive bedrock at depths varying from at the surface just north of the highway and

east of the Hot Wells to as great as possibly 1,800 feet in the extreme southwestern corner of the area. Near Apache Junction the water-bearing materials are very fine and have a large proportion of clay. Therefore the yields will be even smaller than those given for the irrigated section. The yields in the Apache Junction part of the area are probably in the neighborhood of 0.01 to 0.02. The depth to bedrock is unknown. However, bedrock is exposed a few miles west of Apache Junction and a mountain peak sticks out of the valley fill a few miles south of Apache Junction. Therefore, future water production in all of the Apache Junction area is questionable. A large part of this area will run out of water regardless of the cost of pumping because the water will be drawn down to bedrock.

Present and Future Quality of Water in the Apache Junction Area

No quality of water problems have been encountered in this area and none are expected. The hot water developed at the Buckhorn Hot Wells is discharged from a hot spring coming out of the bedrock through a fault at a depth of 800 to 900 feet beneath the surface. The flow of water from this spring has been estimated as 5 to 10 second-feet or 10 to 20 acre-feet of water per day. The water is not highly mineralized and is suitable for irrigation use.

Present and Future Use of Water

The total irrigated acreage in the Apache Junction area is 15,000. One-half of this is in the Roosevelt Water Conservation District and uses about 50% surface water and the remainder ground water. The water pumped from underground amounts to 51,000 acre-feet per annum, or 140 acre-feet per day, or 46 m.g.d. This would supply a population of 230,000. The 17,000 acre-feet of surface water used in the area amounts to 46 acre-feet per day or 15 m.g.d. This would supply an additional 75,000 people.

By 1980, the part of the area near the mountains will be unwatered to bedrock and the pumping lift will be excessive in all the eastern part of the area. Therefore, the water available from underground has been estimated at 10 m.g.d., (see Summary Table). The water available from surface water would be somewhat reduced by upstream development and

is estimated as 12 m.g.d., (see Summary Table).

Salt River Project Area

This area represents many different kinds of conditions with regard to the water resources. The first and major difference between this area and the areas previously described is the fact that this area uses large amounts of surface water derived from the Salt River System.

The ground-water level in this area was first measured by W. T. Lee in 1902-1903 and published by the United States Geological Survey. The Salt River Project has kept excellent records of the water pumped and of the ground-water levels starting soon after Roosevelt Dam was constructed. The ground-water levels for the project area rose rapidly until 1919. A part of the area was water-logged and drainage pumps were installed to drain the land. The peak ground-water level was reached in various parts of the area in 1919 or shortly after. Since that time the level has been receding.

The history of ground-water conditions within the Salt River Project since 1914 may be divided into four periods. The first was the period of rising ground water levels. The next was a period when pumping was increasing and recharge was decreased by the lining of ditches and canals. This ended about 1930. The third period was 1930 to 1940, when additional lining and some increase in pumping took place. The fourth period started in 1940 and has continued to the present with a tremendous increase in pumpage both inside and outside the Project area.

The ground-water yield of the Salt River Project area has been estimated several times in the past. However, the yield under the conditions existing since 1940 is the only item of significance as the yields computed before that time were under different conditions. In 1945 the United States Geological Survey made an estimate of the safe yield of the ground-water reservior in the entire Salt River Valley and this was given as 474,000 to 579,000 acre-feet. No estimate was included for the amount of water that must be allowed to leave the basin to keep a safe salt balance.

The annual safe yield of the Salt River Project area varies directly with the amount of surface water being brought into the area and the amount of rainfall. In the report prepared by this office in 1952, it was found that if the surface-water diverted in the Salt River Project area was 400,000 acre-feet per year, the ground-water use that would cause zero change in water levels was only 100,000 acre-feet. However, if the surface-water diverted was 1,000,000 acre-feet a year, the ground-water use could be 440,000 acre-feet per annum and still cause zero change in water level. If the surface-water diverted was 1,400,000 acre-feet per year, the ground-water use could be increased to 740,000 acre-feet without causing a drawdown.

In the same report, it was shown that the amount of water yielded by unwatering the underground strata or mining water, averaged about 12 percent of the volume unwatered and that it might be as low as 10 percent or as high as 15 percent.

Present Depth to Water and Predicted Future Depth to Water in the Salt River Project Area

The shallowest depth to water in the Salt River Project area is in the area where the shallow materials are very tight and will not yield water to irrigation wells and therefore the water level has not been drawn down. This is the area northeast of Phoenix where water levels of 10 to 12 feet are still found. In the irrigated areas the shallowest depth to water is 50 to 80 feet in the area along the Salt River. The depth to water increases to the north to a maximum of 250 feet north of Peoria, 230 feet north of Scottsdale and 260 feet south of Gilbert.

A graph, not included in this report, representing the average elevation of the ground-water level in the Salt River Project together with the water that is pumped and the surface water diversions has been prepared by the Salt River Valley Water Users Association. A study of this graph indicates that the general trend of the ground-water level is downward, but that each wet year there is some recovery. For instance, the recovery during the 1941 wet season equalled the drawdown for four normal years. The year 1951 produced a raise that equalled approximately one

year's normal drop in level. An extension of the trend of the average decline in level to 1980 gave a level of 300 feet for 1980. This extension did not take into account the hoped for and expected two or three wet years during that period.

On Figure 11 there is shown the water-level records for selected observations wells in the Salt River Project. The distance and direction from the center of Phoenix have been indicated on each record. An extension of the trend of the decline of water levels gives a depth in 1980 varying from 110 feet for the minimum depth to 620 feet for the maximum depth. If 50 feet is added to the maximum static level, it gives 670 feet as the maximum pumping level expected within the Project. Even at this depth it is probable that, with improved well and pump efficiency and possibly reduced power rates, water could still be pumped at low enough cost for irrigation use. The ground-water reserves are being mined in parts of this area but at slower rates than in the other areas discussed.

Present and Future Production Rates in the Salt River Project Area

The present production rates vary tremendously in this area. Where wells have been finished in the gravels deposited by major streams, such as the Salt or the Gila River, the rates have been very large, but in between these major streams and near the sides of the basin the rates at the present time are comparable to those in the areas previously discussed. The rates at depths below 800 feet are nearly the same over the entire Project.

In the area west and northwest of Phoenix, which might be called the Glendale-Peoria-Tolleson area, the present rates of production, using the formation coefficient, vary from a minimum of 0.10 to a maximum of 0.50. The coefficients for the deeper deposits range from a minimum of 0.05 to a maximum of 0.20, with the very deepest deposits, those below 800 feet, being about 0.06 to 0.08.

The wells along the Salt River, south and west of Phoenix, have coefficients varying from 0.5 to 1.5. However, the few wells that have been drilled to greater depths indicate coefficients similar to those given for the area northwest of Phoenix.

In the Scottsdale area, the wells north and east of Scottsdale but away from the river have coefficients varying from 0.07 to as high as 1.0 for wells located in the coarser gravels. At depth, the coefficients range from 0.05 to 0.08.

East and southeast of Phoenix, in the Tempe-Mesa-Chandler areas, some of the wells have had very large yields. The formational coefficient for one well southeast of Mesa was 3.12 for the materials from 100 to 130 feet. Many of the wells in this area have coefficients ranging from 1 to 2 with only a few having coefficients less than 1 for materials at shallow depths. At greater depth, however, the coefficients are smaller as in the other areas, but because there is probably still some production from the upper horizons, the coefficients for the deepest wells in the area range from 0.08 up to 0.5. It is believed that the deeper formations in this area will be similar to those in the other areas and will average about 0.08.

Future production can be maintained at reasonable rates in most of the Salt River Project area. The drawdowns predicted are not excessive and usually leave plenty of water-bearing material to give reasonably good production from the wells. One feature of this area is the occurrence of a thick layer of lake-bed clay with the top at depths varying from 400 to 800 feet and extending down to depths of 1,000 to 1,400 feet. Good water-bearing materials have been found under the lake-bed clay and in many cases the clay is not tight and produces water through fractures or from thin sand and gravel layers in the clay, because good production has been made from wells that have been perforated only in the clay. Therefore, the predicted production rates probably apply to the clay as well as the materials above and below it; the clay level is not taken to mean the maximum depth of production.

