

# Irrigation Management in the Western States

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## ABSTRACT

Irrigation systems have been employed in the American West for several centuries by Native Americans, Spanish explorers, Anglo-American settlers, and farmers working with the Federal Government of the United States. Surface water is the primary water source in the 17 western-most contiguous states in the United States (about 64% of total irrigation withdrawals in 2010 nationwide). However, application of gravity-driven surface irrigation has decreased significantly over years, replaced by pressure irrigation systems in the Western States. Mutual organization, either unincorporated or incorporated, and irrigation districts were the two most common irrigation organizations which delivered irrigation water for 45% of total acres irrigated in the arid west in 1978. These irrigation organizations have helped farmers arrange and pay for irrigation services in the Western States with their distinctive financing mechanisms. Increasing discontinuance of irrigation, growing expenses for irrigation water, and escalating water competition are some challenges for managing irrigation in the Western States. Relying more on groundwater, improving irrigation technologies, and determining what commodities to grow are some of examples on how farmers respond to those challenges.

**KEYWORDS:** Irrigation, the Western States, Management

## INTRODUCTION

Irrigation infrastructure has a foundational role in the history of the 17 western-most contiguous states (hereafter referred to as the Western States) by providing water for agriculture in these driest America's of states, including Arizona, California, Colorado, Idaho, Kansas, Montana, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, Oregon, South Dakota, Texas, Utah, Washington and Wyoming (*United States Department of Agriculture, 2016b*). These infrastructures support life and agricultural prosperity in arid regions in the west and, in many ways, also shape, not only the agricultural economy, but the entire economy of the Western States. Irrigation networks deliver water for about 40 million acres of irrigated agriculture land in the Western States, primarily in the Columbia and Snake River Basins of the Pacific Northwest, California's Central Valley, and the High Plains Ogallala region (*United States Department of Agriculture, 2016b*). These irrigated areas significantly contribute to the United States' economy in general and the Western States' economies in particular, reflected by the sales of agricultural products from dry states. From the 2012 Census of Agriculture, the Western States' share on United States' total agriculture sales are significant, especially for: i) wheat (~70% of United States' total sales); ii) horticulture (more than one third); iii) vegetables (more than a half); iv) fruits, tree nuts and berries (more than 80%); and v) cotton and cottonseed (more than 40%). Without irrigation, millions of acres of western land would be barren desert or low value grazing with far less economic value (*Selby, 1949*). Many of these agriculture products would be imported from other parts of the United States or other countries.

Irrigation infrastructure becomes more important in the Western States today since it conveys water for food production and other purposes. It allows food crop production in arid/semi-arid areas where it otherwise would be largely impossible (*The Office of Technology Assessment, 1983*). Besides supporting various crops, irrigation also supports a wide range industries and economic activities related to agriculture, such as cattle farming and dairying. Irrigated land is needed for the livestock industry to produce feed and pasture for dairying and beef cattle/sheep production. Livestock watering is often fed with irrigation water supplies (*United States Geological Survey, 2016*). Irrigated farm land becomes necessary to make agriculture less subject to drought. Based on United States Department of Agriculture, more than 80% of farmland is in the Western States, and two thirds of irrigated land in the U.S. is in those states. Nearly two thirds of total U.S. sales for cattle in 2012 comes from the Western States (*United States Department of Agriculture, 2015b*) while the share for sheep and goat farming is nearly 60% of U.S. total sales (*United States Department of Agriculture, 2015a*). The share for dairy cattle and milk is also quite significant with around 40% of U.S. sales in 2012 (*United States Department of Agriculture, 2014*). With these shares from the Western States, the United States has the largest fed-cattle industry in the world and is the world's largest producer of beef, primarily high-quality, grain-fed beef for domestic and export use (*United States Department of Agriculture, 2016a*).

How irrigation infrastructure is used and managed in the arid/semi-arid states, is the subject of this paper. This paper begins by introducing the brief history of irrigation infrastructure in the Western States from the early days before and during European exploration to the present period and irrigation application in arid/semi-arid regions such as how water is delivered from point of source to farmland. Arrangements for irrigation service, institutional frameworks, and financing mechanisms will be discussed later as aspects of irrigation management. Finally, some inevitable challenges for irrigation management such as growing discontinuance of irrigation, growing expenses for irrigation water, and escalating water competition, including the recent and predicted future directions to deal with those situations, are reviewed as a growing population shifts to western states (*Kearney et al., 2014*).

## **IRRIGATION DEVELOPMENT**

The development of irrigation systems in the Western States began several hundred years before the earliest European settlements. The first known irrigation system was built in the 7<sup>th</sup> century by the Hohokam people (*Mays, 2016*), a Native population in the American Southwest, that inhabited areas today known as Mesa in central Arizona (Figure 1). The Hohokam culture and their agriculture mostly centered near the Salt River area where their historic irrigation canals were found as illustrated in Figure 3. Their canal was large in the beginning of network to draw water from the Salt river and became smaller as channels supplied more distant parts of the system (*Howard, 2016*). This reduced size allowed water to be delivered in nearly constant velocity in the entire system to avoid canal erosion and silt deposits. Archeologists estimate that around 850 miles of waterways were built by the Hohokam until the early of 15<sup>th</sup> century (*Salt River Project, 2016*) and supported the largest population in the prehistoric American Southwest at that time (*Rose, 2014*). The Hohokam irrigation system was simple but applied hydraulic engineering design features used today. It also became the precursor to modern-day Arizona's major canal system (*Whitley and Letbetter, 2016*). Some major irrigation canals in central Arizona today are quite similar and follow many of the original paths of the Hohokam irrigation system as illustrated in Figure 3. Despite many speculations that irrigation practices in American Southwest were initiated

long before that time, the Hohokam were the only identified culture with a major irrigation system in the prehistoric American Southwest and one of the largest and most sophisticated irrigation networks ever created using preindustrial technology in prehistoric North America (Howard, 1992). Due to limited evidence of other cultures having the large-scale irrigation to intensify food production (Wills and Dorshow, 2012), the Hohokam irrigation system can be considered the first irrigation system in the Western States, and all of North America.

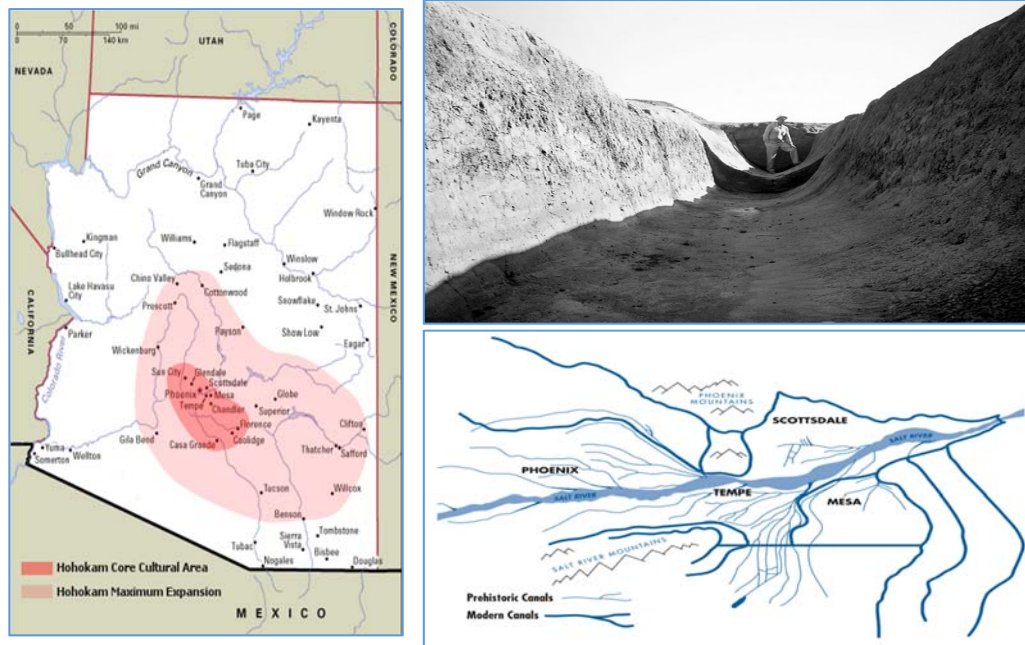


Figure 1 (Left). Map of the Hohokam Cultural Region (Rose, 2014)

Figure 2 (Top Right). Excavated Hohokam Canal at Snaketown in 1964 (Arizona State Museum, 2016)

Figure 3. (Bottom Right) Illustration of the Prehistoric Hohokam Canal compares to Modern Canal (Salt River Project, 2016)

The Western States entered a new era on the development of irrigation system in early 17<sup>th</sup> century when hundreds of the earliest Spanish settlers reached the Pueblo area, the native American culture in Northwestern New Mexico illustrated in Figure 4, and began to colonize the American Southwest (Gale Research Inc, 1997). The need to grow wheat to feed the Spanish settlers led to irrigation canals and the beginning of Spanish irrigation in New Mexico (Wozniak, 1998). Even though there were speculations that the Pueblo people already knew and practiced canal irrigation before the Spanish occupation (Simmons, 1972), the Spaniards intensified the use of irrigation canals in the Pueblo areas. During the early 17<sup>th</sup> to early 19<sup>th</sup> centuries, irrigation systems and availability of irrigable land in the American Southwest supported agriculture and ensured political hegemony in these areas. Many pieces of land were granted to settlers by the Spanish Government to secure and defend the colonized areas with the accessibility of irrigated water to support the existence of settlement in granted land areas. The construction of a complex and expansive irrigation system became one of the most significant accomplishments of Spanish Colonial residents during their occupation period in the American Southwest (City of San Antonio,

2014). About 60 “*acequias*”, (the Spanish word, come from Arabic origin, for irrigation system with dams, gates, and irrigation canals), were operated in New Mexico by the end of 17<sup>th</sup> century, followed with around 400 additional “*acequias*” during 18<sup>th</sup> and 19<sup>th</sup> century (*New Mexico Museum of Art, 2010*). However, the important influence that the Spanish brought to the American Southwest was not only the physical irrigation canal in the ground; they also introduced the water governance for irrigation systems which became essential (*Zarr, 2016*). During their colonization, the Spanish also built many “*acequias*” across the lands in American Southwest which is now known as Texas, Colorado, Arizona and California, but New Mexico developed the most durable system (*Rivera and Glick, 2002*).

