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SOME ECONOMIC EFFECTS OF

Adjusting to a Changing Water Supply

TEXAS HIGH PLAINS

THE AGRICULTURAL AND MECHANICAL COLLEGE OF TEXAS / R. D. LEWIS, DIRECTOR

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Summary

Regional static water levels declined about 43 feet during the 22-year period, 1937-58. This is an average for the groundwater reservoir as a whole. It ranges from a few feet to around 100 feet in different parts of the reservoir. The effects of this decline and the number, types and extent of adjustments vary considerably, depending on major soil types, initial (1938) thickness of the water-bearing stratum, the permeability of water-bearing materials and the proportional amount of depletion experienced in specific hydrologic situations.

The principal short-run physical effects of a decline in water levels are reflected by a reduction in well capacities. The long-run effect is a depleted water supply. The types of special practices or adjustments induced by or associated with the decline in water supplies include: (1) increasing the number of hours of pump operation, (2) lowering pumps, (3) installing additional wells, (4) installing closed water-distribution systems, (5) installing smaller pumps in old wells, (6) decreasing the acreage of summer-irrigated crops and increasing the acreage of crops irrigated in fall and winter, (7) staggering grain sorghum planting dates, (8) concentrating the available water supply on cotton, (9) irrigating alternate rows; and (10) reducing the number of acres of cropland irrigated per farm.

Shifting from butane (L. P. gas) to natural gas for pump engine fuel is another significant economic adjustment. This is an economy measure not necessarily associated with changes in the water supply. As such, it is not included among the adjustments made in response to a decline in water supplies.

Physical patterns of ground water depletion are clearly defined. The number, types and extent of adjustments also are related closely to physical conditions and to the degree of depletion in specific hydrologic situations. The economic patterns stemming from these adjustments are not so clearly defined.

Several factors combine to obscure the full physical and economic effects of water level decline. Among these are: continuation, though at a slower rate, of irrigation development; elimination or reduction of transmission losses through the use of a closed distribution system; inflation; drouth and a modified irrigation program; and the shift from butane to natural gas for pumping fuel.

Elimination or reduction of transmission losses particularly has had a masking effect. In some situations, the quantity of water saved by piping water to the place of use may have been substantial. Thus, although the yield of a well may have deteriorated badly, the acreage served by the well may be near that served before the conduits were installed.

Closed distribution systems, principally underground concrete tile, served approximately 40 percent of the land irrigated in 1958. Approximately 80 percent of the systems used in 1958 were installed during 1954-58. The proportion of farms equipped with these systems ranges from 16 percent in lightly depleted areas to 100 percent in some of those more severely depleted. As the full effect of past water level declines have been offset to some extent by the elimination or reduction of transmission losses, future declines are likely to result in a greater reduction in irrigated acreage and a greater increase in costs than those that occurred during 1954-58.

The effects of adjusting to declining water supplies are reflected in increased per-acre investment in irrigation facilities, increased operating costs per acre and a reduction in the acreage of cropland irrigated per farm.

As the physical and economic effects of adjusting to a declining water supply are not reflected fully by available measurement criteria, the effects of water level decline cannot be expressed in precise mathematical terms. An examination of the series of adjustments, including their cost and effectiveness and the possibility of further adjustments of a similar nature, together with annual water level recession rates and the proportion of depletion in specific hydrologic situations, provide the basis for classifying the effect of water level decline in the following categories.

Areas not particularly affected by water-level decline include about 194,000 acres, or 5.4 percent of the acreage irrigated in 1958. In general, these were poor water areas with relatively high development costs. Both costs and the water supply situation have changed little since irrigation was developed.

Slightly affected areas include 291,200 acres, or 8.2 percent of the land irrigated in 1958. Developments in this category are among the most recent in the reservoir.

Moderately affected areas include sub-areas in which the water-level decline and decline-induced adjustments have increased both investment and operating costs and impaired the water supply to some degree. This group includes 2,283,000 acres or approximately 64 percent of the land irrigated in 1958.

Seriously affected areas include sub-areas in which the decline in water level and decline-induced adjustments have seriously depleted the water supply, sharply increased the investment in irrigation facilities and substantially increased operating costs. Approximately 724,000 acres, or 20 percent of the land irrigated in 1958, are included in this category.

Severely affected areas include sub-areas in which the water supply has been severely depleted and in which further increases in operating cost would impair the economic feasibility of continued water use. Approximately 82,400 acres, or 2.3 percent of the land irrigated in 1958, are included in this category.

Some Economic Effects of Adjusting to a Changing Water Supply, Texas High Plains

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DECLINING WATER LEVELS are a cause of growing concern among farming, business and financial interests on the High Plains. The decline, which began shortly after irrigation was developed on a significant scale, was accelerated by the expanded development and increased rates of water use during the drouth years of 1950-56. It continued, although at a reduced rate in most places, under the improved moisture conditions of 1957-58.

The study reported was designed to assess the effects of the decline in water levels, the part of the area affected and the adjustments that have been made in response to the change in water supplies. It covers a 12-year period that begins with a 1947-49 study reported in TAES bulletins 745 (1), 756 (2) and 763 (3) and ends with a comprehensive survey of 1958 farm operating conditions. A 1955 survey of changes in investment and irrigation costs between 1950 and 1954, which was published in Bulletin 828 (4), provides a measure of conditions about midway in the 12-year period.

Before 1947, water-level declines were slight or economically insignificant. Consequently, the data developed in the 1947-49 study provide a basis for appraising the effects of subsequent changes in water supply. With appropriate adjustment to compensate for possible inflation in the cost of irrigation facilities, for changes in the type and unit cost of fuel or energy and for seasonal effects on the length of the pumping season, the data developed in the 1954 and 1958 studies provide a measure of change that can be attributed to the decline in water supplies.

The study was restricted to the area designated by the State Board of Water Engineers as Subdivision No. 1 of the High Plains Underground Water Reservoir. It includes all or parts of 21 counties and covers a total area of 10,649 square miles. Although the study area was restricted in area, for purposes of simplification, the study area is designated herein as the High Plains.

The study is reported in three parts. The first consists of a description and discussion of conditions for the area as a whole. The second examines development trends, adjustments and other pertinent changes during the 12 years in specific hydrologic sub-areas. The third part assesses some of the economic effects of adjusting to the changing water supply situation.

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Present Situation

WATER RESOURCES

Water resources of the High Plains were studied by Johnson in the late 1890's (5), by Gould in 1904-05 (6) (7), by Mienzer in 1909 (8) and by Baker in 1914 (9). They have been examined in greater detail since irrigation development got underway. Barnes, *et al*, published the most recent comprehensive study of the nature and occurrence of groundwater in the High Plains in 1949 (10). A map showing the location and thickness of the water-bearing strata within the district was compiled and published by the High Plains Under-

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TABLE 1. THICKNESS OF WATER-BEARING STRATA, SUBDIVISION NO. 1 HIGH PLAINS GROUND-WATER RESERVOIR, 1938

Thickness of water-bearing strata	Area[1]	Per-centage of total area	Cumu-lative per-centage
	Square miles	Percent	Percent
Under 50 feet	1424	13.4	13.4
50 to 100 feet	2296	21.6	35.0
100 to 150 feet	2029	19.0	54.0
150 to 200 feet	1633	15.3	69.3
200 to 250 feet	1535	14.4	83.7
250 feet & over	1490	14.0	97.7
Unclassified[2]	242	2.3	100.0
Total	10,649	100.0	

[1]Planimetered from Figure 6.
[2]Mostly in the "under 50 foot" category.

ground Water District No. 1 in 1956 (11). This map, supplemented by data supplied by the U. S. Geological survey and the Board of Water Engineers, is shown as Figure 6.

These reports provide detailed information regarding the geology and occurrence of groundwater in the High Plains. The more salient conclusions concerning the geology and occurrence of groundwater in the study area are summarized by Barnes,

> "The water-bearing formations of the Southern High Plains in Texas are of Triassic, Cretaceous, Tertiary, and Quaternary age. Only a few wells obtain water from the nonmarine Dockum beds of Triassic age, and the potential value of the Triassic groundwater reservoirs appears to be small. Cretaceous formations are found only in the southwestern part of the area where yields of 500 to 1,000 gallons per minute are obtained locally from porous limestones and from basal sands that average about 12 feet thick. The Pliocene series of Tertiary age is represented by the Ogallala formation of alluvial origin, which is the most important water-bearing formation in the region. The Ogallala has an average thickness of about 300 feet, and approximately two-thirds of the saturated portion of the formation is composed of sand from which some wells yield as much as 2,000 gallons per minute." (10)

Regulations of the High Plains Underground Water Conservation District and special studies have provided a large number of well logs which permit more precise mapping of the thickness and extent of the water-bearing strata than was possible in 1949. A comprehensive study based on these data is underway.

Table 1 shows that the initial thickness (1938) of the water-bearing strata was 150 feet or less over about 54 percent of the reservoir area. Only 14 percent was underlain by a water-bearing stratum that was more than 250 feet thick in 1938.

With reference to the annual rate of replenishment, Barnes, *et al.*, states,

> " . . . The average annual recharge to 9,000 square miles in the High Plains, which contained most of the irrigation wells in 1940, was estimated by White, *et al.*, to be on the order of 30,000 acre-feet a year" (10).

An area of some 13,000 square miles is considered to be the contributing area to the groundwater reservoir, but the authorities cited caution that, because of physical differences, the additional 4,000 square miles may not contribute a similar proportional amount of recharge (10).

In their concluding statement, Barnes, *et al.*, say,

> "Groundwater is considered to be a replenishable resource, but the rate of groundwater recharge in the Southern High Plains in Texas is so small compared to present pumpage that for practical purposes withdrawals may be considered as coming from storage . . . " (10)

TABLE 2. ACREAGE IRRIGATED, HIGH PLAINS, TEXAS, 1936-1958[1]

Year	Acres Irri-gated[2]	Year	Acres Irri-gated[2]
1936	80,000	1944	450,000
1937	160,000	1945	550,000
1938	200,000	1946	650,000
1939	230,000	1947	900,000
1940	250,000	1948	1,250,000
1941	[3]	1949	1,496,000[4]
1942	[3]	1954	2,692,000[4]
1943	400,000	1958	3,575,000[5]

[1]Subdivision No. 1, High Plains Underground Water Reservoir, on cover page.
[2]Data for 1936-48 inclusive adopted from Table 8A, Barnes, et al., (10).
[3]Acreage irrigated was small because of exceptionally high or well-distributed precipitation.
[4]Census of irrigation, 1950 and 1955, respectively.
[5]Acreage expanded from comprehensive random sample survey—January, February, 1959.

"Present pumpage" in the above citation was 1.25 million acre-feet. Withdrawals in 1958, which were about a third lower than those of 1956 or 1957, approximate 3,500,000 acre-feet (13).

In summary, the underground water reservoir of the High Plains

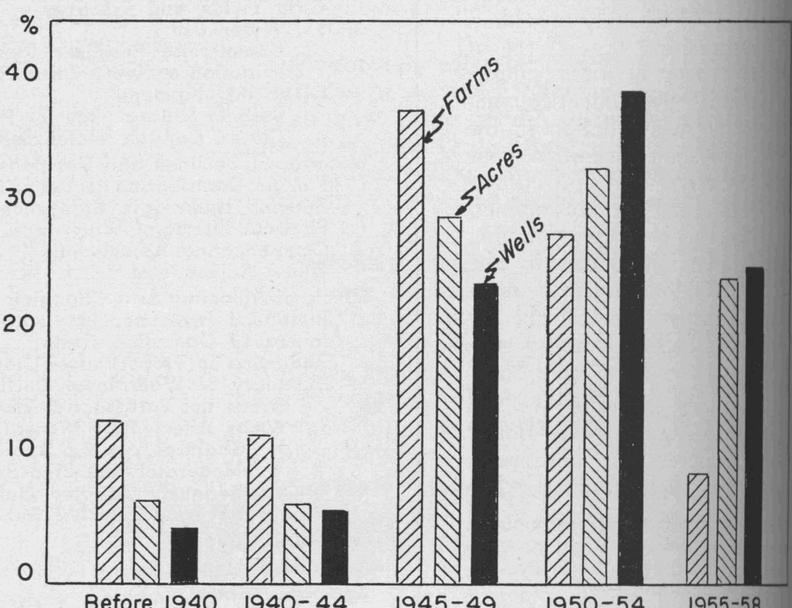


Figure 1. Proportion of farms, acres and irrigation wells by development periods.

contains a definite amount of water, which for all practical purposes is not subject to renewal. Thus with a fixed amount of resources, the problem as with other mining operations, is one of allocating their use through time.

IRRIGATION DEVELOPMENT TRENDS

Irrigation development began near Plainview in 1911 (14). By 1914, it was centered principally in the shallow water areas in the vicinity of Plainview, Muleshoe and Hereford. Development spread slowly until the mid-1930's when technological improvements in pumping and power transmission equipment made it possible to develop irrigation at a moderate cost. Development expanded rapidly thereafter, reaching a peak rate in the drouth years of 1950-54, when a third of the present irrigated acreage was developed. During the 1958 irrigation season, approximately 3,575,000 acres were irrigated on 12,850 farms.[1]

The trend in irrigation development is shown in Table 2. The proportion of farms on which irrigation was developed, the percentage of the acreage developed and the proportion of wells drilled by development periods are given in Figure 1. Irrigation was developed on 38 percent of the farms during 1945-49. The largest increase in irrigated acres and in number of wells drilled occurred during the drouth years of 1950-54, Figure 1. Development continued after 1954, but at a materially reduced rate. A large proportion of the wells drilled after 1950 and particularly after 1955, have been drilled on farms where irrigation had been developed earlier. Irrigation was developed on only 9 percent of the farms during 1955-58.

Figure 1 shows that a disproportionate number of wells have been required for the irrigated acreage added after 1950. There are several reasons for this, but mainly it reflects, (1) drilling on the reservoir fringes where water-bearing strata are thin and well yields are low, and (2) drilling additional wells to offset the effects of declining water supplies. These reasons are discussed in a later part of this report.

[1] A farm in this study includes all land under one management, irrespective of location or ownership.

DECLINE IN WATER LEVEL

A systematic program of well-inventory and water-level measurements was started in 1937 by the State Board of Water Engineers and the U. S. Geological Survey. The well-inventory program became impractical to maintain as development was accelerated during the late forties. However, water-level measurements in a network of representative wells have been continued without interruption since the program was started in January 1937.

Data developed, from these measurements, show that average water levels for the study area declined about 43 feet between January 1937 and January 1959, Table 3. The decline has not been uniform nor has it proceeded at a uniform rate in all parts of the groundwater reservoir. Near the edges of the reservoir, where the water-bearing strata are thin and development is more recent, the 22-year decline amounts to less than 20 feet. In a few small areas near the east-central part of the reservoir, where water-bearing strata are thick and development is both concentrated and older, the 22-year decline approximates 100 feet. Between these extremes, the water-level decline ranges chiefly from 20 to 60 feet.

The location of the parts of the groundwater reservoir affected by declines in the water level are shown in Figure 2. The accumulated change in regional static water levels in relation to acreage irrigated is shown in Figure 3.