Near the edges of the basin, where this occurs in the Salt River Project, there are some local areas where bedrock will limit the deepening of wells. However, the amount of such area is limited.

Present and Future Quality of Water in the Salt River Project Area

The quality of water produced by wells in this area varies markedly

in various parts of the area and in the same place the quality may vary with depth and at the same depth it varies with time. The variation from place to place depends on the types of deposits encountered. The variation with depth depends upon the concentration of irrigation water near the surface and at lower levels, upon the types of deposits encountered. The variation with time depends upon the direction from which water is brought into the well and the changes in quality brought about by the continuous concentration of salt in the area by irrigation use.

Considering the Salt River Valley as a whole, the amount of salt brought into the valley in the water supply varies from a low of 900,000 tons to a high of about 1,400,000 tons per annum. The major part of this salt remains in the basin. Very little is taken out of the basin under present day conditions. Thus, there is a continuous buildup of salt in the basin and this is one of the major reasons why the salt content of most well water in the Salt River Project area is increasing.

In 1947, the U. S. Geological Survey published a report on the ground-water resources of the Salt River Valley and Plate 4 of this report shows the mineral content of the ground-water by means of contours. This map shows that the mineral content of the ground-water in the Salt River Project area varied from a minimum of 500 parts per million to a maximum of more than 4,000 parts per million. In most of the area, the total solids is about 1,000 parts per million.

Northeast of Phoenix, between the center of Phoenix and the Arizona Canal in an area where the formations are almost entirely clay and therefore poorly drained, the salt concentration was up to 3,000 parts per million in 1946. South of Tolleson there was another area of mineralized water where the total solids exceeded 4,000 parts per million. It is believed that this area of salt water was caused by concentration of salt by irrigation use and the drainage of the highly mineralized shallow water to this point.

Southeast of Chandler there was one small localized area of very bad water and a well drilled in this area showed natural salt crystals in the clay and many lime crystals. It is believed likely that the high concen-

tration of salt in this area is caused by the discharge of hot mineralized water from a spring issuing from bedrock up into the overlying fill. Several miles to the south of this area and south-southwest of Chandler, there is a larger area where the total solids exceed 4,000 parts per million. In this area, it is believed that the salt content is caused by poor drainage, as there is much clay in the soil, and that the salt was concentrated there in a dry lake or playa. Part of the salt in this area was deposited in geologic time and part has been increased by recent irrigation concentration.

As stated previously, it is believed that the salt content of the water in the Project area will continue to increase. Although in some areas the quality has been getting better for several years due to better water being brought in from the sides of the basin by the heavy pumping, the concentration of salts by irrigation use and the continued bringing in of additional salt from outside of the Project area can only lead to an increase in salts in at least some parts of the area. Therefore, the major question as to future water supply in this area is not one of quantity, at least not until after 1980, but it is one of quality. The individual farmer can probably protect himself by cementing off the upper layers containing the salty water that has been concentrated by irrigation use and pumping only the lower layers, but if this goes on for many years a drainage problem will result, and there is also the chance that the shallow waters are not completely separated from the deep waters and would be drawn down into the wells at a later date.

Unless additional water can be brought into the basin so that salt water can be flushed out of the Project area, the only answer that will stand for many years will be to have the shallow salt water pumped to the surface and there treated for salt removal or have the salt water pumped into lined ditches and taken out of the basin. This method only adds to the problems of the next basin down stream. Research on economic methods of salt removal and the application of this research to practical use will be the only answer to future ground-water supplies in a part of the Salt River Project area. Some of the areas are already in dire distress because of the bad quality of the water and these areas

will spread unless remedial measures are taken.

Present and Future Use of Water

The Salt River Project has a water supply derived from both surface and ground water. The average pumpage from underground has been about 500,000 acre-feet per year. This equals 1,370 acre-feet per day or 447 m.g.d. This would support a population of 2,235,000. The average surface water diversion into the area is 800,000 acre-feet but a part is lost through canal seepage and about 600,000 acre-feet is all that is available for use. This equals 1,650 acre-feet per day or 538 m.g.d. Thirty-eight m.g.d. of this are included in the City of Phoenix supply, leaving 500 m.g.d. for a population of 2,500,000 people. If the major part of the canal-seepage loss is stopped by lining canals or putting the water into pipes, more surface water will be available but less ground water.

The Roosevelt Irrigation District pumps about 150,000 acre-feet of water each year from within the Project area and takes it outside the area for irrigation use. Most of the water pumped is too highly mineralized for public supply and it will probably increase in mineralization. If usable it would support a population of 670,000 people.

The Phoenix metropolitan area is using an average of 100 m.g.d. derived from surface water and from underground. This would supply about 500,000 people.

It is estimated that by 1980 the amount of usable water that can be pumped inside the Salt River Project will have decreased to 200 m.g.d. as the quality will be unsatisfactory for domestic and most industrial uses in one-half of the area. The part nearest the mountains will be unwatered. The surface water supply will decrease from 500 to 475 m.g.d. due to continued upstream development. The Roosevelt Irrigation District pumpage will be too salty for use by city or industries. The City of Phoenix present use of 100 m.g.d. from surface and underground water will decrease to an available supply of 38 m.g.d. from surface and 25 m.g.d. from underground. Thus the city will have to take over more and more of the surface water available from the Project. See Summary Table.

COST OF PUMPING WATER

As the depth to water increases the cost of pumping becomes a more important item. Therefore, a graph has been provided, Figure 12, showing the average total cost of pumping water from deep wells with various pumping lifts. The maximum depth given by this graph is 750 feet. The cost given on the left hand side of the graph is total cost per acre-foot. However, if this cost is desired in millions of gallons, the cost per acre-foot should be multiplied by three to equal the cost per million gallons. Thus if the cost was $10.00 per acre-foot, it would be $30.00 per million gallons.

With a pumping lift of 350 feet, a cost of $20.00 per acre-foot or $60.00 per million gallons is shown by this graph. If the pumping lift is 700 feet, the cost per acre-foot would be $39.00 and $117.00 per million gallons.

The graph is based on the cost with pumping levels varying from 150 to 550 feet and therefore its extension past 750 feet is not deemed adviseable. There is some reason to expect that the cost will increase at greater depths, out of proportion to the increase in pumping lift. This is because of the smaller yields and the greater investment required in the deep wells.

The greatly increased pumping costs at the depths indicated by the predicted increase in depth to water in some of the area described in this report means that all methods possible will have to be investigated, both to increase the efficiency of the wells and thereby decrease the drawdown and to increase production. All possible ways to bring additional water into the area will have to be investigated.

SOURCES OF ADDITIONAL WATER

Due to the greatly increased costs of pumping water from the deep levels to be faced in the future and to the increased salinity of the water in some areas, additional water must be brought into this region. The increased pumping costs should increase the economic feasibility of bringing in additional water and the increased salinity makes it absolutely necessary for some parts of the general Phoenix area.

Additional water for some industrial uses, irrigation use, and for recharge to push back the shallow salt water can be obtained by making use of treated sewage outflow from the several municipalities. The amount of water available from this source will increase greatly during the years ahead. The water available from this source, like the water from other additional sources discussed later in this report, has not been included in our estimates.

Additional water can be secured by the use of salt removal plants if and when these become economical. Such plants would greatly help some parts of the Phoenix area.

Additional water will be brought into the area by the proposed Colorado River development if and when that is constructed. Bringing in this water, however, also brings additional salt and makes the salt-water removal plants even more imperative or enough water must be allowed to move out of the area to remove the salt.

Additional water can be secured by the control of wasteful vegetation on the streams flowing into this area. This means not only the water-loving vegetation along the stream banks with its extremely high rates of use, but the nonbeneficial vegetation or only slightly beneficial vegetation that uses water on the upland area. The replacement of this brush with a grass that uses a smaller amount of water but gives monetary returns would be beneficial. Research on this phase is greatly needed.

