NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY

QUANTITATIVE HYDROLOGIC STUDY OF A CLOSED BASIN WITH A PLAYA (ESTANCIA VALLEY, NEW MEXICO)

by

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The Hydrologic Cycle in Action
Estancia Valley, New Mexico

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ABSTRACT

Few quantitative hydrologic studies of closed basins discharging ground water through playa systems have been made. A water budget was determined for a small test area of the Estancia Valley in central New Mexico which offers a unique, highly saline, perennially moist, environment in its playa discharge region. Ground water inflow was determined by Darcy's Law in the form: $Q = TIL$, using the results of several aquifer tests and water level data from a well monitoring program. Evaporative discharge was determined from climatic data, collected at a weather station located on a playa near the test area, utilizing several existing techniques. These techniques were modified and adapted to fit the unique conditions of the Estancia playas. Computer programs were developed to process the climatic data. The results show that between 340 and 455 acre-feet of ground water is discharged by evaporation in the test area each year. Extending these results to the entire Estancia system shows that between 27,000 and 36,000 acre-feet of ground water is discharged annually by the playas.

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INTRODUCTION

Purpose and Scope

Topographically and apparently hydrologically closed basins are common in the semi-arid and arid regions of the world. In many such basins, the principal point of discharge is a playa area where ground water is discharged into the atmosphere by evaporation. Undetermined amounts of water, a scarce and essential commodity in these regions of the world, consequently are not being utilized. Increased demands for water have intensified interest in ground water of these regions, both in the peripheral fresh ground waters and in the more saline water commonly found in the central parts of these basins.

Few quantitative studies of the hydrologic systems of these closed basins have been made, particularly for basins where a playa system is the only or the principal discharge point for the ground water. Most playas in the southwestern United States are not of this type but are hydrologic sinks for surface water, not ground water. These playas are dry most of the time except after receiving runoff from surface streams. It is this runoff water that is evaporated, not ground water which moves out of the basins by other paths. Hydrologic budgets for this type of basin are obtained by conventional means such as stream gauging or summation of irrigation and other withdrawals. Ground water losses, evaporative losses, and transpiration use by vegetation are simply added to the budget. Evaporation determinations are thus only part of the discharge, and in most cases, are little more than estimates. For the type of basin where evaporation from a playa system is nearly the entire ground water discharge, errors in calculating evaporation have a very great effect on the total discharge, and therefore must be more accurately determined. This study is an attempt to determine an accurate budget for a basin in which evaporative discharge from a playa system is the principal ground water sink.

The Estancia Valley, located mostly in Torrance County in central New Mexico, provided the site for this study. It has many of the characteristics of a playa-discharge hydrologic system in that the basin is closed both topographically and, as far as present knowledge indicates, hydrologically. However, the suggestion has been made by Titus (1969, p. 141) that some subsurface leakage may occur at the extreme north end of the basin. Evaporation from numerous playas in the central and southern part of the basin appears to be the only point of natural ground water discharge for the greatest part of Estancia Valley. The playa area itself is not subject to large withdrawals by pumpage or transpiration, and essentially all the ground water entering the playa area is ultimately lost by direct evaporation.

The techniques used in other basins for determining evaporative losses have mostly been concerned with evaporation from bodies of water. The Estancia playas for most of the year are not water covered. The surface is generally moist sediment, either salt encrusted or covered by a thin film of saturated brine. Because of these conditions, lake evaporation techniques do not give accurate evaporation values; the conventional techniques were therefore modified to fit the unique environment of the Estancia system.

This study involves the determination of a water budget for a restricted test area within the Estancia Valley. A small playa, somewhat separated from the main playa region, was selected for intensive hydrologic investigation. A series of wells were drilled around this playa to obtain geologic and aquifer information. Pumping tests were run to determine aquifer parameters. The subsurface geology of the vicinity was delineated from the logs of these and other near-by wells, and from a reconnaissance surface investigation of the entire playa area. Climatological data from a weather station, which was installed near-by on one of the major playas, were utilized to calculate evaporation. The selection of a small test area permitted an accurate comparison of the ground water inflow to evaporative discharge as determined by several different techniques. Most studies of closed basins have not been able to do this because it was impossible to isolate the ground water discharge or to accurately determine evapotranspiration losses. The results of this study were then expanded to determine a hydrologic budget for the central and southern part of Estancia Valley.

The study was supported in 1966 and 1967 by the Office of Water Resources Research, New Mexico Water Resources Research Institute Grant B005-WRI-151.

Previous Investigations

The geology and general hydrology of the Estancia Valley have been examined several times, but a quantitative study of the hydrology is lacking. Meinzer (1911) first investigated the geology and water resources of the area soon after the Valley was opened to homesteaders. Personnel of the New Mexico State Engineer Office periodically reported on ground water and irrigation potentialities of the Valley from 1923 through 1930 (French, 1924; Neel, 1926; Yeo, 1928 and 1930). These studies were semiquantitative in that an adequate supply of irrigation water was sought to support the various crops that were being grown in the area. Smith (1957) described the general availability and chemical quality of ground water, and the geology of Torrance County, which includes all of the central and southern part of Estancia Valley. He made use of a well observation program initiated in 1941 by the State Engineer Office and the United States Geological Survey, and of well logs, drillers' reports, quality-of-water information, and water-level maps of those two offices. The report is more an inventory of the water resources of the region than a comprehensive or quantitative study. Titus (1969) reported on the hydrogeology and paleohydrology of the Estancia basin in connection with a research investigation carried out by personnel of New Mexico Institute of Mining and Technology. The present study was a part of the same project.

DESCRIPTION OF THE AREA

Physiography, Area, and Boundaries

Estancia Valley covers an area of about 2,000 square miles in central New Mexico (Fig. 1). The Valley floor is relatively flat and comprises an area of approximately 900 square miles. It is about 50 miles long from north to south and ranges in width from about 12 miles at Moriarty (near the north end) to 30 miles at Willard (near the south end) averaging about 15 miles in width (Smith, 1957, p. 42). The topographic basin is bounded on the north by a divide overlooking the drainage of Galisteo Creek. On the south, it is bounded by Chupadera Mesa. The Manzano Mountains border the Valley on the west, and the Pedernal Hills and associated uplands border it on the east. The eastern border includes a low point in the topographic divide on the southeast that separates Estancia basin from a much smaller closed basin to the east. The topographic low point in Estancia Valley is just under 6,000 feet altitude in the playa area. From the Valley center, altitude rises to 9,000 feet in the Manzano Mountains, to 6,400 feet at the northern plateau boundary, 6,300 to 7,600 feet in the Pedernal Hills, and up to 7,250 feet on Chupadera Mesa.

The south central part of the basin, comprising about 500 square miles, is a relatively flat area once covered by an ancient lake (Meinzer, 1911; Titus, 1969). Within this area, specifically in T4N to T6N, R9E and R10E, is the playa area (Fig. 1). The playas occupy

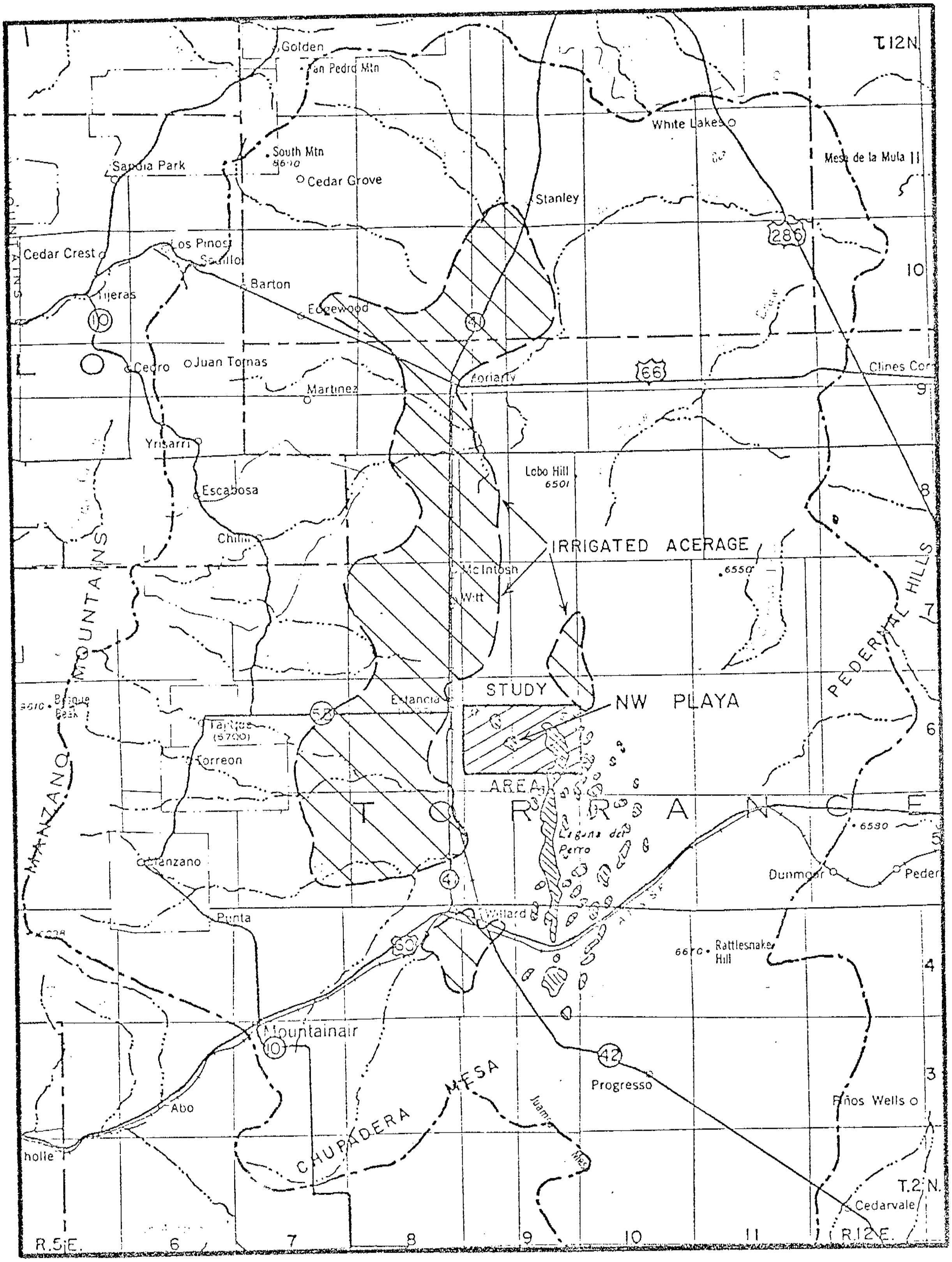


FIG. I Map of Estancia Valley

about 19 square miles, with Laguna del Perro (Dog Lake), the largest, covering about seven and one-half square miles (Smith, 1957, p. 43). The area of particular interest in this study includes a small playa about five miles east southeast of Estancia in Sec. 21, T6N, R9E, and the north end of Laguna del Perro, in Secs. 23 and 24, T6N, R9E.

Surface drainage in the Estancia basin is centripetal with arroyos originating in the surrounding highlands and draining toward the old lake floor in the central part of the Valley. Storm runoff is discharged onto the flat basin floor, and occasionally will flow into the playa area. These events are rare, however, as most of the runoff from the mountain regions infiltrates before it reaches the playas. On occasion, small shallow depressions just outside the playa region proper will receive runoff from the arroyos.

The playa region, on the otherwise flat basin floor, has a local relief of up to 170 feet between the playa bottoms, which are 20 to 40 feet below the general land surface, to the crest of large gypsum-sand dunes associated with the playas, which reach heights of 130 feet. The floor of the ancient lake is covered by grasses, with some scrub salt bush growing in lower areas near the playas. A few cottonwood trees are found near wells and stock tanks, where water leakage is present. The playas are totally devoid of vegetation and the lowermost slopes, just above the playa bottoms, support only widely scattered salt brush. The playas, in the spring and early summer when not water covered, generally develop salt crusts in the central areas, and surrounding the expanse of salt crust is a peripheral belt of perennially moist sand and salt.

Climate

Estancia Valley has a semi-arid climate. According to U. S. Weather Bureau records, annual precipitation ranges from 11.98 inches at the town of Estancia, in the Valley proper to 17.32 inches at Tajique, in the foothills of the Manzano Mountains. Table 1 (p. 102) shows the monthly variations in the rainfall for selected stations in the Valley and Table 2 (p. 103) shows the extent that the precipitation fluctuates from annual and monthly averages. More than half the annual average precipitation occurs in the period from June to September, with the largest monthly amounts occurring in July and August. The period from November through January generally has the least precipitation. It should be noted that most of the rainfall occurs during the months in which potential evapotranspiration is also at a maximum. This is particularly significant when considering the potential for recharge to aquifers in the central part of the Valley.

Temperature extremes in the Valley range from -20°F to about 96°F. January daily temperature averages 30°F at the town of Estancia and July averages 70°F. The crop growing season at Estancia averages about 148 days, from approximately the middle of May to the first of October.

At the Dog Lake North weather station, which was installed at the northeast end of Laguna del Perro as part of this investigation, precipitation averaged about 12 inches per year for the two and one-half years from March, 1967 to October, 1969. A comparison of rainfall at this station with that at the U. S. weather station at Estancia is shown in Table 3 (p. 106). The temperature range at Dog Lake North was from $4^{\circ}F$ to $97^{\circ}F$ ($-15.5^{\circ}C$ to $36^{\circ}C$). Relative humidity during this period ranged from 11% to 100%; monthly averages ranged from a low of 39.9% in May, 1967 to 78.4% in January, 1968.

Wind velocities and directions six feet above the playa surface were measured at Dog Lake North Station. Winds were moderate to strong, with average velocities of 30 to 37 miles per hour recorded during the windy period, which lasts from March to May. These were generally southwest winds. Southerly winds averaging as much as 25 miles per hour were occasionally measured from June through October. From November to February, strong northwest to north winds were recorded with velocities averaging as much as 30 miles per hour.

Land Use, Resources, and History of Water Development

The economy of Estancia Valley is primarily an agricultural one, consisting of farming and stockraising. Farming, principally by irrigation from wells, produced alfalfa, small grains, corn, and beans until 1960. Since 1960, potatoes and lettuce have become important crops (Sorensen and Borton, 1967, p. 116). Irrigation began in the early part of this century, but it was not successful or widespread until after World War II (Reeder and others, 1959, p. 222). Irrigation has increased from about 160 acres in 1941 to 22,000 acres in 1965, down from a high of 25,000 acres in 1955-1957. Estimated irrigation pumpage was about 25,000 acre-feet in 1965 (Busch and Hudson, 1967, p. 72). Most of the irrigated farms are in the western part of the Valley in a belt extending from southwest of Willard north to Stanley (Fig. 1). East of this region, stockraising is the primary occupation. Water use in this part of the Valley is about equally divided between the stock and rural domestic use, and amounts to not more than 1,000 acre-feet per year (Sorensen and Borton, 1967, p. 121).

In the test area for this project, the only diversion of ground water is by wells to stock tanks and by one domestic well at the Berkshire Ranch headquarters (Fig. 2). The nearest agricultural pumping is approximately 2.5 miles north in Sec. 10, T6N, R9E, where several acres of alfalfa are grown and a pasture irrigation system operates during the summer months. A potato farm 3.5 miles southwest of the study area is the nearest diversion point to the west. The town of Estancia water wells are about nine miles west northwest of the area. Pumping at some of these points causes minor fluctuations in the water levels in the study area.

Carbon dioxide was produced commercially from several wells northwest of Estancia between 1931 and 1949 (Smith, 1957, p. 15). Halite has been exploited to a minor extent for centuries from some

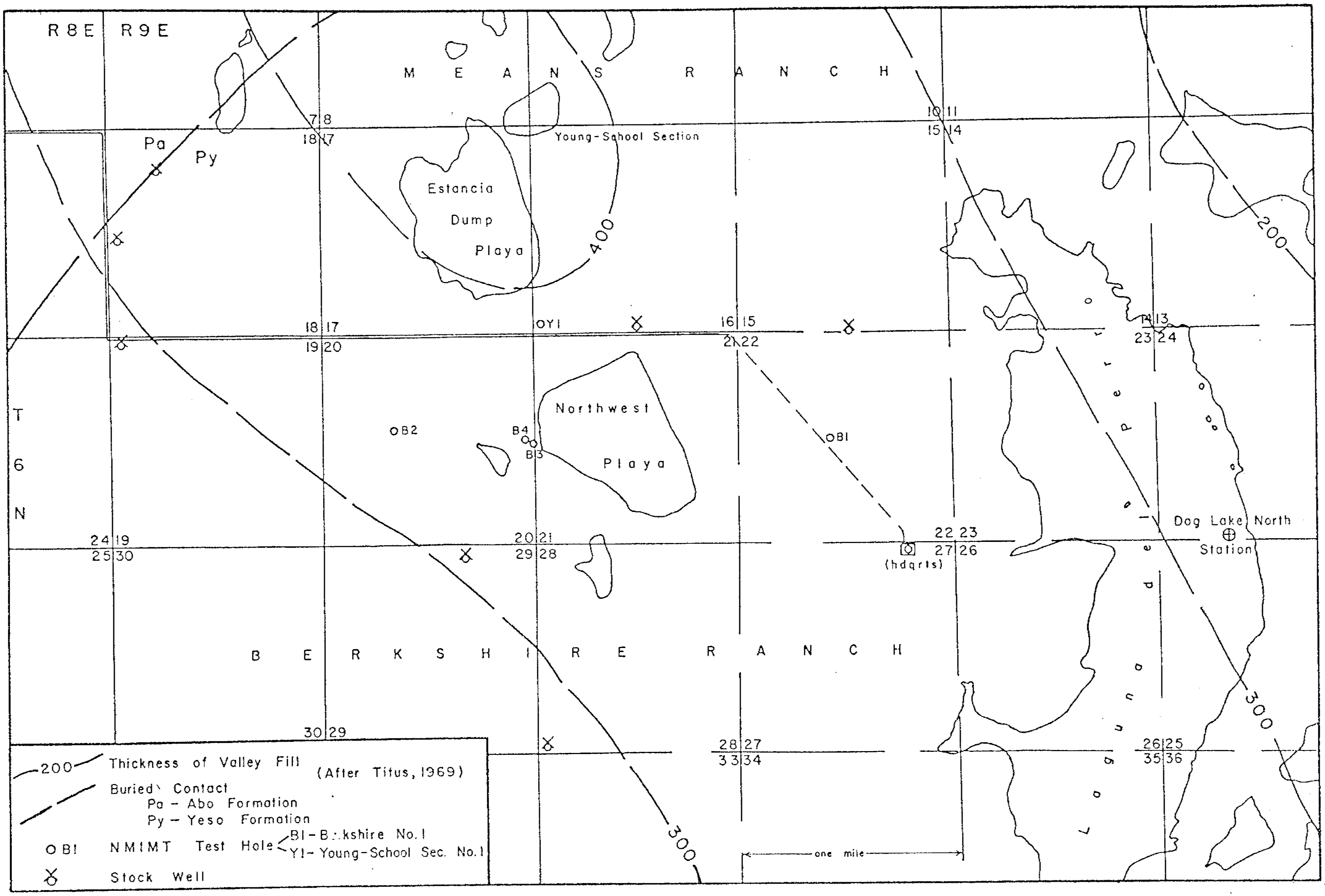


FIG. 2 Map of Study Area Showing Subsurface Geology and Wells

playas, principally Laguna Salina about eight miles southeast of the study area (Titus, 1969, p. 11). Commercial production began in 1915, but production ceased in 1939 (Smith, 1957, p. 16). The only other resource development in the Estancia Valley is small gravel quarrying operations, principally by State Highway Department crews for road maintenance work.

GEOLOGY

General

The flat central floor of Estancia Valley, and the lower slopes on the basin sides, are underlain by unconsolidated to poorly consolidated sediments composing the valley fill (Fig. 3). Higher on the slopes of the Valley, Precambrian, Paleozoic, and Mesozoic rocks crop out and extend under the valley fill into the central part of the Valley (Smith, 1957; Titus, 1969).

Pre-Tertiary Rocks

The distribution, outcrops, subsurface contacts, and relation of the pre-Tertiary rocks to the valley fill have been described by Smith (1957) and, more recently, by Titus (1969). Titus' modifications of earlier studies will be used in this report. Most of the pre-Tertiary units are in low-angle contact with the base of the alluvial valley fill in or near the study area. A brief review of the geology will be presented in order to establish hydrologic relationships such as recharge, inflow, and outflow.

Precambrian rocks crop out on the west side of the Valley in the Manzano Mountains, for the most part outside the drainage area of the basin. On the east side, the Precambrian crops out in the southeastern part of the rim in T4N, R10E and R11E and in the Pedernal Hills northeast of the above area. The valley fill is in contact with the Precambrian

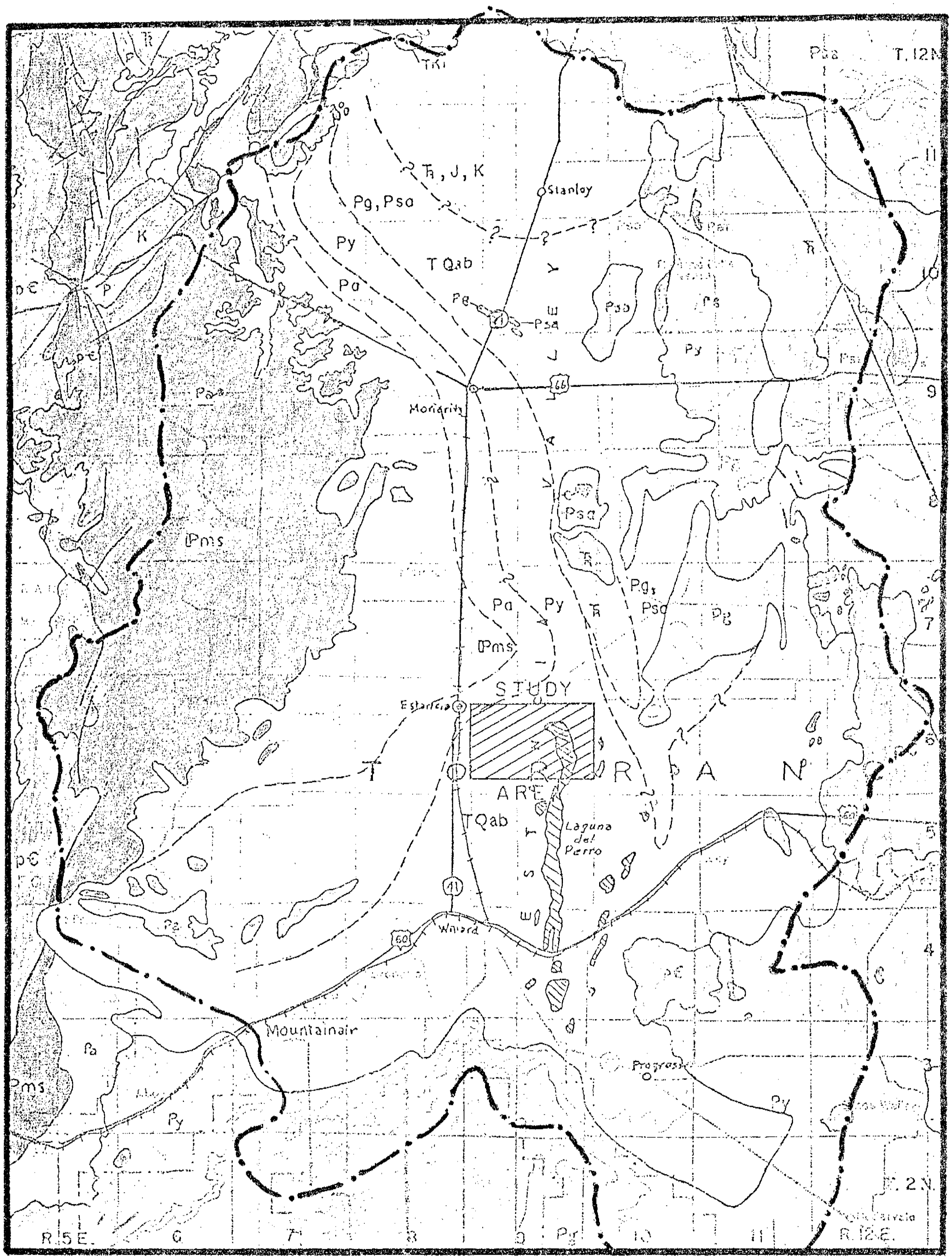
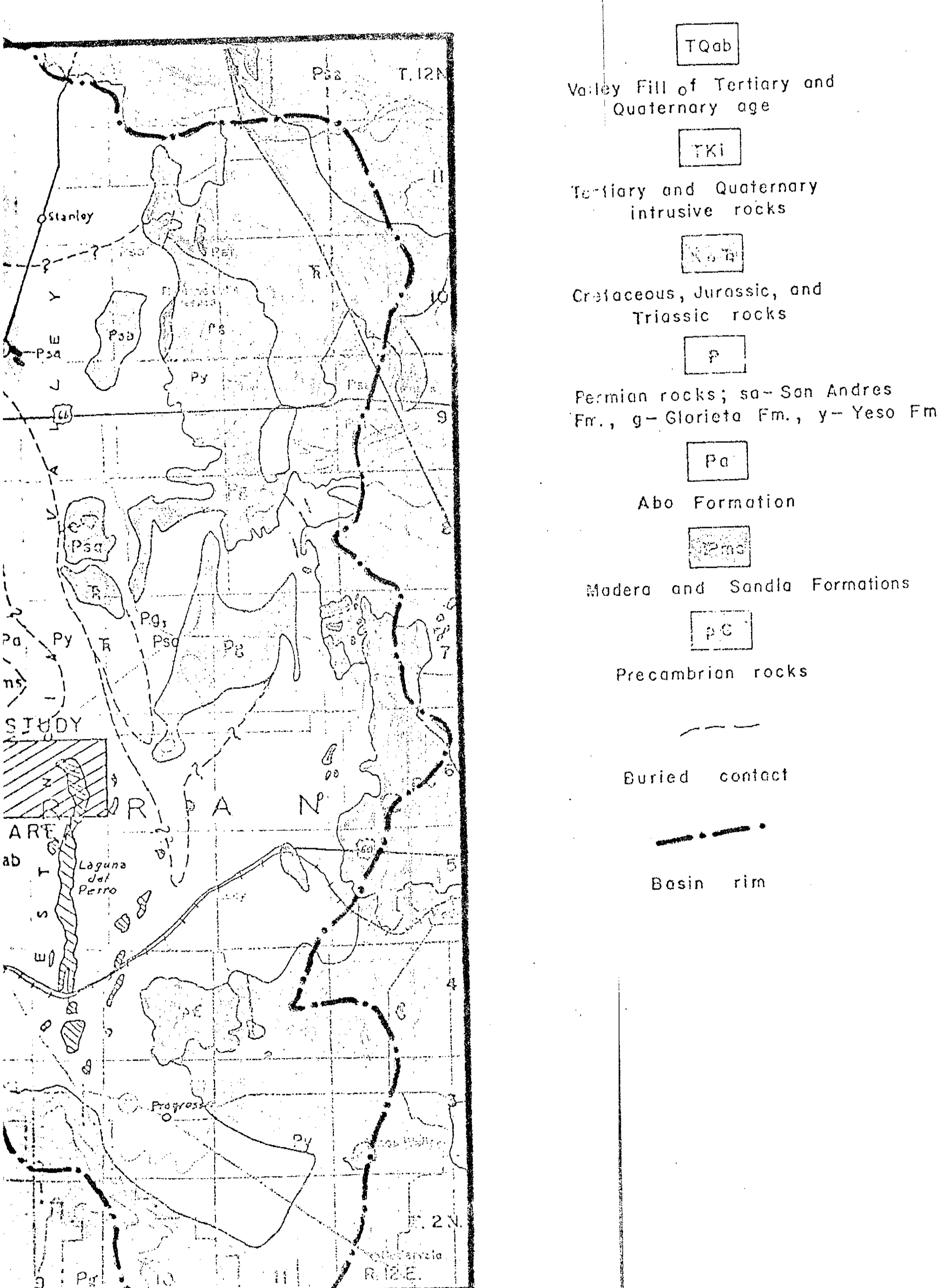


FIG. 3 Generalized Geologic Map of Estancia Valley
(After Titus, 1969)



Map of Estancia Valley
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where the Precambrian has been drilled for ground water production is in the southeastern part of the basin. Smith (1957) tabulated these wells which are mostly 150 to 300 feet deep and yield at most only a few gpm (gallons per minute). Permeability and porosity in these rocks are controlled by fracturing and degree of weathering, both of which are properties that usually decrease with depth. The predominance of low-yield wells reported in these rocks indicates that the amount of water which the Precambrian transmits to the valley fill in the central portion of Estancia Valley is very low (Titus, 1969, p. 19). This conclusion is also supported, a) by the fact that rainfall is low on the east side of the Valley (see Table 1), and b) by the relatively small drainage area on the east side of the Valley. On the west side of the Valley, the Precambrian is overlain by more than 1,000 feet of Pennsylvanian and younger rocks (Titus, 1969). Thick shale beds in these strata, and the low permeability to be expected in deeply buried rocks of this type, appear also to preclude much recharge into the basin through Precambrian rocks on the west.

Pennsylvanian

The Pennsylvanian strata, exposed to the west in a very large area high on the Valley side where precipitation is highest (Table 1), is mostly massive, cherty limestone, interbedded with calcareous shale in the lower part, and alternating cherty limestones, arkosic calcarenite, arkosic sandstone, and shale in the upper part. This formation, particularly the upper member, is shown by Titus (1969, pp. 22-30) to have great potential for collection and transmission of ground water to the valley fill and is probably the source of most of the recharge that enters the valley fill in the playa study area.

Permian

The Abo formation, which overlies the Pennsylvanian Madera, is predominantly a redbed sequence of dark-red shale, interbedded with sandstone and arkose. It is not a prolific aquifer, yielding only a few gpm of water of questionable quality (Smith, 1957, p. 29). The shaly nature of the formation suggests that little flow occurs across its bedding and little recharge to the valley fill should be expected from this formation.

The Yeso formation is present both in outcrop on the east and south sides of Estancia Valley and in subcrop beneath the valley fill in the central part of the basin, where it is more than 1,000 feet thick (Titus, 1969, p. 32). The lower member of the formation is a sandstone uniformly bedded, with associated sandy shales. The thick, middle member of the formation is alternating beds of sandstone, siltstone, limestone, and gypsum. Some gypsum beds are up to 20 to 30 feet thick in Chupadera Mesa at the south end of the Valley. The upper member of the formation is sandstone, silty sandstone, and siltstone. The gently east-dipping Yeso was beveled by erosion in the central part of the Valley before deposition of the valley fill (Titus, 1969, p. 33), so that the middle and lower parts of the formation are in contact with the base of the valley fill in the study area.

Permeability and porosity in the Yeso should vary considerably, owing to the nature of the formation--siltstones grading into sandstone, soluble gypsum beds, with the possibility of cavernous and vuggy-type porosity, and fracturing in structural zones. Smith's (1957, p. 32) tabulation of Yeso wells shows mostly low-capacity wells. Recharge to the valley fill is probably moderate from this formation, with the area of greatest recharge most likely east and northeast of the playa region.

The Glorieta and San Andres formations, sandstone and limestone respectively, may contribute some recharge to the valley fill in the same general area, especially the Glorieta which evidently is highly fractured south of Lobo Hill (Titus, 1969, pp. 34-35).

Triassic

Triassic rocks are in contact with the base of the valley fill in a small area south of Lobo Hill. These rocks are chiefly sandstone and mudstone of the Santa Rosa and Chinle formations. Little recharge should be expected from these rocks due to their relatively impermeable nature and limited outcrop and contact with the valley fill.

Structure

The Estancia Valley is bounded on the west by the uplifted and eastward-tilted Manzano Mountains. The Paleozoic sedimentary formations here all dip to the east beneath the valley fill, and abut the uplifted Pedernal positive element which bounds the east side of the Valley. Titus (1969, p. 39) has presented evidence postulating down-faulting of the basin against the west side of the Pedernal uplift. He indicated that late Tertiary (?) and Quaternary displacement may be a minimum of 650 feet.

Stratigraphy and Hydrologic Properties of the Valley Fill

The valley fill which covers the major portions of the Estancia Valley (Fig. 4) is divided by Titus (1969, p. 40) into two major units; 1) an earlier, alluvial unit that crops out on the lower slopes of the Valley sides and occurs in the subsurface in the study area; and 2) a later, lake-sediment unit, further divided into an upper lake sequence and a lower lake sequence, separated by a medial sand. The upper lake sequence is overlain locally by Recent playa muds and salt in the playas proper, and, in close relationship with the playas, by Pleistocene and Recent dune material scattered along the east sides of the playas. Titus (1969, pp. 40-72) discusses the Quaternary stratigraphy in detail. A generalized picture of these deposits which form the principal aquifers that were investigated in the present study, will be presented here.