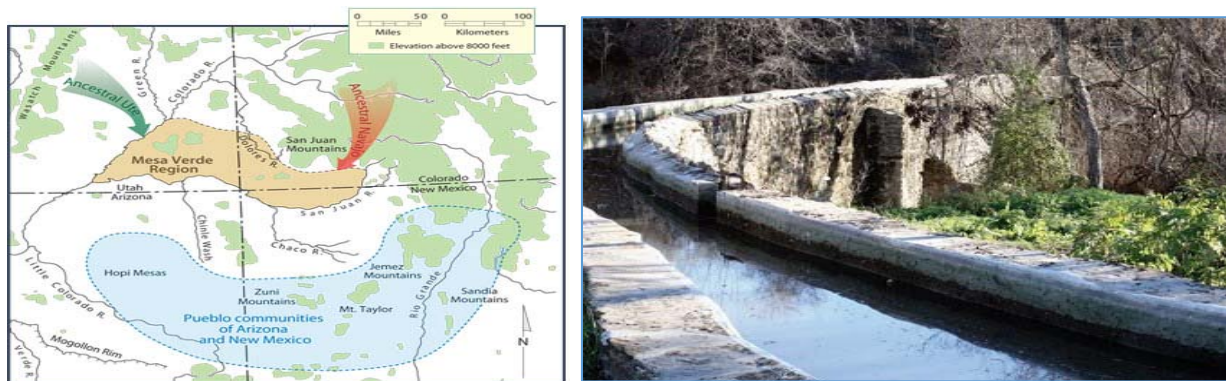


Figure 4. (Left) Map of the Pueblo Cultural Region (*Crow Canyon Archeological Center, 2014*)  
 Figure 5. (Right) One of the Remaining Acequias in American Southwest (*Hull, 2015*)

Irrigation became more common and wide-spread over the Western States since early of 19<sup>th</sup> century by the influence of native Indians or Spanish explorers (*Majumdar, 2013*). Most systems were concentrated in the American Southwest such as California, Arizona, New Mexico, Colorado and Texas as illustrated in Figure 6. In some areas, such as Montana and Wyoming, there is no clear evidence of irrigation before the early of 19<sup>th</sup> century. The later influence on irrigation came from Anglo-American settlers, which initiated the first irrigation development in San Joaquin Valley, California and the border areas between Washington and Oregon, and Mormons settlers in the Salt Lake City Valley, Utah (*Harper, 1974*). Mormons were pioneers of large scale irrigation use in the American West who established “*the first irrigation-based economy in the Western Hemisphere in modern times*” (*Utah Department of Heritage and Arts, 2016*). When the Mormons arrived in Salt Lake City in 1847 from their original hometown in Nauvo, Illinois, they immediately dammed the City’s creek so the overflowing waters softened the surrounded areas’ soil which allowed them to plant potatoes (*Fuller, 1994*). Irrigated farming then spread in the Great Salt Lake Basin as the Mormons dug more irrigation canals to capture water from more streams as Salt Lake City grew. By the end of 19<sup>th</sup> century the Mormons cultivated nearly 2.5 million ha of irrigated land across the inter-mountain of Western United States (*Sojka et al., 2002*). The Mormons also established basic principles of water law which later became an important legal precedent for Western Water Law. They abandoned the conventional water rights doctrine used in the Eastern of the United States (Riparian Water Rights), and adopted the doctrine of “*prior appropriations for beneficial use*” (*Hooton, 1999*). The ones who first made beneficial use of water from a source will continue to get first priority to use water over those who came later.



Figure 6. (Left) Spatial Extent of Irrigation in the Western States: Prehistoric-1847 (*Harper, 1974*)  
 Figure 7. (Right) Irrigation Ditch Built by the Mormons in Salt Lake City (*Utah Department of Heritage and Arts, 2016*)

The development of irrigation systems in the Western States increased considerably after these areas were acquired by the Federal Government of the United States in the mid-1800s to early 1900s. United States Congress passed *the Desert Land Act* on March 3, 1877 that gave the agricultural settlers encouragement to apply for desert-land entry in public lands to promote economic development and speed privatization of newly acquired arid and semiarid public land in the Western United States (*National Archives, 2017*). Based on this act, an agricultural settler could apply for one or more tracts of land in the Western States totaling no more than 320 acres. The Congress also enacted *the Carey Act* on August 18, 1894 that allowed private companies to build irrigation systems and profit from sales of water to agricultural settlers in the western semi-arid states (*Roberts, 2016*). The development of irrigation systems in the Western States reached its peak during the 20<sup>th</sup> century, especially after United States President Theodore Roosevelt signed the Reclamation Act on June 17, 1902 and established the United States Reclamation Service, which later became the United States Bureau of Reclamation. Having substantial federal funding and congressional authority, the scale of irrigation development in the Western States included 70 authorized projects before World War II (*United States Bureau of Reclamation, 2015a*). These projects included monumental projects such the Boulder Canyon Project in Arizona and Nevada that constructed Hoover Dam, the largest dam in the world at the time of its completion in 1935, and the Central Valley Project that became the largest water supplier in California. The development of irrigation in the Western States rapidly expanded when agriculture boomed after World War II (*Sojka et al., 2002*). Hundreds of irrigation projects and major dams were constructed by Federal agencies such as the Bureau of Reclamation and United States Army Corps of Engineers, or by State agencies such as California's State Water Project. Today the Bureau of Reclamation operates about 180 projects in the 17 Western States that provide water for agricultural irrigation and for cities and industries (*United States Army Corps of Engineering, 2012*).

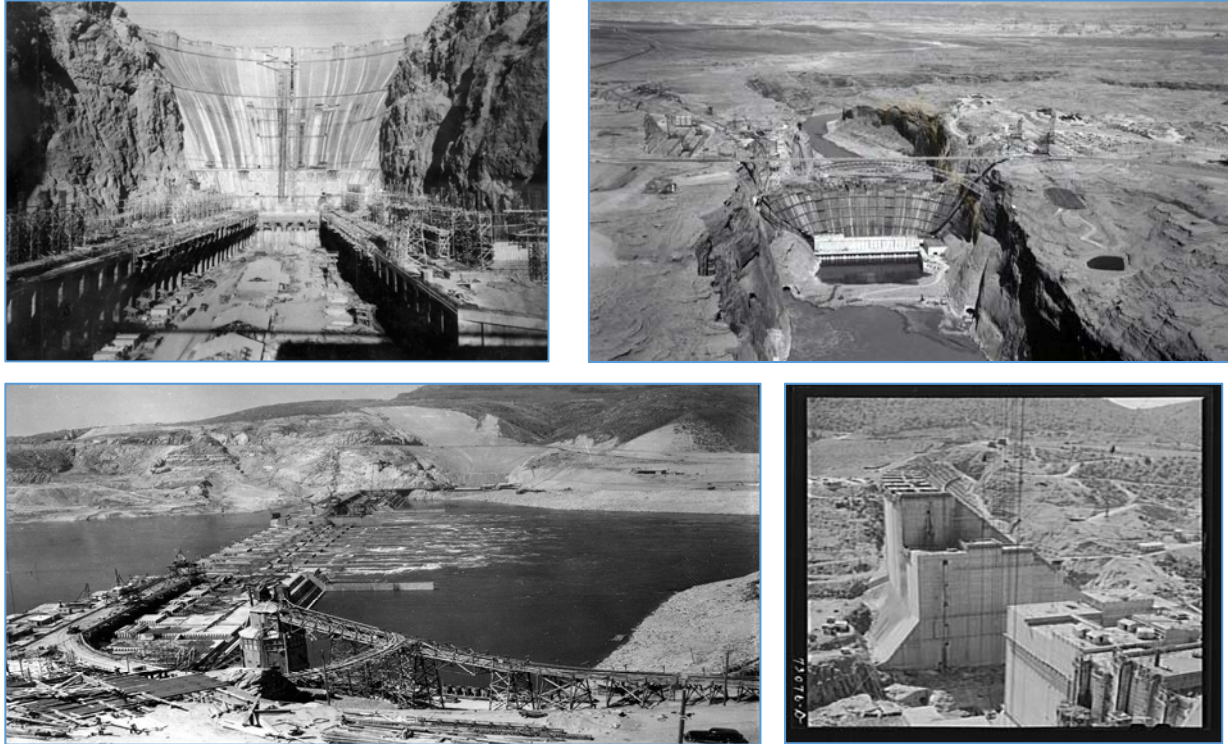


Figure 8. Construction of Various Federal Reclamation Projects that Support Irrigation Development in the American West. Top Left: Hoover Dam, Nevada from the Boulder Canyon Project (*United States Bureau of Reclamation, 2015b*). Top Right: Glen Canyon Dam, Arizona from the Colorado River Storage Project (*United States Bureau of Reclamation, 2016*). Bottom Left: Grand Coulee Dam, Washington from the Columbia Basin Project (*United States Bureau of Reclamation, 2015c*). Bottom Right: Shasta Dam, California from the Central Valley Project (*Library of Congress, 2016*).

**APPLICATION OF IRRIGATION WATER**

Agricultural irrigation is arguably the largest use of surface and ground water throughout the world (*United Nations Educational, Scientific and Cultural Organization, 2017*). About 70% of world’s water withdrawals, either from rivers, lakes, aquifers, or other sources, is for irrigation water used to meet various agriculture’s demands from field preparation, production/growing, protection, harvesting, and post harvesting processes. This percentage is higher in some developing countries where agriculture is a larger economic activity and less efficient surface irrigation is more common. As shown in Figure 9, the percentage of irrigation water use in Asia and Africa is about 10-20% above the world’s average. While in some developed countries in North America, the percentage of irrigation water use is only about 40% of all water withdrawals. High efficiency irrigation, such as sprinkler or micro irrigation systems, is common in this region, triggered by competition for water as a scarce economic resource. As a result, irrigation water withdrawals in this region are less significant than the world’s average percentage.

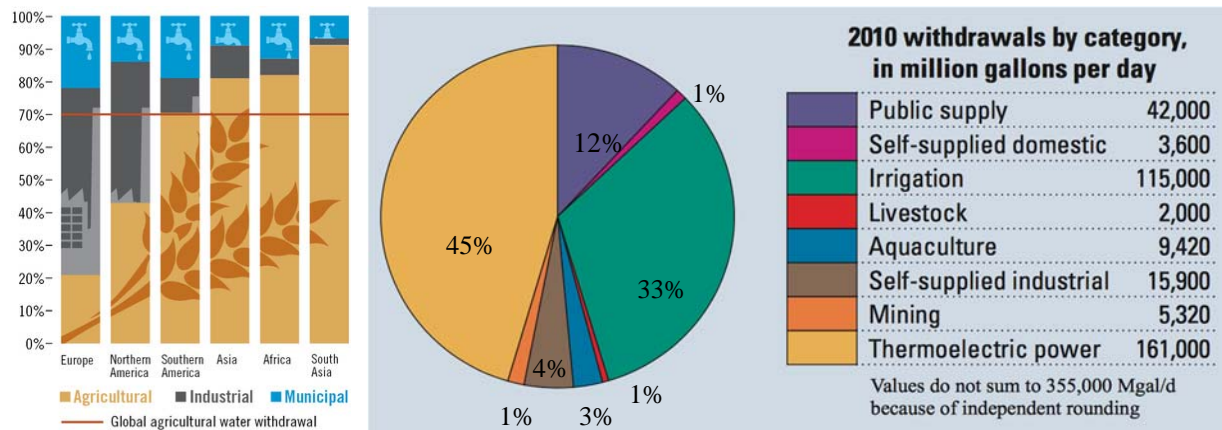


Figure 9. (Left) Water Withdrawal for Agriculture, Industry and Municipal in Different World Regions (*Global Agriculture, 2014*).

Figure 10. (Right) Summary of Estimates Water Use in the United States in 2010 (*United States Geological Survey, 2014*).

