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Irrigating with Windmills on the Great Plains

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F art Worth Museum of Science and History

IRRIGATING WITH WINDMILLS ON THE GREAT PLAINS

T. LINDSAY BAKER

In his 1895 graduation thesis from the state agricultural college at Manhattan, Kansas, Fred E. Rader declared of the windmill, "Without, we must emigrate; with it, we can irrigate."[1] Rader summarized the feelings of many farmers in the Arkansas and Platte valleys and elsewhere across the Great Plains in the mid-1890s. He wrote in the heyday of windmill irrigation in the area, when machines employing the free power of the wind to pump water from the ground were seen as the salvation of the region.

Self-governing windmills had already been used for elevating water in America for four decades by the time that the windmill irrigation fever spread over the Great Plains. The first commercially successful self-governing American windmill was invented in 1854 by a New England Yankee machinist named Daniel Halladay, and from the 1860s onward the machines had been manufactured and used throughout the country but especially in the Midwest and on the Great Plains. The key to the success of the machines was the fact that they were self-governing; that is, they automatically governed their speed of operation so that they did not destroy themselves in high winds.[2]

Windmill irrigation began in scattered locales in the decades preceding the great flurry of activity during the mid-1890s, but during this early period the practice was sporadic. A typical early user was James Vick, who began in 1875 to elevate irrigation water with an Eclipse windmill for his extensive commercial flower gardens and seed farm at Rochester, New York.[3] In another representative instance, the United States Army on the frontier at Fort Elliott, Texas, began in 1879 to use a Halladay Standard windmill to irrigate the post orchard of peach trees.[4] Through the 1870s and 1880s, major windmill manufacturers advertised their products as appliances for irrigation, centering their promotional efforts on sales to truck gardeners.[5]

During the 1870s and 1880s, windmills began to be used on the Great Plains in substantial

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numbers, primarily for pumping water for livestock and for domestic supply. Since the technology of self-governing windmills and their pumps had become comparatively common knowledge by the 1880s, it is not surprising that residents of the Plains saw the potential of windmills for elevating irrigation water.[6]

This familiarity with the technology coupled with a period of protracted drought in the late 1880s and early 1890s prompted the rise of windmill irrigation during the decade of the 1880s and its flourishing during the 1890s. Along river valleys like the Arkansas and the Platte, privately financed surface water developments employing diverted river water and open-ditch delivery to farmers' fields had boomed during the 1880s. Dry weather combined with increased irrigation diversion upstream meant that many of the erstwhile irrigators were forced to look elsewhere for irrigation water, to return to dry-land farming, or to relocate.[7] This situation led to Rader's advice to "irrigate or emigrate." The demand for surface water was greater than the supply.

Irrigation Near Garden City, Kansas

As a result of careful research by Anne M. Marvin, we know perhaps more about the beginnings of windmill irrigation in the Arkansas River Valley area in southwestern Kansas around Garden City than in any comparable areas. Since Garden City became the most publicized center of windmill irrigation on the Plains, it is worthwhile to examine precisely what happened in that area.

During the 1880s, substantial development of the surface flow of the Arkansas River was undertaken in the Garden City area, with a series of ditches being constructed to carry diverted river water to the fields of individual farmers who purchased the water from irrigation companies. Similar irrigation development was taking place upstream in eastern Colorado. Even during good years there was insufficient stream flow to supply the irrigators in both states, and

FIG. 1. *Open back-geared Aermotor steel windmill pumping water into E. H. Hall's irrigation storage tank near Garden City, Kansas, ca. 1895.* Courtesy Kansas State Historical Society, Topeka, Kansas.

when drought struck in the late 1880s the Kansas irrigators found themselves with virtually no supply. The population of the Garden City area began shrinking, with farmer after farmer retreating back toward better watered country. The remaining farmers either practiced dry-land agriculture or searched for alternate water sources.

In 1888 Carter Brothers, Gause and Company, a local farm implement firm at Garden City, sold a number of windmills and tanks to farmers specifically for the purpose of irrigating small acreages. E. N. Gause and his partner, J. V. Carter, believed that wind-powered pumps represented a viable alternative to irrigation with the inadequate supply of surface water available. As a promotional tool, they erected a windmill on the Finney County courthouse square in Garden City and fitted it with a five-inch diameter pumping cylinder rather than the usual one-and-a-quarter-inch pump. The volume of water the mill pumped impressed all the locals. Sales by Carter Brothers, Gause and Company, coupled with their own experiments in wind-powered pumping, sparked a short-lived flurry of windmill irrigation activity in the late 1880s.

The first Carter Brothers, Gause and Company customer to purchase an irrigation pump-

ing plant was W. R. Grace, a truck farmer living at the southeast corner of Garden City.[8] In a farm implement journal, Grace described his pioneer system this way:

> I made a pond or reservoir which holds 6,000 barrels of water and pump the water into it, and from there I draw the water as needed. I irrigated four acres last year, and could have watered two or three times as much if my ground had been ready. My young orchard made a rapid growth from this irrigation, and I marketed in small fruits, garden stuff, etc. $500 from these four acres. Had I not have had the pump I would not have been able to market over $50 from this same ground. . . . My five-inch pump throws one gallon of water at each stroke, and the ten-foot mill runs it and makes forty to sixty strokes per minute in an ordinary wind.[9]

After a brief period of interest in 1889-90, windmill irrigation activity at Garden City waned for a couple of years, only to be renewed in 1893. Farmers reassessed the potential for windmill irrigation and began placing orders for more and more wind-powered machines. Carter and Gause in spring and summer 1893 installed twenty-five windmill irrigation plants, and the local press predicted that another one hundred and fifty plants would be built before the end of the summer. Underground water was becoming recognized as a dependable source of supply. In November 1893, for instance, a Kansas irrigation convention at Wichita pronounced that groundwater was plentiful and that farmers would be farsighted if they installed windmills to take advantage of the resource.[10]

Windmill popularity continued into 1894, and by 1895 it had reached what might be considered a fever pitch. The Finney County Fair

FIG. 2. *Commercial windmill exhibit at the Finney County Fair, Garden City, Kansas, in 1894.* Courtesy Kansas State Historical Society, Topeka, Kansas.

at Garden City in both years boasted commercial displays from more than a dozen different windmill manufacturers. In 1895 the exhibits even included an acre of cultivated crops raised through the application of windmill-pumped irrigation waters.[11]

As increasing numbers of journalists visited Garden City, it gained a reputation as the national center of windmill irrigation. Throughout the United States, both popular and specialized periodicals held up Garden City as the example of what wind-powered irrigation could offer drought-plagued farmers.[12] A newspaperman on an "irrigation excursion train" that ran from Newton, Kansas, to Rocky Ford, Colorado, exclaimed to his readers that at Garden City "the trains ran through a forest of wind mills." He went on to extol the windmill, which he noted, "works for nothing and boards itself."[13]

Windmill irrigation around Garden City leveled off in the second half of the 1890s, beginning a decline by 1899. Among the factors contributing to the slowdown of wind power irrigation were an increase in local rainfall, continued competition from surface water developers, and difficulties in marketing the crops raised under intensive agriculture.[14]

