TEXAS
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Report 138

RELATION OF PONDED FLOODWATER FROM HURRICANE BEULAH TO GROUND WATER IN KLEBERG, KENEDY, AND WILLACY COUNTIES, TEXAS

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RELATION OF PONDED FLOODWATER FROM HURRICANE BEULAH TO GROUND WATER IN KLEBERG, KENEDY, AND WILLACY COUNTIES, TEXAS

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ABSTRACT

Torrential rainfall from Hurricane Beulah caused floods of record-breaking magnitude in a 50,000-square-mile area of south Texas and northeastern Mexico in September and October 1967. In south Texas, a 3,000-square-mile area, having no defined drainage system, was largely inundated by ponded floodwater which collected in hundreds of shallow depressions. The relation of the ponded floodwater to the ground water was studied at three sites in south Texas—King Ranch site in Kleberg County, Armstrong Ranch site in Kenedy County, and La Sal Vieja site in Willacy County.

The various stages of the ponded floodwater relative to those of the contiguous water table at the three sites indicated that conditions were favorable for recharge of ground water at the King Ranch site, but were favorable for both recharge and discharge of ground water at the Armstrong Ranch and La Sal Vieja sites.

As determined from appropriate water-budget equations, the amount of recharge or seepage outflow, in terms of unit area of water surface, was 0.8 foot during a 9½-month period at the Armstrong Ranch site and 3.5 feet during a 12-month period at the King Ranch site. Volume of recharge at the King Ranch site was about 120 acre-feet. Determinations of seepage outflow could not be made at La Sal Vieja because of ungaged inflow of surface water.

A considerable amount of ground water, though not determined quantitatively, was discharged intermittently during an 8-month period at the Armstrong Ranch site as indicated by the relatively small net seepage loss of only 0.2 foot in the water budget of the pond. This small amount represented the excess of recharge of ground water over discharge.

Differences in the salinity of the ponded water among the study sites were controlled by the relationship of the ponded water to the contiguous ground water. The ponded water was considerably more saline at the Armstrong Ranch and La Sal Vieja sites, where ground-water discharge occurred by seepage inflow to the ponds, than at the King Ranch site where ground-water discharge was absent.

Decreases in the salinity of the ground water at the King Ranch site were attributed to dilution of the ground water by seepage outflow of fresher ponded water. Variations of ground-water salinity indicated that the King Ranch pond, as a recharge facility, influenced the quality of the ground water for a distance of at least 100 feet but no more than 600 feet from the pond's perimeter.

Two years after Hurricane Beulah, the hydrologic system was steadily approaching but had not returned to pre-Beulah conditions. At the end of the period of observation in October 1969, hydrologic conditions at the Armstrong Ranch site were probably within a few months of reaching conditions that existed prior to Beulah.

RELATION OF PONDED FLOODWATER FROM HURRICANE BEULAH TO GROUND WATER IN KLEBERG, KENEDY, AND WILLACY COUNTIES, TEXAS

INTRODUCTION

Purpose and Scope

Torrential rainfall from Hurricane Beulah caused floods of record-breaking magnitude in a 50,000-square-mile area of south Texas and northeastern Mexico in September and October 1967. Beulah made landfall on the Texas coast near Brownsville about daybreak on September 20, 1967, and dissipated in the Sierra Madre of northeastern Mexico on September 22. According to the U.S. Weather Bureau, Beulah was the third largest hurricane of record to strike the North American Continent. On the basis of frequency curves (Miller, 1964), the storm produced precipitation in excess of 100-year recurrence interval for durations of 1 to 7 days at a number of weather stations. In some parts of south Texas, precipitation produced by Beulah during the period September 19-25, 1967, exceeded the normal annual precipitation. (See Figure 1.)

In many areas of south Texas, flooding during September and October 1967 was the maximum known. South of Los Olmos Creek, a 3,000-square-mile area having no defined drainage system was inundated by ponded water which collected in hundreds of shallow depressions. These ponds blocked highways for several days and hampered ranching and oil-field operations for at least 6 months after the storm.

High tides caused by the hurricane reached a maximum elevation of about 7 feet above mean sea level. However, sea water did not reach the study sites involved in this project.

Shortly after the storm, a report (Grozier and others, 1968) was prepared by the U.S. Geological Survey to present all of the documented flood data in a comprehensive and readily available form. The report included a brief general discussion of the effects of the storm on water levels in wells, but emphasized a need for detailed information on the relationship of ponded floodwater to the shallow ground-water supply.

The purpose of this investigation was to observe and document this relationship. The specific objectives were to determine (1) the relationship of the water table to the ponded water, (2) the changes in the quality of the water, (3) the approximate amount of recharge of the shallow ground-water supply, and (4) the rate of return of the hydrologic system to pre-Beulah conditions.

Three sites in south Texas, in Kleberg, Kenedy, and Willacy Counties, were selected for study in areas that had large bodies of ponded water, and that were unaffected by tidal water from the storm. The study sites were designated "King Ranch site" (2 1/3 miles due west of Riviera in Kleberg County), "Armstrong Ranch site" (3 1/3 miles due south of Armstrong in Kenedy County), and "La Sal Vieja site" (7 2/3 miles west-northwest of Raymondville in Willacy County) near two closely spaced natural salt lakes of the same name—La Sal Vieja, meaning "the old salt".

Acknowledgments

The author wishes to thank Dr. Frank H. Dotterweich, Dean of the School of Engineering, Texas A&I University, Kingsville, Texas, whose assistance in this research project has been substantial. Acknowledgment is also extended to Richard M. Kleberg, Jr., Chairman of the Board, King Ranch, Inc.; to Thomas R. Armstrong and Tobin Armstrong of the Armstrong Ranch; and to Homer Fasler of the Ring Ranch for permitting the work to be done on their land.

GEOLOGIC AND PHYSIOGRAPHIC FEATURES

All three study sites are on the Gulf Coastal Plain between Corpus Christi and Brownsville, Texas, and are from 25 to 40 miles from the Gulf of Mexico. In this area, geological formations of Pleistocene and Holocene age are exposed for about 85 miles inland from the Gulf. The Pleistocene Beaumont Clay, a coastwise terrace deposit of unconsolidated sand, silt, and clay, crops out at the King Ranch site and at the La Sal Vieja site, and extends inland from the Gulf for at least 50 miles (Darton and others, 1937). The Armstrong Ranch site is in a vast expanse of windblown sand, silt, and clay

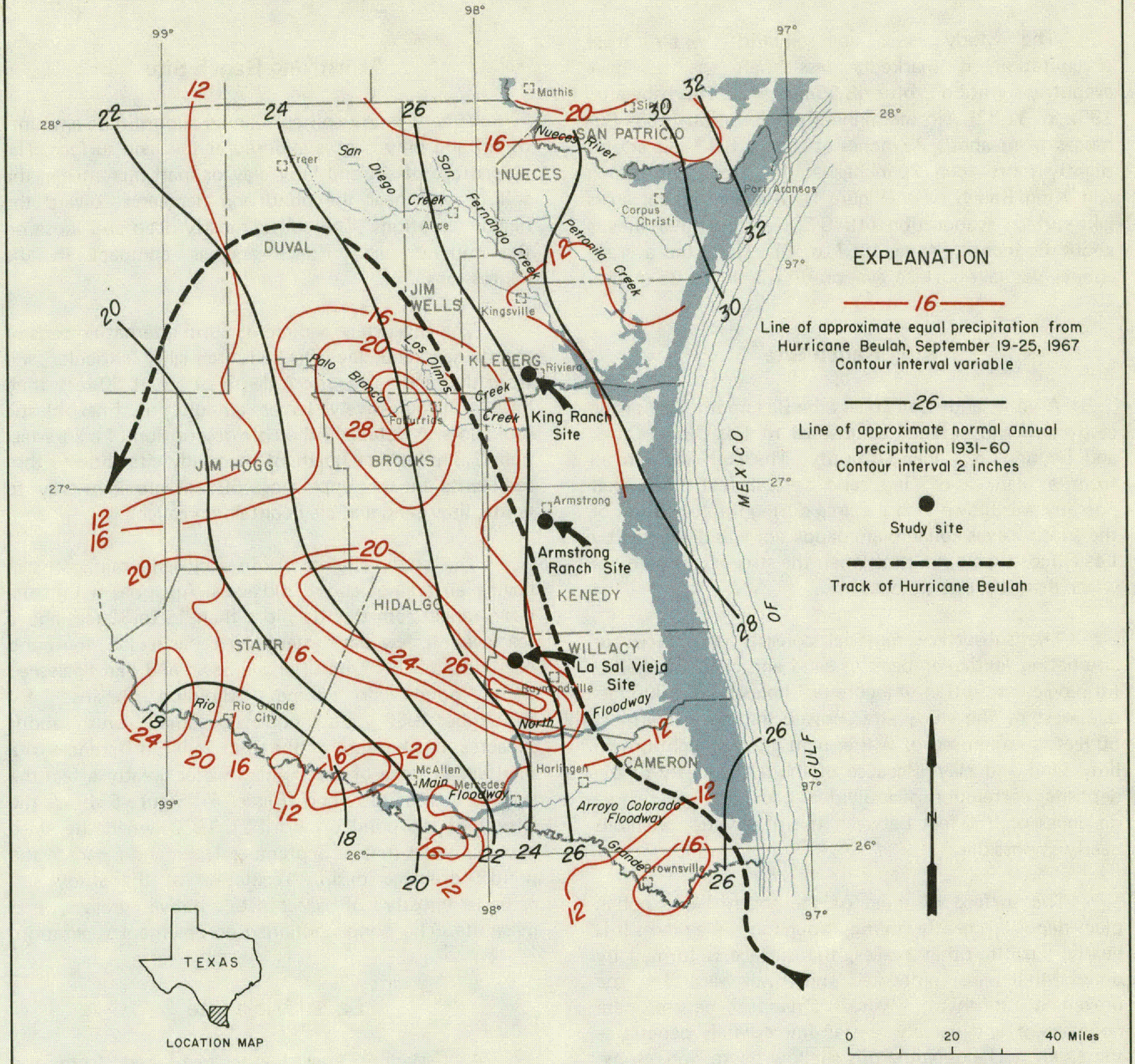


Figure 1

Precipitation From Hurricane Beulah, Normal Annual Precipitation, and Location of Study Sites

Base from U.S. Geological Survey, 1:1,000,000 map referred to in this report as the south Texas eolian plain deposit. This deposit, of Holocene and possibly Pleistocene age, overlies the Beaumont Clay in most of Kenedy County and extends inland from the Gulf for about 85 miles.

The study area is semiarid; water from precipitation is markedly less than the potential evapotranspiration of 48-59 inches (Thornthwaite, 1952, p. 31-32). Normal annual precipitation (1931-60) ranges from about 25 inches at the La Sal Vieja site to slightly more than 26 inches at the Armstrong Ranch and King Ranch sites (Figure 1). Average annual gross lake-surface evaporation (1940-65) at the three sites is about 60 inches (Kane, 1967, pl. 6). Thus, the average annual net lake-surface evaporation is about 35 inches.

King Ranch Site

A very sandy soil covers the Beaumont Clay at the study site and extends southward to Los Olmos Creek and beyond in Kenedy County. The soil was derived from a blanket of fine sand several feet thick that possibly was blown into the area during the formation of the south Texas eolian plain deposit or was deposited by Los Olmos Creek at a time when the stream carried more water than it presently does.

The subsurface material consists of a series of alternating lenticular beds of sand and clay. A detailed lithologic description of a core-test hole about 1,000 feet due west of the study site showed that the uppermost 50 feet is composed of white, light-gray, or light-brown limy sand and clay. Because of the lenticularity of the deposits, correlation of individual beds, even over short distances of 250 feet between the observation wells, is nearly impossible.

The surface of most of the south Texas eolian plain deposit is gently rolling, though in some places it is nearly flat. In other places, the surface is formed by dunes that are elongated northwestward by the prevailing southeast wind. Drainage courses are nonexistent, and usually rainfall immediately penetrates the sandy surface. Numerous shallow depressions, some containing water, dot the landscape. In times of exceptionally heavy rainfall, as during Hurricane Beulah, the ponds overflow and coalesce to form a chain of interconnected ponds which then may function as a waterway to the sea.

The land surface at and around the study site is very gently rolling and contains many small depression ponds. The study pond, which had a surface area of about 30 acres in April 1968, is within a closed drainage basin having an area of about 200 acres. Altitudes of the land surface within the basin range from slightly less than 40 feet to slightly less than 55 feet above sea level. Vegetation consists mostly of mesquite and native grasses. The pond contained no emergent vegetation of any consequence. Figure 2 shows a part of the pond on July 2, 1968, and a part of the shallow depression 14 months later (September 30, 1969) when the pond was dry. The extent of the depression and much of its surrounding drainage area is shown in Figure 3.

Armstrong Ranch Site

A very sandy soil containing subordinate amounts of silt and limy clay is exposed at the land surface. The percentage of silt and limy clay or marl increases in the soil at and near the pond and decreases toward the higher elevations. The soil is mostly deep and loose on the mounds and ridges and is compact in the depressions.

The subsurface sediments form alternating beds of mostly sand and clay. The beds are highly lenticular, and from the land surface to a depth of about 50 feet, they have a progressively larger amount of finer clastic sediments. A detailed lithologic description of a core-test hole 2.8 miles due north of the study site showed that sediments in the uppermost 50 feet are light-gray to white, limy sand and clay containing caliche.

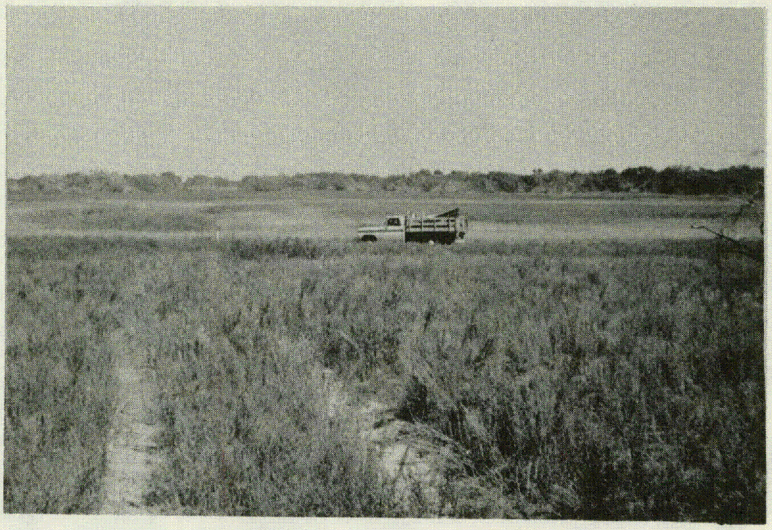
The study site is within a closed drainage basin having an area of about 300 acres. Altitudes within the basin range from slightly more than 15 to 32 feet above sea level. A few days after Hurricane Beulah, the pond occupied much of its drainage basin and had coalesced with ponds in some adjoining basins. By September 1969, the pond occupied only about 20 acres; but because of the small relief, differences of a few feet in stage of the ponded water greatly affect the surface area of the pond (Figure 4). Figure 5 shows the extent of the pond on April 21, 1970, when the stage approximated that of September 1969, and a part of the pond's drainage basin. Vegetation at the study site consists mostly of sacahuista, native grasses, and mesquite. The pond contained no emergent vegetation.