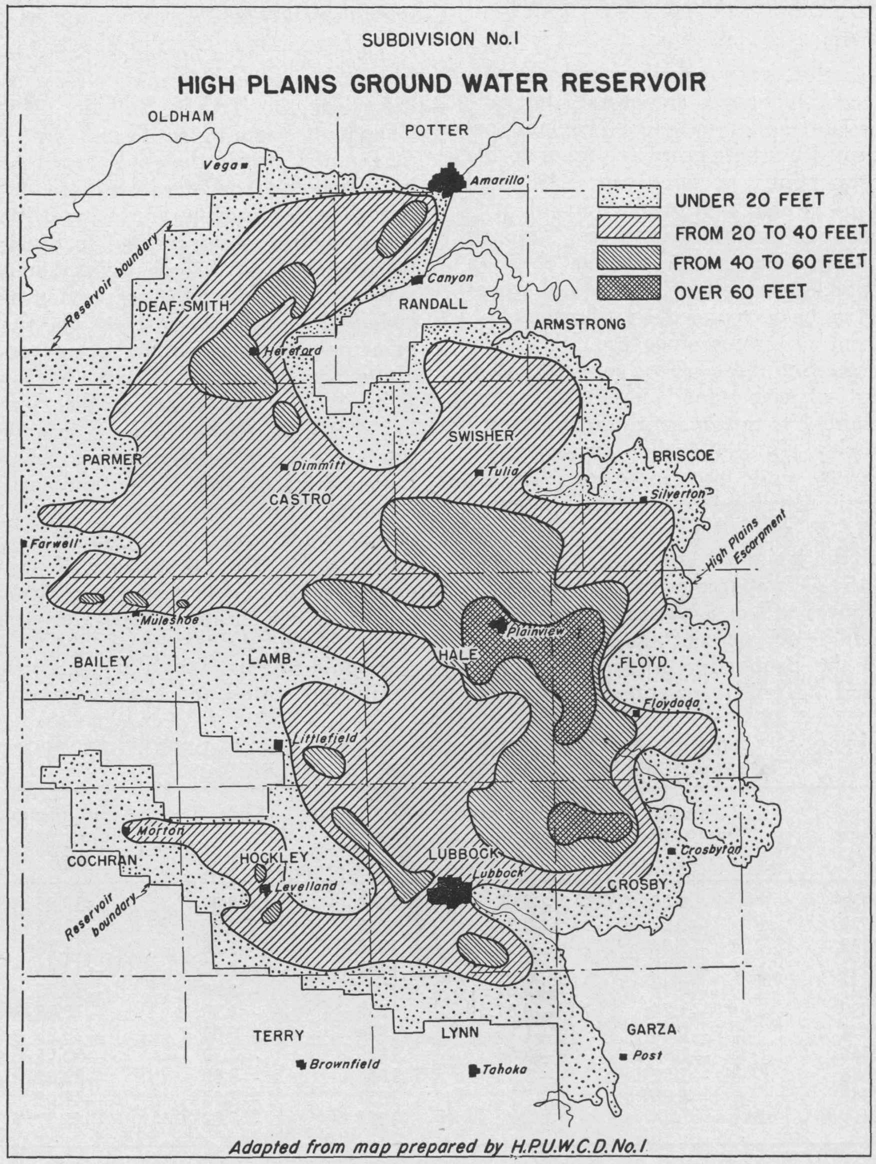


Figure 2. Approximate decline of the water table, 1938-1958.

LAND USE AND TYPE OF FARMING

A high proportion of irrigated farms in the High Plains contain only cropland. The proportion of cropland that is irrigated differs with the hydrologic conditions in different parts of the area.

Cropland Use

Although some new crops, notably soybeans and vegetables, have been introduced in recent years, cotton, grain sorghum and wheat are still the principal crops. In 1958, they occupied about 87 percent of the cropland. All other crops combined occupied less than 6 percent of the total cropland. Slightly more than 7 percent of the normally irrigated cropland was idle or fallow (acreage reserve) in 1958, Table 4.

The acreages of the principal crops —cotton, grain sorghum and wheat— have fluctuated somewhat, but the proportion of irrigated cropland occupied by these crops is similar to the proportions occupied in 1948 and 1954 when the proportion of irrigated cropland classed as "idle or fallow" was much smaller than in 1958. Acreages of cotton and wheat have been reduced by acreage-allotment programs since the 1954 crop year, but most of the acreage taken out of cotton and wheat has been planted to grain sorghum and some barley. In 1948, when acreage allotments were not in effect, cotton, grain sorghum and wheat occupied 35, 38 and 19 percent, respectively, of the irrigated cropland in the area (15). Compared with 1948, the 1958 figures reflect a change of −5.3 percent, +6.5 percent and −4.8 percent in the proportion of irrigated cropland occupied by cotton, grain sorghum and wheat, respectively, Table 4.

Type of Farming

The proportion of cropland devoted to the principal crops is independent of hydrologic conditions. The proportion of cropland irrigated, however, is related to hydrologic conditions, as is brought out in greater detail in later sections of this report.

Since the ability to absorb increased costs or decreased returns is closely associated with specific crops, the emphasis placed on particular crops (or the type of farming) provides a basis for appraising the past and future effects of a decline in water supplies on farm income. Most of the comparisons hereafter are between conditions within a particular type-of-farming area.

The study area includes parts of two major type-of-farming areas, as described in TAES Bulletin 964, "Types of Farming in Texas," by C. A. Bonnen. Since the study reported here involves considerably more detail than is possible in a statewide study, such as was reported in Bulletin 964, the study area is divided into four parts based on the proportion of irrigated cropland devoted to the principal crops — cotton, grain sorghum and wheat — and the major soil types. Thus, none of the four parts used in the study have exactly the same boundaries as the major type-of-farming areas. The four parts or areas used in the study are designated as farming areas A, B, C and D, Figure 4. The proportions of irrigated farms in the respective farming areas are shown in Table 4.

Farming areas A and B are similar in that cotton and grain sorghum are the principal crops, occupying 90 and 80 percent, respectively, of all cropland. Farming area A includes farms producing cotton and grain sorghum on sandy (mixed) soils, whereas on farms in farming area B, cotton and grain sorghum are produced on heavy soils.

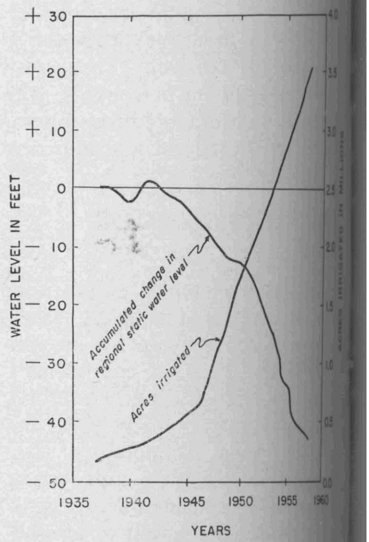


Figure 3. Accumulated change in regional static water level related to the acres irrigated, 1937-1958.

Farms in farming area C include wheat among the principal crops. These farms are similar to those in farming area B in all except the acreage in wheat. Farms in area C have 10 percent or more of all cropland in wheat, Table 4. Farming area C is designated as a cotton-grain sorghum-wheat farming area, Figure 4.

Farming area D is a grain sorghum-wheat producing area. Cotton occupies less than 10 percent of the cropland, Table 4 and Figure 4.

Size of Farm

In 1958, the average irrigated farm contained 405 acres. Cropland constituted 90 percent of the average farm, or 363 acres, with 289 acres irrigated, Table 4. The average size of farm ranged from 293 acres in farming area B to 663 acres in farming area D. Cropland per farm ranged from 82 percent in farming area D to 96 percent in farming area A. The proportion of cropland irrigated in farming area A was only 62 percent, compared with 89, 90 and 83 percent, respectively, in farming areas B, C and D. Farming area A contains a high proportion of the low-yielding wells that have been developed on the fringes of the ground-

TABLE 3. ANNUAL FLUCTUATIONS AND ACCUMULATED DEPARTURE FROM 1937 STATIC WATER LEVEL, TEXAS HIGH PLAINS, 1937-58[1]

Year	Annual fluctuation, feet	Accumulated departure, feet	Year	Annual fluctuation, feet	Accumulated departure, feet
1938	+0.05	+0.05	1948	−2.87	−10.65
1939	−0.92	−0.87	1949	−0.80	−11.45
1940	−2.24	−3.11	1950	−1.30	−12.75
1941	+3.61	+0.50	1951	−2.10	−14.85
1942	+0.37	+0.87	1952	−3.90	−18.75
1943	−1.74	−0.87	1953	−4.90	−23.65
1944	−0.83	−1.70	1954	−5.60	−29.25
1945	−1.86	−3.56	1955	−4.50	−33.75
1946	−1.62	−5.18	1956	−5.60	−39.35
1947	−2.60	−7.78	1957	−2.33	−41.68
			1958	−1.09	−42.77

[1]Based on static water-level measurements by the USGS and State Board of Water Engineers, study area only.

water reservoir, and the water supply is generally insufficient. This is indicated by the 117 acres of dry-farmed land per farm and the 8.2 percent of dry land planted to cotton, Table 4.

Each census report since 1940 has shown an increase in the size of irrigated farms and in the number of acres irrigated per farm. According to the 1954 Census of Agriculture, the average irrigated farm in the 21-county groundwater reservoir area contained 508 acres with 238 acres irrigated (16). Although the figures are not entirely comparable, the average irrigated farm included in the study contained 405 acres in 1958, Table 4.

Data with which to determine the amount of farm subdivision that has occurred in the area as a whole or in each of the four farming areas are not available. Data developed in the 1955 and 1959 surveys provide some measure of the change that occurred in farm size in two of the four farming areas between 1954 and 1958, Table 5.

Changes in farm sizes have moved in opposite directions in Farming areas A and B, Table 5. In area A, the proportion of farms of less than 350 acres decreased between 1954 and 1958. The proportion of farms with less than 350 acres increased slightly in area B. There was a sharp increase in the proportion of 351 to 450-acre farms in area A and an almost equal decline in farms of similar sizes in area B, Table 5.

Farming areas A and B include the portions of the reservoir area that are experiencing the greatest total and proportional declines in water levels.

Tenure

The proportion of owner-operated farms has increased since 1954. For the area as a whole, 64 percent of the 1958 farm operators had an equity interest, that is, they owned all or part of the land they operated, compared with about 50 percent in 1954. The proportion of full owner-operated farms differs considerably between farming areas, ranging from a low of 35 percent in area A to 63 percent in area C, Table 6.

Owner-operated farms contain less cropland per farm than tenant or "owner-additional" operated farms. The land owner who rents additional cropland operated the largest average number of cropland acres per farm, Table 6.

The operators of irrigated farms show a high degree of residential stability. The average length of residence on the farm is closely associated with land tenure. Owner-operators averaged 17 years of occupancy on their farms and tenant operators 8.6 years, Table 6.

The crop share lease predominates on tenant-operated farms of the High Plains. Slightly less than 3 percent of the leasing agreements were cash leases, which were equally distributed among the four farming areas. A few partnership and manager-operated farms were enumerated in the survey. Father-and-son-operated farms, which are included among the owner or owner-additional operator groups, were considerably more numerous than farms operated under cash leases.

CROP YIELDS AND PRACTICES

Moisture conditions during 1957-58 were better than those of the 1950-56 period. The more favorable moisture situation, in conjunction with increased use of fertilizer and hybrid grain sorghum, was reflected in generally higher yields, particularly for dryland crops and irrigated grain sorghum. Dryland and irrigated crop yields are reported in Table 7 by farming area and soil type, and for the reservoir area.

The average yield of dryland crops in 1954-58, which included 3 dry years and 2 years with favorable moisture supplies, approached the longtime average for dryland crops in this part of the High Plains, Table 7.

Because of unfavorable fall weather in 1957, the 5-year (1954-58) average yield of irrigated cotton was somewhat lower than the average yield obtained in 1954. Although the difference is neither so pronounced nor so wide as in 1954, irrigated cotton on heavy soils outyielded irrigated cotton grown on sandy (mixed) soils, Table 7.

Use of hybrid grain sorghum, which has come into general use in recent years, and expanding use of fertilizer have increased grain sorghum yields, particularly in the heavy soil area. The 1954-58 average yield of irrigated grain sorghum in farm area A, is somewhat below the yields obtained in 1954. This is an

TABLE 4. SIZE OF FARM, LAND USE, CROPLAND USE AND ESTIMATED VALUE PER ACRE, BY FARMING AREA, IRRIGATED FARMS ONLY, 1958

Item	Unit	Farm area[1]				Area total
		A	B	C	D	
Proportion of farms	Percent	37	30	19	14	100
Size of farm	Acre	320	293	543	663	405
Cropland per farm	do.	309	269	472	542	363
Noncropland per farm	do.	11	24	71	121	42
Irrigated cropland per farm	do.	192	239	423	450	289
Nonirrigated cropland per farm	do.	117	30	49	92	74
Cropland use:						
Cotton	Percent	38.8	31.3	19.3	3.2	23.7
Grain Sorghum	do.	51.7	48.4	46.8	45.8	48.5
Small grain[2]	do.	1.2	5.2	21.1	38.0	14.7
Other crops	do.	5.0	7.5	4.4	6.4	5.7
Fallow[3]	do.	3.3	7.6	8.4	6.6	7.4
Irrigated cropland use:						
Cotton	do.	57.2	34.7	21.2	3.8	29.7
Grain sorghum	do.	31.7	49.2	48.9	47.6	44.5
Small grain[2]	do.	1.8	2.2	19.3	35.9	14.2
Other crops	do.	6.6	7.7	4.2	7.3	6.4
Fallow[3]	do.	2.7	6.2	6.4	5.4	5.2
Nonirrigated cropland use:						
Cotton	do.	8.2	3.7	3.2	0.0	5.6
Grain Sorghum	do.	84.8	41.8	28.4	36.8	64.1
Small grain[2]	do.	0.0	28.7	37.8	49.4	15.3
Other	do.	2.1	5.9	6.0	1.8	3.0
Fallow[3]	do.	4.9	19.9	24.6	12.0	13.0
Estimated value per acre[4]	Dollar	327	324	267	232	289

[1]See text, pages 6 and 7, for description and Figure 4 for location of farming areas.
[2]Wheat, barley, and oats.
[3]Includes formerly irrigated land that was idle or in acreage reserve in 1958.
[4]Estimated market price of land and buildings for the farm as a unit, January 1959.

area with generally short water supplies, and the available water is usually applied to cotton, see Table 4. Also, grain sorghum is not fertilized as heavily or as commonly in this area as in the heavy soils areas.

Yields of irrigated grain sorghum in areas with heavy soils are up over those received before adoption of hybrids and use of fertilizer. The 1954-58 average yield is 380 pounds greater than in 1954, Table 7. The 1958 average yield of 4,100 pounds per acre is probably more representative of the yields that might be expected with the use of hybrids and fertilizer. The 1954-58 average yield does not reflect 5 years of general fertilizer and hybrid sorghum use. The 5-year period includes the transition from standard to hybrid varieties and a substantial expansion in use of commercial fertilizers.

Water Use

Data are not available to permit a determination of water use for the area as a whole. Few farmers know the exact amount of water applied per irrigation or the total amount applied to a particular crop during the year. But there are sources of data that can be drawn on to provide some estimate of water use. The first of these is a series of water measurements made by the High Plains Underground Water Conservation District No. 1. Second, are the somewhat less precise yet nevertheless useful reports by farm operators of the number of times a particular crop was irrigated, operators' estimate of the amounts they intended to apply, hours of pump operation, and number of acres irrigated per well. This combination of reported activities by farming area or by specific hydrologic sub-area, along with some specific information developed by the HPUWCD No. 1, provides some basis for approximating water use.

The number of times crops were irrigated differed considerably in 1956, 1957 and 1958. Precipitation in 1956 generally was inadequate. Moisture conditions were much improved in 1957-58, but the improvement occurred in different parts of the year. The early part of 1957 was dry, and heavy preplanting irrigation was required. Moisture conditions were fairly adequate during the summer of 1957 and irrigation was reduced. The situation was reversed in 1958. Little or no preplanting irrigation was needed, but during the summer irrigation season, heavy irrigation was required.

Moisture conditions are seldom ample throughout the entire reservoir area. Such was the case in both 1957 and 1958. Locally, but not necessarily in the same location each year, moisture supplies were inadequate and it was necessary to irrigate as in 1956.

Crop yields in relation to number of irrigations and fertilizer use in 1958 are shown in Table 8.

A synthesis of these indicators of water use suggests that the average gross rate of water application in 1958, a year with below-normal irrigation requirements, was similar to that of 1947-49, when 11 acre inches per acre were applied. The amount of water applied on cotton grown on both heavy and sandy soils was generally about a third greater than the amount applied on grain sorghum grown on similar soils. The amount of water applied to grain sorghum grown on heavy soils was about a third greater than the amounts applied on sandy (mixed) soils. This difference in rate of water application reflects a generally more adequate water supply and a greater use of fertilizer in the heavy soil areas.