Other Windmill Irrigation

Garden City, although the best known center of windmill irrigation, was by no means the only one. The Platte River Valley of Nebraska came in a close second for national publicity and probably actual activity. A typical windmill irrigator in the Platte Valley was John Tannahill, owner of a nursery at Columbus, Nebraska. Tannahill observed that the apple trees in his ten-acre orchard seemed to thrive and set their fruit well but that the fruit fell off before it matured. Assuming correctly that the problem was lack of moisture during the growing season, he installed a homemade windmill to pump water from two six-inch diameter wells. The nurseryman stored the pumped water in an earthen reservoir, releasing it to flow through ditches to his trees. Tannahill's experiment proved to be a success, for after he began the regular application of irrigation waters his trees held and ripened the fruit that theretofore had dropped off prematurely.[15]

During the late nineteenth century, windmills were also used for irrigation in locations outside the Arkansas and Platte valleys. Perhaps the best known of these was the San Joaquin Valley around Stockton, California. There windmills elevated large volumes of water from shallow wells to irrigate market gardens that served the urban areas in the state. By the turn of the century, the mills used almost universally for irrigation pumping in the San Joaquin Valley were huge machines with wind wheels averaging twenty-two feet in diameter. The gigantic mills ordinarily pumped water from two adjacent wells by means of a lever mechanism. A writer from the U. S. Department of Agriculture in 1910 noted that some of the old wooden mills in Stockton had been running for thirty years, though by the time of the First World War most of them had been phased out in favor of gasoline or electric pumps.[16]

In Texas during the 1890s and 1900s, windmill irrigation plants could be found scattered from the Gulf Coast inland all the way to the Panhandle. In a representative system, J. H. Wayland near Plainview in 1896 employed three Aermotor windmills to elevate water from wells ranging from 35 to 60 feet deep into a storage reservoir measuring 300 feet long, 75 feet wide, and 6 feet deep, from which it was released to irrigate 10 acres of crops. His total cost for wells, windmills, pumps, and reservoir totaled $505.[17] Other parts of the West boasted of similar systems.[18]

Wells For Windmills

The most important factor in windmill irrigation on the Great Plains was the availability of underground water secured through the use of a variety of wells. The type of well varied according to the subsurface conditions and the depth of the water.

In areas like the immediate Platte and Arkansas river valleys, groundwater could be found easily as underflow at quite shallow depths. Thus the irrigators in such valleys had only to sink their wells ten to twenty feet in order to secure an abundant supply.[19] In such locations, where underflow adjacent to rivers or intermittent streams was easily tapped, the irrigators usually employed hand-dug wells, wells bored with augers, or driven wells.

Hand-dug wells were precisely what their name suggests. They were excavated by well diggers using ordinary manual earthmoving tools such as picks, shovels, and buckets. Averaging three to six feet in diameter, they generally were curbed with wood, with stone, or with brick laid without cement so that water could pass from the surrounding water-bearing strata into the well.[20]

For boring shallow wells, human- or animal-powered augers proved to be successful. The augers, which ranged from two inches to three feet in diameter, rotated and dug into the earth, at the same time lifting the loosened soil to the surface for removal. The bored wells were curbed with wood, cement, tile, or metal casing to prevent them from caving in.[21]

Also popular in areas with shallow underground supply were driven wells. These small wells, often under six inches in diameter, were sunk by hand or animal power by driving a small, pointed, screen-equipped steel cylinder directly into the ground down to the water-bearing level. Depending on the subsurface conditions, well points could reach downward approximately twenty-five to thirty feet provided that difficult rocks were not encountered.[22]

In areas with groundwater available only at considerable depth, wells generally were drilled rather than dug, bored, or driven. This drilling in the nineteenth and early twentieth centuries was predominately done with machines employing the percussion method of well sinking. Percussion rigs repeatedly lifted and then dropped heavy metal bits, usually between 1½ and 12 inches in diameter, which quite literally pounded holes in the ground. The machinery usually was either animal- or steam-powered. As the bits pulverized the soil or rock, the loosened drillings were lifted from the well by a bailer, a long metal bucket fitted with a valve in its lower end.[23]

During the late nineteenth and early twentieth centuries, drillers developed the rotary well drilling technique, which today is common in both oil and water well drilling. The driller used a rotating hollow bit that penetrated the ground through abrasion. Loosened soil and rock then were removed by a flow of water or mud that was forced through the drill pipe, taking the unwanted material up alongside the drilling pipe.[24]

The cost of sinking a well varied with the subsurface conditions and with the depth of the well. If the irrigator sank his own well, the only costs other than for his own time would be for his tools and equipment and for any hired labor. The retail price for a 30-inch long, 3-inch diameter drive well point at Omaha, Nebraska, in 1899, for example, was $20, to which the irrigator would add the desired amount of 3-inch wrought iron pipe costing $.75 a foot.[25] Thus he could sink a 20-foot driven well for approximately $35 plus any paid labor.

Most drilled wells were sunk by professional well drillers who charged their customers by the foot for their services. On the XIT Ranch in the Texas Panhandle, well drillers in the 1880s received an average of $1.50 per foot for the first 150 feet of a well, $2 a foot for the next 100 feet, and then $.50 more per foot for each subsequent foot until a satisfactory flow of water was reached.[26] The costs were similar elsewhere on the Plains. Drilled wells were not cheap.

Types of Windmills Used for Irrigation

Once a well was sunk, the farmer needed a windmill to pump the water to the surface. Throughout the Plains irrigators used a broad range of windmills for this purpose. Judging from historic photographs, written accounts, and the sales literature produced by windmill manufac-

turers, the most common mills used for irrigation on the Plains were the "solid wheel" steel variety. These were similar to those still used by the thousands in the West for general water supply purposes. Their steel vanes directed the rigid steel wheels into changing wind directions. Through a variety of means, the wheels pivoted away from increasing winds to prevent their destruction from centrifugal force, while their governors drew the wheels back to face decreasing winds more squarely. This gave the machines relatively constant rates of operation. Such steel windmills began reaching the Great Plains in substantial numbers during the 1880s, and in time they came to dominate the American windmill market.[27]

The makers of solid-wheel steel windmills boosted the sales of their products by reprinting testimonials from irrigators. For example, a letter by L. L. Doty of Garden City, Kansas, was published about 1895 in a windmill catalog:

> I came to the conclusion in 1893 that it would pay any farmer to pump water for irrigation. I therefore bought a 12-ft. Gem Mill and 8-in. Gause Irrigation Pump that year, and last year I bought another outfit like the first. I have successfully irrigated with these pumps 10 to 20 acres with each pump. The most profitable crop so far has been cabbage and sweet potatoes. I find that it is paying me well for its investment. It would be a paying investment if I could not do more than keep my orchard watered. The last mill I purchased was the Improved Gem on a 60-ft. steel tower, and it is, without doubt, the best mill that was ever turned loose in a Kansas breeze.[28]

Other irrigators preferred the older style wooden windmills, some with rigid "solid" wheels and others with wheels consisting of "sections" of wooden blades that pivoted away from increasing winds. The older style wooden windmills had been used for farm water supply since the 1850s, and they remained on the commercial market until the 1940s.[29]

Windmill Prices

The purchase of a windmill and its appurtenances always represented a fairly substantial investment of money. Through the nineteenth and early twentieth centuries, there was a gradual decrease in purchase prices for windmills, but few of them could be considered cheap. The retail prices for the twelve-foot diameter Halladay Standard windmill, a typical irrigation-sized mill, give some idea of what farmers through the years had to pay for the machines.