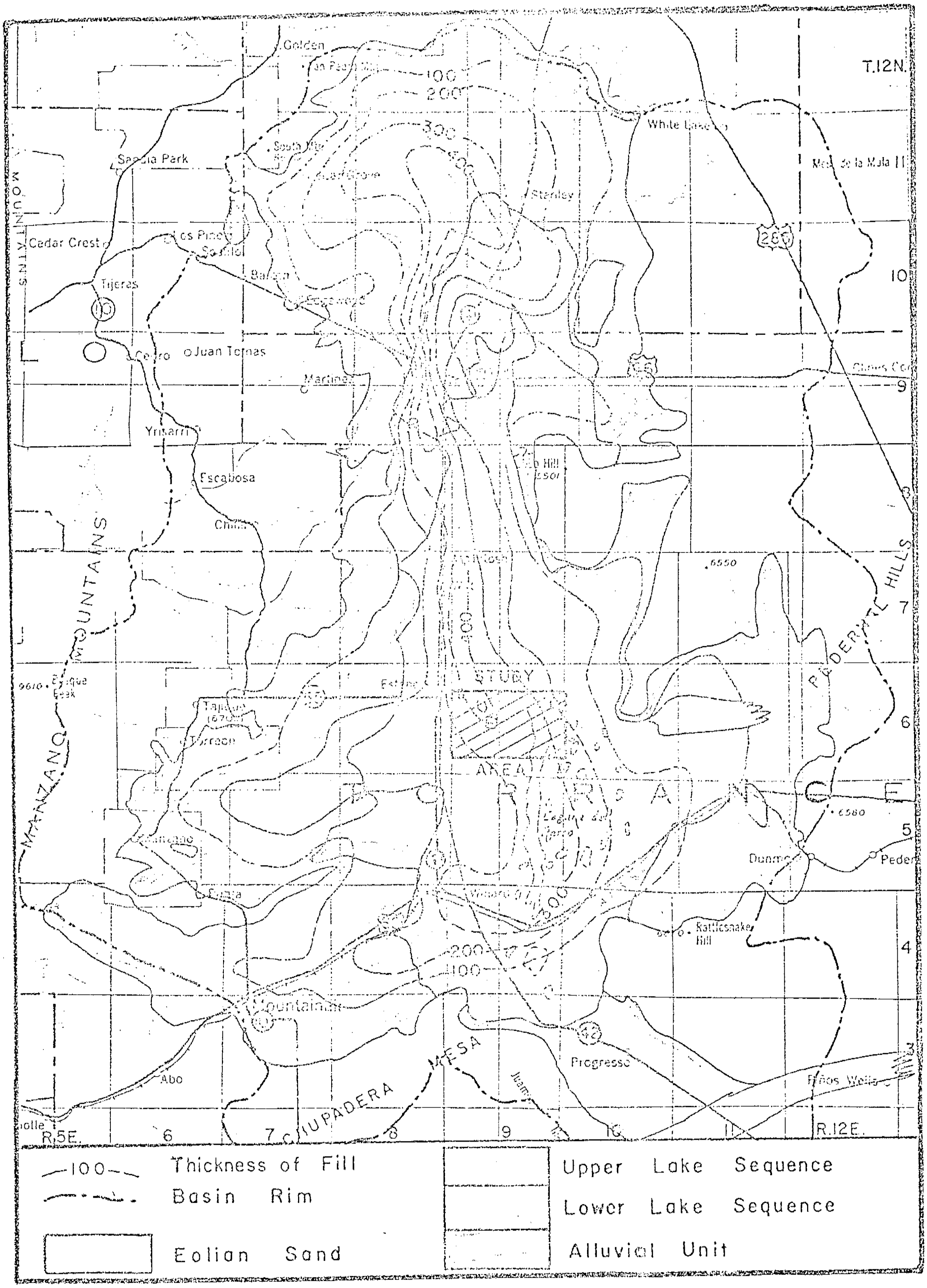


FIG. 4 Geologic Map of Valley Fill

(After Titus, 1969)

Alluvial Unit

The alluvial unit attains a maximum thickness of more than 400 feet, north of the study area, and a 270-feet section was penetrated in section 22 of the study area by the No. 1 Berkshire test hole. It thins radially from the Valley axis to an irregular feather edge lying mostly below an elevation of 6,800 feet (Titus, 1969, pp. 42-44). It consists of reddish-brown to tan silt and sand, interbedded with gravel. In outcrop, clay is commonly a constituent of the silt and sand beds. Generally, the average size of particles comprising the beds becomes finer toward the center of the basin, but gravel beds are found in wells in the study area near the axis of the basin. Silt and silty sand make up more than 80 percent of the sediment in most exposures (Titus, 1969, p. 44). The sands and gravels are thin bedded, locally cross-bedded, lenticular, and exhibit cut-and-fill structure.

Lithologically, the alluvium contains material that reflects the source rocks higher on the basin sides. In the study area, the alluvium contains material most likely derived from the Madera, Abo, and Yeso formations which crop out west of the area.

Most of the data on the alluvium in the central part of the Valley was obtained from test holes drilled during the course of this investigation. Table 4 (p. 108) gives the locations, depths, casing data, and other information on these holes. Sample logs prepared by Titus (1969) are included in the appendix. Four deep tests were drilled, all of which were originally thought to have penetrated through the alluvium.

However, only one, the No. 1 Berkshire, actually reached Yeso bedrock. Figure 5 shows the probable depth of penetration of the alluvial unit by the deep tests.

The alluvium is the principal aquifer in the irrigation area to the west beyond the edge of the overlying lake units. Smith (1957, Table 14) lists more than 30 wells which yielded more than 1,000 gpm. Specific capacities generally ran between 20 and 80 gpm per foot of drawdown in alluvium wells. In pumping tests conducted in the N.M.I.M.T. test holes during this investigation, specific capacities were much lower; the highest was about 1.25 gpm per foot. These lower values are probably due in part to lower aquifer permeability in the central part of the Valley, and in part to the condition of the test holes and to the nature of the well completions. The test holes were completed "open hole" and were never adequately developed. Furthermore, the low-capacity pump that was available for pumping tests could not produce sufficient drawdown in the bore hole, and very likely flow was induced only from a limited portion of the open hole section or, as will be discussed later, the wells only partially penetrated the aquifer.

Lake-Sediment Unit

The lake-bed unit, as defined by Titus (1969, p. 58), has a thickness of slightly more than 100 feet in the central part of the Valley. It overlies the alluvial unit, and consists in part of a lower, lake-clay sequence which is up to 25 feet thick in the N.M.I.M.T. test

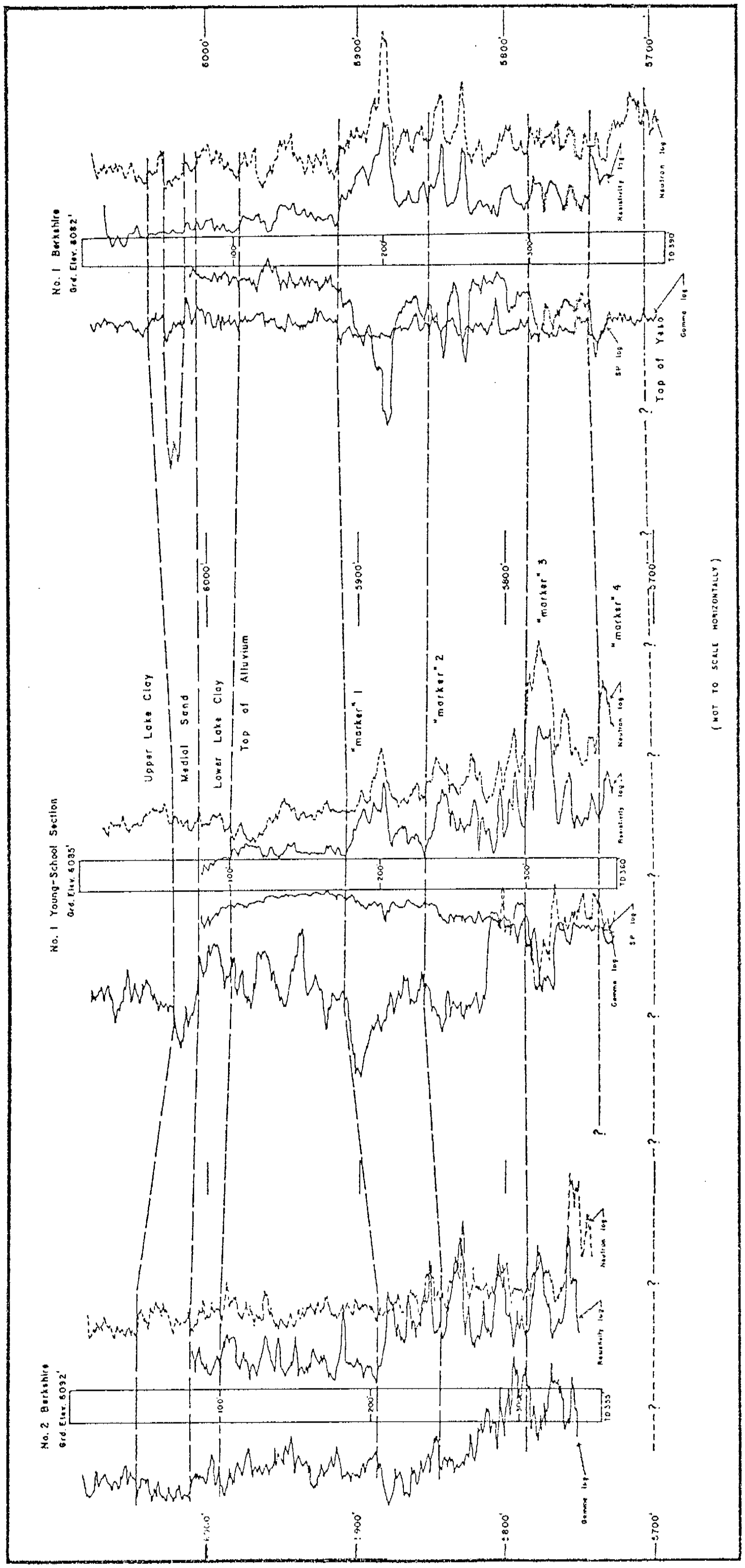


FIG. 5 Log Cross-section of Deep Test Holes

holes (Fig. 5). This sequence, as interpreted from logs of the test holes, interfingers with a medial sand, which is fine- to medium-grained, well sorted, rounded, frosted, and unindurated. The medial sand is up to 50 feet thick in the No. 1 Berkshire test. An upper lake-clay sequence is a gray, tan, yellow, or orange, slightly silty clay containing small selenite crystals. The top 20 to 40 feet of this upper sequence can be seen in the walls of the playa depressions.

Hydrologically, the two clay sequences are confining beds for water in both the medial sand member and the underlying alluvium. The medial sand supplies stock water in the central part of the Valley, but the water is too highly mineralized for domestic or irrigation uses. In some cases, the water quality in this sand has been too poor even for stock use. Westward, near the lateral limit of the lake-sediment beds, the medial sand probably interfingers with an alluvial facies of the lacustrine unit and is hydrologically connected with it. The significance of this interconnection will be discussed in a later section.

Recent Playa Deposits and Dune Sediments

The steep-walled playa depressions and their associated dunes are the dominant topographic features of the otherwise flat central part of Estancia Valley. The floors of the playa depressions are from 20 to 40 feet below the general land surface of the Valley. Laguna del Perro (Fig. 2), the largest of the playas, is at an elevation of 6,034 feet, measured at Dog Lake North Station, which is about 40 feet below the general level of the valley floor in that vicinity. The floor of the playa in Section 21, T6N, R9E in the study area is at an elevation of 6,071 feet and the playa in Section 17, T6N, R9E is at 6,060 feet. These depressions are 18 and 28 feet respectively below the general land surface. The surfaces of the playas are underlain by two feet or more of tan, gypsiferous silt and clay, black to dark brown organic mud, and salt and gypsum crystals. This sediment contains considerable water, but is of very low permeability. Two cores of playa material were set up in the laboratory to test permeability using native playa water. Under a head of 20 centimeters, flow rates of 0.04 to 0.06 cm/day were measured over a period of several weeks. However, numerous "vents" ranging up to one inch in diameter have been observed in the vicinity of Dog Lake North Station. The maximum flow from these vents has been estimated at a fraction of a gpm (Titus, 1969, pp. 122-125).

Associated with the playa depressions are large dunes composed mostly of gypsum of medium-sand size with slight amounts of clay and calcite grains. The dune material is weakly cemented with gypsum (Titus, 1969, p. 103), and the surfaces of the dunes are slightly crusted. Some rainfall infiltrates into the dunes, but most of it is apparently used by the vegetation cover of the dunes or evaporates back to the atmosphere. Along the east edge of Laguna del Perro in several drainage courses, small seeps were observed at the basal contact of the dune material with the lake-bed sequences. The seeps were few and amounts were small, suggesting that little, if any, of the infiltration recharges the lower aquifers.

HYDROLOGY

General Flow Regimen

The natural circulation of the hydrologic system in the Estancia basin is straightforward and simple. Recharge occurs mainly on the higher slopes of the basin where precipitation is highest, and infiltration is more likely to occur. Ground water flows toward the center of the basin where it is discharged by evaporation in the playa region. Surface runoff that reaches the central basin is rare. When it does, the water drains into low areas and is mostly evaporated. A small amount infiltrates into the upper lake sequence beds or the dunes, but is discharged into the playas where it is evaporated. Rainfall in the central basin is used by the vegetation, runs off into the playas and other local depressions to be evaporated, or is evaporated from the ground. Present evidence precludes any sub-surface leakage out of the southern sub-basin of the Valley (Titus, 1969, p. 139).

In the study area, the ground water flow in both the medial sand aquifer and the alluvium is generally eastward to the playa discharge area. Flow directions may be inferred from contours on the piezometric surface shown on Figures 6 and 7. The main component of flow is from the west, discharging into both the NW (northwest) playa in Sec. 21, T6N, R9E, and the Estancia Dump playa in Sec. 17, T6N, R9E. Small components flow westward towards these playas from the east.

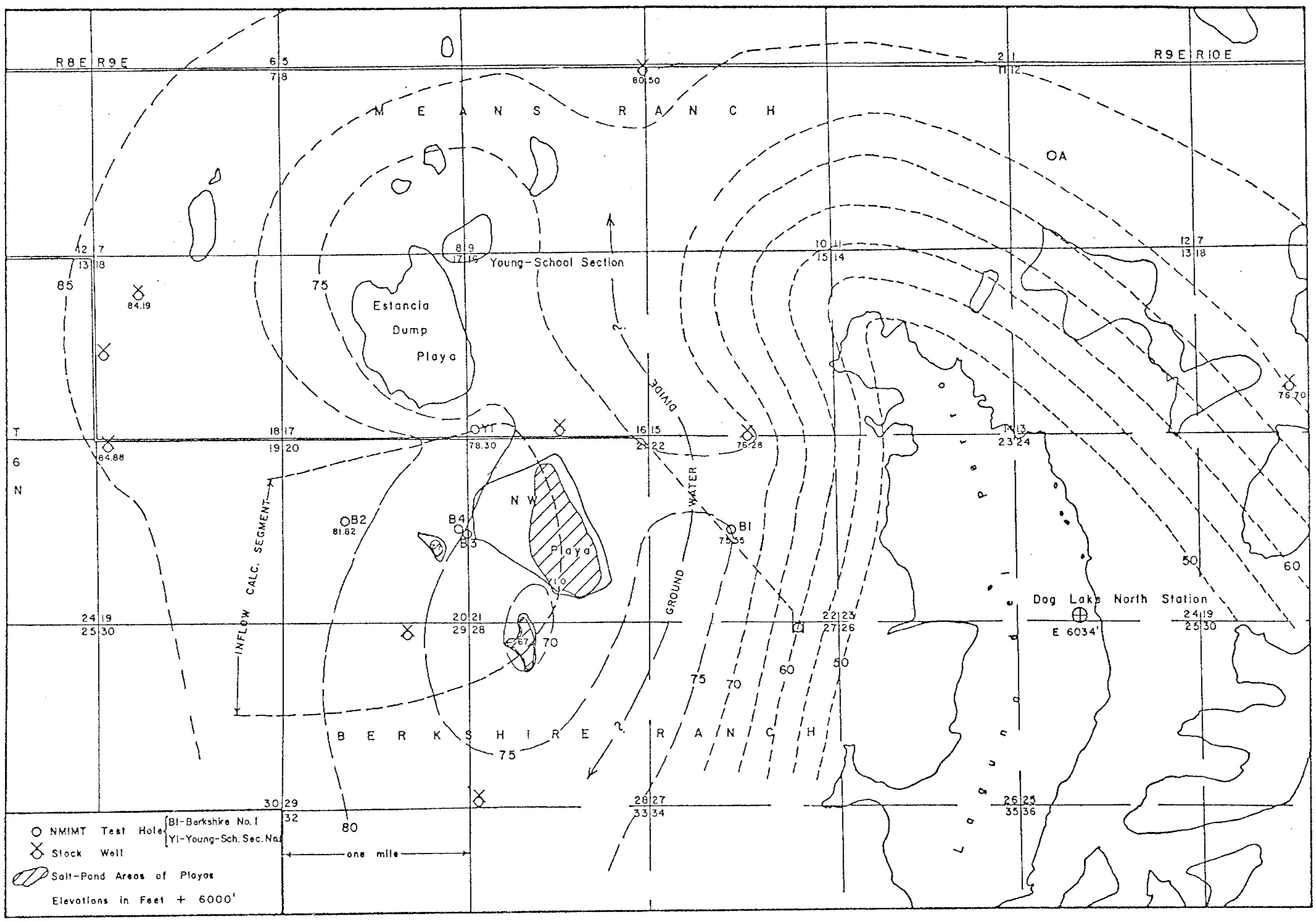


FIG. 6 Map of Piezometric Level in Alluvium Aquifer Showing Inflow Calculation Segment

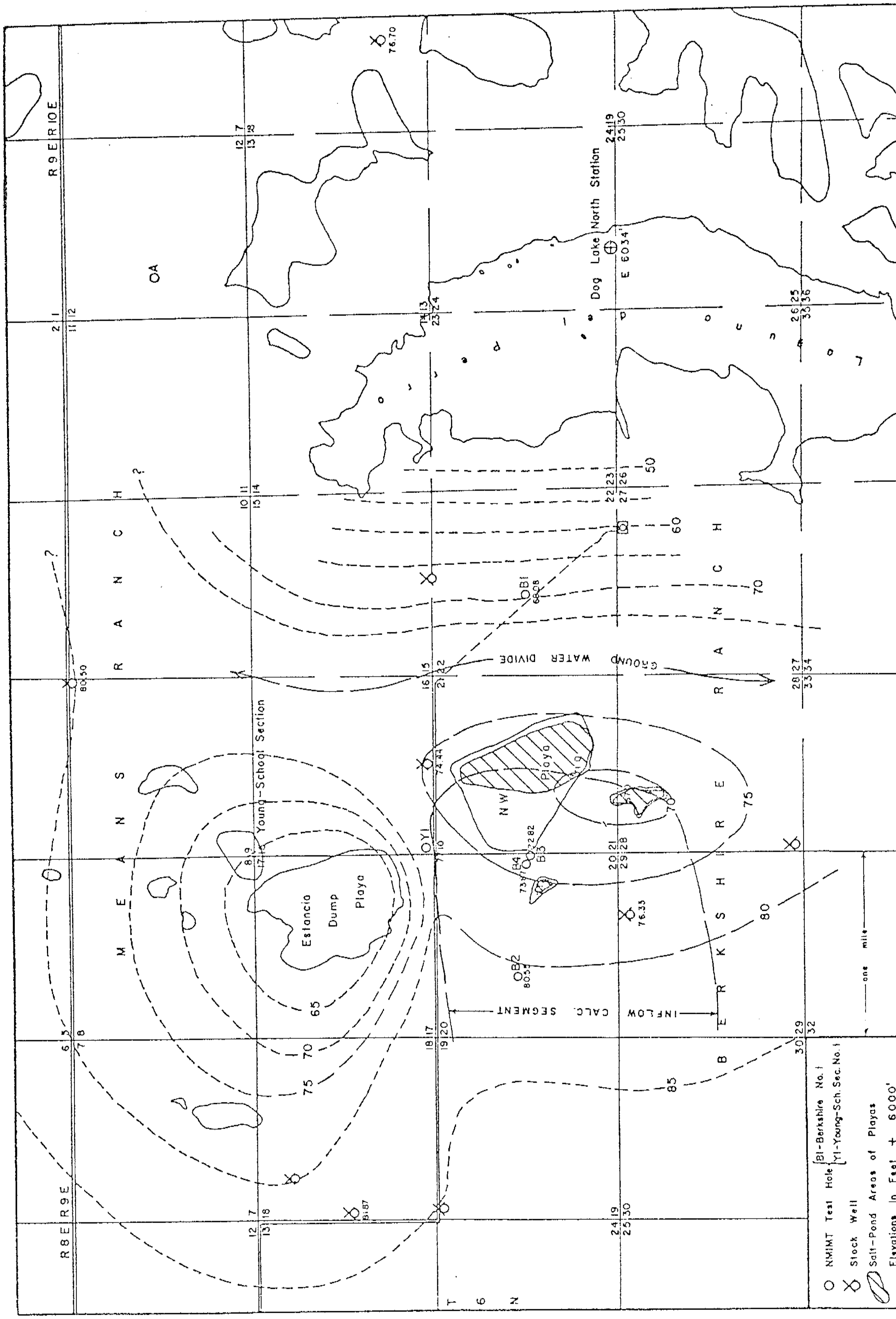


FIG. 7 Map of Piezometric Level in Medial Sand Aquifer Showing Inflow Calculation Segment

East of a local ground water divide in the vicinity of the No. 1 Berkshire test, the flow is again east, discharging in Laguna del Perro.

The ground water in the alluvium is moving down a gradient of about nine feet per mile in the western part of the area near the No. 2 Berkshire test hole (W $\frac{1}{2}$ Sec. 20, T6N, R9E) which increases to about 21 feet per mile between the No. 1 Young-School Section test hole (SW $\frac{1}{4}$ Sec. 16, T6N, R9E) and the NW playa in Sec. 21, T6N, R9E. (Fig. 6). Between the No. 1 Berkshire test hole (Sec. 22, T6N, R9E) and the NW playa is a low ground water divide, but between the No. 1 Berkshire and Laguna del Perro, a distance of slightly under one mile, the eastward gradient steepens to about 40 feet per mile. The gradient toward Laguna del Perro appears to be equally steep on the east side of the Laguna, at least in the area northeast of the lake in Sec. 11, T6N, R9E and Sec. 8, T6N, R10E, where water level data are available (Fig. 6). The gradient is altered during the growing season by heavy withdrawals in the irrigation region to the west, and during the 1969 pumping season, the gradient dropped to about two feet per mile between the No. 2 Berkshire and the No. 1 Young-School Section tests.

In the medial sand aquifer, the gradient on the west side is about six feet per mile between the No. 2 Berkshire test in Sec. 20, T6N, R9E and the No. 3 Berkshire located near the edge of the NW playa (Fig. 7). The gradient from No. 1 Berkshire to Laguna del Perro steepens to 34 feet per mile. The medial sand aquifer does not seem to be affected by the pumpage withdrawals beyond the study area. The ground water flow pattern is similar to that in the alluvium, with strong eastward components west of the Section 17 and 20 playas and Laguna del Perro and a slight westward component for a short distance from the local divide in Sec. 22, T6N, R9E.

Both the alluvium and the medial sand are confined aquifers. Water in the alluvium is under greater confining pressure, as its piezometric levels are from four to nine feet above the levels in the medial sand. The alluvium levels are between five and eight feet below land surface, while the medial sand levels are from 10 to 14 feet below land surface. The heights of these piezometric levels above the bases of the confining beds are about 90 feet and 24 feet respectively.

Direct recharge appears not to occur in either aquifer in the study area. Surface water rarely reaches this part of the Valley. On occasion, however, unusually heavy summer rains higher on the slopes of the Valley generate enough runoff to transport water to ill-defined drainage ways and broad swales on the Valley floor. Such a condition occurred in August, 1967, when three days of heavy rains in the Manzano Mountains flooded the low lying areas of the central Valley and produced a small trickle of runoff into several of the playas. Such an event apparently occurs once in several to many tens of years, as few of the residents of the Valley remember a previous storm of this intensity. During this unusual event, the runoff ponds may have infiltrated a small amount of water to the medial sand aquifer, but no well records are available to substantiate this. The water remained ponded for more than two months, or long enough for evaporation to account for its disappearance. Some water possibly percolated through the upper lake sequence to the playas where it evaporated.

During the short-duration, intense summer storms over the Valley, most of the water collects in swales or runs off into the playas where it is evaporated. A small amount enters the soil, but is apparently quickly transpired or evaporated. Some infiltrates the dune material or upper lake sequence and is discharged into the playas or through the seeps at the dune lake-bed contact. None of the observation holes monitoring the medial sand aquifer showed any evidence of direct recharge from precipitation.

Determination of the Water Budget

Basically a hydrologic budget of any area consists of

$$I = O \pm S$$

where I = total inflow into the area, surface and subsurface,

O = total outflow from the area, surface and subsurface,

and S = net change in storage in the area, both surface and subsurface.

The general area of interest in this investigation for determination of a water budget is centered on the NW playa in Sec. 21, T6N, R9E. It comprises all or parts of Sections 15-22, and 28-30, T6N, R9E, extending from an imaginary north-south line through Sections

18, 19, and 30 to the NW playa. The actual area used for calculation of the budget is shown in Figures 6 and 7. The change in storage can be considered negligible in this area. Water-level records of the U. S. Geological Survey and the State Engineer Office, recorded since 1941, show that the net change in water levels in the study area has been slight. Data on water levels in the test holes suggest that there has been a slight decline, but for the purpose of establishing the budget, S can be assumed to be zero. Since the area receives no surface inflow, the only known discharge is by evaporation from the playa region, and the storage change can be considered to be negligible at the present time; the hydrologic budget reduces to:

$$I_g \pm P = Ev$$

where I_g = ground water inflow,

P = precipitation,

and Ev = evaporation.

Ground water inflow across the western boundary was calculated using aquifer parameters determined by pumping tests in the N.M.I.M.T. test holes and the gradient established from water level measurements and playa surface elevations. Precipitation was measured at Dog Lake North Station for 2.5 years, and from these measurements, along with the U. S. Weather Bureau records for other Valley stations, a representative value of the precipitation in the area was obtained. Evaporation was determined using climatic data collected at the Dog Lake North installation.

Description of Test Holes

A major part of the field effort in this study, involved the drilling, completion, and testing of a series of test holes around the NW playa in Sec. 21, T6N, R9E. The original plan was to surround the playa with concentric rings of holes, but a number of unforeseen factors forced the abandonment of this plan after drilling three deep holes through the alluvial aquifer, and five shallow holes into the medial sand aquifer. Adverse weather, first in the summer of 1967 and then during the severe and prolonges snows of December, 1967, and March, 1968, halted drilling operations intermittently and permitted the drilling of only two deep and two shallow holes from July, 1967 to May, 1968. In June, 1968, the land owner objected to more tests, and the drilling program was terminated in September, after drilling one more deep test on school section land in Sec. 16, T6N, R9E, and three shallow "paired" holes next to the deep tests. Data on these test holes are presented in Table 4 (p. 108).

During the drilling of No. 1 Berkshire, the first test hole, sand problems were encountered upon drilling into the medial sand member of the lake-sediment unit. The sand contains water under artesian pressure, and its unconsolidated and well-sorted nature causes it to "flow" continually into any well drilled in this part of the Valley. Sand from this member was present in all drilling samples from the depth at which it was penetrated until the total depth of the well was reached. Any time that the well was left standing, such as during the August, 1967 flood, considerable fill-up and bridging was experienced. During electrical and radiation logging operations by U. S. Geological Survey personnel, several bridges were encountered. Caving sand had filled the bottom five feet of the hole prior to logging operations. By the end of the operations, 30 feet of hole had been filled. In the subsequent deep holes, No. 2 Berkshire and No. 1 Young-School Section, this problem was partially eliminated by drilling to a point below the main medial sand section and setting five-inch casing, which was cemented to the surface. The rest of the hole was then drilled with a smaller bit. However, the casing depth in both holes was not sufficient to shut off the sand completely, as the logs indicate stringers of the sand to a depth in excess of 100 feet, which was 20 to 25 feet below the casing. In fact, bridging was still encountered and a small amount of fill-up occurred during the rest of the drilling and logging operations. This sand problem appears to be an important factor in the analyses of the pumping tests that were subsequently conducted in these holes. The net effect was to create a partial-penetration situation and to require appropriate adjustments in the aquifer parameters determined from the test analyses. Figures 8, 9, and 10 show schematically the physical situation in these three deep tests. The bridging points shown in these figures are places in the drill holes where the hole diameter is smaller than the rest of the section due to more competent rocks. These places act as possible collection or bridging points for the

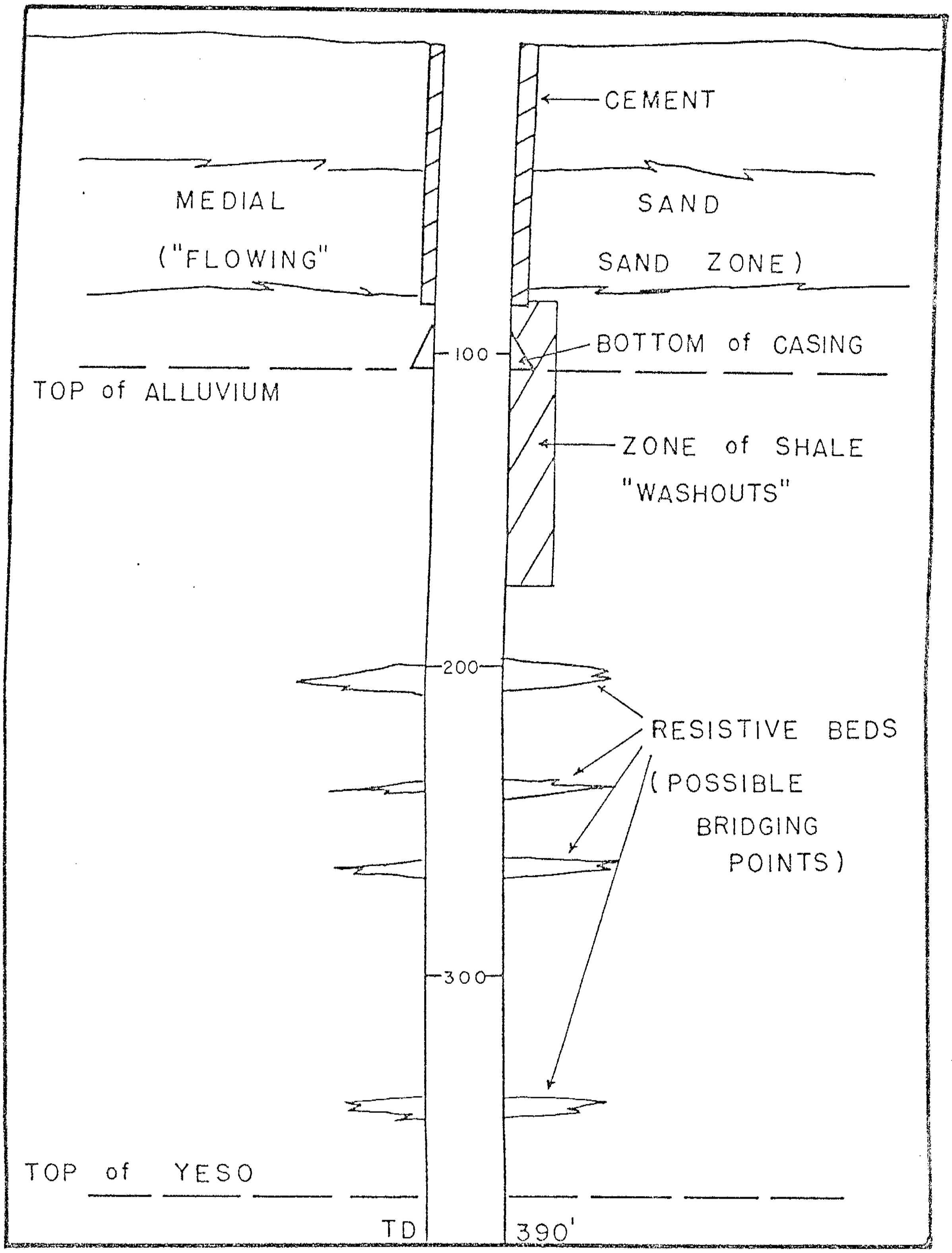


FIG. 8 Schematic Diagram of No. 1 Berkshire

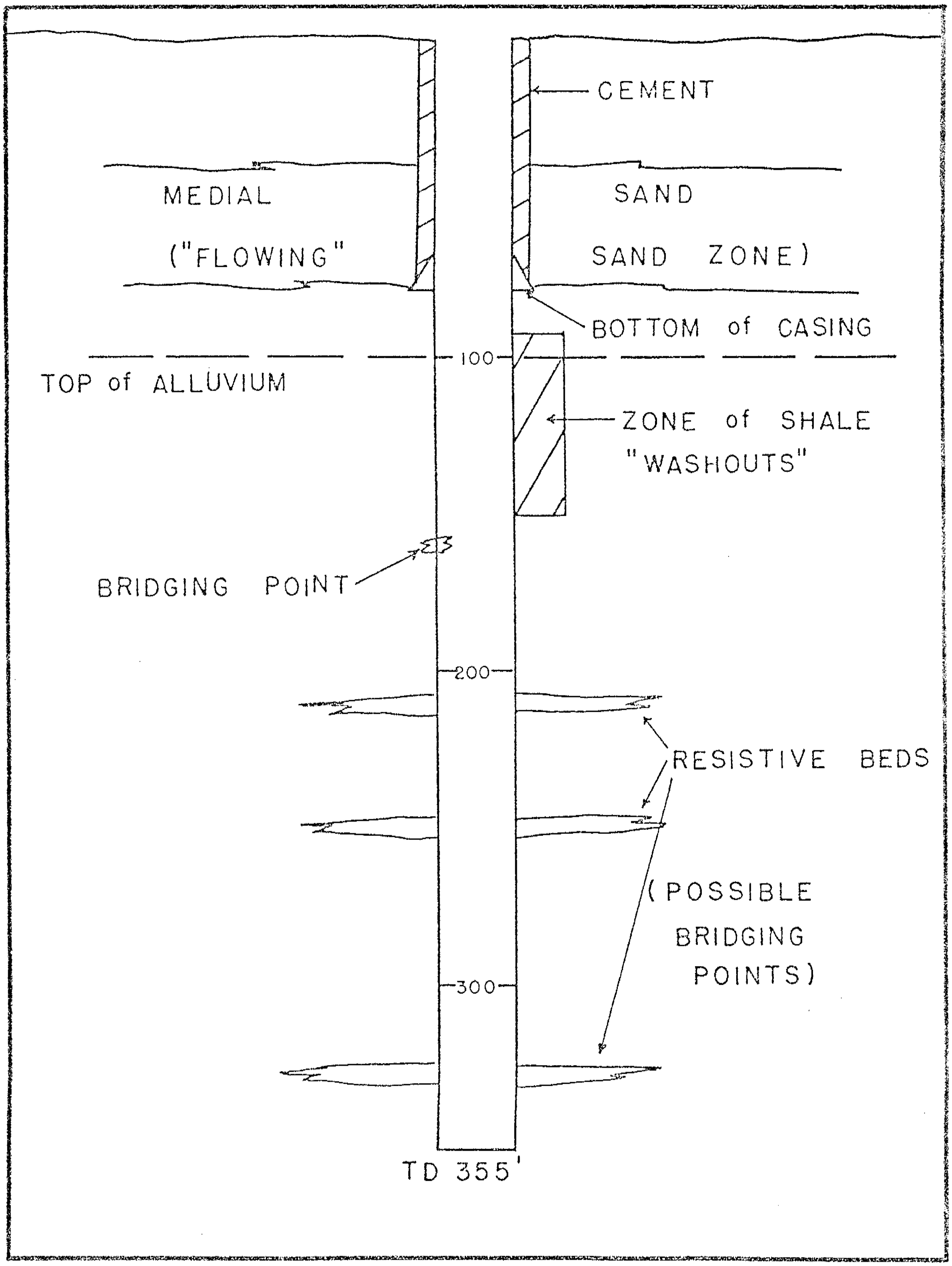


FIG. 9 Schematic Diagram of No. 2 Berkshire

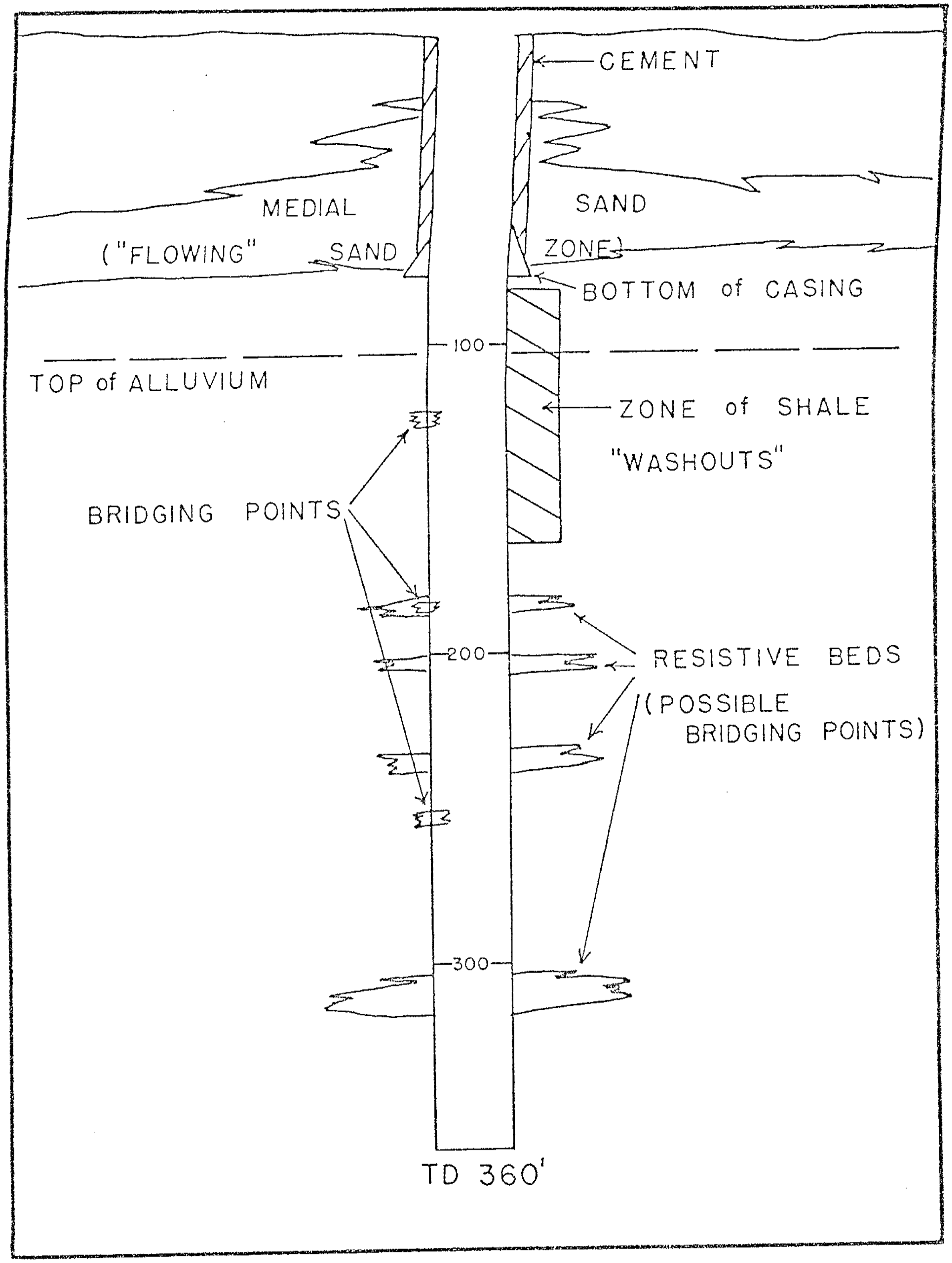


FIG. 10 Schematic Diagram of No. 1 Young-School Section

caving sand from the medial sand section.

