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Cost of Pumping Irrigation Water in the Estancia Valley of New Mexico

Agricultural Experiment Station
NEW MEXICO STATE UNIVERSITY
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CONTENTS

Summary

The cost of water is one of the major items of expense on irrigated farms, particularly where relatively low income crops are produced. Pumping cost data are useful to farmers planning to drill new irrigation wells and for those who plan to replace worn or obsolescent pumping equipment and power units. These data are also used by lending agencies and public agencies charged with responsibility for administering water resources and farm programs.

Since pumping equipment is being constantly improved and since much of the ground-water development in New Mexico occurred in the period immediately after World War II when equipment was scarce and and there was little opportunity to select the best type for a given set of conditions, these data should prove valuable to farmers and others who desire to review current pumping cost situations before purchasing new pumping plant components.

In 1940 there were 1558 irrigation pumping plants operating in the state. By 1950 there were 3942 irrigation pumping plants, and in 1955 there were about 7500 irrigation pumping plants.[1] Since 1955, development has proceeded at a reduced rate due to the fact that many areas are fully developed and have been closed to further appropriation. Also, acreage allotments and the farm cost-price squeeze have reduced economic incentives to further development.

This report is part of a series of studies being made in various ground-water basins of New Mexico by the New Mexico Agricultural Experiment Station.

The station has published Bulletin 383, *Cost of Pumping Irrigation Water, Lea County*, 1952, and Research Report 4, *Cost of Producing Crops on Pump-Irrigated Farms in the Estancia Valley, New Mexico*, 1954.

The Estancia Valley is a broad, closed ground-water basin in central New Mexico. In 1958 some 20,000 acres were irrigated from ground water sources in the valley. The valley lies within a declared ground-water basin under administration of the state engineer and is open to limited appropriation.

Water quality in the western half of the declared ground-water basin is generally suitable for irrigation. Salt problems are encountered in the eastern and southeastern parts of the basin.

Precipitation averages slightly over 12 inches yearly. Sixty-five percent of the annual precipitation falls during the growing season, which averages about 143 days. Alfalfa, pinto beans, corn, small grains, sorghums, potatoes, and sugar beets are important crops in the area.

There are approximately 220 irrigation wells in the area. Cost data were obtained from a stratified random sample of 33 wells. The average acreage served per well was 101 and

[1]Stephens, W. P., "General Observations on Underground Water in New Mexico," **Water Resources and Their Economic Importance in New Mexico,** Agricultural Economics Department, Special Report No. 1, New Mexico State University, University Park, New Mexico, September 1956.

the average lift was 109 feet. The average discharge measured in 1957 was 928 gallons per minute.

Pumping plants studied operated an average of 1801 hours, pumping an average of 283 acre-feet of water or 2.8 acre-feet of water per acre irrigated.

Sixty-one percent of the well installations in the sample surveyed used overnight storage reservoirs. Most of the farms used unlined ditches for farm distribution of water. From the limited data available, it appears that investments in concrete ditch lining and concrete pipe reduced pumping costs more than enough to pay the construction costs. In addition, water conserving practices of this type are eligible for Agricultural Conservation Program cost-sharing. Cost of such improvements usually ranges from $50 to $100 per acre.

In 1957, 45 percent of the irrigation wells were powered by electricity. There were a few diesel-powered pumps, but most of the remaining 55 percent of the power units used butane. Total investment in pumping plant and equipment averaged $6251 for all types of power.

Overhead or fixed costs, including depreciation, interest on investment, taxes, and insurance, averaged $583 yearly per pumping plant. Depreciation accounted for 62 percent of overhead charges. The average overhead cost per plant per hour of operation was 32.4 cents and per acre-foot pumped, $2.06. The more hours a given plant was operated, the lower the overhead cost was per acre-foot of water pumped.

Operating costs include fuel or power, lubricants, repairs, and attendance. About 82 percent of operating costs were charges for fuel or electricity. The average fuel or electricity cost per hour was 52.5 cents. The average operating cost per hour was 63.3 cents and per acre-foot $4.03. Over-all efficiency has an important influence on the amount of fuel or electricity consumed. The use of larger than necessary pumps and power units results in higher operating costs than necessary. Similarly, underpowered, improperly-equipped pumping plants, where a larger plant is needed, result in increased operating costs. In areas where lifts are increasing and pump yields declining, it is difficult to maintain peak operating efficiency. Careful selection of original equipment and prompt installation of well-designed replacement components, when needed, will result in lower operating costs.

The average total cost of pumping for all plants studied in 1957 was 96 cents per hour of operation or $6.09 per acre-foot pumped. The average total cost per acre-foot, per foot of lift, was 5.5 cents for all plants. Average total costs per acre-foot ranged from $3.42 to over $16. The wide differences in costs found between plants operating under similar lift and yield conditions are accounted for by two main factors: low over-all plant efficiency or too much plant investment for the number of acres irrigated.

Over-all plant efficiencies averaged 55 percent of electric-powered pumping plants, almost 11.5 percent for butane-powered plants, and 18.25 percent for diesel-powered plants. Differences between power groups are to be expected because of the different types of energy sources used. There was a wide range of efficiencies within each power group.

Both fixed and total costs per acre-foot decline as the number of acre-feet pumped increase. To minimize pumping costs, pumps should be used on sufficient acreage to spread fixed costs. In some irrigated areas where pump capacity is greater than needed to irrigate the pump owner's farm, pumping plants are used jointly on two or more farms under some form of contract between the pump owner and non-owner user. This arrangement might be feasible in the Estancia Valley.

The average total cost of water per acre ranged from $6.90 for barley to $24.92 for potatoes. Wide variations in yield under fairly uniform soil conditions suggest that timely application of irrigation water is an important factor in obtaining optimum yields.

An Estancia Valley potato field in June 1958. More water was used to irrigate potatoes than any other crop.

Cost of Pumping Irrigation Water in the Estancia Valley of New Mexico

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The Estancia Valley

The Estancia Valley of New Mexico is a broad, closed ground-water basin located east of the Sandia and Manzano mountains in central New Mexico. The basin is some 50 miles long and 25 miles wide and extends from southern Santa Fe County to south-central Torrance County. The western edge of the basin overlaps the Chilili Grant projection of the southeastern boundary of Bernalillo County. About 80 percent of the irrigated area of the basin lies in Torrance County. In 1958, approximately 20,000 acres of farm land were irrigated from ground-water sources.[2]

The total volume of ground water pumped for irrigation in any crop year depends on the seasonal distribution, intensity, and total amount of precipitation and the total acres irrigated. Deficient precipitation during the growing season results in heavier draft on the ground-water basin. Since surface water supplies are not available, all irrigation water is pumped from underground storage.

History of Irrigation Development

A number of efforts have been made to provide background information needed for developing ground water for irrigation in the basin. In 1909 O. E. Meinzer of the U.S. Geological Survey began a study on the geology and hydrology of the Estancia Valley.[3] Early irrigation efforts were unsuccessful, largely because of uneconomical pumping equipment. Renewed interest was stimulated by investigations between 1923 and 1930.

Extensive irrigation trials were conducted under the direction of Dean Bloodgood and Albert S. Curry of the New Mexico Agricultural Experiment Station. Because of generally depressed economic conditions,

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[2] Information from U.S. Geological Survey office, Albuquerque, New Mexico.

[3] Meinzer, O. E., "Geology and Water Resources of Estancia Valley, New Mexico," Geological Survey Water-Supply Paper 275, U.S. Department of Interior, U.S. Government Printing Office, Washington, 1911.

interest in irrigation development diminished in 1930 but began to revive again about 1940.[4] During 1946 and 1947, irrigated acreage expanded rapidly, and in 1948 development of irrigated acreage in Santa Fe County began.[5] From 1949 to 1950, more than 9000 new acres were brought under irrigation in the Estancia Valley. Table 1 and figure 1 show the irrigated acreage and ground water used annually from 1944 to 1957. Since 1950, there has been a relatively slow expansion of irrigated acreage.

The area was declared a ground-water basin January 31, 1950, by order of the state engineer.[6] Limited ground-water appropriations may be made in certain parts of the basin.