In the mid-1850s, when the Halladay Standard was offered for sale as the first commercially successful self-governing American windmill, its twelve-foot model sold for prices ranging from $130 to $160, declining to $135 in 1875. By the next year, 1876, buyers received the choice of a less expensive short-stroke model or a more costly long-stroke version. Consequently prices of $130 and $135 are noted in sales literature from 1876, 1882, 1885, and 1886. By 1899 the price had decreased to as low as $100. The lowest-priced models of the twelve-foot Halladay Standard sold for $84 to $100 in 1905 and then $70.15 to $83.65 in 1916, toward the end of its production history. A great variation in prices also existed according to the size of mill chosen. In 1885, when the short-stroke twelve-foot diameter Halladay Standard sold for $130, the thirty-foot version of the same mill cost a consumer $575.[30]

Homemade Windmills

Some irrigators opted to build their own windmills instead of choosing factory-made models. Homemade mills are best known for their use by the hundreds in the Platte River Valley, but they found employment throughout the Plains for irrigation pumping. These contraptions, some of them built from salvaged materials for as little cash expense as $1.50, took a wide variety of forms.

The greatest virtue of the highly inefficient homemade windmills was their cheapness. They

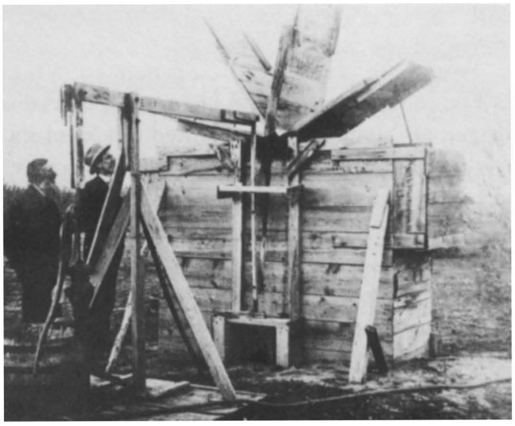

FIG. 3. *Homemade Jumbo style windmill built by J. L. Brown for irrigation at the Midway Nursery east of Kearney, Nebraska.* Photograph by Erwin Hinckley Barbour, ca. 1898, courtesy photo archives, U.S. Geological Survey, Denver, Colorado.

could be made from just about any discarded materials around a farm: old lumber, shingles, old packing crates, barrel staves, feed sacks, or recycled tin roofing. Professor Erwin Hinckley Barbour of the University of Nebraska recounted seeing one homemade mill in the Platte Valley in the late 1890s that had been built in part from hundreds of cast-off tin cans collected from a town dump. The resourceful Nebraskan raked his cans into a heap with some waste straw and lit the straw. After the fire melted the solder that had held the cans together, the windmill builder easily flattened them and nailed them to cover the sides of the wooden framework supporting his ground-tumbler windmill.[31]

STORAGE RESERVOIRS

An unassisted windmill with a constant wind under even the most perfect conditions could pump only a limited amount of water. At optimum efficiency, for example, a twelve-foot diameter back-geared steel Aermotor windmill, one of the most popular styles and sizes of irrigation mills on the Plains, could pump from a seventy-five-foot well only approximately 1175 gallons of water per hour.[32] These figures, importantly, apply only for ideal conditions when the wind was blowing steadily.

With the exception of applications such as the slow watering of fruit trees with a garden hose, windmills were not used for direct irrigation but to fill storage reservoirs built to impound accumulated water for later use. Two factors necessitated reservoirs. First, and most obvious, the windmills could pump only limited amounts of water. Second, and equally important, the stored water in reservoirs had sufficient "head" or pressure to force the water to flow down ditches at speeds sufficient to reach the crops before soaking into the ground.[33] As one writer on Great Plains irrigation noted in 1897, if a windmill pumped directly into a ditch:

> The stream of water . . . may continue for hours or even days without wetting the ditch for a distance of more than 50 to 100 feet from the well. . . . But if this same amount of water is held in a tank or earthen reservoir of sufficient size, and is allowed to accumulate during several days and nights of continuous pumping, there is then at hand a sufficient volume to make it possible to irrigate even the most porous of soils.[34]

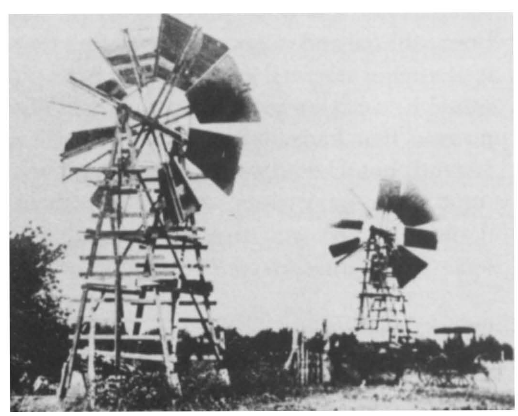

FIG. 4. *Two sixteen-foot diameter homemade Battle Axe style windmills built by J. S. Peckham to irrigate an orchard near Gothenburg, Nebraska.* Photograph by Erwin Hinckley Barbour, ca. 1898, courtesy photo archives, U.S. Geological Survey, Denver, Colorado.

In order for the accumulated water to flow by gravity to the fields for irrigation, the reservoirs were placed at the highest points on the farms. Although tests were made with other types of construction, almost all successful storage reservoirs were built from earth.

In designing their reservoirs, farmers had to consider the two most important causes of water loss, seepage and evaporation. Clayey soils minimized seepage. The configuration of reservoirs greatly influenced their subsequent evaporation losses. A deep reservoir with high sides exposed the smallest surface area to evaporation. Theoretically, round reservoirs were best for combating evaporation, as they presented the least surface for a given quantity of water, but most irrigators chose to construct square or rectangular tanks because they were simpler to build. Most actual reservoirs were rectangular, with some farmers laying them out so that their long sides were at a right angle to prevailing winds in order to reduce bank erosion by wind-created waves.