La Sal Vieja Site

A dark-gray clay loam, weathered from the underlying Beaumont Clay, is exposed at the land surface. Wind and wave erosion has removed much of the soil around the perimeter of La Sal Vieja and in places has exposed the parent material. Salt, which has been deposited by evaporation of the ponded water, and small masses of gypsum are disseminated in the beds of sand and clay that form a low bank near the water.

The subsurface sediments to a depth of 50 feet form alternating beds mostly of sand and clay. Logs of three observation wells showed that individual beds are highly lenticular and that sand grades into clay in very short distances. Correlation of beds between the wells is therefore difficult. A detailed lithologic description of a core-test hole 2¾ miles due north of the study site

A. Pond on July 2, 1968. Well 1 in foreground.



B. Pond dry on September 30, 1969. Grass cover in depression.

Figure 2.—King Ranch Site

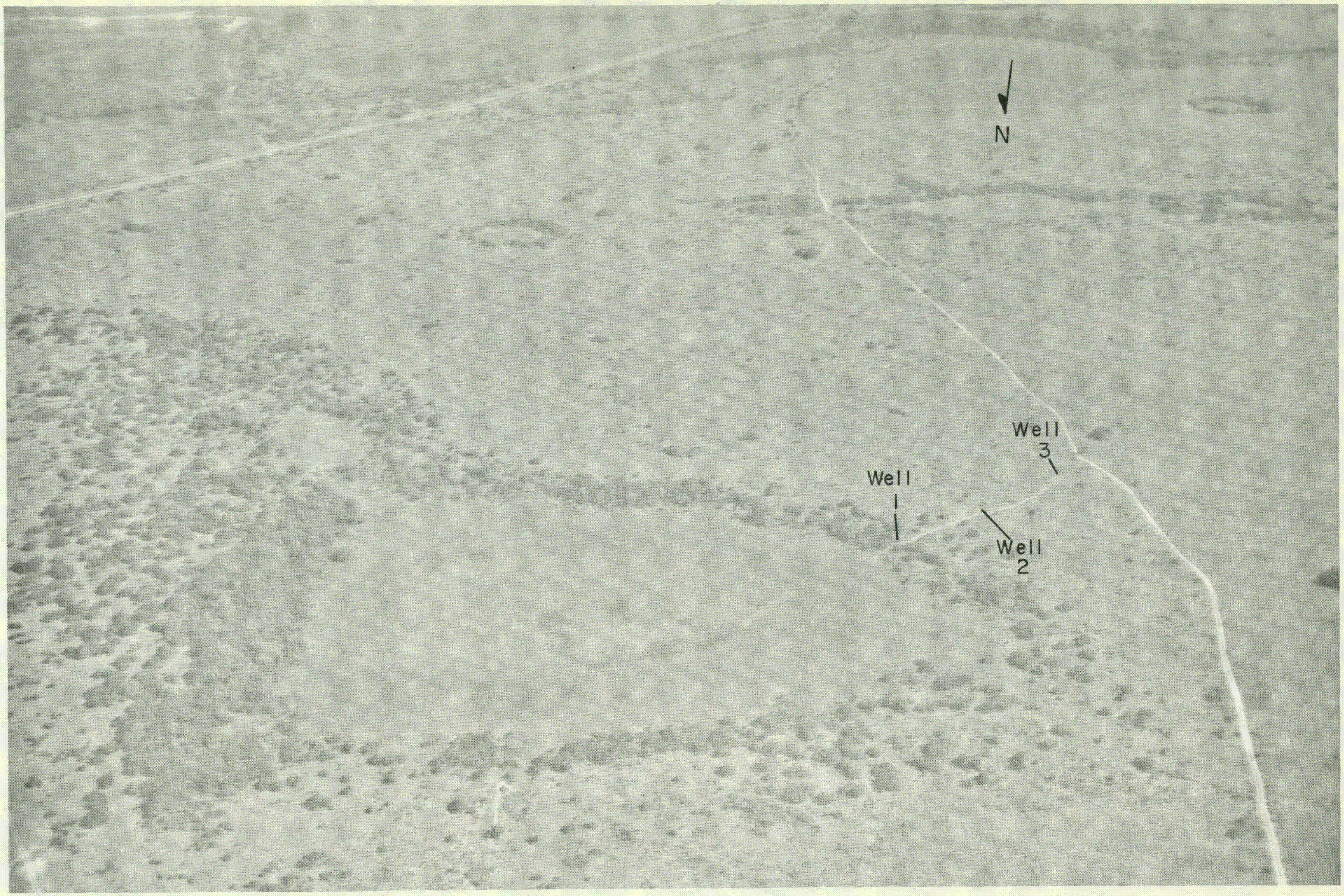
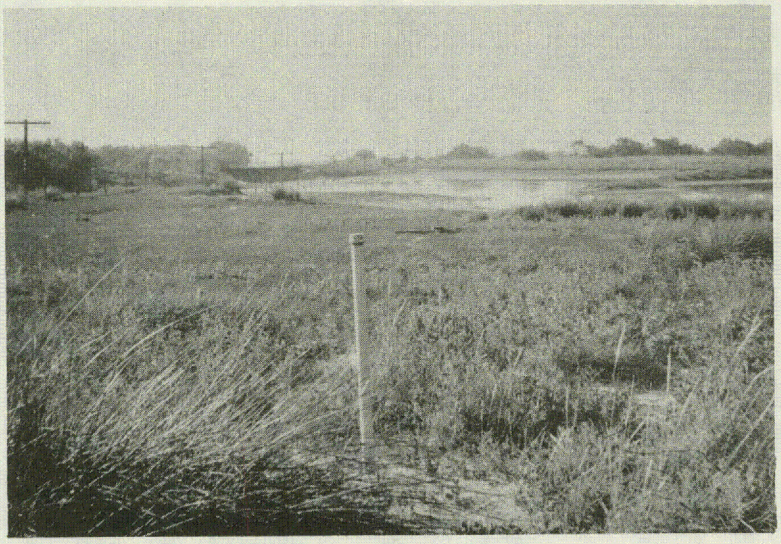


Figure 3.—King Ranch Site on April 21, 1970. Peripheral fringe of mesquite around the dry depression marks approximate maximum limit of floodwater from Hurricane Beulah. Photograph by U.S. Air Force

A. Pond on July 1, 1968. Well 1 in foreground.



B. Pond on October 1, 1969. Pond level 2.98 feet lower than in A.

Figure 4.—Armstrong Ranch Site

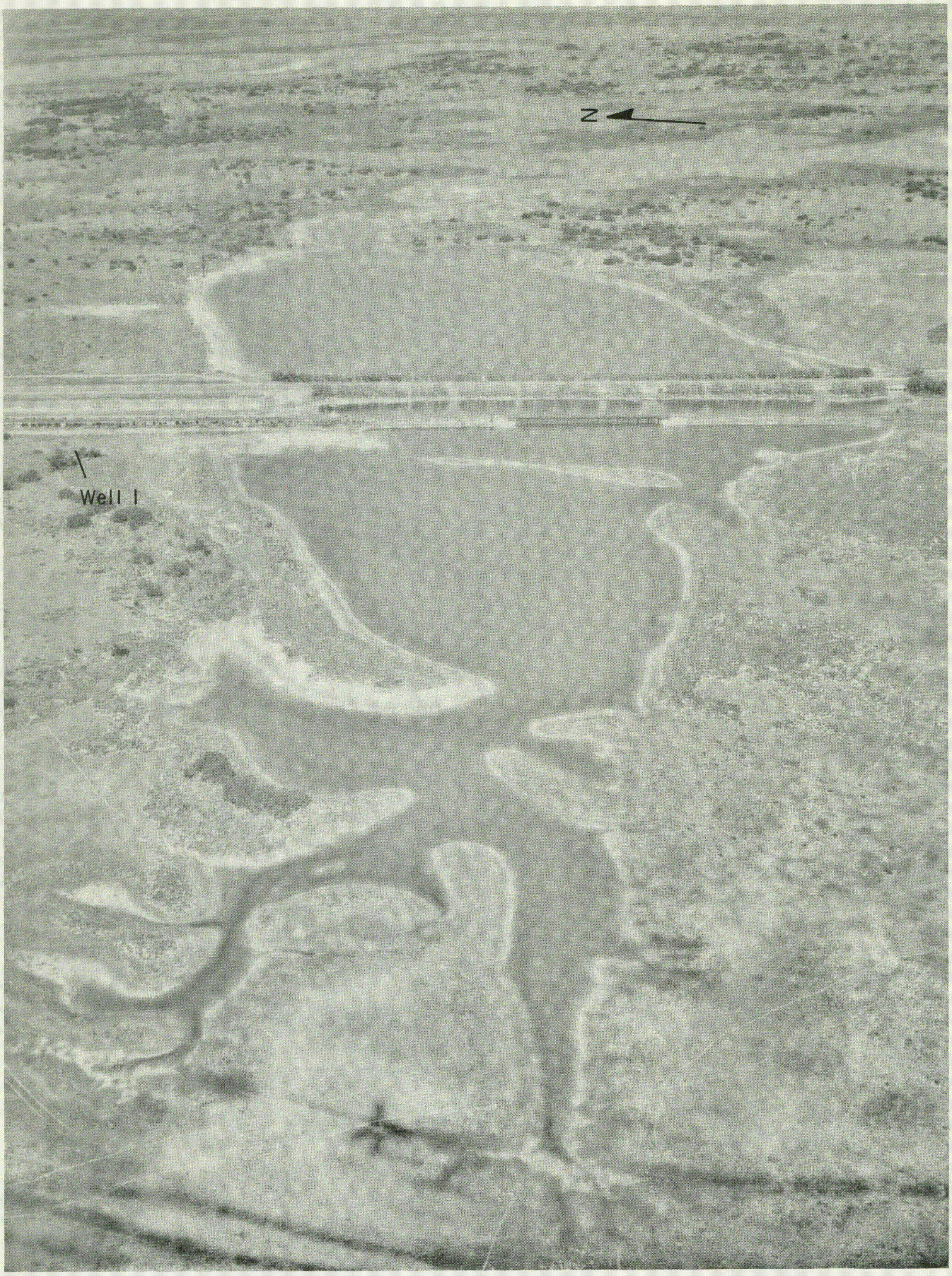


Figure 5.—Armstrong Ranch Site on April 21, 1970. Floodwater from Hurricane Beulah covered most of the less heavily vegetated areas. Photograph by U.S. Air Force

showed that the beds are composed of tan to reddish-brown sand and clay and small amounts of caliche.

The study site is within a closed drainage basin having an area of 32 square miles. Most of the land surface is very gently rolling, but near much of the drainage divide the surface is relatively flat. Altitudes of the land surface within the basin range from about 30 to 94 feet above sea level. The pond, which formed in a large deflation depression, normally occupies an area of 4 square miles. Shortly after Hurricane Beulah, the ponded water breached the basin's drainage divide and merged with an adjacent salt lake. The recession of the shore line at the study site caused by a decrease of 3.5 feet in the level of the ponded water is shown in Figure 6.

Vegetation in the vicinity of the study site consists mostly of mesquite, citrus groves and other cultivated crops, and native grasses. The pond does not contain any emergent vegetation. Figure 7 shows part of the pond and adjacent drainage area on April 21, 1970.

HYDROLOGIC INSTRUMENTATION AND METHODS OF STUDY

Three shallow wells were drilled at each study site to observe fluctuations of the water table and to determine the quality of the water. The wells were aligned perpendicular to the perimeter of the ponds and were placed about 250 feet apart. At each study site, the wells were numbered 1, 2, and 3—well 1 being nearest to the pond. When the wells were drilled in April 1968, the nearest well to the pond at each site was about 100 feet from the water. As the stage of the ponds fell, this distance increased greatly.

Each well was drilled to a depth that was several feet below the water table, which ranged in depth from 19 to 52 feet below land surface. At most of the well sites, the sand beds that were suitable for screening were several feet below the level of the bottom of the ponds. Nevertheless, hydraulic continuity probably was achieved because the lenticular sand and clay beds are interconnected laterally and vertically within short distances.

The wells, which were drilled with a 4-inch hollow-stem auger, were cased with 1 5/8-inch I.D. (inside diameter) black iron pipe and screened with a 4½-foot well point. Positions and thicknesses of sand beds suitable for screening were determined from natural gamma-ray logs which were run inside the hollow-stem auger. (See Table 1.)

Staff gages were set in the ponds to indicate changes in stage of the water surface. Spirit leveling at each study site tied-in the network of wells and staff gages to a common arbitrary datum.

Each study site was equipped with a U.S. Weather Bureau type recording rain gage to aid in interpreting changes of water levels in the wells and of the ponded floodwater.

Measurements of depths to the water table in the wells and stages of the ponded water were made mostly at weekly intervals during the 17-month observation period. (See Table 2.)

Samples of ponded water and ground water were collected for analyses, usually at 3-month intervals, to indicate changes in the chemical quality. Uniform sampling procedures were followed as much as possible. Samples were taken from each of the observation wells at all three sites, usually after 10-15 gallons of water—more than the volume of water standing in the well—had been removed from the well by pumping or bailing. Samples of the ponded water were taken a few inches below the surface of the ponds. (See Table 3.)

Figures 8, 9, and 10 show the locations of observation wells, staff gages, and rain gages at the King Ranch, Armstrong Ranch, and La Sal Vieja sites, respectively.