Description of the Area[7]

The altitude of the Estancia Valley ranges from 6400 feet at the north where it merges with a plateau in southern Santa Fe County to about

Table 1. Irrigated Acreage and Ground Water Used, Estancia Valley, New Mexico, 1944-1957[1]

Year	Irrigated Area (acres)	Water Used (acre-feet)
1944	200	200
1945	250	500
1946	725	1,000
1947	5,000	5,000
1948	6,000	5,400
1949	10,000	8,000
1950	19,000	19,000
1951	20,000	40,000[2]
1952	22,000	33,000
1953	21,000	36,500
1954	23,000	33,000
1955	25,000	36,000
1956	25,000	36,000
1957	25,000	33,000

[1]Smith, R. G., **op cit.**, with supplemental data from U. S. Geological Survey office, Albuquerque, New Mexico.

[2]In 1951, precipitation averaged only 54 percent of normal for the Estancia Valley. In 1950, rainfall at Estancia averaged 100.6 percent of normal but was below normal at other stations in the valley. The low pumpage in 1950 compared to 1951 is primarily attributable to the fact that 95 percent of total annual rainfall in the Estancia Valley in 1950 fell during the growing season, whereas in 1951 rainfall during the growing season was only 54 percent of normal.

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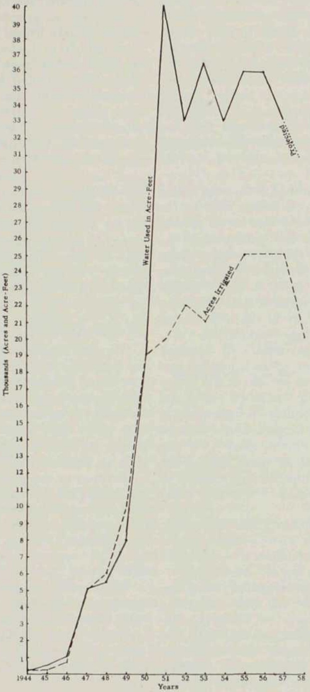
[4]Data from New Mexico state engineer, Sixth, Seventh, Eighth, and Ninth Biennial Reports, Santa Fe.

[5]Smith, R. G., "Geology and Ground-Water Resources of Torrance County, New Mexico," Ground-Water Report No. 5, New Mexico Institute of Mining and Technology, Socorro, New Mexico, 1957.

[6]The 1931 New Mexico statutes declared the waters of underground streams, channels, artesian basins, reservoirs, or lakes having reasonably ascertainable boundaries to belong to the public. Authority to administer the measurement appropriation, and distribution of waters in declared underground water basins is vested in the state engineer. Permits to appropriate waters are required in those underground basins whose boundaries have been officially declared by the state engineer.

[7]Summarized from Smith, R. G., **op. cit.**



Source: U.S. Geological Survey data.

Figure 1. Irrigated acreage and ground water used, Estancia Valley, New Mexico, 1944-58.

6000 feet in the southern part of the valley near an area of playa lakes that provide an interior drainage outlet for basin ground water. The valley floor is relatively flat. The Manzano Mountains form the western boundary of the valley and the southern limit is marked by the prominent escarpment of Chupadero Mesa, which rises some 500 feet above the valley floor. The Pedernal Hills form the eastern rim of the valley.

Surface drainage is into the closed basin and excess water rises to the surface in one or more of several playa lakes in the south end of the valley. Water remains in these playa lakes until it evaporates. Total area of the playa lakes is about 12,000 acres. In the natural state the basin is considered to be in a recharge, discharge-seepage equilibrium.

The principal aquifer is Tertiary and Quaternary valley fill which predominates in 90 percent of the valley area, extending about 15 miles into Santa Fe County. A number of water-bearing formations are of more or less local extent, since they are separated from the main body of the aquifer by impermeable layers of clay. Caliche is encountered is nearly all drilling.

All wells drilled into the water-bearing strata have yielded water, but specific capacities of some wells have been too low for irrigation.

Most of the irrigation wells are drilled in valley fill, but in the area north of Moriarty the Glorieta sandstone is the principal aquifer. The valley fill averages about 300 feet thick with a maximum of approximately 400 feet. Appendix table 1 shows a log of a typical irrigation well in the valley fill.

Recharge of ground-water storage comes largely from local precipitation and from surface runoff from the surrounding mountains and hills. Only when rainfall in the valley is unusually heavy, does significant direct recharge occur in the valley floor. Ground water derived from precipitation and runoff on the east slopes of the Manzano Mountains and percolating downward through the Madera limestone formation provides the largest source of recharge to the valley fill. The rate of movement of ground water is only a few feet a day; consequently, ground-water recharge from the Manzanos may not affect ground-water levels in the valley for several years.

Water Quality

West of State Road 41, well water is generally suitable for irrigation, stock and domestic use, but east of the highway the water becomes increasingly saline as it approaches the playa lake area. Some of this water is unsatisfactory for irrigation or domestic use.[8]

Because of the progressively poorer quality of the water moving eastward from the highway, only limited irrigation development has occurred in that area.

Soils[9]

The valley proper is a level to gently-sloping plain with 0-5 percent slope, usually not more than 3 percent. Witt, Willard, and Manzano soil series are found in approximately the following percentages:

[8]Dregne, H. E., and H. J. Maker, "Irrigation Well Waters of New Mexico," New Mexico Agricultural Experiment Station Bulletin 386, 1954.
[9]Data from Estancia office, Soil Conservation Service.

(1) Witt soil series—50 percent
(2) Willard soil series—40 percent
(3) Manzano soil series—10 percent

Most of the irrigated farms are located on the Witt soil series, which occurs in an area roughly bounded by the town of Willard on the south, Moriarty on the north, and the Manzano Mountains on the west. The following is a typical soil profile for the series:

0-6 inches—light brown loam with faint reddish tinge. Friable, granular, non-calcareous, low in organic matter.

6-12 inches—light brown clay loam. Moderately hard, finely cloddy, non-calcareous to about 12 inches.

12-40 inches—brown clay loam with some faint mottlings and streaks of lime. Hard, faintly cloddy, calcareous to about 40 inches.

Water erosion occurs in these soils under moderate slopes and with heavy rainfall. The main problem however, is wind erosion. Moderate to severe crop damage may occur during spring windstorms, which frequently reach a velocity of 30 to 40 miles an hour.

The Willard soil series lies in the eastern part of the valley. This series is generally found between State Road 41 and the Pedernal Hills, particularly around the playa lakes. The substrata contain salt, which, under irrigation, moves to the surface by capillary action. The percolation rate is low and considerable quantities of water are lost by evaporation, leaving a salt residue which quickly builds up to levels injurious to crops.

The Manzano soil series is found on the drainageways leading from the Manzano Mountains. These deep, fine-textured soils are less permeable than those of the first two series. The surface texture is predominantly clay loam.

Climate

The Estancia Valley climate is semiarid. Precipitation, for the period of record, has averaged 12.48 inches at Estancia, 12.73 inches at McIntosh, and 11.63 inches at Otto. About 65 percent of the rainfall at these three stations falls during the growing season. The length of growing season at Estancia averaged 138 days, at Otto, 142 days, and at McIntosh, 149 days. Appendix tables 2, 3 and 4 summarize climatological data for the valley. Precipitation was below normal for the 14-year period, 1943-1956.

Principal Crops

The comparatively short growing season and damaging spring winds are limiting factors in the choice of crops for the Estancia Valley. At one time, the area specialized in producing pinto beans, under dry-farming conditions; but, due to the long drouth, very little dry farming has been attempted in recent years. Pinto bean production dropped from about 65,000 harvested acres in 1949 to 8000 harvested in 1954. Alfalfa acreage increased almost tenfold during the same period and continues to expand.[10]

The Estancia Valley has the only sugar beet allotment in New Mexico, having planted 602 acres in 1956, 705 acres in 1957, and 755 acres in

[10] "U.S. Census of Agriculture, 1950," U.S. Department of Commerce, Bureau of Census, Volume I, part 30, U.S. Government Printing Office, Washington, 1952.

1958.[11] Potato acreage expanded from garden size in 1949 to 33 acres in 1954,[12] and 1600 acres in 1957.[13] Corn, small grains, and sorghums are other important crops produced in the valley. Small acreages of carrots, onions, and lettuce have been produced successfully and dairying and cattle feeding are other enterprises in the area.

The Estancia Valley is surrounded by extensive range grazing lands on which cattle and sheep raising are major enterprises.

Description of Irrigation Farms, Wells, Storage and Distribution Systems

The 33 wells included in the stratified random sample of approximately 220 wells in the Estancia Valley served an average of 101 acres per well. The acreage served per well ranged from 21 to 265. The average farm size was 465 acres, of which 150 acres was irrigated cropland. Several farms had more than one well. Most of the wells were drilled during 1945-1955. The oldest well in the sample was drilled in 1932. The average depth of drilling was 247 feet, but the depth ranged from 98 to more than 400 feet. Average cost of drilling was $4.05 per foot, and the usual drilling diameter was 18 inches. None of the wells had a gravel envelope.[14] The diameter of casing ranged from 10 to 18 inches, with the 16-inch casing diameter most common. Nearly all the wells were cased for their entire depth. Average cost of casing was $3.57 per linear foot.