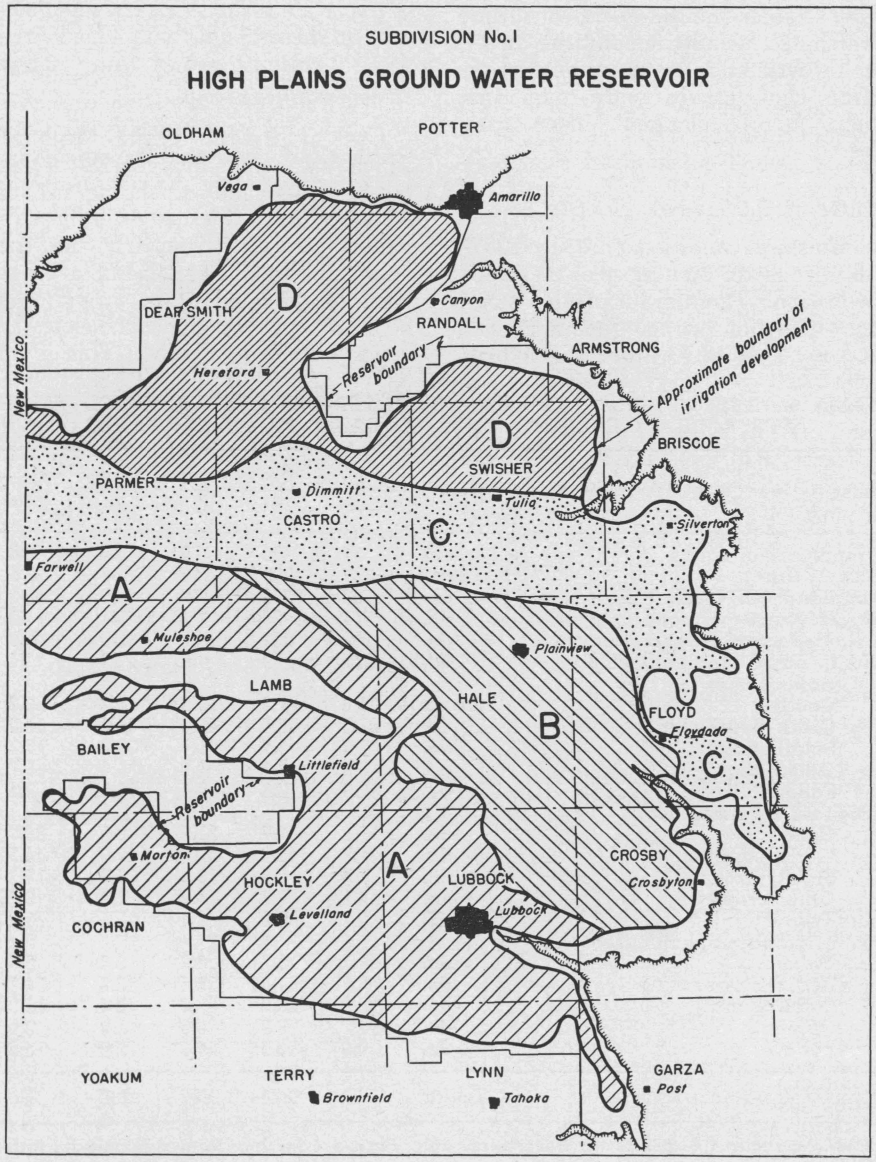


Figure 4. Farming Areas: A. Cotton—grain sorghum, mixed land; B. Cotton—grain sorghum, heavy land; C. Cotton—grain sorghum—wheat; D. Grain sorghum—wheat.

Commercial Fertilizer Use

Use of commercial fertilizer, particularly on grain sorghum and wheat grown on heavy soils, has increased greatly in the last 2 or 3 years.

Farm operators report that they try to maintain a higher soil moisture level, usually by applying at least one additional irrigation, when commercial fertilizers are used on grain sorghum. Because of locally favorable moisture conditions in 1958, it was often possible to maintain high moisture levels with fewer than the usual number of irrigations. In addition to the seasonal difference, there are differences among farm operators in the number of times a crop is irrigated. These seasonal and individual differences in the number of irrigations affect the accuracy of results obtained by comparing the yields obtained with and without commercial fertilizers.

Per acre rates of fertilizer application did not vary widely between farms. Anhydrous ammonia was the predominant fertilizer used on grain sorghum and wheat. A few applications of 60 pounds per acre were reported, but the more common rate of application ranged between 80 and 100 pounds per acre. Some anhydrous ammonia was applied on cotton, but mixed fertilizer at a rate of 200 pounds per acre predominated.

Fertilizer use and yield differences were closely associated with the major soil types. Yields were associated also with practices commonly used with certain soil conditions.

The proportion of farm operators using fertilizer, the proportion of crop acres fertilized, rates of fertilizer use and other pertinent details bearing on the use of commercial fertilizer in 1958 are shown in Table 8. The data in Table 8 are average results obtained with the indicated practices under the weather conditions of 1958. Weather conditions in different years or greater experience with use of fertilizer might lead to different results.

As the data in Table 8 reflect the results from only 1 year, no definite conclusions with respect to the use of commercial fertilizer can be drawn. They are indicative, however, of what might be expected in years with moisture conditions similar to those in 1958. Under these conditions and except for the results obtained with cotton on sandy (mixed) soils, the 1958 results suggest that increasing the number of irrigations provides a low rate of return from the water used, particularly on grain sorghum and wheat. With moisture conditions similar to those of 1958, the use of fertilizer without an additional irrigation was profitable for grain sorghum grown on both heavy and sandy soils and for wheat grown on heavy soils. Although use of fertilizer on cotton following grain sorghum has increased yields as much as 500 pounds per acre under ideal conditions, fertilizer did not increase the yield of cotton grown on heavy soils in 1958, Table 8.

Except for the results obtained with cotton in sandy (mixed) soils, an additional irrigation on fertilized cotton, grain sorghum and wheat was not profitable in 1958. Some increase in yield was obtained in all three instances, but at 1958 prices, the yield increases were not large enough to defray the added water costs, except in the lowest cost water areas.

Under 1958 conditions, the increased production from fertilizer and from added irrigation on cotton grown on sandy (mixed) soils was highly profitable. The yield increases obtained with fertilizer on cotton with less than three irrigations were not as great as those obtained from the use of additional irrigation without fertilization. Despite the lower increase in yield resulting from application of fertilizer, with low well yields and relatively high water costs, it may be more profitable to increase yields by applying fertilizer rather than by applying additional water. When water supplies are ample, the two practices may be combined advantageously.

Irrigation of Every Other Row

Another practice that has come into general use in recent years, particularly in farming areas A and B, is that of irrigating every other row. In 1958, the practice of irrigating every other row was followed by about half of the farm operators in farming areas A and B. Slightly less than a third of the acres irrigated in these farming areas were irrigated by the every other row method. The practice is seldom applied in farming areas C and D.

The practice of irrigating every other row has some advantages. When water supplies are scarce, the practice permits a timely, though reduced, application of water over

TABLE 5. SIZE OF IRRIGATED FARMS BY FARMING AREAS, 1954 AND 1958

Range in farm size	A 1954	A 1958	B 1954	B 1958	C 1958	D 1958	Study area total 1958
	Percent						
150 acres and less	12	8	12	13	3	0	7
151-250 acres	45	40	39	42	16	9	31
251-350 acres	28	21	23	26	36	27	26
351-450 acres	5	15	12	3	6	7	9
451-550 acres	5	7	2	6	3	12	7
551 acres and more	5	9	12	10	36	45	20

TABLE 6. TENURE STATUS OF IRRIGATED-FARM OPERATORS, BY FARMING AREA, HIGH PLAINS, TEXAS, 1958

Farming area[1]	Tenant: Percent	Tenant: Cropland per farm	Tenant: Lived on farm	Owner-additional[2]: Percent	Owner-additional[2]: Cropland per farm	Owner-additional[2]: Lived on farm	Owner: Percent	Owner: Cropland per farm	Owner: Lived on farm	All operated cropland per farm
		Acres	Years		Acres	Years		Acres	Years	Acres
A	48	319	10.1	17	348	15.3	35	280	19.1	309
B	34	289	7.8	10	256	13.5	56	258	15.1	269
C	22	477	6.4	15	563	17.1	63	452	19.7	472
D	30	438	6.9	25	956	12.9	45	380	13.9	542
Average	36	344	8.6	16	515	14.7	48	329	17.0	363

[1]Irrigated farms only, see Figure 4 for farm area delineation.
[2]Part of the farm owned and part rented.

more acres in a similar period of time than otherwise possible by irrigating all rows. Also, its use provides for the building up of larger heads of water, which contributes to a more uniform distribution on sandy soils.

The results obtained in 1958 with this practice are shown in Table 9.

OTHER DEVELOPMENTS

The shift from butane (L. P. gas) to natural gas for pumping and the installation of underground concrete-tile distribution systems, which have occurred mainly during the past 5 years, are very important to the irrigation economy.

Shift to Natural Gas for Pumping

Excluding the area in which the water-bearing stratum was less than 50 feet thick in 1938, natural gas was used on 61 percent of the farms and 68 percent of the wells in 1958. The proportion of wells fueled by natural gas is higher in the heavy soils area, farming areas B, C and D. Pumps powered by butane and electricity predominate in farming area A. Most of the area with an initial water-bearing stratum of 50 feet or less is located in farming area A. In this area of thin, water-bearing stratum, approximately 31 and 62 percent of the wells were powered by butane and electricity, respectively. It is not unusual for both types of power to be used on the same farm.

In the rest of farming area A, Figure 5, where water-bearing strata are thicker, butane and natural gas are used on 38 and 47 percent of the wells, respectively.

A few favorably located wells have been fueled by natural gas since the early 1940's, but the major shift to natural gas began in 1952. Only 3 percent of the wells fueled by natural gas in 1958 began using natural gas before 1952. Approximately 28 percent of the 1958 gas-fueled plants were connected in 1953 and 1954, and 69 percent were shifted to natural gas in the 4-year period, 1955-58.

Because of low energy requirements of pumps and high installation costs of gas lines, natural gas is not a particularly competitive source of power in areas with the thinnest water-bearing strata. In other localities, most of the change to natural gas has been to replace butane. Some plants powered by electricity have been converted to natural gas, but the expense involved has tended to delay the change. Gasline costs are virtually the only investment cost involved in changing from butane to natural gas. The change from electricity to natural gas requires a different type of power unit and a gearhead, as well as the cost of a gasline.

Closed Conduit Water-distribution Systems

In 1958, underground concrete tile or aluminum surface pipe distribution systems were used on approximately 97 percent of the farms and on 90 percent of the acres irrigated in areas with water-bearing strata of 50 feet or less. For the Ground Water Reservoir area as a whole, 50 percent of the irrigated farms were equipped with closed distribution systems in 1958. The proportions of the

TABLE 7. DRYLAND AND IRRIGATED CROP YIELDS, BY FARMING AREAS AND BY SOIL TYPE[1]

	Item	Unit	Average yield by farming area[2]				Average yield by soil type		Reservoir average yield
			A	B	C	D	Sandy (mixed)	Heavy	
Cotton									
Dryland[4]	1954 yield per acre	Pounds	122	[3]	[3]	[3]	122	[3]	[3]
	1957 yield per acre	Pounds	246	275	166	[3]	246	239	245
	1958 yield per acre	Pounds	304	387	250	[3]	304	340	311
	1954-58 average per acre	Pounds	196	200	166	[3]	196	183	195
Irrigated[4]	1954 yield per acre	Pounds	548	600	[3]	[3]	548	600	[3]
	1957 yield per acre	Pounds	497	490	517	550	497	508	503
	1958 yield per acre	Pounds	570	626	639	622	570	629	606
	1954-58 average per acre	Pounds	532	558	561	532	532	555	546
Grain Sorghum									
Dryland[4]	1954 yield per acre	Pounds	1060	[3]	[3]	[3]	1060	[3]	[3]
	1957 yield per acre	Pounds	1140	1270	1930	1160	1140	1330	1180
	1958 yield per acre	Pounds	1300	1380	1270	1700	1300	1490	1350
	1954-58 average per acre	Pounds	980	950	800	1130	980	1000	980
Irrigated	1954[4] yield per acre	Pounds	2750	3220	[3]	[3]	2750	3220	[3]
	1957 yield per acre	Pounds	2800	3590	3880	3770	2800	3720	3470
	1958 yield per acre	Pounds	2900	4140	4030	4160	2900	4110	3780
	1954-58 average per acre	Pounds	2650	3460	3690	3730	2650	3600	3330
Wheat									
Dryland	1957 yield per acre	Bushel	[3]	15	26	11	[3]	15	15
	1958 yield per acre	Bushel	[3]	27	30	25	[3]	27	27
	1954-58 average per acre	Bushel	[3]	14	15	11	[3]	13	13
Irrigated	1957 yield per acre	Bushel	30	25	34	33	30	33	33
	1958 yield per acre	Bushel	30	25	35	34	30	34	34
	1954-58 average per acre	Bushel	27	26	29	29	27	29	29
Barley									
Irrigated	1957 yield per acre	Bushel	[3]	58	48	55	[3]	54	54
	1958 yield per acre	Bushel	[3]	48	49	44	[3]	47	47
	1954-58 average per acre	Bushel	[3]	48	59	52	[3]	52	52

[1]Cotton yields rounded to nearest pound, grain sorghum to nearest 10 pounds, wheat and barley yields rounded to nearest bushel.
[2]See Figure 4 for area included in farming areas.
[3]None reported or not applicable.
[4]1954 survey.

acreage served on farms equipped with closed distribution systems differ considerably between farms, but for the area as a whole, these systems serve 77 percent of the irrigated land on farms so equipped.

Approximately 15 percent of the farms enumerated were equipped with aluminum surface pipe distribution systems. A few were equipped with portable sprinkler systems and and a few used concrete-lined ditches. The oldest concrete-tile distribution system reported, was installed in 1944. However, only 17 percent of the systems enumerated were installed before 1954; 80 percent were installed between 1954 and 1958; and the installation dates of 3 percent were unknown.

Installation of closed distribution systems, chiefly underground concrete-tile are more common in the sandy (mixed) soil areas (farming area A) than in areas with heavy soils.

Water Level Declines and Compensating Adjustments

FACTORS CONTRIBUTING TO DECLINE IN WATER LEVEL

The amount of decline in the water level reflects the amount of water extracted, which is closely associated with (1) length of time irrigation has been practiced or age of development, (2) permeability of the water-bearing formation or (3) a combination of (1) and (2).

The length of time irrigation has been developed is also associated with the initial (1938) thickness of the water-bearing strata, but in the areas of heaviest decline, this association is coincidental. Originally water levels were near the surface in the Plainview-Lockney and Hereford areas and the first irrigation was developed in these "shallowater" areas. A similar situation with respect to depth, to water and to time of development prevailed in the Muleshoe area, but recharge from the adjacent sand hills has permitted long-continued operation without the heavy decline experienced in other areas of older development.

The relation between the age of irrigation development and the amount of water-level decline is shown in Table 10. A similar association between the age of development and the thickness of the water-bearing stratum is shown in Table 11.

The first well was drilled on 37, 50, 85 and 88 percent of the farms in decline intervals 1, 2, 3 and 4, respectively, by 1949. The regional static water level in 1949 had an accumulated decline of 11.45 feet, Table 3. By 1949 only 21, 40, 49 and 55 percent of the wells used in 1958 had been drilled in decline intervals 1, 2, 3 and 4, respectively, Table 10. Some indication of the effects of the decline in water supply is revealed by comparing the proportion of farms on which irrigation was developed and the proportion of wells drilled since 1949. For instance in decline interval 4, irrigation was developed on only 12 percent of the farms between 1950 and 1958 whereas, 45 percent of the wells used in this decline interval in 1958 were drilled during the same 9-year period, Table 10.

Comparisons for the other decline intervals show a similar relationship. The comparison is not entirely accurate, as the entries under "proportion of farms developing irrigation" reflect the date on which the first well was drilled. As few farms are developed completely in a single year, part of the wells drilled after 1949 were drilled to expand the irrigated acreage on farms where irrigation had been developed previously.