RELATION OF THE WATER TABLE TO THE PONDED WATER

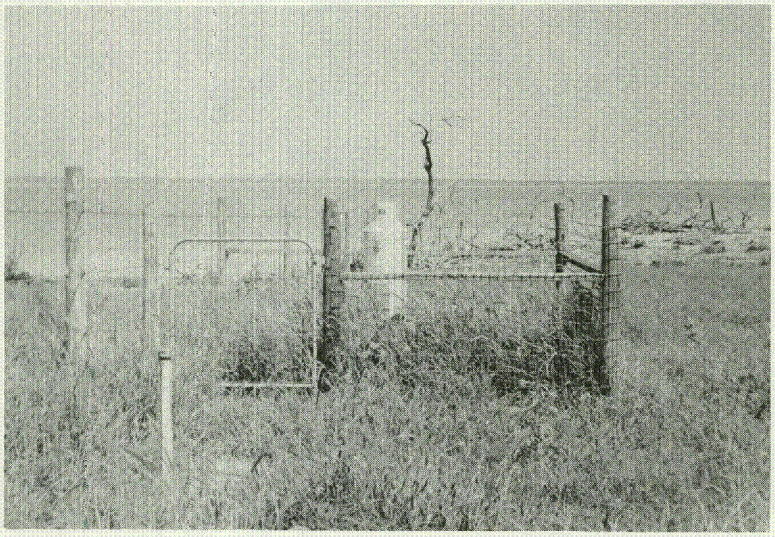
The sections in Figures 11, 12, and 13, and the hydrographs in Figures 14, 15, and 16 show the levels of the ponded water and the adjacent water table plotted to a common arbitrary datum.

Throughout the period of observation at the King Ranch site, the water table as observed in wells 1, 2, and 3 remained below the level of the ponded water. The pond was dry for the first time after Hurricane Beulah in the latter half of April 1969 and was dry again during visits to the site in June, July, and September 1969.

The smallest measured difference in levels of the ponded water and the water table at the King Ranch site was 11.5 feet at well 1, in June 1968. Thereafter, the water table at well 1 generally declined at a faster rate than the depletion rate of the pond, so that in May 1969, when the pond was last observed to contain water, the difference had increased to 15.5 feet (Figure 14).

The position of the water table between the periphery of the King Ranch pond and well 1, a horizontal distance of 100 feet at the beginning of the period of observation, is speculative. Figure 11 indicates a questionable connection of the ponded water and the water table. It is doubtful that the saturated zone, which lies at some undetermined position beneath the pond, actually extends sufficiently upward to intersect the ponded water. The existence of at least a water-table

A. Pond on July 2, 1968. Well 1 and rain gage in foreground.



B. Pond on October 1, 1969. Pond level 3.50 feet lower than in A.

Figure 6.—La Sal Vieja Site

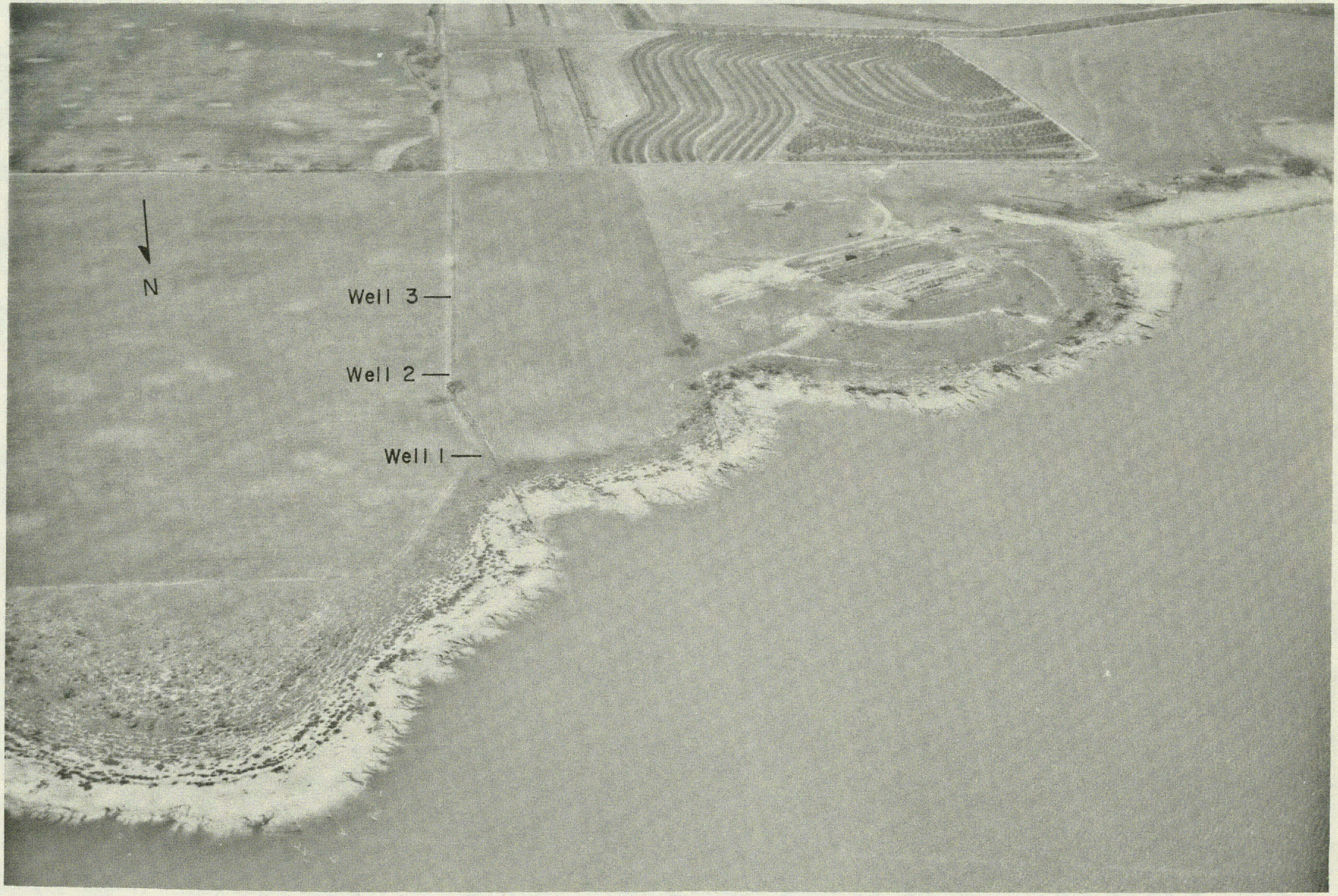


Figure 7.—La Sal Vieja Site on April 21, 1970. Maximum level of ponded floodwater from Hurricane Beulah covered all of shore face. Photograph by U.S. Air Force

mound beneath the pond is entirely reasonable and, in fact, is indicated by the rising altitude of the water table in the direction of the pond.

Levels of the water table relative to the ponded water at the Armstrong Ranch site fluctuated within a vertical distance one-half foot of each other most of the time (Figure 15). At no time during the period of observation did the difference in levels of the water table in wells 1, 2, or 3 and of the surface of the ponded water exceed 1.7 feet.

From the beginning of the period of observation in April 1968, and for the next 9 consecutive months, the level of the ponded water at the Armstrong Ranch site remained above the water table at all three well sites, except for a brief time in May and October when the water table at well 1 was slightly higher than the pond level. A major reversal of the relative levels of the pond and water table began in February 1969. From then until the observation ended in October 1969, the pond level was below the level of the water table at most of the well sites. (See Figure 15.)

The relationship of the levels of the ponded water and the water table at the La Sal Vieja site was similar in some respects to that at the Armstrong Ranch site. Levels of the ponded water relative to the water table at any one time at the La Sal Vieja site were within 1 foot of each other throughout the observation period except for 6 weeks in August and September 1968, when the maximum difference in levels was 1.3 feet (Figure 16). For most of the observation period prior to about the middle of October 1968, the level of the ponded water remained above the water table. This relationship was almost completely reversed in October 1968, and the reversal persisted for the next 11 months.

SEEPAGE INFLOW AND OUTFLOW

The various stages of the ponded-water surface relative to those of the contiguous water table indicate that conditions (1) were favorable for recharge of ground water by seepage outflow of ponded water at certain times during the period of observation and (2) were favorable for discharge of ground water by seepage inflow to the ponds at other times. Conditions were favorable only for recharge of ground water at the King Ranch site, but at the Armstrong Ranch and La Sal sites, conditions were favorable for both recharge and discharge.

Recharge of Ground Water

A determination of the amount of recharge of ground water by seepage outflow of ponded water at the King Ranch site was made for the period from April 24, 1968—the beginning of the period of observation—to April 15, 1969—about the time that the pond became dry. For this period of almost 12 months, the appropriate water budget for the pond, in terms of unit area of water surface, is:

$$S = \Delta H + P + R - E,$$

where

S = seepage outflow (equivalent to recharge),

ΔH = decrease in stage of the pond,

ΔP = precipitation,

ΔR = runoff, and

ΔE = evaporation.

The decrease in stage of the pond was 4.2 feet and precipitation was 2.8 feet. Some assumptions were necessary in regard to runoff and evaporation. Runoff during the period was estimated on the basis of a correlation of daily precipitation with the hydrographs of the pond level (Figure 14). The only obvious occurrences of runoff (estimated at 0.9 foot) were on July 10, and October 7, 9, and 10, 1968. Runoff was probably negligible at other times during the 12-month period.

Free water-surface evaporation at the King Ranch site was determined to be 4.4 feet by applying appropriate monthly coefficients (Kane, 1967, p. 15) to U.S. Weather Bureau records of monthly pan evaporation measured at the weather station near Beeville, 80 miles north of the King Ranch site. The Beeville station and the King Ranch site have equal average free water-surface evaporation as determined by Kane (1967, pl. 6) for a 25-year period. Transpiration was not a factor in the water budget as the pond is largely free of emergent aquatic vegetation.

When the above equation was solved for S, seepage outflow of the ponded water was determined to be 3.5 feet. The outflow of 3.5 feet is equivalent to about 120 acre-feet. This amount of outflow probably represents an increment of recharge to the shallow ground water, although it is not known if this water moved through unsaturated material before reaching the water table.

Conditions were favorable for recharge of ground water from ponded water at the Armstrong Ranch and La Sal Vieja sites during most of the first 10 and 6 consecutive months, respectively, of the 17-month observation period. The high stage of the ponds relative to the water table during most of these periods created hydraulic gradients that sloped away from the ponds at rates of at least 1 foot per 100 feet. At other times the gradients were much less steep, and the levels of ground water and surface water approached equilibrium. (See Figures 12 and 13.) Because of the hydraulic continuity between the ponds and the water table, recharge of the ground water occurred from seepage outflow from the ponds.

A determination of the amount of recharge of ground water that occurred at the Armstrong Ranch site from seepage outflow was made for the 9½-month period from April 24, 1968, to February 4, 1969, when conditions were favorable for recharge. The water-budget equation for the pond, in terms of unit area of water surface, is:

$$S = \Delta H + P - E,$$

where

ΔH = 2.7 feet,

ΔP = 1.9 feet, and

ΔE = 3.8 feet.

During the 9½-month period, runoff was assumed to be negligible because the hydrographs and records of the daily precipitation in Figure 15 show no rises in the pond level in excess of precipitation on the pond. Evaporation (free water-surface) was determined by applying monthly coefficients (Kane, 1967, p. 15) to U.S. Weather Bureau records of monthly pan evaporation near Beeville, 110 miles north of the Armstrong Ranch site. The Armstrong site and the weather station near Beeville are very nearly on a line of equal free water-surface evaporation as determined by Kane (1967, pl. 6). When the above equation was solved for S, seepage outflow was determined to be 0.8 foot. Volume of seepage outflow is not known because during part of the period of observation, the floodwater in the pond remained merged with that of numerous other ponds in the area.

A determination of the amount of recharge of ground water from ponded water at the La Sal Vieja site could not be made because of ungaged inflow and outflow of surface water through canals. The higher levels of ponded water relative to the water tables in July, August, and September, 1968 (Figure 16), however, indicate that most of the recharge of ground water from seepage outflow of the ponded water probably occurred during this period.

Discharge of Ground Water

Conditions were favorable for discharge of ground water to the ponds at the Armstrong Ranch and La Sal Vieja sites mostly at times during the latter half of the 17-month period of observation. These conditions occurred when the pond level dropped below the contiguous water table, thus reversing the hydraulic gradients previously established.

The amount of ground water discharged to the pond at the Armstrong Ranch site was not determined because of several alternating periods of recharge and discharge of ground water from February 4, 1969, to October 1, 1969. In this 8-month period, the pond level was below the water table at well 1 about half of the time. At other times, the relative levels of the pond and the water table were reversed, so that recharge of ground water was occurring by seepage outflow of ponded water.

An indication that considerable discharge of ground water took place, though intermittently, at the Armstrong Ranch site is seen in the relatively small amount of net seepage loss in the water budget of the pond. The water budget of the pond for the 8-month period is:

$$S = \Delta H + P + R - E,$$

where

ΔH = 0.6 foot,

ΔP = 1.7 feet,

ΔR = 1.7 feet, and

ΔE = 3.8 feet.

Some assumptions regarding runoff were necessary. From a study of the relationship of rainfall to ponded-water stage (Figure 15) it was assumed that runoff occurred on only two occasions: on May 10-13, 1969, from an intense rainfall of 7 inches (5.4 inches fell in 90 minutes), which produced an estimated 1.2 feet of runoff; and on August 27-29, 1969, from 3.3 inches of rainfall, which produced an estimated 0.5 foot of runoff. Evaporation was determined in the manner described previously.

When the water budget was solved for S, seepage outflow was determined to be 0.2 foot. This small amount represents the excess of ground-water recharge over ground-water discharge during the 8-month period when conditions were favorable for intermittent discharge. The discharge of ground water during this time probably is partly responsible for decreasing the slope of the hydrograph of the pond level (aside from sharp rises from runoff) in the latter half of the 17-month observation period (Figure 15). Thus, discharge of ground water is probably a principal factor in maintaining or stabilizing the water level of the Armstrong Ranch pond.

Ground water was discharged to the ponded water at the La Sal Vieja site mostly from November 1968 to October 1969, when at times the pond level was below the water table at all three well sites. Discharge was predominant during this 11-month period, but not continuous. Intervening periods of recharge from the pond occurred in January, February, June, and July 1969 when the water table at well 1 was slightly below the pond level. A determination of the amount of ground-water discharge could not be made because of ungaged inflow and outflow of surface water through canals.