The five shallow test holes were drilled into the medial sand aquifer. None of these completely penetrated the sand, although they appear to have penetrated the uppermost, thickest part of the member. Depending on location and depth, the thickness not penetrated varies due to interfingering of the lower part of the medial sand with the lower lake-bed sequence. The percent penetration by each of the five tests is not accurately known. Three of the shallow tests are paired with the deep test holes. These holes have two-inch casing with a three-foot, slotted well point at the bottom of the casing, which is at about 40 feet in all holes.

The No. 3 and No. 4 Berkshire shallow tests are larger diameter holes and have five-inch casing set to total depths of 38 feet and 59 feet respectively. The No. 4 Berkshire has 19.5 feet of slotted casing at the bottom and no well point, while the No. 3 Berkshire is "open-ended", i. e. no well point, without slots in the casing. Neither well is cemented.

These two wells, located 322 feet apart, were originally drilled for injection tests to determine ground water flow patterns in the medial sand. However, problems developed during the completion of the No. 3 Berkshire and the injection tests were not conducted. The well, which was drilled in a playa depression only a few feet above the playa floor (Fig. 2), started flowing before it was finished, and the flow could not be shut off with the equipment available. Figure 11

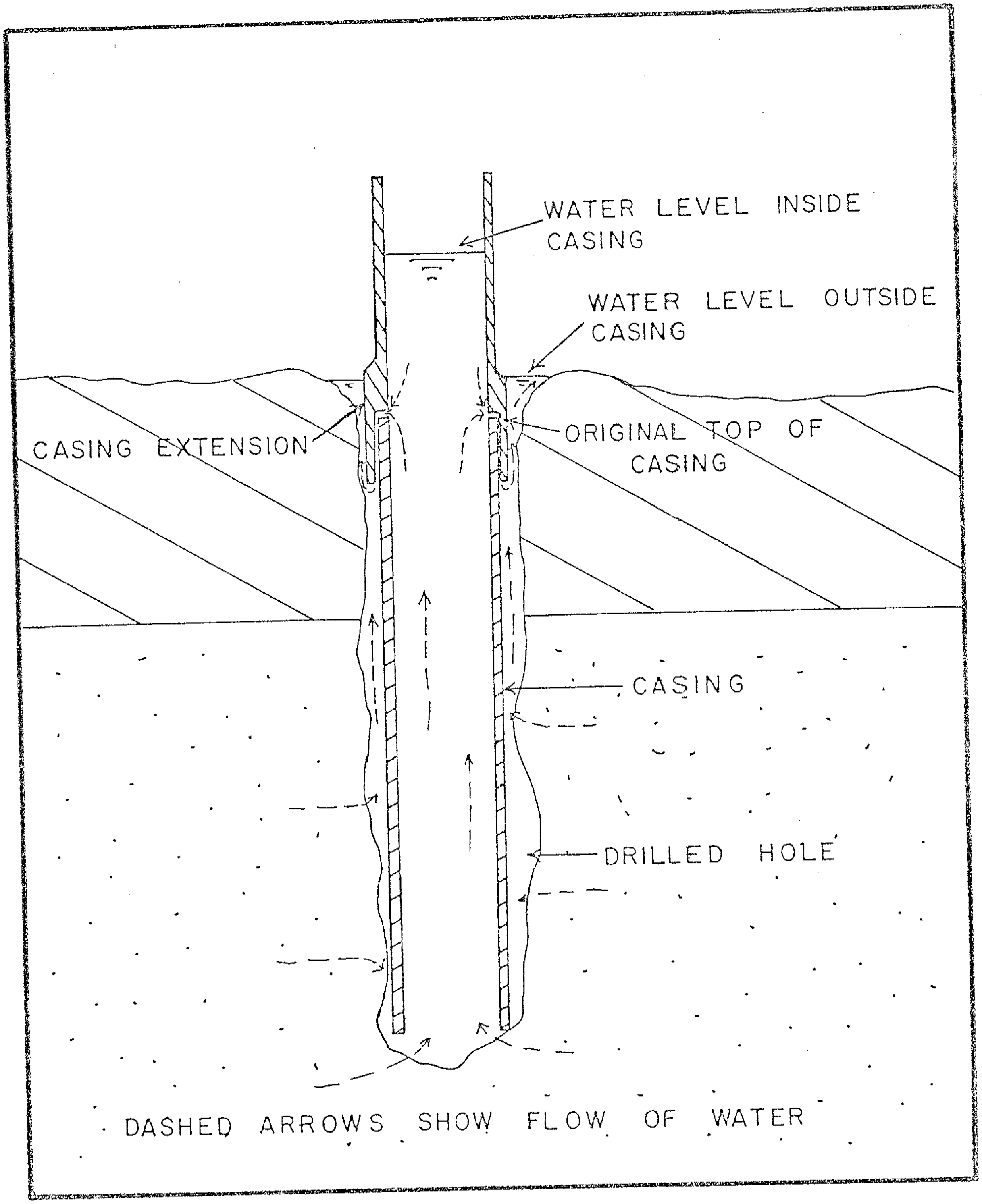


FIG. 11 Schematic Diagram of No. 3 Berkshire

shows schematically the situation in this hole. Discharge is occurring outside of the casing, but flow from inside the pipe may be leaking through the juncture of the main casing string and a three-foot nipple fastened on top of the casing to project the string above ground level (Plate I, p. 158). The flow from this well has decreased from an estimated 18 gpm in January, 1968 (one month after drilling), to 4.5 gpm on October 3, 1969, the date of the last measurement. Figure 12 shows the decline of this flow rate and the cumulative production curve for the well.

Pumping Tests

Six pumping tests were run on four holes in July and September, 1969. Two types of pumps were used. Air-lift tests were run in the No. 1 Berkshire, No. 2 Berkshire, No. 4 Berkshire, and No. 1 Young-School Section holes. Two other tests were run in the No. 1 Young-School Section hole with a vertical lineshaft, or helical pump.

The air-lift tests were run with a compressor rated to deliver 160 cfm (cubic feet per minute) at 100 psig (pounds per square inch gauge). During the tests, line pressure was 40-50 psig, but the volume delivered could not be calculated, because part of the compressor output was vented to keep air from surging in the well and by-passing the water. An estimation of the actual volume of air delivered to the wells can be made from the relationship between percent submergence of the air line and the total lift (Johnson, 1966, p. 389). This was found

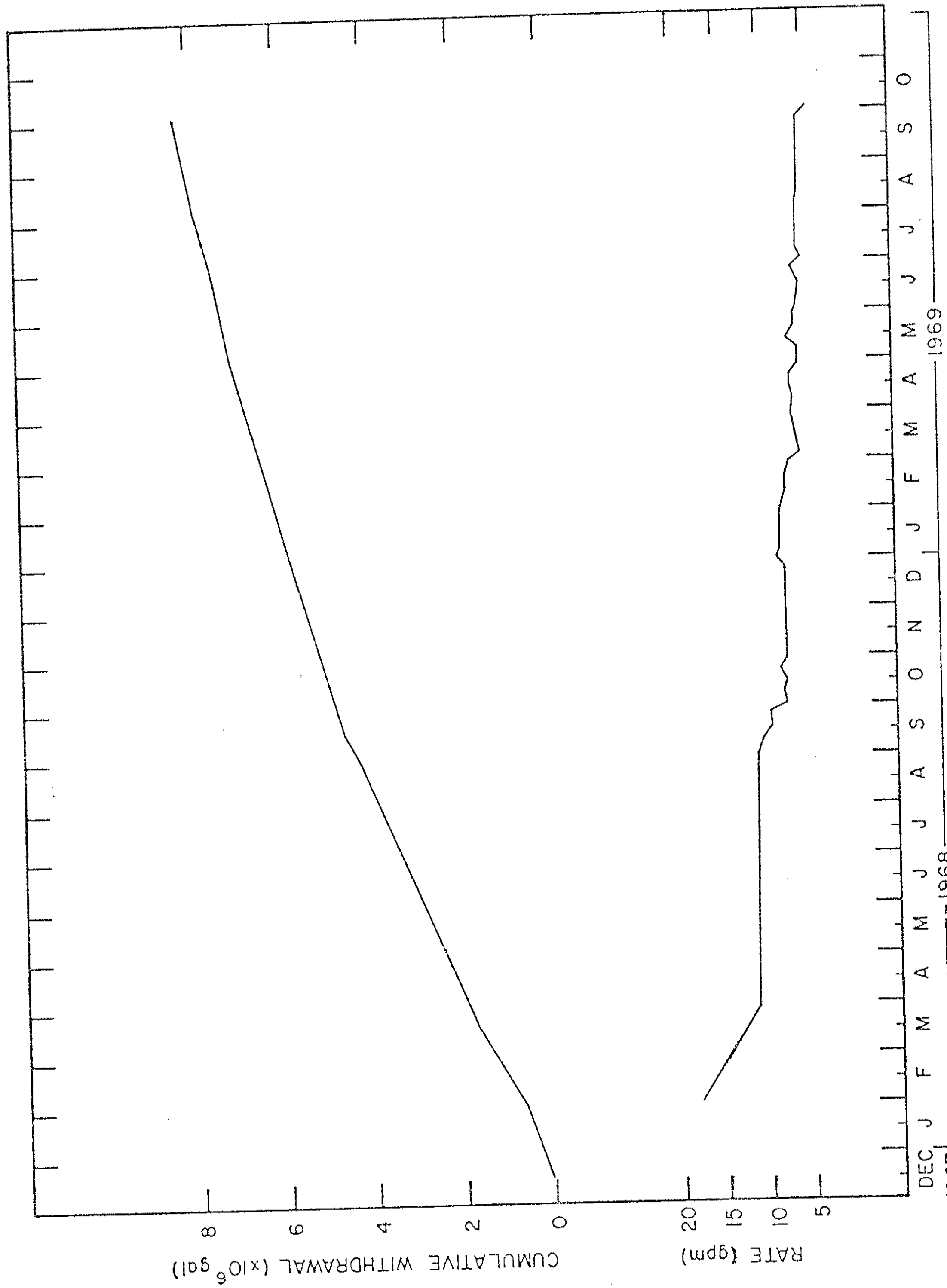


Fig. 12 Flow Rate and Cumulative Discharge,
No. 3 Berkshire

to be approximately 9 cfm, a very low efficiency, as would be expected for this type pump. The eductor pipe was two-inch PVC plastic, to which a one-inch, plastic, external air line was taped. The air line discharged one foot up into the eductor pipe through a one-quarter inch nozzle (Fig. 13). The submergence ratio, the proportion of the total air line that is below water while pumping, was between 51.4% and 56.1% in all tests. This is slightly below the optimum of about 60% (Johnson, 1966, p. 304), which further reduced the pumping efficiency. Discharge was measured at the end of an eight-foot-long wooden sluice box, either with a modified Parshall flume or by the five-gallon-bucket and stop-watch method.

The tests on the No. 1 Young-School Section hole were made with a Peerless Hi-Lift helical pump, serial No. C8007, size 43, having a two and one-half inch column and a one-inch shaft. This pump was powered by a V-belt drive from a gasoline engine having an estimated horesepower between 7.5 and 10. The pump was rated by the manufacturer as follows:

gpm	Head in Feet	HP for Pumping Element	Engine HP
28	600	6.3	10
30	400	4.4	7.5
32	210	2.7	5

The tabulated horsepowers are for electric motors; this figure should be doubled for gasoline engines. Since the pumping lifts in both tests

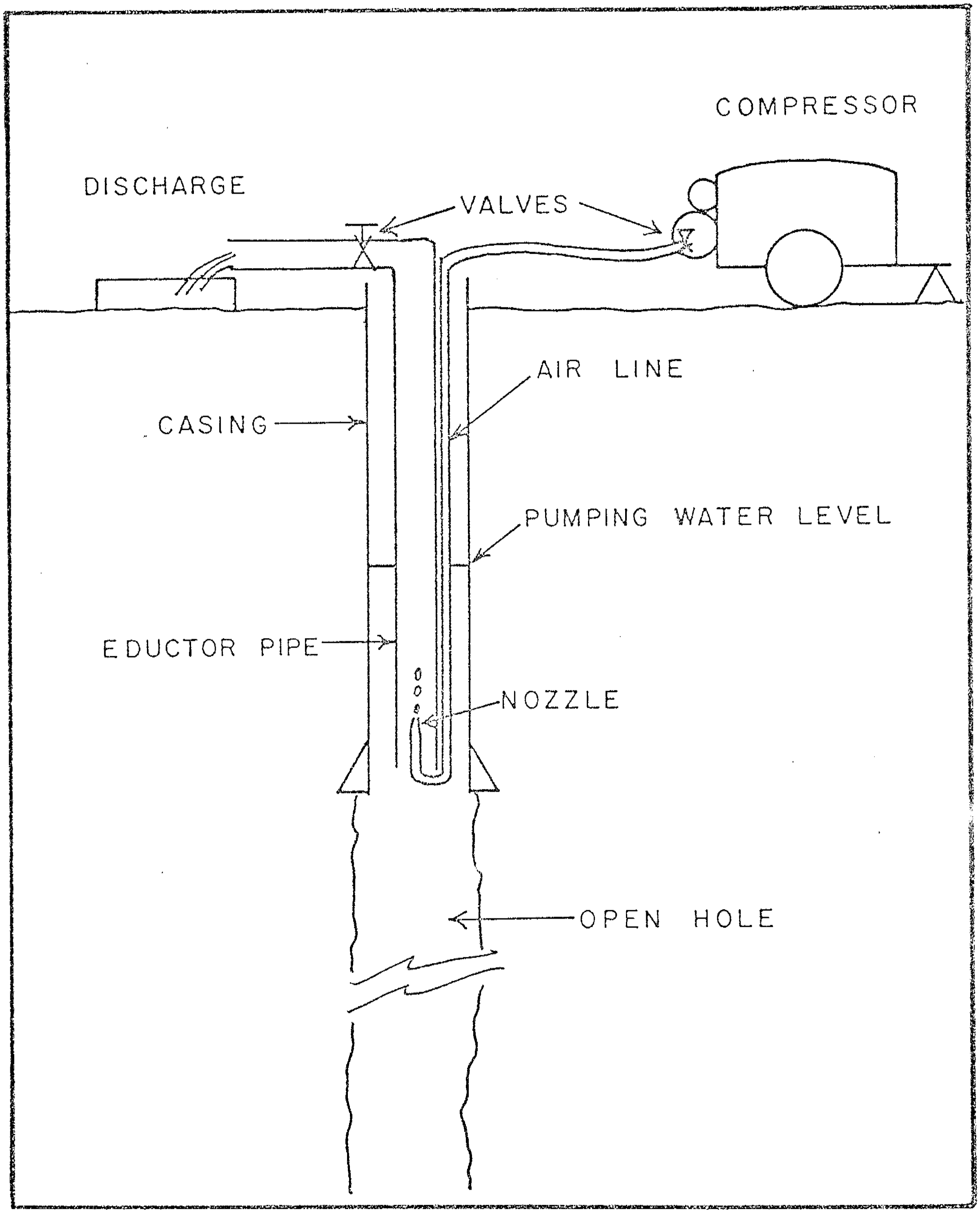


FIG. 13 Schematic Diagram of Air-lift Pump

were 75 feet, the pump and engine were adequate for the tests. The pump and engine were mounted on a jack-supported, two-wheeled, flatbed trailer (Plate II, p. 159). This provided a mobile unit and a fairly stable base for the pump. However, vibration problems developed which, as will be discussed later, terminated the tests before the desired time.

Aquifer Test in No. 1 Berkshire

An air-lift test was run in No. 1 Berkshire on July 18, 1969. The air line and eductor pipe were run to 94.43 feet below the top of casing; the casing terminated 105 feet below ground level. With a pumping water level of 42.52 feet, submergence was

$$\frac{94.43 \text{ feet} - 42.52 \text{ feet}}{94.43 \text{ feet}} = 55\%.$$

The well was pumped 3.5 hours at a discharge rate of 25 gpm. The discharged water was initially very muddy, containing very-fine-grained to fine-grained, light-brown to tan sand and silt. The amount of sediment decreased substantially as pumping continued, but the water was still murky and turbid at the end of the pumping period. Recovery was measured with a tape for one hour, and a Stevens water-level recorder was then re-installed on the well to record long-term recovery. The water level in the well did not recover to the pre-test level but stabilized at a point about 2.4 feet below the pre-test "static" level.

A recovery analysis (Jacob, 1963, p. 283) was made on the test data to determine the transmissivity, T, for the aquifer. The field data and recovery analysis are presented in Tables 5 (p. 110) and 6 (p. 116) and in Figure 14. The relatively low value of 3,420 gallons per day per foot obtained for T is not unreasonable, considering the fine-grained nature of the aquifer sediment in this part of the basin. The figure may be slightly low since the recovery curve suggests that the well behaved as a partially penetrating hole. However, the portion of the curve used to determine T was from the latter part of the recovery period, which corresponds to large values of time in the Theis method of analysis (Theis, 1935, p. 521). In this portion of the time-drawdown curve, effects of partial penetration are not pronounced and the aquifer acts as if the well were fully penetrating; a T-value determined from these data should be fairly reliable (Jacob, 1963, p. 289).

Another factor which may contribute to a low T is the recovery of the well to a level 2.4 feet below pre-test water level. This suggests that the pre-test level may have been higher than the true regional water level, due to partial plugging of the well face because of inadequate well development. This effect was partially eliminated by using the latter part of the recovery curve to determine the value of T.

Aquifer Test in No. 2 Berkshire

An air-lift test was run in No. 2 Berkshire on July 16, 1969. The

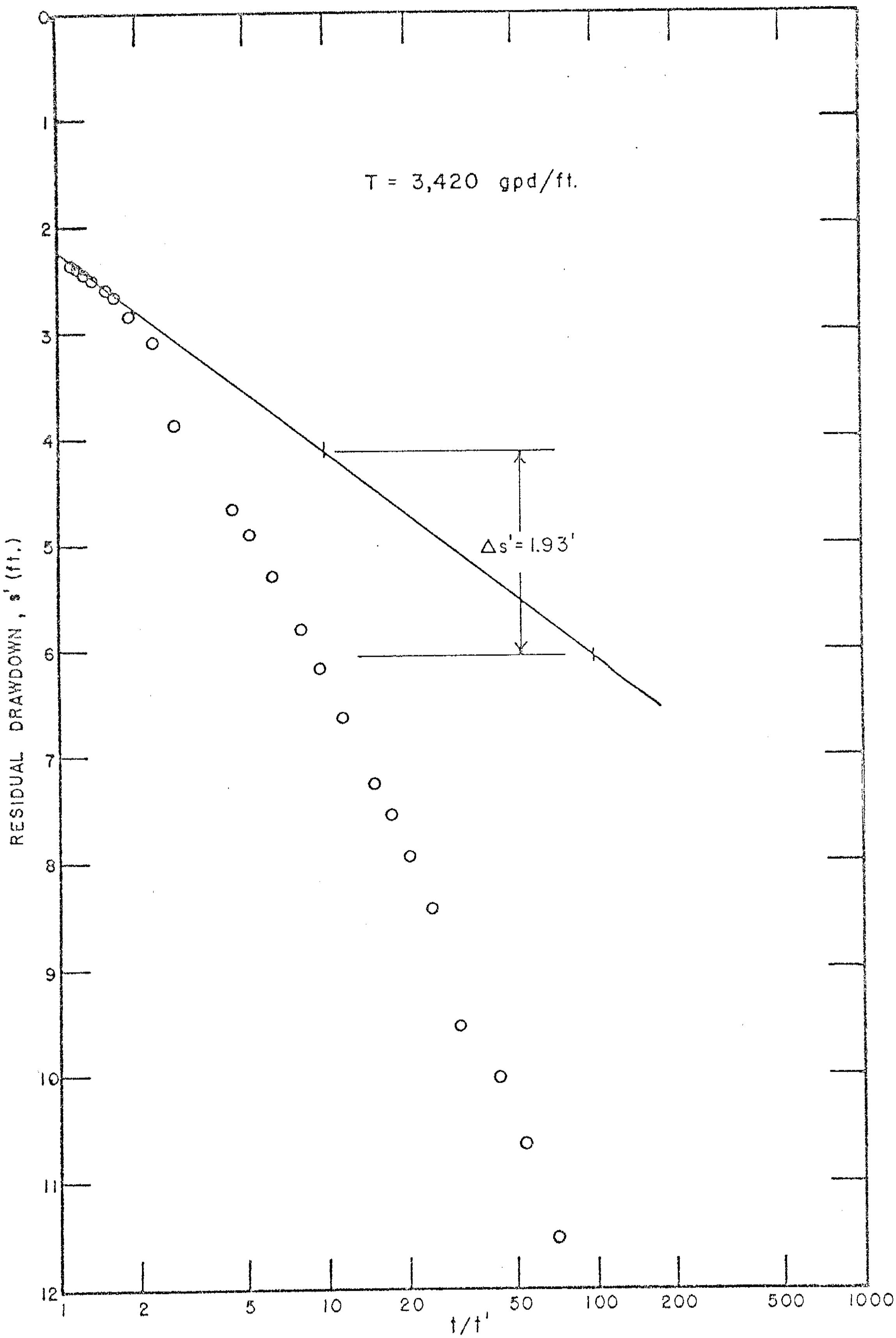


FIG. 14 Recovery Curve, 7-18-69 Test, No. 1 Berkshire

pipe was set at 74.77 feet, 4.73 feet above the bottom of the casing. The pumping level was at about 33.32 feet, resulting in a submergence of

$$\frac{74.77 \text{ feet} - 33.32 \text{ feet}}{74.77 \text{ feet}} = 55.4\%.$$

The well pumped for three hours at an average rate of 15.65 gpm. The discharge was very turbid at the start of the test, but cleared up in 25 to 30 minutes, although it remained slightly murky throughout the test. Recovery was observed for two hours and a Stevens water-level recorder re-installed on the well so that a continuous recovery record was obtained. The level recovered to within 0.3 feet of the pre-test water level.

A recovery analysis was made on the test data (Tables 5 and 6) and the results are presented in Figure 15. The transmissivity of 2,520 gallons per day per foot is of the same order of magnitude as that obtained in the No. 1 Berkshire and probably reflects similar aquifer and well conditions.

Aquifer Test in No. 1 Young-School Section

An air-lift test was conducted in the No. 1 Young-School Section well on July 17, 1969. The eductor pipe was run to 77.81 feet, which was 0.69 feet above the bottom of the casing. The pumping level was 34.1 feet, giving a submergence of

$$\frac{77.81 \text{ feet} - 34.10 \text{ feet}}{77.81 \text{ feet}} = 56.1\%.$$

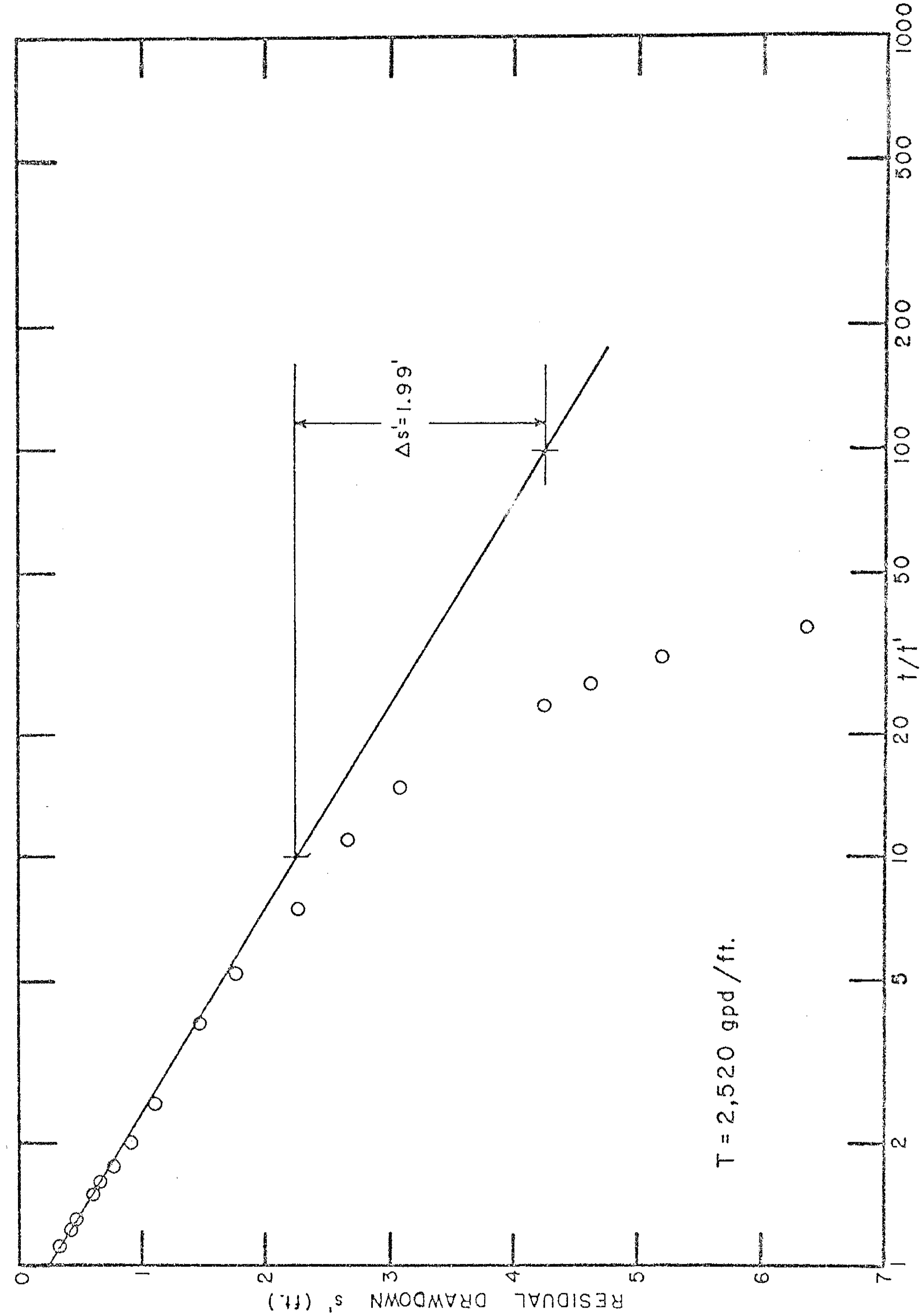


FIG. 15 Recovery Curve, 7-16-69 Test, No. 2 Berkshire

The test ran slightly over two hours and terminated due to engine failure from overheating. The pumping rate was 23 gpm. The discharge was initially murky from orange-tan silt, but the water cleared by the end of the test to a slightly cloudy appearance. Recovery was measured by tape for one hour, after which a Stevens water-level recorder was re-installed so that a continuous recovery record was obtained. It is possible, because of the open-hole completion and the caving tendencies of some of the beds in the well, that the pre-test level, 9.62 feet below the top of the casing, was not a true water level for the entire alluvium section. The well was developed during the test so that more of the alluvium section was open to flow and the post-test water level, 8.64 feet below the top of the casing, more nearly reflects the true regional water level.

A recovery analysis, using the latter part of the curve, was made on the test data and the value of the transmissivity obtained, 4,896 gallons per day per foot, is of the same order-of-magnitude as those obtained in the two previously mentioned tests. The slightly higher value in this well could reflect more favorable aquifer conditions, or, since this well had not been completed as long as the other two wells, it may not have suffered as much caving and fill-up. Therefore, it may effectively penetrate more of the aquifer. This is suggested by the appearance of the discharge in this test as compared with the other tests. The water in this well did not carry as much sediment and cleared up more rapidly than the discharge from either

No. 1 Berkshire or No. 2 Berkshire.

The test data and recovery analysis of this test are presented in Tables 5 and 6 and in Figure 16.