A typical storage reservoir for windmill irrigation measured approximately fifty by one hundred feet and had earthen banks six feet tall. In building such a tank, the irrigator first removed all surface soil and plants from within the area projected for the reservoir and its banks. The roots from plants in the surface soil were believed to create passageways for seepage. Next some builders filled in the excavated area with clay soil if such material did not already underlie the site. Then gradually the sides of the reservoir were built up with soil free from any plants or roots. Some builders mixed water with this soil and drove animals back and forth to pack down the earth. Walls of the reservoirs sloped gradually on the inside to reduce bank erosion from waves while the outer sides were built up more steeply. After the sides of the reservoir were completed to the desired height of about six feet, the builders often lined the reservoir with clay and water, driving animals back and forth over the mud to "puddle" it and create a more or less impervious bottom and sides. Some builders preferred to let the banks settle under several rains or snows before they filled their reservoirs.[35]

Bank erosion from wind-generated waves proved to be a persistent problem for Great Plains irrigators. Some of them planted blocks of sod along the sides of their reservoirs, wedging between them marsh plants that they hoped would take root. Others wove mats from flexible woody plants and pegged them down to the sides as protection. Some irrigators planted tamarisk or willow trees along the sides to retard wave erosion. Others broke the force of the destructive waves by placing floating booms made from old railroad ties or other timbers in the water parallel to the reservoir sides.[36]

Outlets were an important part of reservoir construction. They permitted irrigators to release stored water into the ditches to flow to the fields. Some of the outlets might be as sophisticated as iron or steel pipes fitted with screw type valves, but most of them were much simpler. Outlets commonly consisted of rectangular wooden boxes made from two-inch thick boards nailed together to form hollow tubes measuring eight to eighteen inches in width and height. These horizontal outlets generally were equipped with sliding or hinged wooden gates attached to the inner ends of the outlet tubes. Well-designed outlet works withdrew water two or three feet higher than the bottom of the reservoirs so that at least some water always remained. If a tank dried out completely, its puddled mud bottom would crack open and have to be renewed to avoid leakage.[37]

Irrigating From Reservoirs

Once it was released from the reservoirs, water passed down main ditches and thence through lateral ditches to the fields where it was needed. There the water either flowed down the plowed furrows or was allowed to flood the fields. The irrigation systems depended on gravity flow to force the stored water through the main and lateral ditches and through the furrows or over the fields. Many farmers had to expend considerable effort and expense to construct ditches

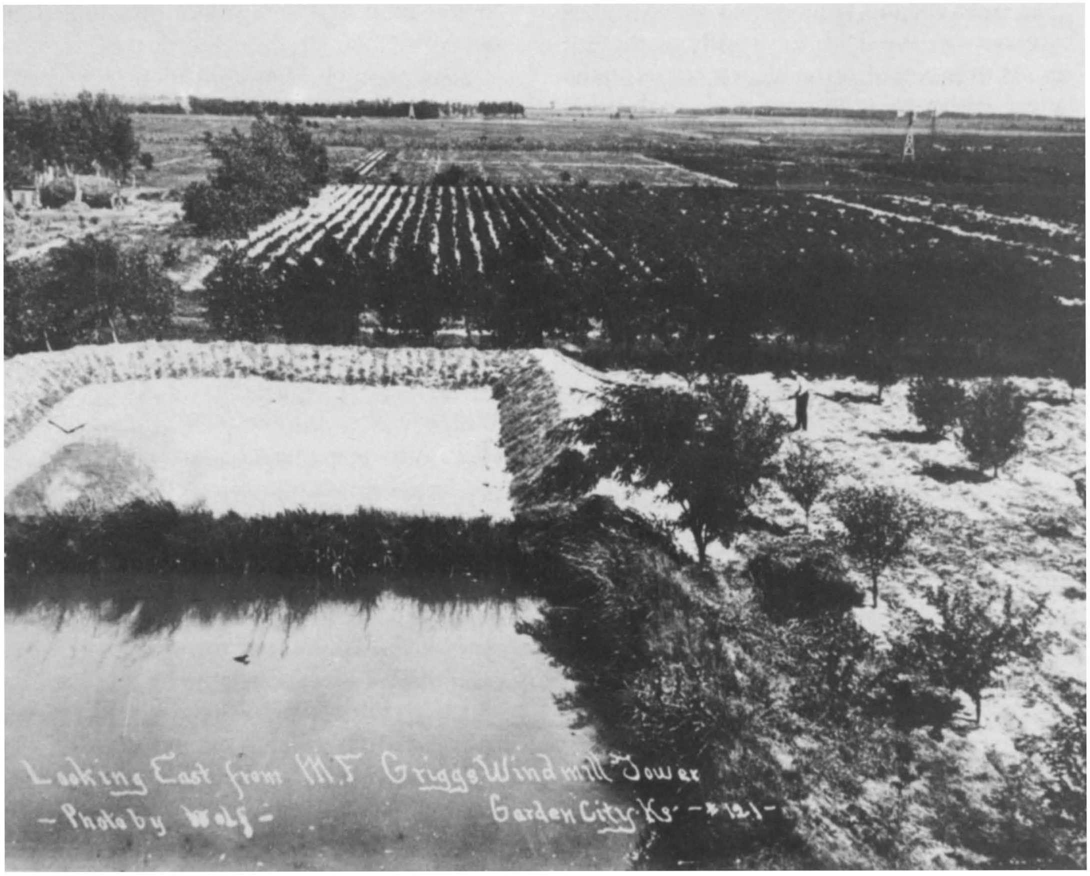

FIG. 5. *View eastward from a windmill tower onto the earthen storage tanks and irrigated orchard and fields belonging to M. F. Griggs near Garden City, Kansas, ca. 1895.* Courtesy Kansas State Historical Society, Topeka, Kansas.

that would provide this flow, in some instances having to build up the ditches two or more feet above normal ground level near the reservoirs. The irrigated farms generally were carefully planned so that their owners could use the limited water supplies in the most efficient manner.[38]

Successful applications of windmill irrigation were found almost always in intensive agriculture. Windmills under the best conditions could water a maximum of only about ten acres per well, although promoters claimed greater acreages served. Such irrigation, employing a finite supply of water, could be satisfactory only if coupled with intensive agriculture. The most successful of the windmill irrigators seem to have been those who specialized in truck gardening and fruit raising. Windmill water supply could never satisfy the needs of extensive agriculture.[39]

THE END OF WINDMILL IRRIGATION

The limitations on acreage eventually spelled the doom for windmill irrigation. Even in the area around Garden City, Kansas, where windmills were used perhaps more commonly for irrigation than anywhere else on the Plains, individual farmers seem to have balked at exclusively practicing intensive agriculture. The

reluctance of farmers to raise only labor-intensive crops prompted them to employ windmills to aid in raising easily grown alfalfa or perhaps a few truck crops while they devoted the remainder of their efforts to growing unirrigated grain on fields where the depth of groundwater made windmill irrigation impractical.