As illustrated in Figure 10, irrigation withdrawals in the United States accounted as second largest water use with about one third of all water withdrawals in 2010 (*United States Geological Survey, 2014*). This category of water withdrawals came second after thermoelectric power, was about 45% of total water withdrawals. Irrigation withdrawals were used either for agricultural irrigation to sustain plant and pasture growth or for non-agricultural maintenance of vegetation in areas such as national parks, national forest, golf courses, and cemeteries. This estimation included water lost in conveyance, water returned to a surface water body, water consumed as evapotranspiration, and water that recharges aquifers. Other agricultural water withdrawals are livestock and aquaculture (*Food and Agriculture Organization of the United Nations, 1998*), classified separately from irrigation in the 2010 estimation and amounting to about 4% of total water withdrawals in the United States. Most livestock water withdrawals are from ground water (about 60%). Other farm water needs are livestock watering, sanitation and cooling of facilities. Water for aquaculture is largely from surface water (about 81%).

Water withdrawals in hydroelectric-power generation is not considered in the 2010 Estimated Water Use as illustrated in Figure 10. Much of the hydropower capacity is in the Western States, mostly in west coast states (California, Oregon, Washington) where they produce more than half of nationwide hydropower capacity for electricity generation (*United States Department of Energy, 2016*). Many of these hydroelectric-power generation plants are installed at large dams in the Western States that were not built only. Many of them were built as major water suppliers for agriculture and as part of flood control systems in the Western States. Most water withdrawn for hydropower is circulated back into water body and conveyed to downstream users, including agriculture. Given that irrigation was 33% of total water withdrawals in the United States in 2010, the percentage of agricultural water withdrawals may be similar to the average irrigation withdrawals in North America region (about 40%) when all related agricultural water use such as irrigation, livestock, aquaculture and hydroelectric-power generation is combined.

The 17 Western States, with 74% of irrigated acres in the United States, accounted for most of national irrigation water withdrawals (about 83%) in 2010 (*United States Geological Survey, 2014*). Several states, such as California, Idaho, Colorado, and Texas, used quantities of irrigation

water larger than the rest of the States in the United States in 2010 (Figure 11). These states cumulatively also accounted for more than one-quarter of all water withdrawn (both fresh and saline water) in the United States in 2010. Most of this water is used to grow corn and forage crops which accounted for the largest share (about 49%) of all harvested irrigated crop acres in the Western States (*United States Department of Agriculture, 2016b*). As illustrated in Figure 12, this irrigation water is largely withdrawn from surface water (e.g., streams, rivers, ponds, and lakes) which is the primary source of water in many States in the arid West, excluding Kansas, Oklahoma, Nebraska, Texas, and South Dakota which use more groundwater (either from local or regional aquifers) as their main source. Nationwide, the 17 Western States cumulatively accounted for 93% of all surface-water irrigation withdrawals and 69% of total groundwater irrigation withdrawals in the United States in 2010. More surface water is used for irrigation in arid Western States (approximately 64% of total irrigation withdrawals) typically because of its advantage for conveying water in long distance between points of diversion and areas where water is used. For example, the All-American Canal, which is the largest irrigation canal in the world (*National Aeronautics and Space Administration, 2009*), conveys water in an 80-mile aqueduct from the Colorado River to 500,000 acres of agricultural lands in the Imperial Valley (*Imperial Irrigation District, 2017*). However, a high percentage of groundwater withdrawals for irrigation (69% nationwide) shows how groundwater has transformed as a reliable major source of freshwater that maintains the continuity of agricultural practices in the Western States, especially when the preferred surface water sources are depleted (*Siebert et al., 2010*). Therefore, it is understandable why in some states with large irrigated land such as California, Texas, and Idaho withdrawn, the amount of irrigation withdrawals was high for both surface water and groundwater (Figure 12).

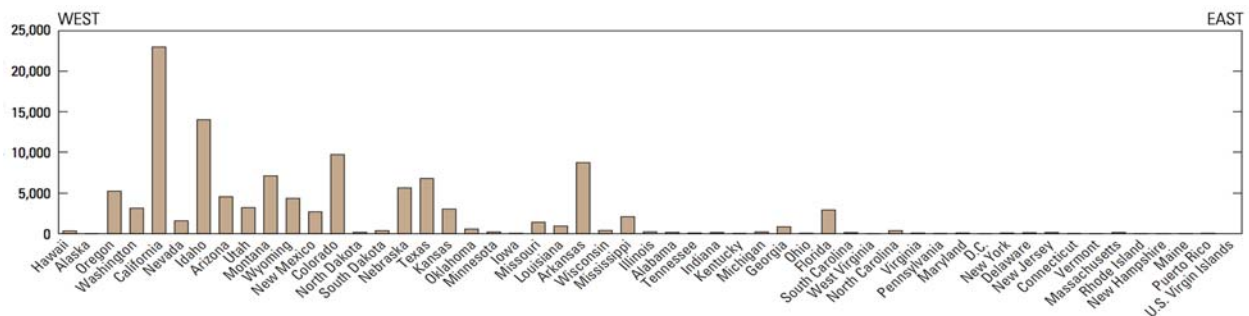


Figure 11. Total Irrigation Withdrawals in 2010 in Million Gallons Per Day (*United States Geological Survey, 2014a*).

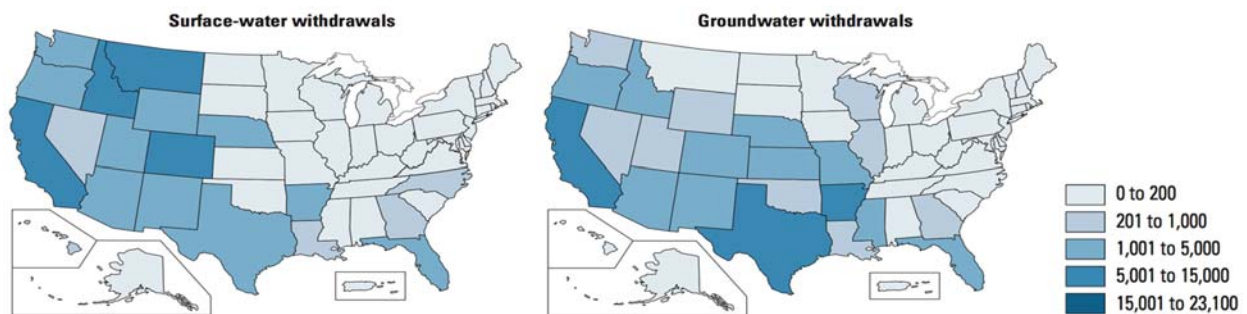


Figure 12. Irrigation Withdrawals by Source and by State in Million Gallons Per Day in 2010 (*United States Geological Survey, 2014a*).



Surface irrigation by gravity is still the most popular irrigation method and is common in much of the world and in Western States (*United States Geological Survey, 2016a*). This method is simple and cheap compared to other irrigation methods. Water is delivered to the field in any type of canals from the point of source (reservoirs, lakes, ponds, streams, aquifers) by using gravity or pump system and flooded along the ground of crops as illustrated in Figure 13. Gates and regulated structures are also common in gravity irrigation to control water flow. Even though surface irrigation is a less efficient, this method often efficiently supplies excess water to groundwater through runoff and deep percolation (*Stubbs, 2016*). Gravity irrigation was 31% of irrigation in the Western States in 2013 with various approaches including down rows or furrows irrigation and controlled or uncontrolled flooding irrigation (*United States Department of Agriculture, 2014a*). Figure 14 shows that irrigation by gravity systems has steadily declined over decades in the Western United States. However, based on Farm and Ranch Irrigation Survey in 2013 (Table 1), some major agriculture states in the Western United States still largely use gravity systems as their main water irrigation distribution method, including Arizona, California, Montana, Nevada, and Wyoming.

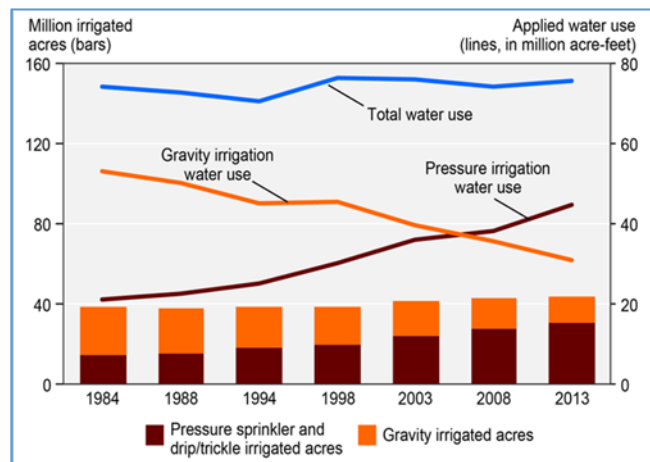


Figure 13. (Left). Furrow Irrigation in the American Southwest in 1970, an Example of Surface Irrigation Method by Gravity System (*Irrigation Museum, 2017*).

Figure 14. (Right). Shifting in Irrigation Methods in the 17 Western States 1984-2013 (*United States Department of Agriculture, 2016b*).

**Table 1. Land Irrigated in the Western States and Method of Water Distribution**

States	Acres Irrigated	Method of Irrigation Distribution		
		Gravity Systems	Sprinkler Systems	Drip, trickle, or low-flow micro sprinklers
1 Arizona	851,407	748,012	240,691	50,208
2 California	7,543,928	4,539,426	1,662,125	2,783,022
3 Colorado	2,309,178	1,196,805	1,470,829	10,126
4 Idaho	3,511,751	757,753	3,088,161	28,149
5 Kansas	2,851,085	106,984	2,865,244	72,663
6 Montana	1,872,286	1,144,584	849,332	1,079
7 Nebraska	8,297,457	1,251,630	7,362,241	36,168
8 Nevada	689,953	469,556	289,042	3,382
9 New Mexico	694,571	289,732	458,284	30,253
10 North Dakota	213,686	28,108	194,545	334
11 Oklahoma	426,296	14,010	429,033	7,747
12 Oregon	1,553,034	571,531	1,141,042	85,456
13 South Dakota	369,802	51,774	332,929	164
14 Texas	4,489,837	560,944	3,980,081	280,045
15 Utah	1,124,729	592,225	663,834	5,859
16 Washington	1,623,123	169,489	1,420,224	250,033
17 Wyoming	1,418,272	1,053,673	452,062	637
<b>Total 17 Western States</b>	<b>39,840,395</b>	<b>13,546,236</b>	<b>26,899,699</b>	<b>3,645,325</b>

Source: United States Department of Agriculture: 2013 Farm and Ranch Irrigation Survey, 2014a.

Note: Several methods of water distribution are applied in some areas.