Twenty of the 33 farms used overnight storage reservoirs for convenience and to increase irrigation heads. The average storage capacity of these reservoirs was 4.4 acre-feet, and the average reservoir construction cost was $188.46 per acre-foot of storage capacity. Two farmers reported that their tanks had been treated with bentonite to reduce seepage losses. The use of storage reservoirs increases the total pumping head by about five feet.

Six farms reported concrete lining for irrigation ditches, and two farms had underground concrete pipe. Farmers who had made such investments reported costs ranging from $905 to $5045 per farm, depending on the percentage of the total distribution system which was lined. Most of the farms used temporary unlined ditches.

On the one farm that reported concrete ditch linings throughout the farm distribution system, the cost per irrigated acre for this improve-

[11]Data from Torrance County Agricultural Stabilization and Conservation Committee.

[12]1950 Census, op. cit.

[13]Ludlow, Lynn S., "Irrigation Study—Central New Mexico Electric Cooperative, Mountainair, New Mexico," Office of Irrigation Specialist, U.S. Department of Agriculture, Rural Electrification Administration, Washington, May 1958. Mimeographed.

[14]In some areas where fine sand creates danger of heavy caving, wells are drilled considerably larger than the casing and graded gravel is run into the well around the casing to reduce the amount of sand entering the casing. This creates what is called a gravel envelope.

ment was $61.52. Per acre investment costs in lined ditches and underground pipe vary with farm layouts and length of the run in the field. Other studies have shown that these improvements usually cost from $50 to $100 per irrigated acre served.[15]

In other states where climatic and topographic features are similar to those found in the Estancia Valley, sprinkler irrigation has proved to be a profitable investment. The cost of a sprinkler system has been found to be in the range of $50 to $100 per acre,[16] in addition to primary pumping costs. The advantages are: less erosion, less water wasted in transportation and deep percolation, more even distribution of water, less land preparation required, irrigation of more acres with small heads, reduction of seepage losses, and elimination of ditch maintenance. Disadvantages are: investment and operating costs including labor are increased, wind creates obvious problems, and moving lateral pipe in soft ground is somewhat disagreeable.

The loss of water from unlined ditches and untreated storage tanks is undoubtedly high. Several farmers in the Estancia Valley have abandoned the use of storage tanks because of high seepage losses. Others used storage tanks occasionally, for convenience, but usually pumped directly into the distribution system. The majority of farmers who have storage tanks still use them for convenient overnight storage and to provide larger irrigation heads, thereby reducing transportation losses in the distribution system.

Although the extent of seepage losses was not evaluated in this study, U. S. Bureau of Reclamation studies have shown that the average transportation loss in unlined laterals is about 25 percent.[17] Substantial reduction in seepage losses lowers the cost of water per acre and permits more efficient irrigation.

Farmers who reported concrete ditch lining and underground pipe installations indicated that the cost of water per acre was reduced and that substantial economies in irrigation time and labor were effected by these improvements. All but one of the farms reporting these improvements had pump operating costs lower than the average for the 33 wells. The USDA Agricultural Conservation Program provides cost-sharing assistance for improving irrigation distribution systems.

The use of siphon tubes to transfer water from irrigation laterals to the field is the usual practice in the Estancia Valley.

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[15] Davis, K. C., and John F. Meek, "Economics of Ground Water Development on Farms in Southwest Oklahoma," Oklahoma Agricultural Experiment Station Bulletin No. B-499, November 1957; Hughes, William F., and A. C. Magee, "Changes in Investment and Irrigation Water Costs, Texas High Plains, 1950-54," Texas Agricultural Experiment Station Bulletin 823, March, 1956; Cole, James F., "Estimated Savings and Costs, Concrete Ditch Lining, Rio Grande Project," New Mexico Agricultural Experiment Station, unpublished manuscript, 1958, a model.

[16] Schwalen, H. C., K. R. Frost, and W. W. Hinz, "Sprinkler Irrigation," Arizona Agricultural Experiment Station Bulletin 250, reprinted September 1957; Tramel, Thomas E., Grady B. Crowe, and J. F. Abel Jr., "Investment and Operating Costs of Irrigation in the Delta Area of Mississippi, A Progress Report," Mississippi Agricultural Experiment Station Bulletin 559, May 1958.

[17] U.S. Department of Interior, Bureau of Reclamation, "Canal Linings and Methods of Reducing Costs," U.S. Government Printing Office, Washington, 1952.

Characteristics of Pump Installations

Lift

Table 2. Total Lift, Estancia Valley, New Mexico, 1957

Item	Lift in Feet				
	55-86	87-118	119-150	151-180	All Wells
Wells measured	10	11	11	1	33
Percentage of total	30.31	33.33	33.33	3.03	100
Average lift	72	106	140	180	109
Range in total lift	55 to 180 feet				

The average total lift[18] for pumping plants included in the study was 109 feet. Table 2 shows that 32 of the 33 wells had pumping lifts of 150 feet or less. The range of lifts was 55 to 180 feet. The average static level was 63 feet and the average drawdown, 46 feet.

The depth of pump setting ranged from 70 to 200 feet with an average setting of 131 feet. Eighteen percent of the pumps had been lowered for an average of 16 feet since the original installation.

Analysis of data from the U. S. Geological Survey's annual water levels report for the Estancia Valley, dated February 1958, indicates the average lowering of the static water level for 112 wells was 11.34 feet. USGS water level measurements in the valley were begun in 1941. In areas of heaviest pumping the decline has been substantially greater.

Yield, Hours Operated, Acre-Feet Pumped

Pump yields were measured in gallons per minute (gpm) and averaged 928 for the 33 wells. Discharge rates ranged from 297 to 2494 gpm. Seventy percent were within the range of 501 to 1250 gpm.

The pumping plants studied operated an average of 1801 hours, and pumped an average of 283 acre-feet of water (table 3). The wells served an average of 101 acres and an average of 2.8 acre-feet of water per acre was pumped.

Table 3. Average Yield of Wells, Hours Plant Operated, and Acre-Feet Pumped, Estancia Valley, New Mexico, 1957

Item	Gallons per minute				
	500 or less	501-1250	1251-2000	2001 or more	All Wells
No. of wells measured	6	23	1	3	33
Yield in gpm	365	843	2,000	2,352	928
Hours operated	2,971	1,584	2,100	1,027	1,801
Acre-feet pumped	201	260	778	453	283
Range in gpm			296.6 to 2494		
Range in hours operated			420 to 4500		
Range in acre-feet delivered			46.7 to 821.2		

[18]Total lift=pumping unit+discharge head. Discharge heads averaged about five feet or 4.6 percent of total lift.

Number and Size of Bowls and Size of Column

More than one third of the pumping plants studied used three stages or bowls to lift the water. Two had only one stage, seven had two stages, five had four, five had five and two had six. An average of 3.3 stages was used per pumping plant. Each bowl assembly is designed to deliver a certain flow of water for a specified lift. The number of stages required depends on the lift. Many different bowl designs and sizes are available. In most cases, operators did not know the type of bowls used except for the size. More than 42 percent of the pumping plants studied had 12-inch bowls, 24 percent had 10-inch bowls, 6 percent had eight-inch bowls, 6 percent had nine-inch bowls, 15 percent had 14-inch bowls, and 6 percent had 16-inch bowls.

More than 45 percent of the pumping plants studied used eight-inch diameter pump column, one third used 10-inch column, and 15 percent used six-inch column. One pump had 12-inch column and one had five-inch column. Almost all the pumps had a 10-foot joint of suction pipe below the bowls.

Type of Power

Of approximately 220 irrigation wells operating in the Estancia Valley, 99 wells or 45 percent were serviced by electricity in 1957.[19] The stratified sample used in this study includes 15 electric-powered pumps, 16 pumps operated by butane engines and two pumps powered by diesel engines. The sample was distributed geographically throughout the Estancia Valley. There are no natural gas distribution facilities in the valley; however, a natural gas main transmission line supplying the Middle Rio Grande Valley lies about 19 miles south of Willard. Using current pipe line costs obtained from a New Mexico natural gas distributor and a hypothetical distribution system plotted on a map of the Estancia Valley, the cost of supplying natural gas was computed. Because of the extended area of pumping and the comparatively small estimated demand for domestic and irrigation use, a natural gas distribution system does not appear to be presently feasible.