Another handicap for the windmill irrigators was difficulty in marketing their products. Often located miles from large urban centers, the farmers encountered problems in selling their truck crops before they spoiled. Soon the local markets in areas with concentrated windmill irrigation became glutted with garden produce, driving the prices downward. The only way to reach places like Denver and Kansas City, the nearest urban markets, was to ship crops by rail, which often left the windmill irrigators with little profit margin. In a generally favorable report on agriculture at Garden City, one writer reported that many farmers had been forced to adopt peddling as a means of marketing their produce. "After the crops are gathered," he wrote, "the farmers load their wagons with vegetables and fruits and travel across the country, selling from the wagon." Some of the farmers traveled as far as seventy-five miles to vend their produce at large cattle ranches.[40]

Research on Windmill Irrigation

Despite the limitations of windmill irrigation, it became and remained for years a subject of investigation and research by both federal and state agencies. During the summers of 1895 and 1896, Edward Charles Murphy from the U. S. Geological Survey conducted scientific trials of a wide range of wooden and steel windmills that he found in service pumping irrigation water at Garden City, Kansas. He chose the Arkansas River Valley for his investigations because, as he wrote, "perhaps nowhere in the United States is irrigation from wells by the use of windmills carried to the same extent as there." Murphy's goal was to secure concrete data concerning the individual performances of a wide range of different styles and sizes of windmills, studying twenty varieties in 1895 and thirty-seven in 1896. His investigations provided consumers with reliable information on numerous irrigation mills then on the market.[41]

While Murphy was busy at Garden City, the Kansas Irrigation Board in 1895-96 was engaged in testing twenty experimental irrigation wells in western Kansas, nineteen of which were pumped by windmills for the purposes of the trials. The Office of Experiment Stations of the U. S. Department of Agriculture in 1904 also conducted experiments at Garden City. Its employees visited 107 wells being pumped by windmills in the Arkansas River Valley, determining the volumes of water elevated, the number of acres served, and the costs per acre for irrigation by wind power.[42]

Also in 1904 the U. S. Department of Agriculture initiated several years of trials with windmills for irrigation at its Cheyenne, Wyoming, demonstration farm. There, over a five-year period, several mills of different sizes and styles were carefully tested, resulting in detailed information comparing and contrasting their efficiencies and costs of operation. One of the results of the Cheyenne experiments was the publication in 1910 of a Department of Agriculture handbook for windmill irrigation as *The Use of Windmills in Irrigation in the Semiarid West*, Farmer's Bulletin No. 394, later revised and reprinted as Farmer's Bulletin No. 866 in 1917. Since that time these two bulletins by P. E. Fuller have remained the most widely read practical manuals for the use of windmills as implements of irrigation.[43]

Windmill irrigation remained a pertinent topic for agricultural research well into the 1920s. From 1924 to 1929, engineers at the Panhandle Agricultural Experiment Station in Oklahoma conducted trials to document and analyze volumes of water pumped, wind velocities and directions, and evaporation losses for water pumped by a 12-foot windmill operating with a 140-foot lift using a 2½-inch pumping cylinder. The purpose of the experiments was to ascertain the viability of windmill irrigation under Oklahoma Panhandle conditions.[44]

CONCLUSION

A form of agriculture that has passed from the scene on the Great Plains, windmill irrigation had both its advantages and its disadvantages. It filled a gap for many irrigators for the few years when steam power pumping was too expensive for most individual farmers but before comparatively inexpensive gasoline or electric pumps became available. For such irrigators the windmill offered independence both from unreliable surface water supplies and from the vagaries of the weather. The *Garden City Imprint* in 1890 declared, "The farmer with a pumping plant has no occasion to go up the ditch and enforce his demand for water with a shot-gun, nor need to be haunted by the suspicion that his best neighbor is 'rustling' his water."[45]

Windmill irrigation, even on a small scale, also brought farmers a measure of independence from the capricious Great Plains weather. Even when drought shriveled away the leaves from unirrigated crops in the fields, windmills watering garden plots often permitted farmers to stick out the hard times. One farm implement industry journal wrote: "Pump water from a well with a wind mill and water a small garden. . . . Then you can laugh at droughts when they come, as you can easily battle against their power to destroy."[46]

Windmills brought to many irrigators measures of luxury that they and their predecessors on the Plains had been unable to enjoy. These benefits were bonuses to the reliable source of water. One writer commented at the turn of the century:

> The reservoirs are stocked with German carp and other varieties, and the farmer living hundreds of miles from the habitat of fish can supply his family table from his private fishing preserves. The same reservoirs afford a crop of ice in the winter that can be stored away for summer use. The reservoirs furnish skating in the winter and boating in the summer for boys who otherwise would be deprived of these sports of youth.[47]

Most irrigators found mixed results from their wind-powered pumping plants. The experiences of a Colorado farm couple illustrate the point. In the 1890s John and Lucinda Rose sank a well at their farm, near Seibert, Colorado, later purchasing and installing a windmill over the well. A wind storm blew the mill down, and the Roses were unable to reerect it for several weeks. During the interim Lucinda Rose hand pumped water five hours a day in order to save her strawberries and a modest fruit orchard. The garden area was only a few rods square, but it was all that the family had. If Lucinda Rose had not saved the garden by her arduous labor, the family would have been compelled to leave the land. Instead they stayed. A decade later she and her husband had become prosperous fruit farmers having three wells, each equipped with a windmill pumping irrigation water. Windmill irrigation, meager though it was, proved to be the key to eventual economic success for John and Lucinda Rose and for many others like them. With the windmill they were farm families that stayed.[48]

NOTES

This paper was prepared for presentation at the Western History Association meeting, Wichita, Kansas, 13 October 1988.

1. Fred E. Rader, "Wind Power and Irrigation," *The Farm Implement News* (Chicago) 16 (15 August 1895): 15.

2. For syntheses of the history of the evolution of self-governing windmills in North America, see T. Lindsay Baker, *A Field Guide to American Windmills* (Norman: University of Oklahoma Press, 1985), pp. 3-111; T. Lindsay Baker, "Turbine-Type Windmills of the Great Plains and Midwest," *Agricultural History* 53 (January 1980): 38-51; A. Clyde Eide, "Free as the Wind," *Nebraska History* 51 (Spring 1970): 25-48.

3. Jas. Vick, Rochester, N. Y., to C. B. Salmon, Eclipse Wind Mill Co., Beloit, Wis., April 1879, *Descriptive Catalogue Eclipse Wind Mill Company, Beloit, Wis.*, 12th ed. (Chicago: H. C. Tiffany & Co., Printers, [ca. 1879]), p. 30 [available in Library of Congress, Washington, D. C.].

4. *Ford County Globe* (Dodge City, Kans.), 25 November 1879, p. 3; Lieut. Thos. Wenie, Fort Elliott, Tex., to Lieut. W. F. Rice, Fort Supply, Indian Territory, 11 June 1879, and Lieut. O. L. Wieting,

Fort Elliott, Tex., to Chief Quartermaster, Department of the Missouri, Fort Leavenworth, Kans., 8 November 1879, U. S. Department of War, Army, Fort Elliott, Texas, Letters Sent by Post Quartermaster (1876-1888), pp. 194, 225, National Archives, Washington, D. C.