Aquifer Test in No. 4 Berkshire

The final air-lift test made during the field phase of this study was run on the No. 4 Berkshire hole on July 18, 1969. The test lasted only two hours and twenty-five minutes, owing to engine problems. The pumping rate was 23 gpm, with a drawdown of 23.19 feet. The eductor air-lift assembly was set at 47.71 feet, which was 10.65 feet above the bottom of the slotted casing and 7.35 feet above the bottom of the hole. The bottom of the hole was "tagged" at 55.06 feet when running the air-line and eductor pipes, indicating a fill-up of 3.94 feet in slightly more than 14 months. The submergence in this test was

$$\frac{47.71 \text{ feet} - 23.19 \text{ feet}}{47.71 \text{ feet}} = 51.4\%.$$

During the test, drawdown was observed in No. 3 Berkshire, located 322 feet east of the pumped hole and completed in the same part of the medial sand aquifer. Both recovery and interference analyses were made on the data for this test. The data and analyses results are included in Tables 5 and 6 and are summarized in Figures 17, 18, and 19. Values of transmissivity varied from about 4,900 gallons per day per foot, in the air-lift recovery analysis, to more than 13,000 gallons per day per foot from the interference analysis. The

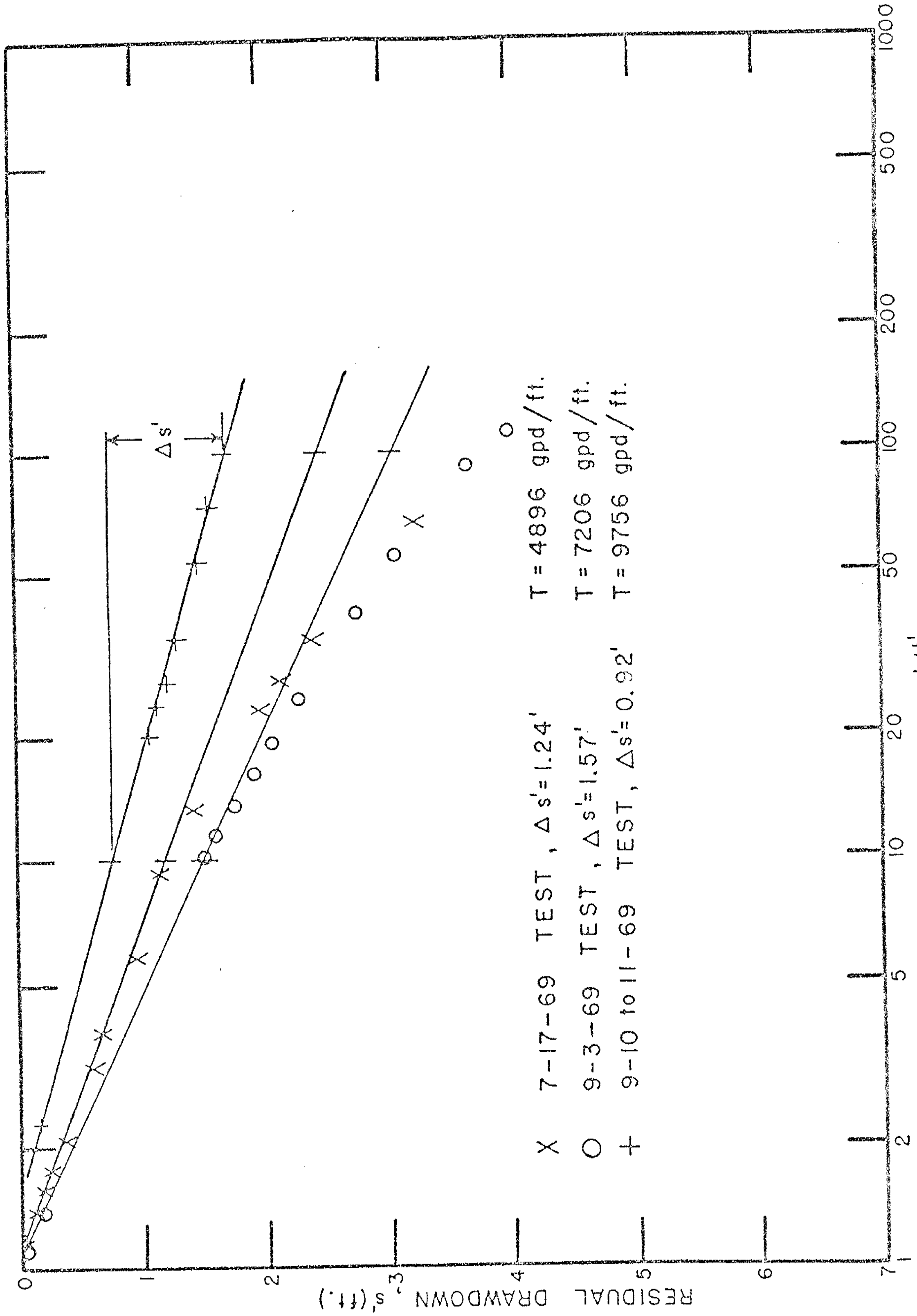


FIG. 16 Recovery Curves, No. I Young-School Section Tests

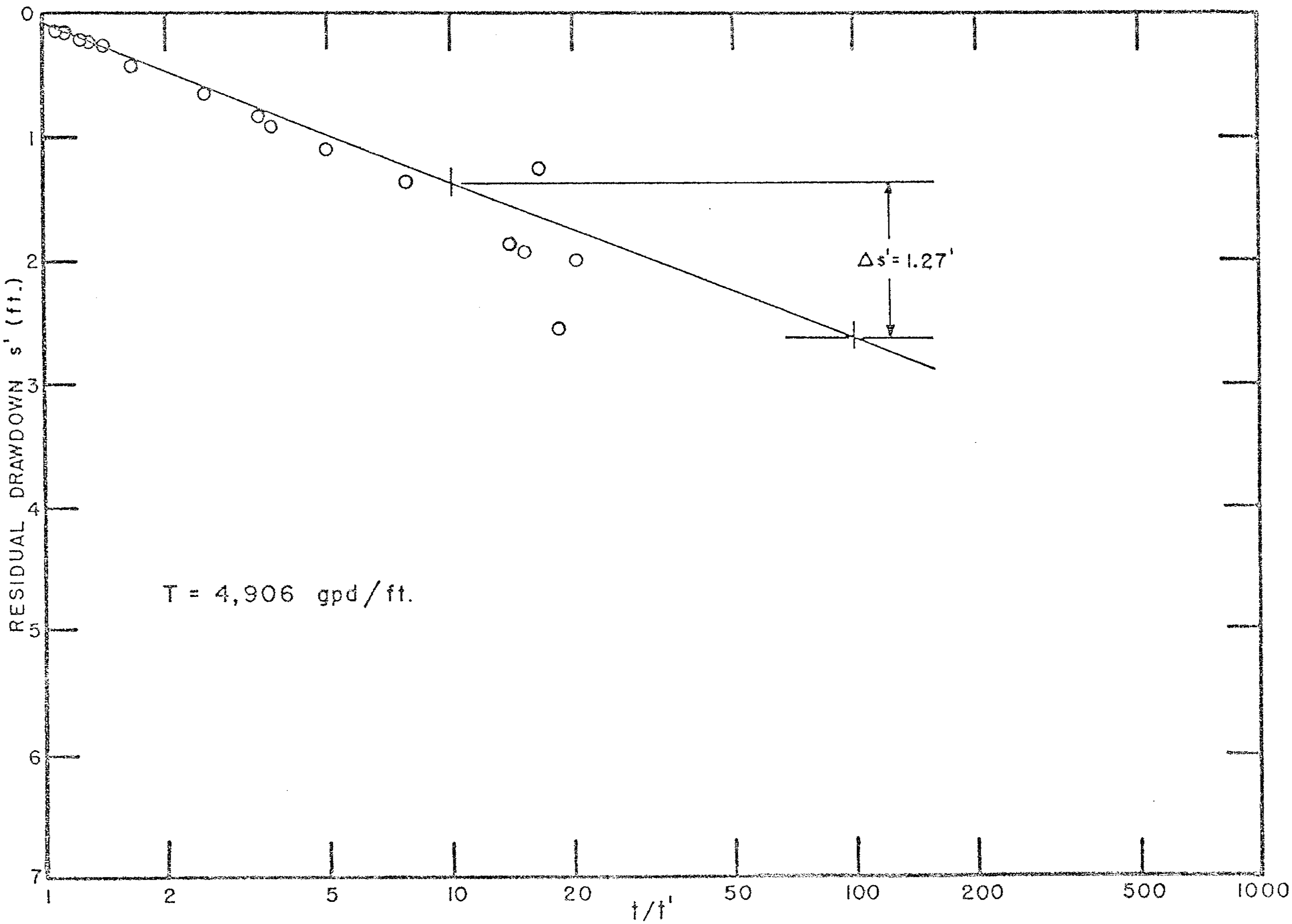


FIG. 17 Recovery Curve, 7-19-69 Test, No. 4 Berkshire

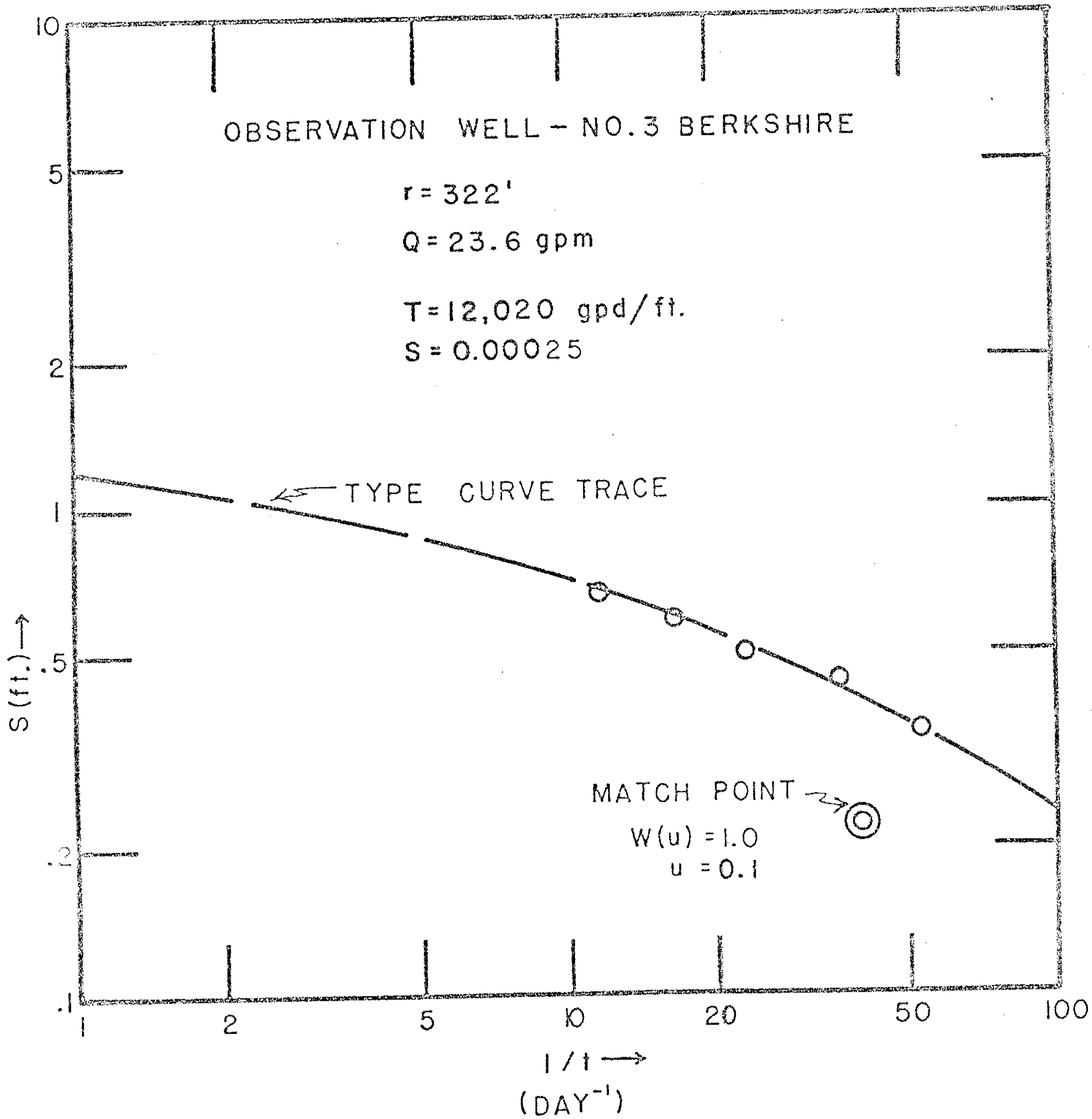


FIG. 18 Theis Interference Analysis, 7-19-69 Test, No.4 Berkshire

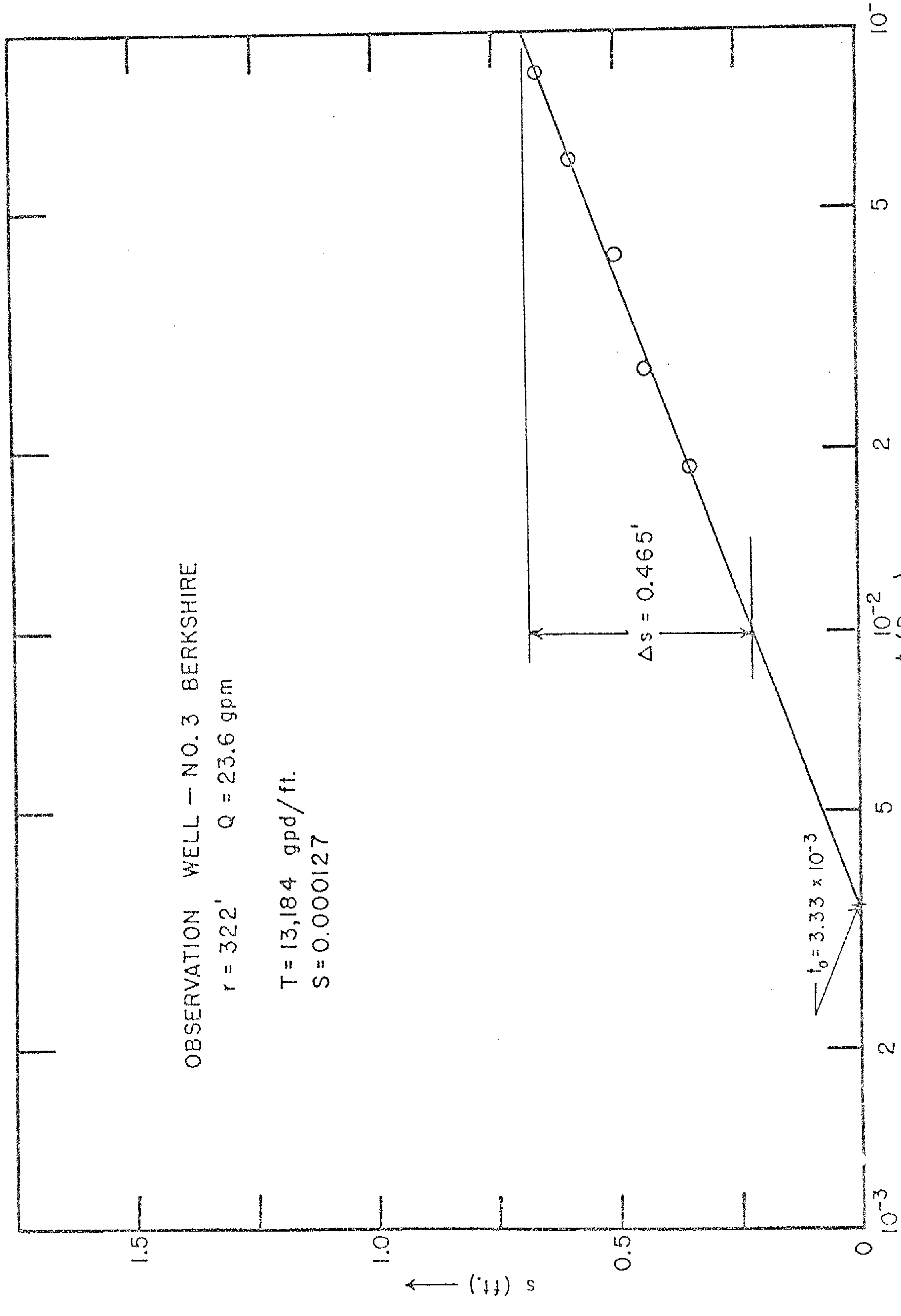


FIG.19 Jacob Analysis, 7-19-69 Test, No.4 Berkshire

lower value is questionable, since the exact time of engine shut-down was not recorded, and all recovery times are in error by being high. This error tends to make the value for t/t' on the recovery plot too low; the resulting steeper curve introduces an error on the low side in the calculation of transmissivity.

The interference data probably yield close to the true value of transmissivity for this aquifer. Some question as to precision could be raised, since the wells do not completely penetrate the aquifer, and this could mean that the transmissivity is somewhat low. In addition, the low-volume, short-duration test may have compounded this effect, but the value obtained is believed to be reasonably accurate.

One effect that has not been considered in these analyses is the anisotropic character of the aquifer. The degree of anisotropy is not known, but, considering the nature of the sediments, the ratio of horizontal to vertical permeability may be high. In the case of a partially penetrating well, any anisotropy correction would tend to increase the value for transmissivity.

The average storage coefficient, 0.00019, obtained from the interference analyses is in the appropriate range for artesian aquifers.

Additional Aquifer Tests on No. 1 Young-School Section

Two tests were conducted in the No. 1 Young-School Section hole using the helical pump. A nine-hour test was run on September 3, 1969, and a 29-hour test on September 10-11, 1969. The pump was set at 75 feet below the top of the casing on both tests. This placed the pump intake about 3.5 feet above the bottom of the casing. Discharge during the first test was steady at 42.85 gpm. In the second test, throttle troubles on the engine varied the discharge between a high of 41.70 gpm and a low of 31.25 gpm. The average over the 29 hours was about 34 gpm. Both tests were terminated prematurely by engine failure caused by excessive vibration that shook parts off the motor in the first test and broke a gas line in the second. The water discharged in both tests cleared up after a short initial murky discharge to a slightly murky condition.

No interference was noted in No. 2 Berkshire, located 4,300 feet southwest of this hole, during the September 3 test. During the September 10-11 test, drawdown was noted in No. 2 Berkshire after No. 1 Young-School Section had been pumping about 12 hours. An interference analysis was made of this latter test data, and recovery analyses were made on the data from both tests. The data and analyses are included in Tables 5 and 6 and the results are shown in Figures 16 and 20.

The transmissivity and storativity values obtained from these analyses are somewhat greater than those determined in the previous test analyses. Transmissivity ranged from about 7,200 to about 11,800 gallons per day per foot, and storativity was 0.00029.

The analyses and summary of the results of all tests are presented in Table 6. The transmissivity values are considered to be

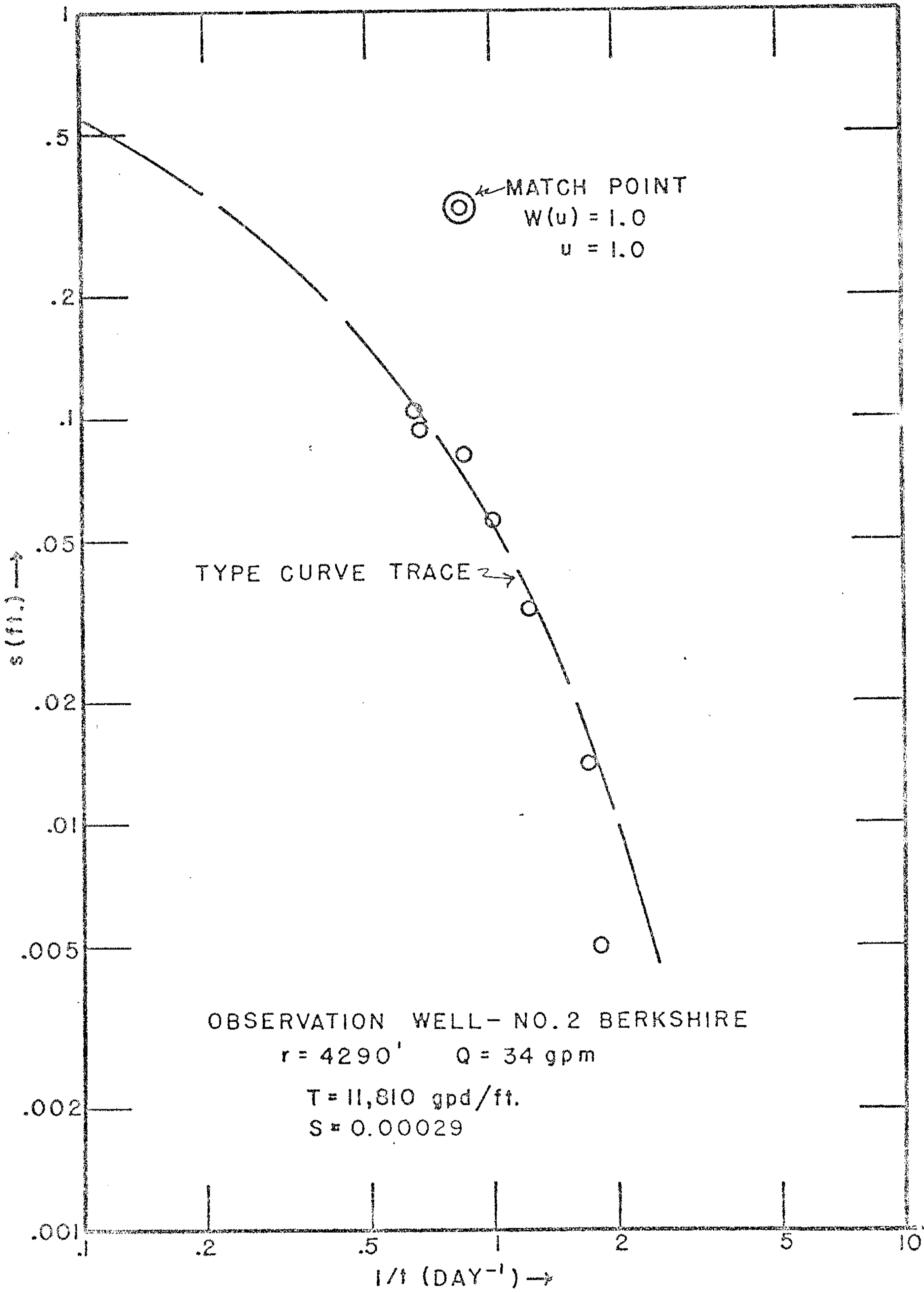


FIG. 20 Theis Interference Analysis, 9-10 to 11-69 Test, No. 1 Young-School Section

gross average values for the aquifers in the immediate vicinity of the test holes. However, the areal coverage of the test holes extends over a considerable portion of the study area and by proper weighting of transmissivity values obtained in the various tests, it is felt that a reliable first approximation of this aquifer parameter is realized. The combined effects of partial penetration, inadequate well development prior to the tests, and aquifer anisotropy that may have influenced well performance would tend to yield low values for transmissivity. All of these factors probably influenced the tests in the deep holes producing from the alluvial unit, to a greater degree than the tests in No. 4 Berkshire producing from the medial sand. This conclusion results from consideration of the following factors: 1) the deep holes are open over much greater lengths, and therefore are more likely to be partially filled by cavings; 2) most values for T in the deep holes were derived from the air-lift pumping in which the holes are known to have been developed during the tests; and 3) the alluvial aquifer, owing to greater lenticularity and sediment textural variation, probably exhibits greater anisotropy. Considering these factors, a transmissivity of 10,000 gallons per day per foot is selected as the best available figure for the alluvium aquifer. This value is heavily weighted to the transmissivity calculated from the final test in No. 1 Young-School Section. It is felt to be more reliable because the No. 1 Young-School Section hole had not been completed as long as the other deep tests and therefore was in better condition. More and longer tests were run in this hole and as a result, it was developed more properly than the No. 1 and No. 2 Berkshire deep tests. The final test in this hole was longer than any other test and sampled a larger portion of the aquifer. This should partially eliminate the effects of partial penetration and aquifer anisotropy and result in a more reliable transmissivity.

For the medial sand aquifer, the average value of transmissivities determined by Theis and Jacob analyses of test data from No. 4 Berkshire is acceptable. This value is 12,600 gallons per day per foot.

Ground Water Inflow Determination

The areas selected for determining the ground water inflow in the alluvium and medial sand aquifers is shown in Figures 6 and 7 respectively. These areas are somewhat arbitrary, but since well control is lacking, particularly north, northeast, and south of the NW Playa, and the pumping test analyses show that transmissivity varies considerably even in the relatively small area tested, it was not considered feasible to extend the calculations over a larger area.

Since the NW Playa and the two small playas south and west of it are the discharge points in the study area, the inflow calculation segment was selected to encompass as much of these playas as could be included with available well control. Admittedly there is inflow from the east and south, but as will be discussed later, this is not large compared to inflow from the west, and is not included in the present determination.

The ground water inflow is determined from a form of Darcy's Law:

$$Q = TIL$$

where Q = inflow in cubic feet per day,

T = transmissivity in cubic feet per day per foot,

I = hydraulic gradient in feet per foot, and

L = width of flow cross section in feet.

The inflow determinations for the aquifers are included in Table 7 (p. 124). They show that 150 acre-feet per year flows eastward to the NW Playa and the small playas south and west of it through the alluvium, and 190 acre-feet per year through the medial sand; hence, a total of 340 acre-feet per year reaches the playa discharge. The only withdrawal in the segment is the flow from No. 3 Berkshire, amounting to an average of 15 acre-feet per year. The stock well shown in the NW$\frac{1}{4}$ Sec. 29, T6N, R9E has been abandoned for several years because of a deterioration of water quality in the well. As mentioned previously, precipitation in the area does not recharge either aquifer. Any infiltration moves directly to the playas through the overlying beds and is discharged there by evaporation. For water budget purposes, the precipitation is considered in the evaporation-discharge portion of the determination.

By planimetering the area of the playas through which discharge occurs, it was determined that the inflow rate of ground water at the playas is equivalent to about 28 inches of water per year.

Determination of Evaporation Discharge

Climatic Conditions

A weather station was established as part of this investigation in the northeast part of Laguna del Perro to obtain climatic parameters for use in determining the evaporation rates from the playa surfaces. This station, Dog Lake North, is located in the SW$\frac{1}{4}$, Sec. 24, T6N, R9E (Fig. 6).

The station is situated about 400 feet from the east shore of the playa on a platform approximately eight inches above the playa surface. The west portion of the platform supported a continuous-recording anemometer and a tilting bucket type recording rain gauge. The recorders were enclosed in a weather-tight shelter on which the anemometer vane and cups and the precipitation gauge collector were mounted. The anemometer cups were situated slightly more than six feet above the playa surface so that in effect wind run at about two meters was recorded.

The east platform held a standard Weather Bureau type louvered shelter in which a meteorograph was housed. This instrument continuously records air temperature, relative humidity, and barometric pressure. Adjacent to the east platform, a stilling well was installed and a Stevens water-level recorder monitored the water level on the playa. About eight feet from the southeast corner of the east platform, three evaporation pans were installed in which weekly evaporation rates of fresh and lake water were measured. In addition, near-surface temperature measurements in the playa sediments were recorded weekly. A general view of the station is shown in Plate III (p. 160) and close-up views of the various instruments are shown in Plate IV (p. 161).

Dog Lake North Station is located about three miles east of the NW Playa study area for which the water budget was determined. Climatic conditions in both places are quite similar, with the only difference being the amount of rain received from any given shower. Total precipitation at both playas is not thought to be significantly different. Precipitation in the playa area causes ponds to accumulate in the playas. During most of the field investigation, weekly observations of the presence and the estimated size of any surface pools in the playas were made. For most of the period of record, when surface pools were present in the north end of Laguna del Perro there was a pool present in the NW Playa and the small playas south and west of it. The principal effect of these surface pools on microclimatic factors is to increase humidity. The humidity recorded at Dog Lake North probably did not differ drastically from conditions in the NW Playa.

Playa Conditions Affecting Evaporation

Evaporative discharge of the ground water is affected to varying degrees by several factors. The presence of a surface pool on the playa should not decrease the ground water discharge, since the pools are never deep enough to overcome the head in the two aquifers. Maximum pool depths noted during the two and one-half year field investigation was nine inches, recorded at Dog Lake North Station after the August, 1967 flood. In the study area playas, maximum depth probably did not exceed six inches. These pools, moreover, did not last for any great length of time. They probably contributed to a temporary increase in the evaporation rate, however, since these pools were formed by precipitation and storm runoff, and their salinity, initially, was lower than that of the ground water inflow. In time, the runoff water dissolves the salt crust on the playa, increasing its salinity, which reduces the evaporation rate. The time period for evaporative disappearance of the pool is thus lengthened.

Another factor which affects the evaporation rate is the salt crust. This reduces the rate of evaporation of the ever-present interstitial water, owing to the higher reflective power of the salt relative to that of water (Titus, 1969, p. 128).

The vertical movement of ground water in the central moist areas of the playas is mostly through vents, not through the relatively impermeable sediments (Titus, 1969, p. 123). The water table is thought to be minutely concave, with a small gradient towards center in a "halo" zone surrounding the salt encrusted central area. This "halo" zone, in which the sediment surface slopes toward the playa center, may exist in part because of the sloping water table, which holds the sediment in place by wetting it. The ground water rise in this zone is also abetted by capillarity, which tends to increase the evaporation rate in this crust-free zone. Precipitated salt from evaporation in the "halo" zone is periodically washed into the area of the central pool by rain-water. In the central free-water area, ground water flow is not aided by capillarity, and water salinity is higher; hence, evaporation rates are lower than in the surrounding "halo".

Methods of Determining Evaporation

Numerous methods have been advanced by meteorologists, agriculturalists, soil scientists, hydrologists, and others for the determination of evaporation from bodies of water and for the determination of evapotranspiration by native vegetation and croplands. In this study, several of the methods are compared, and correction factors are chosen that allow the techniques to be applied to the special environment of the moist playa. Most of the schemes have proposed an empirical expression for the particular area and environment for which they were developed (see for example: Lee, 1927; Penman, 1940; Gatewood et al, 1950; Thornthwaite and Mather, 1957; Blaney and Criddle, 1962). Several attempts have been made to extend some of these limited formulas, and by prudent application, make them of more general use. Two have found wide use, especially in the determination of consumptive use and evapotranspiration investigations. These are the Thornthwaite method of determining the potential evapotranspiration for an area, and the Blaney-Criddle technique for the determination of consumptive use by crops. Recently, Cruff and Thompson (1967) made a comparison of several methods of estimating potential evapotranspiration from climatological data. Their evaluations include the Thornthwaite method and the Blaney-Criddle method. They compared the different methods with adjusted pan evaporation, a standard parameter that is measured at numerous weather stations throughout the country. They found that the results predicted by the several techniques varied considerably, which is to be expected considering that the methods use, or emphasize, different factors, and were developed for different environments.

The Thornthwaite method was found to underestimate the adjusted pan evaporation by 25 to 60 percent. When it is noted that this technique was developed in the humid northeastern part of the United States, and that the Cruff and Thompson comparison was made in arid and subhumid environments, part of this discrepancy can be explained. The Thornthwaite method, however, needs a minimum of climatic data, and if applied with discretion, can be useful in obtaining a first approximation of the potential evapotranspiration. This method was one of those used to determine the evaporative discharge potential for the playa area. A correction factor, based on the differences found by Cruff and Thompson (1967), has been applied in this study to obtain greater accuracy.

The Blaney-Criddle method was found by Cruff and Thompson to be most nearly in agreement with the adjusted pan evaporation for the sites studied, differing by a median of 11 percent. The key to the Blaney-Criddle determination is their K factor (consumptive-use coefficient). By considering all parameters and judiciously selecting the K factor, reliable potential evapotranspiration values can be obtained. The Blaney-Criddle formula was used in this study using a K value of 0.64 which is based on several values reported in the literature as being applicable to environments similar to the Estancia playas, and modified to fit the Estancia playa conditions. The adjusted Thornthwaite and the Blaney-Criddle evaporation values determined for this study agree rather closely.

These two methods were originally developed for use in agricultural environments and for determining evapotranspiration from land surfaces. Evaporation from bodies of water has been of concern to other investigators including Langbein (1961) and Harbeck et al (1954). The evaporation occurring in the Estancia playas is essentially evaporation from a continuously moist land surface. When the shallow runoff pools cover parts of the playa depressions, open water evaporation does occur, but it is of relatively short duration, and involves water that is not part of the ground water inflow. The shallow nature of the pools creates a condition which is different from that of normal lake evaporation, and this, coupled with the high salinity of the water present in Estancia playas, suggests that the evaporation from the playa ponds can be considered to be more nearly like evaporation from land surfaces.

Thornthwaite Method. Using a technique described by Hantush (1959, p. 4), the Thornthwaite formula is given by the following set of equations:

$$i = (T_m/5)^{1.514} ,$$

$$I = \sum_{n=1}^{12} i_n ,$$

$$a = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + 0.49 ,$$

$$UPE = 1.6(10T/I)^a ,$$

$$PE = (b/30)UPE ,$$

where

T_m = mean monthly temperature in $^\circ C$,

i = a monthly heat index, a function of T_m (tabulated in Thornthwaite and Mather, 1957; and Hantush, 1959),

i_n = the value of i for any particular month,

I = the annual heat index, the sum of the monthly heat index values,

a = an empirical exponent dependent on I (tabulated in Thornthwaite and Mather, 1957; and Hantush, 1959),

T = mean temperature for the chosen period in $^\circ C$ (daily, monthly, annual, etc.),

UPE = monthly unadjusted potential evapotranspiration in cm (30 day month of 12 possible sunshine hour days),

PE = monthly potential evapotranspiration in cm,

b = adjustment factor for duration of sunshine for the month and latitude expressed in terms of a 12-hour day (tabulated in Thornthwaite and Mather, 1957, and Hantush, 1959).

Using these equations and the monthly temperatures as recorded at Dog Lake North Station, potential evapotranspiration was calculated for the years 1967, 1968, and 1969. Temperatures for the portions of 1967 and 1969 when no values were recorded at Dog Lake North Station were estimated using records of the Estancia weather station. The computations and results are presented in Table 8 (p. 126).

The values of potential evaporation as determined by this method are probably low and should be corrected upwards. Part of this error is due to the assumption by Thornthwaite that evapotranspiration ceases when average temperatures are below freezing. This is not the case in the environment at the Estancia playas. Above-freezing temperatures were recorded during part of almost every day at Dog Lake North, and evaporation did occur. In addition, the saline water in the playa does not freeze, and although some of the incoming radiation is used to raise the saline water temperature to a higher level before evaporation starts (Harbeck, 1955), some evaporation does occur. This means that the evaporation in the colder months is under-estimated, and an upward revision of the annual figure is required.

Comparing the climatic conditions at Dog Lake North with those reported by Cruff and Thompson (1967), a 50 percent increase, called an environmental adjustment was applied to the PE values at Dog Lake. Cruff and Thompson found that the values of PE determined by the Thornthwaite method averaged 30 to 35 percent low for the types of climates they investigated. Cruff and Thompson's environments were classed as subhumid and modified arid. The Dog Lake North environment is interpreted to be more similar to a semiarid or arid type environment, having lower temperatures, stronger winds, intermediate precipitation, and generally lower humidity than the environments of Cruff and Thompson. Cruff and Thompson reported some PE values for an arid climate, but did not use them in their analysis as control data were considered inadequate. The Thornthwaite method values that they reported for this environment were from 40 to 70 percent lower than their comparison standard. As the Dog Lake North environment is considered to be something between the subhumid-modified arid and arid of Cruff and Thompson, an environmental correction factor of 50 percent was used on the PE values obtained there.