CHEMICAL QUALITY OF THE WATER

Results of chemical analyses of 63 samples of ponded water and ground water are given in Table 3. From four to seven water analyses are listed for each well and pond sampled periodically during the period of observation.

The dissolved-solids content of the water, rather than concentration of individual chemical substances, is emphasized because suitability of the water for use was not considered. As used in the following discussion, water containing less than 1,000 mg/l (milligrams per liter) dissolved solids is considered fresh; 1,000 to 3,000 mg/l, slightly saline; 3,000 to 10,000 mg/l, moderately saline; 10,000 to 35,000 mg/l, very saline; and more than 35,000 mg/l, brine (Winslow and Kister, 1956, p. 5).

Ponded Water

The salinity of the ponded water varied considerably among the three study sites as well as at each site. The water was fresh at the King Ranch site, slightly to moderately saline at the Armstrong Ranch site, and very saline at the La Sal Vieja site. Dissolved-solids content ranged from 40 to 205 mg/l, from 1,500 to 9,220 mg/l, and from 14,000 to 23,700 mg/l at the King Ranch, Armstrong Ranch, and La Sal Vieja sites, respectively. The ponded water was a sodium-chloride type exclusively at La Sal Vieja and predominantly at the Armstrong Ranch. At the King Ranch site, the ponded water was a mixed type with calcium and sodium being the principal cations and chloride and bicarbonate being the principal anions.

The variation in salinity of the ponded water at each of the three sites was largely a function of evaporation and rainfall. Evaporation, which consumes more than twice the amount of water than is available from rainfall in the report area, increased the salinity by concentrating the dissolved solids, whereas rainfall decreased the salinity by diluting the dissolved solids. As the stage of the ponds gradually decreased from excess of evaporation over rainfall, the salinity gradually increased.

All three ponds had large net increases in salinity since the beginning of the period of observation in April 1968. By September 1969, 2 years after Hurricane Beulah, the salinity of the remaining ponded water at the Armstrong Ranch site had increased at least 6 times. The salinity of the ponds at the La Sal Vieja and the King Ranch sites increased about 1.5 and 4 times, respectively.

Differences in the salinity of the water from pond to pond are basically controlled by the relationship of the ponded water to the contiguous ground water. Where ground-water discharge occurs by seepage inflow to the ponds, such as at the Armstrong Ranch and La Sal Vieja sites, the ponded water is considerably more saline than where ground-water discharge is absent, as at the King Ranch site. This general relationship also was found to be valid by Eisenlohr and Sloan (1968, p. 7) in North Dakota, where the salinity of water in any pond is a good indicator of whether the pond is in a region of ground-water discharge or recharge.

At the Armstrong Ranch and La Sal Vieja sites, the rate and salinity of the seepage inflow determines the degree of salinity of the ponded water. At La Sal Vieja, where the salinity of the ponded water ranged from 14,000 to 23,700 mg/l dissolved solids, the rate of seepage inflow of ground water probably is greater than at the Armstrong Ranch site where the dissolved-solids content of the ponded water ranged from 1,500 to 9,220 mg/l.

Ground Water

The salinity of the ground water varied to a moderate extent among the three study sites and to a lesser extent among the wells at each site, but remained essentially constant in most of the individual wells. The water was moderately to very saline at the King Ranch site, brine at the Armstrong Ranch site, and very saline at the La Sal Vieja site. Dissolved solids ranged from 8,550 to 21,900 mg/l, from 40,000 to 57,100 mg/l, and from 31,700 to 34,800 mg/l at the King Ranch, Armstrong Ranch, and La Sal Vieja sites, respectively. The ground water at all sites was a sodium-chloride type having magnesium and sulfate as the next most abundant cation and anion.

The salinity of the ground water at the King Ranch site changed significantly in well 1, but remained essentially unchanged in wells 2 and 3. From September 1968 to June 1969, the dissolved-solids content decreased from 10,600 mg/l to 8,550 mg/l in well 1, which was about 100 feet from the pond. This decrease is attributed to the dilution of the ground water by seepage outflow of the fresh ponded water. Such outflow probably was occurring continually from at least the time of Hurricane Beulah in September 1967, when the pond stage was maximum, to April 1969 when the pond first went dry. The increase in salinity from 8,550 mg/l dissolved solids in June 1969 to 9,410 mg/l in September 1969 is due to less dilution, probably from a reduction in the rate of recharge after the pond went dry in April 1969.

It is not known if the recharge water from the pond extended as far as well 2, because this well was about 20 feet deeper than well 1 and consequently may have tapped the saturated zone at a point below the immediate influence of any recharge. Obviously the recharge from the pond did not reach well 3, which was completed at about the same stratigraphic level as well 1. The salinity of the water in well 3, which was about 600 feet from the pond, remained essentially constant at almost 22,000 mg/l dissolved solids. The variation in the salinity of the water in well 1 and the large difference in salinity of the water in well 1 relative to that in wells 2 and 3 indicate that the pond, as a recharge facility, influenced the quality of the adjacent ground water for a distance of at least 100 feet but not as much as 600 feet from its perimeter.

The salinity of the ground water tapped by the wells at the Armstrong Ranch and La Sal Vieja sites remained essentially unchanged during the period when the chemical quality was being monitored. Presumably, the period of recharge of ground water from outflow of considerably fresher ponded water was not long enough to allow the recharge water to reach even the wells nearest to the ponds.

RETURN OF THE HYDROLOGIC SYSTEM TO PRE-BEULAH CONDITIONS

A study of the hydrographs in Figures 14, 15, and 16 reveals trends which indicate that 2 years after Hurricane Beulah, the hydrologic system was steadily approaching, but had not reached, the probable pre-Beulah conditions. Records of water levels near the study sites prior to Hurricane Beulah, which would definitely establish the pre-Beulah conditions, are not available.

The hydrographs of the water table at the King Ranch site (Figure 14) show the water table still adjusting toward equilibrium by September 1969. Although levels of the water table at the site prior to April 1968 were unavailable, Figure 14 shows that the water table in all three wells was rising at the beginning of the period of observation. This upward trend prior to April 1968 probably was in response to rainfall from Hurricane Beulah. If this interpretation of an early upward trend is correct, then the maximum effect on the water table from Hurricane Beulah was reached in May, June, and July 1968, from 8 to 10 months after the storm, when the highest water level in each well was recorded. Because the water table was steadily declining by September 1969, from 14 to 16 months after it peaked, the period of decline toward pre-Beulah conditions was requiring more than about twice the time required for the water table to peak.

Hydrographs of the water table and pond level at the Armstrong Ranch site (Figure 15) show a gradual decrease in the rate of recession of the water levels (aside from the effects of runoff) in the latter half of the period of observation. This gradual decrease in the rate of recession persisted in spite of intense rainfall in May and August 1969, which caused sharp increases in the water levels. The hydrologic conditions that existed in October 1969 were perhaps within a few months of reaching hydrologic conditions that probably existed prior to Beulah.

Hydrographs of the water table at the La Sal Vieja site (Figure 16), as at the King Ranch site, show that the water table was declining fairly steadily over the period of observation and was still seeking equilibrium by October 1969, in spite of the fact that heavy rainfall in the latter half of September 1969 produced a moderate rise in water levels.

SUMMARY

At the King Ranch site, the level of the ponded water remained considerably above the water table throughout the observation period. The smallest measured difference in the two levels was 11.5 feet.

The stage relationship of the ponded water and contiguous water table was similar at the Armstrong Ranch and La Sal Vieja sites. During most of the first 10 and 6 months of the 17-month observation period at the Armstrong Ranch and La Sal Vieja sites, respectively, the level of the ponded water was above the water table. At the end of the 10- and 6-month periods, this relationship was reversed, and the pond level was mostly below the water table during the remainder of the period of observation. Levels of the ponded-water surface and water table frequently fluctuated within 1 foot of each other, and at no time did the difference in levels exceed 1.7 feet.

The amount of recharge of ground water by seepage outflow of ponded water at the King Ranch site from the beginning of the period of observation in April 1968 to the time when the pond first went dry in April 1969 was 3.5 feet (equivalent to about 120 acre-feet). This amount of water probably represents recharge to the shallow ground water although it is not known if the water had to move through the unsaturated zone to reach the water table.

Conditions were favorable for recharge of ground water by seepage outflow from the ponds at the Armstrong Ranch and La Sal Vieja sites during the times when the pond level was above the water table. At the Armstrong Ranch site, the amount of ground-water recharge or seepage outflow, in terms of unit area of water surface, was 0.8 foot during a 9½-month period. A determination of the amount of recharge at La Sal Vieja could not be made because of ungaged inflow and outflow of surface water through canals.

Conditions were favorable for discharge of ground water to the ponds at Armstrong Ranch and La Sal Vieja mostly at times during the latter half of the period of observation when the water table was higher than the pond levels. The amount of ground water discharged at the Armstrong Ranch site is not known because periods of discharge were alternating with periods of recharge from February to October, 1969. Considerable discharge occurred in this period, though intermittently, as indicated by the relatively small amount of net seepage loss of only 0.2 foot in the water budget of the pond.

The discharge of ground water probably is a principal factor in maintaining or stabilizing the water level in the Armstrong Ranch pond as well as in certain other ponds in the area. At La Sal Vieja, ground water was discharged to the pond mostly from November 1968 to October 1969. During this time discharge was predominant but not continuous.

The salinity of the ponded water varied considerably among the three study sites as well as at each site. The water was fresh at the King Ranch site, slightly to moderately saline at the Armstrong Ranch site, and very saline at the La Sal Vieja site. Differences in the salinity of the water from pond to pond were controlled basically by the relationship of the ground water to the ponds. Where ground-water discharge occurred by seepage inflow to the ponds, such as at the Armstrong Ranch and La Sal Vieja sites, the ponded water was considerably more saline than where ground-water discharge was absent, as at the King Ranch site. All three ponds had large net increases in salinity since 1968.

The salinity of the ground water varied to a moderate extent among the three study sites but remained essentially constant in most of the individual wells. The water was moderately to very saline at the King Ranch site, brine at the Armstrong Ranch site, and very saline at the La Sal Vieja site.

The only significant variation in salinity in an individual well was in well 1 at the King Ranch site. In this well, the dissolved solids decreased by 2,050 mg/l from September 1968 to June 1969 after which time the dissolved solids increased by 860 mg/l by September 1969. The decrease in salinity is attributed to dilution of the ground water by seepage outflow of the fresh ponded water, whereas the increase is attributed to decreased dilution, probably from a reduction in the rate of recharge after the pond went dry in April 1969.

This variation in salinity of the water in well 1, and the large difference in salinity of the water in well 1 relative to that in wells 2 and 3, indicate that the pond, as a recharge facility, influenced the quality of the adjacent ground water for a distance of at least 100 feet but not as much as 600 feet from the pond.

At the Armstrong Ranch and La Sal Vieja sites, where the salinity of the ground water tapped by each well remained essentially unchanged, the period of ground-water recharge from the fresher ponded water presumably was not long enough to allow the recharge water to reach even the wells nearest to the ponds.

Two years after Hurricane Beulah, the hydrologic system at all three study sites was steadily approaching, but had not reached, the probable pre-Beulah conditions. Only at the Armstrong Ranch site did the trend of the water table and pond level indicate a gradual decrease in the rate of water-level decline in the latter half of the period of observation. Hydrologic conditions that existed in October 1969 were perhaps within a few months of reaching hydrologic conditions that probably existed prior to Hurricane Beulah.

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Table 1.—Records of Wells

(AQUIFER: S, south Texas eolian plain deposit; B, Beaumont Clay)

WELL NUMBER		OWNER	DRILLER	DATE DRILLED	DEPTH OF WELL (FT)	CASING		SCREENED INTERVAL (FT)	AQUIFER
STATE	LOCAL					DIAMETER (IN.)	DEPTH (FT)		
KING RANCH SITE									
RR-83-42-402	1	King Ranch, Inc.	U.S. Geological Survey	1968	31	1 5/8	26.5	26.5-31	B
RR-83-42-403	2	do	do	1968	52	1 5/8	47.5	47.5-52	B
RR-83-42-404	3	do	do	1968	38	1 5/8	33.5	33.5-38	B
ARMSTRONG RANCH SITE									
RD-88-02-901	1	Armstrong Ranch	U.S. Geological Survey	1968	19	1 5/8	14.5	14.5-19	S
RD-88-02-902	2	do	do	1968	24	1 5/8	19.5	19.5-24	S
RD-88-02-903	3	do	do	1968	20	1 5/8	15.5	15.5-20	S
LA SAL VIEJA SITE									
ZJ-88-25-901	1	Ring Ranch	U.S. Geological Survey	1968	20	1 5/8	15.5	15.5-20	B
ZJ-88-25-902	2	do	do	1968	25	1 5/8	20.5	20.5-25	B
ZJ-88-25-903	3	do	do	1968	35	1 5/8	30.5	30.5-35	B