5. For representative samples of such promotional literature, see Eclipse Wind Engine Company, Beloit, Wis., *Illustrated Catalogue of Eclipse Pumping and Geared Windmills as Adapted to the Water Supply of Farms, Dairies, Residences, and Other General Domestic Uses, and to the Grinding, Shelling, Sawing Wood, Threshing, Churning and Pumping of General Farm Work, Etc.* (Racine, Wis.: Manufacturers Printing Company, [ca. 1885]), p. 18 [available in John Crerar Library, Chicago, Ill.]; *Descriptive Catalogue Twenty Sixth Edition U. S. Wind Engine & Pump Co. [,] Factory & Principal Office Batavia, Ill. [,] U. S. A. [,] Manufacturers of Halladay Standard Pumping & Geared Wind Mills, U. S. Solid Wheel Wind Mills, IXL Iron Feed Mills, IXL Corn Shellers, IXL Stalk Cutters, Horse Powers, Jacks, Standard Haying Tools, and a Full Line of Tanks, Tank Fixtures, and Pumps, for Railway, Village, Farm, and Ornamental Purposes* (Batavia, Ill.: U. S. Wind Engine & Pump Co., [ca. 1885]), pp. 13, 25, 26 [available in F. Hal Higgins Agricultural History Collection, University Library, University of California at Davis, Davis, Calif.].

6. For surveys of water problems and solutions sought by farmers on the Great Plains during the latter nineteenth and early twentieth centuries, see Everett Dick, "Water, a Frontier Problem," *Nebraska History* 49 (Autumn 1968): 215-45; A. Bower Sageser, "Windmill and Pump Irrigation on the Great Plains 1890-1910," *Nebraska History* 48 (Summer 1967): 107-18.

7. For overviews of water resource development, including that of underground water, in the Arkansas and Platte valleys, see Erwin Hinckley Barbour, *Wells and Windmills in Nebraska*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 29 (Washington, D. C.: Government Printing Office, 1899), and Anne M. Marvin, "The Fertile Domain: Irrigation as Adaptation in the Garden City, Kansas Area, 1880-1910," Ph. D. diss., University of Kansas, Lawrence, 1975.

8. Marvin, "The Fertile Domain," pp. 244-66.

9. "Wind Mills for Irrigation," *The Farm Implement News* 14 (9 November 1893): 19.

10. Marvin, "The Fertile Domain," pp. 264-74.

11. Ibid., pp. 266-68.

12. For representative articles describing windmill irrigation at Garden City, see Philip Eastman, "Windmill Irrigation in Kansas," *Review of Reviews* 29 (February 1904): 183-87; "Irrigation by Windmills," *Scientific American Supplement* 41 (11 April 1896): 16981; W. S. Marshall, "Wind Mill Irrigation in Kansas," *The Farm Implement News* 17 (13 February 1896): 21-22.

13. "Irrigation on the American Desert," *The Farm Implement News* 16 (23 May 1895): 16.

14. Marvin, "The Fertile Domain," pp. 285-97.

15. For descriptions of John Tannahill's windmill irrigation plant, see Erwin Hinckley Barbour, "The Homemade Windmill in Nebraska," *The Nebraska Irrigation Annual. 1897—Second Number* (Lincoln: A. G. Wolfenbarger, 1897), p. 82; Erwin Hinckley Barbour, *The Homemade Windmills of Nebraska*, Nebraska Agricultural Experiment Station Bulletin No. 59 (Lincoln: University of Nebraska, 1899), pp. 26-27; Erwin H. Barbour, "The Nebraska 'Go-Devil' Windmill: Ingenious Homemade Contrivances," *The Rural New-Yorker* (New York) 16 (28 August 1897): 561-63; Barbour, *Wells and Windmills in Nebraska*, p. 41; Erwin Hinckley Barbour, "Western Home-Made Wind Mills: Types of the 'Poor Man's Mill'—the Turbine, Jumbo and Merry-go-round," *The Farm Implement News* 18 (8 July 1897): 13-14.

16. P. E. Fuller, *The Use of Windmills in Irrigation in the Semiarid West*, U. S. Department of Agriculture, Farmers' Bulletin No. 394 (Washington, D. C.: Government Printing Office, 1910), pp. 41-44; P. E. Fuller, *The Use of Windmills in Irrigation in the Semiarid West*, rev. ed., U. S. Department of Agriculture, Farmers' Bulletin No. 866 (Washington, D. C.: Government Printing Office, 1917), pp. 34-37; W. C. Mendenhall, R. B. Dole, and Herman Stabler, *Ground Water in San Joaquin Valley, California*, U. S. Department of the Interior, Geological Survey, Water-Supply Paper No. 398 (Washington, D. C.: Government Printing Office, 1916), pp. 178-80; "Windmills," *The Engineering and Mining Journal* (New York) 49 (17 May 1890): 556.

17. For documentation on windmill irrigation systems in Texas during the years around the turn of the century, see Charles N. Gould, *The Geology and Water Resources of the Eastern Portion of the Panhandle of Texas*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 154 (Washington, D. C.: Government Printing Office, 1906), p. 48; William Ferguson Hutson, *Irrigation Systems in Texas*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 13 (Washington, D. C.: Government Printing Office, 1898), pp. 20, 27-28, 49-50, 58, 60-61; "Personal Mention," *Texas Live Stock and Farm Journal* (Fort Worth) 14 (9 February 1894): 12; Thomas U. Taylor, *Irrigation Systems of Texas*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 71 (Washington, D. C.: Government Printing Office, 1902), pp. 58-59, 75-80, 112-13. As early as 1870 the *Texas Almanac* predicted that "we expect to see much of western Texas-irrigated by wind power before many years"

and that through this means "irrigation will render western Texas the 'paradise of the world.'" *Texas Almanac for 1870* (Galveston, Tex.: Richardson & Co., 1870), p. 154.

18. F. C. Barker, *Irrigation in Mesilla Valley, New Mexico*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 10 (Washington, D. C.: Government Printing Office, 1898), pp. 34-35; Frank N. Brown, "Irrigation from Windmills," in New Mexico, Territorial Engineer, *First Biennial Report of the Territorial Engineer to the Governor of New Mexico Including Water Supply 1907-1908* (Albuquerque: Albuquerque Morning Journal, 1908), pp. 21-23; Charles Newton Gould, *Geology and Water Resources of Oklahoma*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 148 (Washington, D. C.: Government Printing Office, 1905), pp. 140-41; "Irrigation by Wind in the West," *The Farm Implement News* 16 (13 June 1895): 26; B. A. McAllester, "Irrigation by the Use of Windmills" *Scientific American Supplement* 37 (17 March 1894): 15189-90; Oscar E. Meinzer, *Geology and Water Resources of Estancia Valley, New Mexico, with Notes on Ground-Water Conditions in Adjacent Parts of Central New Mexico*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 275 (Washington, D. C.: Government Printing Office, 1911), pp. 54, 59-60; Oscar E. Meinzer, *Preliminary Report on the Ground Waters of Estancia Valley, New Mexico*, U.S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 260 (Washington, D. C.: Government Printing Office, 1910), pp. 24, 28-29; O. E. Meinzer and R. F. Hare, *Geology and Water Resources of Tularosa Basin, New Mexico*, U.S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 343 (Washington, D. C.: Government Printing Office, 1915), pp. 217-18; G. E. P. Smith, *Windmills for Irrigation Pumping*, Arizona Agricultural Experiment Station, Timely Hints for Farmers No. 95 (Tucson: University of Arizona, 1916), pp. 1-6; "Wind Mill Irrigation," *The Farm Implement News* 16 (12 September 1895): 23; "Windmill Irrigation," *Scientific American* 70 (2 June 1894): 346.