SPECIFIC HYDROLOGIC SUB-AREAS

The greatest decline in water level has occurred in areas in which the initial water-bearing stratum was thickest, Figures 6 and 2. This suggests that the deleterious effects of

TABLE 8. FERTILIZER USE AND CROP YIELDS RELATED TO SOIL TYPE AND NUMBER OF IRRIGATIONS, 1958

Item		Farming area A Sandy (mixed) soils		Farming areas B, C and D heavy soils		
	Unit	Cotton	Grain Sorghum	Cotton	Grain Sorghum	Wheat
Number of farms reporting fertilizer use[1]	No.	45	24	90	164	165
Proportion of farm operators using fertilizer	Percent	31.5	16.6	37.0	67.5	67.7
Proportion of acreage fertilized	Percent	15.5	17.9	26.0	66.2	43.5
Rate of fertilizer application[2]						
Nitrogen, per acre fertilized	Pounds	56.0	82.6	45.8	76.0	74.1
Phosphorus, per acre fertilized	Pounds	42.7	2.7	18.5	1.0	2.2
Potassium, per acre fertilized	Pounds	11.4	0.0	6.7	0.0	0.0
Fertilizer cost per acre	Dollars	11.21	6.79	6.29	6.55	6.63
Crop Yields per acre						
No fertilizer						
Fewer than three irrigations[3]	[5]	515	2,617	636	3,083	26
Three or more irrigations[4]	[5]	623	3,125	707	3,596	29
Fertilized						
Fewer than three irrigations[3]	[5]	600	3,880	632	4,270	36
Three or more irrigations[4]	[5]	734	4,150	662	4,471	38
Estimated yield differences from						
Increased irrigation[6]	[5]	108	508	71	513	3
Fertilizer alone[7]	[5]	85	1,263	—4	1,187	10
Fertilizer and increased irrigation[8]	[5]	219	1,533	26	1,388	12

[1]Data are average for the number of farms indicated.
[2]Pounds of elemental nitrogen, phosphorus and potassium per acre.
[3]Average of 2.6 irrigations per acre.
[4]Average of 3.6 irrigations per acre.
[5]Pounds of lint, pounds of sorghum grain and bushels of wheat per acre.
[6]Difference in yield between "less than three irrigations" and "three or more irrigations" with no fertilizer.
[7]Difference between "nonfertilized" and fertilized yields with "less than three irrigations."
[8]Difference between "fertilized" yields with "three or more irrigations" and "unfertilized" yields with "less than three irrigations."

water-level decline would depend more upon the proportion of total water extracted than upon the total amount of decline experienced. A moderate amount of decline in an area underlain by a thin water-bearing stratum, may constitute a high proportional decrease in water supplies and may have more immediate implications, than a heavy decline in an area with a thicker water-bearing stratum.

The reservoir area is delineated in specific areas wherein the effects of depletion can be ascertained. The decline in water levels between 1938 and 1958, Figure 2, in combination with the original (1938) thickness of the water-bearing strata, Figure 6, provides the basis for such delineations. For purposes of this study, each combination of a "decline interval" with an original "water-bearing thickness interval" constitutes a specific hydrologic sub-area, Table 12.

The approximate location of these specific hydrologic sub-areas is shown in Figure 7. Water level profiles of the hydrologic sub-areas selected for study are shown in Figure 5.

Since "more than 60 feet" of water-level decline could not be experienced in an area where the initial thickness of the water-bearing stratum was "under 50 feet" thick, the procedure followed provided 23 possible combinations of water-level decline and thickness of water-bearing strata, specific hydrologic sub-areas. An examination of the adjustments and their effects in these specific hydrologic situations permitted some combination of areas for this study. When the initial thickness of the water-bearing stratum exceeded 150 feet, the type and extent of adjustments were closely associated with the amount of decline, whereas, when the initial thickness of water-bearing stratum was less than 150 feet, the extent and effects of adjustments were related chiefly to the proportion of water resources that have been extracted and the initial thickness of water-bearing strata.

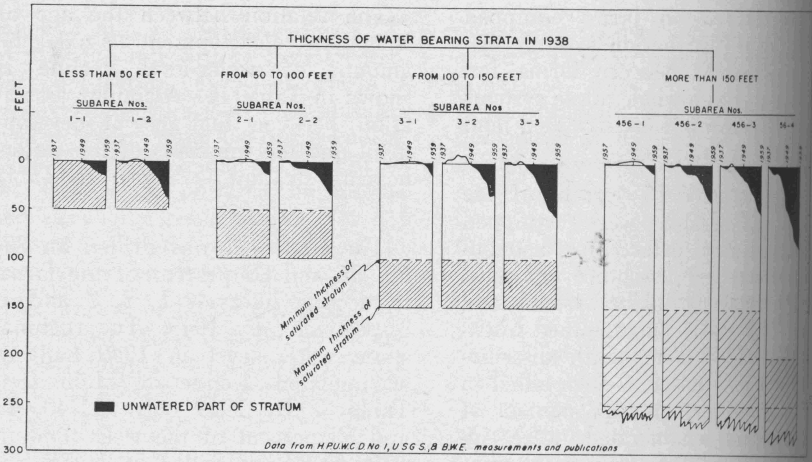


Figure 5. Hydrologic sub-area profiles.

For purposes of analysis, the 12 specific hydrologic sub-areas that include those situations in which the initial thickness of the water-bearing stratum exceeds 150 feet are combined in four sub-areas. The acreage included in some of the sub-areas is so small that sufficient data are not available for appraisal. For these reasons, the 23 possible specific hydrologic sub-areas are reduced to 11 for further study. Since there are wide differences among parts of some of the selected sub-areas, further subdivisions are made as indicated in later tables.

The square miles and the proportion of the total area in different intervals of water-level decline are shown in Table 12. The area and proportion of the six water-bearing strata thickness intervals affected by different amounts of water-level decline are shown in Table 12.

Each specific hydrologic sub-area is identified by a code number or symbol which indicates the water-bearing strata "thickness interval" and the water-level "decline interval" combined in the specific sub-areas. The numbering system combines the "thickness" and "decline" interval numbers used in Table 12. The first digit in the symbol indicates the thickness interval and the second the decline interval combined in the specific sub-area. Thus symbol 1-1 denotes an area in which the initial (1938) water-bearing stratum was "under 50 feet" thick and the water-level decline is "0 to 20 feet"; the symbol 1-2 denotes an area with a similar initial thickness of water-bearing stratum that has experienced a water-level decline of "20 to 40 feet." Similarly, the symbol 3-3 indicates an area with an initial water-bearing stratum ranging from "100 to 150 feet" thick and a water-level decline ranging from "40 to 60 feet."

Where sub-areas have been grouped for discussion, a series of digits is used to denote the thickness of the water-bearing stratum intervals combined. Some parts of the individual or grouped sub-areas are further subdivided depending on permeability of the water-bearing formation, well yields, pumping lifts, or a combination of the three. These areas are designated by the addition of a small letter following the sub-area symbol.

The areas of irrigated land within the various hydrologic sub-areas are shown in Table 13.

PHYSICAL EFFECTS OF WATER-LEVEL DECLINE

The principal physical effects of the decline in water levels are reflected in a reduction in well yield

TABLE 9. COMPARISONS OF YIELDS OBTAINED BY IRRIGATING EVERY OTHER ROW WITH YIELDS OBTAINED BY IRRIGATING ALL ROWS, FARMING AREAS A AND B, 1958

Item	Irrigating every other row		Irrigating all rows	
	Number of farms	Yields	Number of farms	Yields
Cotton, pounds per acre[1]				
No fertilizer	13	543	17	579
Fertilized	8	585	12	628
Grain Sorghum pounds per acre[1]				
No fertilizer	12	2481	15	2967
Fertilized	4	3550	9	3757

[1]Average yields from the number of farms shown.

TABLE 10. PROPORTION OF FARMS DEVELOPING IRRIGATION AND PROPORTION OF WELLS DRILLED, BY PERIODS, RELATED TO WATER LEVEL DECLINE

Item and development period	1938-58 Water level decline intervals[1]			
	1 (0-20 feet)	2 (20-40 feet)	3 (40-60 feet)	4 (60+ feet)
Proportion of farms developed for irrigation[2]	Percent			
Before 1940	5	10	20	47
1940-44	2	10	27	6
1945-49	30	30	38	35
1950-54	40	30	9	6
1955-58	23	20	6	6
Proportion of wells drilled[3]				
Before 1940	1	4	7	17
1940-44	3	5	13	17
1945-49	17	31	29	21
1950-54	43	38	35	24
1955-58	36	22	16	21

[1]Intervals as delineated in Figure 2.
[2]Year first well was drilled on the farm.
[3]Wells used in 1958 only; this excludes farms and wells where the original water level was 165 feet or more below land surface.

The reduction in well yield began during the late 1940's and further reductions have been experienced as the decline in water level progressed. Evidence of decreases in well yields in certain locations was obtained during the course of the well-measuring study conducted by the Texas Agricultural Experiment Station in 1947-49, (1), (2) and (3). There are many reports of declining well performance. However, the only authoritative evidence of changes in well yield was reported by Leggat, in 1954, (17). According to Leggat, the comparative performance of 51 wells in Deaf Smith, Floyd, Hale and Swisher counties between 1938 and 1951 showed an average decrease in yield ranging from 11 percent in Floyd county to 20 percent in Hale and Deaf Smith counties. A larger decrease was reported for the old municipal well field at Lubbock, in which the average well yield decreased from 625 to 250 gallons per minute, (17).

Similar information covering well performance since 1951 is not available. Other indicators, however, can be used to approximate the changes in well performance. Chief among these is the change in number of acres irrigated per well which, although subject to modification by management practices, generally reflects additional wells installed to maintain the irrigated acreage on the farm. Decreases in number of acres irrigated per well, particularly since the early 1950's, along with adoption of longer pumping seasons, lowering of pumps, installation of closed distribution systems and installation of smaller pumps in old wells, indicate a decrease in water supplies. Changes in numbers of acres irrigated per well between 1947 and 1958 are shown in Table 14.

COMPENSATING ADJUSTMENTS

Several factors may combine to influence the type and extent of special practices adopted by a farm operator. The tendency of these special practices to be more widely adopted in some situations than in others, suggests that these special practices are required to cope with conditions in the area of their adoption. Such is the case with respect to certain types of special practices or adjustments made in response to declining water levels in the High Plains. The types of adjustments or special practices induced by, or associated with water-level declines, are outlined below. The extent to which the more important practices are applied in specific hydrologic situations is shown in Table 15.

Increasing the hours of pump operation was among the first and most frequently reported adjustments made in response to a decline in water supplies. Changed irrigation practices, mainly adoption of preplanting irrigation, since 1947-49, and differences in annual irrigation requirements that stem from seasonal variations in precipitation, preclude a precise measurement of the extent to which pumping seasons have been lengthened to meet a decline in water supplies.

Lowering of Pumps was an early adjustment. Its application was generally restricted to those parts of the area in which water-bearing strata were thick enough to make the practice feasible. Some of the pumps in earlier wells drilled in the sub-areas with less than 100 feet of water-bearing materials were lowered as the water level declined, but pumps in many wells drilled after 1950 were usually set at or near the bottom of these thinner water-bearing strata.

The extent to which this practice has been followed in the various hydrologic sub-areas is shown in Table

TABLE 11. PROPORTION OF FARMS DEVELOPING IRRIGATION AND PROPORTION OF WELLS DRILLED, BY PERIODS, RELATED TO ORIGINAL (1938) THICKNESS OF WATER-BEARING STRATUM

Item and development period	Thickness of water-bearing stratum, 1938[1]					
	1 (0-50 feet)	2 (50-100 feet)	3 (100-150 feet)	4 (150-200 feet)	5 (200-250 feet)	6 (250 feet +)
Proportion of farms developed for irrigation[2,3]	Percent					
Before 1940	7	6	11	27	19	27
1940-44	0	4	19	11	20	20
1945-49	19	54	44	33	48	31
1950-54	30	30	16	24	10	22
1955-58	44	6	10	5	3	0
Proportion of wells drilled[3]						
Before 1940	0	2	3	13	5	9
1940-44	0	3	9	8	9	14
1945-49	11	31	28	21	36	22
1950-54	37	45	37	42	31	33
1955-58	52	19	23	16	19	22

[1]As delineated in Figure 6.
[2]Year first well was drilled on the farm.
[3]Wells used in 1958 only; this excludes farms and wells where original water level was 165 feet or more below land surface.

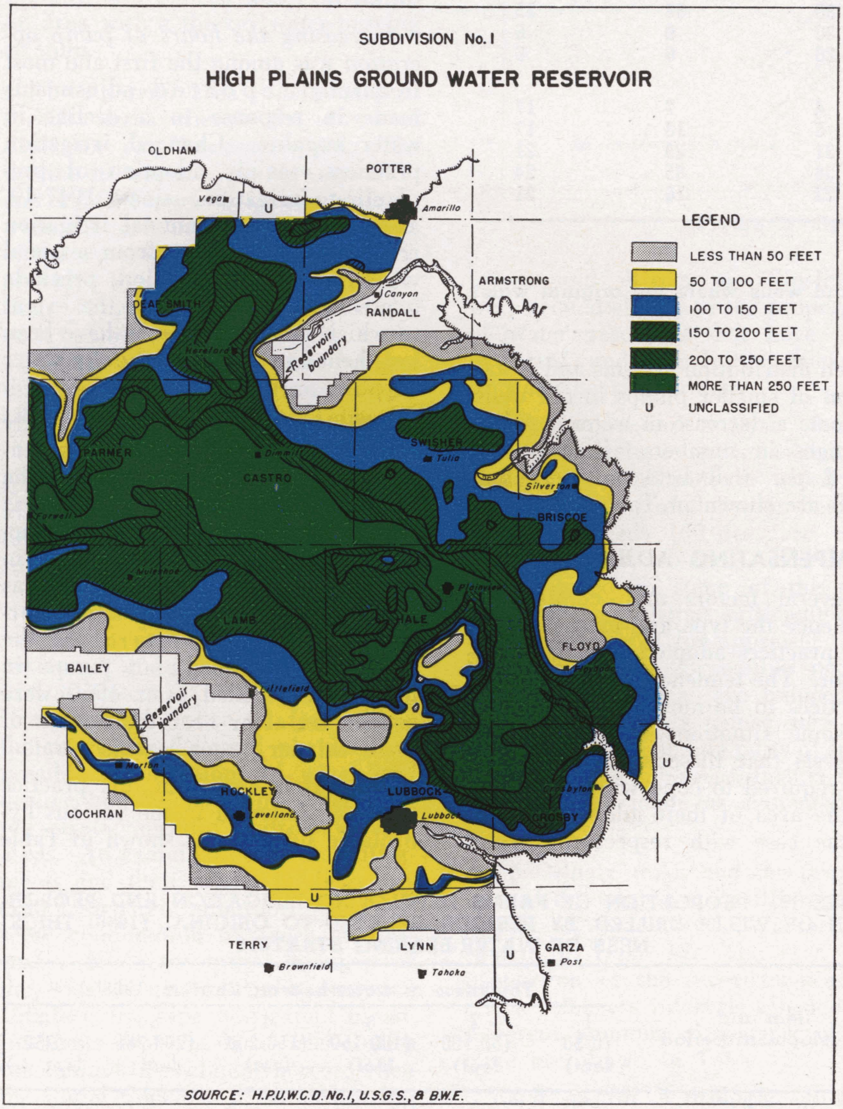
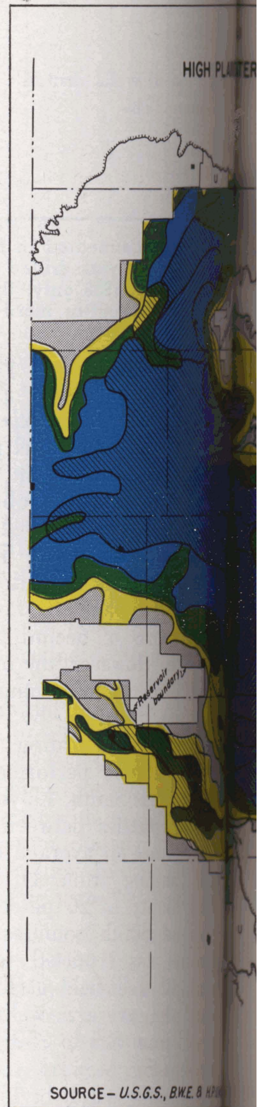
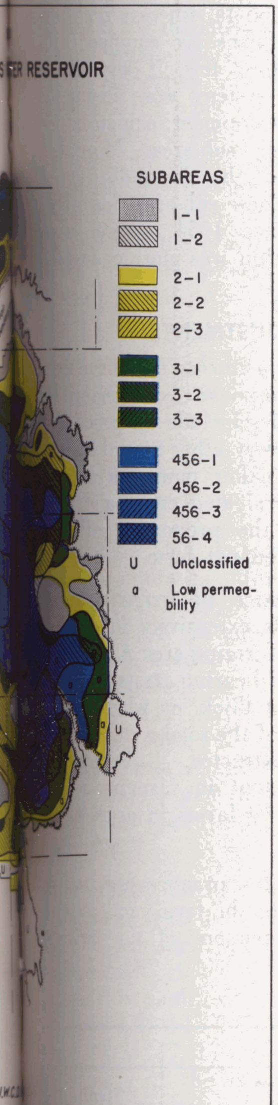


Figure 6. Thickness of the water-bearing strata, 1938.