Table 2.—Measurements of Water Levels in Wells and Ponds

DATE OF MEASUREMENT	WATER LEVEL						
	WELL 1		WELL 2		WELL 3		POND
	DEPTH BELOW LAND SURFACE (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)	DEPTH BELOW LAND SURFACE (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)	DEPTH BELOW LAND SURFACE (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)
KING RANCH SITE							
Apr. 24, 1968	16.09	85.85	22.47	82.44	30.03	77.23	98.55
May 1	15.70	86.24	22.15	82.76	29.71	77.55	98.57
May 10	15.65	86.29	21.93	82.98	29.51	77.75	98.49
May 13	15.50	86.44	21.89	83.02	29.45	77.81	98.45
May 14	15.60	86.34	21.96	82.95	29.47	77.79	98.41
May 21	15.53	86.27	21.90	83.01	29.34	77.92	98.19
June 13	16.07	85.87	21.87	83.04	29.06	78.20	97.37
July 2	16.59	85.35	21.98	82.93	23.86	78.40	97.05
July 9	16.64	85.30	21.98	82.93	28.76	78.50	96.93
July 16	16.75	85.19	22.03	82.88	28.72	78.54	97.17
July 18	16.80	85.14	22.06	82.85	28.72	78.54	97.09
July 30	17.16	84.78	22.18	82.73	28.63	78.63	96.63
Aug. 5	17.51	84.43	22.35	82.56	28.64	78.62	96.45
Aug. 21	18.55	83.39	22.92	81.99	28.75	78.51	95.93
Aug. 26	18.69	83.25	23.00	81.91	28.73	78.53	95.92
Sept. 10	19.26	82.68	23.33	81.58	28.79	78.47	95.74
Sept. 16	19.29	82.65	23.35	81.56	28.79	78.47	95.71
Sept. 27	19.70	82.24	23.90	81.01	28.89	78.37	96.04
Oct. 1	19.68	82.26	23.90	81.01	28.87	78.39	96.02
Oct. 7	19.82	82.12	24,02	80.89	28.90	78.36	96.03
Oct. 22	19.87	82.05	24.15	80.76	28.98	78.28	96.70
Oct. 31	20.01	81.93	24.27	80.64	29.00	78.26	96.51
Nov. 13	20.02	81.92	24.24	80.67	28.98	78.28	96.24
Nov. 19	20.36	81.58	24.51	80.40	29.20	78.06	96.16
Dec. 4	20.33	81.61	24.50	80.41	29.04	78.22	95.96
Dec. 10	20.57	81.37	24.68	80.23	29.21	78.05	95.87
Jan. 8, 1969	20.71	81.23	24.79	80.12	29.06	78.20	95.37
Jan. 14	21.05	80.89	25.05	79.86	29.28	77.98	95.29
Jan. 28	21.21	80.73	25.14	79.77	29.27	77.99	95.11
Feb. 4	21.49	80.45	25.30	79.61	29.40	77.86	95.05
Feb. 12	21.45	80.49	25.29	79.62	29.26	78.00	94.94
Feb. 18	21.75	80.19	25.48	79.43	29.49	77.77	94.95
Feb. 25	21.71	80.23	25.49	79.42	29.42	77.84	95.01
Mar. 11	21.89	80.05	25.61	79.30	29.47	77.79	94.81
Mar. 25	22.28	79.66	25.90	79.01	29.64	77.62	94.63

Table 2.—Measurements of Water Levels in Wells and Ponds—Continued

DATE OF MEASUREMENT	WATER LEVEL WELL 1 DEPTH BELOW LAND SURFACE (FT)	WELL 1 HEIGHT ABOVE ARBITRARY DATUM (FT)	WELL 2 DEPTH BELOW LAND SURFACE (FT)	WELL 2 HEIGHT ABOVE ARBITRARY DATUM (FT)	WELL 3 DEPTH BELOW LAND SURFACE (FT)	WELL 3 HEIGHT ABOVE ARBITRARY DATUM (FT)	POND HEIGHT ABOVE ARBITRARY DATUM (FT)
Apr. 1, 1969	22.08	79.86	25.77	79.14	29.49	77.77	94.49
Apr. 15	22.34	79.60	25.94	78.97	29.48	77.78	94.35
Apr. 21	22.55	79.39	26.11	78.80	29.67	77.59	Dry
May 6	22.69	79.25	26.18	78.73	29.64	77.62	94.73
May 15	22.76	79.18	26.24	78.67	29.75	77.51	94.63
June 12	23.18	78.76	26.57	78.34	29.86	77.40	Dry
June 17	23.25	78.69	26.63	78.28	29.90	77.36	Dry
July 24	23.86	78.08	27.17	77.74	30.20	77.06	Dry
Sept. 17	24.67	77.27	27.86	77.05	30.67	76.59	Dry
Sept. 30	24.75	77.19	27.98	76.93	–	–	Dry
ARMSTRONG RANCH SITE							
Apr. 24, 1968	3.57	22.42	6.46	22.43	8.58	22.49	22.65
May 1	3.66	22.33	6.65	22.24	8.77	22.30	22.59
May 9	3.14	22.85	6.75	22.14	8.94	22.13	22.76
May 14	3.28	22.71	6.29	22.60	8.67	22.48	22.67
May 22	3.28	22.71	6.31	22.58	8.63	22.44	22.69
June 12	3.98	22.01	6.93	21.96	9.11	21.96	22.37
July 1	3.84	22.15	6.78	22.11	9.01	22.06	22.35
July 10	3.85	22.14	6.79	22.10	9.00	22.07	22.31
July 16	3.73	22.26	6.57	22.32	8.82	22.25	22.43
July 17	3.90	22.09	6.69	22.20	8.87	22.20	22.39
July 30	4.16	21.83	7.25	21.64	9.36	21.71	22.15
Aug. 5	4.11	21.88	7.31	21.58	9.47	21.60	22.09
Aug. 21	5.00	20.99	7.91	20.98	9.92	21.16	21.63
Aug. 26	5.16	20.83	8.03	20.86	10.04	21.03	21.49
Sept. 10	5.63	20.36	8.45	20.44	10.44	20.63	21.17
Sept. 17	5.49	20.50	8.58	20.31	10.60	20.47	21.09
Sept. 25	5.40	20.59	8.71	20.18	10.72	20.35	21.07
Oct. 1	4.88	21.11	8.52	20.37	10.69	20.38	21.09
Oct. 8	4.98	21.01	8.22	20.67	10.41	20.66	21.09
Oct. 22	5.14	20.85	7.97	20.92	10.14	20.93	21.01
Oct. 31	5.21	20.78	8.07	20.82	10.22	20.85	20.97
Nov. 13	5.58	20.41	8.22	20.67	10.47	20.60	20.77
Nov. 19	5.78	20.21	8.56	20.33	10.59	20.48	20.65
Dec. 4	5.95	20.04	8.79	20.10	10.79	20.28	20.51
Dec. 10	6.01	19.98	8.84	20.05	10.83	20.24	20.43

Table 2.—Measurements of Water Levels in Wells and Ponds—Continued

DATE OF MEASUREMENT	WATER LEVEL: WELL 1 DEPTH BELOW LAND SURFACE (FT)	WELL 1 HEIGHT ABOVE ARBITRARY DATUM (FT)	WELL 2 DEPTH BELOW LAND SURFACE (FT)	WELL 2 HEIGHT ABOVE ARBITRARY DATUM (FT)	WELL 3 DEPTH BELOW LAND SURFACE (FT)	WELL 3 HEIGHT ABOVE ARBITRARY DATUM (FT)	POND HEIGHT ABOVE ARBITRARY DATUM (FT)
Jan. 8, 1969	6.04	19.95	8.95	19.94	10.94	20.13	20.17
Jan. 14	6.25	19.74	9.01	19.88	11.05	20.02	20.07
Jan. 28	6.33	19.66	9.06	19.83	11.13	19.94	19.95
Feb. 4	6.33	19.66	9.10	19.79	11.18	19.89	19.91
Feb. 11	6.45	19.54	9.17	19.72	11.19	19.88	19.82
Feb. 18	6.02	19.97	9.09	19.80	11.20	19.87	19.85
Feb. 25	5.58	20.41	8.76	20.13	10.98	20.09	19.97
Mar. 11	5.97	20.02	8.76	20.13	10.88	20.19	19.85
Mar. 26	6.32	19.67	8.93	19.96	10.99	20.08	19.67
Apr. 1	6.44	19.55	9.06	19.83	11.10	19.97	19.55
Apr. 15	6.67	19.32	9.28	19.61	11.30	19.77	19.35
Apr. 21	6.71	19.28	9.31	19.58	11.36	19.71	19.29
May 6	6.85	19.14	9.49	19.40	11.53	19.54	19.07
May 15	3.44	22.55	7.15	21.74	10.91	20.16	20.85
June 18	5.02	20.97	7.67	21.22	9.70	21.37	20.81
July 23	6.70	19.29	9.18	19.71	11.06	20.01	19.67
Aug. 27	7.37	18.62	9.95	18.94	11.88	19.19	18.91
Sept. 18	6.09	19.90	9.04	19.85	11.23	19.84	19.29
Oct. 1	5.89	20.10	8.91	19.98	11.01	20.06	19.37
LA SAL VIEJA SITE							
Apr. 24, 1968	3.21	31.91	7.41	32.14	7.94	32.54	31.73
May 1	3.25	31.87	7.37	32.18	7.94	32.54	31.69
May 9	3.17	31.95	7.47	32.08	8.01	32.47	31.77
May 15	3.36	31.76	7.46	32.09	8.04	32.44	31.67
May 22	3.04	32.08	7.64	31.95	8.44	32.04	32.07
June 12	3.96	31.16	8.10	31.45	8.87	31.61	31.69
July 2	4.12	31.00	8.50	31.05	9.24	31.24	31.71
July 9	4.06	31.06	8.56	30.99	9.33	31.15	31.73
July 16	4.38	30.74	8.73	30.82	9.53	30.95	31.57
July 17	4.46	30.66	8.78	30.77	9.57	30.91	31.54
July 30	4.55	30.57	9.02	30.53	9.82	30.66	–
Aug. 5	4.74	30.38	9.17	30.38	9.99	30.49	31.45
Aug. 21	5.02	30.10	9.55	30.00	10.34	30.14	31.31
Aug. 26	4.81	30.31	9.49	30.06	10.29	30.19	31.27
Sept. 11	4.44	30.68	9.36	30.19	10.14	30.34	31.31
Sept. 17	4.41	30.71	9.13	30.42	9.97	30.51	–

Table 2.—Measurements of Water Levels in Wells and Ponds—Continued

DATE OF MEASUREMENT	WATER LEVEL						
	WELL 1		WELL 2		WELL 3		POND
	DEPTH BELOW LAND SURFACE (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)	DEPTH BELOW LAND SURFACE (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)	DEPTH BELOW LAND SURFACE (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)	HEIGHT ABOVE ARBITRARY DATUM (FT)
Sept. 25, 1968	4.67	30.45	9.13	30.42	10.02	30.46	31.17
Oct. 1	4.69	30.43	9.11	30.44	9.98	30.50	31.11
Oct. 7	4.26	30.86	8.98	30.57	9.87	30.61	31.25
Oct. 22	4.04	31.08	8.41	31.14	9.21	31.27	31.19
Oct. 31	4.20	30.92	8.41	31.14	9.20	31.28	31.03
Nov. 13	4.18	30.94	8.21	31.34	9.12	31.36	30.81
Nov. 19	4.35	30.77	8.50	31.05	9.29	31.19	30.77
Dec. 4	4.50	30.62	8.66	30.89	9.46	31.02	30.61
Dec. 11	4.48	30.64	8.68	30.87	9.45	31.03	30.59
Jan. 8, 1969	4.61	30.51	8.75	30.80	9.61	30.87	30.39
Jan. 14	4.77	30.35	8.99	30.56	9.86	30.62	30.31
Feb. 4	4.96	30.16	9.23	30.32	10.02	30.46	30.27
Feb. 11	4.92	30.20	9.13	30.42	9.99	30.49	30.21
Feb. 25	4.61	30.51	9.05	30.50	9.86	30.62	30.35
Mar. 13	4.82	30.30	9.13	30.42	9.90	30.58	30.21
Mar. 26	4.88	30.24	9.10	30.45	9.87	30.61	30.09
Apr. 1	4.90	30.22	9.02	30.53	9.82	30.66	30.05
Apr. 15	5.04	30.08	9.09	30.46	9.87	30.61	29.91
Apr. 21	5.20	29.92	9.22	30.33	9.99	30.49	29.81
May 8	5.45	29.67	9.44	30.11	10.22	30.26	29.61
June 18	5.76	29.36	9.62	29.93	10.37	30.11	29.43
July 23	6.58	28.54	10.50	29.05	11.32	29.16	28.60
Sept. 17	6.86	28.26	11.14	28.41	11.94	28.54	27.99
Oct. 1	6.59	28.53	10.90	28.65	11.65	28.83	28.21

Table 3.--Chemical Analyses of Ponded Water and Ground Water

(Analyses given are in milligrams per liter except percent sodium, SAR, RSC, specific conductance, pH, and temperature.