Two additional corrections must be applied to the Thornthwaite values to account for the salinity at Dog Lake North and for the adjustment from open water to bare ground evaporation. Cruff and Thompson

(1957) made a comparison between potential evapotranspiration and lake (open-water) evaporation. At Dog Lake North, evaporation is primarily from open, bare, moist ground, and as such, should be reduced by some factor. Penman (1948, p. 137) states that,

> "... the evaporation rate from a freshly wetted bare soil will be about 90% of that from an open water surface exposed to the same weather."

Harbeck (1955) and Lee (1927) found that an approximate straight-line relationship existed between salinity increase and evaporation rate reduction for concentrations up to 300,000 ppm (parts per million). They reported that evaporation rates were reduced by about one percent for a salinity increase of 10,000 ppm. Analyses of playa waters from the study area (Table 11, p. 139) show an average dissolved-solids content of about 250,000 ppm, suggesting that a 25 percent salinity reduction should be applied to the evaporation rate, based on Lee's and Harbeck's criterion above. This was adjusted to 20 percent for this study on the basis of the chemical composition of the Estancia playa water as compared to those reported by Harbeck (1955) and Lee (1927). This choice is also substantiated by a study made by Moore and Runkles (1968). Combining the lake-to-ground and salinity corrections, and other environment adjustments, the calculated PE values were adjusted by a factor of 1.08, obtained by multiplying the lake-to-ground correction (0.90) by the salinity correction (0.80) by the environmental adjustment (1.50), i.e.,

$$0.90 \times 0.80 \times 1.50 = 1.08.$$

The corrected values for the Thornthwaite calculations are:

Year	Evaporation cm	Evaporation inches
1967	72.94	28.71
1968	67.20	26.46
1969	67.81	26.70
Average	69.32	27.29

Blaney-Criddle Determination. The Blaney-Criddle method of estimating potential evapotranspiration or consumptive water use is based on the assumption that temperature is the most important climatic factor affecting evaporation. For long-term periods, temperature is a good measure of solar radiation, which is a fundamental factor in evaporation (Blaney and Criddle, 1962). Humidity and wind movement are also important, and this method takes these into account in the consumptive-use crop coefficient, K. This empirical coefficient is selected for a particular area on the basis of experiment or experience. The consumptive-use formula is given by:

$$U = KF = \sum_{n=1}^{12} kf \, ,$$

where

$f = p \frac{45.7t + 813}{100}$ = monthly consumptive use factor,

p = monthly percentage of daytime hours of the year, based on latitude (tabulated in Blaney and Criddle, 1962),

t = mean monthly temperature in ^{o}C,

k = monthly empirical consumptive-use coefficient,

U = seasonal or annual evaporation in mm,

F = sum of monthly consumptive-use factors for the year, or other period of consideration,

K = empirical consumptive-use coefficient.

In this study, the coefficient, K, is more properly called an evaporation coefficient, since evaporation is from a vegetation-free area. As K here is dependent on certain factors in addition to temperature, the adjustments for playas herein applied to the Thornthwaite method are incorporated into this empirical coefficient. Cruff and Thompson (1967, p. 22) found that Blaney-Criddle method underestimates adjusted pan (open water) evaporation by 11 percent. The underestimation is compensated in this application by the 10 percent adjustment of Penman (1940, p. 137) from open water to bare ground, so that no correction is needed here for these two factors. The 20 percent reduction for saline water still applies. To account for the other climatic factors, a 0.80 value for K, suggested for the type of climate at Dog Lake North, is used (Cruff and Thompson, 1967, p.16). Combining these, 0.80 X 0.80, 0.64 is obtained as the evaporation coefficient for use in this determination. The calculations and results for this method are presented in Table 8. The final results for the three years investigated are:

Year	Evaporation	
	cm	inches
1967	89.20	35.12
1968	83.19	32.75
1969	84.03	33.08
Average	85.47	33.65

Pan Evaporation Measured at Dog Lake North. Three non-standard evaporation pans were installed at the Dog Lake North Station in June, 1967. The pans were 16.5 inches in diameter by 8.5 inches deep (41.91 cm in diameter and 21.59 cm deep). Two of the pans were stainless steel and the third was new sheet steel. They were set about two inches into the soft playa floor, and playa sediment was placed around the sides so that in effect they were sunken land pans. Figure 21 is a diagrammatic sketch of the installation. A photograph of the installation is shown on Plate III (p. 160). The pans were located about eight feet southeast of the station platform, in such a position that they were shadow-free. The pans were filled as follows:

west pan---lake brine, pan periodically cleaned of salt accumulation, especially that which formed around the rim of the pan above the water;

center pan---fresh water from Socorro, New Mexico water system. This pan was flooded several times by playa water (as were the others), and probably received salt spray. If left uncleaned for

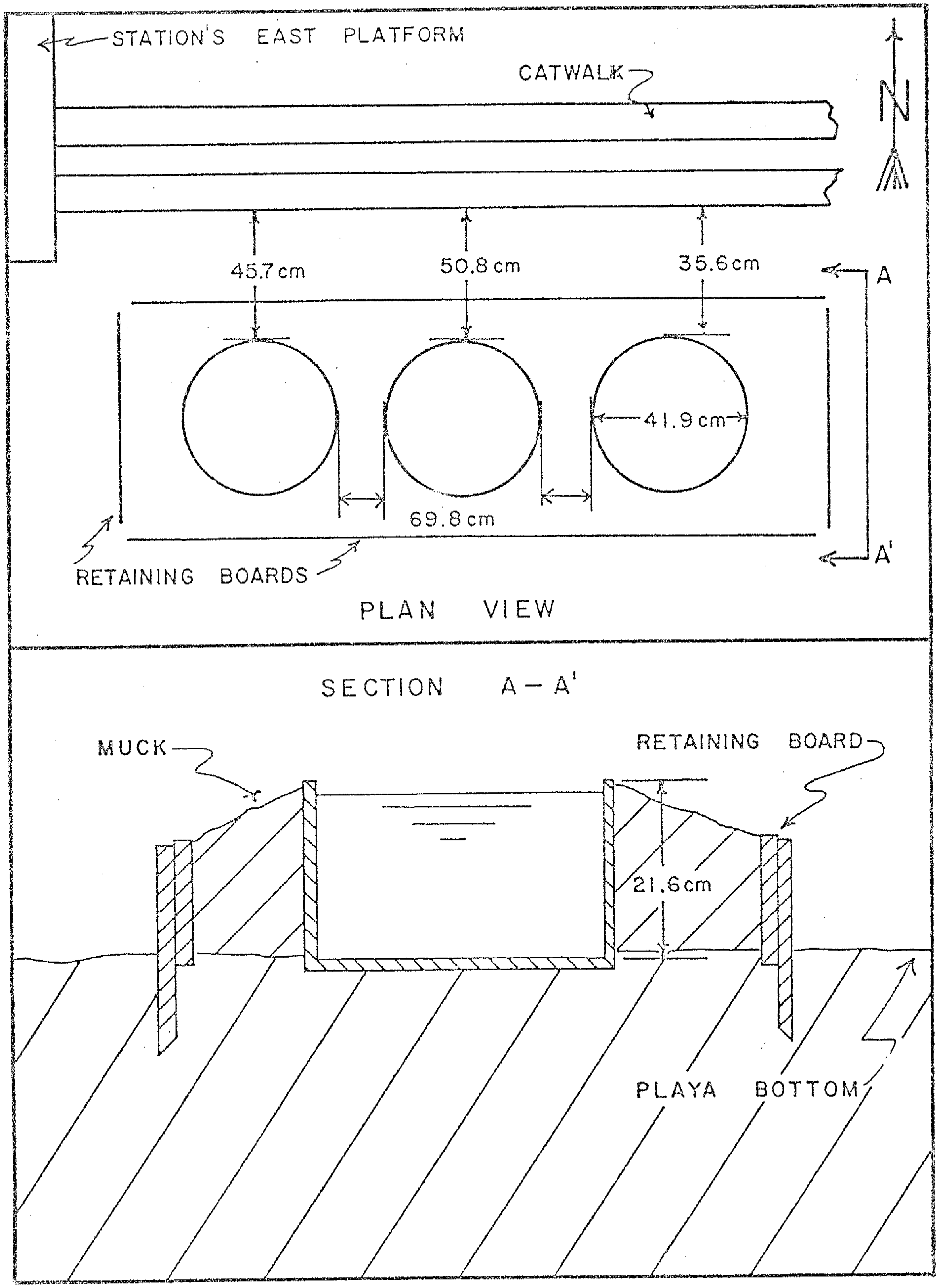


FIG. 21 Schematic Diagram of Evaporation Pans at Dog Lake North Station

excessive lengths of time, the water supported brine shrimp. This phenomenon was not noted in the other pans;

east pan---lake brine, not cleaned of salt except on two occasions when the pan became completely filled with salt.

The weekly change in water level in each pan was used as an indication of evaporation. Because change of stage in the pan containing salt at the surface could not be related to volume of evaporation, the record of the east (uncleaned, lake brine) pan is not quantitatively useful.

By plotting evaporation for the fresh-water pan versus the pan evaporation for the Estancia weather station, a ratio of 0.64 was obtained (Fig. 22). A plot of the cleaned lake-brine pan evaporation versus the fresh-water evaporation showed a more complex relationship (Fig. 23). Two apparently linear relationships could be selected from the plot. For lower evaporation rates, below 200 mm fresh water per month and 150 mm brine per month, a ratio of brine evaporation to fresh-water evaporation of 0.80 was obtained. At higher evaporation rates, a ratio of 0.51 was obtained. The difference in ratios may be explained as follows. Higher evaporation rates occur in the summer, when playa brine used to fill the brine pan is more concentrated. The fresh water has a proportionately higher evaporation rate than the brine during this period, so that the ratio is lower.

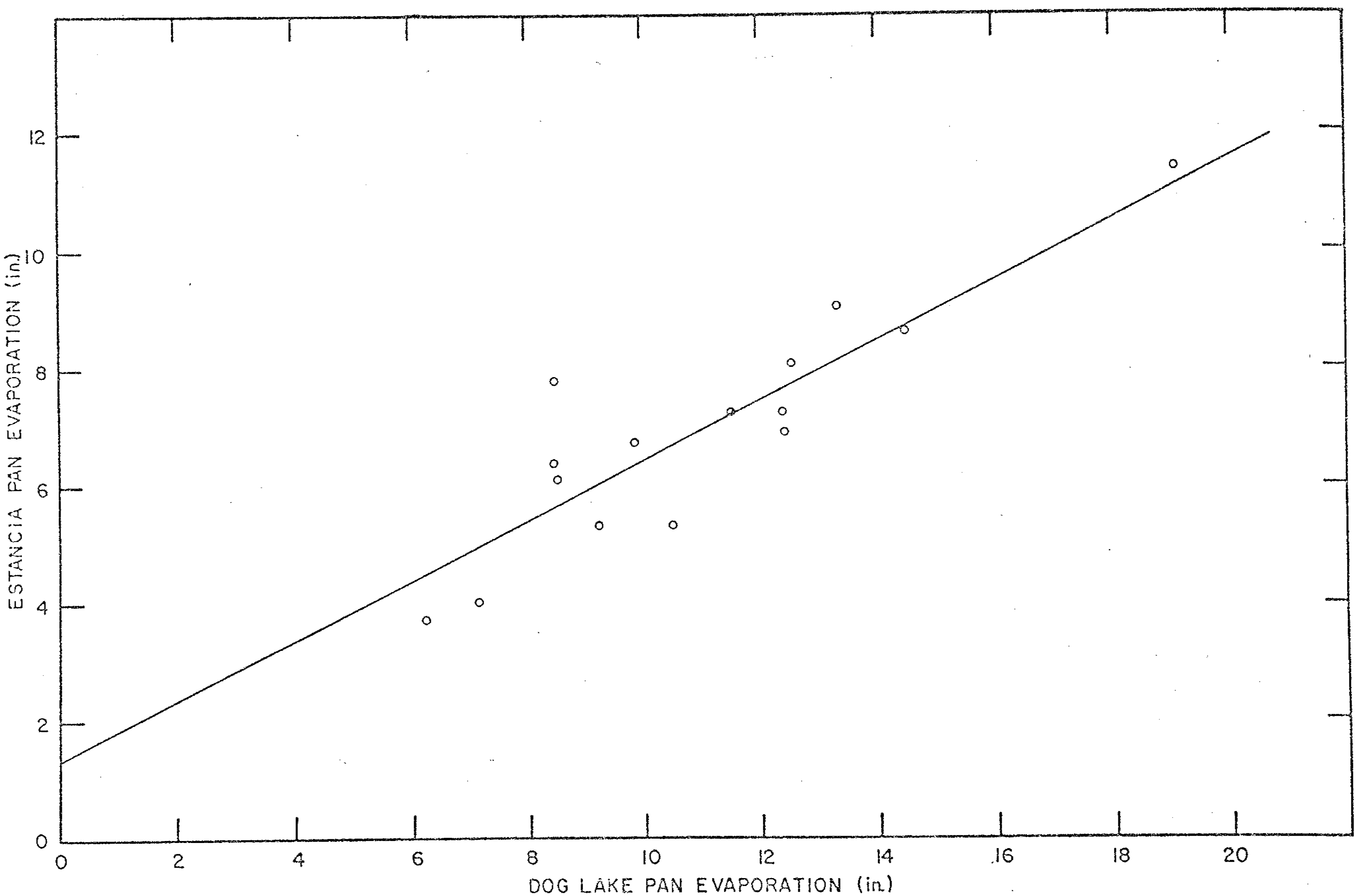


Fig. 22 Estancia Pan Evaporation vs. Dog Lake North Fresh Pan Evaporation

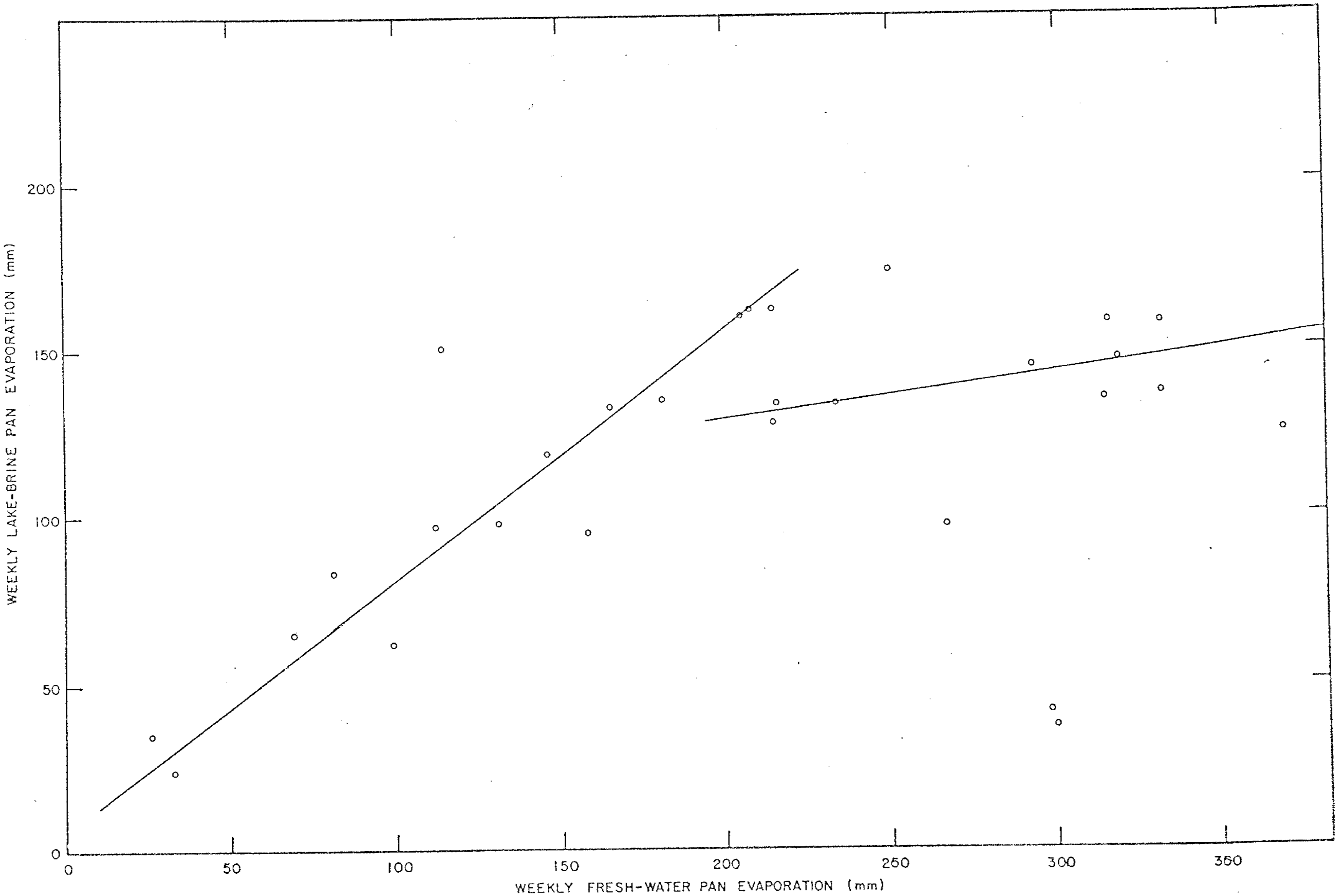


FIG. 23 Plot of Dog Lake North Pan Evaporation, Fresh-Water vs. Lake-Brine

The ratios were determined in order to obtain an estimate of evaporation from the salt-free areas around the edges of the playas. A technique used by Gatewood et al (1950, p. 47) in a water-use investigation in the Lower Safford Valley, Arizona suggested a method by which evaporation from the salt-free flats could be related to evaporation from the brine pan. These investigators assumed that the relationship between evaporation from a sunken, bare (no vegetation) soil tank and evaporation from wet sand bars along a river was the same as the known relationship between evaporation from a sunken land pan and that from a reservoir. An analogous relationship can be devised at the Estancia playas.

The technique proposed here is based on use of coefficients that, first, relate Weather Bureau standard-pan evaporation to open-water evaporation, and, second, relate open-water evaporation to evaporation from moist soil. Inasmuch as the water that evaporates from salt-free areas around the playas is highly saline, and furthermore the salinity presumably fluctuates seasonally, much as does the salinity of water in the brine evaporation pan, it is appropriate to relate evaporation from the moist sediment to the measured rate in the brine pan. The published coefficients cannot be applied directly to the brine pan at the Dog Lake North Station because of its non-standard design. The technique devised is as follows. A factor is obtained that relates evaporation from the Estancia Weather Bureau pan to that from the Dog Lake North brine pan, by dividing the ratio (Estancia Weather

Bureau pan)/(Dog Lake North fresh pan) by the ratio (Dog Lake North brine)/(Dog Lake North fresh). There are two values for the ratio of Dog Lake (brine)/(fresh) as noted above, one for the warmer, drier months and one for the cooler months. The resulting factors are:

warm-month factor 0.60/0.50 = 1.20

cool-month factor 0.60/0.80 = 0.75.

(The ratio between the Estancia Weather Bureau pan and the Dog Lake North fresh pan was lowered to 0.60 from the value 0.64 mentioned previously to adjust for a lower evaporation rate assumed for the Dog Lake North pan owing to intermittent salt contamination in the pan.) The two factors are then multiplied by the product (0.63) of the accepted coefficient (Kohler et al., 1955, p. 17) for converting from Weather Bureau pans to open water evaporation (0.70) times Penman's (1940, p. 137) open water to land surface coefficient (0.90). The final factors for converting from the Dog Lake North brine pan to salt-free shore areas are:

warm months	1.20 X 0.63	=	0.75
cool months	0.75 X 0.63	=	0.47.

Table 12 (p. 142) lists the monthly estimates of evaporation rate for the salt-free areas as determined from the recorded brine pan evaporation rates at Dog Lake North Station. The average annual evaporation from the moist sediment was calculated to be 37.29 inches (94.71 cm).

Harbeck-Shjeflo Determination of Evaporation. Harbeck (1962) reported on a method for calculating reservoir evaporation using mass-transfer theory. The mass-transfer method relates the exchange of water vapor between a water surface and the atmosphere to such parameters as air and water temperature, humidity, and wind speed. The relationships are developed into a quasi-empirical equation that includes a coefficient of proportionality called the mass-transfer coefficient. For a description of the theory, see Marciano and Harbeck (1954). A general expression for the mass-transfer equation is given by Harbeck (1962):

$$E = Nu(e_o - e_a)$$

where

E = evaporation in inches per day,

N = the mass-transfer coefficient,

u = wind speed in miles per hour at a fixed height above the surface,

e_o = saturation vapor pressure in millibars, corresponding to the temperature of the water surface, and

e_a = vapor pressure of the air in millibars.

The mass-transfer coefficient combines many variables that are not directly measured, such as variation of wind with height, size of the surface, stability of the atmosphere, barometric pressure, and density and viscosity of the air. These factors can be combined into lengthy mathematical expressions (Harbeck, 1962) which defy direct solution. As such, they are not of practical use in field determinations of evaporation. Harbeck adopted a technique to evaluate the mass-transfer coefficient that was first described by Langbein et al. (1951) for measuring evaporation and seepage losses from small lakes and reservoirs. The basic assumptions of the method are, 1) that during periods of neither surface inflow nor outflow, the fall in reservoir stage is composed of two parts, evaporation and seepage; and 2) when the product $u(e_o - e_a)$ is zero, evaporation is negligible. By restricting the analysis to periods of no surface inflow or outflow, the first assumption is satisfied. The second assumption is reasonable because, if $(e_o - e_a)$ is zero, the air is saturated and evaporation is negligible (Harbeck, 1962); or if u is zero, evaporation proceeds only by the extremely slow process of molecular diffusion. As Marciano and Harbeck showed (1954, p. 61), even with convection resulting from substantial differences between air and surface temperatures, if there is no wind, evaporation is quite small.

This method is relatively easy to use and adapts very well to conditions at the Dog Lake North Station. All the necessary parameters were recorded at the station, i. e., wind run at two meters, air temperature, humidity, surface temperature, precipitation, and lake stage or ground water level. The usual procedure is to compute the vapor pressure difference from vapor pressure tables for the temperatures of the air and the surface, (either water or moist sand), compute the wind speed from the wind run for the time period in question, and then to plot the product $u(e_o - e_a)$ versus change in water level for the period under consideration. Periods of rainfall are not considered, so that the water level changes reflect only seepage and/or evaporation. The plot produces two kinds of information: 1) the slope of the line is the mass-transfer coefficient N; and 2) because seepage is considered to be constant, the value of ΔH at the Y intercept gives rate of seepage, or ground water inflow to the playa. Evaporation is then calculated from

$$E = Nu(e_o - e_a).$$

Shjeflo (1968) utilized this method to study the evapotranspiration and water budget of prairie potholes in North Dakota. The method of calculation used in the present study is based on procedures developed by him, modified to handle unique conditions encountered in the Estancia playas. Because of the large amount of data and the lengthy, repetitive calculations, a computer program was developed to process and reduce the data. This program is included in the Appendix (p. 150). It is actually several subprograms designed to handle particular phases of the data reduction, rather than one master program into which the raw data is fed and the finished product, evaporation, is produced. The first part of the program is a time correction that was applied to the field data to compensate for time that was lost or gained by the clocks of the various recorders. Another part computes $(e_o - e_a)$ values from the raw temperature and humidity data, and the rest of the program computes $u(e_o - e_a)$, N, and evaporation, E.

Unique conditions for which adjustments were added in this study were the salinity correction for the vapor pressure values, and the determination of proper surface temperatures, since only air temperature was continuously recorded.

The surface temperature was obtained from the relationship found in fitting a line through the plot of the weekly measurements of the air and water temperatures. The water temperature was recorded when measurable water was present at the station. This relationship is (Fig. 24):

$$T_w = 0.9725 \ T_a + 0.8$$

where

T_w = water temperature, ^{o}C, and

T_a = air temperature, ^{o}C.

In order to determine whether the temperature of the playa sediment surface differs appreciably from the water temperature, plots of the near-surface temperature gradients in the sediment at the Dog Lake North Station were made (Fig. 25). In the absence of a surface pool, two conditions were observed for the playa surface: 1) bare wet sand with little or no salt crust; and 2) salt crust either thin and wet or thick and dry. The temperature gradient plots show that in the absence of a salt crust, the surface temperature was very close to the air temperature. When a thin, damp crust was present, the surface temperature tended to be higher than the air temperature, while when a thicker, dry crust existed, surface temperature was lower, probably because of the high reflectivity of the dry crust.

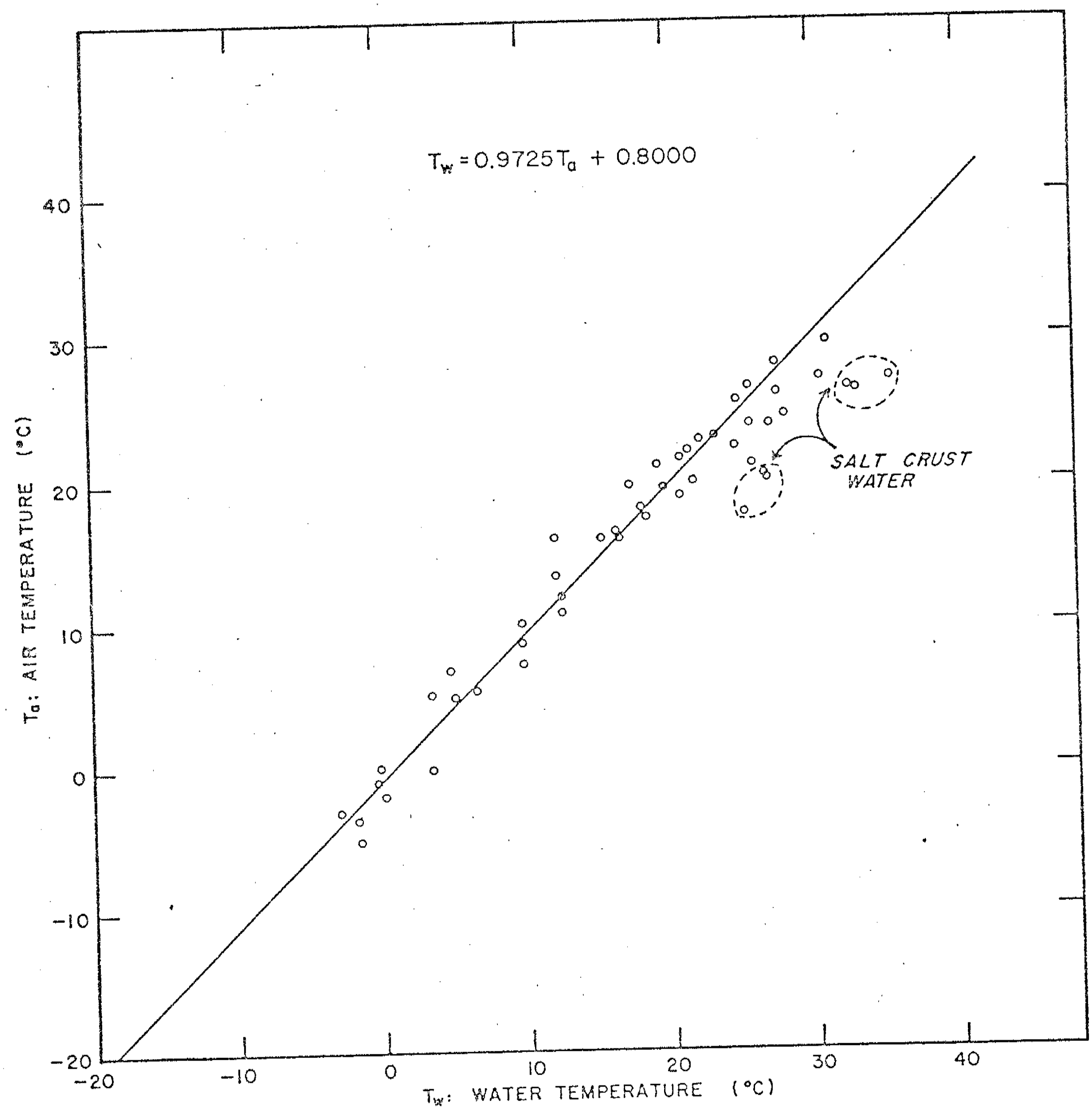


Fig 24 Air/Water Temperature Relationships
(DOG LAKE NORTH STATION)

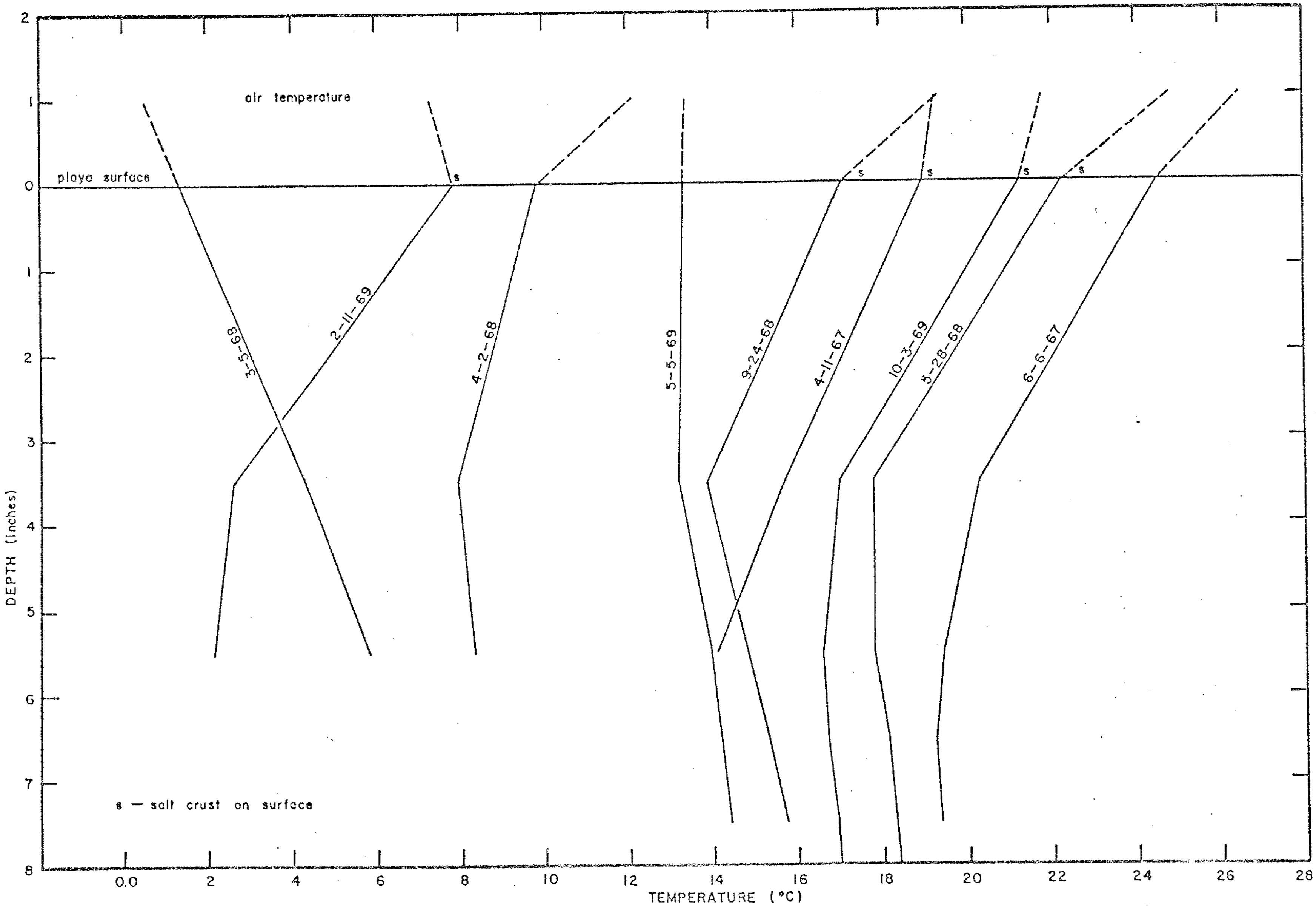


FIG. 25 Selected Near-Surface Sediment Temperature Gradients

For a short-term evaporation determination, this difference in temperature between the surface and water should be considered when a salt crust is present. However, on a long-term basis, monthly or greater, the different surface conditions and their attendant temperatures would tend to balance out any effects on evaporation rates. The air-water temperature relationship described above was therefore used to obtain surface temperatures from the continuously recorded air temperature in all evaporation determinations.

It is well known that dissolved solids in water reduce the saturation vapor pressure of the solution, but the effects of specific salts on vapor pressure have not been extensively investigated. Studies by Lee (1927), Harbeck (1955), and Moore and Runkles (1968) show the effects of varying concentrations of salts and varying temperatures on the saturation vapor pressure. A 0.83 salinity correction for the surface vapor pressures of Laguna del Perro, for either water, brine, or wet, salty mud, was obtained from an average of the values reported in the above-mentioned studies for conditions comparable to those at Dog Lake North Station.

The procedure for the evaporation determination using the Harbeck-Shjeflo method is as follows:

(1) Determine surface temperature from air-water temperature relationship;

(2) Determine e_o and correct for salinity;

(3) Determine e_a;

(4) Compute $\Delta e = (e_o - e_a)$ and multiply by u for corresponding time period;

(5) Plot $u \Delta e$ versus change in water level for time period under consideration;

(6) Obtain N from plot;

(7) Calculate E from

$$E = Nu(e_o - e_a).$$

This procedure is modified slightly for the computer program that was developed to make the determination. The graphical method of steps 5 and 6 is replaced by a least-squares fit routine of the $u \Delta e$ versus water-level change (ΔH) data, which directly calculates the N-coefficient and Y-intercept, or seepage. Tables 9 (p. 128) and 10 (p. 137) list the results of this determination for the months for which weather records were available. The individual monthly values for evaporation when compared to the corresponding values from the Thornthwaite and Blaney-Criddle determinations, are erratic, and in some cases, show considerable variance. Although the total annual evaporation compares favorably with the other methods, the monthly distribution does not, as is evidenced by extremely high evaporation in August and December, 1968, and low values in June and July for that yea

Shjeflo developed this method for use in small lakes and ponds, where the surface pool was more or less permanent and where water salinity was not excessive. At the Estancia playas, the salinity of the water increases as the surface ponds dry up, and any N-coefficient determined must necessarily be for a short time interval, a condition that was not exactly realized when computing evaporation on a daily basis. In the measurement area at Dog Lake North Station, the stage in water levels was constantly affected by the wind shifting the shallow body of water. Evidently these wind-induced changes were not completely eliminated in selecting the rating periods. The high evaporation values for August and December, 1968 are not considered to reflect the actual evaporative discharge of ground water. They include some surface run-off and precipitation, since the months mentioned had unusually high pond stages. The values of the mass-transfer coefficient calculated for these two months, and for other months in which the playa ponds were prevalent, probably are valid for evaporation from the pools, but are too high for evaporation solely of ground water. Conversely, low evaporation values obtained for some months reflect invalid mass-transfer coefficients caused by unstable conditions during low pond stages. At these times, wind shift of the pools and changes in salinity are substantial and preclude the selection of reliable rating periods, in which conditions must be unchanging.