Most of the engines using butane were industrial type and both diesel engines were industrial type. Both diesel engines were used on wells with higher than average yields in gpm. Electric motors ranged from 15 to 60 horsepower. Sixty percent of the electric motors were 40 horsepower or more.

Ninety-four percent of the power units included in the sample were purchased during 1950-56.

Investment in Plants

Most of the pumping plants included in the study were installed during 1945-1955. Investment costs were remarkably uniform during this period. A check on investment costs in 1958 showed little change from the earlier periods, and it is believed the costs presented in table 4 are fairly representative of current investment costs in the Estancia

[19] Ludlow, Lynn S., op. cit.

Valley. The highest investment costs were recorded for diesel-powered pumps which showed considerably higher costs of power units. Investment costs of butane-powered pumping plants were higher than investment costs of electric-powered pumping plants, largely because of the added cost of the butane storage tank. Reservoir costs were higher for diesel - powered plants because of greater storage capacity needed for the higher-producing wells included in that group. Farmers using butane had greater investments in structures, including lined ditches, and their average reservoir investment costs were lower since several pumped directly into the farm distribution system and saved reservoir construction costs.

Table 4. Average Original Investment Costs by Type of Power, Estancia Valley, New Mexico, 1957

Item	Type of Power			Average All Types
	Electric	Butane	Diesel	
Number	15	16	2	33
Investment costs for:				
Drilling	$ 995	$ 997	$1,021	$ 998
Casing	694	780	813	743
Total well development	1,689	1,777	1,834	1,741
Structures	371	758	80	541
Power unit	862	828	3,629	1,013
Pump	2,298	2,332	2,600	2,333
Reservoir	583	273	1,200	470
Fuel tank	—	308	50	153
Total investment	$5,803	$6,276	$9,393	$6,251

Overhead Costs

Overhead or fixed costs include depreciation, interest on investment, taxes, and insurance.[20] Table 5 shows the depreciation rates used in this study. These rates were determined by interviewing business establishments handling pumping equipment and also from estimates made by farmers. They are similar to depreciation rates used in pumping cost studies in other states. Depreciation charges made up about 62 percent of the total overhead costs of pumping.

Taxes and insurance were charged at 1 percent of total investment and interest was charged at 2.5 percent of total investment or 5 percent of average investment. The annual interest charge averaged $156.26 per plant. Interest charge per plant averaged $145.10 for electric-powered pumping plants, $156.90 for butane-powered pumping plants, and $234.82 for diesel-powered pumping plants (table 10).

[20]When insurance is not carried, the risk must be assumed by the owner and becomes an imputed cost.

Table 5. Depreciation Rates Used for Investment Items, Estancia Valley, New Mexico, 1957

Item	Estimated Years of Life	Depreciation Rate (%)
Well (including casing)	25	4.0
Pump	15	6.6
Electric motor	15	6.6
Butane and diesel engines	8	12.5
Underground pipe and ditch structures	25	4.0
Fuel tank	20	5.0
Well house	20	5.0
Reservoir	25	4.0

Overhead Costs per Hour of Operation

The overhead cost per hour of operation for electric-powered pumping plants was 23.5 cents. For butane-powered plants the overhead cost per hour of operation was 43.3 cents and for diesel-powered plants, 44 cents (table 6).

With the rates of depreciation, interest, taxes, and insurance given, overhead or fixed costs per hour are determined by the amount of investment and the total number of hours the plant is operated. Increasing the number of hours of operation reduces the fixed cost per hour. Overhead costs ranged from six cents to 80 cents per hour of operation for electric-powered plants and from 13 cents to $2.10 per hour of operation for butane-powered plants.

Overhead Costs per Acre-Foot

The overhead cost per acre-foot is probably more meaningful than overhead cost per hour since it involves both hours of operation and pump yield in gallons per minute. The overhead cost per acre-foot of water pumped averaged $2.06 for all wells.

Overhead costs per acre-foot averaged $1.78 for plants with electric motors, $1.71 for plants using diesel engines, and $2.46 for plants with butane engines (table 6).

Table 6. Average Overhead Cost per Plant Hour of Operation and per Acre-Foot of Water Pumped, by Type of Power, Estancia Valley, New Mexico, 1957

Item	Type of Power			
	Electric	Butane	Diesel	All Plants
No. plants	15	16	2	33
Hours operated	2,206	1,399	1,931	1,801
Total overhead costs	$520	$606	$871	$583
Overhead cost per hour of operation	23.5¢	43.3¢	44.0¢	32.4¢
Acre-feet of water pumped	291	246	509	283
Overhead cost per acre-foot of water	$1.78	$2.46	$1.71	$2.06
Range in overhead costs per acre-foot of water	$.74-6.63	$1.04-10.44	$1.46-2.23	....

Operating Costs

Table 7. Average Operating Costs per Pumping Plant, Estancia Valley, New Mexico, 1957

Type of Power	No.	Hours Operated	Fuel or Electricity	Repairs to Power Unit	Repairs to Pump	Lubricants	Attendance	Total
Electric	15	2,206	$1,184.36	$ 30.01	$29.79	$ 18.94	$27.53	$1,290.68
Butane	16	1,399	713.96	111.94	48.93	47.74	34.99	957.61
Diesel	2	1,981	1,011.00	237.72	69.33	105.45	49.55	1,473.05
All plants	33	1,801	$ 945.78	$ 82.32	$41.49	$ 38.15	$32.51	$1,140.25

Operating costs include fuel or power, oil and grease for pump and motor, repairs, and attendance (labor for servicing the plant). The cost of fuel or electricity accounted for 83 percent of total operating costs (table 7).

The average energy or fuel cost per hour was 52.5 cents. This was 55 percent of the total hourly cost of pumping. Expenditures for energy and fuel constituted the largest single item of expense in the total cost of pumping (table 7). Average unit costs for electricity, butane, and diesel are shown in table 8.

Unlike overhead costs, which continue whether or not the pump is in use, operating costs were more or less proportionate to the hours of plant operation, except for electricity, which had a power rate structure providing lower costs per connected horsepower at the 100, 200, 400, and 700 KWH intervals. A deposit and minimum annual guarantee were required for electric service.

Repair of power units was the second largest operating cost factor, averaging more than $82 per pumping plant. Electric motor repairs were less than one third as much as for butane engines, and butane engines required less than half as much repair expense as diesel engines. Repairs were calculated by dividing the total repairs for the calendar year in each power group by the total hours that all units were operated in each power group. This rate was then multiplied by the number of hours each plant operated under the respective power groups. Repairs averaged 1.36 cents per hour for electric motors, eight cents hourly for butane engines and 12 cents per hour for diesel engines.

Pump repairs were calculated in

Table 8. Energy or Fuel Costs, Estancia Valley, New Mexico, 1957

Energy or fuel	Average cost per unit	Energy or fuel, consumption per hour	Average energy or fuel cost per hour	Percent of total operating cost	Percent of total cost of pumping
Electricity	$.01975 KWH	27.2 KWH	53.7¢	92	65
Butane	.09 gal.	5.7 gal.	51.0¢	75	46
Diesel	.14 gal.	3.6 gal.	51.0¢	69	43
All pumps	....	....	52.5¢	83	55

similar fashion. The average annual repair expense for pumps was $41.49 per plant or 4.6 cents per hour of operation.

To broaden the base for computing repairs, data were obtained from 18 additional operators.

The average annual cost of oil, grease, turbine oil, and filters for pumps and power units was about $38. Electric-powered installations required only about $19 and diesel-powered units required more than $105 for lubricants. This difference in cost was primarily caused by the large engine oil requirements for internal combustion engines. Three electric-powered pumps and six butane-powered pumps had water-lubricated turbine shafts.

Labor or attendance, largely an imputed cost, averaged less than $33 per pumping plant and was calculated at 30 cents per day for electric-powered plants, 60 cents per day for butane-powered plants and 60 cents per day for diesel-powered plants. Attendance includes servicing pumps and motors, minor repairs and adjustments made by the operator, and starting and stopping the motor.

Operating Costs per Hour of Operation

Operating costs per hour operated averaged 63.3 cents for all plants. The lowest hourly operating costs were for electric-powered plants, which amounted to 58.5 cents; and the highest operating costs per hour of operation were for diesel-powered pumping plants, 74.4 cents. Average hourly operating cost for butane-powered pumping plants was 68.4 cents (table 9). Operating costs per hour ranged from 33.5 cents to $1.16.