Additional water can be developed on the head waters of several of the streams leading into the area by lowering the outlets of artesian springs. These springs are fed by recharge in the Mogollon Rim area,

the area of highest rainfall in the State. At present, a large part of this recharge feeds northward. Lowering the spring outlets on this side and possibly tunneling and deep well drilling can bring more of this water toward the Salt River Valley. This phase needs a large amount of investigation.

Another phase of upstream development should be the interception of the highly saline waters that are fed into the Salt and Verde Rivers at a few places. The interception of this water and its evaporation, the salt being captured for economic use, or the interception of this water and the salts being taken out by a salt treatment plant would be of tremendous value to the basin. It is believed that about half of the salts that are presently entering the basin could be thus captured at a great saving to the area.

CONCLUSIONS AND RECOMMENDATIONS

If the area described in this report is to continue to prosper in spite of the greatly increased pumping lifts and the increase in salinity, a unified program must be undertaken. The first step would be the setting up of an overall cooperative water plan with the present irrigation districts and municipalities playing a leading part. This overall plan would include the research and development suggested. Additional water developed by this plan would be allocated according to prior agreements.

It is possible that this plan should include a greater area than that described in this report. A large part of the research, investigation and development that is recommended in this report would apply with almost equal force to the water-deficient areas in Pinal County and in the Gila Bend area of Maricopa County.

Unless additional water is brought into the general Phoenix area by some method, industry and urban development will have to replace a large part of the area that is at present under irrigation. It would be wise if this industry and urban development could be directed toward those lands that will be retired from irrigation and again this can only be done according to some overall plan.

This report is based on an analysis of the available data and the straight-line extension of these data into the future. This is all that could be done with the money available, but better estimates should be made and be kept up to date. The best way to do this would be to make an electrical model of the basin using all determined basin characteristics. Where data is lacking it would be obtained by field electrical tests with special emphasis on the deep strata and the total depth of the basin.

The model would be expensive because of the time necessary to determine the ground-water characteristics and translate these into electrical characteristics and build the model. But after it is built, various recharge, pumping and underflow conditions could be put into the model and the resulting changes quickly determined for any time in the future. The accuracy of the model could be checked by building it based on the original conditions in 1902-03, putting in the known recharge and dis-

charge for certain periods and determining if the effect obtained equaled the known effect. The model would be kept available for future changes and additional estimates needed in the future.

Research and the application of this research to salt water removal will have to be started. The need is urgent as some areas are already in distress because of the heavy concentration of salt water. This same program should be applied to the upstream areas which are at present supplying the major part of the salt in the water coming into the Salt River Basin. This includes the water coming in at the Salt Banks and in Carrizo Creek in the Salt River Basin, and from several of the small hot springs in the Verde River Basin.

Research and the rapid application of the findings to the control of water-loving vegetation along stream banks and to non-beneficial vegetation in the upland areas should be encouraged.

Detailed studies should be started immediately of the possibilities of recovering more of the recharge from underneath the Mogollon Rim, including lowering the outlets of artesian springs, tunneling, and the drilling of deep wells. As soon as possible some practical work should be underway.

Only the forceful carrying out of the program outlined can save this area from reaching a peak in development and then falling off from that peak as both agricultural and industrial production decreases due to lack of water and to the prevalence of salty water.

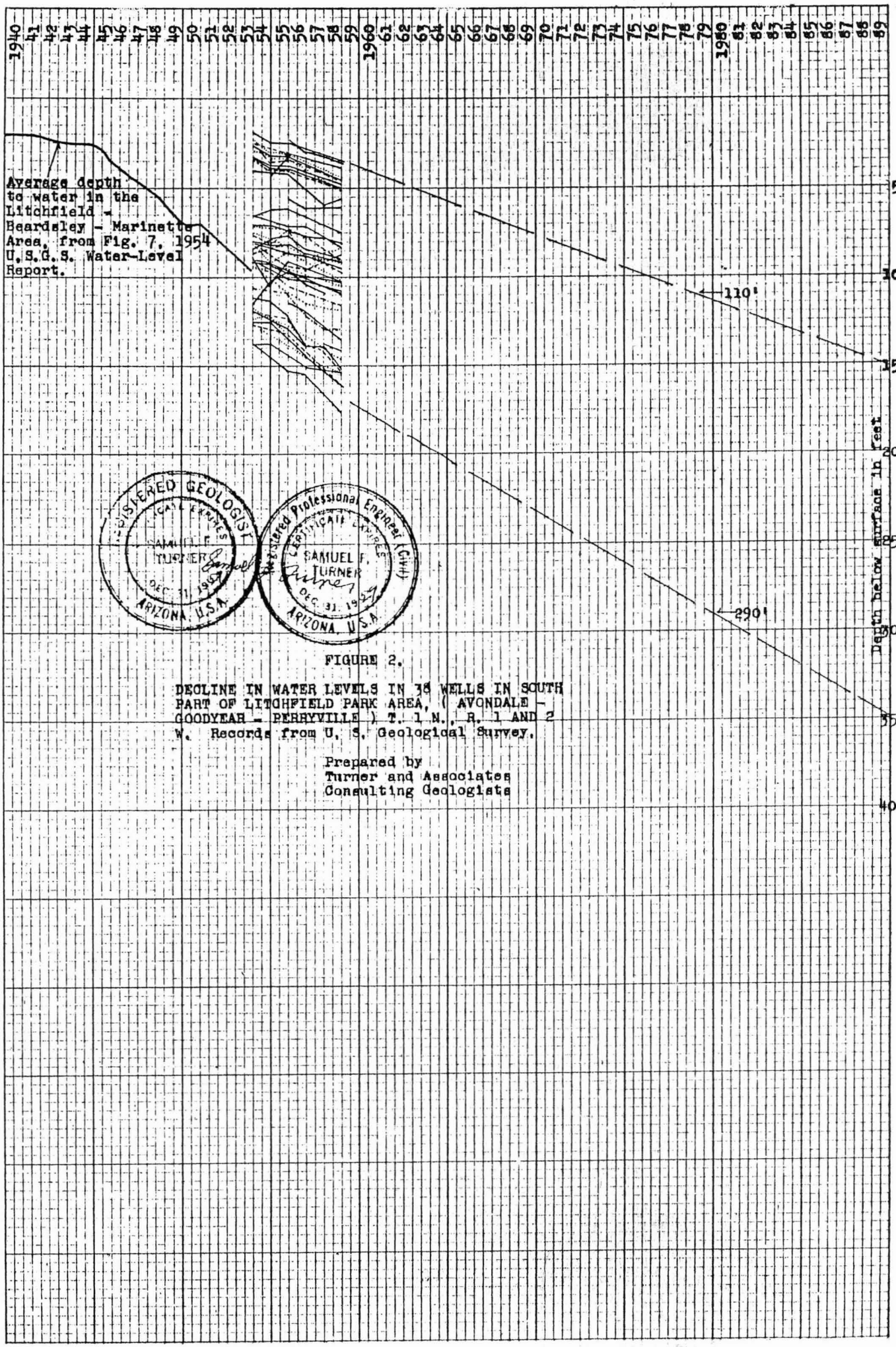


FIGURE 2.

DECLINE IN WATER LEVELS IN 38 WELLS IN SOUTH PART OF LITCHFIELD PARK AREA, (AVONDALE - GOODYEAR - PERRYVILLE) T. 1 N., R. 1 AND 2 W. Records from U. S. Geological Survey.