The surface ponds of the Estancia playas are the result of rain and run-off, and are not considered to be a part of evaporative discharge of ground water. Therefore the seepage value as determined from the Y-intercept of the plot of $u \Delta e$ versus ΔH is felt to be a more reliable indicator of evaporative ground water discharge than evaporation calculated by using the mass-transfer equation. At Dog

Lake North Station the changes in stage during dry periods unquestionably reflect mainly the evaporation of ground water. However, during these periods in which water salinity is near saturation, it is difficult to obtain reliable records of stage change, owing to salt precipitation in the stilling well of the water level recorder. At this season also, large diurnal temperature fluctuations introduce errors into the selection of reliable water-level changes. Therefore, the seepage (Y-intercept) values, determined from the data of several months, are considered to be more accurate indicators of ground water evaporative discharge than are the calculations of evaporation which depend on the changes in water level because the errors would tend to be "averaged out" over the period of record. Moreover, the seepage or ground water inflow will not be affected as much by salinity variations, temperature changes, and wind effects. The average seepage, that is used for ground water evaporation, is 0.2316 cm per day or 84.53 cm (33.28 inches) per year (Table 10).

The following list compares the average annual evaporation rates as determined by each of the methods described in the preceding pages:

Method	Water Depth Evaporated
Thornthwaite	69.32 cm (27.29 in.)
Blaney-Criddle	85.47 cm (33.65 in.)
Harbeck-Shjeflo	84.53 cm (33.28 in.)
Evaporation pans (for moist sediment)	94.71 cm (37.29 in.) .

The Water Budget

The basic water budget equation that is used in this study for both aquifers is simply:

ground water inflow = evaporation discharge.

Inflow, Alluvial Aquifer

The results of the aquifer tests show that the alluvial aquifer has a transmissivity of 10,000 gallons per day per foot and a storativity of 0.00029. Using this transmissivity value and the slope of the piezometric surface as determined from Figure 6, 150 acre-feet per year of ground water flows from the west to become available for discharge by evaporation (Table 7).

Pumping withdrawals from the alluvial aquifer lower the water level in the study area during the growing season, May through August, but the water level recovers during the winter months to near the pre-pumping-season level. During the summers of 1968 and 1969, the levels in the No. 2 Berkshire and the No. 1 Young-School Section test holes temporarily declined five and six feet respectively. A slight annual (long-term) water level decline, presumably due to pumpage, was noted, averaging about 0.27 feet for the 1968-1969 period. This decline is within the range of that which has occurred in the area for several years, as determined from inspection of the State Engineer Office water level change maps. Combining the 0.27 feet decline with the storativity of 0.00029 indicates that an insignificant storage change of about 0.11 acre-feet per year is occurring in the alluvium.

Inflow, Medial Sand Aquifer

The results of the aquifer tests show that the medial sand aquifer has a transmissivity of 12,600 gallons per day per foot and a storativity of 0.00019. Using this transmissivity value and the slope of the piezometric surface as determined from Figure 7, 190 acre-feet per year of ground water flows from the west to become available for discharge by evaporation (Table 7).

The water level has declined 0.85 feet during the period of observation (1968-1969) in the medial sand aquifer. The decline of 0.85 feet combined with the storativity of 0.00019 yields a negligible storage change of 0.23 acre-feet per year for the aquifer. Most of the decline can probably be attributed to the artesian flow that has been occurring since December 12, 1967 from the No. 3 Berkshire test hole. As shown in Figure 12, this discharge amounted to about 26 acre-feet through October 3, 1969; this is 0.04 acre-feet per day, or 15 acre-feet annually. Since this dischrage is in the study area, it must be included in the discharge portion of the water budget.

Total Ground Water Inflow

The combined total ground water inflow in the study area for both aquifers is 340 acre-feet per year. This value should be considered as a lower limit for this part of the water budget because of limitations that became apparent in analyzing the aquifer tests. These limitations tended to introduce an error in the aquifer parameters in the direction of low transmissivity values. The magnitude of the cumulative error is not known, but it may be between 10 and 20 percent. An even greater source of error probably results from the inability, owing to lack of water-level and other data, to consider ground water inflow to the playa from directions other than west. In particular, inflow from the south may be significant.

Evaporation Discharge

The outflow side of the water budget, or evaporation, as calculated by the four methods summarized in the list on page 91, shows an average rate of 31.4 in. (80 cm) for the central pond, or salt area, of the test playa and 37.3 in. (95 cm) for the moist sand surrounding the salt. For the pond-salt area, consisting of 66 acres, this is 170 acre-feet discharge per year. For the moist sand "halo" region, consisting of 87 acres, this is 270 acre-feet discharge per year. The average annual evaporation from the discharge area of the northwest playa, then, is 440 acre-feet (Table 7). The 15 acre-feet per year flow from No. 3 Berkshire added to this total results in a discharge of 455 acre-feet per year.

These calculations indicate a discrepancy of 115 acre-feet per year between ground water inflow and evaporative discharge. The most important factor contributing to the discrepancy is thought to be that ground water inflow from the south could not be determined. Other possible sources of error contributing to the discrepancy are present on both sides of the water budget. The effect of the salt crust on evaporation may be greater than previously thought. The salt crust is thickest during the hottest months, and this, combined with the fact that the water during these months is at its highest salinity, could effectively reduce the actual evaporation rate during the summer period. A study in the salt-pan area of Death Valley, California (Hunt et al, 1966, p. 8), suggested that evaporation is reduced drastically upon formation of a crust over the evaporating surface. This is especially true if the upper surface of the crust is dry, a situation that was observed at the Estancia playas during some of the hot, dry months.

The calculation of evaporation from the moist sediment "halo" around the pond-salt area is based, among other things, on the assumption that evaporation from moist, bare ground is about 90% of the evaporation from open water. This is probably not exactly true in this study due to the salinity of the water and to salts in the sediment. In open water, dispersion mixes the chemically concentrated water, while in the moist sediment, precipitation removes the salts from the water near the surface where evaporation occurs. This reduces the pore space and thus lowers the amount of water moving to the discharge or evaporation point.

The preceding sources of error all suggest that the actual evaporation is less than that which was calculated. As previously discussed, the aquifer test data suggest that the calculated ground water inflow is probably lower than the actual inflow. Thus, the two sides of the budget could be used as maximum and minimum limits for the actual budget values. This would mean that the water budget is reliable to within ± 15%.

Considering the total playa area of 12,000 acres in the Estancia Valley (Smith, 1957, p. 52), and assuming that hydrologic conditions are the same throughout the basin, the data and procedures developed in this study allow the calculation that between 27,000 and 36,000 acre-feet per year of ground water are being discharged by evaporation.

General Hydrologic Conditions

At the present time, a sensitive balance appears to exist in the hydrologic system in this part of the Valley. Pumping withdrawals west of the lake area do not currently seem to be upsetting this balance. Water level fluctuations observed in the wells in the area are consistent with long-term trends.

The sensitivity of the balance is shown by the growing-season drops noted in 1968 and 1969 in No. 2 Berkshire and No. 1 Young-School Section. Water levels declined five feet in the summer of 1968 and more than six feet in 1969. These declines lowered the head in the alluvial aquifer below the head in the medial sand aquifer by 1.38 feet in the No. 1 Young-School Section well and by 1.21 feet in the

No. 2 Berkshire well. If this trend continues, a permanent change in relative heads will occur and a reversal of flow patterns result in the playa discharge region. This could mean that the more saline water in the medial sand aquifer would eventually begin moving into the lower aquifer, and continued withdrawals in excess of recharge could result in contamination of the better quality water in parts of the alluvial aquifer. This is not likely to occur however, since high capacity wells have not been constructed in the alluvium in this area due to unfavorable aquifer characteristics. Figure 26 shows flucuations that have occurred in some wells in the area. However, additional development of the alluvial aquifer is probably feasible and advisable in order to salvage some of the evaporative discharge. Accurate and frequent monitoring of water levels in both aquifers is advisable now, and would be even more desirable as additional pumping occurs, to detect reversals or modification of the present flow system. The information thus obtained would be needed to preclude contamination of the better quality water west of the playa region.

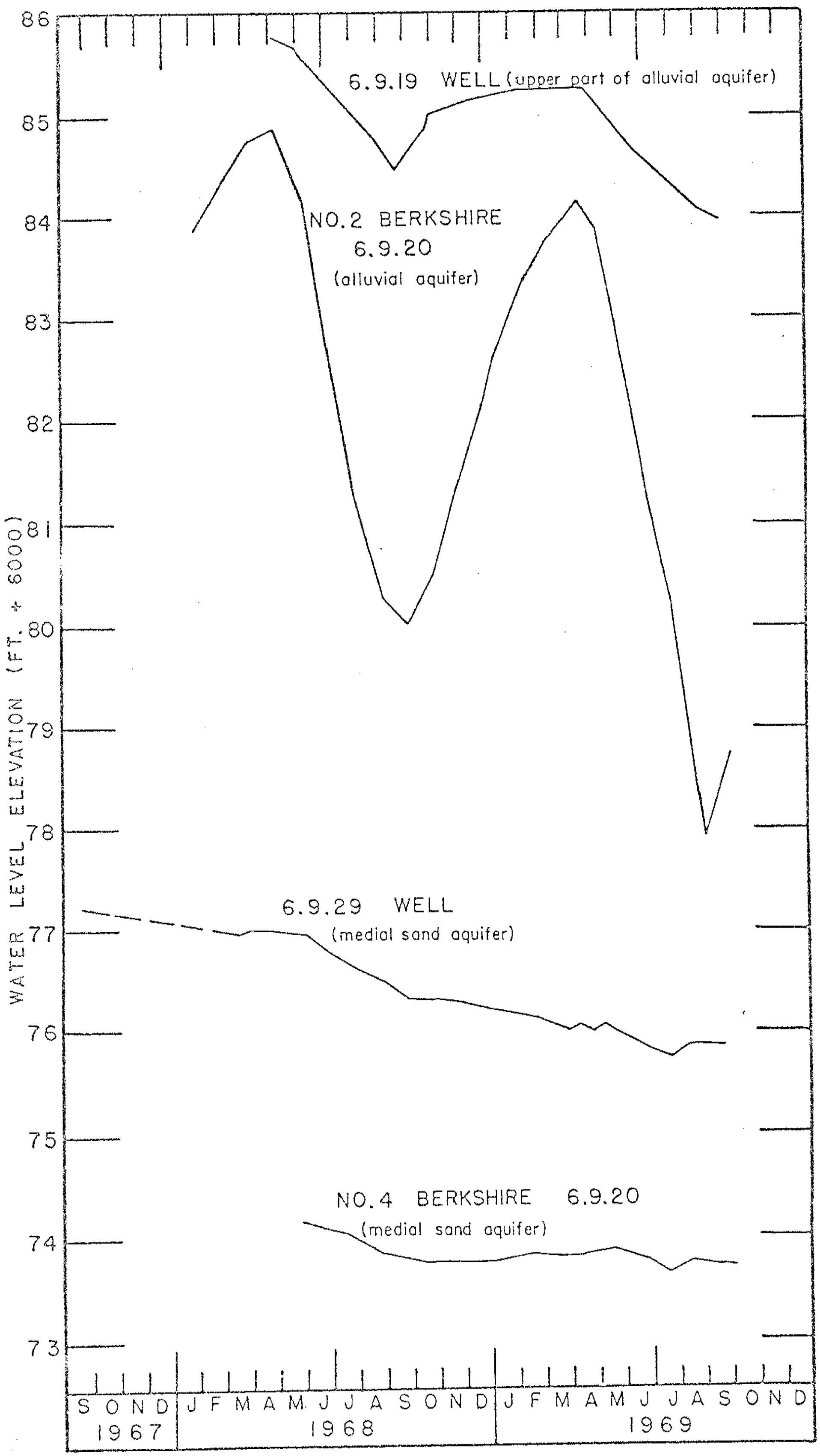


FIG. 26 Water Level Fluctuations in Selected Wells in Study Area

SUMMARY AND CONCLUSIONS

This study has been an attempt to establish a water budget for a small portion of a hydrologically closed basin that is discharging by evaporation from a moist playa. Geologic, hydrologic, and climatological data were collected in order to establish the budget.

Several test holes were drilled in the playa region of Estancia Valley to evaluate the hydrology of the area and to obtain subsurface geologic information. Pumping tests were conducted in the test holes, which permitted evaluation of aquifer parameters and, coupled with the geologic data from the holes, permitted delineation of the hydrologic system in the region of the playa discharge.

Climatic data, gathered from a weather station which was established on a playa surface, were processed and techniques were developed to calculate evaporation from a moist, saline, playa environment. Two existing methods of determining evaporation from climatic data (Thornthwaite and Blaney-Criddle) were evaluated, modified, and applied to the Estancia system. A third method (Harbeck-Shjeflo mass-transfer) was also adapted to this unique environment, and a computer program was developed to determine evaporation by this technique. Close agreement among the three methods was obtained. A fourth technique, based on measured pan evaporation and analogy to coefficients reported in the literature, was devised to determine the amount of evaporation from the moist, bare-sand peripheral areas of the playas. These areas are relatively salt-free in comparison to the central portion of the playas where the previously mentioned techniques were used to determine evaporation.

The evaporative discharge determined by the above techniques was compared to ground water inflow determined from measured aquifer parameters. The results suggest that 455 acre-feet per year is discharged by evaporation, whereas only 340 acre-feet per year of ground water can be shown to flow into the region, a difference of $\pm$ 15%. These two values are considered to be the upper and lower limits of the ground water budget for the area, and, within the limits of the data, they are considered to be reasonable.

The value for ground water inflow could probably be improved if the test holes were completely developed and if the depth of penetration of the wells in the alluvial aquifer were accurately known. The tests did show that the medial sand aquifer is more transmissive than the alluvium, a conclusion substantiated by well logs, which show very little sand present in the alluvial section.

The evaporation calculations could be improved by using shorter time intervals when analyzing the weather data and by refining the correction factor for water salinity. More than one correction factor should be used to relate more closely to the variable conditions that exist in the playas at different times of the year rather than one average value for all conditions. This could be realized by sampling the playa waters year-round to obtain more representative water analyses to better sample the seasonal conditions. The effects of this parameter on evaporation rates were probably under-estimated in this study.

The study shows that between 27,000 and 36,000 acre-feet of ground water is being discharged annually from all of the Estancia playas.

Table 1.

Monthly Average Precipitation in Estancia Valley Stations

(from U. S. Weather Bureau Records)

Month	Estancia	McIntosh	Mountainair	Pedernal	Progresso	Tajique
Jan.	.47	.39	.72	.33	.52	.95
Feb.	.57	.49	.83	.46	.53	1.17
Mar.	.59	.52	.79	.50	.60	1.28
Apr.	.81	.66	.87	.58	.60	1.24
May	.83	1.15	.95	.88	.82	1.42
June	.86	.96	.96	1.08	1.13	1.21
July	2.03	2.22	2.63	2.30	2.88	2.77
Aug.	2.33	2.70	2.66	2.73	2.51	3.01
Sept.	1.26	1.51	1.48	1.15	1.48	1.78
Oct.	1.11	.99	1.05	.79	.75	1.35
Nov.	.43	.39	.66	.41	.48	.86
Dec.	.69	.52	.98	.52	.79	1.26
Annual	11.98	12.27	13.72	11.59	12.86	17.32

Years of record available listed in Table 2.

Table 2.

Precipitation Fluctuations for Estancia Valley Stations

Station	Years record available	Average ann. precip.	Minimum	% of average	Maximum	% of average
Estancia	49	11.24	4.87	43	23.63	210
McIntosh	42	12.30	4.07	33	22.30	181
Mountainair	45	13.13	7.50	57	27.00	206
Pedernal	31	11.59	3.91	34	26.74	230
Progresso	35	12.37	5.13	41	30.74	249
Tajique	49	17.11	8.51	50	32.21	188

Table 2 (cont.)

Deviation of Precipitation from Annual Averages
for Estancia Valley Stations

Year	Estancia +	Estancia -	McIntosh +	McIntosh -	Mountainair +	Mountainair -	Pedernal +	Pedernal -	Progresso +	Progresso -	Tajique +	Tajique -
1950	1.45			2.99	0.29			5.04		2.56		5.05
1951		6.21		6.01		6.08		4.16		6.47		7.93
1952		2.17		4.80		0.19		4.00		5.33		2.67
1953		1.07		4.60		5.33		3.60		4.30		5.41
1954		2.15		2.09		2.65		2.41		3.54		6.94
1955		6.39		2.58		6.02		3.32		4.39		6.69
1956		6.39		8.07		6.22		4.63		6.67		9.56
1957	4.92		3.66		1.64			0.07	0.51		7.14	
1958	6.22		6.07		4.05		2.62		1.67		8.06	
1959	1.12		0.79			0.67	1.33		4.07		1.70	
1960	0.70		0.98		1.08			0.85		0.92	1.37	
1961	0.83		2.00			1.10	1.02		1.48			0.86
1962		1.66		1.72		0.22		3.09		1.85		2.51
1963		2.24		2.85		3.78		4.92		3.57		3.58
1964		3.53		5.41		2.63		7.61		3.47		2.71
1965	3.00		4.64		1.16			0.28	0.03		2.91	

Table 2 (cont.)

Deviation of Precipitation from Annual Averages
for Estancia Valley Stations

Year	Estancia		McIntosh		Mountainair		Pedernal		Progresso		Tajique	
	+	-	+	-	+	-	+	-	+	-	+	-
1966		3.36		3.54		0.83		0.43	0.80			7.29
1967	2.85		3.55			1.91		1.46	2.02		3.50	
1968		2.10		0.38		0.52	1.27		1.84		3.57	
1969	6.55		7.75		7.23		3.26		2.36			2.38
Averages	3.07	3.39	3.60	3.75	2.58	2.72	1.90	3.06	1.64	3.92	4.03	4.81
20 Year average deviation	-0.48		-0.78		-1.14		-1.82		-1.41		-1.72	

Table 3.

Precipitation at Estancia and Dog Lake North Stations

	1967			1968			1969			
	Dog Lake (cm)	Dog Lake (in)	Estancia (in)	Dog Lake (cm)	Dog Lake (in)	Estancia (in)	Dog Lake (cm)	Dog Lake (in)	Estancia (in)	Averages (cm) Dog Lake
Jan.			.08	.36	.14	.06	.25	.10	.03	.30
Feb.			.27	1.56	.62	.54	1.37	.54	1.06	1.47
Mar.	.24P	.09P	.32	2.08	.82	1.52	.65	.26	.80	1.36
Apr.	.24	.09	.16	1.17	.46	.46	3.68	1.45	1.53	1.70
May	.52	.20	.20	2.23	.88	1.11	4.90	1.93	2.60	1.08
June	7.39	2.91	2.02	.06	.02	T	1.62	.64	.62	3.02
July	3.41	1.34	1.79	10.96	4.31	2.36	6.00	2.36	2.55	6.79

Table 3 (cont.)

Precipitation at Estancia and Dog Lake North Stations

	1967			1968			1969			
	Dog Lake (cm)	Dog Lake (in)	Estancia (in)	Dog Lake (cm)	Dog Lake (in)	Estancia (in)	Dog Lake (cm)	Dog Lake (in)	Estancia (in)	Averages (cm) Dog Lake
Aug.	12.20	4.80	5.82	5.88	2.31	1.03	8.49	3.34	2.61	8.86
Sept.	4.11	1.62	1.36	.02	.01	.10	1.90	.75	1.27	2.01
Oct.	.14	.06	.17	2.21	.87	.81			2.33	1.18
Nov.	.90	.35	.00	1.28	.50	.81			.77	1.09
Dec.	.42	.16	1.84	.39	.15	.25			1.62	4.02
Total	29.57P	11.62P	14.03	28.10	11.09	9.05	28.86P	11.37P	17.79	29.16

P = partial record

T = trace

Table 4.

Physical Data on NMIMT Test Holes

Well	Location	Elevation Ground Level	Depth	Casing Set At
No. 1 Berkshire	SE, SE, NW, 22, 6N, 9E	6082.48'	390'	105', cmt. 85' to surface
No. 2 Berkshire	SE, SE, NW, 20, 6N, 9E	6091.50'	355'	79.5', cmt. to surface
No. 3 Berkshire	NE, NE, SE, 20, 6N, 9E	6069.92'	37.5'	36.93' no cement
No. 4 Berkshire	SE, SE, NE, 20, 6N, 9E	6086.19'	59'	58.36' no cement
No. 1-A Berkshire	3' West No. 1 Berkshire	6082.48'	45'	45' no cement
No. 2-A Berkshire	3' East No. 2 Berkshire	6091.50'	41.5'	41.5' no cement
No. 1 Young	SW, SW, SW, 16, 6N, 9E	6085.19'	360'	78.5', cement to surface
No. 1-A Young	3' North No. 1 Young	6085.19'	42.5'	42.5' no cement.

Table 4 (cont.)

Physical Data on NMIMT Test Holes

Measured distances between wells

No. 1 Young to No. 4 Berkshire	2800'
No. 1 Young to No. 2 Berkshire	4290'
No. 4 Berkshire to No. 2 Berkshire	1950'
No. 3 Berkshire to No. 4 Berkshire	322'

TABLE 5

PUMPING TESTS DATA
ESTANCIA VALLEY

7-16-69 TEST - NO.2 BERKSHIRE

TIME (HR)	ELAT (MIN)	RECT (MIN)	EL/RT	Q (GPM)	S (FT)	RESS (FT)	WL (FT)
1100	0000	START TEST - PRE-TEST LEVEL FROM CHART					11.510
1108	8			13.50	21.810		33.320
1122	22				22.590		34.100
1133	33				22.140		33.650
1224	84			13.50	22.290		33.800
1307	127				22.780		34.290
1315	135			19.00			
1328	148				22.950		34.460
1358	178			19.00			
1359	179				22.740		34.250
1400	180	0	00.00	PUMP OFF - START RECOVERY			
1403	183	3	61.00			17.456	29.000
1404	184	4	46.00			8.236	19.780
1405	185	5	37.00			6.346	17.890
1406	186	6	31.00			5.176	16.720
1407	187	7	26.70			4.606	16.150
1408	188	8	23.50			4.226	15.770
1413	193	13	14.80			3.066	14.610
1418	198	18	11.00			2.645	14.190
1428	208	28	7.44			2.245	13.790
1443	223	43	5.19			1.765	13.310
1501	241	61	3.95			1.465	13.010
1600	300	120	2.50			1.104	12.650
1700	360	180	2.00			0.903	12.420
1800	420	240	1.75			0.762	12.300
1900	480	300	1.60			0.671	12.220
2000	540	360	1.50			0.600	12.150
2400	780	600	1.30			0.470	12.025
400	1020	840	1.22			0.403	11.963
800	1260	1080	1.16			0.366	11.930
1200	1500	1320	1.14			0.352	11.921
1800	1860	1680	1.11			0.314	11.890

TABLE 5 (CONT.)

PUMPING TESTS DATA
ESTANCIA VALLEY

7-17-69 TEST - NO.1 YOUNG-SCHOOL SECTION

TIME (HR)	ELAT (MIN)	RECT (MIN)	EL/RT	Q (GPM)	S (FT)	RESS (FT)	WL (FT)
0	0000	START TEST - PRE-TEST LEVEL FROM CHART					9.620
1155	10				24.680		34.300
1202	17				24.480		34.100
1211	26			23.00			
1213	28				24.110		33.730
1230	45				24.900		33.520
1303	78				24.009		33.630
1330	105				24.528		34.150
1357	133	0	00.00	ENGINE STOPPED - START RECOVERY			
1359	135	2	67.50			3.257	11.860
1401	137	4	34.20			2.397	11.000
1402	138	5	27.60			2.117	10.720
1403	139	6	23.20			1.977	10.580
1408	144	11	13.10			1.407	10.010
1413	149	16	9.32			1.157	9.760
1425	161	28	5.75			0.967	9.570
1445	181	48	3.77			0.637	9.240
1500	196	63	3.12			0.596	9.200
1600	256	123	2.08			0.339	8.945
1700	316	183	1.73			0.221	8.828
1800	376	243	1.55			0.172	8.780
1900	436	303	1.44			0.114	8.723
2000	496	363	1.37			0.110	8.720
2100	556	423	1.31			0.084	8.695
2200	616	483	1.28			0.076	8.688
2400	736	603	1.22			0.056	8.670
400	976	843	1.16			0.033	8.652
1200	1456	1323	1.10			0.017	8.645

TABLE 5 (CONT.)

PUMPING TESTS DATA
ESTANCIA VALLEY

7-18-69 TEST - NO.1 BERKSHIRE

TIME (HR)	ELAT (MIN)	RECT (MIN)	EL/RT	Q (GPM)	S (FT)	RESS (FT)	WL (FT)
		START TEST - PRE-TEST LEVEL FROM CHART					8.050
1048	0000				33.010		41.060
1051	3						
1053	5			25.60			
1057	9				33.700		41.750
1100	12			25.00	34.150		42.200
1106	18				34.470		42.520
1120	32				33.630		41.680
1146	58			25.00	34.589		42.640
1222	94			25.00	33.938		41.990
1247	119			25.00	33.848		41.900
1333	165			25.00	33.868		41.920
1414	206			25.00	34.108		42.160
1418	210	0	00.00	PUMP OFF - START RECOVERY			
1419	211	1	211.00			20.520	28.580
1420	212	2	106.00			15.098	23.150
1421	213	3	71.00			11.518	19.570
1422	214	4	53.50			10.648	18.700
1423	215	5	43.00			10.018	18.070
1425	217	7	31.00			9.538	17.590
1427	219	9	24.30			8.448	16.500
1429	221	11	20.10			7.958	16.010
1431	223	13	17.20			7.558	15.610
1433	225	15	15.00			7.238	15.290
1438	230	20	11.50			6.618	14.670
1443	235	25	9.40			6.168	14.220
1448	240	30	8.00			5.788	13.840
1457	249	39	6.38			5.298	13.350
1508	260	50	5.20			4.888	12.940
1518	270	60	4.50			4.658	12.710
1532	284	74	3.84			4.387	12.440
1545	297	87	3.41			4.097	12.150
1618	330	120	2.75			3.857	11.910
1818	550	240	2.29			3.081	11.135
2018	670	360	1.86			2.825	10.880
2218	790	480	1.64			2.664	10.720
18	910	600	1.52			2.583	10.640
218	1030	720	1.43			2.537	10.595
418	1150	840	1.37			2.500	10.560
618	1270	960	1.32			2.464	10.525
1018	1510	1200	1.26			2.428	10.490
1418	1750	1440	1.21			2.390	10.455
1818	1990	1680	1.18			2.368	10.435
2018	2110	1800	1.17			2.362	10.430

TABLE 5 (CONT.)

PUMPING TESTS DATA
ESTANCIA VALLEY

7-19-69 TEST - NO.4 BERKSHIRE

TIME (HR)	ELAT (MIN)	RECT (MIN)	EL/RT	Q (GPM)	S (FT)	RESS (FT)	WL (FT)
1155	0000	START TEST - PRE-TEST LEVEL FROM CHART					14.968
1202	7				7.572		22.540
1208	13				7.712		22.680
1211	16			25.00			
1212	17				7.722		22.690
1227	32				8.532		23.400
1230	35				8.392		23.360
1231	36			25.00			
1239	44				8.732		23.700
1242	47			23.00	8.942		23.910
1253	58				9.332		24.300
1307	72				8.492		23.460
1318	83			23.00	7.732		22.700
1354	119			23.00	7.382		22.350
1430	155	0	00.00	ENGINE STOPPED - START RECOVERY			
1438	163	8	20.40			1.982	16.950
1439	164	9	18.20			2.562	17.530
1440	165	10	16.50			1.222	16.190
1441	166	11	15.10			1.922	16.890
1442	167	12	13.90			1.862	16.830
1453	178	23	7.74			1.342	16.310
1509	194	39	4.97			1.092	16.060
1529	214	59	3.63			0.902	15.870
1535	220	65	3.38			0.812	15.780
1600	225	90	2.50			0.637	15.605
1800	345	210	1.64			0.406	15.474
2000	465	330	1.41			0.271	15.239
2200	585	450	1.30			0.231	15.199
2400	705	570	1.24			0.201	15.169
800	1185	1050	1.13			0.152	15.120
1400	1545	1410	1.10			0.137	15.105

NO.3 BERKSHIRE-OBSERVATION WELL
7-19-69 TEST NO.4 BERKSHIRE

TIME (HR)	ETIM (MIN)	ETIM (DAY)	1/ET (1/D)	RTIM (MIN)	S (FT)	RESS (FT)
1222	27	0.0188	53.40		0.35	
1234	39	0.0271	36.90		0.44	
1256	61	0.0424	23.60		0.50	
1323	88	0.0611	16.35		0.59	
1358	123	0.0855	11.70		0.67	
1457	182			27		0.46
1541	226			71		0.32

TABLE 5 (CONT.)

PUMPING TESTS DATA
ESTANCIA VALLEY

9-03-69 TEST - NO.1 YOUNG SCHOOL SECTION (HELICAL PUMP)

TIME (HR)	ELAT (MIN)	RECT (MIN)	EL/RT	Q (GPM)	S (FT)	RESS (FT)	WL (FT)
755	0000	START TEST - PRE-TEST LEVEL FROM CHART					10.540
759	4			42.85	38.260		48.800
808	13				39.470		50.010
820	25				39.540		50.080
1000	125			42.86	40.660		51.190
1040	165			42.86			
1125	210			42.86			
1152	237			42.86	41.180		51.700
1313	318			42.86			
1327	333				41.270		51.780
1355	360			42.86	41.260		51.770
1452	417				41.260		51.770
1625	510			42.86	41.110		51.610
1700	545	0	00.00	ENGINE STOPPED - START RECOVERY			
1702	547	2	273.50			6.470	16.970
1705	550	5	110.00			3.980	14.480
1706	551	6	91.80			3.660	14.160
1710	555	10	55.50			3.070	13.570
1714	559	14	39.90			2.730	13.230
1723	568	23	24.70			2.280	12.780
1730	575	30	19.20			2.060	12.560
1736	581	36	16.10			1.900	12.400
1744	589	44	13.40			1.740	12.240
1752	597	52	11.50			1.600	12.100
1800	605	60	10.10			1.500	12.000
758	1988	1443	1.38			0.150	10.600

TABLE 5 (CONT.)

PUMPING TESTS DATA
ESTANCIA VALLEY

9-10,11-69 TEST - NO.1 YOUNG SCHOOL SECTION (HELICAL PUMP)

TIME (HR)	ELAT (MIN)	RECT (MIN)	EL/RT	Q (GPM)	S (FT)	RESS (FT)	WL (FT)
750	0000	START TEST - PRE-TEST LEVEL FROM CHART					9.940
752	2				28.810		38.750
754	4			38.45	34.560		44.500
807	17				36.270		46.210
820	30			40.50			
822	32				37.290		47.230
900	70			40.50			
902	72				38.150		48.090
933	103			40.50	38.320		48.260
1034	164			40.05	38.500		48.440
1135	225			40.50	38.320		48.250
1235	285			40.50			
1238	288				38.590		48.520
1332	342			33.70			
1336	346				31.920		41.840
1340	350			35.70			
1344	354				32.580		42.500
1501	431			34.90			
1503	433				32.090		42.000
1555	485			34.10			
1557	487				32.650		42.560
1655	545			34.90			
1657	547				33.200		43.100
1855	605			35.30			
1858	608				33.600		43.500
511	1281			32.60			
514	1284				32.090		41.940
651	1381			34.10			
655	3850				31.890		41.740
920	1530			33.35			
923	1533				31.140		40.970
1034	1604			31.25			
1037	1607				30.720		40.550
1245	1795	0	00.00	ESTIMATED END OF TEST			
1310	1820	25	72.80			1.580	11.410
1319	1829	34	53.70			1.490	11.320
1338	1848	53	34.80			1.310	11.130
1353	1863	68	27.40			1.220	11.040
1404	1874	79	23.80			1.150	10.970
1419	1889	94	20.10			1.080	10.890
1217	3207	1412	2.27			0.140	9.870

NO.2 BERKSHIRE - OBSERVATION WELL
9-10,11-69 TEST NO.1 YOUNG SCHOOL SECTION

ETIM (MIN)	ETIM (DAY)	1/ET (1/D)	WL (FT)	REWL (FT)	S (FT)
780	0.542	1.845	16.265	16.260	0.005
8400	0.583	1.718	16.273	16.259	0.014
1320	0.817	1.223	16.290	16.256	0.034
1440	1.000	1.000	16.310	16.254	0.056
1680	1.170	0.855	16.333	16.252	0.081
2160	1.500	0.667	16.342	16.248	0.094
2220	1.542	0.648	16.352	16.247	0.105

Table 6.

Calculations and Analyses Results of Aquifer Tests
(see calculations following)

Well	Type of Test	Analysis	Transmissivity	Storativity
		Alluvial Aquifer		
No. 1 Berkshire	air-lift	recoverey	3420 gpd/ft	
No. 2 Berkshire	air-lift	recovery	2520 gpd/ft	
No. 1 Young	air-lift	recovery	4896 gpd/ft	
No. 1 Young	helical lineshaft 9/3/69	recovery	7206 gpd/ft	
No. 1 Young	helical 9/10-11/69	recovery	9756 gpd/ft	
No. 2 Berkshire	test in No. 1 Young on 9/10-11/69	interference (Theis)	11,810 gpd/ft	0.00029

Table 6 (cont.)