Operating Costs per Acre-Foot Pumped

The average operating cost per acre-foot pumped was $4.03. Operating costs per acre-foot ranged from $2.22 to $9.68. Diesel-powered plants had the lowest operating cost per acre-foot, $2.90. Butane-powered plants had an operating cost of $3.89 per acre-foot pumped, and electric-powered plants, $4.43 (table 9).

Table 9. Average Operating Costs per Hour of Pumping and per Acre-Foot Pumped, by Type of Power, Estancia Valley, New Mexico, 1957

Item	Type of Power			
	Electric	Butane	Diesel	All Plants
No. plants	15	16	2	33
Hours operated	2,206	1,399	1,931	1,801
Total operating cost	$1,291	$953	$1,473	$1,140
Operating cost per hour	58.5¢	68.4¢	74.4¢	63.3¢
Acre-feet of water pumped	291	246	509	283
Operating cost per acre-foot	$4.43	$3.89	$2.90	$4.03
Range in operating costs per acre-foot	$2.51-9.68	$2.22-9.35	$2.34-3.17	....

Total Cost of Pumping

Total cost of pumping averaged about $1723 per plant (table 10). Fuel or energy was the largest item of expense, accounting for 55 percent of the total.

Total cost of pumping per plant ranged from $748 to $3149. The number of acre-feet pumped per

Table 10. Average Total Cost of Pumping, Estancia Valley, New Mexico, 1957

Item	Type of Power			All Plants
	Electric	Butane	Diesel	
Number wells	15	16	2	33
Operating costs:				
Fuel	$1,184	$ 714	$1,011	$ 946
Repairs to power unit	30	112	238	82
Repairs to pump	30	49	69	41
Lubricants	19	48	105	38
Attendance	28	35	50	33
Total operating costs	$1,291	$ 958	$1,473	$1,140
Overhead costs:				
Depreciation				
Pump	$ 153	$ 155	$ 173	$ 155
Well	68	71	73	70
Power unit	57	104	242	91
Fuel tank	....	15	3	8
Reservoirs	23	11	48	19
Structures	15	30	3	22
Interest on investment	145	157	235	156
Taxes and insurance	58	63	94	62
Total overhead costs	$ 519	606	871	583
Total all costs	$1,810	$1,564	$2,344	$1,723

plant ranged from 47 to 821. The smallest number of hours operated was 420, and the greatest number of hours operated per plant was 4500.

Total Cost per Hour of Operation

Diesel-powered pumping plants had the highest total cost per hour of operation—$1.18 (table 11). For butane plants, the total cost per hour was $1.12 and for electric-powered plants, 82 cents.

The average total cost of pumping for all plants was 96 cents per hour. Total cost per hour ranged from 39.7 cents to $3.13.

Table 11. Average Total Cost per Hour of Pumping and per Acre-Foot Pumped, by Type of Power, Estancia Valley, New Mexico, 1957

Item	Type of Power			All Plants
	Electric	Butane	Diesel	
No. pumps	15	16	2	33
Hours operated	2,206	1,399	1,931	1,801
Total cost per plant	$1,810	$1,564	$2,344	$1,723
Total cost per hour	$0.82	$1.12	$1.18	$0.96
Acre-feet of water pumped	291	246	509	283
Total cost per acre-foot	$6.21	$6.35	$4.61	$6.09
Range in total cost				
per acre-foot	$3.89-15.07	$3.42-16.03	$4.57-4.63	....
Cost per acre-foot				
per foot of lift	5.5¢	6.1¢	3.8¢	5.5¢
Total cost per acre-inch	52¢	53¢	38¢	51¢

Total Cost per Acre-Foot

Total cost per acre-foot ranged from $3.42 to more than $16. Average total cost per acre-foot for all plants was $6.09. The diesel-powered plants were on high-yielding wells and had a total cost per acre-foot of $4.61, the lowest power group cost. For electric-powered pumping plants, the total cost per acre-foot was $6.21 and for butane-powered plants, $6.35. The total cost per acre-foot per foot of lift averaged 5.5 cents, and the average total cost of water per acre-inch was 51 cents.

Figures 2, 3, 4 and 5 show the breakdown of total costs per acre-foot into input components. The two diesel engines were on high-yielding wells, for which they were well designed. This accounts for the comparatively low cost per acre-foot of $4.61. The diesel cost per hour of operation was $1.18, highest of the three power groups.

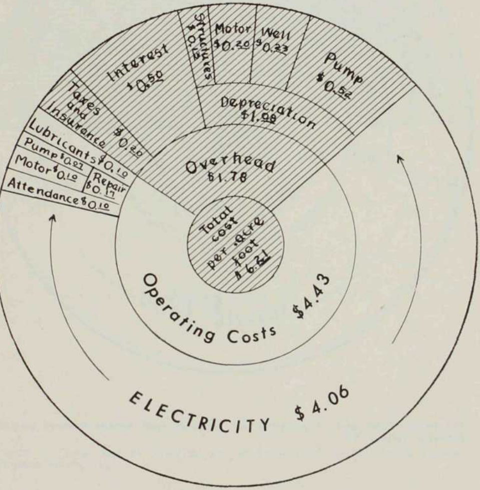

Figure 2. Total cost of pumping per acre-foot with electric-powered pumps, Estancia Valley, 1957.

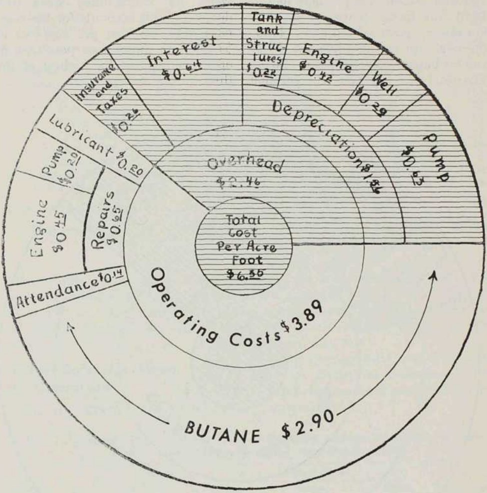

Figure 3. Total cost of pumping per acre-foot with butane-powered pumps, Estancia Valley, 1957.

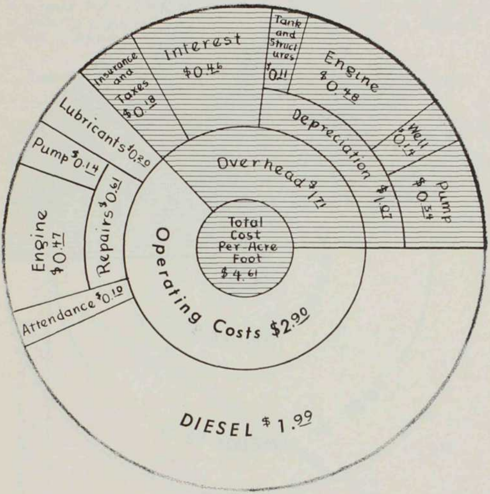

Figure 4. Total cost of pumping per acre-foot with diesel-powered pumps, Estancia Valley, 1957.

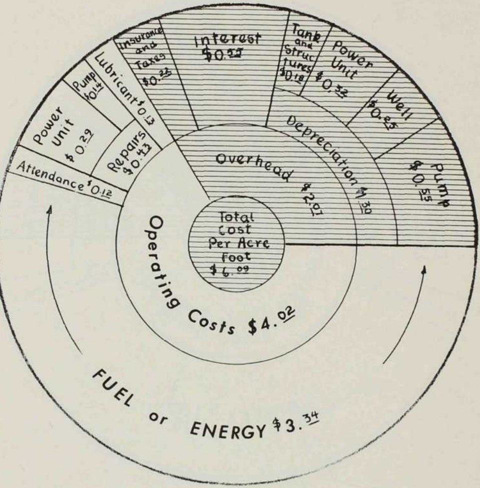

Figure 5. Total cost of pumping per acre-foot, all types of power, Estancia Valley, 1957.

Factors Affecting Total Costs

Yield of Wells

Discharge in gallons per minute is a major factor affecting the cost of pumping irrigation water. Figures 6 and 7 illustrate the influence of pump discharge in gallons per minute on operating cost. Pumps with greater yield in gallons per minute normally have lower operating costs per acre-foot. Total costs per acre-foot are also lower as indicated in table 12.