WELL OR POND	WELL DEPTH OR PRODUCING INTERVAL (FT)	DATE OF COLLECTION	SILICA (SiO_2)	CALCIUM (Ca)	MAGNESIUM (Mg)	SODIUM (Na)	POTASSIUM (K)	BICARBONATE (HCO_3)	SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	BORON (B)	DISSOLVED SOLIDS	HARDNESS AS $CaCO_3$	PERCENT SODIUM	SODIUM ADSORPTION RATIO (SAR)	RESIDUAL SODIUM CARBONATE (RSC)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C)	pH	TEMPERATURE °C	TEMPERATURE °F
King Ranch Site																						
Pond	--	Apr. 4, 1968	0.5	7.2	2.8	5.4	4.2	36	0.4	9.3	0.2	2.4	--	51	29	24	0.4	0.00	99	6.7	16	61
		July 16, 1968	--	4.0	1.9	5.5	5.7	8	--	12	.1	4.9	--	40 a/	18	32	.6	.00	77	5.3	--	--
		Sept. 16, 1968	2.4	5.0	2.6	9.2	7.5	22	.6	20	.3	3.5	--	62	23	38	.8	.00	115	6.6	--	--
		Dec. 10, 1968	--	12	4.1	--	--	68	--	16	--	--	--	121 a/	47	--	--	.18	229	6.5	15	59
		Mar. 25, 1968	3.4	25	8.7	24	19	94	.0	59	.2	20	--	205	98	--	--	--	393	6.3	12	54
Well 1	26.5 - 31	Sept. 16, 1968	13	428	240	2,960	25	376	2,300	4,450	1.6	.0	--	10,600	2,060	76	--	.00	16,300	--	--	--
		Dec. 10, 1968	--	308	222	--	--	574	--	3,950	--	--	--	10,000 a/	1,680	--	--	.00	15,000	6.7	24	75
		Mar. 25, 1969	--	355	195	* 2,870	--	256	2,410	3,700	--	--	--	9,660	1,690	--	--	--	14,000	--	24	75
		June 17, 1969	--	310	178	* 2,550	--	220	2,000	3,400	--	--	--	8,550	1,510	--	--	.00	13,100	--	24	75
		Sept. 17, 1969	--	292	178	2,820	20	2	2,090	4,000	--	--	7.4	9,410	1,460	80	--	.00	13,700	--	25	77
Well 2	47.5 - 52	Dec. 10, 1968	--	1,050	620	--	--	5	--	9,800	--	--	--	21,300 a/	5,170	--	--	.00	31,000	--	24	75
		Mar. 25, 1969	--	950	665	* 5,940	--	32	4,290	9,600	--	--	--	21,500	5,100	--	--	--	31,500	--	24	75
		June 17, 1969	--	900	732	* 5,990	--	14	4,540	9,600	--	--	--	21,800	5,260	--	--	.00	31,600	--	25	77
		Sept. 17, 1969	--	900	698	5,800	46	0	4,340	9,800	--	--	8.6	21,600	5,120	71	--	.00	31,600	--	25	77
Well 3	33.5 - 38	Sept. 16, 1968	--	930	670	5,520	42	24	4,310	9,700	1.9	2.2	--	21,200	5,080	70	--	.00	30,300	--	--	--
		Dec. 10, 1968	--	940	675	--	--	46	--	9,900	--	--	--	21,900 a/	5,120	--	--	.00	31,800	--	24	75
		Mar. 25, 1969	--	915	685	* 6,110	--	52	4,350	9,800	--	--	--	21,900	5,100	--	--	--	31,700	--	24	75
		June 17, 1969	--	905	695	* 6,040	--	23	4,380	9,700	--	--	--	21,700	5,120	--	--	.00	31,700	--	24	75
		Sept. 17, 1969	--	910	675	5,740	40	0	4,330	10,000	--	--	8.2	21,700	5,050	71	--	.00	32,000	--	25	77
Armstrong Ranch Site																						
Pond	--	Apr. 6, 1968	30	77	45	399	9.1	240	224	592	.1	3.0	--	1,500	377	69	8.9	.00	2,630	7.2	22	72
		July 16, 1968	--	91	34	576	9.8	40	--	900	--	1.1	--	--	367	77	13	.00	3,440	7.0	--	--
		Sept. 17, 1968	3.2	139	43	886	12	32	601	1,380	.6	.1	--	3,080	524	78	17	.00	5,470	7.2	--	--
		Dec. 10, 1968	--	207	66	--	--	28 b/	--	1,950	--	--	--	--	788	--	--	.00	7,160	8.6	17	63
		Mar. 26, 1969	--	348	119	* 2,050	--	54	1,340	3,100	--	--	--	6,980	1,360	--	--	--	11,200	7.1	19	66
		June 18, 1969	--	178	68	* 91	--	50	704	1,360	--	--	--	2,430	724	--	--	.00	5,410	7.3	29	84
		Sept. 18, 1969	2.9	545	182	2,460	36	72	2,060	3,900	--	--	1.4	9,220	2,000	71	--	.00	14,000	7.1	30	86
Well 1	14.5 - 19	Sept. 17, 1968	29	920	1,690	17,200	156	378	8,440	27,800	1.9	.0	--	56,400	9,250	80	--	.00	71,800	6.8	--	--
		Dec. 10, 1968	--	860	1,690	--	--	416	--	28,000	--	--	--	55,900 a/	9,100	--	--	.00	75,700	6.7	24	75
		Mar. 26, 1969	--	870	1,720	*17,900	--	404	8,110	28,000	--	--	--	56,800	9,240	--	--	--	76,600	7.0	23	73
		June 18, 1969	--	810	1,750	*17,600	--	452	7,930	27,500	--	--	--	55,800	9,220	--	--	.00	75,500	7.1	24	75
		Sept. 18, 1969	13	900	1,680	17,200	160	340	7,830	27,500	--	--	4.7	55,500	9,160	80	--	.00	74,600	6.7	26	79
Well 2	19.5 - 24	Sept. 17, 1968	16	960	1,970	16,600	145	318	9,920	26,800	2.2	.1	--	56,600	10,500	77	--	.00	70,400	6.9	--	--
		Dec. 10, 1968	--	870	2,020	--	--	358	--	26,800	--	--	--	57,100 a/	10,500	--	--	.00	74,600	6.9	24	75
		Mar. 26, 1969	--	890	2,040	*16,900	--	296	9,800	26,200	--	--	--	56,000	10,600	--	--	--	73,500	6.8	24	75
		June 18, 1969	--	880	1,960	*16,800	--	334	9,560	26,000	--	--	--	55,400	10,300	--	--	.00	71,900	6.9	24	75
		Sept. 18, 1969	7.0	870	1,990	17,100	150	224	10,100	26,800	--	--	3.5	57,100	10,400	78	--	.00	74,000	6.7	26	79
Well 3	15.5 - 20	May 15, 1968	26	925	1,140	12,200	100	174	4,720	20,800	--	.0	--	40,000	7,000	79	--	.00	64,300	--	26	79
		Sept. 17, 1968	35	870	1,220	12,800	112	266	6,590	20,500	2.0	5.8	--	42,300	7,190	79	--	.00	56,600	6.8	--	--
		Dec. 10, 1968	--	910	1,180	--	--	268	--	20,600	--	--	--	42,200 a/	7,120	--	--	.00	58,800	--	24	75
		Mar. 26, 1969	--	780	1,220	*13,200	--	300	6,340	20,400	--	--	--	42,100	6,960	--	--	--	58,700	7.3	24	75
		June 18, 1969	--	765	1,280	*13,100	--	310	6,410	20,400	--	--	--	42,100	7,170	--	--	.00	59,000	7.3	24	75
		Sept. 18, 1969	21	800	1,230	12,800	100	260	6,320	20,800	--	--	3.0	42,200	7,060	79	--	.00	59,000	7.3	25	77
La Sal Vieja Site																						
Pond	--	Apr. 9, 1968	5.3	465	410	5,020	26	358	2,560	7,800	--	--	--	16,500	2,850	79	--	.00	26,800	7.5	--	--
		May 9, 1968	--	260	324	--	--	187	--	6,900	--	.0	--	--	1,980	--	--	.00	24,400	7.3	22	72
		July 16, 1968	--	320	378	5,000	42	226	--	7,800	--	--	--	14,000 a/	2,350	82	--	.00	22,800	7.4	--	--
		Dec. 11, 1968	--	358	420	--	--	242	--	9,000	--	--	--	--	2,620	--	--	.00	27,900	7.7	15	59
		Mar. 26, 1969	--	395	438	* 6,060	--	244	2,540	9,300	--	--	--	18,900	2,790	--	--	--	28,800	7.5	18	--
		June 18, 1969	--	410	510	* 6,460	--	220	2,780	10,000	--	--	--	20,300	3,120	--	--	.00	31,600	7.4	29	84
		Sept. 17, 1969	.7	470	555	7,500	63	210	3,190	11,800	--	--	12	23,700	3,460	82	--	.00	36,200	7.4	31	88

See footnotes at end of table.

Table 3.--Chemical Analyses of Ponded Water and Ground Water--Continued

WELL OR POND	WELL DEPTH OR PRODUCING INTERVAL (FT)	DATE OF COLLECTION	SILICA (SiO_2)	CALCIUM (Ca)	MAGNESIUM (Mg)	SODIUM (Na)	POTASSIUM (K)	BICARBONATE (HCO_3)	SULFATE (SO_4)	CHLORIDE (Cl)	FLUORIDE (F)	NITRATE (NO_3)	BORON (B)	DISSOLVED SOLIDS	HARDNESS AS $CaCO_3$	PERCENT SODIUM	SODIUM ADSORPTION RATIO (SAR)	RESIDUAL SODIUM CARBONATE (RSC)	SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C)	pH	TEMPERATURE	
																					°C	°F
											La Sal Vieja Site--Continued											
Well 1	15.5 - 20	Sept. 17, 1968	6.8	1,580	800	9,360	32	109	4,280	17,500	2.7	0.4	--	33,600	7,230	74	--	0.00	47,500	--	--	--
		Dec. 11, 1968	--	1,380	750	--	--	120	--	17,300	--	--	--	34,300 a/	6,530	--	--	.00	49,100	--	24	75
		Mar. 26, 1969	--	1,140	870	*10,400	--	308	4,980	16,700	--	--	--	34,200	6,420	--	--	--	49,400	6.7	24	75
		June 18, 1969	--	1,090	850	*10,700	--	332	5,240	16,800	--	--	--	34,800	6,220	--	--	.00	49,500	6.9	25	77
		Sept. 17, 1969	9.1	1,080	870	10,300	36	195	4,960	16,900	--	--	21	34,300	6,270	78	--	.00	49,100	6.9	26	79
Well 2	20.5 - 25	Sept. 17, 1968	9.2	985	820	9,300	28	104	5,070	15,400	2.2	.4	--	31,700	5,830	78	--	.00	45,200	--	--	--
		Dec. 11, 1968	--	1,000	825	--	--	326	--	15,800	--	--	--	32,900 a/	5,890	--	--	.00	47,100	--	24	75
		Mar. 26, 1969	--	910	840	*10,100	--	498	5,140	15,600	--	--	--	32,800	5,730	--	--	--	47,000	6.7	25	77
		June 18, 1969	--	880	865	*10,100	--	486	5,150	15,500	--	--	--	32,700	5,750	--	--	.00	46,900	6.8	25	77
		Sept. 17, 1969	14	870	840	9,920	36	302	5,180	15,800	--	--	23	32,900	5,630	79	--	.00	46,900	6.9	26	79
Well 3	30.5 - 35	Dec. 11, 1968	--	860	845	--	--	458	--	16,000	--	--	--	33,200 a/	5,620	--	--	.00	47,600	6.8	25	77
		Mar. 26, 1969	--	830	850	*10,300	--	516	5,100	15,700	--	--	--	33,000	5,570	--	--	--	47,200	7.1	25	77
		June 18, 1969	--	820	850	*10,300	--	526	5,060	15,700	--	--	--	33,000	5,540	--	--	.00	47,400	7.2	26	79
		Sept. 17, 1969	8.9	790	855	10,200	46	232	5,070	15,900	--	--	20	33,000	5,490	80	--	.00	47,100	7.2	26	79

* Sodium and potassium calculated as sodium (Na).

a/ Estimated from specific conductance.

b/ Includes the equivalent of 9 mg/l carbonate.