As shown in Figure 14, the number of acres irrigated by the less-efficient surface-irrigation methods decreased significantly over years, replaced by more efficient sprinkler and micro irrigation which currently irrigate more lands in the Western States. Sprinkler irrigation systems is a modern way of irrigating that requires machinery to spray water in all directions and is currently applied in large scale to agriculture in the Western States (*United States Geological Survey, 2016a*). The center-pivot system is the most common type of sprinkler irrigation today (*United States Department of Agriculture: 2013 Farm and Ranch Irrigation Survey, 2014*). This system uses a number of metal frames, long tube, where water flows through in it from the water sources, and water-gun systems which allows water being shot out to the field, typically in a circular pattern. Using this system, water, which is sprayed into the air through a sprinkler or nozzle over a crop area, is used not only for providing adequate soil moisture, but also for crop cooling, frost protection, and dust control (*United States Geological Survey, 2016c*). Compared to surface irrigation based on gravity flow, sprinkler irrigation requires much more energy for pumping. Another drawback from this system is a lot of the water sprayed, up to 35%, can evaporate or blows away before it hits the ground due to the dry and windy air of the Western

States, particularly during summer (*United States Geological Survey, 2016b*). Drip irrigation is much more efficient than flood irrigation or even sprinkler irrigation because water is applied directly to the root zone of crops and evaporation can be reduced. Water is delivered through plastic pipes, with holes in them, that are commonly laid along the rows of crops or even buried along their root lines (Figure 16). However, application of this method is not easy in some field crops because it is quite difficult to operate tractor in a field with fragile drip lines.



Figure 15. (Left). Sprinkler Irrigation with Center Pivot System (*United States Geological Survey, 2016c*)

Figure 16. (Right). Application of Drip Irrigation in the Salinas Valley, California (*Kearns, 2016*)

## IRRIGATION MANAGEMENT

After acquisition of the West by the United States, farmers were the primary and the earliest irrigation institutions that delivered water into the arid agriculture lands in the American West (*Bretsen and Jill, 2007*). Most farmers employed water for riparian lands or developed appropriative water rights to build and operate single farm irrigation networks. Construction and maintenance of irrigation network from intake/point of diversion, distribution system and application of water to agriculture fields became the responsibility of farmers who fully owned the irrigation system. However, single farm irrigation networks are not listed in the Census of Agriculture. Therefore, acres irrigated under this category was only estimated based on the difference in areas between acres irrigated under irrigation organizations and total acres irrigated in the Western States as in Bretsen and Jill's paper in 2007. Until the latest Census of Agriculture in 1978, specifically on Type of Irrigation Organization and Acres Irrigated by States (this information discontinued in the 1982 census and afterward), individual farmers with single farm irrigation networks were still the largest type of irrigation organization in the American West, with more than a half of total irrigated acres in these areas (Table 2). Most were in California, Nebraska, Kansas, Oklahoma and Texas which, together in 1978, accounted for almost 80% of total irrigated acres by single farm irrigation networks in the American West (Table 2).

Meanwhile, farmers with appropriative water rights might need to work together with other farmers when their fields were farther from point of diversion and single farm irrigation networks were not feasible. In this case, groups of appropriators, who were usually neighbor-farmers, create coownership in joint irrigation network to gain more financial advantages where a common water diversion and distribution system were built, and operated at cost to supply their water needs (*Hutchins et al., 1971*). Many cooperative irrigation systems are small and operated with little or

**Table 2. Acres Irrigated in the 17 Western States Based on Type of Irrigation Organization in 1978**

States	Acres Irrigated	Individual/ Single Farm <sup>1</sup>	Type of Organization and Acres Irrigated									
			Unincorporated Mutual	Incorporated Mutual	District	Bureau of Reclamation Constructed & Operated	Bureau of Reclamation Constructed & User Operated <sup>2</sup>	Bureau of Indian Affairs	Commercial	State & Local Government	Other <sup>3</sup>	Total by Organization Irrigation
1 Arizona	1,210,568	598,288	11,384	79,103	405,076	-	324,413	115,064	1,653	-	-	612,280
2 California	8,603,719	2,754,887	78,439	695,987	4,886,510	78,395	2,274,285	2,386	9,691	47,871	49,553	5,848,832
3 Colorado	3,458,031	754,558	410,746	2,006,899	246,989	-	198,450	17,157	19,082	2,600	-	2,703,473
4 Idaho	3,508,254	1,024,855	210,469	1,426,246	780,478	1,533	577,459	64,673	n/a	n/a	n/a	2,483,399
5 Kansas <sup>4</sup>	2,685,758	3,194,762	n/a	n/a	93,199	-	93,199	-	-	-	-	93,199
6 Oklahoma <sup>4</sup>	602,203											
7 Montana	2,085,759	424,606	364,942	656,058	416,577	10,920	277,392	163,156	n/a	49,500	n/a	1,661,153
8 Nebraska	5,697,779	4,907,121	n/a	60,023	730,635	-	366,717	-	-	-	-	790,658
9 Nevada	899,204	656,415	64,866	67,548	110,375	-	106,232	n/a	-	-	-	242,789
10 New Mexico	904,235	412,062	116,110	80,359	159,597	84,000	120,376	48,524	3,500	83	-	492,173
11 North Dakota	141,434	141,214	-	n/a	n/a	220	24,050	-	-	-	-	220
12 Oregon	1,920,318	850,192	197,863	185,920	648,218	23,240	464,963	60	14,825	-	-	1,070,126
13 South Dakota	341,110	243,775	8,286	7,577	81,472	-	74,283	-	-	-	-	97,335
14 Texas	7,018,411	5,949,537	9,764	5,969	762,400	48,257	273,650	-	93,117	149,367	-	1,068,874
15 Utah <sup>5</sup>	1,185,315	(198,397)	133,839	1,048,643	83,500	2,650	108,343	60,248	52,717	2,115	-	1,383,712
16 Washington	1,681,268	504,043	34,307	90,470	911,562	-	795,461	140,886	-	-	-	1,177,225
17 Wyoming	1,685,215	336,267	376,724	516,898	416,967	1,625	236,224	31,245	5,489	-	-	1,348,948
<b>Total</b>	<b>43,628,581</b>	<b>22,554,185</b>	<b>2,017,739</b>	<b>6,927,700</b>	<b>10,733,555</b>	<b>250,840</b>	<b>6,315,497</b>	<b>643,399</b>	<b>200,074</b>	<b>251,536</b>	<b>49,553</b>	<b>21,074,396</b>
<b>17 Western States<sup>6</sup></b>		<b>52%</b>	<b>5%</b>	<b>16%</b>	<b>25%</b>	<b>1%</b>		<b>1%</b>	<b>0%</b>	<b>1%</b>	<b>0%</b>	<b>48%</b>

Source: Modified from Table 2 of Chapter 2. 1978 Census of Irrigation Organizations (United States Department of Agriculture, 1982)

Note: <sup>1</sup> Acres that were not irrigated by any type of organization. Adopted from Bretzen and Jill, 2007 which used this approach to calculate acres irrigated by individual/single farm.

<sup>2</sup> Most of these acres were operated by Irrigation District. Data not included in total to avoid double counting.

<sup>3</sup> Organizations which cannot be included in one of the categories given.

<sup>4</sup> Kansas and Oklahoma was classified together in this census.

<sup>5</sup> There is an inconsistency of data in Utah where total acres irrigated by irrigation organization was larger than the recorded acres irrigated.

<sup>6</sup> There is an inconsistency data between the aggregate data and the by state's data. This total does not match with 1978 data in Table 3.

no official formal organization (*United States Department of Agriculture, 1982*). The early Mormons communities applied this approach which later became known as an unincorporated mutual. They built and operated irrigation systems cooperatively in Salt Lake City in 1847 based upon trust and common interest (*Bakken, 2011*). The number of unincorporated mutual irrigation organizations increased four times from 1,664 in 1940 to 6,417 in 1950 but steadily decreased in the following decades (Table 3). Nevertheless, the unincorporated mutual was still the largest number of irrigation organization with 3,557 organization in 1978 (Table 3). This type of organization only irrigated a small area of the American West, about 5% of total acres irrigated in the Western States in 1978, largely scattered in several states especially in Colorado, Montana, New Mexico and Wyoming (Table 2).

**Table 3. Type of Irrigation Organization and Acres Irrigated in the 17 Western States 1940-1978**

Year		Type of Organization and Acres Irrigated								
		Un-incorporated Mutual	In-corporated Mutual	District	Bureau of Reclamation Constructed & Operated	Bureau of Reclamation Constructed & User Operated <sup>1</sup>	Bureau of Indian Affairs	Commercial	State & Local Government	Other <sup>2</sup>
1940	Number	1,664	2,670	441	97	n/a	188	245	205	25
	Acres	907,049	5,710,388	3,573,754	1,824,004	n/a	515,765	850,345	100,167	6,833
1950	Number	6,417	2,880	483	37	79	141	131	81	-
	Acres	2,113,642	5,635,630	4,962,413	682,413	1,539,737	506,076	705,087	108,627	-
1959	Number	4,952	2,736	558	54	147	123	81	42	-
	Acres	2,067,317	6,732,204	6,920,527	710,904	3,301,541	578,635	397,075	117,793	-
1969	Number	4,202	2,570	719	57	259	56	96	34	-
	Acres	2,194,115	7,040,472	9,689,181	363,320	5,501,715	577,860	403,610	37,725	-
1978	Number	3,557	2,431	831	86	307	139	55	74	17
	Acres	2,030,607	6,979,406	10,769,762	250,840	6,315,497	661,756	219,836	252,756	201,536

Source: Modified from Table 2 of Chapter 2, *1978 Census of Irrigation Organizations (United States Department of Agriculture, 1982)*

Note: <sup>1</sup> Most of these acres were operated by Irrigation District.

<sup>2</sup> Organizations which cannot be included in one of the categories given.

Incorporated mutual is another type of cooperation among farmers to deliver water where farmers form a legally constituted cooperative corporation under states law for irrigation operation and maintenance at their cost (*United States Department of Agriculture, 1982*). The incorporated mutual organization was developed for larger-scale funding to finance expansion of irrigation networks, either for agriculture or for community development in general (*Hutchins, 1929*). Money needed for these irrigation projects was usually raised locally, either from the sale of stocks or water rights or from bank loans. Water then was delivered to the stockholders or those entitled to receive the water. This expansion of irrigation networks was usually related with community irrigation, similar to the Mormons communities who was the pioneers of large scale irrigation in the American West (*Bakken, 2011*). Most of irrigated acres under incorporated mutual organization are in Colorado, Idaho, and Utah (Table 2), often with Mormon origins. The Burlington Ditch, Reservoir & Land Company is an example of mutual irrigation organization

which has operated since 1885 and became part of history of Adams and Weld Counties, Colorado (*Burlington Ditch Reservoir & Land Company, 2011*). Acres irrigated under incorporated mutual organizations increased significantly during 1940-1978, from 5.7 million acres in 1940 to 7.0 million acres in 1978, but the number of irrigation organizations decreased over time with 2,431 organization in 1978 (Table 3). In total, incorporated mutual organizations were responsible to deliver water for about 16% of total acres irrigated in the Western States in 1978 (Table 2).