Calculations and Analyses Results of Aquifer Tests
(see calculations following)

Well	Type of Test	Analysis	Transmissivity	Storativity
		Medial Sand Aquifer		
No. 4 Berkshire	air-lift	recovery	4906 gpd/ft	
No. 3 Berkshire	test on No. 4 Berkshire	interference (Theis)	12,020 gpd/ft	0.00025
No. 3 Berkshire	test on No. 4 Berkshire	interference (Jacob)	13,184 gpd/ft	0.00013

Table 6 (cont.)

Calculations of aquifer parameters

from pumping tests

Recovery analyses by residual drawdown method.

Residual drawdown is related to the logarithm of the ratio t/t' as follows (Johnson, 1966, pp. 140 and 428):

$$s' = \frac{264Q}{T} \log t/t'$$

where Q = pumping rate (gpm),

T = transmissivity, gallons per day per foot,

t = time since pumping started

t' = time since pumping stopped, and

s' = residual drawdown.

From this, by plotting s' versus t/t' on a semilog graph, T can be found from

$$T = \frac{264Q}{\Delta s'}$$

where $\Delta s'$ is the change in residual drawdown per log cycle of values of t/t'

7-18-69 test, No. 1 Berkshire

Q = 25 gpm

$\Delta s'$ = 1.93 feet (from Fig. 14)

$$T = \frac{264 \times 25}{1.93} = 3420 \text{ gallons per day per foot}$$

Table 6 (cont.)

7-16-69 test, No. 2 Berkshire

$Q = 19$ gpm (average)

$\Delta s' = 1.99$ feet (from Fig. 15)

$$T = \frac{264 \times 19}{1.99} = 2520 \text{ gallons per day per foot}$$

7-17-69 test, No. 1 Young-School Section

$Q = 23$ gpm

$\Delta s' = 1.24$ feet (from Fig. 16)

$$T = \frac{264 \times 23}{1.24} = 4896 \text{ gallons per day per foot}$$

9-3-69 test, No. 1 Young-School Section

$Q = 42.86$ gpm (average)

$\Delta s' = 1.57$ feet (from Fig. 16)

$$T = \frac{264 \times 42.86}{1.57} = 7206 \text{ gallons per day per foot}$$

9-10 to 9-11-69 test, No. 1 Young-School Section

$Q = 34$ gpm (average)

$\Delta s' = 0.92$ feet (from Fig. 16)

$$T = \frac{264 \times 34}{0.92} = 9756 \text{ gallons per day per foot}$$

Table 6 (cont.)

7-19-69 test, No. 4 Berkshire

$Q \quad = 23.6$ gpm

$\Delta s' \quad = 1.27$ feet (from Fig. 17)

$$T = \frac{264 \text{ X } 23.6}{1.27} = 4906 \text{ gallons per day per foot}$$

Interference analysis using Theis non-equilibrium formula

In its simplest form, the Theis formula is (Johnson, 1966, p. 109):

$$s = \frac{114.6\,Q}{T} W(u)$$

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

Q = constant pumping rate in gpm,

T = transmissivity of the aquifer in gallons per day per foot, and

$W(u)$ = "well function of u", short for the exponental integral

$$\int_u^{\infty} \frac{e^{-u}}{u} du$$

in which $u = \dfrac{1.87\, r^2 S}{Tt}$

where r = distance in feet from pumped well to observation point,

S = storativity, and

t = time in days since pumping started.

Table 6 (cont.)

The type curve method of solution is used by plotting s, drawdown versus 1/t on a log-log graph, and overlaying a "type" curve plot of W(u) versus u, values are obtained for s, 1/t, W(u), and u from a "match" point. These values are substituted in the above equations to obtain T and S as follows:

$$T = \frac{114.6Q}{s} W(u)$$

and

$$S = \frac{uT}{1.87r^2} \; 1/t \; .$$

Observations in No. 2 Berkshire during 9-10 to 9-11-69 test in No. 1 Young-School Section

$r = 4290$ feet

$Q = 34$ gpm (average)

From match point on curves (Fig. 20)

$W(u) = 1.0$

$u = 1.0$

$1/t = 8.4 \times 10^{-1}$ day^{-1}

$s = 0.33$ feet

$T = \frac{114.6 \times 34}{0.33} \times 1.0 = 11,810$ gallons per day per foot

$S = \frac{1.0 \times 11,810}{1.87 \times 4290^2} \times 8.4 \times 10^{-1} = 0.00029$

Table 6 (cont.)

Observations in No. 3 Berkshire during 7-19-69 test in No. 4 Berkshire

$r \quad = 322$ feet

$Q \quad = 23.6$ gpm

From match point on curves (Fig. 18)

$W(u) = 1.0$

$u \quad = 0.1$

$1/t \quad = 40.1 \text{ day}^{-1}$

$s \quad = 0.225$ feet

$$T = \frac{114.6 \times 23.6}{0.225} \times 1 = 12{,}020 \text{ gallons per day per foot}$$

$$S = \frac{0.1 \times 12{,}020}{1.87 \times 322^2} \times 40.1 = 0.00025$$

Jacob's modified non-equilibrium formula was used to calculate T and S for this test also, using the following equations (Johnson, 1966, p. 113):

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

and

$$S = \frac{0.3Tt_o}{r^2} .$$

From Figure 19, values for s and t_o are:

$$\Delta s = 0.465 \text{ feet}$$

$$t_o = 3.33 \times 10^{-3} \text{ days}$$

Table 6 (cont.)

and as before

$$r = 322 \text{ feet}$$

$$Q = 23.6 \text{ gpm}$$

$$T = \frac{264 \times 23.6}{0.465} = 13,184 \text{ gallons per day per foot}$$

$$S = \frac{0.3 \times 13,184 \times 3.33 \times 10^{-3}}{10.3684 \times 10^{4}} = 0.00013$$

Table 7

Water Budget Calculations

Ground Water Inflow Calculations

	Alluvium	Medial Sand
T	1340 ft^3/day-ft (10,000 gpd/ft)	1685 ft^3/day-ft (12,600 gpd/ft)
I	14 ft/1.32 miles (Fig. 6)	12 ft/1.32 miles (Fig. 7)
L	1.26 miles (Fig. 6)	1.5 miles (Fig. 7)
IL	13.36 ft.	13.60 ft.
TIL	17,900 ft^3/day	23,000 ft^3/day
	= 6,530,000 ft^3 per year	= 8,400,000 ft^3 per year
	= 150 acre-feet per year	= 190 acre-feet per year

Total inflow of ground water, both aquifers, 340 acre-feet per year.

Inflow determined from Darcy's Law in form:

$$Q = TIL$$

where Q = inflow in cubic feet per day,

T = transmissivity in cubic feet per day per foot,

I = hydraulic gradient in feet per foot,

and

L = width of flow cross section in feet.

Table 7 (cont.)

Evaporation Discharge Calculations

Salt-pond area

average evaporation rate = 31.5 inches per year

or = 2.6 feet per year

total area of salt-pond = 66 acres

discharge = 2.6 feet per year X 66 acres

= 170 acre-feet per year

Moist sand area

average evaporation rate = 37.3 inches per year

or = 3.1 feet per year

total area of moist sand = 87 acres

discharge = 3.1 feet per year X 87 acres

= 270 acre-feet per year.

Total evaporation discharge = 170 acre-feet per year

+ 270 acre-feet per year

440 acre-feet per year.

TABLE 8

POTENTIAL EVAPOTRANSPIRATION (THORNTHWAITE)
ESTANCIA VALLEY. LATITUDE - 34 44 DEG. NORTH.

1967

MONTH	TEMP	IND.	10T/I	(10T/I)	UPE(CM)	B	PE(CM)
JAN.	-0.7833	0.000	0.000	0.000	0.000	26.18	0.000
FEB.	3.3460	0.544	0.680	0.614	0.982	25.58	0.837
MAR.	7.8100	1.964	1.588	1.795	2.872	30.90	2.958
APR.	11.4083	3.484	2.319	2.882	4.611	32.70	5.026
MAY	15.3104	5.445	3.112	4.205	6.728	36.22	8.123
JUN.	19.5750	7.895	3.979	5.750	9.200	36.22	11.108
JUL.	24.0120	10.758	4.881	7.440	11.904	36.82	14.610
AUG.	19.9032	8.102	4.046	5.860	9.376	34.80	10.876
SEP.	16.5625	6.131	3.367	4.650	7.440	30.90	7.663
OCT.	11.7823	3.661	2.395	3.015	4.824	29.10	4.679
NOV.	5.6740	1.212	1.153	1.197	1.915	25.88	1.652
DEC.	-1.3005	0.000	0.000	0.000	0.000	25.58	0.000

SUM.IND. = 49.196 a = 1.266 YEARLY PE. = 67.532 (CM)

1968

MONTH	TEMP	IND.	10T/I	(10T/I)	UPE(CM)	B	PE(CM)
JAN.	-1.6510	0.000	0.000	0.000	0.000	26.18	0.000
FEB.	1.9700	0.244	0.477	0.428	0.684	25.58	0.583
MAR.	3.6410	0.618	0.882	0.866	1.385	30.90	1.427
APR.	8.0875	2.075	1.958	2.160	3.456	32.70	3.767
MAY	14.0600	4.786	3.405	4.080	6.528	36.22	7.881
JUN.	19.8916	8.094	4.817	6.080	9.728	36.22	11.745
JUL.	20.7258	8.608	5.019	6.370	10.192	36.82	12.509
AUG.	18.9758	7.536	4.595	5.740	9.184	34.80	10.653
SEP.	15.8250	5.722	3.832	4.670	7.472	30.90	7.696
OCT.	10.4717	3.066	2.536	2.900	4.640	29.10	4.501
NOV.	3.2833	0.527	0.795	0.768	1.228	25.88	1.059
DEC.	1.4234	0.022	0.345	0.295	0.472	25.58	0.402

SUM.IND. = 41.298 a = 1.147 YEARLY PE. = 62.223 (CM)

1969

MONTH	TEMP	IND.	10T/I	(10T/I)	UPE(CM)	B	PE(CM)
JAN.	2.4032	0.331	0.568	0.518	0.829	26.18	0.723
FEB.	0.5290	0.033	0.125	0.089	0.142	25.58	0.122
MAR.	2.2200	0.294	0.524	0.472	0.755	30.90	0.778
APR.	10.3692	3.018	2.449	2.835	4.536	32.70	4.944
MAY	13.7046	4.602	3.237	3.921	6.274	36.22	7.575
JUN.	17.3791	6.598	4.105	5.170	8.272	36.22	9.988
JUL.	21.6250	9.185	5.108	6.680	10.688	36.82	13.118
AUG.	20.6129	8.538	4.869	6.310	10.096	34.80	11.711
SEP.	16.2833	5.972	3.846	4.790	7.664	30.90	7.894
OCT.	10.1900	2.936	2.407	2.778	4.445	29.10	4.312
NOV.	3.8600	0.678	0.912	0.898	1.437	25.88	1.240
DEC.	1.4150	0.152	0.334	0.280	0.448	25.58	0.382

SUM.IND. = 42.337 a = 1.163 YEARLY PE. = 62.787 (CM)

TABLE 8 (CONT.)

POTENTIAL EVAPOTRANSPIRATION (BLANEY-CRIDDLE)
ESTANCIA VALLEY. LATITUDE - 34 44 DEG. NORTH.

MONTH	TEMP	FT	P	UKP	PE(MM)
1967					
JAN.	7.8330	11.7092	7.06	4.518	52.9021
FEB.	3.3460	9.6578	6.90	4.416	42.6488
MAR.	7.8100	11.6987	8.36	5.350	62.5880
APR.	11.4083	13.3439	8.82	5.645	75.3263
MAY	15.3104	15.1279	9.75	6.240	94.3980
JUN.	19.5750	17.0777	9.75	6.240	106.5648
JUL.	24.0120	19.1063	9.92	6.349	121.3058
AUG.	19.9032	17.2277	9.35	5.984	103.0905
SEP.	16.5675	15.7004	8.36	5.350	83.9971
OCT.	11.7823	13.5149	7.88	5.043	68.1556
NOV.	5.6740	10.7222	6.98	4.467	47.8960
DEC.	-1.3005	7.5334	6.87	4.397	33.1243

K = 0.64 YEARLY PE. = 891.997 (MM)

MONTH	TEMP	FT	P	UKP	PE(MM)
1968					
JAN.	-1.6510	7.3732	7.06	4.518	33.3121
FEB.	1.9700	9.0287	6.90	4.416	39.8707
MAR.	3.6410	9.7927	8.36	5.350	52.3909
APR.	8.0875	11.8256	8.82	5.645	66.7555
MAY	14.0600	14.5562	9.75	6.240	90.8306
JUN.	19.8916	17.2224	9.75	6.240	107.4677
JUL.	20.7258	17.6038	9.92	6.349	111.7665
AUG.	18.9758	16.8037	9.35	5.984	100.5533
SEP.	15.8250	15.3632	8.36	5.350	82.1931
OCT.	10.4717	12.9157	7.88	5.043	65.1338
NOV.	3.2833	9.6291	6.98	4.467	43.0131
DEC.	1.4234	8.7788	6.87	4.397	38.6003

K = 0.64 YEARLY PE. = 831.886 (MM)

MONTH	TEMP	FT	P	UKP	PE(MM)
1969					
JAN.	2.4032	9.2267	7.06	4.518	41.6862
FEB.	0.5290	8.3699	6.90	4.416	36.9614
MAR.	2.2200	9.1430	8.36	5.350	48.9150
APR.	10.3692	12.8688	8.82	5.645	72.6443
MAY	13.7046	14.3937	9.75	6.240	89.8166
JUN.	17.3791	16.0737	9.75	6.240	100.2998
JUL.	21.6250	18.0150	9.92	6.349	114.3772
AUG.	20.6129	17.5522	9.35	5.984	105.0323
SEP.	16.2833	15.5727	8.36	5.350	83.3139
OCT.	10.1900	12.7869	7.88	5.043	64.4843
NOV.	3.8600	9.8928	6.98	4.467	44.1911
DEC.	1.4150	8.7749	6.87	4.397	38.5832

K = 0.64 YEARLY PE. = 840.304 (MM)

TABLE 9

EVAPORATION – SHJEFLO MASS TRANSFER
ESTANCIA VALLEY

DAY EVAP.(FT/DY)
APR. 1967

MASS TRANS COEF = 0.000038
SEEPAGE = -0.0069

DAY	EVAP.(FT/DY)
1	0.00226
2	0.00095
3	0.00098
4	0.00120
5	0.00112
6	0.00117
7	0.00165
8	0.00273
9	0.00177
10	0.00120
11	0.00247
12	0.00173
13	0.00084
14	0.00103
15	0.00216
16	0.00334
17	0.00161
18	0.00191
19	0.00299
20	0.00248
21	0.00091
22	0.00276
23	0.00214
24	0.00253
25	0.00339
26	0.00150
27	0.00144
28	0.00137
29	0.00646
30	0.00293

MONTHLY EVAP. = 1.8603(CM)

DAY EVAP.(FT/DY)
MAY 1967

MASS TRANS COEF = 0.000007
SEEPAGE = -0.0017

DAY	EVAP.(FT/DY)
1	0.00017
2	0.00014
3	0.00032
4	0.00057
5	0.00075
6	0.00081
7	0.00105
8	0.00075
9	0.00099
10	0.00125
11	0.00136
12	0.00105
13	0.00114
14	0.00027
15	0.00012
16	0.00044
17	0.00036
18	0.00053
19	0.00039
20	0.00010
21	0.00011
22	0.00025
23	0.00067
24	0.00085
25	0.00053
26	0.00034
27	0.00034
28	0.00061
29	0.00024
30	0.00043
31	0.00038

MONTHLY EVAP. = 0.5267(CM)

DAY EVAP.(FT/DY)
JUN. 1967

MASS TRANS COEF = 0.000024
SEEPAGE = -0.0104

DAY	EVAP.(FT/DY)
1	0.00182
2	0.00167
3	0.00026
4	0.00040
5	0.00041
6	0.00116
7	0.00164
8	0.00324
9	0.00251
10	0.00304
11	0.00258
12	0.00312
13	0.00514
14	0.00439
15	0.00150
16	0.00218
17	0.00118
18	0.00049
19	0.00009
20	0.00072
21	0.00057
22	0.00082
23	0.00128
21	0.00053
25	0.00047
26	0.00065
27	0.00138
28	0.00206
29	0.00089
30	0.00077

MONTHLY EVAP. = 1.4308(CM)

TABLE 9 (CONT.)

DAY EVAP.(FT/DY)
JUL. 1967

MASS TRANS COEF = 0.000072
SEEPAGE = -0.0107

DAY	EVAP.(FT/DY)
1	0.00405
2	0.00523
3	0.00363
4	0.00646
5	0.00646
6	0.00312
7	0.00283
8	0.00248
9	0.00367
10	0.00331
11	0.00259
12	0.00234
13	0.00276
14	0.00227
15	0.00991
16	0.00221
17	0.00120
18	0.00345
19	0.00224
20	0.00210
21	0.00230
22	0.00290
23	0.00275
24	0.00306
25	0.00324
26	0.00226
27	0.00619
28	0.00415
29	0.00188
30	0.00277
31	0.00322

MONTHLY EVAP. = 3.2625(CM)

DAY EVAP.(FT/DY)
AUG. 1967

MASS TRANS COEF = -0.000843
SEEPAGE = -0.0019

DAY	EVAP.(FT/DY)
1	0.05914
2	0.03079
3	0.01677
4	0.01799
5	0.01244
6	0.01582
7	0.01652
8	0.02936
9	0.01971
10	-0.00027
11	0.00337
12	-0.00637
13	0.01483
14	0.01239
15	0.01610
16	0.01513
17	0.01741
18	0.03472
19	0.02659
20	0.02153
21	0.02404
22	0.01166
23	0.01840
24	0.01263
25	0.01924
26	0.02559
27	0.01395
28	0.01480
29	0.02339
30	0.03014
31	-0.00117

MONTHLY EVAP. = 17.2705(CM)

DAY EVAP.(FT/DY)
SEP. 1967

MASS TRANS COEF = -0.000283
SEEPAGE = -0.0021

DAY	EVAP.(FT/DY)
1	0.00153
2	0.00578
3	0.00739
4	0.01008
5	0.00406
6	0.00351
7	0.00979
8	0.00678
9	0.00571
10	0.00220
11	0.00475
12	0.01442
13	0.00795
14	0.00331
15	0.00583
16	0.00403
17	0.00717
18	0.00504
19	0.00522
20	0.00403
21	0.01054
22	0.00425
23	0.00886
24	0.00770
25	0.00295
26	0.00559
27	0.00412
28	0.00258
29	0.00327
30	0.00576

MONTHLY EVAP. = 5.3096(CM)

TABLE 9 (CONT.)

DAY EVAP.(FT/DY)
OCT. 1967

MASS TRANS COEF = 0.000043
SEEPAGE = -0.0065

1	0.00115
2	0.00097
3	0.00093
4	0.00081
5	0.00101
6	0.00202
7	0.00049
8	0.00046
9	0.00090
10	0.00096
11	0.00055
12	0.00187
13	0.00152
14	0.00194
15	0.00084
16	0.00043
17	0.00054
18	0.00097
19	0.00128
20	0.00073
21	0.00103
22	0.00130
23	0.00236
24	0.00218
25	0.00147
26	0.00433
27	0.00090
28	0.00388
29	0.00361
30	0.00066
31	0.00106

MONTHLY EVAP. = 1.3156(CM)

DAY EVAP.(FT/DY)
NOV. 1967

MASS TRANS COEF = -0.000120
SEEPAGE = -0.0112

1	0.00118
2	0.00419
3	0.00074
4	0.00215
5	0.00131
6	0.00011
7	0.00035
8	0.00074
9	0.00119
10	0.00511
11	0.00258
12	0.00061
13	0.00145
14	0.00204
15	0.00213
16	0.00085
17	0.00118
18	0.00091
19	0.00085
20	0.00174
21	0.00272
22	0.00199
23	0.00325
24	0.00439
25	0.00268
26	0.00172
27	0.00026
28	-0.00014
29	0.00075
30	0.00060

MONTHLY EVAP. = 1.5126(CM)

DAY EVAP.(FT/DY)
DEC. 1967

MASS TRANS COEF = 0.000004
SEEPAGE = -0.0093

1	*.*****
2	*.*****
3	*.*****
4	*.*****
5	*.*****
6	0.00006
7	0.00003
8	0.00008
9	0.00003
10	0.00006
11	0.00011
12	0.00012
13	0.00007
14	0.00000
15	-0.00000
16	0.00000
17	0.00001
18	*.*****
19	*.*****
20	*.*****
21	*.*****

MONTHLY EVAP. = 0.0173(CM)

TABLE 9 (CONT.)

DAY EVAP.(FT/DY)
JAN. 1968

MASS TRANS COEF = -0.003612
SEEPAGE = 0.0043

DAY	EVAP.(FT/DY)
1	*.*****
2	*.*****
3	0.00769
4	0.00402
5	0.00607
6	0.01795
7	0.00199
8	0.00363
9	0.00247
10	0.00280
11	0.03561
12	0.00475
13	0.00950
14	0.00556
15	0.00324
16	0.00409
17	0.00963
18	0.00896
19	0.00377
20	0.00816
21	0.02341
22	0.01108
23	0.01059
24	0.01206
25	0.01740
26	0.01596
27	0.01613
28	0.03478
29	0.02301
30	0.01554
31	0.07832

MONTHLY EVAP. = 12.1369(CM)

DAY EVAP.(FT/DY)
FEB. 1968

MASS TRANS COEF = 0.000925
SEEPAGE = -0.0144

DAY	EVAP.(FT/DY)
1	0.02403
2	0.00646
3	0.01719
4	0.00462
5	0.00213
6	0.00741
7	0.00414
8	0.00542
9	0.00581
10	0.00652
11	0.00264
12	-0.00636
13	0.00084
14	0.00037
15	0.00239
16	0.00636
17	0.00594
18	0.01967
19	0.01246
20	*.*****
21	*.*****
22	*.*****
23	*.*****
24	*.*****
25	*.*****
26	*.*****
27	*.*****
28	0.00005
29	0.00097

MONTHLY EVAP. = 3.9334(CM)

DAY EVAP.(FT/DY)
MAR. 1968

MASS TRANS COEF = -0.000288
SEEPAGE = 0.0048

DAY	EVAP.(FT/DY)
1	0.00094
2	0.00509
3	0.00110
4	0.00118
5	0.00199
6	0.00289
0	0.00000
8	0.00378
9	0.00359
10	-0.00062
11	0.00120
12	0.00219
13	0.00482
14	0.00516
15	0.00470
16	0.00237
17	0.00639
18	0.00707
19	0.00344
20	-0.00015
21	0.00102
22	0.00194
23	0.00565
24	0.01339
25	0.00398
26	0.01223
27	0.00447
28	0.00500
29	0.00474
30	0.01367
31	0.00703

MONTHLY EVAP. = 3.9694(CM)

TABLE 9 (CONT.)

DAY EVAP.(FT/DY)
APR. 1968

MASS TRANS COEF = 0.000172
SEEPAGE = -0.0186

DAY	EVAP.(FT/DY)
1	0.00074
2	0.00683
3	0.00373
4	0.00287
5	0.00293
6	0.02066
7	0.00933
8	0.00272
9	0.00392
10	0.00202
11	0.00295
12	0.00590
13	0.01535
14	0.00608
15	0.00871
16	0.01737
17	0.01494
18	0.00571
19	0.00949
20	0.01003
21	0.01364
22	0.00163
23	0.00305
24	0.00476
25	0.01392
26	0.01717
27	0.00647
28	0.00289
29	0.00210
30	0.00635

MONTHLY EVAP. = 6.8352(CM)

DAY EVAP.(FT/DY)
MAY 1968

MASS TRANS COEF = 0.000039
SEEPAGE = -0.0082

DAY	EVAP.(FT/DY)
1	0.00138
2	0.00182
3	0.00111
4	0.00061
5	0.00098
6	0.00285
7	0.00252
8	0.00152
9	0.00112
10	0.00109
11	0.00089
12	0.00118
13	0.00234
14	0.00286
15	0.00324
16	0.00222
17	0.00082
18	0.00084
19	0.00168
20	0.00149
21	0.00239
22	0.00709
23	0.00522
24	0.00368
25	0.00442
26	0.00369
27	0.00505
28	0.00149
29	0.00136
30	0.00253
31	0.00251

MONTHLY EVAP. = 2.1942(CM)

DAY EVAP.(FT/DY)
JUN. 1968

MASS TRANS COEF = 0.000021
SEEPAGE = -0.0070

DAY	EVAP.(FT/DY)
1	0.00072
2	0.00065
3	0.00137
4	0.00125
5	0.00127
6	0.00210
7	0.00118
8	0.00070
9	0.00131
10	0.00097
11	0.00089
12	0.00138
13	0.00234
14	0.00182
15	0.00225
16	0.00165
17	0.00095
18	0.00159
19	0.00161
20	0.00123
21	0.00246
22	0.00214
23	0.00144
24	0.00240
25	0.00150
26	0.00092
27	0.00157
28	0.00226
29	0.00666
30	0.00288

MONTHLY EVAP. = 1.5686(CM)

TABLE 9 (CONT.)

DAY EVAP.(FT/DY)
JUL. 1968

MASS TRANS COEF = 0.000176
SEEPAGE = -0.0380

DAY	EVAP.(FT/DY)
1	0.01035
2	0.01651
3	0.00735
4	0.00366
5	-0.00155
6	0.00155
7	0.00506
8	0.00766
9	0.00905
10	0.00654
11	0.00518
12	0.00996
13	0.00860
14	0.00932
15	0.02735
16	0.00717
17	0.00752
18	0.01324
19	0.00657
20	0.00692
21	0.00665
22	0.00808
23	0.00984
24	0.00478
25	0.00498
26	0.00492
27	0.00280
28	0.00234
29	0.00326
30	0.00712
31	0.00122

MONTHLY EVAP. = 6.8281(CM)

DAY EVAP.(FT/DY)
AUG. 1968

MASS TRANS COEF = -0.001367
SEEPAGE = 0.0191

DAY	EVAP.(FT/DY)
1	0.00189
2	0.03414
3	0.03096
4	0.02334
5	0.02555
6	0.01829
7	0.01813
8	0.03066
9	0.01935
10	0.02197
11	0.02536
12	0.01649
13	0.02751
14	0.03773
15	0.03739
16	0.05100
17	0.05287
18	0.07219
19	0.04351
20	0.03320
21	0.02970
22	0.06403
23	0.06975
24	0.04015
25	0.02405
26	0.01485
27	0.02192
28	0.03467
29	0.03180
30	0.01802
31	0.03209

MONTHLY EVAP. = 30.5574(CM)

DAY EVAP.(FT/DY)
SEP. 1968

MASS TRANS COEF = 0.000241
SEEPAGE = -0.0161

DAY	EVAP.(FT/DY)
1	0.00378
2	0.01219
3	0.00742
4	0.00911
5	0.00680
6	0.00677
7	0.00553
8	0.00758
9	0.00900
10	0.00558
11	0.00421
12	0.00739
13	0.00181
14	0.00769
15	0.02710
16	0.01817
17	0.00423
18	0.00737
19	0.00895
20	0.01060
21	0.01259
22	0.01093
23	0.00796
24	0.00613
25	0.00353
26	0.00854
27	0.00354
28	0.00450
29	0.01303
30	0.00656

MONTHLY EVAP. = 7.5772(CM)

TABLE 9 (CONT.)

DAY EVAP.(FT/DY)
OCT. 1968

MASS TRANS COEF = -0.000180
SEEPAGE = -0.0093

DAY	EVAP.(FT/DY)
1	0.00989
2	0.00961
3	0.00331
4	0.00058
5	0.00429
6	0.00279
7	0.00359
8	0.00302
9	0.00298
10	0.00227
11	0.00308
12	0.00451
13	0.00272
14	0.00581
15	0.01374
16	0.01061
17	0.00314
18	0.00222
19	0.00477
20	0.00239
21	0.00312
22	0.00305
23	0.00592
24	0.00121
25	0.00166
26	0.00422
27	0.00256
28	0.00313
29	0.00471
30	0.00580
31	0.00769

MONTHLY EVAP. = 4.2183(CM)

DAY EVAP.(FT/DY)
NOV. 1968

MASS TRANS COEF = 0.000132
SEEPAGE = -0.0090

DAY	EVAP.(FT/DY)
1	0.00204
2	0.00183
3	0.00132
4	0.00255
5	0.00184
6	0.00211
7	0.00046
8	0.00055
9	0.00587
10	0.00567
11	0.00257
12	0.00287
13	0.00210
14	0.00040
15	0.00070
16	0.00414
17	0.00170
18	0.00165
19	0.00229
20	0.00134
21	0.00084
22	0.00203
23	0.00191
24	0.00166
25	0.00833
26	0.00125
27	0.00125
28	0.00087
29	0.00032
30	0.00084

MONTHLY EVAP. = 1.9294(CM)

DAY EVAP.(FT/DY)
DEC. 1968

MASS TRANS COEF = 0.000897
SEEPAGE = -0.0227

DAY	EVAP.(FT/DY)
1	0.00834
2	0.00288
3	0.01033
4	0.01012
5	0.00588
6	0.01726
7	0.00356
8	0.00077
9	0.00604
10	0.00875
11	0.01897
12	0.03072
13	0.00926
14	0.00528
15	0.00525
16	0.00921
17	0.00979
18	0.01569
19	0.01183
20	0.01619
21	0.01668
22	0.01189
23	0.01508
24	0.01623
25	0.01870
26	0.01251
27	0.01091
28	0.01157
29	0.01200
30	0.01511
31	0.01468

MONTHLY EVAP. = 11.0186(CM)

TABLE 9 (CONT.)

DAY EVAP.(FT/DY)
JAN. 1969

MASS TRANS COEF = 0.000166
SEEPAGE = -0.0132

DAY	EVAP.(FT/DY)
1	0.00073
2	0.00137
3	0.00280
4	0.00052
5	0.00174
6	0.00184
7	0.00293
8	0.00994
9	0.00068
10	0.00141
11	0.00170
12	0.00315
13	0.00113
14	0.00323
15	0.00234
16	0.00229
17	0.00335
18	0.00132
19	0.00154
20	0.00295
21	0.00438
22	0.00350
23	0.00729
24	0.00174
25	0.00274
26	0.00390
27	0.00679
28	0.00748
29	0.00619
30	0.00419
31	0.00338

MONTHLY EVAP. = 3.0044(CM)

DAY EVAP.(FT/DY)
FEB. 1969

MASS TRANS COEF = 0.000085
SEEPAGE = -0.0064

DAY	EVAP.(FT/DY)
1	0.00178
2	0.00283
3	0.00095
4	0.00085
5	0.00287
6	0.00294
7	0.00223
8	0.00038
9	0.00100
10	0.00176
11	0.00132
12	0.00134
13	-0.00002
14	0.00135
15	0.00093
16	0.00109
17	0.00080
18	0.00031
19	-0.00022
20	0.00012
21	0.00041
22	0.00074
23	0.00078
24	0.00096
25	0.00223
26	0.00300
27	0.00173
28	0.00150

MONTHLY EVAP. = 1.0963(CM)

DAY EVAP.(FT/DY)
MAY 1969

MASS TRANS COEF = -0.000142
SEEPAGE = -0.0088

DAY	EVAP.(FT/DY)
1	*.*****
2	*.*****
3	*.*****
4	*.*****
5	*.*****
6	*.*****
7	*.*****
8	*.*****
9	*.*****
10	*.*****
11	*.*****
12	*.*****
13	0.00240
14	0.00262
15	0.00475
16	0.00509
17	0.00128
18	0.00401
19	0.00766
20	0.00365
21	0.00483
22	0.00055
23	0.00334
24	0.00669
25	0.00209
26	0.00839
27	0.00849
28	0.00446
29	0.00633
30	0.00795
31	0.02731

MONTHLY EVAP. = 3.4099(CM)

TABLE 9 (CONT.)

SEP. 1969

MASS TRANS COEF = -0.001004
SEEPAGE = 0.0075

DAY	EVAP.(FT/DY)	DAY	EVAP.(FT/DY)	DAY	EVAP.(FT/DY)
		1	0.01832		
		2	0.01154		
		3	0.01833		
		4	0.03253		
		5	0.01768		
		6	0.01486		
		7	0.03237		
		8	-0.00730		
		9	0.00592		
		10	0.00108		
		11	0.00559		
		12	0.01520		
		13	0.01935		
		14	0.01343		
		15	0.01735		
		16	0.00926		
		17	0.02047		
		18	0.01691		
		19	0.01724		
		20	0.01529		
		21	0.00860		
		22	0.00949		
		23	0.01522		
		24	0.02376		
		25	0.01506		
		26	0.01659		
		27	0.02364		
		28	0.01478		
		29	0.01055		
		30	0.02481		

MONTHLY EVAP. = 13.9576(CM)

Table 10.

Shjeflo Mass Transfer Evaporation Summary and Monthly Averages

	1967 Evaporation (cm)	1967 N-Coeff.	1967 Seepage (ft/day)	1968 Evaporation (cm)	1968 N-Coeff.	1968 Seepage (ft/day)
Jan.				12.1369	-.003612	.0043
Feb.				3.9334	.000925	-.0144
Mar.				3.9694	-.000288	.0048
Apr.	1.8603	.000038	-.0069	6.8352	.000172	-.0186
May	0.5267	.000007	-.0017	2.1942	.000039	-.0082
June	1.4308	.000024	-.0104	1.5686	.000021	-.0070
July	3.2625	.000072	-.0107	6.8281	.000176	-.0380
Aug.	17.2705	-.000843	-.0019	30.5574	-.001367	.0191
Sept.	5.3096	-.000283	-.0021	7.5772	.000241	-.0161
Oct.	1.3156	.000043	-.0065	4.2183	-.000180	-.0093
Nov.	1.5126	-.000120	-.0112	1.9294	.000132	-.0090
Dec.		.000004	-.0093	11.0186	.000897	-.0227
Total or Average	32.4886		-.0067	92.7667		-.0058

Table 10 (cont.)