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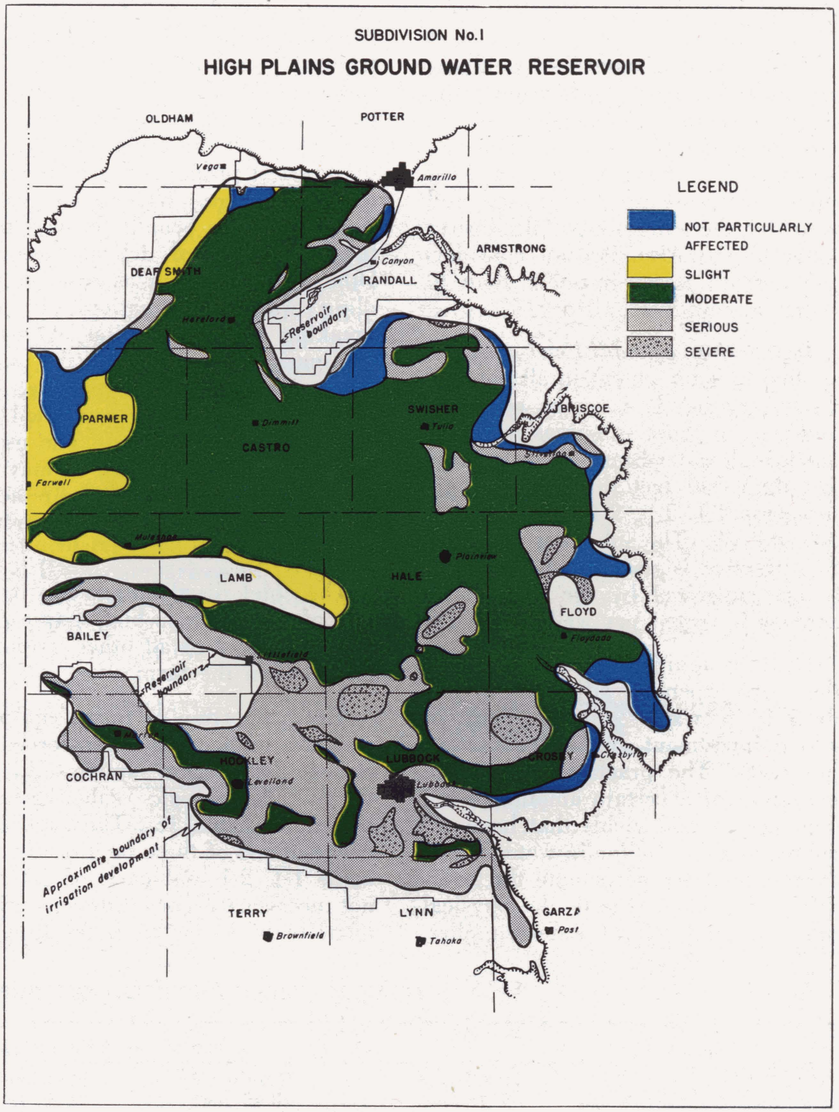

Figure 8. Areas affected by water level decline.

15. The practice has been extensively adopted in the older developed areas where the water-bearing strata are more than 150 feet thick—(hydrologic sub-areas 456-2, 456-3 and 56-4). In these sub-areas, pumps have been lowered, some of them as many as six times, in almost all wells drilled before 1940 and in more than three-fourths of all wells drilled before 1950.

Farm operator reports of well performance before and after lowering, along with the smaller decrease in acreage irrigated per well, Table 14, indicate that the practice has been among the most effective means used to offset the effects of a decline in water levels. Also, it costs considerably less to lower a pump than to install a new well.

Installation of additional wells is applied to some extent in all parts of the reservoir. It is more common, however, in those sub-areas in which the initial water-bearing strata were less than 150 feet thick, hydrologic sub-areas 1-1, 1-2, 2-1, 2-2, 2-3, 3-1, 3-2 and 3-3. The sub-areas in which this practice is used most extensively are suggested by the changes in acreage irrigated per well, Table 14.

Drilling additional wells is among the more expensive adjustments to a decline in water supplies both in added investment and added operating costs. The practice permits the offsetting of a certain amount of the decrease in well yields that have accompanied the decline in water levels. It also tends to perpetuate the overdraft and shortens both the physical and economic life of water supplies, particularly in those areas in which the initial water-bearing strata were less than 100 feet thick.

Closed distribution systems, principally underground concrete tile are another adjustment to a change in water supplies in certain situations. Elimination or reduction of transmission losses between the well or wells and the point of water distribution is the major benefit derived from the use of this facility. This water-conserving effect largely explains the frequent installation of this type of facility in areas experiencing the greatest proportional depletion of water resources. Water conservation is not the only benefit derived from the use of closed delivery systems. Other benefits, such as ease of handling water, elimination of ditch breaking by wind action on water, elimination or reduction of ditch construction and maintenance, and reduction in land area needed for ditches also are realized. The use of this type of facility may or may not reduce irrigation labor requirements, depending on individual circumstances.

The chief disadvantage lies in the cost of the system, which may exceed the entire cost of all other irrigation facilities on the farm.

The proportion of farms equipped and the number of acres served by closed distribution systems in the various hydrologic sub-areas are shown in Table 15. The high incidence of use of these facilities in sub-areas 1-1, 2-1 and parts of 3-1 does not necessarily constitute an adjustment to a change in water supplies. A high proportion of the wells in parts of these sub-areas initially were low-capacity wells and closed systems were part of the equipment installed at time of development. Also, the predominant soils in these areas are open textured, which increases the need to reduce transmission losses.

In sub-areas 1-2, 2-2, 2-3, 3-2, 3-3, 456-3a and 56-4a, where a high percentage of farms are equipped with these facilities, few, if any, closed distribution systems were among the original development equipment on farms in these sub-areas. More than 70 percent of the closed distribution systems in these sub-areas have been installed since 1954, several years after irrigation was more or less fully developed.

OTHER ADJUSTMENTS

Other adjustments that have been made in response to a change in water supplies include the practice of irrigating every other row, the installation of smaller pumps, a shift to off-season irrigated crops and a reduction in the proportion of cropland irrigated per farm.

The practice of irrigating every other row is extensively followed in portions of farming area A where the initial water-bearing strata were less than 50 feet thick, or where a high proportion of the total water resource has been extracted. It is practiced to some extent in farming area B and on a few farms in areas C and D.

In 1958, the practice was used on 60 percent of the farms and approximately 40 percent of the irrigated

TABLE 12. SIZE OF HYDROLOGIC SUB-AREAS[1]

1938 Thickness of water-bearing strata Interval		Water level decline intervals in feet[2]									
		Number 1 0-20 feet		Number 2 20-40 feet		Number 3 40-60 feet		Number 4 60 feet +		Total	
Number	Feet	Square mile	Percent[3]	Square mile	Percent[3]	Square mile	Percent[3]	Square mile	Percent[3]	Square mile	Percent[4]
1	Under 50	1317	92.5	101	7.1	6	.4	0	0	1424	13.4
2	50-100	1240	54.0	994	43.3	62	2.7	0	0	2296	21.6
3	100-150	533	26.3	1166	57.5	325	16.0	5	.2	2029	19.0
4	150-200	442	27.1	814	49.8	353	21.6	24	1.5	1633	15.3
5	200-250	218	14.2	845	55.1	395	25.7	77	5.0	1535	14.4
6	250 and over	94	6.3	701	47.0	435	29.2	260	17.5	1490	14.0
—	Unclassified[5]	242	100	0	0	0	0	0	0	242	2.3
	Total	4086	38.4[4]	4621	43.4[4]	1576	14.8[4]	366	3.4[4]	10649	100.0

[1]Each combination of intervals ("Thickness of water-bearing strata" and "Water level decline") constitutes a specific hydrologic sub-area, (See Figure 7).
[2]Based on water level declines from January 1938 to January 1958.
[3]Percentage of area with different thicknesses of water-bearing strata included in the decline interval.
[4]Proportion of reservoir area.
[5]Most of the unclassified area has a water-bearing stratum in the 0 to 50 feet range and is included hereafter with this group.

acreage in farming area A, Figure 4. The proportion of the acreage irrigated by this method differs considerably among the hydrologic sub-areas included in farming area A. Excluding sub-areas in which the initial water-bearing strata were less than 50 feet thick—sub-areas 1-1 and 1-2—the proportion of the acreage irrigated by this method decreases as the thickness of the water-bearing stratum increases. For example, the proportion was 36 percent in sub-area 2-1, 17 percent in the sub-area 3-1 and 6 percent in sub-area 4-1. Also, the proportion of land irrigated by this method increases as the decline in water level increases. For example, the practice is applied on 36, 70 and 89 percent of the land irrigated in sub-areas 2-1, 2-2 and 2-3, respectively.

The practice of irrigating every other row is followed on 82 and 86 percent of the farms in sub-areas 1-1 and 1-2, respectively. The time that the practice was adopted in these sub-areas suggests that it has been used to offset the effects of water-level declines, but it does not necessarily constitute an adjustment to a change in water supplies, particularly in sub-area 1-1. In general, wells in this sub-area were low-capacity wells, and the practice was initiated when, or shortly after, irrigation was developed. In other sub-areas involved in farming area A, where irrigation development is generally older, the practice has been adopted chiefly since 1954.

The installation of smaller pumps in the older wells is another indication of a decreased water supply and reduced well yields. The practice generally is confined to hydrologic sub-areas 1-2, 2-1, 2-2, 2-3 and 3-2 where 30, 25, 17, 17 and 17 percent, respectively, of the original pumps have been replaced by pumps of smaller size. Most of the wells, where pumps have been replaced by smaller pumps, were drilled before 1955. Pumps similar in size to the replacement pumps have been installed in most wells drilled in these areas since 1955.

Decreasing the acres of summer-irrigated crops and increasing the acres of fall-and-winter-irrigated crops is another adjustment to a change in water supplies. This is not an extensive practice and is reported only in farming areas C and D, where wheat is a principal irrigated crop. A number of farm operators in these farming areas report that, because of reduced well yields, they have reduced acreages of summer-irrigated crops — grain sorghum— and increased acreages of crops irrigated during the fall and winter. Adoption of this practice lengthens the irrigation season, permitting a larger acreage to be irrigated with a given head of water. It accounts, in part, for the difference in the reduction in "acres irrigated per well" between comparable hydrologic situations in farming areas A and B and in C and D, Table 14.

Staggering grain sorghum planting dates is another reported adjustment associated with a decrease in water supplies. The practice involves two or more plantings at 10-to-14-day intervals, thus lengthening the time in which sorghum can be effectively irrigated. The practice was reported only in farming areas C and D.

Concentrating the available water on cotton rather than on cotton and grain sorghum as in the past, is an adjustment reported in farming areas A and B. A comparison of 1958 and 1954 irrigated land use shows that grain sorghum occupied only 11, 31 and 12 percent of the 1958 irrigated cropland in sub-areas 1-1, 1-2, and 2-2 respectively, compared with 37, 37 and 31 percent, respectively, in these sub-areas in 1954. The proportion of irrigated cropland in grain sorghum remained unchanged or increased between 1954 and 1958 in sub-areas 2-1, 3-1, 3-2, 3-3, 4-1 and 4-2 in farming area A.

A reduction in proportion of cropland irrigated per farm constitutes a more drastic, though not extensive, adjustment to a change in water supplies. Most of the adjustment of this type has occurred in farming area A. For the areas as a whole, the proportion of cropland irrigated per farm declined 7, 28, 10, 10, 12 and 10 percent in hydrologic sub-areas 1-1, 1-2, 2-2, 2-3, 3-3 and 56-4a, respectively, between 1954 and 1958.

The shift from butane to natural gas fueled pump engines is not included among the adjustments made in response to a change in water supplies. The shift, an economy measure, is not necessarily related to declines in water level, as the availability of natural gas is conditioned primarily by the size of energy requirements. The shift to natural gas has provided substantial immediate benefits in the form of lower fuel

TABLE 13. ESTIMATED IRRIGATED ACREAGE BY FARMING AREAS AND BY SPECIFIC HYDROLOGIC SUB-AREAS, 1958

Sub-area number	Farming Area A	Farming Area B	Farming Area C and D	Total	Percent of total
	— — — —	— — — —	Acres — —	— — — —	— — — —
1-1	121,500		17,800	139,300	3.9
1-2	31,000			31,000	.9
2-1	102,000	22,300	78,000	202,300	5.7
2-2	235,000		54,300	289,300	8.2
2-3	43,300			43,300	1.2
3-1	81,600		94,700	176,300	4.9
3-1a[7]		14,700[1]		14,700	.4
3-2	146,000	20,000	277,600	443,600	12.4
3-2a[7]		22,000[1]		22,000	.6
3-3	47,500		14,800	62,300	1.7
456-1	56,600		234,600	291,200	8.1
456-1a[7]		6,400[1]		6,400	.2
456-2	80,000	319,300	698,700	1,098,000	30.7
456-2a[7]		20,000		20,000	.6
456-3		167,300[2]	328,500[3]	495,800	13.9
456-3a[7]		87,300[4]		87,300	2.4
56-4		144,100[5]		144,100	4.0
56-4a[7]		8,100[6]		8,100	.3
Total	944,500	831,500	1,799,000	3,575,000	
	Percent 26.4	Percent 23.3	Percent 50.3	Percent 100	Percent 100

[1]High-lift areas of eastern Crosby and Floyd counties.
[2]Lamb, Hale and Floyd county portion of sub-area.
[3]Swisher, Castro and Deaf Smith county portion of sub-area.
[4]Lubbock and Crosby county portion of sub-area.
[5]Hale, Floyd county portion of sub-area.
[6]Crosby county portion of sub-area.
[7]Water-bearing formation with low permeability.

costs, but, like the previously discussed adjustment involving the installation of additional wells, it also contributes to a continued overdraft of water supplies.

Effects of Adjusting to a Changing Water Supply

The physical patterns of ground-water depletion are rather clearly defined, Figures 2 and 7. The type and extent of major adjustments are also closely related to the extent of depletion in specific hydrologic sub-areas, Table 15. The economic patterns that stem from these adjustments are not so clearly defined.

Several factors combine to mask the full physical and economic effects of water-level decline on the High Plains. Among them are a continued though slowed rate of irrigation development, elimination or reduction of transmission losses through the use of closed distribution systems, inflation, drouth, a modified irrigation program and the shift from butane (L. P. gas) to natural gas for pumping.

Continued development, as reflected by continued well drilling, precludes a precise measurement of the effects of a given amount of water-level decline, i.e., the effects of each 10 feet of decline in an area in which the total decline amounts to 40 feet. A period of stable water use would be required for this purpose. Even with a period of relatively stable water use, a knowledge of the amount of water saved by reducing or eliminating transmission losses would be required to appraise the full effect of a specific amount of water-level decline.

In some situations, the amount of water saved by piping it to the place of use is likely to be substantial. Thus, although the yield of a well may have been reduced, the acreage served by the well may be near that served before the conduits were installed.

On the farms included in the study, closed distribution systems, principally underground concrete-tile or aluminum surface pipe, served approximately 40 percent of the land irrigated in 1958. Approximately 80 percent of these systems were installed in whole or in part during 1954-58. The full effect of the decline in water levels, therefore, is reduced or masked by the amount of water saved by reducing transmission losses. This would suggest that future declines in water level are likely to effect a greater reduction in the number of acres irrigated and a greater increase in operating costs than those occurring between 1954 and 1958.

Although continued development, coupled with a reduction in transmission losses, precludes a precise measurement of the effects of specific amounts of water level decline, the type, number and extent of adjustment associated with local hydrologic conditions permits an appraisal of some of the effects that may reasonably be attributed to water level declines from the time that the local area was developed.

Economic effects are reflected primarily in three ways: (1) increased per-acre investment in irrigation facilities, (2) increased operating costs and (3) a reduction in the proportion of cropland irrigated per farm.

INCREASED INVESTMENT IN IRRIGATION FACILITIES

The most widespread and pronounced effect of adjusting to a changing water-supply situation is reflected by an increase in the investment required to maintain and supply the irrigated acreage. In each instance, when data for earlier years are available, the 1958 investment per acre in irrigation facilities represents a substantial increase over those reported in 1947 and in 1954.