Commercial organizations began involvement in irrigation development when irrigation based communities became more popular and continued as a common feature of many settlements in the American West (*Bakken, 2011*), especially after *the Carey Act*, the Federal law in 1894 that allowed private companies to profit from sales of water (Roberts, 2016). The commercial irrigation company was one of the earliest corporate institutions that started to build large irrigation projects in the American West (*Bretsen and Jill, 2007*). Most commercial irrigation organizations were controlled by owners and usually are profit oriented. In this type of organization, irrigation services were an incidental function and not the main purpose of the organization (*United States Department of Agriculture, 1982*). In the late of 19<sup>th</sup> century, many private or corporate entities were land developers, who held an appropriative water right, that mostly looked for profit from land sales and they used irrigation networks to help sell land to settlers (*Hutchins, 1929*). A large block of land, later divided into several parcels, was installed with irrigation networks and then sold as new farms to settlers along with its share of water rights. The control of the irrigation system was usually transferred to the landowners where the operation and maintenance of the infrastructure was no longer the responsibility of the land developer. Another example of commercial irrigation organization was a private corporation which produces electricity from water then to landowners for irrigation. Numerous commercial irrigation companies existed by the 1880s (especially in California, Colorado, Texas and Utah) and reached their peak in 1920 when 1.6 million acres of agriculture land were irrigated by this organization type, or about 11% of total acres irrigated in the American West that year (*Bretsen and Jill, 2007*). The acres irrigated by these commercial networks decreased significantly during 1920-1978 and few remain. The existence of commercial irrigation companies was superseded by incorporated mutual and irrigation districts that deliver more water to more agriculture land in arid west. Commercial irrigation organizations irrigated less than 1% of total acres irrigated in the American West by 1978 (Table 2).

Initially formed based on the Wright Act in California in 1887, which was later followed by others Western States' legislations during 1890-1917 (*Figure 17*), irrigation districts became another significant form of irrigation organization which use a large portion of surface water rights in the American West (*Ghimire and Griffin, 2014*). Irrigation districts are public special entities formed in accordance with state law for constructing and operating irrigation systems within its boundaries and serve as political subdivisions of state government at the local level (*Hutchins, 1931*). Difficulty in raising large amounts of capital to finance large-scale irrigation and market failure issues in commercial irrigation companies were among main origins of irrigation districts (*McDevitt, 1996*). Irrigation districts were developed as a new institution which held public prerogatives such as the power to issue bonds and exemptions from state and federal income taxes, but retained many attributes of private corporations (*Bretsen and Jill, 2007*). Combination of public authorization and private benefits made this type of irrigation organization gain popularity in the American West and was preferred by farmers over early commercial and mutual companies. Irrigation districts flourish as the major irrigation organization in the American West, especially after the Congress enacted laws in 1922 and 1926 (*Figure 17*) which mandated irrigation districts as the exclusive organization that could contract with the Federal Government for water from

Reclamation projects (Bakken, 2011). The opportunity to get water from Reclamation projects attracted many earlier irrigation organizations to transform into irrigation districts as mentioned in Bretsen and Jill's paper in 2007 where 69% of 29 studied irrigation districts in the American West in 1940 began their institutional forms as mutual or commercial irrigation companies. As a result, the number of irrigation districts and the acres irrigated under this irrigation organizations increased significantly from 441 irrigation districts with 3.5 million acres irrigated in 1940 to 831 irrigation districts with 10.7 million acres irrigated in 1978 (Table 3). California, with the Federal Central Valley Project as the largest Bureau of Reclamation's irrigation project (Austin, 2014), has the most irrigation districts and the largest acres supplied by irrigation districts. About 45% of total acres irrigated under irrigation districts in 1978 were in California (Table 2) with 225 irrigation districts, or about 30% of all irrigation districts in the American West (United States Department of Agriculture, 1982).

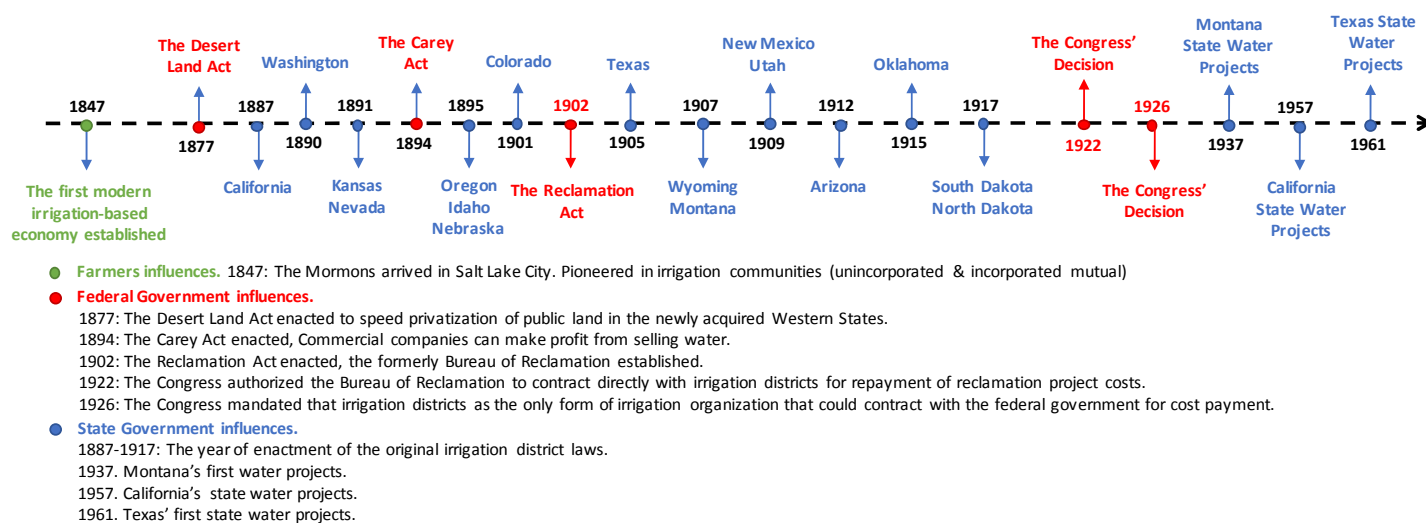


Figure 17. Important Timeline of Irrigation Organization's Development in the Western States (summarized from various sources: Hutchins, 1931; Fuller, 1994; State Impact Texas, 2013; United States Bureau of Reclamation, 2015a; Roberts, 2016; The California Department of Water Resources, 2017; The Montana Department of Natural Resources and Conservation, 2017)

Other forms of irrigation organizations in the arid west come from various government agencies such as the United States Bureau of Reclamation, United States Bureau of Indian Affairs, and many water agencies from state and local government levels (United States Department of Agriculture, 1982). The United States Bureau of Reclamation, established in 1902, has constructed more than 600 dams and 8,000 miles' irrigation canals (the United States Bureau of Reclamation, 2016a). These deliver water for 10 million acres of agricultural land, which makes the United States Bureau of Reclamation as the nation's largest wholesale water supplier. Most of these facilities had been delegated to irrigation districts after 1940 (Table 3) where the control of the systems (operations, maintenances, personnel) was transferred to the contracting organizations but the United States Bureau of Reclamation still owns the assets. For example, the All-American Canal, built by the United States Bureau of Reclamation in 1930s, is currently operated by the Imperial Irrigation District (Imperial Irrigation District, 2017). Based on the 1978 Agricultural Census, the United States Bureau of Reclamation only operated several facilities, mainly in California and New Mexico (Table 2). The United States Bureau of Indian Affairs, another federal

agency, provides water to over 780,000 acres of land in the Western States, for Indian Reservations (*the United Bureau of Indian Affairs, 2017*). Most of these irrigated areas were in Arizona, Montana and Washington (Table 2). These areas slightly increased from 0.52 million acres in 1940 to 0.66 million acres in 1978 (Table 3) and then became 0.78 million acres in 2017 (*the United Bureau of Indian Affairs, 2017*). Several state and local government agencies, mainly California, Montana and Texas, also are involved in irrigation projects (Table 2) but at smaller scales. These other government agencies, in total, irrigate about 1 million acres' land or about 3% of total acres irrigated in the Western States in 1978 (Table 2).

## **FINANCING ON IRRIGATION SERVICES**

Irrigation infrastructures in the Western States and its services were largely financed by farmers in many different ways, either using fully private farmer funding, employing cost sharing among farmers, or utilizing financing mechanisms that involve other entities. Farmers who had parcels of land adjacent to a stream or had their own wells were most likely just pay their own supply cost for diverting water from rivers or for pumping groundwater from nearby aquifers (*Wichelns, 2010*). An improvement on pumping technology during 1940s also made these individual farmers rely more on their own wells rather than depend on irrigation organizations to irrigate their land (*Bretsen and Jill, 2007*). It was understandable why groundwater became more preferable since the only costs needed were just for operating and maintaining wells and pumps. In this case, either farmers with riparian water rights or groundwater wells, usually do not need to cooperate with other farmers mostly build, operate, maintain and repair their own individual irrigation network at their own cost. While farmers without these advantages required cooperation with other farmers to move water from a surface stream to their agriculture land. Either informal or formal contractual arrangements as forms of cooperation created by these two or more individual farmers were usually based on trust, common sense, and well-established common law principles in their areas which they may adopt (*Bretsen and Jill, 2007*). For a relatively simple irrigation project that does not require storage works or relatively simple circumstances, a small group of farmers could form an unincorporated mutual association where each party voluntarily agreed to share in the construction costs. Since there was no formal organization created by this type of cooperation, ownership of the system belonged to farmers who became members of these an unincorporated mutual association which shared any cost needed to operate, maintain and repair their joint irrigation supply systems.

For larger irrigation projects that involve large scale economies and capital expenditures, more advanced forms of financing than simple cost sharing were needed. Groups of farmers formed private associations of water users based on corporation laws (known as incorporated mutual organizations or mutual irrigation companies) to build larger complex irrigation systems in which its construction costs were usually repaid through the purchase of stocks or water rights and the cost of operation and maintenance were rendered at cost to the members who received water (*Bretsen and Jill, 2007*). These irrigation services were exempt from federal income tax and state taxation that were generally assessed for corporations as long as irrigation water is delivered only for their members (*Hutchins, 1929*). The ownership of these systems belonged to farmers or water users as stockholders but water rights could be held individually by the members or collectively by the mutual irrigation companies. Unlike the incorporated mutual organization or mutual irrigation companies, a larger irrigation systems built by commercial irrigation companies had a different purpose than just benefiting water users. The purpose of irrigation services in



commercial irrigation companies was to provide a profit for shareholders who made speculation investments on land development (*Bretsen and Jill, 2007*). Where the commercial irrigation companies were land developers, the construction costs of irrigation infrastructures for large block of land were included in the price of subdivided farms sold by the companies as the entities which also held appropriative water rights (*Hutchins, 1929*). Control and ownership of the irrigation systems were usually transferred to the new landowners which then operated and maintained the services using their preferred type of irrigation organization, either forming incorporated mutual organizations or irrigation districts. Another case where the commercial irrigation companies were not land developers is shown in Table 4.

Financing mechanisms for irrigation services under irrigation districts were more complex and slightly different the previous types of irrigation organizations. Rather than just including farmers as water users and irrigation organizations as water suppliers, financing in irrigation districts involved at least three parties: farmers, irrigation districts as representatives of water users' associations, and federal or state agencies as constructors of large-scale irrigation projects in many areas of the Western States. Farmers, who are members of irrigation districts, usually do not make agreements with or give their payments to parties who build irrigation infrastructures like farmers in the mutual irrigation companies or commercial irrigation companies. Instead of paying directly to the Bureau of Reclamation or state-level department of water resources, money needed to repay project construction costs or capital costs and annual costs for operating (including salaries), maintaining, and repairing the irrigation systems (*Teerink and Nakashima, 1993*). Most of these payments, especially which were under the Reclamation Projects, were also affected by federal financial subsidies that allow farmers to get interest-free repayment of a project's construction costs and reduced repayment obligation based on ability to pay and other consideration such as economic hardship, unproductive lands, or drought (*United States General Accounting Office, 1996*). In some circumstances, the federal government also can cancel some of farmers' repayment obligations and shifts them to other beneficiaries (*Wichelns, 2010*). Tualatin Irrigation Project in Oregon is an example where the 81% of the allocated costs was shifted to commercial users which receive electricity generated by the projects since farmers could only repay \$ 5.9 million of the \$ 31.5 million's construction costs allocated to irrigation (*United States General Accounting Office, 1996*).