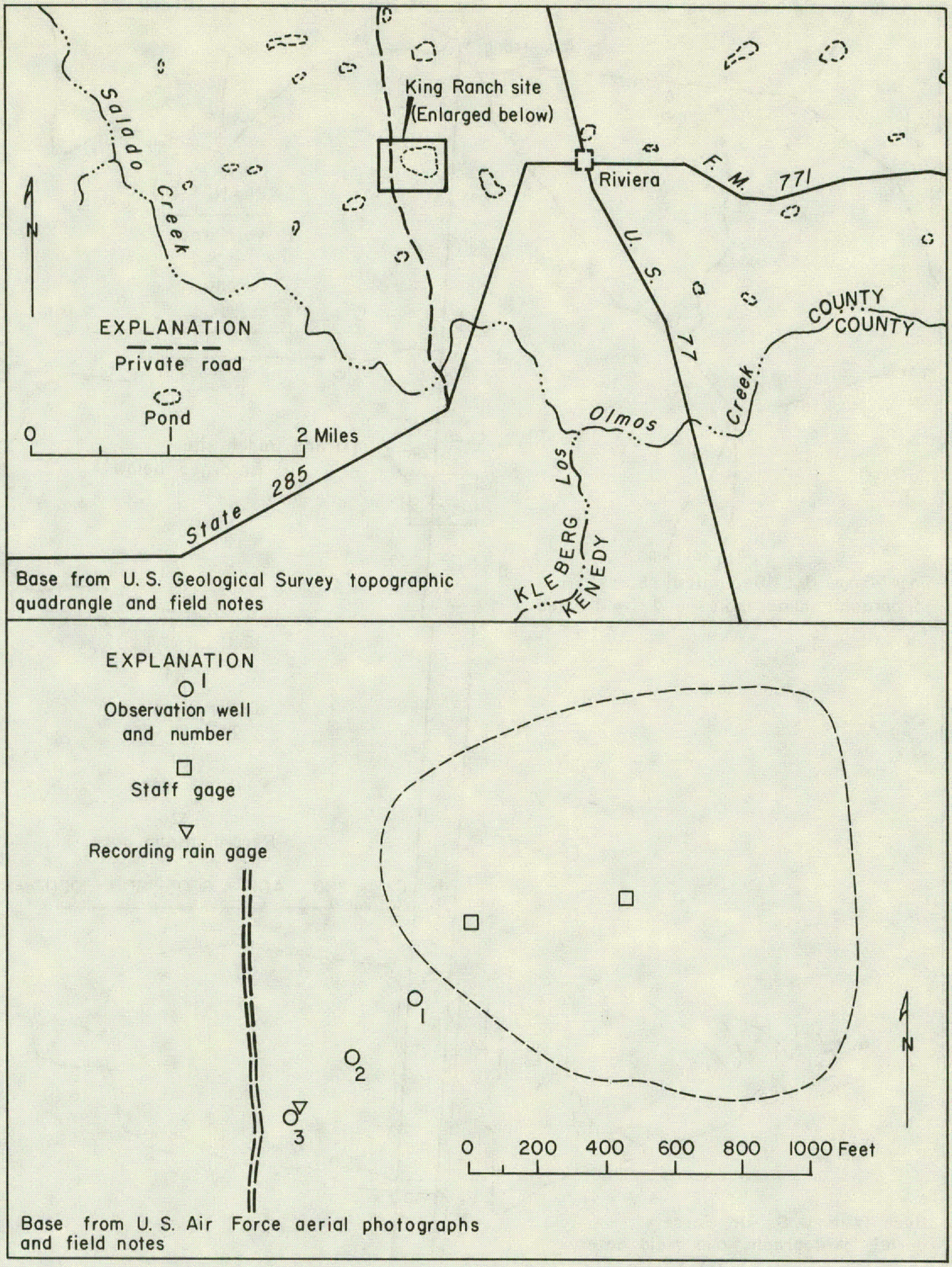

Figure 8

Location of Hydrologic Instruments at the King Ranch Site

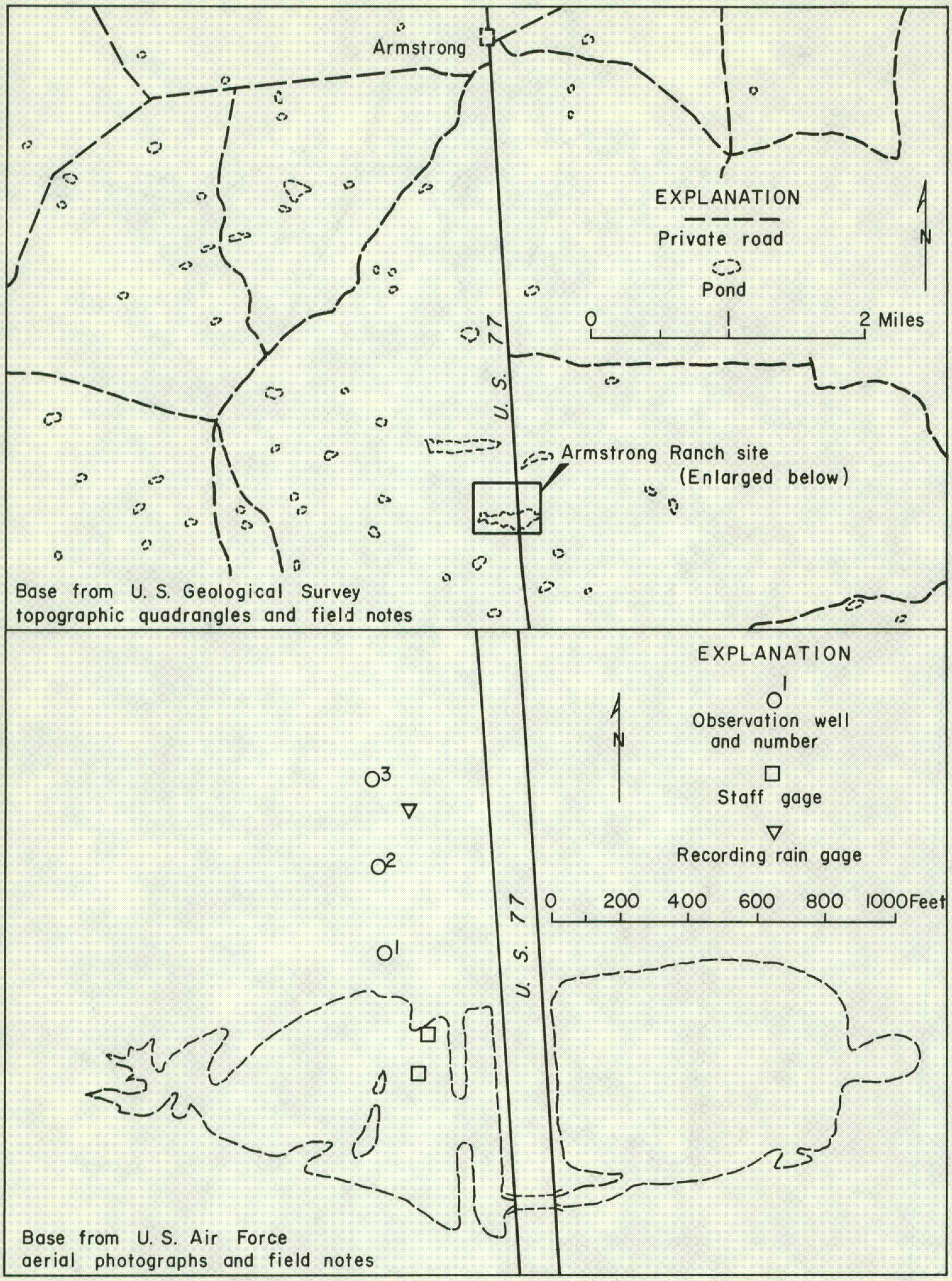

Figure 9

Location of Hydrologic Instruments at the Armstrong Ranch Site

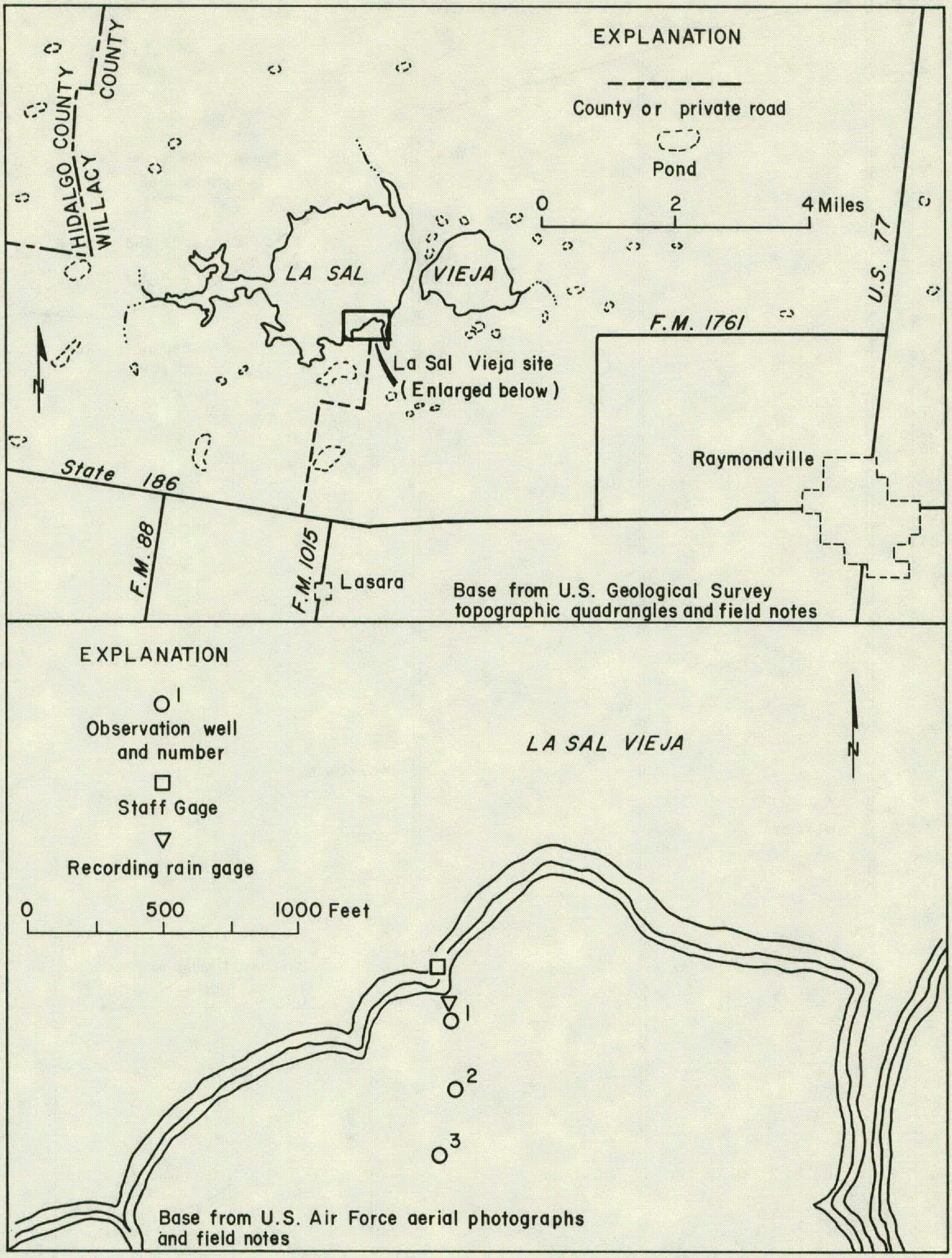

Figure 10

Location of Hydrologic Instruments at the La Sal Vieja Site

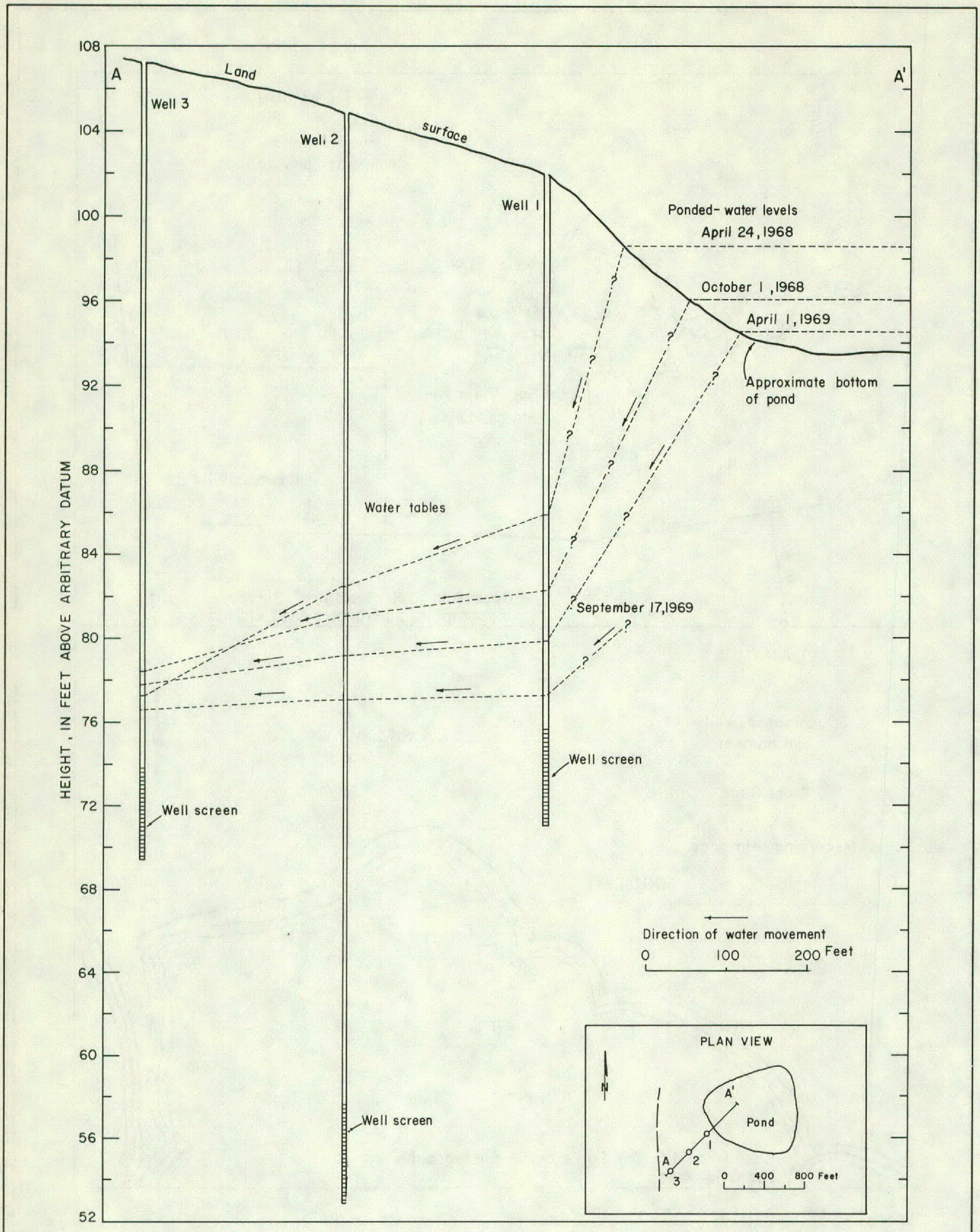

Figure 11

Levels of the Ponded Water and the Water Table at Various Times at the King Ranch Site

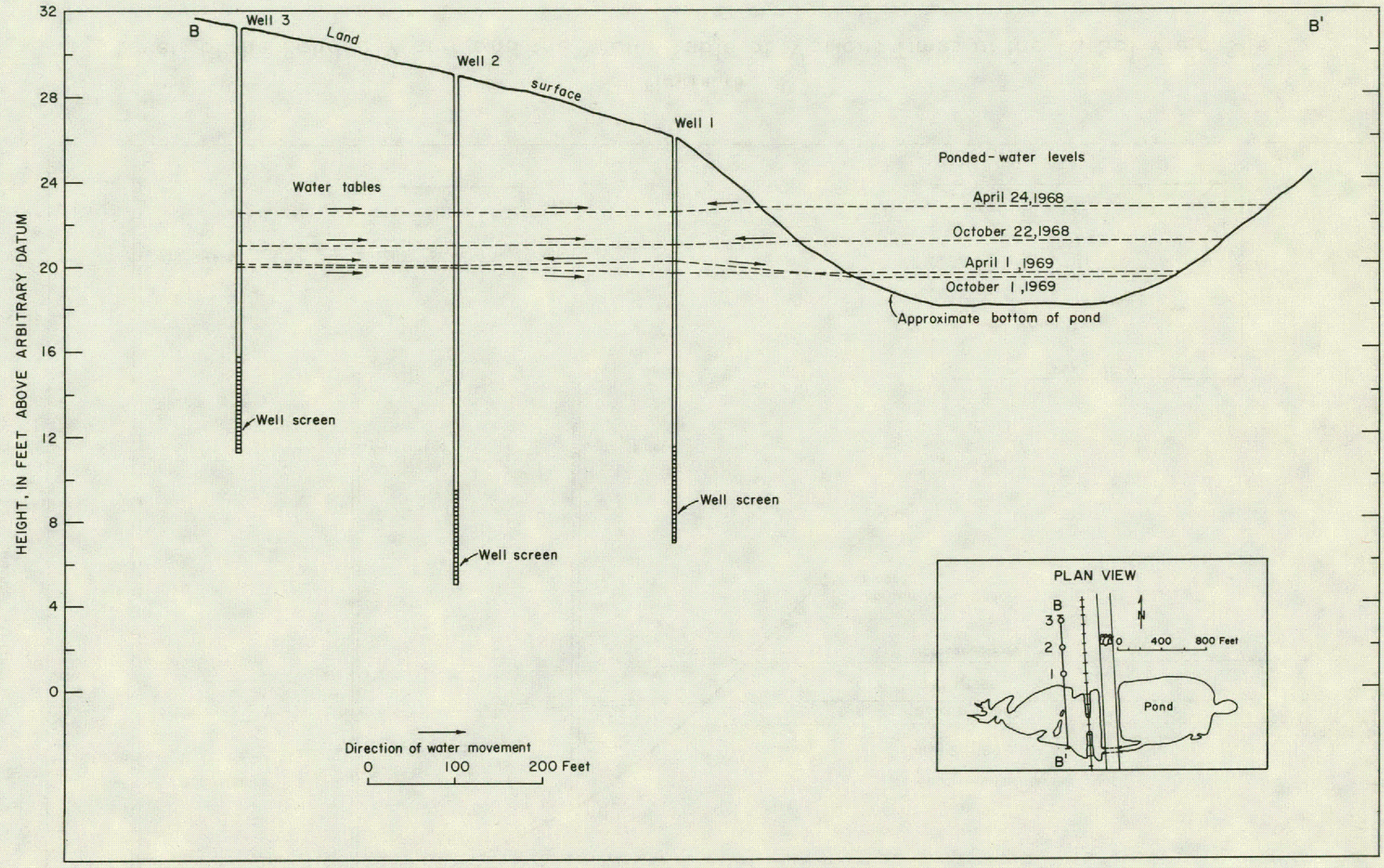

Figure 12

Levels of the Ponded Water and the Water Table at Various Times at the Armstrong Ranch Site