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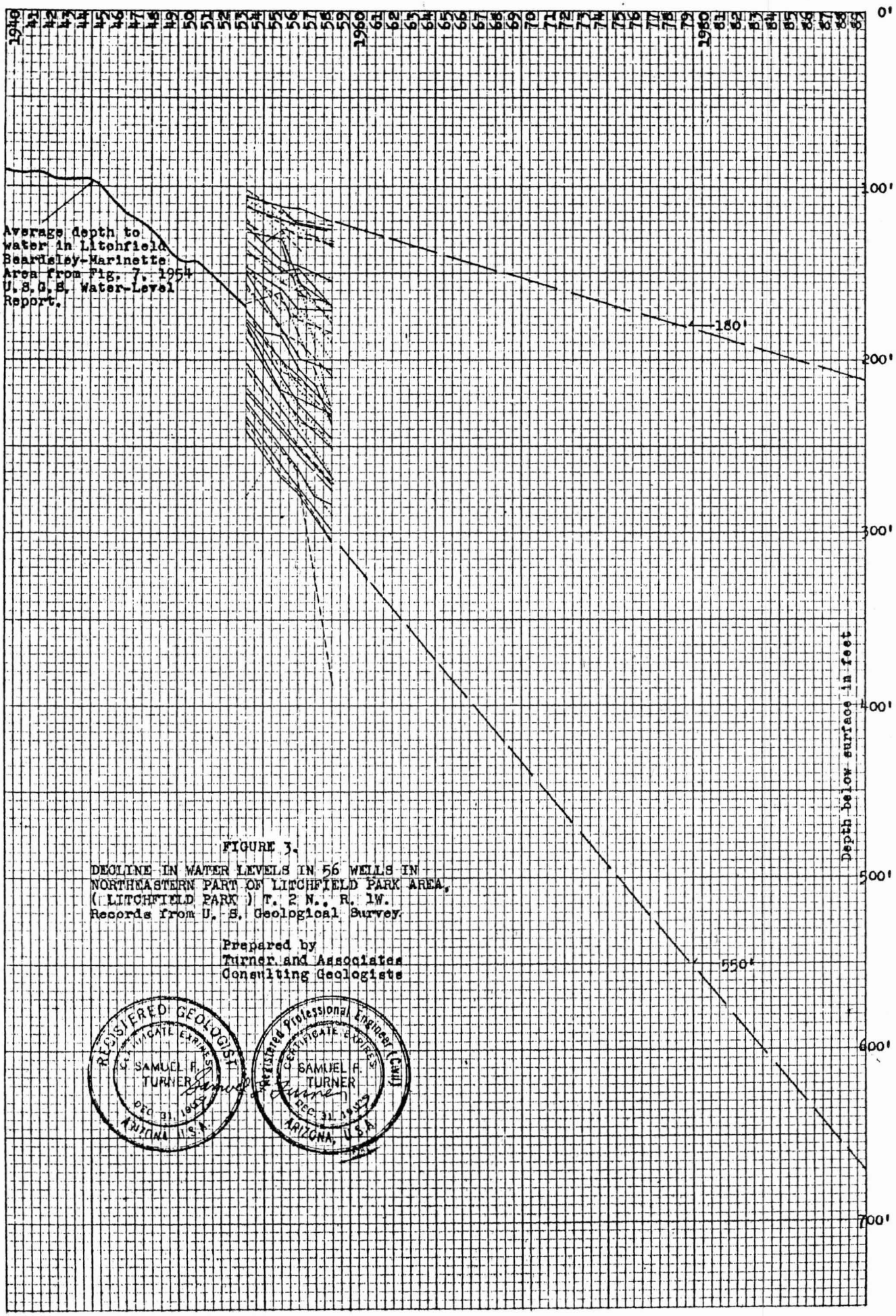

FIGURE 3.

DECLINE IN WATER LEVELS IN 56 WELLS IN NORTHEASTERN PART OF LITCHFIELD PARK AREA, (LITCHFIELD PARK) T. 2 N., R. 1W. Records from U. S. Geological Survey.

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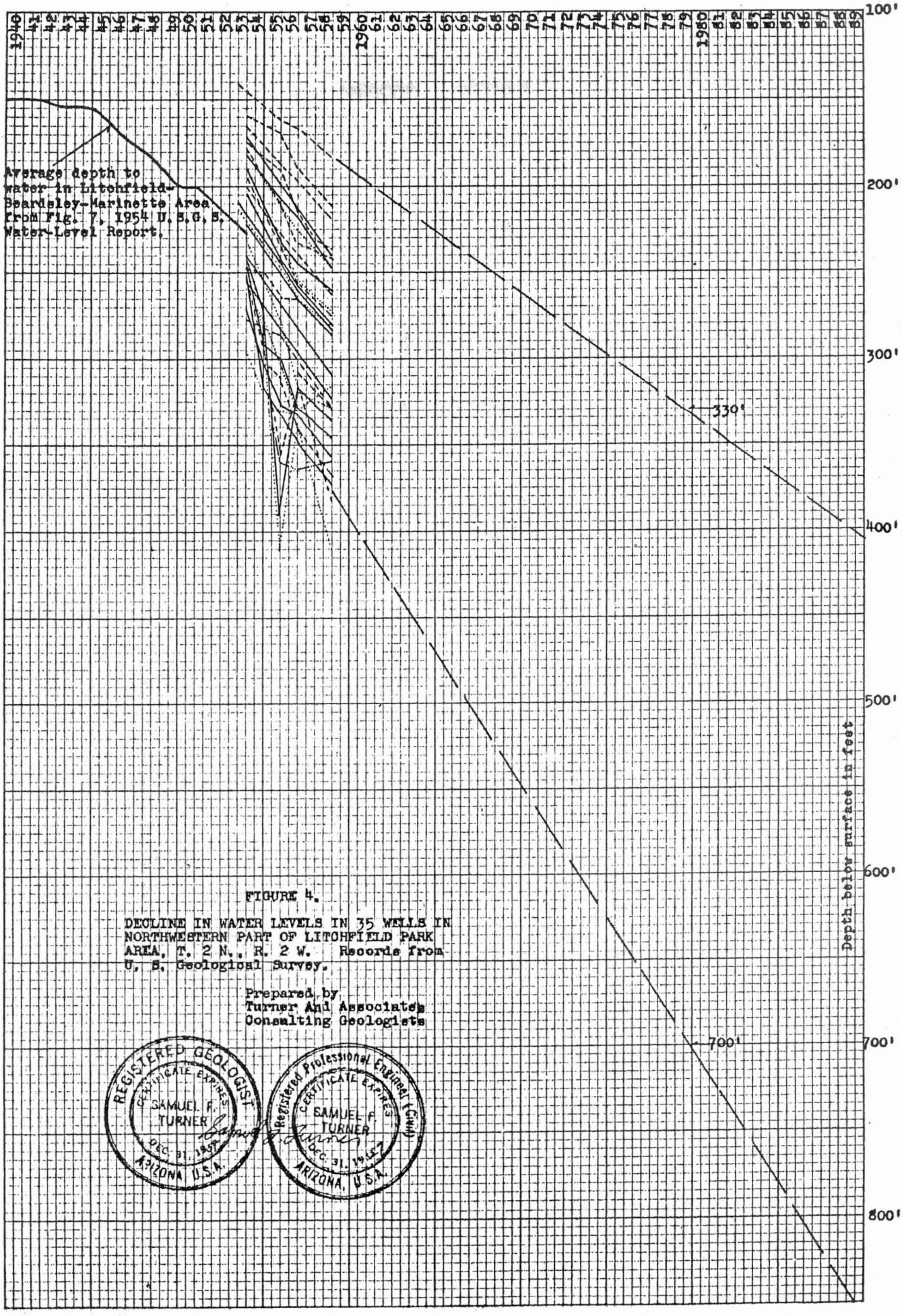

FIGURE 4.

DECLINE IN WATER LEVELS IN 35 WELLS IN NORTHWESTERN PART OF LITCHFIELD PARK AREA, T. 2 N., R. 2 W. Records from U. S. Geological Survey.