Prices and costs of irrigation water in the Western States are largely affected by geographic location, availability and accessibility of water, and institutional arrangements adopted in each region. Farmers in Washington or Oregon might spend less for water than farmers in California or Texas. Farmers with riparian water rights could have low cost of irrigation water due to their location near water. While farmers with appropriative water rights might need to spend more on irrigation infrastructure or pumping costs, if there are nearby aquifers, to get their water. Farmers in irrigation districts that have contracts to receive water from the Reclamation Projects, also enjoy low costs of irrigation water due to economies of scale and federal subsidies from interest-free repayment of project construction costs and flexible repayments which consider farmers' ability to pay (*United States Department of Justice, 2015*). These advantages were hardly found in any irrigation projects with mutual irrigation companies, commercial irrigation companies or even with other governmental irrigation projects, such as the California State Water Projects where farmers must pay fixed cost repayments for (initial investments plus interest) and the annual costs of operation and maintenance even if there is no water available to be delivered (*Teerink and Nakashima, 1993*). As a comparison, farmers with riparian water rights or contracts under the Re-

**Table 4. Summary of Financing Mechanism on Irrigation Services in the Western States**

Type of Irrigation Organization	Irrigation Systems			Financing Mechanism
	Constructed by	Ownership	Operated & Maintained by	
Single farm	Individual farmers	Individual farmers	Individual farmers	Private funding for construction, operation & maintenance.
Unincorporated Mutual	Group of individual farmers	Farmers as members of unincorporated mutual	Group of individual farmers	Cost sharing between farmers for construction, operation & maintenance.
Incorporated Mutual	Mutual irrigation companies	Farmers/water users as stockholders.	Mutual irrigation companies	Cost of constructions were usually repaid through the purchase of stocks or water rights. While the costs for operation & maintenance, including organizational costs, were rendered at cost to members only. These irrigation services were exempt from the Federal income tax and state taxation.
Commercial	Commercial irrigation companies	In case commercial companies were land developers, control and ownership of systems usually were transferred to the new landowners/settlers.	Individual/group of farmers as the landowners/settlers.	Cost of constructions were included in the price of off-farms land. While costs for operation & maintenance, including organizational costs, were determined later based on preferred type of irrigation organization that was formed to provide the irrigation services (such as mutual irrigation companies or irrigation districts).
Commercial	Commercial irrigation companies	In case irrigation services are just additional function, the companies mostly still own the systems (for example private water companies with hydroelectric generation as their main operation).	Commercial irrigation companies	Cost of irrigation services were represented on the price of water delivered by these irrigation companies.
Irrigation district	United States Bureau of Reclamation	United States Bureau of Reclamation	Irrigation District	Irrigation districts collected fees from their farmers' member and used their revenue to pay interest-free repayment of a project's construction costs and to recover the capital costs of district facilities and the annual costs of operation, maintenance, and repairs of irrigation systems.
	State-level department of water resources.	State-level department of water resources.	Irrigation District	In California State Water Projects, farmers are responsible for the full supply-costs of water development and delivery. Irrigation districts charged fees from their farmers' member to pay fixed cost repayments (initial investments plus interests), capital costs and annual costs needed in their irrigation systems (operation, maintenance, repairs, salaries). These fees are charged even if there is no water to be delivered from the State Water Projects.
	Irrigation District	Irrigation District	Irrigation District	Irrigation districts issued bonds to raise money for constructing, completing, and extending irrigation systems and charged fees to farmers for bond's repayments and cost recoveries of irrigation services (operation, maintenance, repairs).

*Summarized from various sources: Hutchins, 1929; Hutchins, 1931; Teerink and Nakashima, 1993; Bretsen and Jill, 2007; Burt, 2007; Wichelns, 2010.*

clamation Projects could get their water for very low cost (\$ 5 - \$ 10 per 1,000 m<sup>3</sup>) while other farmers with different type of delivery water's contracts could pay from \$ 20 to \$ 100 per 1,000 m<sup>3</sup> (Wichelns, 2010). In average, farmers in California, Kansas, Nebraska, and New Mexico paid the most expensive price of water from off-farm suppliers (more than \$ 40 per acre-foot) in 2013 while farmers in Oklahoma and Wyoming paid the lowest price, less than \$ 10 per acre-foot (Table 5). Farmers in California, together with Arizona, also spent more for extracting ground water in the same year (more than \$ 120 per acre water from wells) than any other western states (Table 5).

**Table 5. Expenses for Irrigation Water 2013 by Water Source**

	States	Off-Farm Suppliers			On-Farm Pumping		
		Total Cost (\$1,000)	Average Cost		Total Cost (\$1,000)	Expenses per acre <sup>1</sup>	
			Per Acre (\$)	Per Acre- Foot (\$)		Water from wells (\$)	Surface water (\$)
1	Arizona	63,322	132.39	29.43	42,674	126.12	22.36
2	California	480,932	132.51	45.59	631,515	127.51	47.28
3	Colorado	17,796	29.83	16.96	77,386	71.26	20.63
4	Idaho	35,326	31.80	17.65	180,959	72.08	46.57
5	Kansas	1,119	36.21	47.16	166,176	56.73	26.64
6	Oklahoma	334	7.47	8.76	22,160	51.99	16.92
7	Montana	11,755	13.89	10.98	19,138	28.91	17.08
8	Nebraska	18,078	42.91	42.19	405,034	48.39	25.32
9	Nevada	2,869	28.10	13.60	31,674	83.51	25.86
10	New Mexico	4,583	49.99	41.46	41,953	80.74	37.34
11	North Dakota	814	29.94	38.85	5,914	28.85	25.19
12	Oregon	20,194	41.79	20.18	53,003	49.38	46.11
13	South Dakota	1,285	22.58	16.80	8,841	26.28	23.93
14	Texas	14,215	46.84	31.05	327,390	75.73	38.16
15	Utah	14,305	26.72	13.34	23,445	56.45	19.09
16	Washington	47,545	71.35	32.01	93,964	76.05	52.16
17	Wyoming	7,428	13.08	8.14	16,470	50.06	18.11
<b>17 Western States</b>		<b>741,900</b>			<b>2,147,696</b>		
<b>The United States</b>		<b>764,367</b>			<b>2,669,965</b>		

Source: United States Department of Agriculture: 2013 Farm and Ranch Irrigation Survey, 2014a.

Note: <sup>1</sup> For operations with only acres in the open.

## CHALLENGES IN IRRIGATION MANAGEMENT

Irrigated land across the United States has decreased by nearly one million acres during 1997-2013 with surprisingly 4 million acres decline in the Western States (Figure 18 and Table 6). Most of the decrease areas occurred across the region where water scarcity occurred due to drought conditions (United States Department of Agriculture, 2016b). All western states, especially in West and South (geographic region defined by United States Census Bureau), shared the same decline while the others in Midwest experienced the opposite. California, Colorado and Texas had the most decreased acreage with more than 3.5 million acres lost (combined) while others experienced up to 20% decreases (Table 6). These trends, to some point, showed that agriculture slowly shifted to more humid areas in the eastern part of country, reflected by increasing irrigated acreage in all states in Midwest and many states in the Mississippi Delta and Southeast regions

such as Arkansas, Mississippi, and Georgia (*United States Department of Agriculture, 2016b*). Nebraska (included in this study under Western States based on the United States Department of Agriculture along with North Dakota, South Dakota and Kansas) led as the largest states where the highest expansion of irrigated area (1.2 million acres increase); Arkansas came second with 1.1 million acres increase, while Indiana had the highest percentage with 78% increase from 1997 (*United States Department of Agriculture, Various Censuses Year*). Even though declines on irrigated acreage could benefit other water users by lowering water's competition water during scarcity periods, decreased acreages could lead to economic losses for agriculture in western states, with more agriculture growth in eastern states. In the long term, California and Texas, which had the most decreased acreage, might not stay as the 1<sup>st</sup> and 3<sup>rd</sup> of top 10 agricultural producing states in term of cash receipt, as they were in 2015 (*United States Department of Agriculture, 2017*).

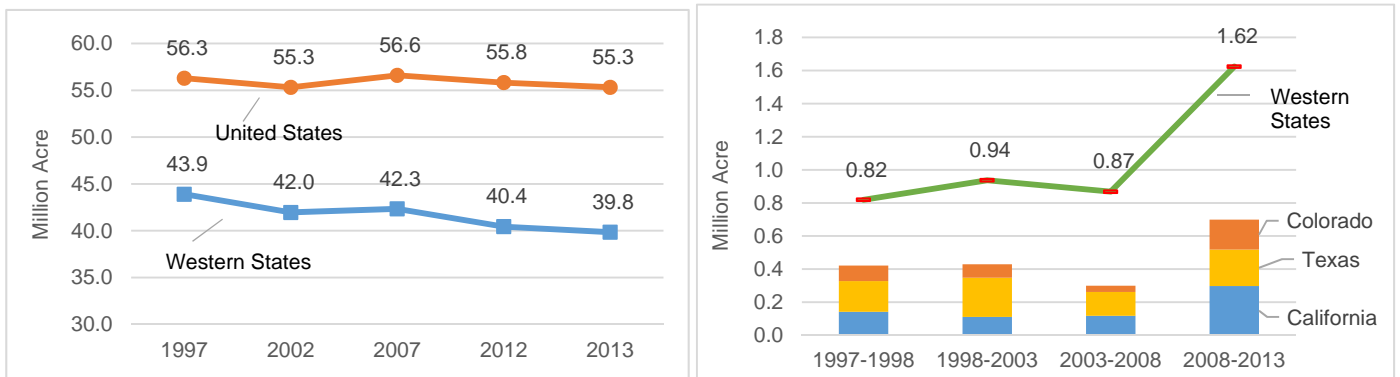


Figure 18. (Left) Acre Irrigated in the Western States and the United States 1997-2013 (*Source: United States Department of Agriculture, Farm and Ranch Irrigation Survey, Various Year*)

Figure 19. (Right) Discontinuance of Irrigation in the Western States<sup>1</sup> (*Source: United States Department of Agriculture, Farm and Ranch Irrigation Survey, Various Year*)

Note: <sup>1</sup> California, Texas, and Colorado were states with the largest discontinuance of irrigation.