19. Barbour, *Wells and Windmills in Nebraska*, pp. 13-24; Marvin, "The Fertile Domain," pp. 244-51; Edward Charles Murphy, *The Windmill: Its Efficiency and Economic Use*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Papers Nos. 41-42 (Washington, D. C.: Government Printing Office, 1901), pp. 22-23.

20. Myron L. Fuller, *Underground Waters for Farm Use*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 255 (Washington, D. C.: Government Printing Office, 1910), pp. 28, 36, 39-46.

21. Isaiah Bowman, *Well-Drilling Methods*, U. S. Department of the Interior, Geological Survey, Water-Supply Paper No. 257 (Washington, D. C.: Government Printing Office, 1911), pp. 88-91.

22. Ibid., pp. 91-92; Earl W. Hayter, "The Western Farmers and the Drivewell Patent Controversy," *Agricultural History* 16 (January 1942): 16-28.

23. Bowman, *Well-Drilling Methods*, pp. 28-30, 34-59; Fuller, *Underground Waters for Farm Use*, pp. 28, 38, 46-49.

24. Bowman, *Well-Drilling Methods*, pp. 70-75; Fuller, *Underground Waters for Farm Use*, pp. 28, 30, 39.

25. *1899 Illustrated Catalogue "U" United States Supply Co.* (Omaha, Neb.: United States Supply Co., 1899), pp. 1, 456 [available in personal library of T. Lindsay Baker, Rio Vista, Texas].

26. "Well Contracts," Wallet No. 1, Capitol Freehold Land and Investment Company Papers (XIT Ranch Papers), Research Center, Panhandle-Plains Historical Museum, Canyon, Texas.

27. Baker, *Field Guide to American Windmills*, pp. 33-40; "Steel Wind Mills," *The Farm Implement News* 13 (24 March 1892): 12-17. For reports on the trials of windmills actually used for irrigation purposes at Garden City, Kansas, in 1895-96, see Edward Charles Murphy, *Windmills for Irrigation*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 8 (Washington, D. C.: Government Printing Office, 1897), pp. 1-48, and Murphy, *The Windmill: Its Efficiency and Economic Use*, pp. 1-143.

28. L. L. Doty, Garden City, Kans., to [unidentified addressee, ca. 1895], in *Irrigation by Wind Power* (Batavia, Ill.: U. S. Wind Engine & Pump Co., [ca. 1895]), p. 22 [available in Southwest Collection, Texas Tech University, Lubbock, Tex.].

29. Baker, *Field Guide to American Windmills*, pp. 16-24; T. Lindsay Baker, "Steel Windmills *versus* Wooden: A War of Words," *Windmillers' Gazette* (Rio Vista, Tex.) 7 (Winter 1988): 8-10.

30. *Halladay's New Wind Engine* (South Coventry, Conn.: Halladay Wind Mill Co., [ca. 1856]), unpaged [available in Batavia Historical Society, Batavia, Ill.]; *Pendleton & Lucasse, Manufacturers['] Agents for Halladay's Standard Wind Mills, Force and Lift Pumps, Etc., No. 5 Eleanor St., Gale Block, Kalamazoo, Michigan* (Kalamazoo, Mich.: Pendleton & Lucasse, 1875), unpaged [available in Research Center, Panhandle-Plains Historical Museum, Canyon, Tex.]; Perry Thayer, South Groton, Mass., *Halladay's New Wind Engine Patented Aug. 29th, 1854* (New York: Oliver & Brother, Printers, [ca. 1855]), unpaged [available in Print Collection, Connecticut Historical Society, Hartford, Conn.]; U. S. Water and Steam Supply Company, Kansas City, Mo., *Catalogue No. 11[,] U. S. Water and Steam Supply Co.[,]*

Manufacturers and Jobbers of Plumbing, Heating, Steam and Waterworks Supplies, Windmills, Pumps, Etc. ([Chicago]: R. R. Donnelley & Sons Co., 1916), p. 841 [available in Research Center, Panhandle-Plains Historical Museum, Canyon, Tex.]; U. S. Water and Steam Supply Company, Kansas City, Mo., *1899 Illustrated Catalogue No. 7 of U. S. Water and Steam Supply Co.[,] Wholesale Dealers in Plumbers', Gas, and Steam Fitters' Supplies, Wind-Mills, Pumps, Tanks, Feed-Mills, Steam Engines and Boilers, Gasoline Engines, Tools, Rubber and Leather Belting, Hose, Packing, Etc.* (Cincinnati: Krehbiel & Co., Printers, Binders, Electrotypers, [1899]), p. 487 [available in Nebraska State Historical Society, Lincoln, Neb.]; *January 1st, 1885. Price List U.S. Wind Engine & Pump Co. Incorporated 1857. Batavia, Ill.[,] U.S.A.*, Publication 10M-1-1-85 (Chicago: Brown, Pettibone & Kelly, Stationers and Printers, [1885]), p. 2 [available in Minnesota Historical Society, St. Paul, Minn.]; *January 1st, 1886. Price List U.S. Wind Engine & Pump Co. Incorporated 1857. Batavia, Ill.[,] U.S.A.*, Publication 10M-1-1-86 (Batavia, Ill.: U. S. Wind Engine & Pump Co., [1886]), p. 3 [available in Minnesota Historical Society]; *March 1st, 1882. Price List U.S. Wind Engine & Pump Co. Incorporated 1857. Batavia, Ill., U.S.A.*, Form 4 10M-3-1-82 (Chicago: Culver, Page, Hoyne & Co., Printers, [1882]), p. 2 [available in Chicago Historical Society, Chicago, Ill.]; U. S. Wind Engine and Pump Company, Batavia, Ill., *Net Prices of Wind Mills and Towers Taking Effect June 11th, 1900*, Publication B.1M 10-15-91. M.ho. (Chicago: A. R. Barnes & Co., Printers, [1901]), unpaged [available in Windmill Files, Division of Mechanical and Civil Engineering, National Museum of American History, Smithsonian Institution, Washington, D. C.]; *Price List[,] U.S. Wind Engine and Pump Company, Batavia, Ill.* (Chicago: Rand, McNally & Co., Printers, [ca. 1876]), unpaged [available in Library of Congress, Washington, D. C.]; U. S. Wind Engine and Pump Company, Batavia, Ill., *U.S. Wind Engine & Pump Company General Catalogue No. 15[,] Halladay and Other Wind Mills[,] Steel Towers, Wood and Steel Tanks, Steel Trestles for Tanks, Pumps and Pump Cylinders, Water Supplies for the Farm, Suburban Residence and Village, Feed Grinders, Corn Shellers, Wood Saws, Horse Powers and Jacks, Pipe and Fittings, Brass Goods, Hose, Belting, Etc.* ([Grand Rapids, Mich.]: Grand Rapids Engraving Co., Printers, [ca. 1905]), p. 19 [available in Research Center, Panhandle-Plains Historical Museum, Canyon, Tex.].