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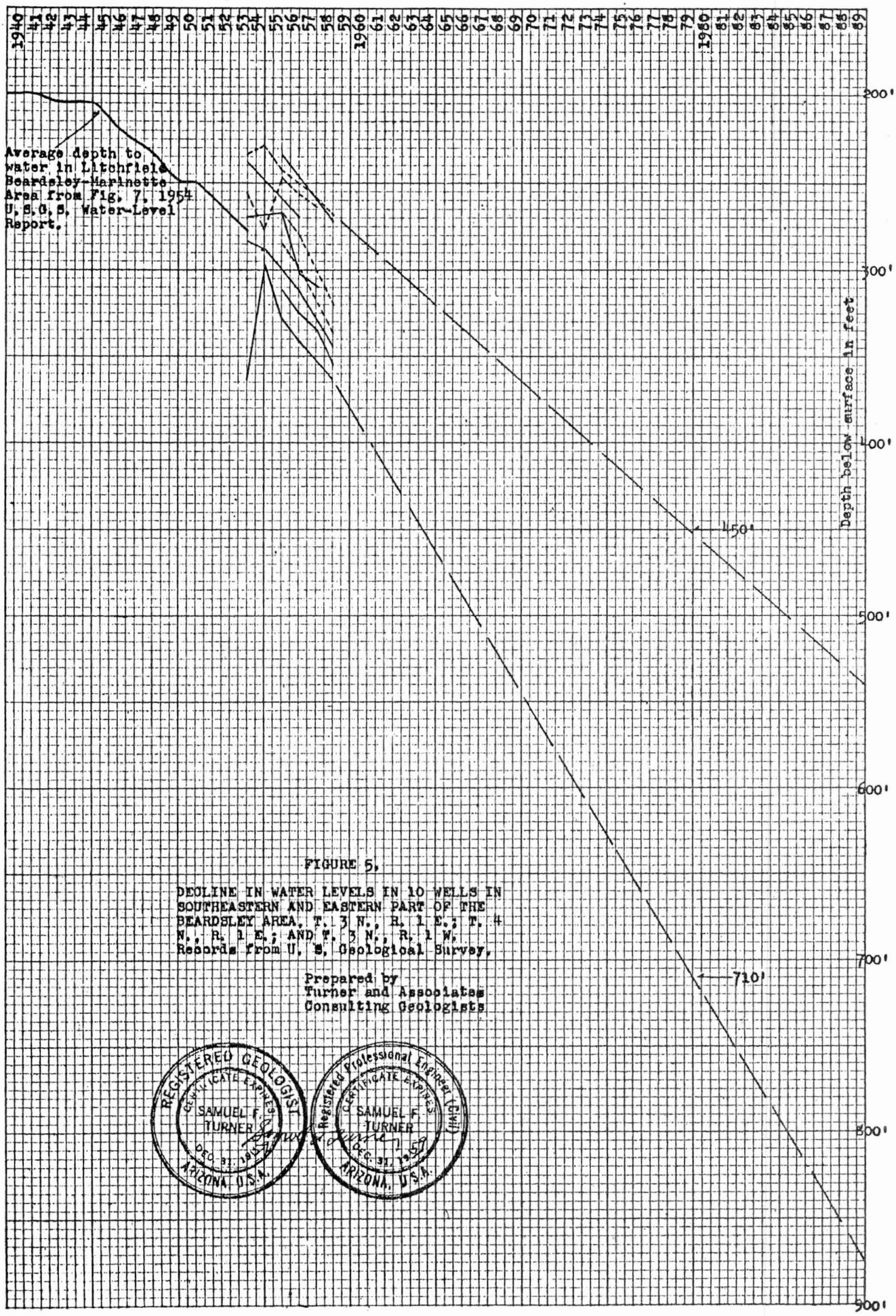

FIGURE 5.

DECLINE IN WATER LEVELS IN 10 WELLS IN SOUTHEASTERN AND EASTERN PART OF THE BEARDSLEY AREA, T. 3 N., R. 1 E.; T. 4 N., R. 1 E.; AND T. 3 N., R. 1 W. Records from U. S. Geological Survey.

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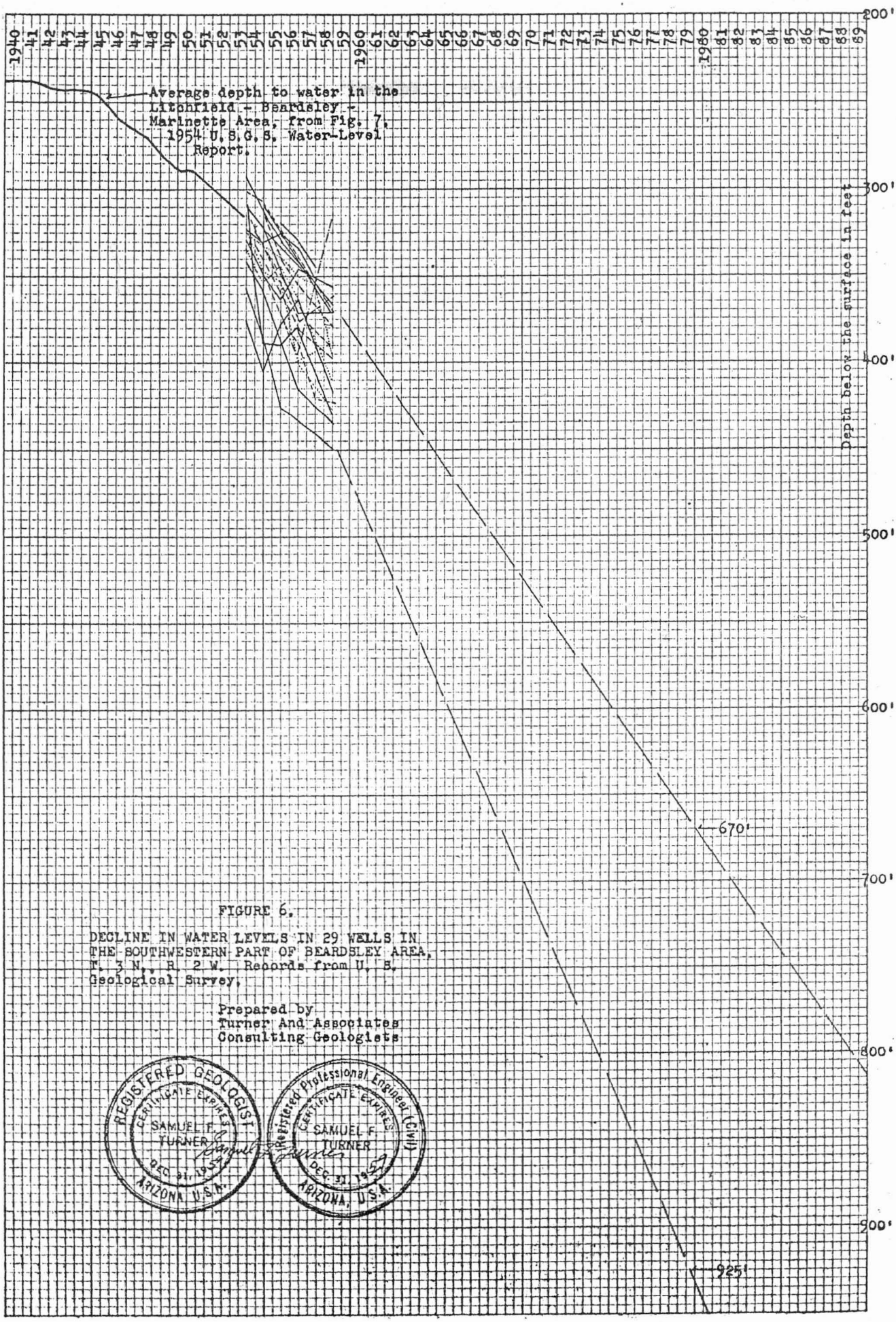

FIGURE 6.

DECLINE IN WATER LEVELS IN 29 WELLS IN THE SOUTHWESTERN PART OF BEARDSLEY AREA, T. 3 N., R. 2 W. Records from U. S. Geological Survey.