Table 12. Total Cost per Acre-Foot Based on Hours of Pumping and Yield in Gallons per Minute, Estancia Valley, New Mexico, 1957

Hours Pumped	Average Hrs. Pumped by Groups	Gallons per Minute: Less than 750	750-1,500	More than 1,500
Less than 1,000	740	$11.89	$8.29	$5.43
1,000-2,000	1,482	10.36	6.10	3.42 (a)
More than 2,000	2,805	7.47	5.28	3.89 (b)

(a) is lower than (b) largely because of a substantially higher discharge flow. Both were over 1500 gpm and each represents one observation only.

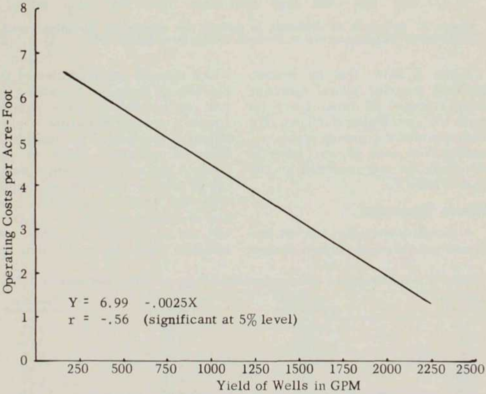

Figure 6. Influence of discharge in gallons per minute on operating costs, electric-powered pumping plants, Estancia Valley, New Mexico, 1957.

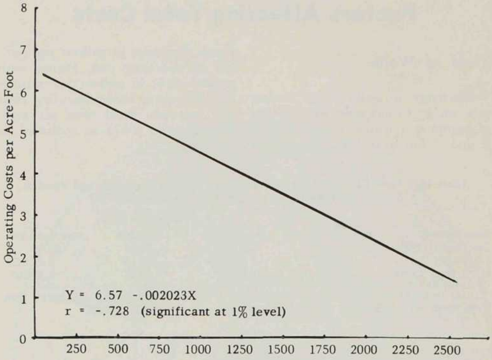

Figure 7. Influence of discharge in gallons per minute on operating costs, butane-powered pumping plants, Estancia Valley, New Mexico, 1957.

Figure 6 shows that for electric-powered pumping plants, operating costs averaged 25 cents lower for each 100 gpm higher discharge. For butane-powered pumping plants, operating costs were 20 cents lower as the discharge rate increased by 100 gpm (figure 7).

Hours Operated

Although depreciation, interest, taxes and insurance are annual charges which must be met regardless of the number of hours of operation, the cost per acre-foot of water pumped (given a specific discharge rate) is largely a function of the number of hours of operation. Table 13 and figure 8 illustrate this point through use of average data from this study, with the further assumption that fuel or energy expenses are constant and not on a declining power rate schedule. From this model, it is ap-

Table 13. Total Pumping Cost per Acre-Foot, Estancia Valley, New Mexico, 1957

Acre-Feet Pumped	Fixed Cost per Acre-Foot	Operating Cost per Acre-Foot	Total Cost per Acre-Foot
50	$11.66	$4.03	$15.69
100	5.83	4.03	9.86
200	2.91	4.03	6.94
283[1]	2.06[1]	4.03[1]	6.09[1]
300	1.94	4.03	5.97
400	1.46	4.03	5.49

[1]Average data, all types of power, Estancia Valley, 1957.

parent that fixed costs per acre-foot and total costs per acre-foot decrease as the hours of operation and the quantity of water pumped per season increase. To minimize pumping costs, farmers should irrigate sufficient acreage to get maximum benefit from each pumping plant and at the same time reserve the necessary pumping capacity to meet peak requirements.

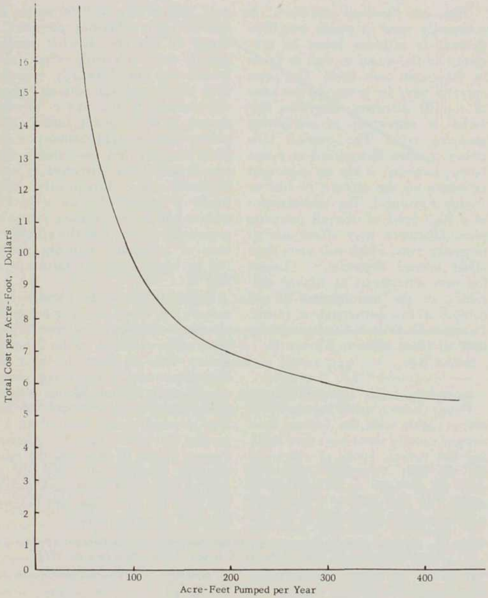

Figure 8. Total pumping cost per acre-foot, Estancia Valley, New Mexico, 1957.

In table 12, pumps in the study were divided into groups based on hours of operation and discharge in gallons per minute. Since operating costs remain fairly constant regardless of the number of hours of operation, the variation in total cost per acre-foot is primarily caused by the spreading of fixed costs.

Efficiency

The term "over-all efficiency" is commonly used in pump irrigation studies. It includes losses in efficiency in the motor as well as losses in the pump unit itself. The farm operator pays for power on the basis of over-all efficiency; therefore, this factor is important in computing pumping costs. The over-all efficiency is often disregarded as a cost factor; however, it has an important influence on the amount of fuel or energy consumed. The maintenance of a high level of over-all pumping plant efficiency may effect savings in power costs, which will more than offset annual depreciation charges for new equipment of higher efficiency or the maintenance of old equipment in a better state of repair. In appendix table 5, the formula for over-all plant efficiency given is:

$$\frac{\text{output h.p.}}{\text{input h.p.}} \times 100 = \text{over-all plant efficiency}$$

Pump characteristics curves which are available with the various bowl designs usually show one curve locating the various levels of efficiency for the unit. Pumping efficiencies may be as high as 80 percent or more. The efficiency of a new electric motor may be as high as 90 percent. Multiplying 80 × 90 we get an over-all plant efficiency potential of about 72 percent. Electric motors operate most efficiently when fully loaded and are frequently operated with small overload without apparent damage to the motor. Electric motors have a much higher efficiency than internal combustion engines because they use energy that has already been converted to high efficiency. Not infrequently, electricity is generated with a hydrocarbon fuel as the primary source of generating power. Periodic efficiency tests of irrigation pumping plants can be easily made by farm operators.

Table 14 shows the average h.p. output, h.p. input, and percent over-all plant efficiency for the various types of power used in the Estancia Valley. Over-all plant efficiency for electric-powered pumping plants ranged from about 32 percent to more than 72 percent and for butane-powered plants, from about 5.5 percent to more than 18 percent. Figures 9 and 10 illustrate the relationship between the percent of over-all plant efficiency and operating costs for electricity and butane-powered pumping plants.

Table 14. Average Output Horsepower, Input Horsepower and Percent of Over-All Plant Efficiency, by Type of Power, Estancia Valley, New Mexico, 1957

Type Power	Output HP	Input HP	Over-All Plant Efficiency, %
Electric	20.6	37.4	55.01
Butane	25.3	221.1	11.46
Diesel	40.7	222.8	18.25

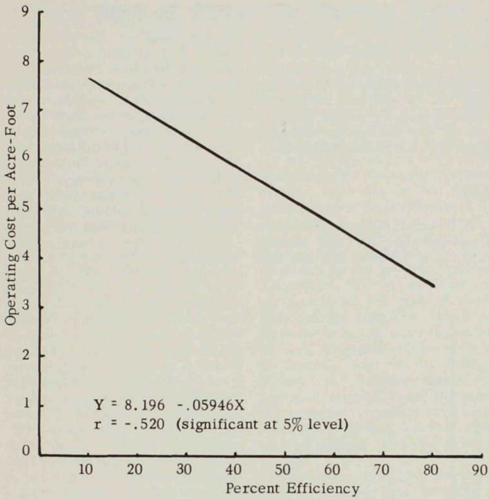

Figure 9. Influence of efficiency on operating costs per acre-foot, electric-powered pumping plants, Estancia Valley, New Mexico, 1957.

The wide variation in over-all efficiency illustrates the importance of obtaining the best engineering advice available in the selection of proper pumping equipment. The development of optimum efficiency begins with the engaging of a competent driller, who often precedes the actual drilling with a test well of small diameter to determine the characteristics of the water-bearing strata. A production test on the well after the casing is in enables the pump engineer to calculate the well characteristics curve and also saves the new pump from injury to bearings and impellers. Knowing the well characteristics, the pump engineer can correlate them with pump characteristics curves for the lift to be overcome and the discharge rate wanted, and a pumping plant of efficient design can be installed.