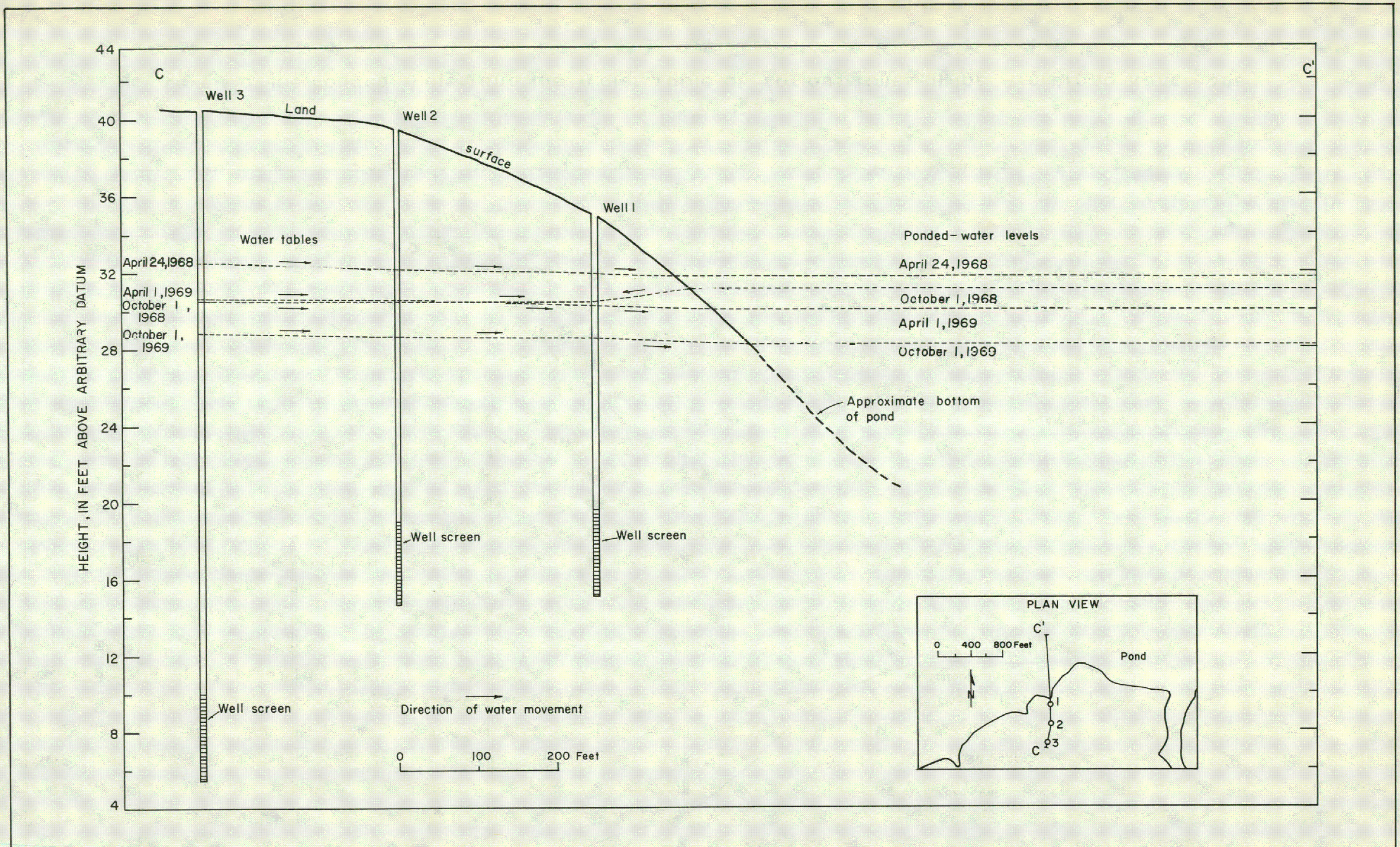

Figure 13

Levels of the Ponded Water and the Water Table at Various Times at the La Sal Vieja Site

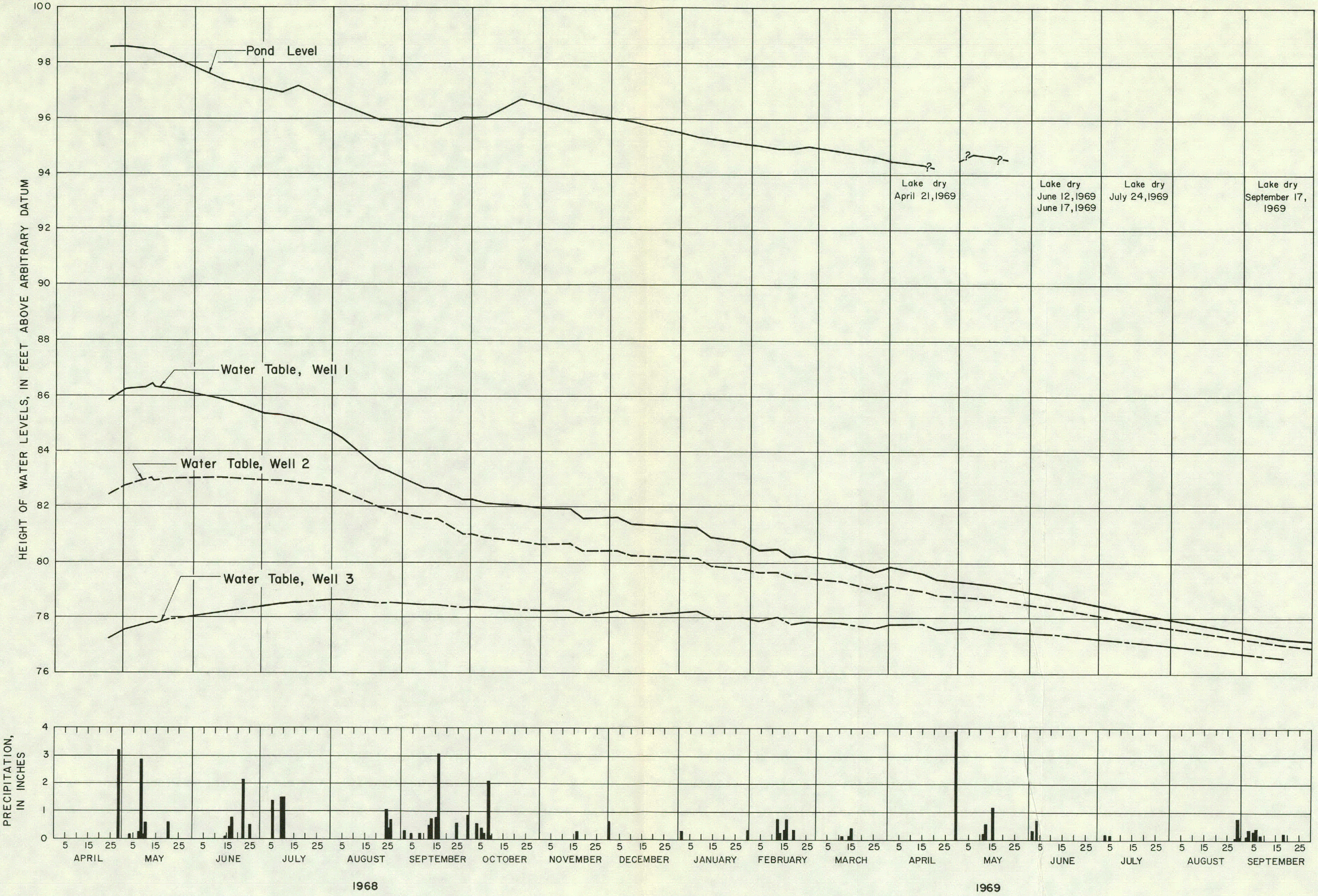

Figure 14

Levels of the Ponded Water and the Water Table and Daily Precipitation at the King Ranch Site, April 1968 - September 1969

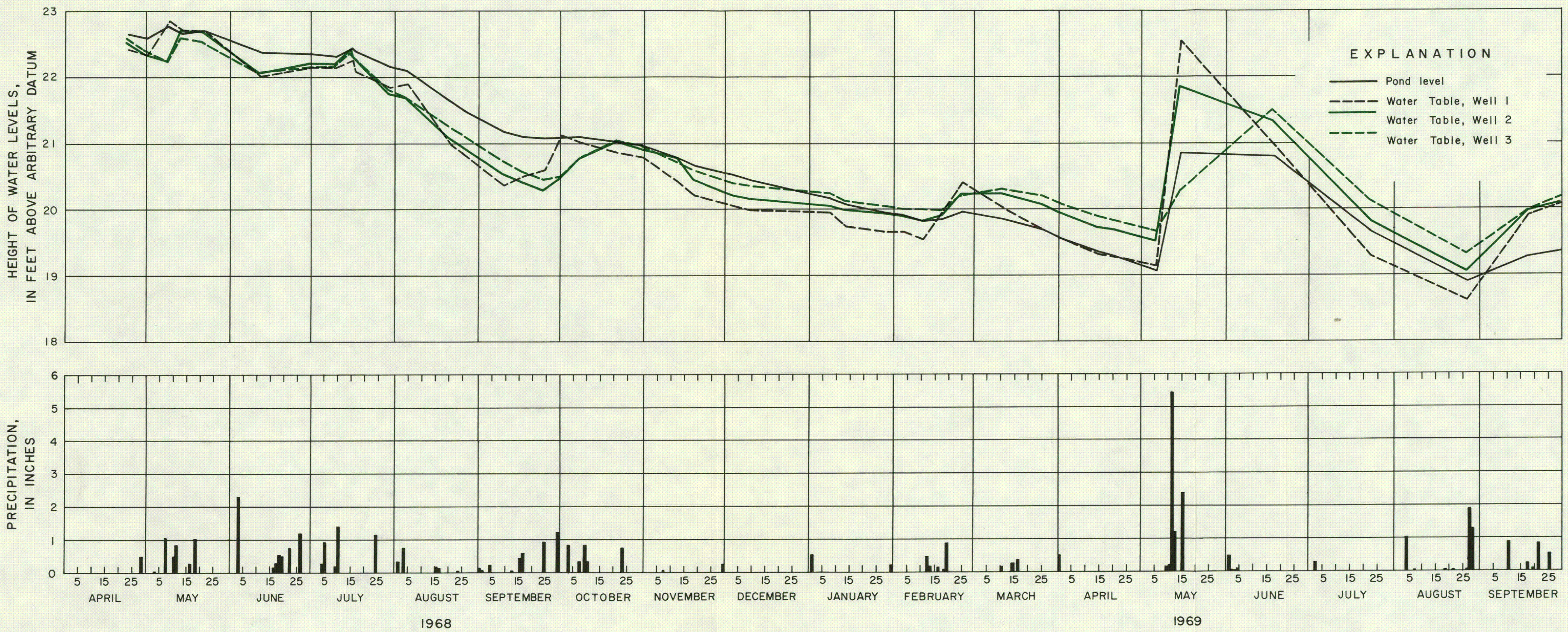

Figure 15

Levels of the Ponded Water and the Water Table and Daily Precipitation at the Armstrong Ranch Site, April 1968 - September 1969

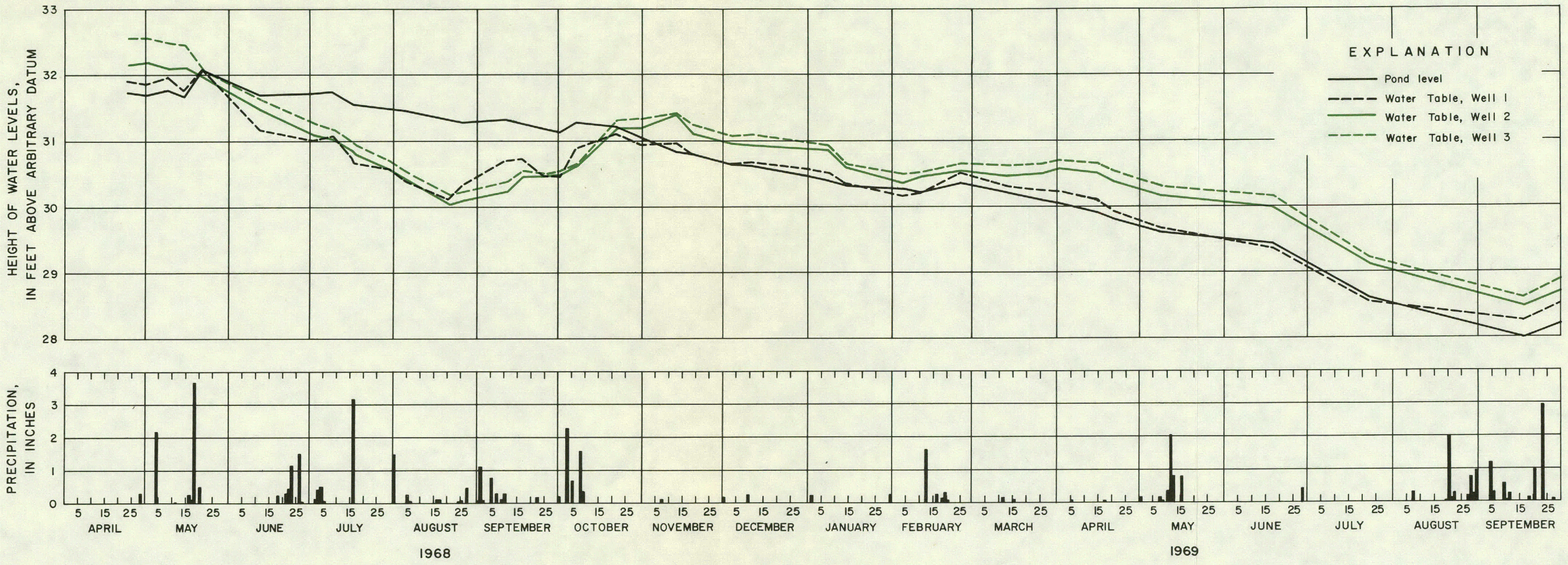

Figure 16

Levels of the Ponded Water and the Water Table and Daily Precipitation at the La Sal Vieja Site, April 1968 - September 1969