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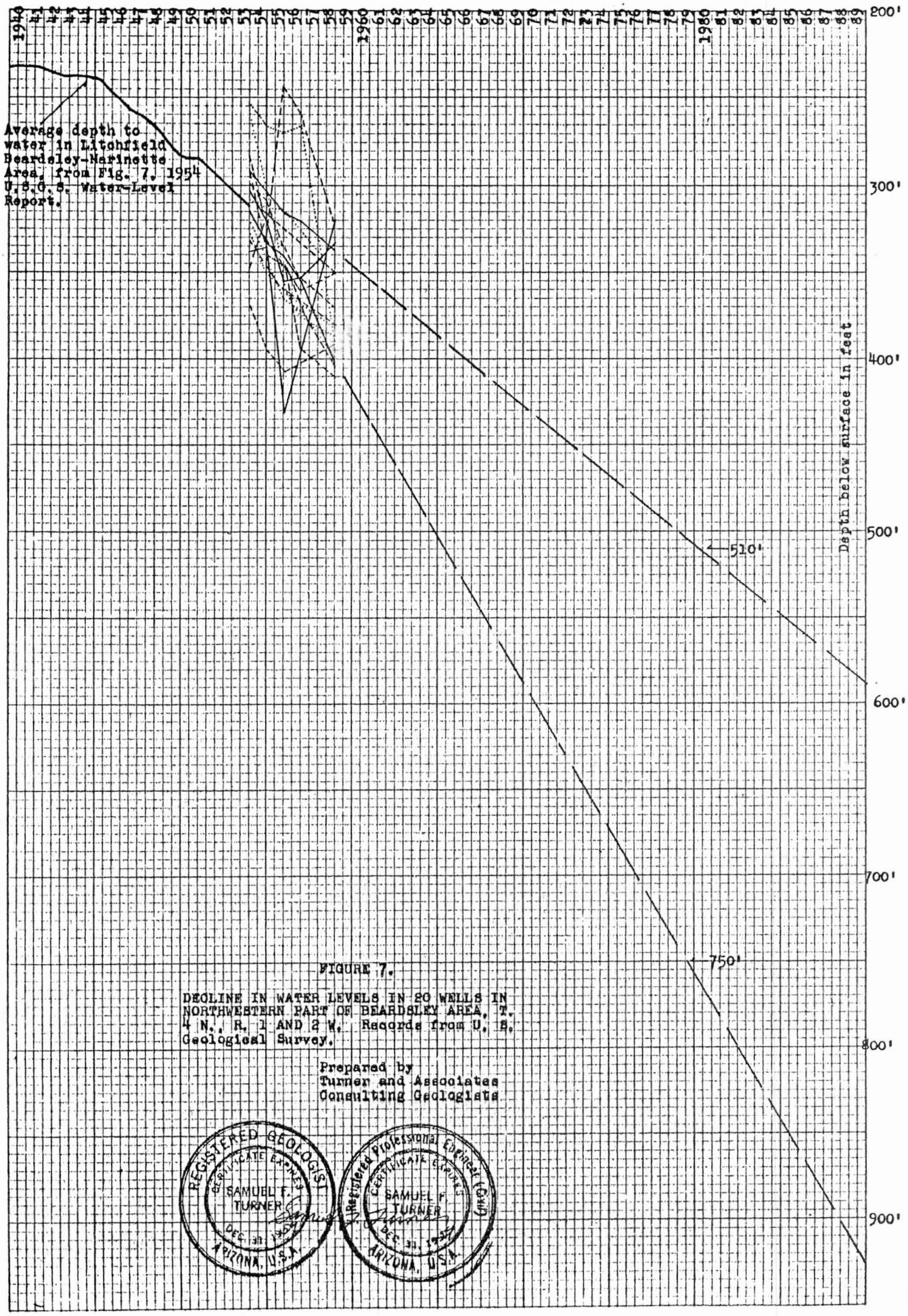

FIGURE 7.

DECLINE IN WATER LEVELS IN 20 WELLS IN NORTHWESTERN PART OF BEARDSLEY AREA, T. 4 N., R. 1 AND 2 W. Records from U. S. Geological Survey.

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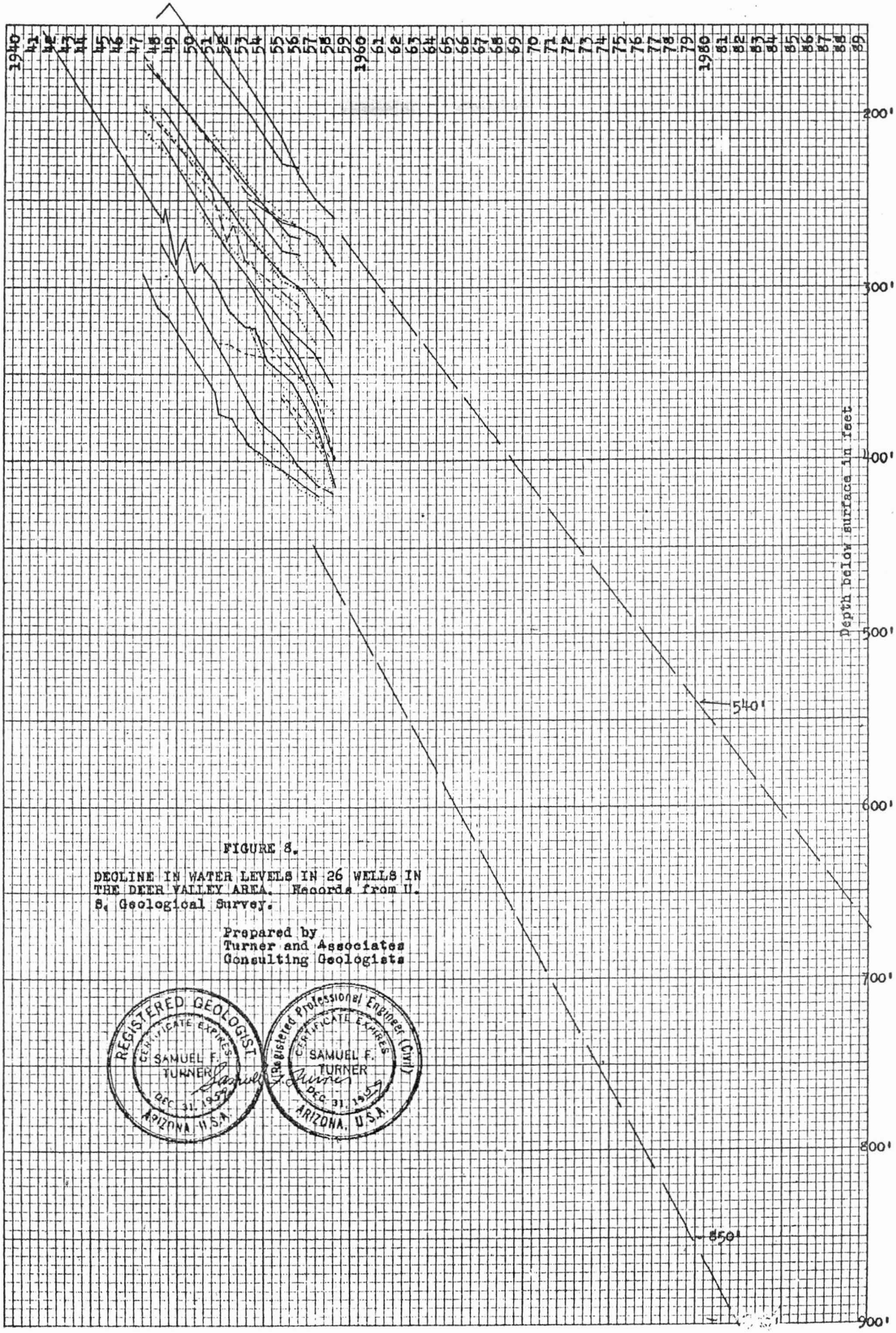

FIGURE 8.

DECLINE IN WATER LEVELS IN 26 WELLS IN THE DEER VALLEY AREA. Records from U. S. Geological Survey.