A reduction in over-all plant efficiency from 60 percent to 40 percent for electric-powered pumping plants would result on the average in an increase in operating costs of more than one fourth; and a reduction in over-all plant efficiency from 16 percent to 12 percent for butane-powered pumping plants would result on the average in increasing operating costs almost 40 percent.

Lift

In this study, little correlation was found between lift and pumping costs. It is believed that the wide variation in pumping efficiencies and equipment, coupled with a relatively narrow range of lifts, accounts for this lack of correlation. The cost per acre-foot per foot of lift averaged 5.5 cents for all pumping plants. Lifts ranged from 55 to 180 feet, with 67 percent falling within the 87- to 150-foot range (table 2). Total costs per acre-foot per foot of lift ranged from 3.4 cents to 15 cents. Disproportionately high costs per acre-foot per foot of lift for several low-lift plants lend additional credence to the belief that these plants were not properly designed for their present operating conditions.

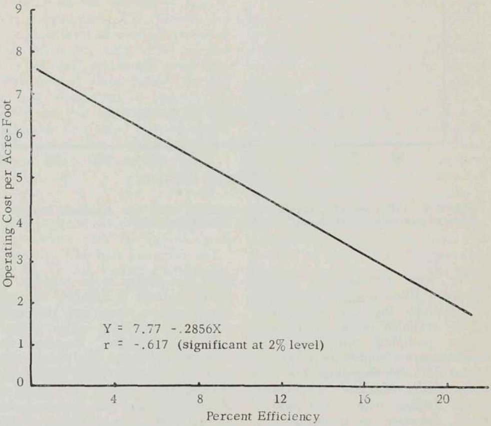

Figure 10. Influence of efficiency on operating costs per acre-foot, butane-powered pumping plants, Estancia Valley, New Mexico, 1957.

Total Cost of Water for Various Crops

The amount of water used per acre on the various crops in the Estancia Valley was calculated from discharge measurements and the number of hours of pumping reported by farmers for each crop. On most farms, irrigation water was pumped into earthen tanks or directly into earthen ditches. The actual amount of water applied to the crop depends to a certain extent on seepage and other transportation losses which occur in the storage and distribution system.

Table 15 summarizes pertinent information with regard to the cropping pattern on the sample of farms in the Estancia Valley. Crop data obtained were for the 1956 crop year. Weighted averages were used and the cost of water was based on the average total cost per acre-foot of $6.09 for all wells. The average water cost per acre varied from $6.90 for barley to $24.92 for potatoes. The cost of water calculated as a percentage of the farm value of the various crops ranged from a low of 5 percent on potatoes to 32.7 percent on hegari bundles. In most instances the actual amount of water used per acre as reported by farmers was fairly close to the irrigation requirement calculated for the various crops by the Soil Conservation Service.

Water used per acre ranged from 13.6 acre-inches for barley to 49.1 acre-inches for potatoes. The average number of irrigations for barley was two and for potatoes, 10.8. The acre-inches of water used per irrigation ranged from about five to 7.5 for most crops. Since loams and clay loam soils such as are found in much of the Estancia Valley will hold 1.5 to two acre-inches of water per acre-foot of soil depth, this means that the average depth of moisture penetration, per irrigation, in the Estancia Valley was from 2.5 to five feet.

Prices used in table 15 are average farm prices for 1956 in New Mexico and do not purport to represent prices received in the Estancia Valley.

The actual amount of water used per acre on the various crops in the Estancia Valley fluctuates from year to year, depending on the rainfall pattern during the growing season.

Although conditions vary, depending on the cropping pattern, the slope, and the soil texture, it is a rule of thumb in the western irrigation areas that a flow of one cubic foot per second, or 449 gpm, of water, will provide irrigation water for between 40 and 80 acres, depending on farm irrigation efficiency. Since the average well in the Estancia Valley had a discharge rate of 928 gpm and serviced about 101 acres, the irrigation efficiency was somewhat below average; however, there was considerable variation between farms.

It has been noted that there is a general tendency for farmers, in areas that were previously operated under dry-farming conditions, to postpone the application of irrigation water needed for maximum growth of crops in the hope that timely rains will alleviate crop distress and reduce irrigation costs. Evidences of this tendency were noted among some farmers in the Estancia Valley and there was a wide range of yields reported by farmers. Since crops in the Estancia Valley returned from three to 20 times the cost of water (table 15), depending on the crop, careful planning for the most efficient and timely use of irrigation water is an important function of farm management.

Table 15. Cropping Pattern, Irrigation Requirements of Crops, and Cost

Crop	Acreage	Percent of Total Acres	Yield per Acre	Yield[1] Potential	Avg. No. Irrig.	Acre-Inches Used per Irrig.	Actual Acre-Inches of Water Used per Acre
Alfalfa	1,177	35.2	4.5 tons	5-6 tons	7.1	5.6	39.8
Corn for ensilage	355	10.6	8.5 tons	22-26 tons	3.5	7.6	26.7
Sugar beets	316	9.5	9.5 tons	9-13 tons	6.8	6.3	42.5
Potatoes	275	8.2	190 cwt.	N.A.	10.8	4.5	49.1
Dry Beans	204	6.1	5.6 cwt.	16-18 cwt.	3.7	6.6	24.3
Corn for grain	197	5.9	22.1 cwt.	N.A.	3.8	5.1	19.4
Permanent pasture	112	3.3	N.A.	N.A.	4.2	5.0	21.1
Sorghum forage	85	2.5	4.4 tons	N.A.	3.4	5.4	18.4
Barley	70	2.1	1.1 tons	1.2 tons	2.0	6.8	13.6
Hegari bundles	40	1.2	2.0 tons	N.A.	3.0	7.5	22.5
Sorghum grain	36	1.1	50 cwt.	50-60 cwt.	5.0	3.2	16.2
Wheat	30	.9	9.0 cwt.	N.A.	5.0	2.8	14.0
Oats	28	.8	10.0 cwt.	N.A.	2.0	7.9	15.7
Other crops	420	12.6	N.A.	N.A.	N.A.	N.A.	N.A.
Total	3,345	100.0	......	....	....	....	....

N.A.=Not Available.

[1]Best results of demonstration plots in the Estancia Valley from Department of Agricultural

[2]See: Blaney, Harry F., Eldon G. Hanson and G. Marvin Litz, "Consumptive Use and Irrigation ton, D.C., December 1950.

Note: Consumptive use is defined as the "sum of the volumes of water used by the veget from adjacent soil, or intercepted precipitation on the area in any specified time, divi

[3]Irrigation requirement=net consumptive use−rainfall÷farm irrigation efficiency (estimat Harry F., Eldon G. Hanson, and G. Marvin Litz, **Op. Cit.**

[4]1956 prices from "Agricultural Statistics, 1957" and from the USDA agricultural statistician,

of Water per Acre for Crops in the Estancia Valley, New Mexico, 1957

Est.[2] Annual Consumption Use (inches)	Irrigation[3] Requirement (inches)	Average Water Cost per Acre	Yield per Acre-Inch (lbs.)	Water Cost per Unit of Crops	Price per Unit[4]	Water Cost, cwt. of Crop ÷ Value of Crop per cwt.
24.6	32.4	$20.20	244.5	$4.16 ton	$27.60 ton	15.5%
18.8	21.1	13.55	631.5	$1.16 ton	$10.00 ton	14.5%
N.A.	N.A.	21.57	516.7	$1.96 ton	$14.20 ton	13.8%
N.A.	N.A.	24.92	399.5	$0.13 cwt.	$ 2.55 cwt.	5.0%
11.5	10.2	12.33	25.5	$1.99 cwt.	$ 6.50 cwt.	30.6%
18.8	21.1	9.85	118.7	$ .24 bu.	$ 1.63 bu.	14.7%
24.6	N.A.	10.71	N.A.	N.A.	N.A.	N.A.
18.8	20.0	9.34	492.7	$2.06 ton	$16.00 ton	12.9%
12.5	14.9	6.90	163.6	$0.15 bu.	$ 1.05 bu.	14.2%
N.A.	N.A.	11.42	177.8	$5.10 ton	$18.00 ton	32.7%
18.8	20.0	8.22	311.1	$0.16 cwt.	$ 1.93 cwt.	8.4%
12.5	14.9	7.11	64.3	$0.47 bu.	$ 1.89 bu.	25.0%
12.5	14.9	7.97	63.7	$0.25 bu.	$ 0.89 bu.	28.7%
N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
....	....	....	....	....	....	....