The initial cost of irrigation facilities used in 1958, along with 1958 operating costs, by hydrologic sub-

TABLE 14. ACREAGE IRRIGATED PER WELL BY HYDROLOGIC SUB-AREAS AND BY FARMING AREAS

Hydrologic[1] sub-area	Farming areas A and B[1]						Farming areas C and D[1]			
	1947[2]	1954[3]	1955[4]	1956[4]	1957[4]	1958[4]	1955[4]	1956[4]	1957[4]	1958[4]
	Acres									
1-1	[5]	36	35	35	35	33	77[6]	44	54	30
1-2[6]	[5]	78	42	45	58	44				
2-1	[5]	71	65	64	63	57	124	148	154	137
2-2	118	63	62	63	59	58	108[6]	109	106	90
2-3[6]	[5]	[5]	77	77	77	72				
3-1	[5]	[5]	131	118	97	88	159	151	150	133
3-1a[6,7]	[5]	93	87	78	78	65				
3-2	118	84	97	88	86	78	138	138	139	123
3-2a[6,7]	[5]	[5]	94	87	84	77				
3-3[6]	118	94	97	95	95	88	107[6]	107	107	104
456-1	[5]	[5]	117	114	114	114	228	223	208	195
456-1a[6,7]	[5]	[5]	95	80	80	61				
456-2	155	158	145	136	126	118	172[6]	164	163	145
456-2a[6,7]	[5]	[5]	132	127	106	101				
456-3	140	124	119	117	108	96	149	149	142	129
456-3a[6,7]	127	[5]	99	91	86	78				
56-4	147	153	138	127	121	120				
56-4a[6,7]	[5]	[5]	83	83	62	56				

[1]Hydrologic sub-areas as delineated in Figure 7, farming areas as in Figure 4.
[2]Average acres per well on farms studied in 1947.
[3]Average acres per well on farms studied in 1954.
[4]Average for farms included in January 1959 survey, includes some, but not all farms covered in 1947 and 1954.
[5]No record for these years.
[6]Small sample.
[7]Water-bearing formation with low permeability.

areas, are shown for farming areas A and B in Table 16 and for farming areas C and D in Table 17. The amount of increase between survey periods in the per-acre cost of irrigation facilities and the cost of particular items contributing to the increase are shown in Table 18.

All the increase in investment cost per acre irrigated is not necessarily attributable to the decline in water levels. Although the data do not reflect it, some of the increase after 1947 may be due to increased equipment costs. An examination of some 2,500 well-installation cost records indicates that, with comparable conditions, the cost of installing wells changed little during 1945-58. Wells drilled before 1945 originally cost less to install, but subsequent lowering of pumps and the installation of larger engines has brought the investment in some of the older wells up to about the levels of those drilled later.

Some wells installed in recent years have cost substantially more than those drilled earlier. But higher cost well installations are caused more by the use of higher priced industrial engines, drilling in areas in which the depth to water was greater, or deeper setting of pumps, than to an increase in the cost of equipment and services required to install an irrigation well. The price of some items of pumping equipment advanced during 1947-58. Competition, which was not so pronounced in the early part of 1947-58, has reduced the cost of services and the price of some items required to install a well. Thus, price rises in some items have been largely offset by competition-induced price declines, with little consequent changes in the total cost of installing comparable wells between 1947 and 1958.

The bulk of the 12-year increase in the per-acre cost of irrigation facilities stems from the installation of additional wells, closed distribution systems, lowering pumps and natural gas lines. The decrease in the number of acres irrigated per well, Table 14, which in most instances reflects the effects of wells added to augment the water supply, results in an increased well-cost per acre. The amount of increase in the per acre costs of wells by hydrologic sub-areas is shown in Columns 1, 2 and 4, Table 18.

The amount and time of increase in the per acre cost of irrigation facilities resulting from installation of closed distribution systems and natural gas lines are shown by the difference in Columns 2 and 3 and in Columns 5, 6, 9 and 10, Table 18. The 1947 cost per acre irrigated represents well costs only, whereas the 1954 cost includes a few distribution systems and a few natural gas lines, Columns 2 and 3. The per-acre costs of these facilities, shown in Table 18, are average for the respective sub-areas. Consequently, the differences between the per-acre costs in the respective sub-areas generally reflect differences in the proportion of farms and proportion of acres equipped with these facilities. These proportions, by respective sub-areas, are shown in Table 15.

Although there has been some change in the portion of costs borne by the Agricultural Conservation Program, the total installed cost per foot of underground concrete tile has changed very little since the early 1950's.

The amount invested per acre in gas lines is also an average for the respective sub-areas. But differences between the sub-areas reflect two conditions. In the lower investment costs per acre ($1 to $3), it reflects the small proportion of wells connected to gas lines. In the upper brackets ($10 to $12 per acre) it reflects both the proportion of wells connected and the cost of the longer lines required to connect wells on larger farms. The proportion of wells with natural gas connections in the various sub-areas is shown in Table 15.

TABLE 15. PROPORTION OF PUMPS LOWERED, FARMS EQUIPPED WITH CLOSED DISTRIBUTION SYSTEMS, ACREAGE SERVED BY CLOSED DISTRIBUTION SYSTEMS, AND PROPORTION OF WELLS FUELED BY NATURAL GAS, BY HYDROLOGIC SUB-AREAS AND FARMING AREAS, 1958

Hydrologic sub-area[1]	Farming area A[2,3]				Farming area B[2,3]				Farming areas C and D[2,3]			
	Pumps lowered	Closed dist. system: farms equipped	Closed dist. system: acres served	Wells fueled by nat. gas	Pumps lowered	Closed dist. system: farms equipped	Closed dist. system: acres served	Wells fueled by nat. gas	Pumps lowered	Closed dist. system: farms equipped	Closed dist. system: acres served	Wells fueled by nat. gas
	Percent											
1-1	0	100	97	8	0	100	100	0	0	66	84	60
1-2	0	86	92	11								
2-1	2	100	95	12					14	45	50	54
2-2	25	73	70	56					6	40	35	100
2-3[4]	27	100	100	13								
3-1	8	80	80	50	0	100	100	33	18	44	31	91
3-2	34	40	35	68					22	76	55	75
3-2a[4,5]					0	57	70	100				
3-3	29	50	59	57					0	50	68	55
456-1	8	57	25	54					25	57	50	100
456-1a[4,5]					33	50	44	100				
456-2	21	16	21	43	39	49	33	78	32	60	36	92
456-2a[4,5]					50	33	23	100				
456-3					65	37	37	74	43	62	49	70
456-3a[4,5]					41	71	68	84				
56-4					55	64	33	52				
56-4a[4,5]					71	66	30	71				

[1]As shown in Figure 7.
[2]Farming areas shown in Figure 4.
[3]Proportion of pumps, farms, acres and wells affected in the respective hydrologic sub-areas.
[4]Small sample.
[5]Water-bearing formation with low permeability.

Most of the increase in the per acre cost of wells and much of the investment in distribution systems reflect the costs of coping with declining water levels. There are some minor exceptions; for example, in sub-area 1-1, as well as in some of the sandy portions of other sub-areas in Farming Area A, the installation of closed distribution systems, although influenced by declines in water level, is not necessarily related to these declines. Because of low well capacities and open sandy soils, alone or in combination, closed distribution systems were part of the initial equipment or were installed shortly after development.

The investment in natural gas lines reflects a shift to cheaper fuels, and the availability of this fuel is closely associated with gross energy requirements.

For two principal reasons, the overhead costs (depreciation and interest on the amount invested in irrigation facilities) are not treated in this report. First, the area is generally developed; the investment is made and many of the items involved in development have little or no salvage value. Second, as the depletion of the water supplies in some hydrologic situations may occur before the useful life of the equipment is exhausted, there is no common basis for comparing overhead costs.

This treatment of overhead costs does not apply when an individual is contemplating new development or when capital improvements to existing facilities are involved. In these situations, the entire cost, including interest, depreciation, taxes, risk, or insurance, must be recovered within the economic life of the water supply. The magnitude of these costs as related to the investment in irrigation facilities in the various hydrologic sub-areas is shown in Appendix Table 1.

INCREASED OPERATING COSTS

Operating costs, which include expenditures for fuel or energy, lubricants and repairs for irrigation equipment, have been affected by declines in water levels. However, the full change in operating costs per acre between 1947 and 1958 is not the result of water-level declines alone. The adoption of preplanting irrigation, changes in fuel or energy unit prices, the shift from butane to natural gas or, where power requirements are low, to electricity, and seasonal weather differences, which affect the length of the pumping season, have also influenced per acre operating costs in one way or another since 1947.

The operating cost per acre for the various hydrologic sub-areas, with and without adjustment to compenstate for fuel and seasonal differences in amount of water needed, are shown in Table 19. The costs per acre shown in Columns 2, 3, 4 and 10, Table 19, are the estimated costs obtained from farmers for the three seasons, 1947, 1954 and 1958, in the respective sub-areas. In the first adjustment, Columns 5, 6 and 7, these reported costs are adjusted to a natural gas equivalent fuel cost to standardize for fuel type and unit cost differences between the three periods. Reported costs per acre in farming areas C and D are for 1958 only, as operating cost data for earlier years are considered inadequate for comparison. Operating costs in sub-areas 1-1 and 1-2 are not adjusted to this base. Because of generally low energy requirements for power units, natural gas probably will not become a competitive fuel in these sub-areas.

The second ajustment, Columns 8, 9 and 11, Table 19, is designed to standardize for yearly differences in the length of the pumping season. The adjusted operating costs for 1947, Column 5, Table 19, are not included in this second adjustment. In 1947, preplanting irrigation was not a standard practice, although it was rather widely used on the sandy (mixed) lands in farming area A. By 1954, preplanting irrigation was standard practice throughout the area. The adoption of preplanting irrigation in itself substantially increased the length of the irrigation season. Also, the 1954 growing season was one of the hottest and driest ever experienced on the High Plains. Thus, because of modification in the irrigation program and weather-increased water demands, both of which materially increased the length of the pumping season, there is little basis for comparing the 1947 and 1954 pumping season.

In contrast to 1954, the 1958 season was relatively cool and moist and the irrigation season was among the shortest of recent years. To compensate for these seasonal differences and to provide a common basis for comparison, the operating season has

TABLE 16. IRRIGATION INVESTMENT COST, HOURS OF PUMP OPERATION, AND OPERATING COST PER ACRE IRRIGATED, BY HYDROLOGIC SUB-AREAS, FARMING AREAS A AND B[1]

Hydrologic sub-area	Investment per acre irrigated	Hours of pump operation per acre irrigated		Operating[2] cost per hour	Operating cost per acre irrigated			
	1958	1958	4 yr. Av.[3]	1958	1947	1954	1958	4 Yr. Av.[4]
	Dollars	Hours	Hours	Cents	Dollars			
1-1	116.00	43	72	19		9.43	8.12	13.48
1-2	97.00	23	51	18		12.69	4.16	9.35
2-1	89.00	26	35	30		10.68	7.76	10.56
2-2	100.00	22	32	31	3.16	11.08	6.63	9.77
2-3	67.00	15	25	51			7.46	12.65
3-1	86.00	17	22	39			6.42	8.59
3-1a[5]	120.00	17	27	47			7.91	12.80
3-2	72.00	15	22	36	3.49	9.28	5.26	7.90
3-2a[5]	81.00	11	16	64			6.96	10.03
3-3	66.00	8	13	47	3.49	9.85	3.78	6.35
456-1	55.00	9	14	60			4.69	6.83
456-1a[5]	108.00	9	22	32			2.95	6.90
456-2	58.00	9	15	51	3.26	8.32	4.65	7.51
456-2a[5]	97.00	13	18	41			5.52	7.48
456-3	67.00	13	16	37	3.23	7.17	4.83	5.97
456-3a[5]	85.00	12	19	46	3.32		5.41	8.75
56-4	59.00	12	15	37	3.20	6.90	4.31	5.66
56-4a[5]	126.00	21	30	42			8.96	12.55

[1]Sub-areas as delineated in Figure 7, farming areas as in Figure 4.
[2]Fuel, oil and repair cost per hour of pump operation.
[3]Average based on 1954, 1956, 1957 and 1958 hours of pump operation.
[4]Calculated costs based on 1954, 1956, 1957 and 1958 average hours of pump operation at 1958 costs per hour of operation.
[5]Permeability of water-bearing formation below normal for sub-area.

been adjusted to the average hours of pump operation in the respective hydrologic sub-areas during 1954, 1956, 1957 and 1958 for farming areas A and B. Since a representative sample of farms in farming areas C and D was not obtained in the 1954 survey, the seasonal adjustment is based on the average hours of pump operation in 1956, 1957 and 1958.

The two adjustments are designed to provide a basis for comparing changes attributable primarily to declines in water level by first eliminating or reducing operating cost differences owing to fuel type or fuel unit costs and second, by minimizing cost differences arising from variations in the length of the pumping season. Obviously, because of the many variables involved, no process of adjustment can eliminate the effects of all other factors that bear upon operating costs. The two factors that have been adjusted, fuel type and length of operating season, are among the most important factors affecting the operating cost per acre associated with irrigation. With these two factors reduced to a common base, most of the change in operating costs per acre between 1954 and 1958, Columns 8 and 9, Table 19, reflects the cost of operating wells added to maintain farm water supplies. (See Table 14 for changes in acres irrigated per well.)

The greater increases in operating cost between 1954 and 1958 occurred in those situations in which the water-bearing strata were less than 150 feet thick in 1938 or in the deep water-bearing strata with low permeability, Table 19. The increase in cost attributable to water-level declines was particularly heavy in sub-area 3-3. When seasonal and fuel differences are eliminated or reduced, the adjusted operating cost per acre in sub-areas 1-1, 2-3, 3-1a and 56-4a of farming areas A and B, approach or exceed the economically feasible maximum expenditure for water under 1959 cotton and sorghum grain prices, Appendix Table 2, (18).

A slight decrease in the adjusted operating costs per acre between 1954 and 1958 is indicated for sub-areas 1-2. The number of farms included in the 1954 sample was small with a consequent possibility of sampling error between the 1954 and 1958 surveys. Table 14 shows a decline from 78 to 44 acres per well between 1954 and 1958. A comparison of land use (tabulation not included) shows a decline from 77 percent of the cropland irrigated per farm in 1954 to 49 percent in 1958. During this period, underground concrete tile distribution systems capable of serving 92 percent of the irrigated acreage were installed, Table 15. Assuming that the data are reasonably comparable, this suggests that a considerable portion of the previously irrigated acreage in sub-area 1-2 has been returned to dryland farming.

A comparison of the individual sub-area data presented in Tables 14, 15, 16 and 17 provides a partial explanation for differences in the 1954-58 increase in operating costs per acre in the various sub-areas shown in Table 19. The bulk of the 1954-58 increase in the adjusted operating costs per acre in the various sub-areas can be attributed to the fact that under present conditions more hours of pump operation are required to irrigate an acre.

Similar historical data are not available in farming areas C and D. Declines in water level, compensating adjustments and declines in the number of acres irrigated per well have been experienced in these areas, as in farming areas A and B, Table 15. It seems reasonable to expect, therefore, that the effects of water-level decline in farming areas C and D will be similar though perhaps not as great as in farming areas A and B.

REDUCTION IN PROPORTION OF CROPLAND IRRIGATED PER FARM

The effects of adjusting to declining water levels are reflected by a reduction in the proportion of cropland irrigated per farm. Unlike the other two ways in which the effects of water-level decline are reflected—increased investment cost per acre in irrigation facilities and increased operating costs per acre—which are area wide in their application, reductions in the proportion of cropland irrigated per farm occur principally in certain hydrologic situations. On the farms included in this study, the decline between 1954 and 1957 in the proportion of cropland irrigated per farm was 7 percent in sub-area 1-1, 28 percent in sub-area 1-2, 10 percent in sub-area 2-2, 10 percent in sub-area 2-3, 12 percent in sub-area 3-3 and 10 percent in sub-area 56-4a. The proportion of cropland irrigated per farm increased 14 and 18 percent, respectively, in sub-areas 4-1 and 6-1 during this same period. A large part of the 1958 irrigated acreage was developed in these latter sub-areas during 1954-58.