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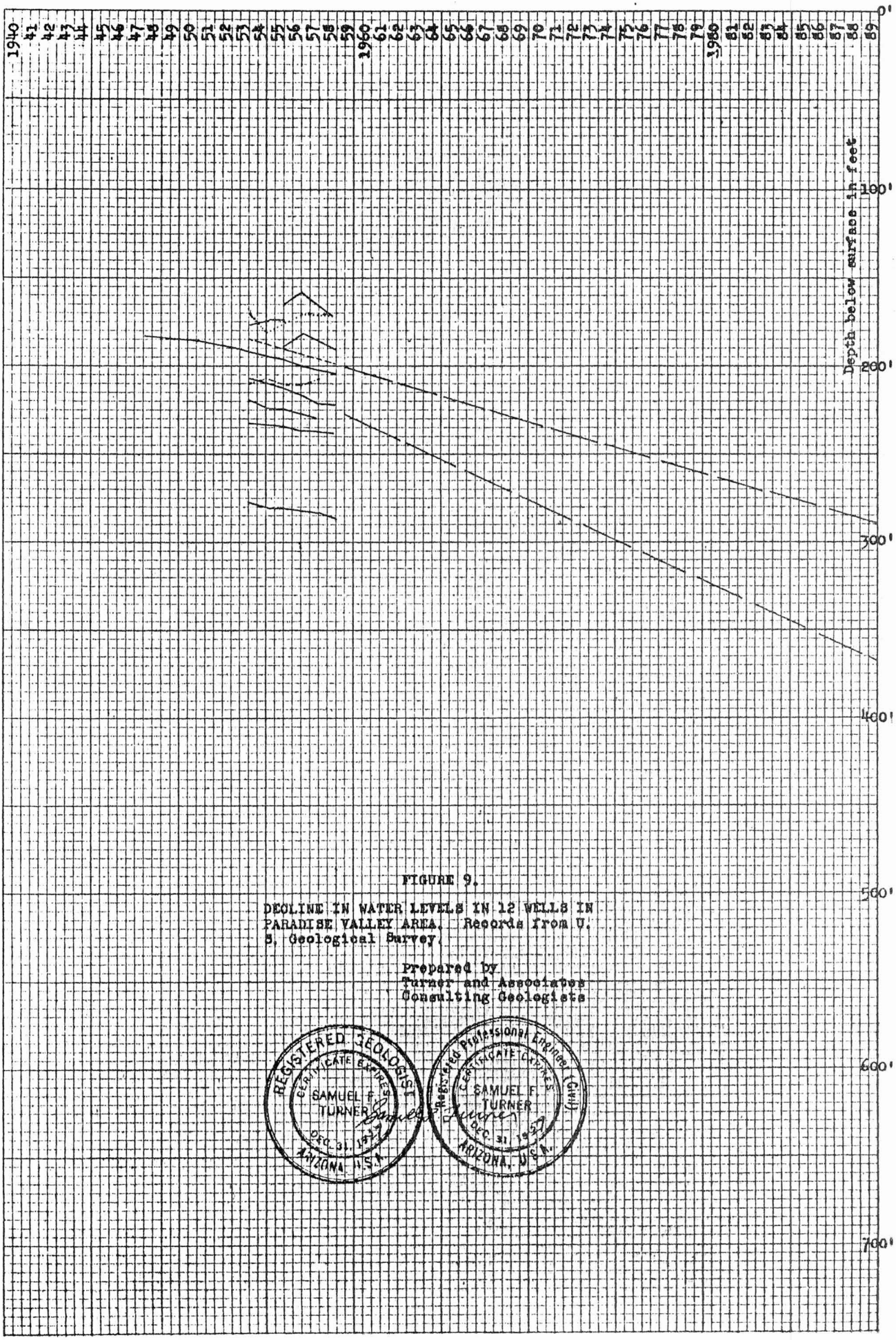

FIGURE 9.

DECLINE IN WATER LEVELS IN 12 WELLS IN PARADISE VALLEY AREA. Records from U. S. Geological Survey.

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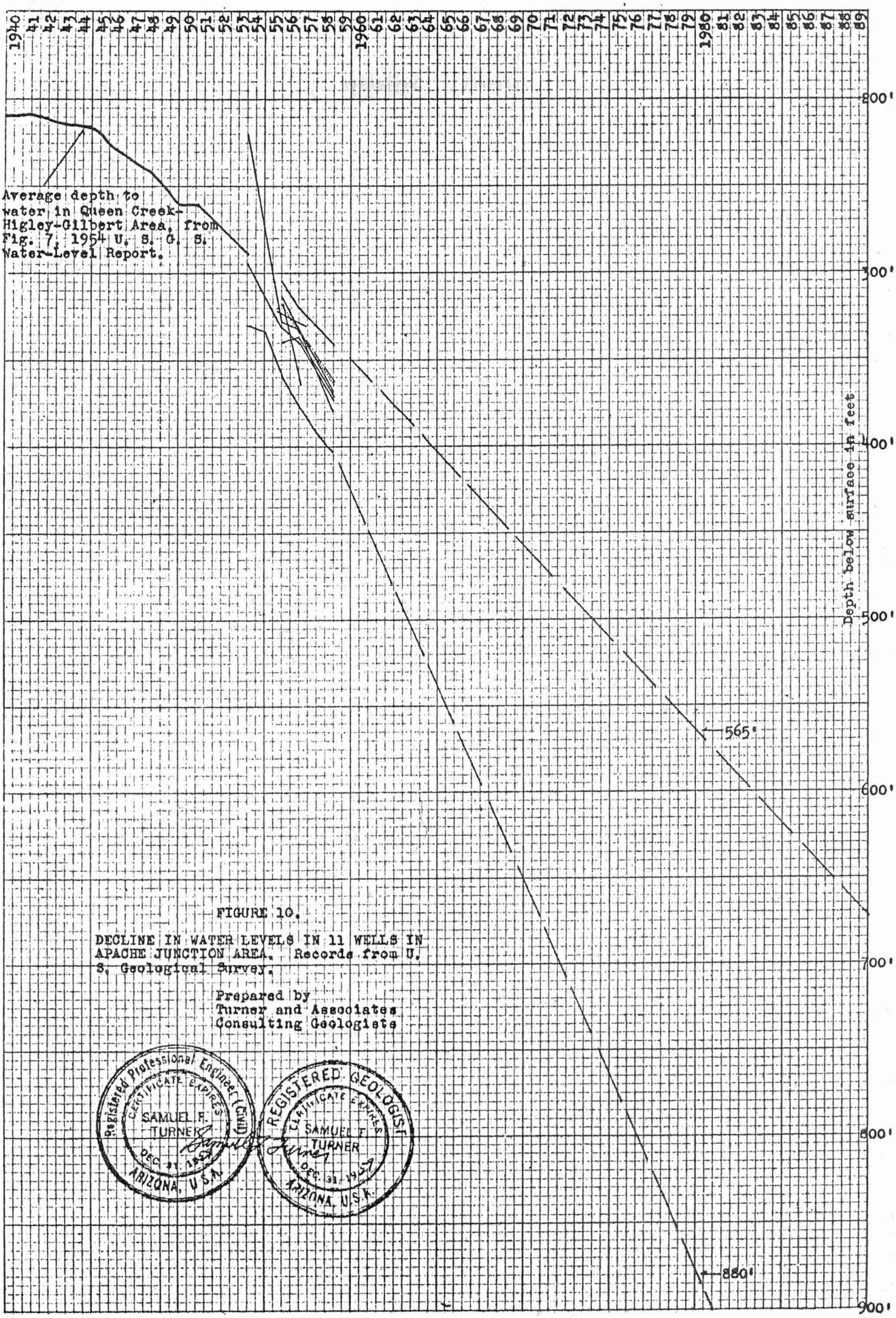

FIGURE 10.

DECLINE IN WATER LEVELS IN 11 WELLS IN APACHE JUNCTION AREA. Records from U. S. Geological Survey.