Services, New Mexico State University.
Water Requirements of Crops in New Mexico." USDA, Soil Conservation Service, Washing-

ative growth of a given area in transpiration and building of plant tissue and that evaporated ded by the given area." It does not include waste, runoff, and deep percolation losses.
ed 55%)=amount of water required in inches per acre at the farm headgate. See Blaney,

Las Cruces, New Mexico.

Acknowledgments

The author wishes to acknowledge the able assistance of W. P. Stephens, associate agricultural economist, New Mexico Agricultural Experiment Station. Professor Stephens directed the sampling and assisted with the farm interviews in addition to giving many helpful suggestions. Appreciation is also expressed to the farmers who cooperated in the study and the following agencies in Torrance County: Central New Mexico Electrical Cooperative, New Mexico State University county extension agent, Farmers Home Administration, Soil Conservation Service, Agricultural Stabilization and Conservation Committee, and a number of local farm and pump supply businesses.

This work was completed under New Mexico Agricultural Experiment Station Research Project No. H-31 (revised).

Appendix

Appendix Table 1. Log of Well 9.8.26.430, Two Miles South of Moriarty, Estancia Valley, New Mexico[1]

Material	Thickness (feet)	Depth (feet)
Quaternary and Tertiary valley fill		
Soil	3	3
Caliche	9	12
Clay, sticky	28	40
Clay, sandy	31	71
Sand and gravel; water	5	76
Clay	22	98
Sand and gravel; water	4	102
Clay	10	112
Gravel; water	6	118
Clay	10	128
Sand and gravel; water	6	134
Clay, sandy	21	155
Sand and gravel	8	163
Clay	8	171
Sand and gravel	9	180
Gravel	12	192
Clay	6	198
Sandstone shells	4	202
Gravel	8	210
Sand and gravel	5	215
Gravel	5	220
Conglomerate	21	241
Clay and gravel	7	248
Conglomerate	23	271
Clay	7	278
Probably Abo formation		
Clay, light red	4	282
Sandstone, red	5	287
Clay, red	6	293
Conglomerate	7	300
Red bed	3	303

[1]Smith, R. G., "Geology and Ground-Water Resources of Torrance County, New Mexico," Ground-Water Report 5, New Mexico Institute of Mining and Technology, Socorro, New Mexico, 1957.

Appendix Table 2. Average Monthly Precipitation for Estancia, McIntosh, and Otto Airport in the Estancia Valley, New Mexico[1]

	Years of Record	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Estancia	43	.55	.63	.59	.91	.97	.81	2.27	2.22	1.36	1.04	.48	.65	12.48
McIntosh	27	.49	.49	.55	.77	1.38	.91	2.28	2.60	1.45	.88	.45	.48	12.73
Otto Airport	42	.49	.49	.47	.61	.99	1.03	2.27	1.97	1.37	.98	.46	.53	11.63
Average (3 stations)		.50	.54	.54	.76	1.11	.92	2.27	2.26	1.39	.97	.46	.55	12.27

[1]Source: "Climatological Summary," New Mexico Technical Report No. 6, State Engineer's Office, Santa Fe, New Mexico.

Appendix Table 3. Frost Data, Estancia Valley[1]

	Average Date Last Spring Frost	Average Date First Fall Frost	Extremes of Frost Dates	Average No. of Frost-Free Days
Estancia	May 17	Oct. 2	June 12-Sept. 8	138
McIntosh	May 17	Oct. 13	June 19-Sept. 16	149
Otto Airport	May 16	Oct. 5	June 9-Sept. 13	142

[1]Source: "Climatological Summary," New Mexico Technical Report No. 5, State Engineer's Office, Santa Fe, New Mexico.

Appendix Table 4. Average Minimum and Maximum Temperatures at Estancia, McIntosh, Stanley, and Otto Airport (1952-1958)[1]

Months	Estancia Min. — Max.	McIntosh Min. — Max.	Stanley Min. — Max.	Otto Airport Min. — Max.
January	18.9 — 49.1	20.5 — 48.1	19.6 — 44.3	16.8 — 49.5
February	19.8 — 52.0	19.8 — 50.7	18.1 — 48.5	19.0 — 50.9
March	25.6 — 56.9	25.1 — 55.6	23.9 — 54.0	23.5 — 55.0
April	31.4 — 66.4	31.8 — 65.5	32.0 — 62.2	29.3 — 67.0
May	39.5 — 76.2	40.8 — 74.8	40.2 — 73.8	39.1 — 73.2
June	48.4 — 88.1	50.9 — 86.6	49.9 — 85.4	48.7 — 86.9
July	53.4 — 89.4	54.4 — 87.3	55.6 — 87.1	53.2 — 87.9
August	52.6 — 86.3	53.2 — 84.8	53.5 — 83.9	51.6 — 85.8
September	42.2 — 83.5	43.4 — 82.3	44.1 — 82.1	41.8 — 81.4
October	33.3 — 71.1	28.6 — 70.0	32.1 — 68.1	33.3 — 70.7
November	20.6 — 55.9	22.6 — 54.5	21.0 — 50.8	18.8 — 53.3
December	14.9 — 48.8	17.3 — 47.6	13.7 — 47.0	18.6 — 41.8
Temperature extremes[2]	−33° 102°	−22° 98°	....	−27° 99°
Average pan evaporation[1] (nearest station—Santa Fe)			64.7 inches	

[1]Source: "U. S. Weather Bureau Annual Reports, 1952-58," State Engineer's Office, Santa Fe, New Mexico.
[2]Source: "Climate and Man," 1951 Yearbook of Agriculture.

Appendix Table 5. Useful Equivalents and Formulae

1 acre	=	43,560 square feet
1 acre-foot	=	43,560 cubic feet or 325,851 U.S. gallons
1 acre-inch	=	27,152 U.S. gallons
1 U.S. gallon of water	=	8.33 pounds
1 cubic foot per second	=	448.8 U.S. gallons per minute
1 cubic foot per second	=	.9917 acre-inch per hour (almost 1")
1 cubic foot per second	=	1.9835 acre-feet per 24 hours
1 cubic foot per second for 12 hours	=	1 acre-foot (approx.)
1 horsepower	=	33,000 foot-lbs. per minute
1 horsepower hour	=	.746 kwh

Horsepower required at pump shaft $= \dfrac{\text{gpm} \times \text{total pumping head in feet}}{3960 \times \text{pump efficiency } (\%)}$

Over-all plant efficiency $= \dfrac{\text{output HP}}{\text{input HP}} \times 100$

Output HP $= \dfrac{\text{gpm} \times \text{lift}}{3960}$

Input HP (1) Butane $=$ fuel consumption per hr. (gals.) $\times$ 38.4857

(2) Electric $= \dfrac{\text{total electric bill}}{\text{rate per kwh}} \times \dfrac{1.34}{\text{hours pumped}} \times 100$

(3) Diesel $= \dfrac{139{,}750 \text{ (BTU's)}}{42.44 \text{ (BTU's) per HP}} \times \dfrac{\text{gallons per hr.}}{60}$

Acre-feet pumped $= \dfrac{\text{gpm} \times \text{hours pumped}}{5400}$

Reading an electric meter: (voltage 220)

Kwh per hour $= \text{Kh} \times \dfrac{\text{revolutions counted}}{\text{seconds taken per count}} \times \dfrac{3600 \text{ (seconds per hr)}}{1000 \text{ (watts per kw)}}$

$3.6 \times \text{Kh} \times \dfrac{\text{rev. counted}}{\text{seconds per count}}$

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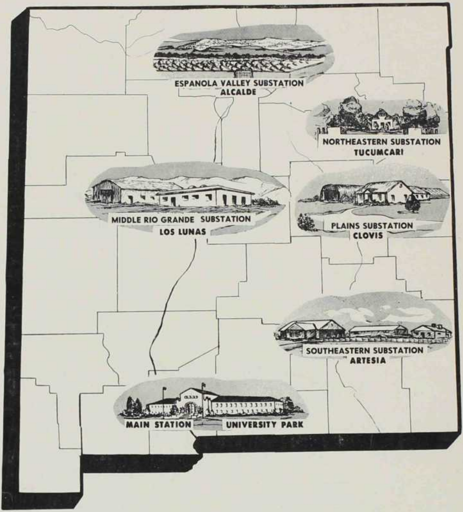

The Agricultural Experiment Station system of New Mexico State University is shown above. Headquarters of the system is the main station at University Park. The five substations carry on research that especially applies to agriculture in their areas.