Shjeflo Mass Transfer Evaporation Summary and Monthly Averages

	1969			Monthly Averages	
	Evaporation (cm)	N-Coeff.	Seepage (ft/day)	Evaporation (cm)	Seepage (ft/day)
Jan.	3.0044	.000166	.0132	7.5706	-.0044
Feb.	1.0963	.000085	-.0064	2.5148	-.0104
Mar.				3.9694	.0048
Apr.				4.3478	-.0128
May		-.000142	-.0088	1.3604	-.0062
June				1.4997	-.0087
July				5.0453	-.0244
Aug.				23.9140	.0086
Sept.	13.9576	-.001004	.0075	8.9481	-.0036
Oct.				2.7670	-.0079
Nov.				1.7210	-.0101
Dec.				11.0186	-.0160
Total or Average	18.0583		-.0052	74.6821	-.0076
					= 0.2316 cm/day

Table 11.

Analyses of Playa Waters, Estancia Valley

Specific Gravities (Density) in g/ml at 20°C
Measured by U.S.G.S.

Location	Date Collected	Water Depth	Density	Rain, Runoff, etc.
Dog Lake North Station SW/4 SW/4 SW/4 Sec 29, T6N, R9E	5/2/67	Infiltration pit 1 foot deep	1.2571	No rain since 4/5/67, playa surface dry
"	4/11/67	Surface dry; sample from beneath crust	1.272	Rain 4/5/67
"	8/8/67	2-1/2 inches	1.089	Heavy rain 8/4/67 before 8/12 storm
"	9/7/67	1/8 inch - dug pit to collect	1.264	No rain since 8/12/67 flood
"	1/2/68	6-1/2 inches	1.060	Lake water mostly snow melt; 12/12/67 storm
"	5/21/68	- from evapo. supply pit	1.260	Station area dry; no rain since 5/12/68

Table 11 (cont.)

Location	Date Collected	Water Depth	Density	Rain, Runoff, etc.
West Satellite in NW/4 SE/4 Sec 20, T6N, R9E	2/6/68	2 inches, skim of ice along shore	1.013	No precip. since Jan. snow 1/8/68
"	4/30/68	2-1/2 inches	1.028	Reported almost full on 4/16/68
South Satellite in NE/4 NW/4 Sec 28, T6N, R9E	2/6/68	2 inches	1.104	No precip. since Jan. storm 1/8/68
"	4/30/68	1/2-1 inch salt mush	1.268	Reported full on 4/16/68
NW playa NE/4 NW/4 Sec 21, T6N, R9E	6/22/67	3/8 inch - dug pit to sample	1.067	Playa 50% covered on east side; 93 mm rain on 6/17/67
NW playa NE/4 SE/4 SW/4 Sec 21, T6N, R9E	2/6/68	1/4-1/2 inch - dug pit to sample	1.142	No precip. since Jan. 8 snow
Playa east of Dog Lake in NE/4 NE/4 SW/4 Sec 19, T6N, R10E	6/22/67	3 inches	1.010	Runoff and heavy rain 6/17/67, filled playa

Table 11 (cont.)

Location	Date Collected	Water Depth	Density	Rain, Runoff, etc.
Salt playa east of Means Ranch NW/4 SW/4 SW/4 Sec 6 T6N, R10E	6/22/67	3-1/2 inches	1.142	Runoff and heavy rain 6/17/67, filled playa

Table 12.

Brine Pan Evaporation, Dog Lake North Station, and Monthly Estimates of Evaporation from Salt-Free Areas of Estancia Playas

	1967 Pan (cm)	1967 Mud Flats (cm)	1968 Pan (cm)	1968 Mud Flats (cm)	1969 Pan (cm)	1969 Mud Flats (cm)	Average
Jan.			3.5	1.645	6.2	2.914	2.279
Feb.			6.5	3.055	9.7	4.559	3.807
Mar.			11.9	5.593	13.3	9.975	7.784
Apr.			17.4	13.050	16.2	12.150	12.587
May			14.5	10.875	14.7	11.025	10.950
June			11.5	8.625	12.5	9.375	9.000
July	15.8	11.850	15.8	11.850	13.5	10.125	11.275
Aug.	15.1	11.325	12.8	9.600	16.2	12.150	11.025
Sept.	16.0	12.000	13.4	10.050	9.7	4.559	8.870
Oct.	13.4	10.050	13.5	10.125			10.087
Nov.	9.8	4.606	9.5	4.465			4.535
Dec.	2.4	1.128	8.3	3.901			2.514
Total		50.959		92.834		76.832	94.713

Pan evaporation $>$ 13.0 cm multiplied by 0.75
Pan evaporation $<$ 13.0 cm multiplied by 0.47
Pan evaporation for June and August, 1968, and June, 1969 multiplied by 0.75.

APPENDIX

Sample logs from deep test holes drilled by personnel of New Mexico Institute of Mining and Technology (from Titus, 1969)

Location: SE$\frac{1}{4}$, SE$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 22, T. 6 N., R. 9 E.

Name: No. 1 Berkshire

Sample Description	Thickness	Depth
Upper Lake Sequence		
Clay, gray, pale yellow to orange, disseminated small gypsum crystals, ostracods and charophytes	44	44
Medial Sand Sequence		
Sand, fine to medium, rounded, frosted, quartzose	11	55
Clay, sandy, tan, slightly gypsiferous, ostracods and charophytes	12	67
Sand, partly clayey, medium to very coarse, rounded, frosted, partly cemented	13	80
Gravel, very sandy, very fine, rounded, mostly quartz and limestone, small caliche fragments and thin clay beds in lower part	15	95
Lower Lake Sequence		
Clay, silty, tan, gray, some pale green, contains small caliche fragments (allochthonous?)	10	105
Alluvial Unit		
Sand, silty, tan to brown, very fine gravel size caliche, rounded (allochthonous?)	15	120

No. 1 Berkshire continued:

Sample Description	Thickness	Depth
Clay, silty, sandy, red to pink	10	130
Sand and red to pink silty clay interbedded	40	170
Gravel, very sandy, very fine to fine, rounded, calcium carbonate cement	38	208
Clay, silty, sandy, tan, reddish brown, little pale green; thin sand interbeds	27	235
Sand, fine, cemented	7	242
Clay, silty, reddish brown, pale green	8	250
Sand, reddish brown, coarse, well sorted, subangular	7	257
Clay, reddish brown, gray, sticky	23	280
Sand, very coarse to fine, rounded to subrounded, poorly cemented	8	288
Clay, gray, reddish brown, sticky	12	300
Sand and very fine gravel, subrounded to subangular, sand fine to coarse, partly cemented with calcium carbonate, gravel contains few feldspar grains; interbeds of reddish brown, gray clay	42	342
Limestone, clayey, light brown, few chips mollusk shell, highly permeable (taking water), fresh-water limestone?; interbedded with coarse sand and gray to red clay	10	352

No. 1 Berkshire continued:

Sample Description	Thickness	Depth
Clay, silty, partly sandy, red in top 5+ feet, becoming a yellow to gray below, contains unidentified black mineral grains and few chert fragments; seed pod from 360-362.5, gastropod fragments	22	374
Yeso Formation		
Shale, very silty, sandy, red, little green clay; light-gray sandstone, white gypsum at base	16	390

Location: SE$\frac{1}{4}$, SE$\frac{1}{4}$, NW$\frac{1}{4}$, Sec. 20, T. 6 N., R. 9 E.

Name: No. 2 Berkshire

Sample Description	Thickness	Depth
Upper Lake Sequence		
Clay, light gray, pale yellow, small gypsum crystals	43	43
Medial Sand Sequence		
Sand, fine to medium, rounded, frosted	3	46
Clay, light gray to white	6	52
Sand, fine to coarse, rounded; little light-gray clay in upper part, little light-red clay; fine gravel in lower part	28	80
Lower Lake Sequence		
Clay, tan to white, gray; thin beds of red silt near base	20	100
Alluvial Unit		
Clay, gray, red; caliche	12	112
Clay, silty, red	16	128
Caliche; red clay	7	135
Sand, medium to coarse, rounded; interbedded red clay, silty, partly sandy; caliche bed at 181-184	74	209
Caliche, sandy, white; little red sand	9	218
Sand, silty, red, coarse	6	224
Clay, silty, sandy, red to tan; thin sand layers interbedded	26	250

No. 2 Berkshire continued:

Sample Description	Thickness	Depth
Sand, gray to red, coarse to very coarse; caliche fragments	12	262
Silt, clayey, sandy, red, gray; little fine gravel at 274-275	21	283
Sand, tan to gray, coarse to very coarse, few feldspar grains	7	290
Sand, very clayey, silty, gray, dark red, fine to coarse, quartzose, feldspar grains	19	309
Gravel, sandy, fine, rounded to sub-angular	11	320
Sand, clayey, silty, gray, red, fine to coarse; clay, red, gray; little gravel, sandy, granule	10	330
Limestone, clayey, brown to light brown, light gray, coarse sand	10	340
Clay, sandy, red to dark red, contains fragments of gastropod shells	10	350

Location: SW$\frac{1}{4}$, SW$\frac{1}{4}$, SW$\frac{1}{4}$, Sec. 16, T. 6 N., R. 9 E.

Name: No. 1 Young-School Section

Sample Description	Thickness	Depth
Upper Lake Sequence		
Clay, light gray to tan, contains fine gypsum crystals, fibrous organic material in lower part	60	60
Medial Sand Sequence		
Sand, fine, well sorted, rounded, frosted	18	78
Lower Lake Sequence		
Clay, gray, tan, little orange	24	102
Alluvial Unit		
Clay, brown to reddish brown; thin sand beds	28	130
Sand and clay, brown, red toward base	50	180
Sand, medium to coarse, very permeable	28	208
Clay, reddish brown; thin sand beds	27	235
Sand, coarse, little very fine; thin granule gravel beds, partly cemented; orange clay beds near base	40	275
Sand, silty, red, fine; red, gray clay; silty gravel at 290-295	25	300
Sand, very fine to coarse, partly cemented; little red, tan, white clay	20	320
Clay, brown, red	5	325
Sand, medium to coarse, partly cemented with calcium carbonate	5	330

No. 1 Young-School Section continued:

Sample Description	Thickness	Depth
Clay, silty, red, tan; very fine, silty sand beds	20	350
Sand, silty, tan, red, very fine, poorly cemented; red clay	10	360

Program TIMCOR for time correction of field data

This program computes the time correction necessary because of gain or loss of time by the spring driven clocks on the recorders during a weeks run of the recorder. The example shown is for the wind run data with the data read on two hour intervals from the week's record. The print out gives daily sum of wind run, monthly sum and the daily average wind speed.

```
FORTRAN IV     MODEL 44  PS        VERSION 3,  LEVEL 1   DATE  70138         N.M.I.M.T.
              DIMENSION  ID(20),MONTH(20),IDAY(20),DATA(20,15),CDATA(20,15),
             8TDATA(20,15),WINSUM(20),A(20)
              REAL INVAL,LASTR,MONSUM
            1 READ(5,1000,END=400) (A(I),I=1,11),NUM,IWEEKS
              PRINT 2000, (A(I),I=1,11)
              MONSUM=0.
              DO 340 LW=1,IWEEKS
C
C             COMPUTE TIME CORRECTIONS + CHART INTERVALS
C             (ACTUAL ELAPSED TIME - CHART ELAPSED TIME)/ACTUAL ELAPSED TIME
C
              READ 1001, NDAYS,CBT,ABT,CET,AET,FIRSTR,LASTR
              ATIME=24.-ABT+(NDAYS-2.)*24.+AET
              CTIME=24.-CBT+(NDAYS-2.)*24.+CET
              DELTIM=(ATIME-CTIME)/ATIME
              INVAL=CTIME/2.-1.
C             WEEKLY DATA INPUT
              READ 1002, (ID(I),MONTH(I),IDAY(I),(DATA(I,J),J=1,12),I=1,NDAYS)
              DO 40 I=1,NDAYS
              DO 40 J=1,12
              IF(DATA(I,J).EQ.-99.9) DATA(I,J)=9999999.9
           40 CONTINUE
              N1=NDAYS-1
C             N2=NDAYS+1
              JL=CET/2.
C             DELINV=(CET-JL*2.)/2.
              DO 41 JD=1,12
              IF(DATA(1,JD).NE.-99.8) GOTO 42
           41 CONTINUE
           42 JDM=JD-1
              JDP=JD+1
              IF(DELTIM) 50,60,70
           50 DO 52 J=1,JDM
           52 CDATA(1,J)=TDATA(1,J)
              CDATA(1,JD)=PLASTR+FIRSTR
              DO 54  J=1,12
           54 TDATA(1,J)=0.
              ACCERR=DELTIM
              DO 56 J=JDP,12
              J1=J-1
              CDATA(1,J)=((DATA(1,J)-DATA(1,J1))*ACCERR)/INVAL+DATA(1,J)
           56 ACCERR=ACCERR+DELTIM
              DO 57 I=2,N1
              DO 57 J=1,12
              J1=J-1
              IF(J1.GT.0) GOTO 49
```

Program TIMCOR (cont.)

```
      DAT=DATA((I-1),12)
      GOTO 51
   49 DAT=DATA(I,J1)
   51 CDATA(I,J)=((DATA(I,J)-DAT)*ACCERR)/INVAL+DATA(I,J)
   57 ACCERR=ACCERR+DELTIM
      DO 58 J=1,JL
      J1=J-1
      IF(J1.GT.0) GOTO 59
      DAT=DATA(N1,12)
      GOTO 61
   59 DAT=DATA(NDAYS,J1)
   61 TDATA(1,J)=((DATA(NDAYS,J)-DAT)*ACCERR)/INVAL+DATA(NDAYS,J)
   58 ACCERR=ACCERR+DELTIM
      GOTO 100
   60 DO 62 J=1,JDM
   62 CDATA(1,J) = TDATA(1,J)
      CDATA(1,JD)=FIRSTR+PLASTR
      DO 64  J = 1,12
   64 TDATA(1,J) = 0.0
      DO 66  J=JDP,12
   66 CDATA(1,J) = DATA(1,J)
      DO 67  I = 2,N1
      DO 67  J = 1,12
   67 CDATA(I,J) = DATA(I,J)
      DO 68  J = 1,JL
   68 TDATA(1,J) = DATA(NDAYS,J)
      GO TO 100
   70 DO 72 J=1,JDM
   72 CDATA(1,J) = TDATA(1,J)
      CDATA(1,JD)=FIRSTR+PLASTR
      DO 74  J = 1,12
   74 TDATA(1,J) = 0.0
      ACCERR = DELTIM
      DO 76  J=JDP,12
      J1 = J+1
      IF (J1.GT.12)  DATA(1,J) = DATA(2,1)
      CDATA(1,J) = ((DATA(1,J1) - DATA(1,J))*ACCERR)/INVAL+DATA(1,J)
   76 ACCERR = ACCERR + DELTIM
      DO 77  I=2,N1
      DO 77  J=1,12
      J1 = J+1
      IF (J1.GT.12)   DATA(I,J1) = DATA((I+1),1)
      CDATA (I,J) = ((DATA(I,J1) - DATA(I,J))*ACCERR)/INVAL+DATA(I,J)
   77 ACCERR = ACCERR + DELTIM
```

Program TIMCOR (cont.)

```
          DO 78  J = 1,JL
          J1 = J + 1
          IF (J1.GT.JL)  GO TO 79
          TDATA(1,J) = ((DATA(NDAYS,J1)-DATA(NDAYS,J))*ACCERR)/INVAL
         B+DATA(NDAYS,J)
       78 ACCERR = ACCERR + DELTIM
       79 IF (DELINV.EQ.0)  TDATA(1,JL) = DATA(NDAYS,JL+1)
          IF(DELINV.NE.0) TDATA(1,JL)=((LASTR-DATA(NDAYS,JL))*ACCERR/DELINV
         B+DATA(NDAYS,JL))
      100 CONTINUE
          PLASTR = LASTR
          I=NDAYS
          IF (ID(I).NE.6)  GO TO 200
C         (INSERT WATER LEVEL CONVERSION)
      200 IF (ID(I).NE.4)  GO TO 300
          DO 210  I = 1,N1
          WINSUM(I) = 0.0
          DO 210  J=1,12
      210 IF(CDATA(I,J).LT.99999.) WINSUM(I)=WINSUM(I)+CDATA(I,J)
      300 DO 330 I=1,N1
          IF (NUM.EQ.1)  GO TO 320
          IF (MONTH(I).LT.NUM)  GO TO 330
          IF (MONTH(I).GT.NUM)  GO TO 340
          GO TO 325
      320 IF (MONTH(I).EQ.12)  GO TO 330
          IF (MONTH(I).EQ.2)  GO TO 340
      325 MONSUM=MONSUM+WINSUM(I)
          RAY=IDAY(I)
          PRINT 2001, IDAY(I),(CDATA(I,J),J=1,12),WINSUM(I)
      330 CONTINUE
      340 CONTINUE
          DAYAV=MONSUM/RAY
          PRINT 2002, MONSUM,DAYAV
          GOTO 1
      400 STOP
     1000 FORMAT(2X,11A4,2I6)
     1001 FORMAT(I2,4F7.2,2F8.1)
     2000 FORMAT('1',8X,7A4,8X,4A4,/,8X,'DAY',4X,'0200',4X,'0400',4X,
        1    '0600',4X,'0800',4X,'1000',4X,'1200',4X,'1400',4X,'1600',
        2    4X,'1800',4X,'2000',4X,'2200',4X,'2400',4X,'SUM')
     1002 FORMAT (I1,2X,2I2,12F5.1)
     2001 FORMAT(9X,I2,13(3X,F5.1))
     2002 FORMAT(/,50X,'MONTHLY SUM = ',F8.1,5X,'DAILY AVERAGE = ',F8.1)
          END
```

Program EVAPOT for computation of Evaporation by
Shjeflo-Harbeck method

This program computes the evaporation according to the equation:

$$Ev = Nu(e_o - e_a)$$

where N is obtained from a comparison of

$$u(e_o - e_a) \text{ vs. } \Delta H.$$

The symbols have been explained in the text (p. 82).

Sufficient comment cards are in this program to explain the various data inputs and the steps in the program. The print out gives values of daily evaporation, mass-transfer, coefficient, and seepage.

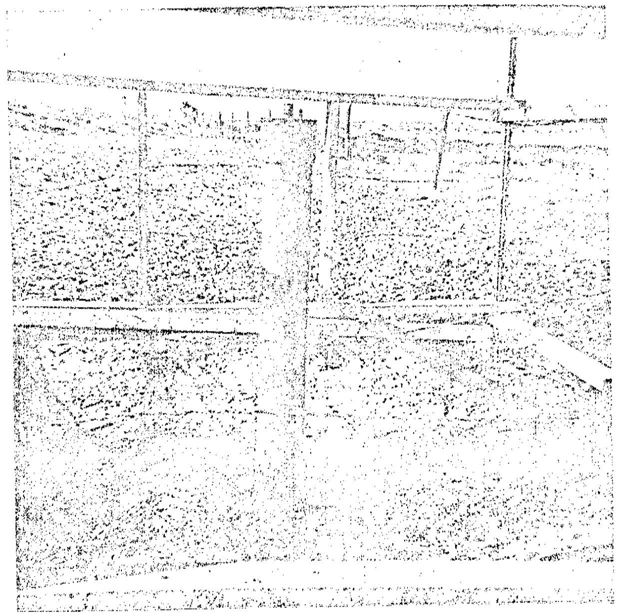
```
FORTRAN IV    MODEL 44  PS       VERSION 3,  LEVEL 1   DATE  70154        N.M.I.M.T.
 0001               DIMENSION TAIR(40),HUMID(40),WINRUN(40),DELTAH(40),A(100),
                  BMDAY(40),TSUR(40),ALSAP(40),SAP(40),ALSSP(40),SSP(40),CSAP(40),
                  CCSSP(40),ACSAP(40),ACSSP(40),DELE(40),UDELE(40),CUDELE(40),
                  DWINRC(40)
              C         TAIR=AVERAGE DAILY AIR TEMPERATURE DEG. CENTIGRADE
              C         HUMID=AVERAGE DAILY RELATIVE HUMIDITY  PERCENT
              C         WINRUN=DAILY WIND RUN  KM/DAY
              C         DELTAH=DAILY CHANGE IN WATER LEVEL  FT/DAY
 0002               PRINT 501
 0003               READ (5,500) (A(I),I=1,88)
 0004               WRITE (6,502)(A(I),I=1,88)
 0005               READ (5,503) DATE,MYEAR,NDAYS
 0006               READ (5,504)(MDAY(I),TAIR(I),HUMID(I),WINRUN(I),DELTAH(I),I=1,NDAY
                  BS)
 0007               PRINT 505, DATE,MYEAR
 0008               DO 60 I1=1,NDAYS
 0009               TSUR(I1)=(TAIR(I1)*0.9725)+.8000
 0010               TA = TAIR(I1)
 0011               TS = TSUR(I1)
 0012               T1 = 273.16 + TA
 0013               T2 = 273.16 + TS
 0014               IF (TAIR(I1).LT.0.0) GO TO 30
              C         COMPUTE SATURATION VAPOR PRESSURES FOR ABOVE ZERO TEMPS.
 0015               T3 = .01038*TA
 0016               ALSAP(I1) = ((19.890-T3)*(TA/T1))
 0017               SAP(I1) = 4.579 * EXP(ALSAP(I1))
 0018            20 IF (TSUR(I1).LT.0.0) GO TO 40
 0019               T4 = .01038 * TS
 0020               ALSSP(I1) = ((19.890-T4)*(TS/T2))
 0021               SSP(I1) = 4.579*EXP(ALSSP(I1))
 0022               GO TO 50
              C         COMPUTE SATURATION VAPOR PRESSURES FOR BELOW ZERO TEMPS.
 0023            30 T01 = ALOG10(T1)
 0024               SUM1=((-2445.5646-(1.1489*TA))/T1)+((-1.2486+(.09084*TA))*TA*TA)*1
                  BO**(-6)+(8.2312*T01)-10.43824
 0025               SAP(I1) = EXP(2.303*SUM1)
 0026               GO TO 20
 0027            40 T02 = ALOG10(T2)
 0028               SUM2=((-2445.5646-(1.1489*TS))/T2)+((-1.2486+(.09084*TS))*TS*TS)*1
                  BO**(-6)+(8.2312*T02)-10.43824
 0029               SSP(I1) = EXP(2.303*SUM2)
 0030            50 CSAP(I1) = SAP(I1)*(1.000775-(.00000313*TA))
 0031               CSSP(I1) = SSP(I1)*(1.000775-(.00000313*TA))
 0032               ACSAP(I1) = CSAP(I1)*HUMID(I1)
 0033               ACSSP(I1) = CSSP(I1)*.830
 0034               DELE(I1) = ACSSP(I1)-ACSAP(I1)
```

Program EVAPOT (cont.)

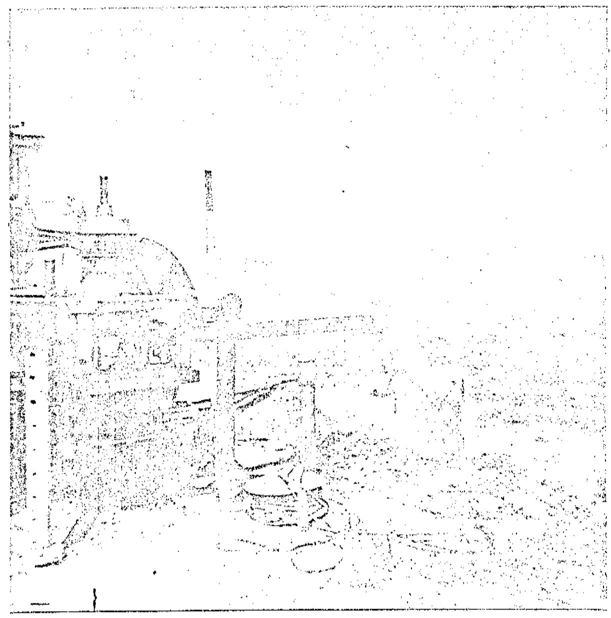
```
      WINRC(I1) = WINRUN(I1)*.034515
      UDELE(I1) = WINRC(I1)*DELE(I1)
      IF (TAIR(I1).EQ.-99.999) UDELE(I1) = 0.0
      IF(WINRUN(I1).EQ.-999.9) UDELE(I1) = 0.0
   60 CONTINUE
C        DETERMINE MASS TRANSFER COEFFICIENT AND SEEPAGE BY LEAST
C        SQUARES FIT OF CHANGE IN WATER LEVEL VS WIND TIMES VAPOR
C        PRESSURE DIFFERENCE
      SUMX = 0.0
      SUMY = 0.0
      SUMXY = 0.0
      SUMXS = 0.0
      SUMN = 0.0
      DO 70 I2=1,NDAYS
      IF (DELTAH(I2).EQ.-99.999) GO TO 70
      IF (UDELE(I2).EQ.0.0) GO TO 70
      SUMX = SUMX+UDELE(I2)
      SUMY = SUMY+DELTAH(I2)
      SUMXY= SUMXY+UDELE(I2)*DELTAH(I2)
      SUMXS= SUMXS+UDELE(I2)*UDELE(I2)
      SUMN = SUMN + 1.0
   70 CONTINUE
      DENOM = (SUMN*SUMXS-SUMX*SUMX)
      SLOPE = (SUMN*SUMXY-SUMX*SUMY)/DENOM
      YCEPT = (SUMXS*SUMY-SUMX*SUMXY)/DENOM
      PRINT 509, SLOPE,YCEPT
      SUDELE = 0.0
C         DETERMINE DAILY EVAPORATION = MASS TRANSFER COEFFICIENT
C         TIMES WIND RUN TIMES VAPOR PRESSURE DIFFERENCE
      DO 80 I3 = 1,NDAYS
      ASLOPE = ABS(SLOPE)
      CUDELE(I3) = ASLOPE*UDELE(I3)
      SUDELE = SUDELE+CUDELE(I3)
      IF (CUDELE(I3).EQ.0.0) GO TO 75
      PRINT 506,MDAY(I3),CUDELE(I3)
      GO TO 80
   75 PRINT 510, MDAY(I3)
   80 CONTINUE
      SUDELC = SUDELE*30.48
   90 PRINT 507,SUDELC
      READ (5,500) (A(I), I=1,44)
      DO 100  J=1,8
  100 WRITE(6,511) (A(I), I=1,44)
      PRINT 508
```

Program EVAPOT (cont.)

```
  500 FORMAT (20A4/2A4)
  501 FORMAT ('1',102X,'.'/////////)
  502 FORMAT (22A4//22A4/22A4//22A4)
  503 FORMAT (1X,A4,I6,I4)
  504 FORMAT (2(I5,F8.3,F6.3,F6.1,F8.3))
  505 FORMAT (4X,A4,I5/)
  506 FORMAT (4X,I4,F12.5)
  507 FORMAT (/4X,'MONTHLY EVAP. = ',F7.4,'(CM)')
  508 FORMAT ('1')
  509 FORMAT (4X,'MASS TRANS COEF = ',F9.6/4X,'SEEPAGE = ',F7.4/)
  510 FORMAT (1X,I4,5X,'*.*****')
  511 FORMAT ('1'//////////22A4//22A4)
      CALL EXIT
      END
```

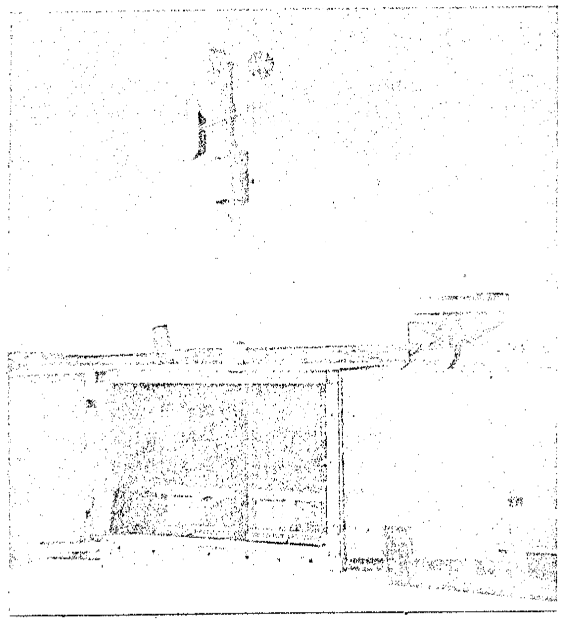


No. 3 Berkshire — Flowing Test Hole
on West Shore of NW Playa

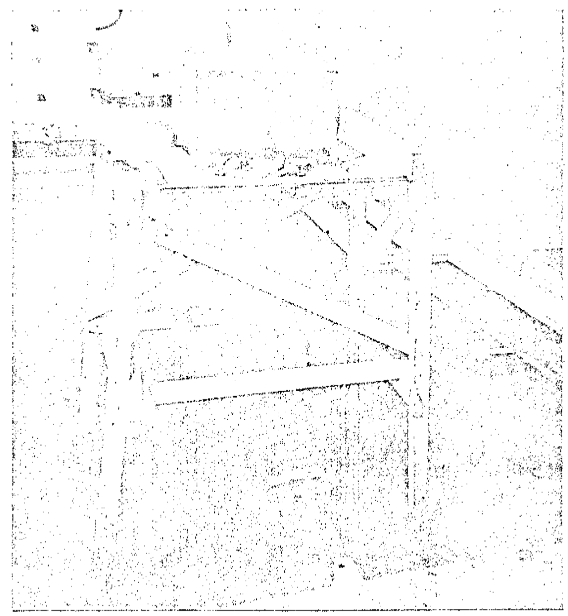


Pumping Test in No. I Young-School Section
on September 3, 1969

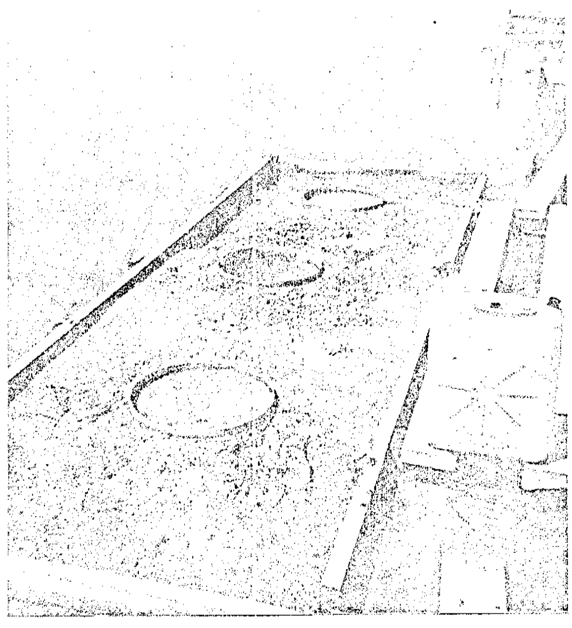
PLATE III



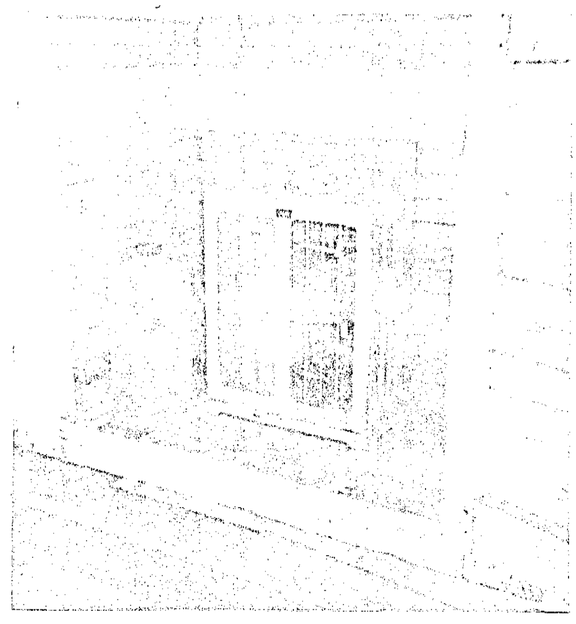
Anemograph and precipitation recorder



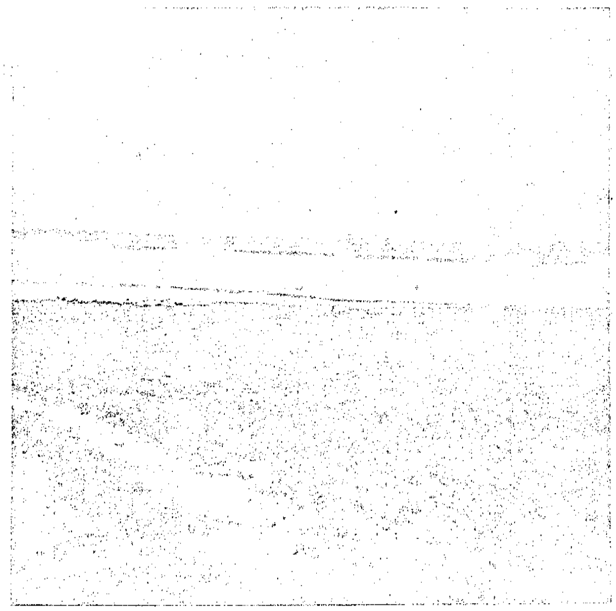
Water level recorder



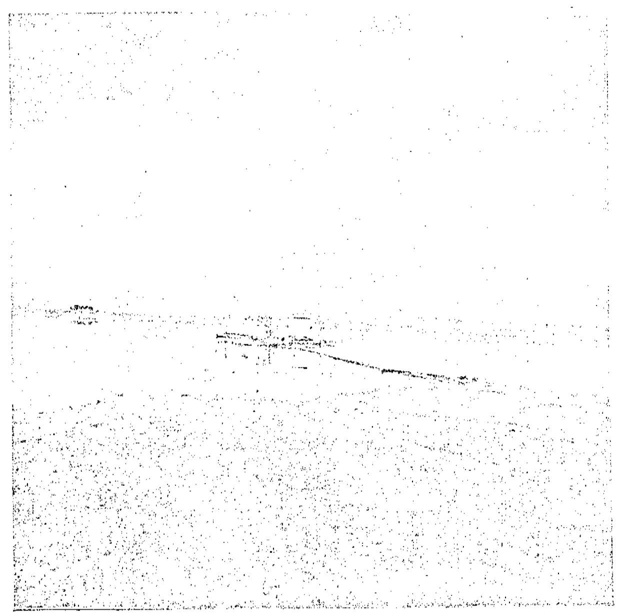
Evaporation pans



Meteorograph



Southwest view of north lobe of Laguna del Perro, Dog Lake North Station in center near east shore



Close up of Dog Lake North Station from east shore

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This thesis is accepted on behalf of the faculty of the

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