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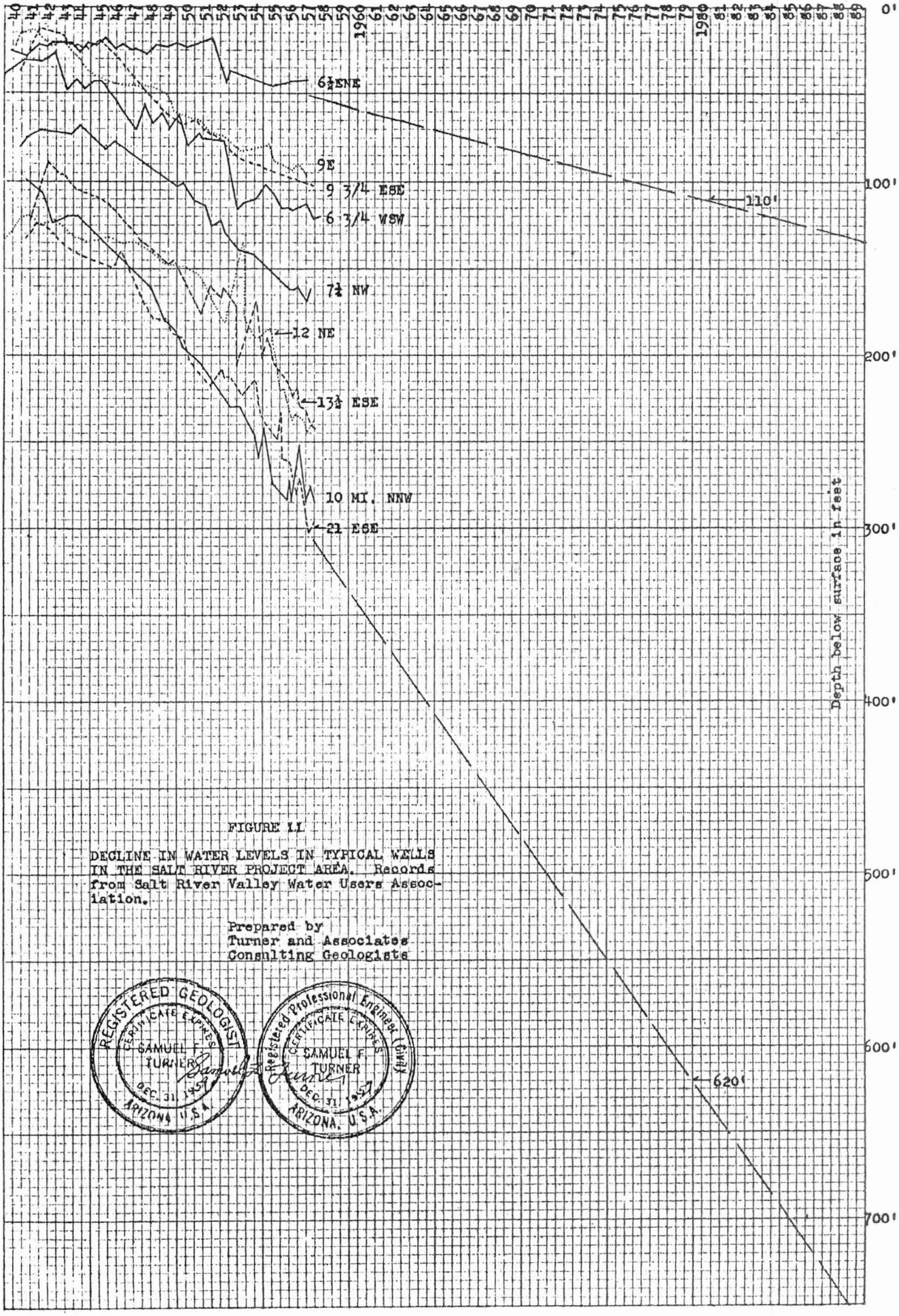

FIGURE 11

DECLINE IN WATER LEVELS IN TYPICAL WELLS IN THE SALT RIVER PROJECT AREA. Records from Salt River Valley Water Users Association.

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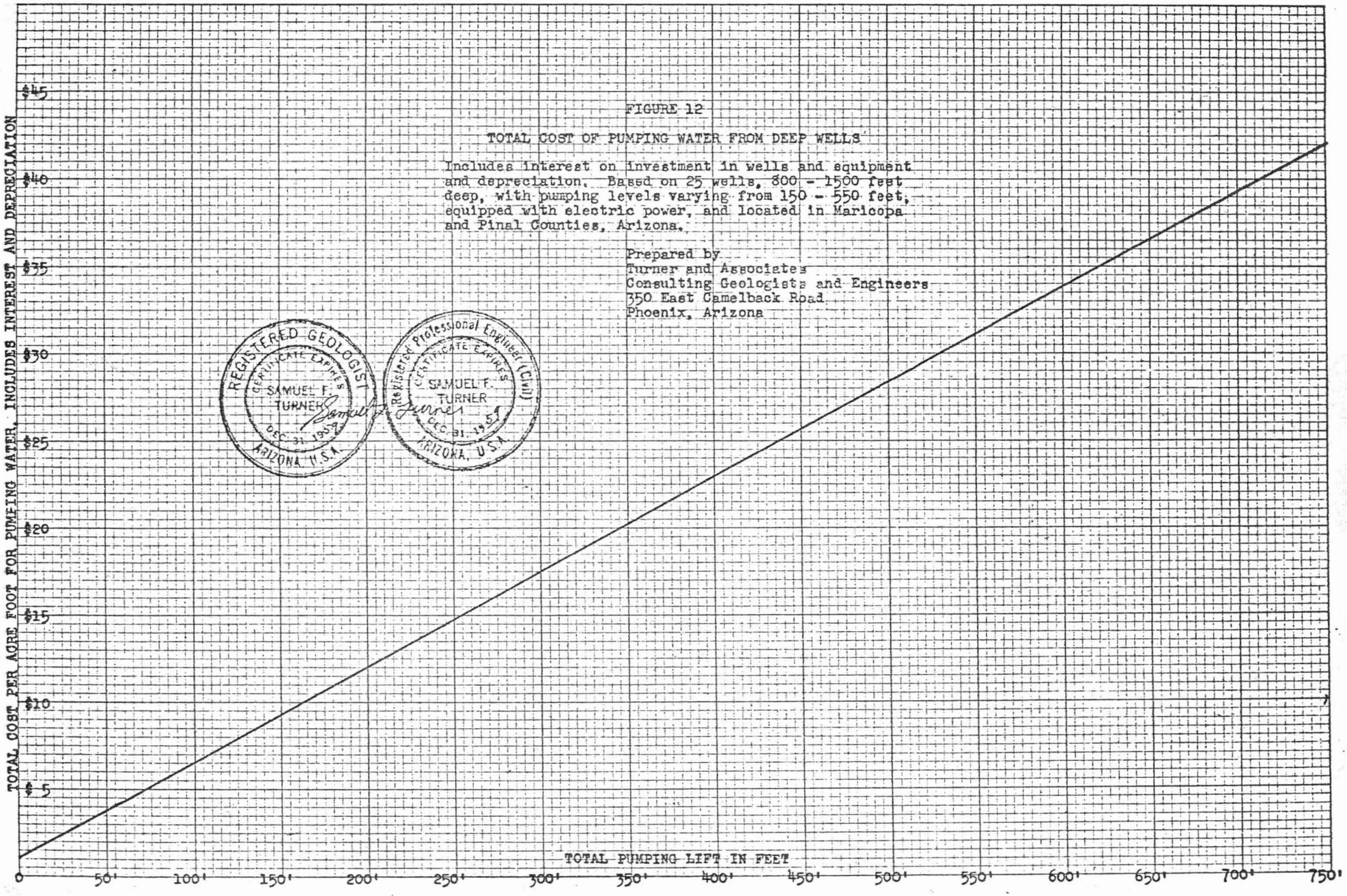

FIGURE 12

TOTAL COST OF PUMPING WATER FROM DEEP WELLS

Includes interest on investment in wells and equipment and depreciation. Based on 25 wells, 800 - 1500 feet deep, with pumping levels varying from 150 - 550 feet, equipped with electric power, and located in Maricopa and Pinal Counties, Arizona.

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