**Table 6. Acres Irrigated in the Western States 1997-2013**

States	Acres Irrigated					1997-2013
	1997	2002	2007	2012	2013	
1 Arizona	1,075,336	931,735	876,158	880,613	851,407	(223,929)
2 California	8,886,693	8,709,353	8,016,159	7,861,964	7,543,928	(1,342,765)
3 Colorado	3,374,233	2,590,654	2,867,957	2,516,785	2,309,178	(1,065,055)
4 Idaho	3,543,805	3,288,522	3,299,889	3,365,292	3,511,751	(32,054)
5 Kansas <sup>1</sup>	2,695,816	2,678,277	2,762,748	2,881,292	2,851,085	155,269
6 Montana	2,101,548	1,976,111	2,013,167	1,903,019	1,872,286	(229,262)
7 Nebraska <sup>1</sup>	7,065,556	7,625,170	8,558,559	8,296,573	8,297,457	1,231,901
8 Nevada	763,742	746,653	691,030	687,790	689,953	(73,789)
9 New Mexico	851,735	844,799	830,048	680,318	694,571	(157,164)
10 North Dakota <sup>1</sup>	183,004	202,817	236,138	218,407	213,686	30,682
11 Oklahoma	509,109	517,553	534,768	479,750	426,296	(82,813)
12 Oregon	1,963,478	1,907,627	1,845,194	1,629,735	1,553,034	(410,444)
13 South Dakota <sup>1</sup>	367,195	401,083	373,842	378,678	369,802	2,607
14 Texas	5,764,295	5,074,638	5,010,416	4,489,163	4,489,837	(1,274,458)
15 Utah	1,218,474	1,091,011	1,134,144	1,104,257	1,124,729	(93,745)
16 Washington	1,787,120	1,823,155	1,735,917	1,633,571	1,623,123	(163,997)
17 Wyoming	1,749,908	1,541,688	1,550,723	1,435,710	1,418,272	(331,636)
<b>Total 17 Western States</b>	<b>43,901,047</b>	<b>41,950,846</b>	<b>42,336,857</b>	<b>40,442,917</b>	<b>39,840,395</b>	<b>(4,060,652)</b>

Source: United States Department of Agriculture: Farm and Ranch Irrigation Survey, Various Years.

Note: <sup>1</sup> Kansas, Nebraska, North Dakota and South Dakota and other Midwest<sup>2</sup> States (Illinois, Indiana, Iowa, Kansas, Michigan, Missouri, Ohio, Wisconsin) experienced increasing in acres irrigated 1997-2013.

<sup>2</sup> One of the four geographic regions (West, South, Midwest, Northeast) defined by the United States Census Bureau which is different from two geographic regions (Western, Eastern) defined by the United States Department of Agriculture.

Decreasing irrigated acreage was affected by discontinuances of irrigation which increased in all western states during 1997-2013, doubled from 0.82 million acres to 1.62 million acres (Figure 19). California, Texas, and Colorado, as major western states with the most irrigated acreage decrease during 1997-2013, also experienced the most discontinuance of irrigation and accounted for more than a half of total discontinuances of irrigation in the Western States during 2008-2013 (Table 7). Considering the recent drought that occurred in many western states, the inability to get irrigation water was expected to be the main reason for irrigation discontinuances 2008-2013. Farm and Ranch Irrigation Survey 2013 showed that the inability to get irrigation water contributed about 34% and the economic driven factors such as land conversion or uneconomical irrigation contributed to about 14% (Table 7). The main reason for irrigation discontinuance remains unknown since most of these discontinuances (about 64%) were listed under unspecified reasons (Table 7). Farm and Ranch Irrigation Survey 2013 also revealed that, from 1.6 million-acre discontinuances that occurred during 2008-2013, only 5% of them (about 73 thousand acres) which were listed to be permanent. These permanent discontinuances were smaller than the decreased acreage in the Western States 2008-2013 listed in Table 6 (about 0.6 million acres). Through this calculation, decreasing of irrigated land in the Western States might be temporary losses where irrigated land became dormant and could still be employed again in the future.

**Table 7. Discontinuance of Irrigation in the Western States in 2013**

States	Acres Irrigated in 2013	Discontinued Irrigation <sup>1</sup>				Reason for Discontinuance <sup>2</sup> (Acres)											
		Farms	Acres	Farms reporting discontinuance to be permanent		Sufficient soil moisture	Shortage of water surface	Shortage of ground water	Irrigation is un-economical	Loss of water right	Sold or leased water rights or annual water allocation	Sold or leased irrigated land or irrigated area under protection	Restrictions on water use	Converted to non-agricultural uses	Converted to agricultural enterprise not requiring irrigation	Available surface water too salty	Other or un-specified <sup>3</sup>
				Farms	Acres												
1 Arizona	1,210,568	419	23,911	-	-	3,840	868	-	-	-	-	n/a	-	-	1,440	-	19,443
2 California	8,603,719	3,874	298,099	450	13,111	20,652	106,583	97,319	6,008	-	n/a	22,838	16,840	24	-	-	216,681
3 Colorado	3,458,031	2,302	180,931	249	5,667	17,882	68,824	9,466	4,413	-	n/a	-	29,250	-	n/a	-	68,465
4 Idaho	3,508,254	1,254	67,641	8	80	2,480	-	24	-	-	7,122	10,240	6,906	-	2,580	-	52,317
5 Kansas	2,685,758	509	63,058	125	16,954	2,224	-	1,400	9,720	8,400	-	25,222	-	8	8,320	-	27,934
6 Oklahoma	602,203	579	30,429	49	1,192	-	2,150	4,921	7,313	-	-	6,500	-	-	1,160	800	12,624
7 Montana	2,085,759	1,452	152,970	92	2,648	16,981	14,609	83	752	332	-	13,706	7,204	-	332	-	110,493
8 Nebraska	5,697,779	580	164,535	8	8	n/a	11,907	-	90	-	-	n/a	-	-	-	-	147,630
9 Nevada	899,204	248	29,369	-	-	-	20,166	1,200	2,700	-	-	-	1,200	-	-	1,800	7,403
10 New Mexico	904,235	1,549	52,056	192	4,245	13,540	18,190	3,340	1,710	131	-	786	4,470	-	3,761	4,335	26,998
11 North Dakota	141,434	132	18,362	10	1,250	3,843	710	-	600	-	n/a	1,025	-	-	1,240	n/a	12,275
12 Oregon	1,920,318	1,213	86,528	140	3,287	3,886	15,049	n/a	3,000	-	1,500	6,372	11	6	3,006	-	59,715
13 South Dakota	341,110	156	12,463	1	n/a	n/a	1,170	-	1,248	-	-	1,155	-	-	3,723	-	6,897
14 Texas	7,018,411	3,499	219,848	188	18,171	11,781	16,816	24,808	18,108	-	-	13,756	498	-	16,034	5,312	134,879
15 Utah	1,185,315	1,715	66,969	66	2,427	1,890	27,867	627	816	-	2,121	-	4,820	-	684	-	36,219
16 Washington	1,681,268	1,824	65,747	44	59	15,559	-	n/a	10	-	-	-	-	15	81	690	47,764
17 Wyoming	1,685,215	380	91,049	13	4,030	9,900	9,364	n/a	4,760	-	n/a	5,239	7,504	-	-	-	61,786
<b>Total 17 Western States</b>	<b>43,628,581</b>	<b>21,685</b>	<b>1,623,965</b>	<b>1,635</b>	<b>73,129</b>	<b>124,458</b>	<b>314,297</b>	<b>143,164</b>	<b>61,248</b>	<b>8,863</b>	<b>10,743</b>	<b>106,839</b>	<b>78,703</b>	<b>53</b>	<b>42,361</b>	<b>12,937</b>	<b>1,049,523</b>

Source: Modified from Table 27 of the 2012 Census of Agriculture: Farm and Ranch Irrigation Survey 2013 (United States Department of Agriculture, 2014)

Note. <sup>1</sup> Since previous census year (2008).

<sup>2</sup> Respondents could choose more than one reason for not irrigating.

<sup>3</sup> This category is for any discontinuance reason that was not specified on the Agriculture Census' report form

Beside the high rate of discontinuances of irrigation, farmers in the Western States are also facing the rising cost of irrigation water over the last few decades. The cost of irrigation water from off-farm suppliers such as federal/state government agencies, irrigation districts, and mutual irrigation companies has gradually increased since 1979. California has been consistent as the most expensive state for irrigation water in the Western States. The cost of irrigation water from off-farm suppliers in California was up to four times higher than any other western states. The average cost per acre irrigated in California ramped up from below \$40 in 1979 to more than \$140 in 2008 (but surprisingly decreased about \$10 in 2013), while the other western states experienced more steady increases during 1979-2013 (Figure 20). Since most of those off-farm suppliers, unincorporated mutual, mutual irrigation companies, irrigation districts, the bureau of reclamation, which covered almost a half of total acre irrigated in the Western States (Table 2), are not supposed to profit from sales of water, the rising cost of irrigation water could be affected by greater costs of irrigation services such as operation and maintenance. [Costs for irrigation services in unincorporated mutual and incorporated mutual organizations were rendered at cost to their member who received the benefit of irrigation services. The biggest cost component of water supply from irrigation districts was repayment of Reclamation Project's cost which was free from interest. – Refer back to “Financing in Irrigation Services” (Table 4)]. Expenses for maintenance and repairs of irrigation per acre irrigated in the most irrigated Western States did increase 1.9-3.9 times during 1979-2008 (Figure 21). It costed more than \$35 per acre irrigated in California and varied around \$8 to \$25 in other western-most irrigated states in 2008 (Figure 21).

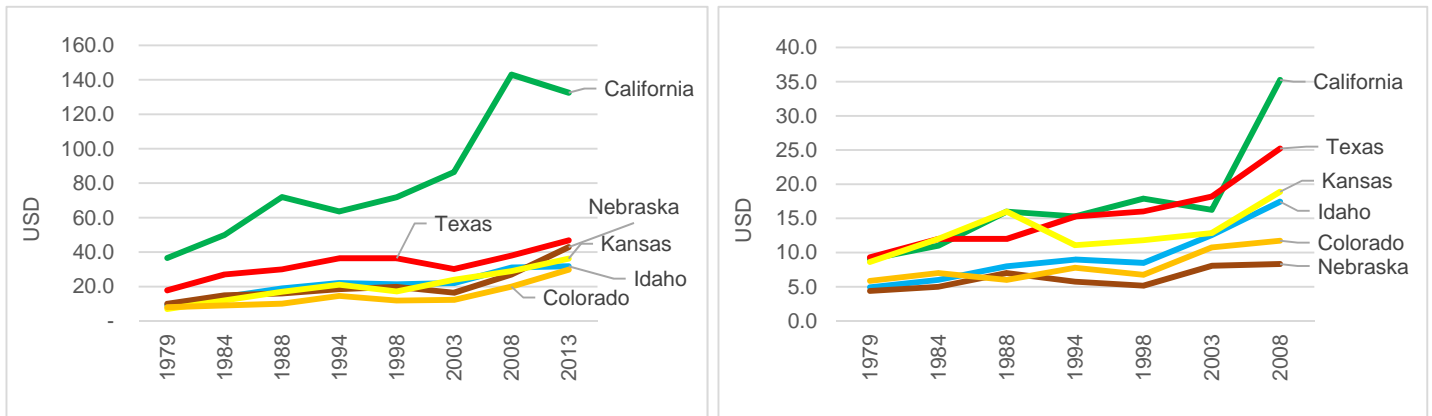


Figure 20. (Left) Average Cost Per Acre<sup>1</sup> Irrigated from Off-Farm Water Suppliers in Six Most Irrigated States<sup>2</sup> in the Western States (Source: United States Department of Agriculture, Farm and Ranch Irrigation Survey, Various Census Years).