Reduction in the proportion of cropland irrigated per farm accounts in part for some of the per acre increase in investment in irrigation facilities. It also has another and more important effect in that it reduces

TABLE 17. IRRIGATION INVESTMENT COST, HOURS OF PUMP OPERATION, AND OPERATING COST PER ACRE IRRIGATED, BY HYDROLOGIC SUB-AREAS IN FARMING AREAS C AND D[1]

Hydrologic sub-area	Investment per acre irrigated	Hours of pump operation per acre irrigated		Operating[2] cost per hour	Operating cost per acre irrigated	
	1958	1958	3 Yr. Av.[3]	1958	1958	3 Yr. Av.[4]
	Dollars	Hours	Hours	Cents	Dollars	Dollars
1-1	81.00	53	61	13	6.67	7.76
2-1	62.00	15	18	41	6.01	7.23
2-2	59.00	14	27	20	2.69	5.26
3-1	61.00	14	19	49	6.60	9.25
3-2	53.00	14	19	31	4.23	5.84
3-3	73.00	9	17	27	2.49	4.65
456-1	57.00	9	10	49	4.56	4.99
456-2	54.00	10	13	38	3.85	5.04
456-3	52.00	11	16	37	4.10	6.07

[1]Hydrologic sub-areas as delineated in Figure 7, farming areas Figure 4.
[2]Reported fuel, oil, and repair cost per hour of operation.
[3]Average hours of pump operation per acre irrigated, 1956, 1957 and 1958.
[4]Calculated costs based on 1956, 1957 and 1958 average hours of pump operation at 1958 cost per hour of operation.

total farm output with little or no decrease in farm operating costs.

SUMMARY OF WATER-LEVEL DECLINE EFFECTS

The effects of water-level declines fall into two categories — physical and economic. Some of the physical effects are shown in Tables 12, 13, 14, 15 and 20; the effects with economic implications are shown in Tables 16, 17, 18 and 19 and summarized in the concluding parts of this report.

The water-level decline rates shown in Table 20 are average for the indicated period of years in the respective hydrologic sub-areas. These rates *are not averages for the full period of water-level measurement. They are the average rates sustained since irrigation was more or less fully developed in the individual sub-areas.*

The depletion range represents the proportion of the water-bearing formation that has been unwatered since the systematic water-level measurement program was started in 1937. The range is based on the amount of water-level decline shown in the hydrographs, Figure 5. The range in depletion results from the thickness of water-bearing strata intervals used in this study. For instance, with sub-area 2-2, the amount of water-level decline shown in the hydrographs, Figure 5, is equivalent to a depletion rate of 70 percent where the water-bearing stratum was 50 feet thick and 35 percent where it was 100 feet thick. Depletion ranges for the other hydrologic sub-areas are similarly derived.

The figures under "residual life" reflect the range in years required to deplete the remaining water resource, *assuming an annual recession rate equivalent to the indicated average in the respective sub-areas,* Table 20.

The entries under "estimated residual life" represent a possible maximum physical life rather than a "useful life" of water resources in the respective hydrologic sub-areas. Obviously, because of the cost involved in extracting and using decreasing heads of water with increasing pumping lifts, the useful or economic life of water resources is likely to be less, considerably less in some situations, than the residual life shown in Table 20.

The economic feasibility of the use of water resources in any of the hydrologic sub-areas will be affected by the profit afforded by the use of these resources. Commodity prices have an important bearing on profit margins; however, high commodity prices do not in themselves provide a high profit margin. Increasing costs, such as those that have been and are being sustained in adjusting to certain changing water-supply situations, could shorten the economic life of these resources, even with favorable commodity prices. In combination with these increased costs, declining commodity prices would have a more immediate impact on the economic life of water resources.

Most of the present as well as the increased costs of adjusting to declining water supply situations are shown in Tables 16, 17, 18 and 19. It has been pointed out also that the full effects of adjusting to water-level declines are partly obscured by continued development, by the elimination or reduction of transmission losses, by changed irrigation practices including an adjustment in planting

TABLE 18. IRRIGATION INVESTMENT COST PER ACRE, BY HYDROLOGIC SUB-AREAS, 1947-58

Hydrologic sub-areas	Development cost per acre[1]										
	Farming areas A and B							Farming areas C and D			
	1947	1954		1958				1958			
	Wells	Wells	Total	Wells	Dist. system	Gas lines	Total	Wells	Dist. system	Gas lines	Total
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Dollars										
1-1	[2]	77	93	83	31	2	116	57	14	10	81
1-2	[2]	55	69	69	26	2	97				
2-1	[2]	57	72	57	31	1	89	49	10	3	62
2-2	28	70	86	76	21	3	100	34	13	12	59
2-3	[2]	[2]	[2]	50	15	2	67				
3-1	[2]	[2]	[2,3]	49	31	6	86[4]	49	2	10	61
3-1a[5]	[2]	59	65	87	30	3	120				
3-2	26	62	69	60	7	5	72	39	10	4	53
3-2a	[2]	[2]	[2,6]	71	4	6	81				
3-3	26	47	58	55	7	4	66	59	6	8	73
456-1	[2]	[2]	[2,7]	42	9	4	55[8]	45	6	6	57
456-1a	[2]	[2]	[2]	89	7	12	108				
456-2	23	38	41	45	8	5	58	40	8	6	54
456-2a	[2]	[2]	[2]	78	11	8	97				
456-3	23	39	46	49	9	9	67	36	11	5	52
456-3a	33	[2]	[2]	59	20	6	85				
56-4[9]	27	31	34	45	10	3	59				
56-4a[6]	[2]	[2]	[2]	108	14	4	126				

[1]Average cost of irrigation facilities on sample farms in respective sub-areas.
[2]Data inadequate or not available.
[3]Bailey-Lamb county portion of sub-area 3-1.
[4]Briscoe, Swisher, Deaf Smith and Parmer county portion of sub-area 3-1.
[5]Crosby-Floyd county portion of sub-area 3-1.
[6]Crosby county area (see Figure 7).
[7]Bailey-Lamb-Hale counties.
[8]Deaf Smith-Parmer counties.
[9]Hale-Floyd county area.

dates, and to some extent by the shift to cheaper pump fuel.

As the physical and economic effects of adjusting to declining water levels are only partly reflected by the measurement criteria used in this study, these effects necessarily cannot be expressed in their entirety. An examination of the series of compensating adjustments, with their costs and partial effects in specific hydrologic sub-areas provides the basis for approximating these effects and the location, extent, time and magnitude of adjustments that may be required in the future. A broad general classification follows.

Areas Not Particularly Affected by Water-level Decline

Approximately 194,000 acres or 5.4 percent, of the land irrigated in 1958, are included in this category. Irrigation developments in this category are chiefly recent and are characterized usually by high-lift, low-capacity wells. The acreage included here is located in sub-areas 2-1 (78,000 acres) and 3-1 (94,700 acres) in farming areas C and D and in sub-areas 3-1a (14,700 acres) and 456-1a (6,400 acres) in farming area B, see Figures 4, 7 and 8. Generally, these were initially high-cost, relatively poor water areas, and the cost situation has not particularly worsened or improved since irrigation was developed.

Areas Affected by Water-level Decline

The second and major category includes parts of the area in which irrigated farm operations have been affected in varying degrees by a diminishing water supply. The category is further divided according to the degree of these effects.

Slightly Affected Sub-areas

This group includes sub-area 456-1 with 291,200 acres of irrigated land located in farming areas B, C and D. Irrigation developments in this sub-area are among the most recent in the area.

A slight reduction in number of acres irrigated per well, which may or may not be related to water-level declines, is the principal change occurring on farms in sub-area 456-1 during 1955-58. Although irrigation development is characterized by the highest investment per well in the area and pumping lifts are considerably greater than in most other parts, the per acre investment in irrigation facilities and the operating cost per acre, are among the lowest.

The average annual water-level decline rate is somewhat lower than that in adjacent sub-area 456-2. As most conditions except pumping lift and age of development are similar between the two sub-areas, it seems reasonable to expect that future adjustments in sub-area 456-1 will parallel those that have been applied under the more aggravated conditions in sub-areas 456-2 and 456-3.

Moderately Affected Sub-areas

Included in this group are sub-areas in which the water-level decline and decline-induced adjustments have increased both the investment and operating costs and impaired the

TABLE 19. ANNUAL OPERATING COSTS ASSOCIATED WITH IRRIGATION WATER, PER ACRE, BY TYPE OF FARMING AREAS AND BY HYDROLOGIC SUB-AREAS, 1947-58

Hydrologic sub-area[2]	Operating cost per acre[1]									
	Farming areas A and B[2]								Farming areas C and D[2]	
	Reported[1]			Fuel costs standardized[3]			Seasonal adjustment[4,5]		Reported[1,6]	Adjusted[1,7]
	1947	1954	1958	1947	1954	1958	1954	1958	1958	1958
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
	Dollars									
1-1		9.43	8.12	[8]	[8]	[8]	7.97	13.48	6.67	7.76
1-2		12.69	4.16	[8]	[8]	[8]	10.48	9.35		
2-1		10.68	7.76		6.07	5.96	5.81	9.07	6.01	7.23
2-2	3.16	11.08	6.63	1.81	7.35	4.34	6.09	9.77	2.69	5.26
2-3[9]			7.46			7.46		12.65		
3-1			6.42			6.42		8.59	6.60	9.25
3-1a[9,10]			7.91			7.91		12.80		
3-2	3.49	9.28	5.26	1.84	5.06	3.77	4.21	5.32	4.23	5.84
3-2a[9,10]			6.96			6.96		10.03		
3-3	3.49	9.85	3.78	1.84	5.86	3.20	3.63	8.03	2.49	4.65
456-1			4.69			4.69		6.83	4.56	4.99
456-1a[9,10]			2.95			2.95		6.90		
456-2	3.26	8.32	4.65	2.12	2.54	4.10	4.38	6.50	3.85	5.04
456-2a[9,10]			5.52			5.52		7.48		
456-3	3.23	7.17	4.83	2.12	5.52	4.17	4.71	5.61	4.10	6.07
456-3a[10]	3.32		5.41	2.09		5.41		8.75		
56-4	3.20	6.90	4.31	2.04	3.84	4.87	3.87	6.27		
56-4a[9,10]			8.96			8.96		12.55		

Reported expenditures for fuel or energy, oil, repairs and maintenance; per-acre average for respective situations and years.
Farming areas as shown in Figure 4; hydrologic sub-area, Figure 7.
Reported costs adjusted to a standard fuel and rate, 100 percent natural gas used at 1958 gas rates.
Average costs with standardized fuel costs adjusted to a standard pump operation season, 4-year average (1954, 1956, 1957 and 1958) hours of pump operation at 1958 costs per hour of operation.
1947 costs not included in seasonal adjustment because of the adoption of preplanting irrigation after 1947.
Because of the high proportion of wells on natural gas, 1958 reported costs in farming areas C and D are not adjusted to a standard fuel cost.
1958 costs adjusted to 1956, 1957, 1958 average hours of pump operation at 1958 cost per hour of operation.
Costs not adjusted to natural gas equivalent costs.
Small sample.
Water-bearing formations with low permeability.

water supply to some degree. This group includes 2,283,100 acres, approximately 64 percent of the acres irrigated in 1958, see Figure 8.

The following sub-areas and parts of sub-areas are included in this category:

SUB-AREA 3-1, FARMING AREAS A AND B, 81,600 ACRES: Water levels declined at an average rate of 3.75 feet per year during 1955-58 and some 10 to 15 percent of the initial water-bearing formation has been unwatered. On the the farms included in this study, the acreage irrigated per well declined 43 acres, or 33 percent, in 1955-58. Most development in this sub-area is relatively recent and little data are available on development or operating costs prior to 1958. The 1958 per acre investment in irrigation facilities and the per acre operating cost were above average for the area, Tables 16, 17, 18 and 19.

SUB-AREA 3-2, FARMING AREAS A, B, C AND D, 443,600 ACRES: Water levels declined at an average rate of 3.5 feet per year from 1949 to 1958 inclusive, and about 23 to 35 percent of the initial water-bearing strata were unwatered by January 1959. The number of acres irrigated per well decreased from 118 to 78, or 34 percent, between 1947 and 1958 in farming areas A and B, and from 138 to 123, 11 percent, in farming areas C and D. Adjusting to this change in water supplies has raised the investment in irrigation facilities from $26 per acre in 1947 to $72 per acre in farming areas A and B. Operating costs per acre, adjusted basis, increased about 25 percent between 1954 and 1958.

SUB-AREA 456-2, FARMING AREAS B, C AND D, 1,098,000 ACRES: Some 13 to 26 percent of the initial water-bearing formation has been unwatered in this sub-area since 1945. The acreage irrigated per well declined from 155 to 118, or 24 percent, between 1947 and 1958. Adjusting to this decline has raised the investment in irrigation facilities from $23 per acre in 1947 to $58 per acre in 1958 in farming areas A and B. The amount of increase in farming areas C and D is not known. The present per acre investment in farming areas C and D is only $4 less than that in areas A and B and much the same kinds of adjustments have been applied as in areas A and B. Operating costs, adjusted basis, have

TABLE 20. RATES OF DECLINE IN WATER LEVEL, DEPLETION RATE AND ESTIMATED RESIDUAL LIFE OF WATER RESOURCES BY HYDROLOGIC SUB-AREAS

Hydrologic sub-area	Acreage irrigated in 1958		Decline in water-level		Depletion[2] range	Estimated residual life range[3]
			Av. rate	Years		
	Acres	Percent	Feet per year	Number	Percent	Years
1-1	139,300	3.9	1.50	10	[4]	0 to 23
1-2	31,000	.9	3.50	10	[4]	0 to 4
2-1	202,300	5.6	2.15	6	13-26	17 to 40
2-2	289,300	8.2	2.75	10	35-70	5 to 24
2-3	43,300	1.2	[5]	[5]	[5]	[5]
3-1	176,300	4.9	3.75	4	10.15	23 to 36
3-1a[6]	14,700	.4	3.50	[5]	[5]	[5]
3-2	443,600	12.4	3.50	10	23-35	14 to 28
3-2a[6]	22,000	.6	[5]	[5]	[5]	[5]
3-3	62,300	1.7	3.90	14	37-55	12 to 24
456-1	291,200	8.1	2.50	4	3- 7	56 to 116
456-1a[6]	6,400	.2	[5]	[5]	[5]	[5]
456-2	1,098,000	30.8	2.80	14	13-26	40 to 93
456-2a[6]	20,000	.5	[5]	[5]	[5]	[5]
456-3	495,800	13.9	3.50	15	17-35	28 to 71
456-3a[6]	87,300	2.4	3.24	15	19-32	31 to 78
56-4	144,100	4.0	3.86	22	28-42	30 to 55
56-4a[6]	8,100	.3	5.00	12	20-30	28 to 48

[1]Average annual rate of water-level decline for the indicated period of years preceding and including 1958.
[2]Proportion of water-bearing formation unwatered, January 1959.
[3]Range in years required to deplete remaining water-bearing formation with decline at the indicated average annual rate.
[4]Total thickness of initial water-bearing strata unknown.
[5]Largely in small isolated tracts or data too few for valid comparison.
[6]Indicates areas wherein the permeability of water-bearing formation is below normal for the sub-area.

increased about 31 percent since 1954. Other adjustments of a cost-increasing nature during the 1947-58 period have been minor.

Conditions in sub-area 456-2 are similar in all respects to those in the adjacent sub-area 456-3 except the age of development and the amount of water-level decline. This would suggest that future adjustments and their effects in sub-area 456-2 are likely to be similar to those in sub-area 456-3.

SUB-AREA 456-2a, FARMING AREA B, 20,000 ACRES: Irrigation development in this sub-area is more recent than that of sub-area 456-2. With local exceptions, it is characterized by low-capacity, high-lift wells. Data prior to the 1958 survey are scarce and because of the relatively small acreage, only a few sample farms were enumerated in the 1959 survey. On the farms enumerated, the acreage irrigated per well decreased from 132 to 101 acres, or 23 percent, between 1955 and 1958. The 1958 investment in irrigation facilities averaged $97 per acre, among the highest investment costs in the area. Although data prior to 1955 are not available for this sub-area, it is included here because of its high development cost and the sharp decline in the number of acres irrigated per well during the 4-year period.