31. Baker, *Field Guide to American Windmills*, pp. 29-32; Barbour, *Homemade Windmills of Nebraska*, pp. 1-78.

32. *Aermotor Company Aug. 1895. 7th Annual Catalogue* (Chicago: Aermotor Company, 1895), p. 59 [available in personal library of T. Lindsay Baker, Rio Vista, Tex.].

33. Fuller, *Use of Windmills in Irrigation in the Semiarid West* (1910), pp. 28-30; Herbert M. Wilson, *Pumping Water for Irrigation*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 1 (Washington, D. C.: Government Printing Office, 1897), pp. 54-56.

34. Frederick H. Newell, "Irrigation on the Great Plains," in U. S. Department of Agriculture, *Yearbook of the United States Department of Agriculture 1896* (Washington, D. C.: Government Printing Office, 1897), p. 187.

35. *Aermotor Irrigation* (Chicago: Aermotor Co., [ca. 1895]), pp. 3-5 [available in personal library of T. Lindsay Baker, Rio Vista, Tex.]; Elias Branson Cowgill, *Irrigation Practice on the Great Plains*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 5 (Washington, D. C.: Government Printing Office, 1897), pp. 14-17; Fuller, *Use of Windmills in Irrigation in the Semiarid West* (1910), pp. 28-35; Newell, "Irrigation on the Great Plains," pp. 187-90; "Irrigation by the Use of Wind Mills and Pumps: Practical Suggestions and Directions," *The Farm Implement News* 15 (11 October 1894): 22, 24; Stover Manufacturing Company, Freeport, Ill., *Irrigation Illustrated. The Ideal Irrigator Wind Mill as the Motor Power*, Publication 25M-3-95 (Freeport, Ill.: Journal Printing Company, 1895), pp. 13-15, 36 [available in Amador Family Collection, Rio Grande Historical Collections, University Library, New Mexico State University, Las Cruces, N.M.].

36. Fuller, *The Use of Windmills in Irrigation in the Semiarid West* (1910), p. 33; Newell, "Irrigation on the Great Plains," p. 190; "Irrigation by the Use of Wind Mills," p. 22; Stover Manufacturing Company, *Irrigation Illustrated*, p. 14.

37. Cowgill, *Irrigation Practice on the Great Plains*, pp. 17-19; Fuller, *The Use of Windmills in Irrigation in the Semiarid West* (1910), pp. 31-33; Newell, "Irrigation on the Great Plains," p. 189; Stover Manufacturing Company, *Irrigation Illustrated*, p. 15.

38. *Aermotor Irrigation*, pp. 5-8; Cowgill, *Irrigation Practice on the Great Plains*, pp. 19-33; Samuel Fortier, *Conveyance of Water in Irrigation Canals, Flumes, and Pipes*, U. S. Department of the Interior, Geological Survey, Water-Supply and Irrigation Paper No. 43 (Washington, D. C.: Government Printing Office, 1901), pp. 11-45; Samuel Fortier, "The Use of Small Water Supplies for Irrigation," in U. S. Department of Agriculture, *Yearbook of the United States Department of Agriculture, 1907* (Washington, D. C.: Government Printing Office, 1908), pp. 416-18; "Irrigation by the Use of Wind Mills and Pumps," p. 24; Newell, "Irrigation on the Great Plains," pp. 190-93; J. E. Payne, "Fruit Growing on the Plains," in *Dry-Land Agriculture: Papers Read at the Second*

Annual Meeting of the Cooperative Experiment Association of the Great Plains Area, Held at Manhattan, Kans., June 26-27, 1907, U. S. Department of Agriculture, Bureau of Plant Industry, Bulletin No. 130 (Washington, D. C.: Government Printing Office, 1908), pp. 65-67; Stover Manufacturing Company, *Irrigation Illustrated*, pp. 16-18.

39. Don H. Bark, *Irrigation in Kansas*, U. S. Department of Agriculture, Office of Experiment Stations, Bulletin No. 211 (Washington, D. C.: Government Printing Office, 1909), pp. 19-20, 27-28; Nelson Horatio Darton, "Preliminary Report on the Geology and Water Resources of Nebraska West of the One Hundred and Third Meridian," in U. S. Department of the Interior, Geological Survey, *Nineteenth Annual Report of the United States Geological Survey to the Secretary of the Interior 1897-98*, 6 vols. (Washington, D. C.: Government Printing Office, 1899) vol. 4: 780; Fuller, *The Use of Windmills in Irrigation in the Semiarid West* (1910), pp. 36-41; "Irrigation by the Use of Wind Mills and Pumps," pp. 24, 26; Marshall, "Wind Mill Irrigation in Kansas," pp. 21-22; Elwood Mead, "Report of Irrigation and Drainage Investigations, 1904," in U. S. Department of Agriculture, Office of Experiment Stations, *Annual Report of the Office of Experiment Stations for the Year Ended June 30, 1904* (Washington, D. C.: Government Printing Office, 1905), pp. 430-33; Newell, "Irrigation on the Great Plains" pp. 173-74.

40. Eastman, "Windmill Irrigation in Kansas," p. 187; Marvin, "The Fertile Domain," pp. 285-88.

41. Murphy, *The Windmill: Its Efficiency and Economic Use*, pp. 21-143; Murphy, *Windmills for Irrigation*, pp. 9-48.

42. Marvin, "The Fertile Domain," pp. 290-92; Sageser, "Windmill and Pump Irrigation," pp. 110-11; Mead, "Report of Irrigation and Drainage," pp. 430-33.

43. Fortier, "The Use of Small Water Supplies for Irrigation," pp. 413-18; Fuller, *The Use of Windmills in Irrigation in the Semiarid West* (1910), pp. 14-21; John M. Gordon, *Experiments in Supplemental Irrigation with Small Water Supplies at Cheyenne, Wyo., in 1909*, U. S. Department of Agriculture, Office of Experiment Stations, Circular No. 95 (Washington, D. C.: Government Printing Office, 1910), pp. 10-11; R. P. Teele, "Review of Ten Years of Irrigation Investigations," in U. S. Department of Agriculture, Office of Experiment Stations, *Annual Report of the Office of Experiment Stations for the Year Ended June 30, 1908* (Washington, D. C.: Government Printing Office, 1909), pp. 390-93.

44. F. P. Eshbaugh, "The Use of Windmills in Irrigation on the High Plains," *Panhandle Agricultural Experiment Station Bulletin* (Goodland, Okla.), No. 16 (May 1930), pp. 3-13.

45. *Garden City* (Kans.) *Imprint*, 15 February 1890, cited in Marvin, "The Fertile Domain," p. 275.

46. "Wind Mill Irrigation," p. 23.

47. Eastman, "Windmill Irrigation in Kansas," p. 187.

48. Payne, "Fruit Growing on the Plains," p. 67.