Figure 21. (Right) Expenses for Maintenance and Repairs of Irrigation Equipment and Facilities<sup>3</sup> Per Acre Irrigated in Six Most Irrigated States<sup>2</sup> in the Western States (Source: United States Department of Agriculture, Farm and Ranch Irrigation Survey, Various Census Years).

Note: <sup>1</sup> Average costs per acre foot of water were not listed in the earlier censuses.

<sup>2</sup> Accounted for more than 70% of total irrigated land in the Western States in 2013.

<sup>3</sup> This category was not available on Farm and Ranch Irrigation Survey 2013.

The cost of irrigation water from on-farm supply (groundwater extractions) in the Western States also has risen in recent decades. Again, California became the most expensive state for irrigation water from underlying aquifers in the entire western states. Prior to the recently enacted groundwater act in 2014, California had left groundwater extractions largely unregulated (Halverson, 2015; Escriva-Bou et al., 2016). Groundwater has become an insurance for farmers with intensive agriculture who needed to keep their long-term investment safe especially when surface water could not guarantee their water supply need (Lund and Harter, 2013). Over drafting was unavoidable and significantly contributed to declining of groundwater levels in some areas of California, especially in the San Joaquin Valley with 10 feet or more decrease (Figure 22). As groundwater levels fell, along with increasing of electricity prices (Figure 23), farmers in California faced increasing of pumping costs, for pumping energy demand and well replacement/deepening. Even though high rates of irrigation withdrawal from groundwater happened also in Texas (Figure 12), differences in electricity prices has made groundwater extraction more expensive in California. As a result, expenses for pumping groundwater in California were up to twice costs (more than \$120 per acre in 2013) of other western irrigated states (Figure 24).

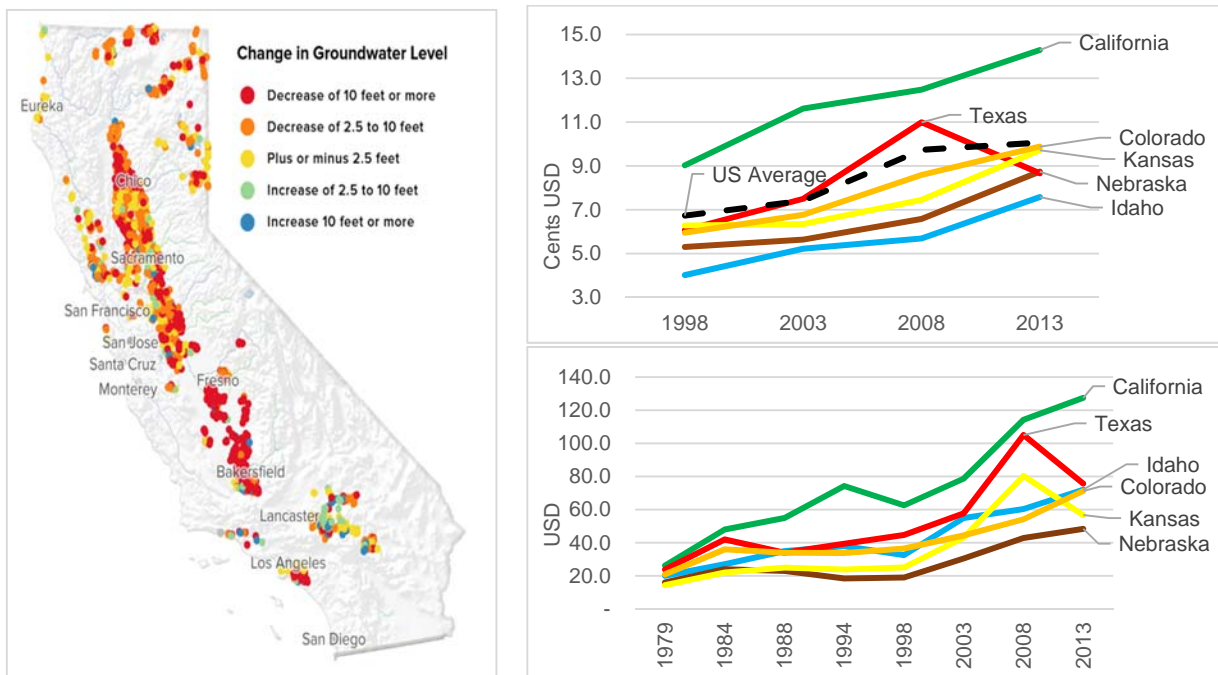


Figure 22. (Left) Change in Groundwater level in California 2004-2014 (Source: Moran et al, 2014)

Figure 23. (Top Right) Annual Average Electricity Price Comparison (Cents USD per Kilowatt-hour) in Six Most Irrigated States<sup>1</sup> in the Western States 1998-2013 (Source: Nebraska Energy Office Services, Various Year)

Figure 24. (Bottom Right) Expenses Per Acre for Pumping Water from Wells in Six Most Irrigated States<sup>1</sup> in the Western States (Source: United States Department of Agriculture, Farm and Ranch Irrigation Survey, Various Census Years).

Note: <sup>1</sup> Accounted for more than 70% of total irrigated land in the Western States in 2013.



## PROMISING FUTURE DIRECTION

Growing concern for the environment and sustainability puts more pressure on irrigation water in the American West. In the foreseeable future, competition for surface water will involve more long-established water uses (agriculture, energy, urban) and environmental water uses which was rarely counted as major water uses in past projected water demand reports. Requirements to protect endangered species and to preserve wild, scenic and recreational river systems, along with necessities to meet water quality standards under federal and state regulation, have forced some surface water dedication for ecological benefits (*Escriva-Bou et al., 2016*). Instream flows for recreational and environmental purposes increases competition for available surface water and makes water for irrigation purpose more vulnerable to cut backs, especially during droughts (*Peterson, 2015*). Environmental water uses vary across the western states. Recreation, fisheries, and in-stream flows were counted as about 3% of Colorado’s water use (*Colorado Foundation for Water Education, 2017*) while in California approximately 50% of total water use in 2010 was used for “environmental” purposes, surpassed agriculture (40%) and urban (10%) water use (*Mount and Hanak, 2016*). California’s Sustainable Groundwater Management Act in 2014 and similar regulations in other states, will also shape how groundwater is managed in the coming years with farmers and ranchers as the most affected users, especially those who used to turn to groundwater to supplement or replace unavailable surface water supplies (*Rice, 2016*). Since high risk of drought will always be characteristic of the American West (Figure 25), any periods of water shortages, along with requirements to fulfill water demand from various sectors, will continue as challenges for farmers who need to irrigate agricultural land.

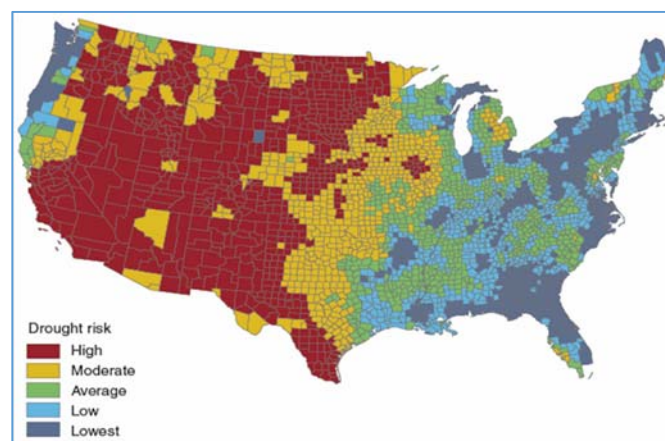


Figure 25. Drought Risk’s Map (*Source: United States Department of Agriculture, 2013*).

Increasing risk of drought and its impacts (such as competition for available water, mandatory water restriction/curtailment) will continue as challenges and shape how water is delivered in the American West, but farmers have adapted to these situations quite well over decades. Water scarcity have led farmers in western states to consider using less water, seek more reliable source of water for their investments and shift some of their fields to higher revenue perennial crops such as nuts and grapes (*Mount and Hanak, 2016*). Application of newer and improved irrigation technologies (such as drip irrigation or similar irrigation system that could

deliver water directly to the root zone) is expected for agriculture, especially for in high value crops (such as almonds that involves long term investments), not only as responses to drought, but also because it helps farmers improve crop yields (*Peterson, 2015*). Beside using temporary transfers of water from one water user to another user to meet water demand (*California State Water Resources Control Board, 2017*), farmers are predicted to still rely on groundwater as an alternative source of water during drought years despite increasing expenses of groundwater extraction. Recently enacted California groundwater act in 2014 could be challenges but will not discourage groundwater extractions, at least for the near future, since it takes some years for this law to be fully implemented. [Based on California Groundwater Legislation Timeline, identified critically over drafted high and medium priority basins began to be managed under a groundwater sustainability plan by January 31, 2020] Some irrigation districts also have viewed modernization of irrigation system (canals' automation or upgrading irrigation ditches to achieve more precision on water delivery) as alternative approaches to minimize spills and to support high-tech on-farm irrigation methods (*Burt and Styles, 2000*), but application of this approach might be difficult in the near future because it could require massive new investments. If severe drought happens again in the future and water restriction/curtailments applied, farmers might prefer to fallow some of fields (and convert the rest to grow higher value crops) and sell their water for temporary periods.

## CONCLUSIONS

History showed how irrigation has a foundational role in the development of the American West. Over centuries, irrigation infrastructure has served various purposes, from supporting Native population in central Arizona before the earliest European settlements, ensuring political hegemony during Spanish colonization, until speeding economic expansion in the beginning of 20<sup>th</sup> century. The need of irrigation water in these arid regions has triggered, not only improvement in irrigation technology, but also transformation within irrigation communities itself. While gravity-based irrigation systems were mostly used in the earliest civilizations, pressure based irrigation systems are currently common across the western states. Development of irrigation organizations, which started with co-ownership of irrigation networks (created by neighbor appropriator farmers with cost sharing) and moved largely to establishment of irrigation districts (which served most non-riparian water right farmers with more advanced financing mechanisms), also helped transformation of the American West from barren desert and low value grazing into the largest agriculture areas in the United States by expanding delivery of irrigation water across the western states.

As population grows in western states, along with increasing concern for environment and sustainability, some challenges for managing irrigation could lead to decreasing acres of irrigated land in the West, including discontinuance of irrigation, greater expenses for irrigation water, and escalating competition for water. For the last few decades, farmers with intensive agriculture have turned to groundwater when surface water could not guarantee water supply for their long-term crop investments. These practices are predicted to continue in the foreseeable future even though the California Sustainable Groundwater Management Act or similar regulations in other states have been enacted. Increasing risk of drought and experiences of severe water allocation curtailment in the past will force farmers to consider using less water. Farmers are likely to consider modernizing their irrigation systems to have more precision in water delivery to minimize spills and to improve on-farm irrigation efficiencies. Farmers also have an option to abandon some agriculture and try make money from selling their water rights during drought years.

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