SUB-AREA 456-3, FARMING AREAS B, C AND D, 495,800 ACRES: Water levels have declined at an average rate of 3.5 feet since 1944 and 17 to 35 percent of the initial water-bearing strata has been unwatered since 1937. Generally, irrigation development in this sub-area is a few years older than that in the adjacent sub-area 456-2. Conditions in this sub-area represent a slightly aggravated condition from those reported for sub-area 456-2. Adjustments of the same type have been applied but have been used more frequently. The acreage irrigated per well declined from 140 to 96, 31 percent, in farming areas A and B and from 149 to 129 or 13 percent in farming areas C and D between 1947 and 1958. Adjusting to this change in water supplies raised the investment in irrigation facilities from $23 in 1947 to $67 per acre in 1958 in farming areas A and B. Like sub-area 456-2, data prior to 1955 are not available for the portion of sub-area 456-3 in farming areas C and D. Adjustments similar in type and number to those in farming areas A and B have been made in farming areas C and D, and it seems reasonable to expect that similar effects have been experienced.

SUB-AREA 56-4, FARMING AREA B, 144,100 ACRES: The greatest decline in water level in the Reservoir has been experienced in this sub-area. Proportionally, however, only about one-third of the initial water-bearing stratum was unwatered during the 1937-58 period. From 1937 to 1958 inclusive, water levels declined at an average rate of 3.86 feet per year. Despite this apparent severity of conditions, the effects of adjusting to the change in water supplies has been among the lightest in the Reservoir. Water levels were initially near the surface and the thick water-bearing stratum has made it possible to adjust to the decline by lowering pumps, which is one of the lower cost adjustments.

Adjusting to the change in water levels has raised the investment in irrigation facilities from $27 per acre in 1947 to $59 per acre in 1958. Although operating costs per acre, adjusted basis, increased 62 percent between 1954 and 1958, they are still below average for the entire area. Most of the increase during 1947-58 in the per acre investment in irrigation facilities stems from the cost of lowering pumps and the installation of additional wells. Additional well installations are reflected in the changes in acreage irrigated per well, which decreased from 147 to 120 acres, or 18 percent, between 1947 and 1958.

Seriously Affected Sub-areas

Included here are sub-areas in which the decline in water levels and decline-induced adjustments have seriously depleted the water supplies, sharply increased the investment in irrigation facilities, and/or substantially increased the operating costs. More than one of these effects is found usually in the individual sub-areas. Approximately 724,000 acres, or 20 percent of the acreage irrigated in 1958, are included in this category.

The following sub-areas are included in the seriously affected group:

SUB-AREA 1-1, PRINCIPALLY FARMING AREA A AND D, 139,300 ACRES: Irrigation development in this sub-area has occurred principally since 1950. It is characterized by low-capacity wells and, except for the developments in farming area D, by relatively low pumping lifts. Water levels declined at an average rate of 1.5 feet per year during January 1949-58. As the thickness of the initial water-bearing stratum ranges from 0 to 50 feet, the proportional amount of depletion cannot be ascertained. The effects of adjusting to this decline include an increase in the amount invested in irrigation facilities from $93 in 1954 to $116 per acre in 1958 and an increase of 69 percent in operating costs during this period.

The number of acres irrigated per well declined about 10 percent from 1954 to 1958, in farming area A and 61 percent in farming area D during 1955-58. The practice of irrigating every other row, which permits irrigation of almost twice the acreage possible with each row irrigated, is followed on 82 percent of the land irrigated in Farming Area A. During this period, 1954-58, there was a decline of 7 percent in the proportion of cropland irrigated per farm.

The per acre investment in irrigation facilities is among the highest and operating costs, adjusted basis, are the highest in the sub-area. Present cash outlays for water (operating costs) approach the upper limits of economic feasibility under present price levels, see Appendix Table 2. Further adjustments of a cost-increasing nature, or a decline in commodity prices, could easily remove the profit margin from irrigation in this sub-area.

SUB-AREA 2-1, FARMING AREAS A AND B, 124,300 ACRES: Conditions in this sub-area are similar in many respects to those in adjacent sub-area 1-1. Irrigation was generally developed a little later, pumps are generally larger, and serve about twice the acreage served per well in sub-area 1-1.

Water levels have declined at an average rate of 2.15 feet per year since 1952, the last year in which they stood at 1937 levels. From 13 to 26 percent of the initial water-bearing formation was unwatered during 1953-58. Adjusting to this decline in water supplies has decreased the number of acres irrigated per well by 20 percent, increased the investment in irrigation facilities from $72 to $89 per acre, and increased per acre operating costs, adjusted basis, 56 percent between 1954 and 1958. Some 36 percent of the acreage irrigated in 1958 was irrigated by the every-other-row method and 95 percent of the acreage received water through some form of closed delivery system. These two practices have masked at least part of the effects of water-level decline. Although this is one of the most recently developed areas, approximately 17 percent of the original pumps have been replaced by pumps of smaller size.

SUBAREA 2-2, FARMING AREAS A AND D, 289,300 ACRES: Irrigation expanded rapidly in this sub-area during 1940-50. The number of acres irrigated per well in 1947 indicates that wells in this sub-area initially were average to above-average capacity. This condition has been altered materially as the water supply has diminished. Water levels declined at an average rate of 2.75 feet per year and 35 to 70 percent of the water-bearing strata was unwatered, chiefly during the 1949-58 period.

Extensive use of several types of adjustment have been applied in an attempt to cope with the problem of declining water supplies, particularly in the 235,000 acres located in farming area A. A principal adjustment has been the drilling of additional wells, which is reflected by a 49 percent decrease in acreage irrigated per well from 1947 to 1958. This decrease in acreage irrigated per well does not fully reflect the effects of a diminished water supply, since 70 percent of the acreage irrigated in 1958 was irrigated by the every-other-row method. Also, water was delivered to 70 percent of the acreage irrigated in 1958 by some form of closed delivery system. Approximately 25 percent of the pumps used in 1958 have been lowered one or more times since they were installed and 17 percent have been replaced by smaller pumps.

The measurable effects of adjusting to the decline in water levels in farming area A include: (1) an increase from $28 to $100 per acre from 1947 to 1958 in the per acre investment in irrigation facilities, (2) a 60 percent increase in operating costs per acre, adjusted cost basis, during 1954-58 and (3) a 10 percent decrease in the proportion of cropland irrigated per farm from 1954-58.

Previous surveys have not covered sub-area 2-2 in farming areas C and

D. The 1958 survey shows that many of the same type of adjustments, though less extensively used, have been made as in farming areas A and B.

SUB-AREA 3-3, FARMING AREAS A, C AND D, PRINCIPALLY 62,300 ACRES: Sub-area 3-3 occurs in all four farming areas, but only the larger bodies located in farming areas A and C were covered in earlier surveys. Water levels declined at an average rate of 3.90 feet per year and 37 to 55 percent of the initial water-bearing strata was unwatered during the 14-year period of 1945-58.

Adjustments in this sub-area are much the same as those made in sub-area 2-2. Approximately 29 percent of the pumps used in 1958 have been lowered once or twice since they were initially installed and 59 percent of the acreage irrigated in 1958 received water through closed delivery systems. Additional wells were installed as the water level declined. This is reflected partly by the reduction in number of acres irrigated per well, which ranges from 25 percent in the mixed lands of farming area A since 1947 to 3 percent from 1955 to 1958 on the hardlands of farming area C. During 1954-58, the proportions of cropland irrigated per farm in farming areas A and C were reduced by 10 percent.

Adjusting to the change in water supplies has increased the per acre investment in irrigation facilities from $26 and $23 per acre in 1947 to $66 and $73 in 1958 in farming areas A and C, respectively. The per acre operating cost, adjusted cost basis, increased 121 and 87 percent during 1954-58, respectively, in farming areas A and C.

SUB-AREA 3-2a, FARMING AREA B, 22,000 ACRES: Development and adjustment data prior to the 1958 survey are not available for this sub-area. Irrigation developments are characterized by generally high lift, low-capacity wells and relatively high investment and operating costs per acre. Although the data with respect to adjustments are few, with a consequent possibility of sampling error, this subgroup is placed in the seriously affected category because of the high investment and operating costs and the 18 percent decline in acres irrigated per well during 1954-58.

SUB-AREA 456-3a, FARMING AREA B, 87,300 ACRES: Irrigation developments in these sub-areas are characterized by generally lower capacity wells and somewhat greater pumping lifts than those in sub-area 456-3. The average annual water-level decline of 3.24 feet per year since 1945 is slightly lower than the annual recession rate experienced in sub-area 456-3 for the same period. The types of adjustment in the two parts of this sub-area are similar. However, they have been applied with greater frequency in sub-area 456-3a. Approximately 71 percent of the farms enumerated were equipped with closed distribution systems in 1958. As in most of the other sub-areas, these systems were installed principally after 1954. The acreage irrigated per well declined from 99 to 78 acres, a decrease of 21 percent during 1955-58. Here too, much of the effect of water-level declines is obscured by the water-conserving effects of closed distribution systems.

Development costs in 1947 and 1954 are not available. In 1958, they averaged $85 per acre, $18 per acre greater than in sub-area 456-3. Operating costs per acre, adjusted cost basis, are about $3, or 56 percent, greater than those in sub-area 456-3.

Severely Affected Sub-areas

Included here are areas in which the water supply has been severely depleted and/or where further increases in operating costs would impair the economic feasibility of continued water use. Approximately 82,400 acres, 2.3 percent, of the acreage irrigated in 1958 are included in this category.

The following sub-areas are included:

SUB-AREA 1-2, FARMING AREAS A AND B, 31,000 ACRES: Water levels declined at an average rate of 3.5 feet per year during the 10-year period, 1949-58. As the initial water-bearing stratum in sub-area 1-2 was less than 50 feet thick, the 10-year decline of 35 feet has unwatered much of it. Irrigation developments in this sub-area were highly similar to those in adjacent sub-area 2-2. The adjustment to a decrease in water supplies also is similar in many respects.

SUB-AREA 2-3, FARMING AREAS A AND C, 43,300 ACRES: Conditions in sub-area 2-3 reflect a more aggravated situation than those in sub-area 2-2 with which it is associated.

SUB-AREA 56-4a, FARMING AREA B, 8,100 ACRES: Conditions in 56-4a offer a sharp contrast to those in 56-4, which had a similar initial thickness of water-bearing stratum and which has experienced a similar amount of water-level decline. Irrigation developments in sub-area 56-4a are more recent and are characterized by low-capacity wells with pump settings averaging 290 feet, compared with an average pump-setting depth of 170 feet in sub-area 56-4.

Water levels declined at an average rate of 5.0 feet per year, highest in the Reservoir, during 1947-58. Part of the effects of this decline are reflected by a drop from 83 to 56 acres irrigated per well, a 33 percent decrease, during 1955-58. A reduction of 10 percent in the proportion of cropland irrigated per farm occurred during this 4-year period.

Adjustments to meet this change in water supplies consisted principally of lowering pumps, 71 percent, and installation of closed delivery systems (66 percent of farms equipped by 1958). The cost of adjusting to this change in water supplies is not known, as data for this small area were not obtained in 1947 or in 1954. The present investment in irrigation facilities, $126 per acre, is the highest, and operating costs per acre, adjusted cost basis, are among the highest in the area.

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APPENDIX TABLE 1. INVESTMENT IN IRRIGATION FACILITIES AND OVERHEAD COSTS PER ACRE IRRIGATED, BY FARMING AREAS AND HYDROLOGIC SUB-AREAS

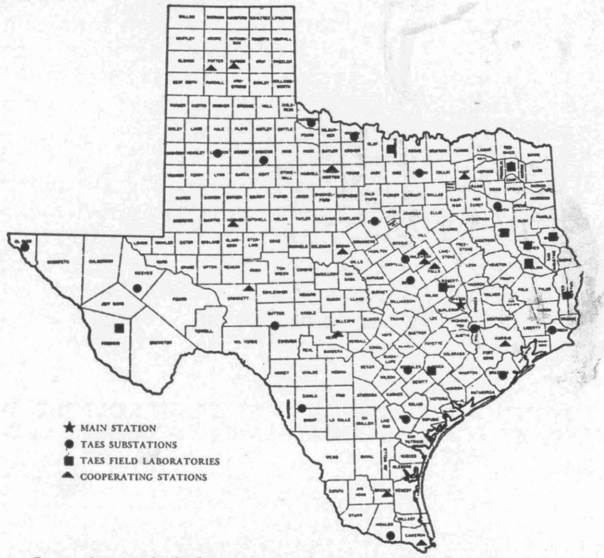
Hydrologic sub-area	Farming areas A and B[1]		Farming areas C and D[1]	
	Investment per acre irrigated	Ownership cost per acre irrigated	Investment per acre irrigated	Ownership cost per acre irrigated
	Dollars			
1-1	116.00	11.60	81.00	9.62
1-2	97.00	9.16		
2-1	89.00	10.38	62.00	7.43
2-2	100.00	11.90	59.00	6.71
2-3[3]	67.00	7.90		
3-1	86.00	9.87	61.00	7.30
3-1a[3,4]	120.00	14.22		
3-2	72.00	8.72	53.00	6.30
3-2a[3,4]	81.00	9.56		
3-3	66.00	7.98	73.00	8.75
456-1	55.00	6.57	57.00	6.73
456-1a[3,4]	108.00	12.74		
456-2	58.00	6.84	54.00	6.37
456-2a[3,4]	97.00	11.25		
456-3	67.00	7.96	52.00	6.06
456-3a[4]	85.00	10.00		
56-4	59.00	7.00		
56-4a[3,4]	126.00	15.24		

[1]Farming Areas shown in Figure 4, sub-areas shown in Figure 7.
[2]Amount required to defray interest, depreciation, taxes, risk or insurance costs on investment in irrigation facilities. Variations in overhead costs per acre reflect the amount and type of facilities involved in the various sub-areas, see Table 18.
[3]Small sample.
[4]Indicates areas where the permeability of water-bearing formation is low.

APPENDIX TABLE 2. APPROXIMATE BREAKOVER POINT FOR OPERATING WATER EXPENDITURES PER ACRE AT SPECIFIED LINT AND GRAIN SORGHUM PRICES, 320-ACRE IRRIGATED FARM[1]

Seasonal average price per pound of lint cotton	Seasonal average price per hundredweight of grain sorghum										
	Dollars										
	3.25	3.00	2.75	2.50	2.25	2.00	1.75	1.50	1.25	1.00	0.75
Cents											
34	32.83	30.49	28.14	25.80	23.47	21.12	18.78	16.44	14.10	11.76	9.42
33	32.14	29.80	27.46	25.12	22.78	20.44	18.10	15.76	13.42	11.08	8.74
32	31.46	29.12	26.78	24.44	22.10	19.76	17.42	15.08	12.74	10.40	8.06
31	30.78	28.44	26.10	23.76	21.42	19.08	16.74	14.40	12.06	9.72	7.38
30	30.10	27.76	25.42	23.08	20.74	18.40	16.06	13.72	11.38	9.04	6.70
29	29.42	27.08	24.74	22.40	20.06	17.72	15.38	13.04	10.70	8.36	6.02
28	28.74	26.40	24.06	21.72	19.38	17.04	14.70	12.36	10.02	7.68	5.34
27	28.05	25.71	23.37	21.03	18.69	16.35	14.01	11.67	9.33	6.99	4.65
26	27.37	25.03	22.69	20.35	18.01	15.67	13.33	10.99	8.65	6.31	3.97
25	26.69	24.35	22.01	19.67	17.33	14.99	12.65	10.31	7.97	5.63	3.29
24	26.01	23.67	21.33	18.99	16.65	14.31	11.97	9.63	7.29	4.95	2.61

[1]Adapted from Table 9, "Economics of Water Management for Cotton and Grain Sorghum Production, High Plains," Texas Agricultural Experiment Station Bulletin 931, May, 1959.



Location of field research units of the Texas Agricultural Experiment Station and cooperating agencies

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IN THE MAIN STATION, with headquarters at College Station, are 16 subject-matter departments, 2 service departments, 3 regulatory services and the administrative staff. Located out in the major agricultural areas of Texas are 21 substations and 9 field laboratories. In addition, there are 14 cooperating stations owned by other agencies. Cooperating agencies include the Texas Forest Service, Game and Fish Commission of Texas, Texas Prison System, U. S. Department of Agriculture, University of Texas, Texas Technological College, Texas College of Arts and Industries and the King Ranch. Some experiments are conducted on farms and ranches and in rural homes.

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Conservation and use of water	Dairy cattle
Grasses and legumes	Sheep and goats
Grain crops	Swine
Cotton and other fiber crops	Chickens and turkeys
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Citrus and other subtropical fruits	Fish and game
Fruits and nuts	Farm and ranch engineering
Oil seed crops	Farm and ranch business
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